UNIVERSITI TEKNOLOGI MALAYSIA

KITABINA SDN BHD
CONSTRUCTION COMPANY

Integrated Design Project 2 Report: Group 28

SEAA4032-01 | INTEGRATED DESIGN PROJECT 2 | SESSION 23/24-1

TEAM MEMBERS

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SUPERVISORS

PM. DR. ZULHILMI BIN ISMAIL (Drainage)
DR. MOHD HAFIZ BIN PUTEH (Sewerage)
PM. IR. DR. SITTI ASMAH HASSAN (Road)
PM. DR. KAMARUDIN HJ. AHMAD (Geotechnical)
IR. WAN IKRAM WAJDEE WAN AHMAD (Reinforced Concrete)

Acknowledgement

After a prolonged and challenging journey, we are delighted to announce the successful completion of our project, and our hearts are filled with gratitude for all those who played a role in making this achievement possible. The magnitude of such a large-scale endeavor necessitated support from numerous individuals, and we extend our sincere thanks to each one of them.

Throughout the execution of our assignment, we sought guidance from esteemed individuals whose wisdom and direction were invaluable to our success. Completing this project brings us immense joy, and we express our deepest appreciation to PM. Ir. Dr. Sitti Asmah Hassan, PM. Dr. Kamarudin Hj. Ahmad, PM. Dr. Zulhilmi, Ir. Wan Ikram Wan Majdee, and PM. Dr. Mohd Hafiz Puteh for their continuous guidance and numerous consultations.

Our project has benefitted greatly from the insightful comments provided by various individuals, particularly our team members. Their constructive feedback has served as inspiration, propelling us to enhance the quality of our work. We are grateful for the assistance of everyone involved, whether directly or indirectly, in the successful culmination of our project.

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1.A Company Profile

1.A Company Profile

1.A.1 Company Background

Kitabina is a new civil engineering consulting firm founded in 2023 with the goal of providing innovative solutions to infrastructure concerns. Our unique company name is derived from the Malay word meaning the We build, and it represents our dedication to providing innovative and forward-thinking engineering solutions. Project management, site evaluation, design, and construction supervision are among the services we provide.

We aim to provide new ideas and inventive solutions to every project we work on. We provide civil and environmental engineering, water management, and infrastructure design services with a focus on sustainability. Our skilled staff works hard to provide cost-effective solutions that exceed our clients' expectations.

Vision

To create a premier construction consulting firm that transforms the industry through innovation, sustainability, and service excellence.

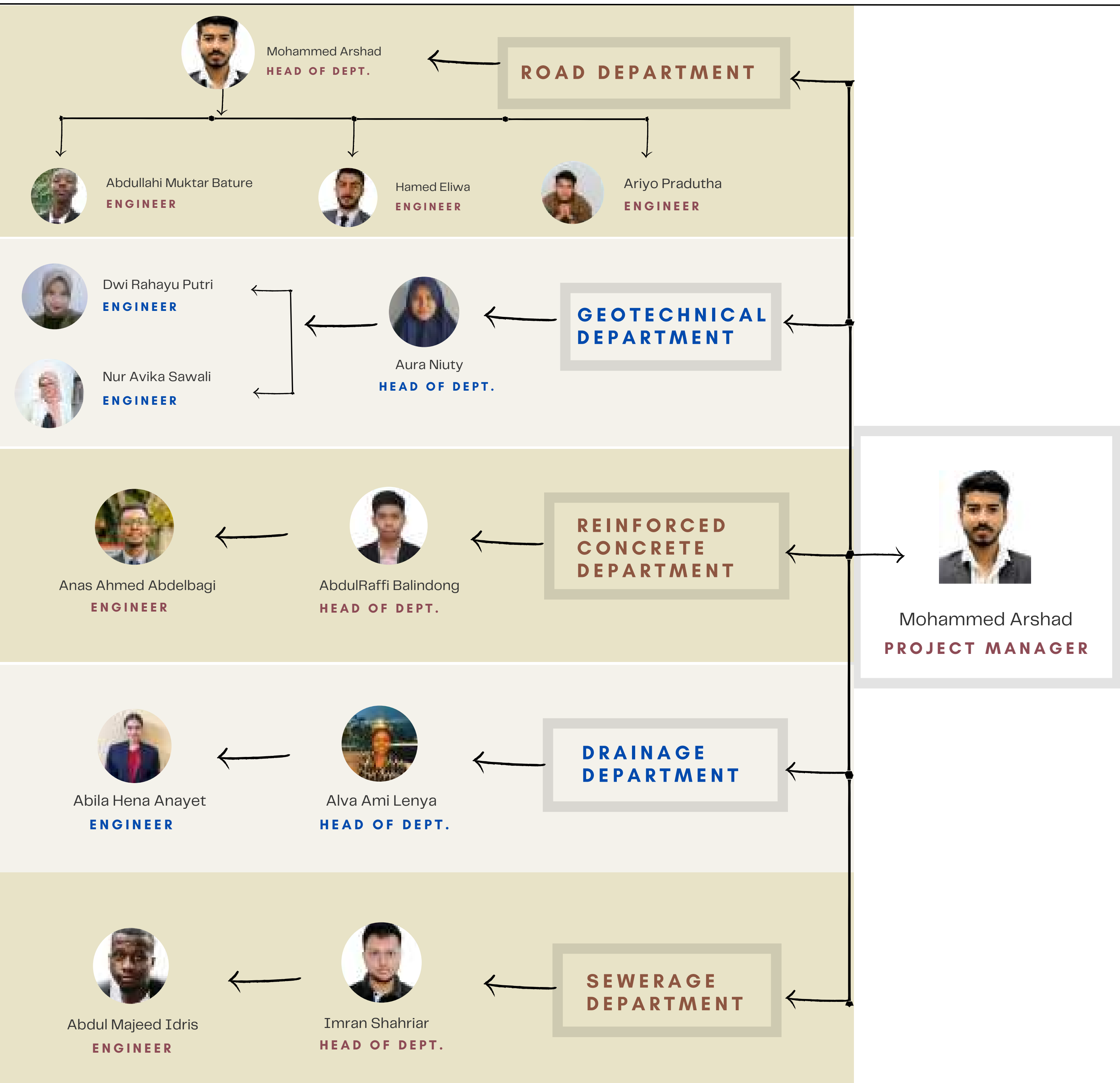
Mission

Our skilled staff combines varied skills and expertise to deliver unique and long-term solutions for every project we take on. We are dedicated to building long-term relationships with our clients, workers, and partners that are founded on integrity, transparency, and mutual respect. Our ultimate mission is to improve society by providing safe, functional, and inspirational built environments that improve people's lives.

Motto

Connecting Minds, Creating the Future.

1.A.2 Organizational Chart



1.A.3 Scope of Work

Department	Job Scope
Road	• Road network proposal and existing contour. • Circulation of internal traffic, including road classification and width. • Design of intersection for the main entrance. • Design of Pavement Structure and Cross section. • Design for horizontal and vertical alignments where applicable • Road signage, traffic signs and markings
Geotechnical	• To identify the project's soil profile. • To examine eccentricity and settlement while designing a shallow foundation. • To design and inspect single and group pile foundations for settlement, eccentricity, and geotechnical and structural capacity. • To design and evaluate the retaining wall's stability.
Reinforced Concrete	• To perform site evaluation and inventory. • To develop an optimal structural plan for the project. • Software-based design of the project's framework. • To determine the capacity specifications for a structure utilizing the Eurocode.
Drainage	• To devise a drainage system. • To determine rainfall and rainwater discharge through the drain. • Design of detention ponds. • To develop culverts and outlets that satisfy the defined requirements.
Sewerage	• To determine the total population equivalent of the proposed area. • To develop a sewerage layout design. • To identify the dimensions and type of sewer conduit. • To figure out the location of manholes. • To locate the suitable STP location.

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1.B Project Profile

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1.B Project Profile

1.B.1 Project Description

The proposed housing development in Gambang Pahang, Malaysia spans 95.3 acres and aims to create a sustainable, self-sufficient community. It features amenities like parks, praying area, multi-purpose hall and green initiatives such as solar panels. The development emphasizes public spaces and communal areas for social interaction and connectivity among residents, with the goal of providing a model for sustainable and community-focused living.

Project Title

Housing Complex Project in Gambang, Malaysia

The project's approximate latitude and longitude is 3°41'50.42"N, 103° 2'34.97"E

Project Location

The proposed housing complex is conveniently close to the E coast Epoxy (Toll Road), which connects to Kuantan, and is situated in the perfect area of Gambang, Pahang. The project area offers quick access to key services including educational institutions like SMK Gambang and Pahang Matriculation College as it is flanked by well-established housing neighborhoods, including Taman Gambang Damai.

The region is further enhanced by its closeness to Jalan Gambang, a vital road system that links the project area to other settlements and amenities. The project's approximate latitude is 3°41'50.42"N, 103° 2'34.97"E, providing a gorgeous and tranquil environment that is ideal for a good quality of life.

Overall, the proposed housing development offers a unique blend of convenience and tranquility, with easy access to essential services and amenities, surrounded by an established community, and situated in a picturesque location.

Figure 1 Site location from Google Earth

1.B Project Profile

Project Participants

i. Owner of Project : Perbadanan Setiausaha Kerajaan Pahang
Address : Unit Perancang Ekonomi Negeri Tingkat 4, Wisma Sri Pahang, 25646 Kuantan, Pahang Darul Makmur.

ii. Civil Engineering Consultant: Kitabina Consultants SDN.BHD.
Address : A-39, Tingkat 1, Bandar Indera Mahkota, 25200 Kuantan, Pahang Darul Makmur.

1.B.2 Land Use Details

Land Use Details			
Land Use	GFA (m2)	Unit	Quantity
Semi-Detached House	--	Dwelling Units	648
Kindergarten	3960	TSF	42.625
Community Hall	4081	Units	10
Market Place	1987	Units	12
Recreational Park	55,513	Acre	13.72
Substation	2096	Acre	0.518
Surau	7331	TSF	78.91

1.C Minutes of Meeting

Meeting Minutes - [Kitabina]

Location: M47-316

Date: Thursday 9th November, 2023

Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Presentation slides were reorganized to make the goals and tasks covered.
- For a thorough grasp of the project scope, important topics like land use, drainage length, temporal concentration, peak flow, drain section sizing, culvert design, and Detention Pond issues were emphasized.

Geotechnics Department

- **Members present during the discussion:** Dwi Rahayu, Aura Niuty, Nur Avika
- Reviewed all the material related to geotechnics (geotechnics 1 and 2) that was learned in the previous year.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Revised the beam and column sizings upon Dr's recommendation.
- Drafted the structural layouts for ground, 1st, and roof floor.
- Drafted the design specifications and load assumptions.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed, Dr. Sitti Asmah
- Made corrections on the traffic volume generated from the main road outside.
- Given a trip generation manual book of Malaysia 2010 and obtained the copies of graphs and IN/OUT ratio distribution for relevant land uses present in our study area.
- Carried out discussion on planning of road layout and entrances to our study area.

Sewerage Department

- **Members present during discussion**: Imran, AbdulMajeed, Dr Hafiz (Online)
- Presented chosen STP type, sewer system type and pipe type.
- Given advice for STP location and factors based on location placement.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)

Date: Tuesday 14th November, 2023

Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- We had a thorough conversation on how to divide up the work and computations among the team members.
- During the meeting, each team member's unique duties with reference to the drainage project's calculations and assignments were assigned.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Discussed and listed the details for geotechnics department.
- Reviewed and analyzed some document such as borehole log and all stuff that related for our works next.
- Selected borehole log for our area.

Reinforced Concrete Design Department

- **Members present during the discussion:** Anas, Raffi
- Adjusted the column locations along the first floor to determine the appropriate load distribution.
- Finalized the structural layouts for all floor level.
- Confirmed with Dr the appropriate load assumptions for each floor.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Identified and listed the Land use details present in our proposed area.
- Obtained the Gross Floor Area for each of the identified Land use.
- Interpolated the trip generation graphs for each land use type and obtained the equation to calculate the AM and PM peak trips per hour based on the standard units such as dwelling units for semi-detached houses and Thousand Square feet for land use types that are based on Gross Floor Area.

Sewerage Department

- **Members present during discussion**: Imran, AbdulMajeed, Dr Hafiz
- Compiled report consisting from Introduction to Sewer Layout.
- Calculated PE and class of STP.
- Determined STP location.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 16th November, 2023
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- During the discussion, we went over our previous work and discussed where to best position the catchment regions for the drainage project.
- We also concentrated on the details that would be on our future poster, making sure that all of the important information that was included was covered, including catchment area placement and drainage techniques.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Reviewed previous work and discussed for soil profile.
- Discussed details to be put on our poster.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Compared the design layouts between ETABS and Prota.
- Carried out the remaining changes for the input analysis.
- Ran the output analysis.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed, Dr. Sitti Asmah
- Calculated Trip Generation based on regression equation and compared with the average rate value.
- Tabulated highest value based on worst case scenario.
- Carried out discussion and identified three main entrances leading to ingress and egress to the proposed study zone and carried out further planning on trip distribution based on the land use aggregates and assumptions.

Sewerage Department

- **Members present during discussion**: Imran, AbdulMajeed
- Determined locations and type of manholes and bedding.
- Design calculation - Hydraulic Design and Flow Rates on Excel.
- Determined pipe diameter.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)
Date: Tuesday 21st November, 2023
Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- We discussed the best places for the Detention Ponds, keeping in mind the site's elevation changes.
- We spoke about how to best position detention ponds in relation to site elevations to maximize their effectiveness in controlling runoff.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Finalized the soil profile with our supervisor.
- Started to do the next task which is find allowable bearing capacity.
- Discussed details to be placed on our poster.

Reinforced Concrete Design Department

- **Members present during the discussion:** Anas**,** Raffi
- Re-run iterations for the design output.
- Showed the supervisor the beam detailing.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed, Dr. Sitti Asmah
- Identified and located the entrances, possible locations for signalized intersection.
- Marked locations for vertical and horizontal alignment and calculations that are needed to be carried out.

Sewerage Department

- **Members present during discussion**: Imran, AbdulMajeed
- Recalculate population equivalent (PE).
- Discussing about reposition of STP with supervisor.
- Discussing about pipes position.
- Discussing about flow rate calculation.

Meeting Minutes - [Kitabina]

Location: M47-316

Date: Thursday 23rd November, 2023

Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- During the conversation, the best places for the major and secondary drains were discussed.
- We considered factors such as topography and water flow patterns to determine the most effective positioning for both the main and secondary drainage systems.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Discussed how to do the calculation for finding the bearing capacity in shallow foundation and Retaining wall based on SPT-N.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Discussed with the Dr on the details required to be included in the poster.
- Discussed the distribution of work for the Poster Making.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Calculated Trip Distribution for three scenarios, Existing 2023, Interim 2033 and Ultimate 2043.
- Prepared Internal Circulation Road Layout, Labeling the minor and major roads present in the locality.
- Tabulated the trip distribution and major volume per direction assumptions.

Sewerage Department

- **Members present during discussion**: Imran, AbdulMajeed
- Continue working of manhole and flow rate.
- Collecting ideas of drawing pipes on AutoCAD.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)
Date: Tuesday 5th December, 2023 **[Poster presentation day]**
Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the presentation:** Alva, Abila
- We determined the necessity for drainage in particular places by analyzing land use trends.
- Critical zones that needed to be addressed for efficient drainage planning were identified.
- We spoke about possible tactics to deal with issues related to land use that are under the drainage purview.

Geotechnics Department

- **Members present during the presentation:** Aura, Nur Avika and Dwi Rahayu
- Presented bearing capacity for shallow foundation, and bored pile for both dimensions (150mm x 150mm and 200mm x 200mm).
- Comments and feedback given by Dr. Kamarudin were noted down for further enhancement and correction.

Reinforced Concrete Design Department

- **Members present during the presentation:** Raffi, Anas
- Presented School 3d layout, Structural Layout, Beam detailing and Desgin specifications.
- Comments and feedback given by Dr. Wan Ikram were noted down for further enhancement and correction.

Road Design Department

- **Members present during the presentation:** Arshad, Abdullah, Ariyo, Hamed
- Presented Roadwork design and layouts related to Proposed Road Network, Trip Generation, Trip Distribution and Road Align
- Comments and feedback given by Dr. Sitti were noted down for further enhancement and correction.

Sewerage Department

- **Members present during the presentation**: Imran, AbdulMajeed
- Finalized pipe materials and specifications.
- Continued with node and manhole labelling.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 7th December, 2023
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- We evaluated the necessary distance for drainage systems to span allotted zones.
- We examined the required length of drainage systems across designated zones.
- Considered geographical factors influencing drainage network layout.
- Initiated discussions on optimizing drainage lengths for efficient water management.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Proceeded to the next step after revising.
- Discussed with fellow geotechnical member from other group as well.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Proceeded with a discussion on making corrections based on the comments given on our presentation.
- Started altering the foundation into pile foundations.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Prepared Trip Distribution layout for three scenarios, Existing 2023, Interim 2033 and Ultimate 2043.
- Carried out road classification exercise for Jalan Kuantan-Maran, Jalan Gambang, Major and Minor road inside the Study development zone A.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Finalized node and manhole labelling, pipes and AutoCAD Layout Drawing.
- Counted quantity of houses per manhole, PE factor and PE at each manhole.
- Calculated $Q_{average}$, PFF and Peak Flow.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)

Date: Tuesday 12th December, 2023

Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Analyzed time concentration patterns to understand peak water flow periods.
- Investigated methods for adjusting drainage in a time-sensitive manner.
- Discussed potential time-based challenges and proposed mitigation measures.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Discuss about stability of retaining wall.
- Determine the dimensions for the retaining wall design.
- re-design the retaining wall depend on stability.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Further Discussed about the pile cap design.
- re-designed members in order for them to carry a water tank.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Proceeded with topography calculations required for road capacity analysis.
- Upon discussion, we decided to use two different analysis processes for road capacity whereby for Jalan Kuantan-Maran, Exhibit 23: Design for multilane highways was chosen. On the contrary, Exhibit 21: Design for basic freeways was chosen for other three roads.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Performed calculations for pipe velocity and capacity at 225mm diameter.
- Calculated depth through RL and IL; some did not match specifications.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 14th December, 2023
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- We considered several situations that might cause the drainage system's water flow to peak.
- We investigated methods for efficiently handling and controlling peak flow.
- We considered the impact of peak flow on existing infrastructure and proposed improvements.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Showing design retaining wall with Dr Kamaruddin.
- And discuss for the dimension of retaining wall with Dr Kamaruddin.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Proceeded with redesigning the whole structure using the full version of prota, due to the trial version not being able to generate full reports.
- Revised AutoCAD structural layout.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Completed road capacity analysis and determined the required number of lanes, class and Level of Service for all four roads.
- For Jalan Kuantan-Maran, further breakdown of capacity analysis for existing, interim and ultimate year scenarios were carried out.
- The outputs obtained from previous analysis were used to estimate the ESAL required for structural pavement design.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Completed detailed calculations of 225mm and 250mm diameter manholes.
- Present calculations to Dr Hafiz, he advised us to adjust the gradient of some pipelines.
- Adjusted gradient and obtained new depths which all met the requirements.
- Determined type of bedding and manhole for each manhole.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)

Date: Tuesday 19th December, 2023

Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Discussed the optimal size for drain sections to accommodate varying water flows.
- Studied the connection between system efficiency and drain size.
- Investigated the viability of uniform drain diameters in various zones.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Start making a report.
- Discussion about the division of task for making reports.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Proceeded with the generation of the beam detailing using Prota Detail.
- Revise column and stair layout

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Identified Traffic Category based on ESAL values obtained for the roads and selected the most suitable subgrade layer properties.
- Performed extensive analysis to determine the thickness of each pavement layer based on the ATJ 5/87 (2013) catalog.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Initiated longitudinal section calculation and drawing from Manhole 56 to STP.
- Addressed any specific considerations for the chosen sewer line.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 21st December, 2023
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Summarized recommended drain sizes based on the comprehensive analysis.
- We spoke about the benefits and possible drawbacks of standardizing drain sizes.
- We investigated methods for putting the suggested drain size guidelines into practice.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Discussion about foundation design with fellow geotechnical member from other group.
- Discussion about RC design of retaining wall.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Distributed tasks for the manual calculations and report.
- Brushed up on continuous beam and column design.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Distributed tasks related to Cross-section design whereby two of the members took care of design aspects and the remaining were in charge of plotting the cross-sectional layouts using AutoCAD for the four design roads.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Completed longitudinal section drawing from Manhole 56 to STP on AutoCAD.
- Completed longitudinal section of the report.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)

Date: Tuesday 2nd January, 2024

Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Explored culvert design outputs and discussed potential variations.
- Reviewed proposed inlet and outlet control measures for effective water flow management.
- Analyzed the impact of culvert design on overall drainage system performance.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Got the load of superstructure from RC dept.
- Started designing for shallow foundation dimensions.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Discussed the initial outline/flow of the report.
- Started with the design of two-way restrained slab.
- Started manual design of stairs.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Discussed the intersection control required at the major entry/exit points, identified critical intersections that required traffic control such as roundabout, signals and interchange.
- Carried out phasing and fixed time signal calculations for a major signalized intersection present at Jalan Gambang, between study development zones A and B.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Completed detailed drawings of manholes and relevant details.
- Discussed bedding, manhole covers, connections, and other relevant details.
- Resolved any concerns or modifications raised during the discussion.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 4th January, 2024
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Delved into headwater computation methods for accurate drainage infrastructure planning.
- Investigated the impact of headwater on the effectiveness of drainage systems.
- Discussed strategies to minimize headwater-related challenges.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Continued designing for shallow foundation dimensions.
- Designed eccentricity and settlement for shallow foundations.
- Checked the design with dr to get corrected.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Finalized the pile design in Prota structures.
- Started with the manual design calculations for simply supported beam.
- Started with the manual design calculations for Column and foundations.
- Discussed the remaining tasks left to fill in the report.
- Summarized the Excel design specifications as well as the load assumption to be included in the report.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Performed Operational Impact Assessment aka Traffic Impact Studies for the 2043 ultimate scenario of roundabouts, signal and Left OUT using SIDRA Intersection software.
- Upon obtaining LOS F for major signal, mitigation of geometry as well as phase timings were carried out on SIDRA, improving the LOS to LOS D, which is in par with the design standard.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Completed report introduction, conclusion and attached finalized Excel Data.
- Finalized report draft.

Meeting Minutes - [Kitabina]

Location: M47-216 (Smart Classroom)

Date: Tuesday 9th January, 2024

Time: 8:00 am - 10:00 am

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Studied stream and catchment characteristics before designing Detention Ponds.
- Discussed outflow limits for Detention Ponds and their impact on water management.
- Analyzed the stage-discharge relationship for Detention Ponds and proposed adjustments.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Designed bored pile, eccentricity and settlement, etc.
- Checked with Dr. Kamarudin.
- Finalized report.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Did thorough checking with the AutoCAD structural drawings and Prota layout plans.
- Finalized the generated design results from Prota structures.
- Performed comparison between the results of manual calculations and Prota results for two-way slab, simply supported and continuous beam.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Identified ideal location within the development to design vertical and horizontal alignments.
- Distributed tasks related to design of road furniture that included design of kerbs, traffic signs and road markings.
- Additionally, we decided to look into road infrastructure aspects such as design of pedestrian crossways, cycle lanes and bus stops.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Presented final report draft and calculations to Dr Hafiz.
- Made slight adjustments based on his feedback.

Meeting Minutes - [Kitabina]

Location: M47-316
Date: Thursday 11th January, 2024
Time: 2:00 pm - 4:00 pm

Drainage Department

- **Members present during the discussion:** Alva, Abila
- Concluded discussions by sizing major design storm outlets for optimal drainage.
- Investigated secondary outlet configurations to improve the robustness of the drainage system.
- Summarized key findings and decisions made during the drainage planning meetings.

Geotechnics Department

- **Members present during the discussion:** Aura, Nur Avika and Dwi Rahayu
- Completion and wrapping up the geotechnical report.
- Make a design of RC retaining wall.

Reinforced Concrete Design Department

- **Members present during the discussion:** Raffi, Anas
- Completion and wrapping up of RC design report.
- Discuss with the lecturer regarding the column calculations.
- Further revise the Report and insert manual calculations.

Road Design Department

- **Members present during the discussion:** Arshad, Abdullah, Ariyo, Hamed
- Completion and wrapping up of Road Work design report.
- Added a few necessary appendices in the report that provided a complete output summary from Sidra software related to Operational Impact Assessment of various junctions.
- Comparison of Jalan Kuantan-Maran in terms of road capacity and design across existing, interim and ultimate year scenarios were summarized and documented at the last two pages of the final report.

Sewerage Department

- **Members present during the discussion**: Imran, AbdulMajeed
- Completed and wrapped up Sewerage Design Report.

UNIVERSITI TEKNOLOGI MALAYSIA

SEAA4032 | INTEGRATED DESIGN PROJECT 2
SEMESTER SESSION 2023/2024-1

REINFORCED CONCRETE DEPARTMENT

TEAM MEMBERS | GROUP 28

ABDULRAFFI BALINDONG
A19EA4008

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CHAPTER 2

REINFORCED CONCRETE DEPARTMENT

2.1 INTRODUCTION

Reinforced concrete is one of the principal materials used in many civil engineering applications, such as construction of buildings, retaining walls, foundation, highways, and bridges. It is a composite material consisting of steel reinforcing bars embedded in concrete. The reason concrete is so good at withstanding various kinds of stresses is the interaction between the steel reinforcement and the concrete. In general, reinforced concrete can sustain tension in addition to shear, tensile, and compressive pressures because it combines the compression strength of concrete with the tension strength of reinforcing steel (Chahar & Pal, 2022). These materials' complimentary behaviors allow for a successful integration that maximizes the benefits of each (Guo, 2014). Because of this, reinforced concrete is frequently used as the main structural element in engineered construction projects worldwide.

Structural design, on the other hand, is a meticulous process complementing the significance of reinforced concrete in construction. It involves determining a reliable structural system, selecting materials, and optimizing member sizes to ensure the structure's satisfactory performance throughout its designated design life. The aim of the structural design is to ensure that the structure performs satisfactorily during its design life. In this context, reinforced concrete's unique ability to combine the strengths of its components plays a crucial role in the structural design process, allowing engineers to create robust and enduring constructions that meet performance expectations over time. As a result, reinforced concrete stands not only as a material choice but as an integral component in the broader orchestration of structural design, contributing to the overall success and longevity of engineered constructions.

The connection between structural design and reinforced concrete structure lies in a series of individual members that are interconnected to support the loads imposed on them. A complete building structure can comprise of the following elements: beams, slabs, columns, walls, foundations, and stairs. In order to design a reinforced concrete structure, engineers or architects must adhere to a standardized building code specified in their respective countries. This code of practice gives recommendations for the design and construction of structure. It also ensures the safety, integrity, and performance of constructed buildings and infrastructure. Among the most widely adopted codes globally is the International Building Code (IBC), developed by the International Code Council (ICC). The IBC provides comprehensive guidelines for structural design, including specifications for materials, load requirements, and construction practices. Another prominent code is the American Society of Civil Engineers (ASCE) 7, which focuses on minimum design loads for structures, considering factors such as wind, earthquake, and live loads. The Eurocode, used in European countries, offers a unified approach to structural design, and includes specific sections for different materials and types of structures.

2.1.1 PROJECT BRIEFING

In this section of the report, a comprehensive overview of the work and responsibilities of the Reinforced Concrete Design Department. This department deals with the design of a structure from inception to completion. The several design phases include drafting and analyzing the structural drawings, to designing of the structural elements such as beams, columns, stairs, slabs, and foundations followed by the continuous progression to the complete calculations and detailed drawings of the structural elements. As mentioned in the previous paragraphs, reinforced concrete is widely known for its versatility and durability in constructing various structures worldwide. For this reason, the project's design will use reinforced concrete to withstand the external forces acting on it, ensuring the structure's safety and longevity.

A two-storey school building has been assigned to this department for design and analysis. To help with the design, architectural drawings and design procedures have been provided. The architectural drawings consist of layout plans from every floor, front and side elevations along with section views. From the drawings, various information can be obtained such as the dimensions of the structure, layout of each room and positioning of the structural elements. The total design area of the school is approximately 1386 m^2 with a floor-to-floor level of 3.6 m.

This project examines the integrity and assessment of the structural building, which are strongly influenced by design parameters like material properties, load distribution, and geometrical properties. These parameters must be thoroughly analyzed and evaluated to determine their effects on the structure's behavior. Design calculations utilizing software like Prota Structures to assess structure load distribution are emphasized. However, manual calculations are also done to understand load distribution between structural elements.

2.1.2 Objectives

i. To design the structure based on the ultimate and serviceability limit states

ii. To gain a better understanding of the phases and procedures in designing a reinforced concrete structure

iii. To provide comparison between the results of manual and software calculations

2.1.3 Gantt Chart

		Progress Report (Weekly)														
No	**Activity**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**	**W15**
		Phase 1 (Input Analysis)														
1	Project Briefing															
2	Structure Department Intro/Briefing															
3	RC Structure Design Briefing															
4	Architectural Layout Discussion															
4	Design Specifications															
5	Design Actions (Load Assumption)															
6	Structural Layout Drafting															
7	3D Modelling															
		Phase 2 (Output Analysis)														
8	Poster Submission and Presentation															
9	Design of Staircase															
10	Design of Beam & Slab															
11	Design of Column															
12	Design of Foundation															
13	Analysis and Revision															
14	Interview Session															
15	Final Report Submission															

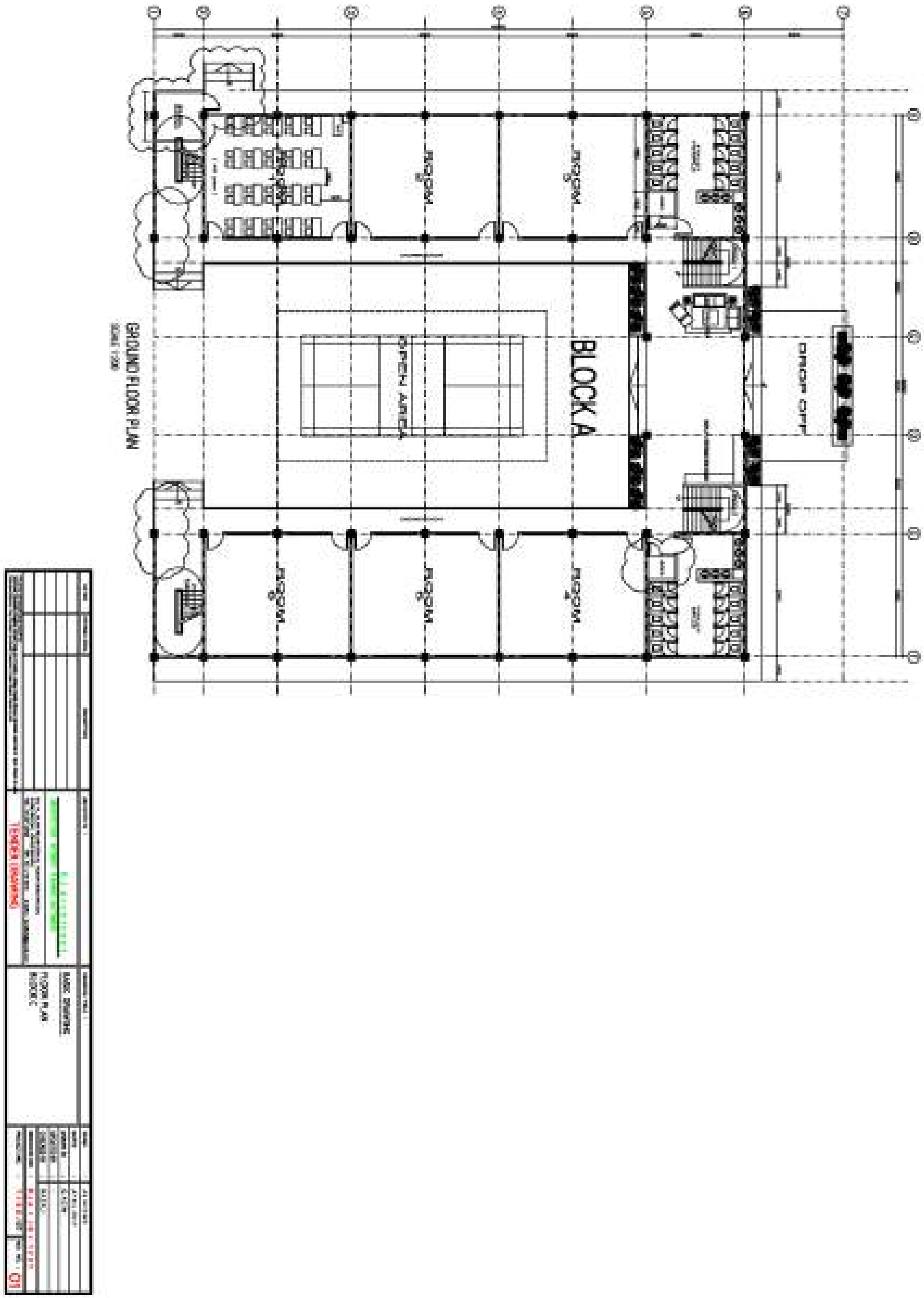
Figure 2.1 Work Schedule Gantt Chart

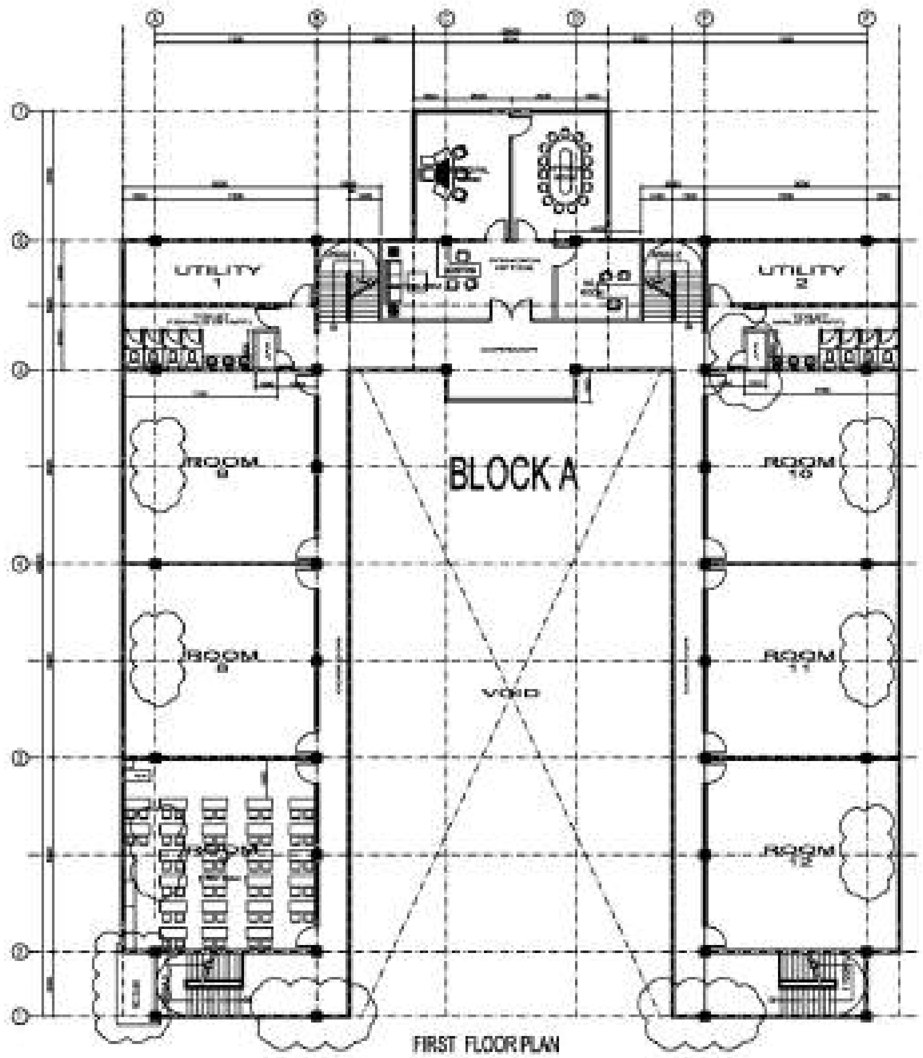
2.2 Architectural Layout

The architectural drawings of the two-storey school building consisted of layout plans, elevation views, and section views. The dimensions of each layouts are specified in the drawings. The architectural drawings are arranged as follows:

i. Layout plans

ii. Elevation and section views

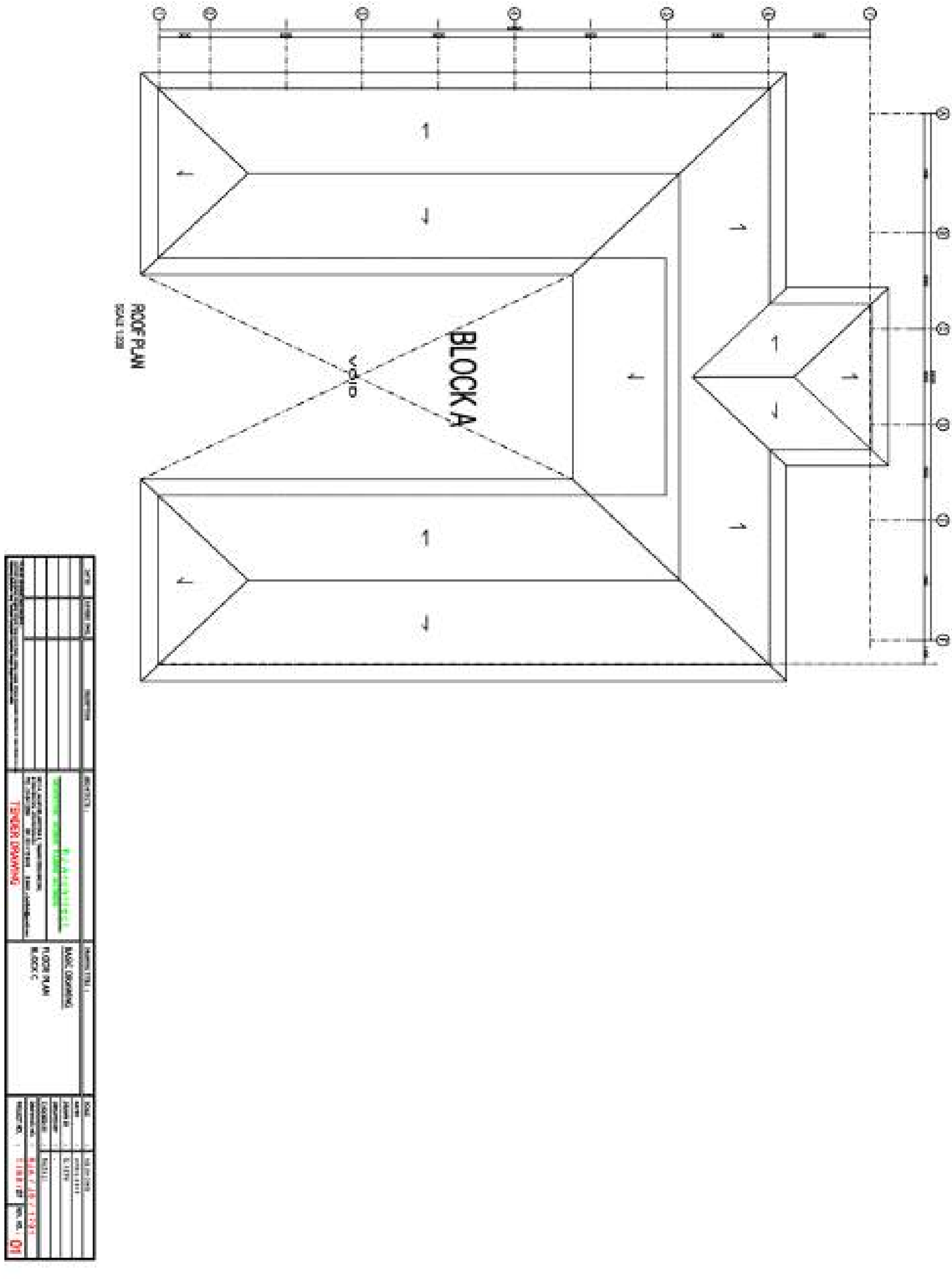

BLOCK A
OPEN AREA
DROP OFF
GROUND FLOOR PLAN
ROOM
TENDER DRAWING

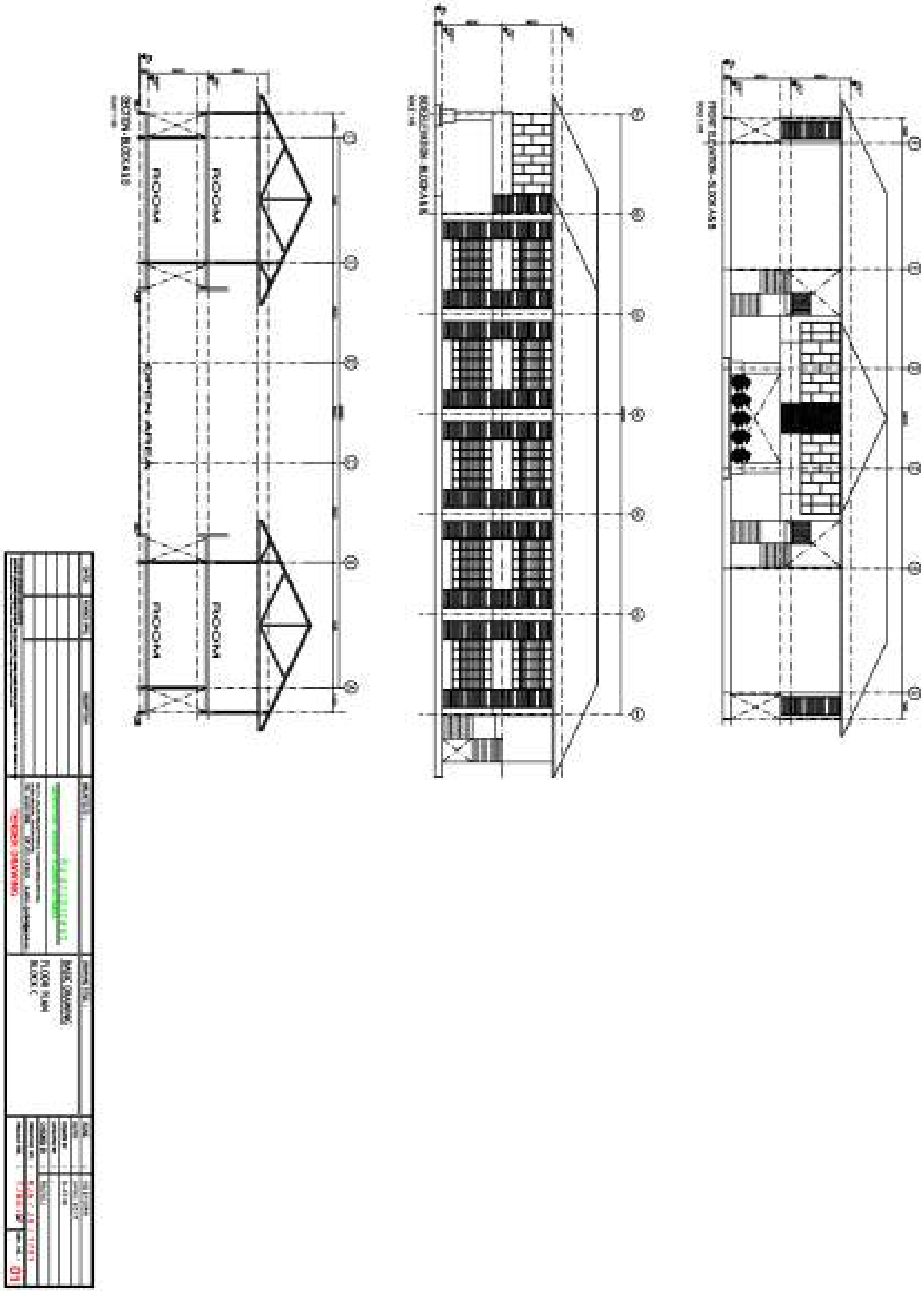


FIRST FLOOR PLAN

SCALE 1:200

DATE	REVISION	DESCRIPTION	ARCHITECTS :	DRAWING TITLE :	
			TENDER DRAWING	BASIC DRAWING FLOOR PLAN BLOCK C	SHEET NO. 01


BLOCK A
VOID
ROOF PLAN
TENDER DRAWING
BASIC DRAWING
FLOOR PLAN

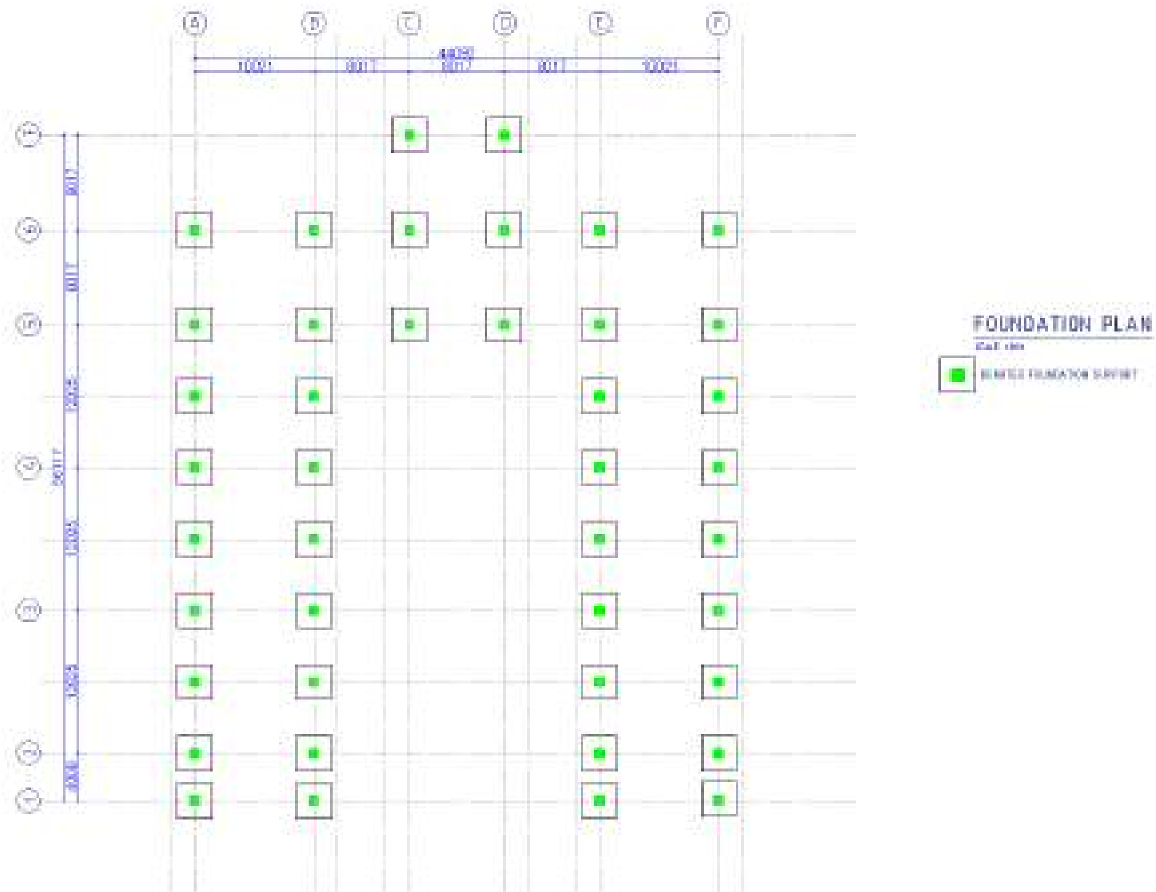

ROOM
ROOM
OPEN AREA
ROOM
ROOM

2.3 Structural Drawings

The proposed structural layouts are drafted using AutoCAD following the information obtained from the architectural drawings. Each positioning of the structural elements is based on the knowledge, experience, and judgement of the engineers. The layout plans consist of the following:

i. Foundation Plan
ii. Ground Floor Plan
iii. First Floor Plan
iv. Roof Floor Plan
v. Truss Plan

The drawings are illustrated below.



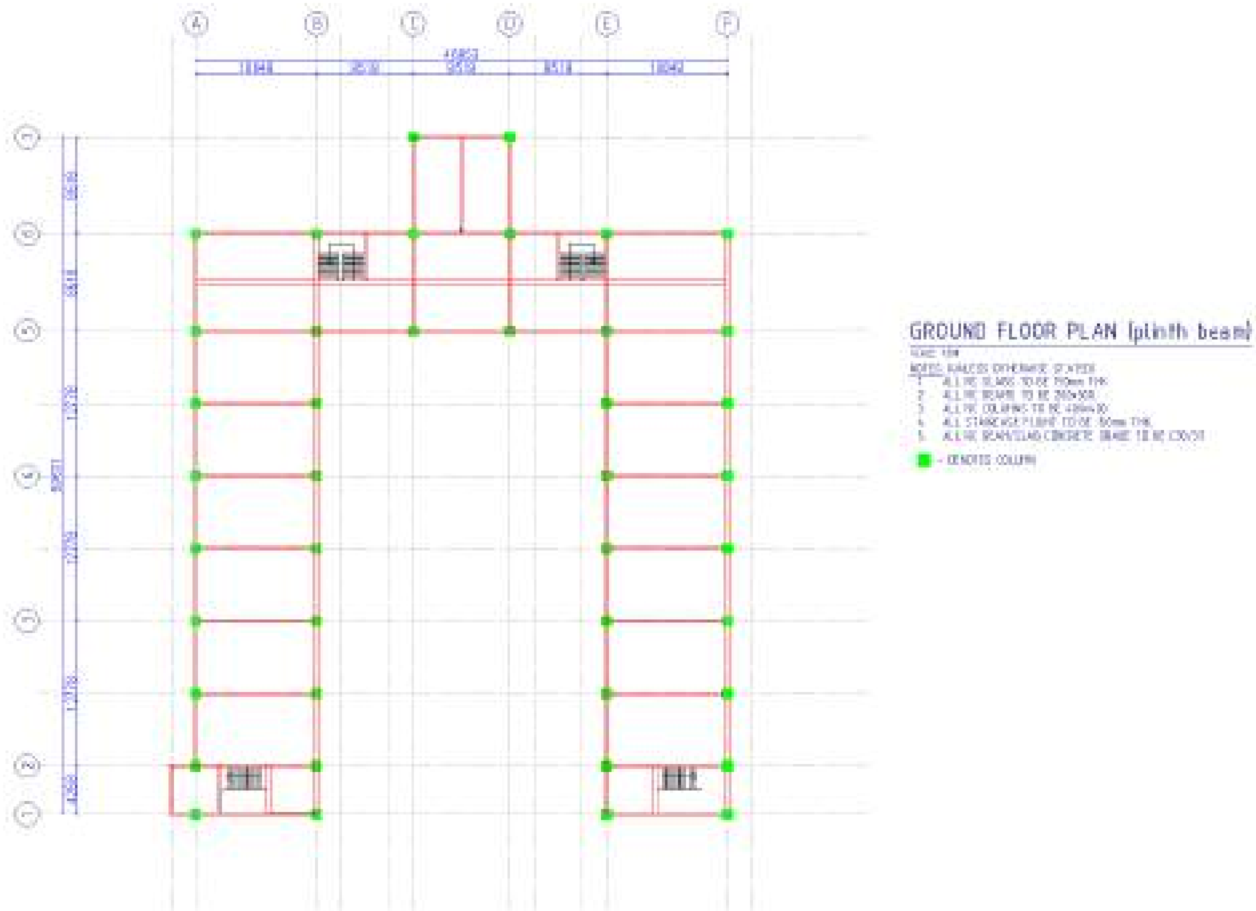
PROJECT: TWO STOREY SCHOOL BUILDING

TITLE: FOUNDATION PLAN

PREPARED BY:
ANAS AHMED
ABDULRAFFI BALINDONG

DATE : 11/1/2024

SCALE 1:200



PROJECT: TWO STOREY SCHOOL BUILDING

TITLE: GROUND FLOOR PLAN

PREPARED BY:
ANAS AHMED
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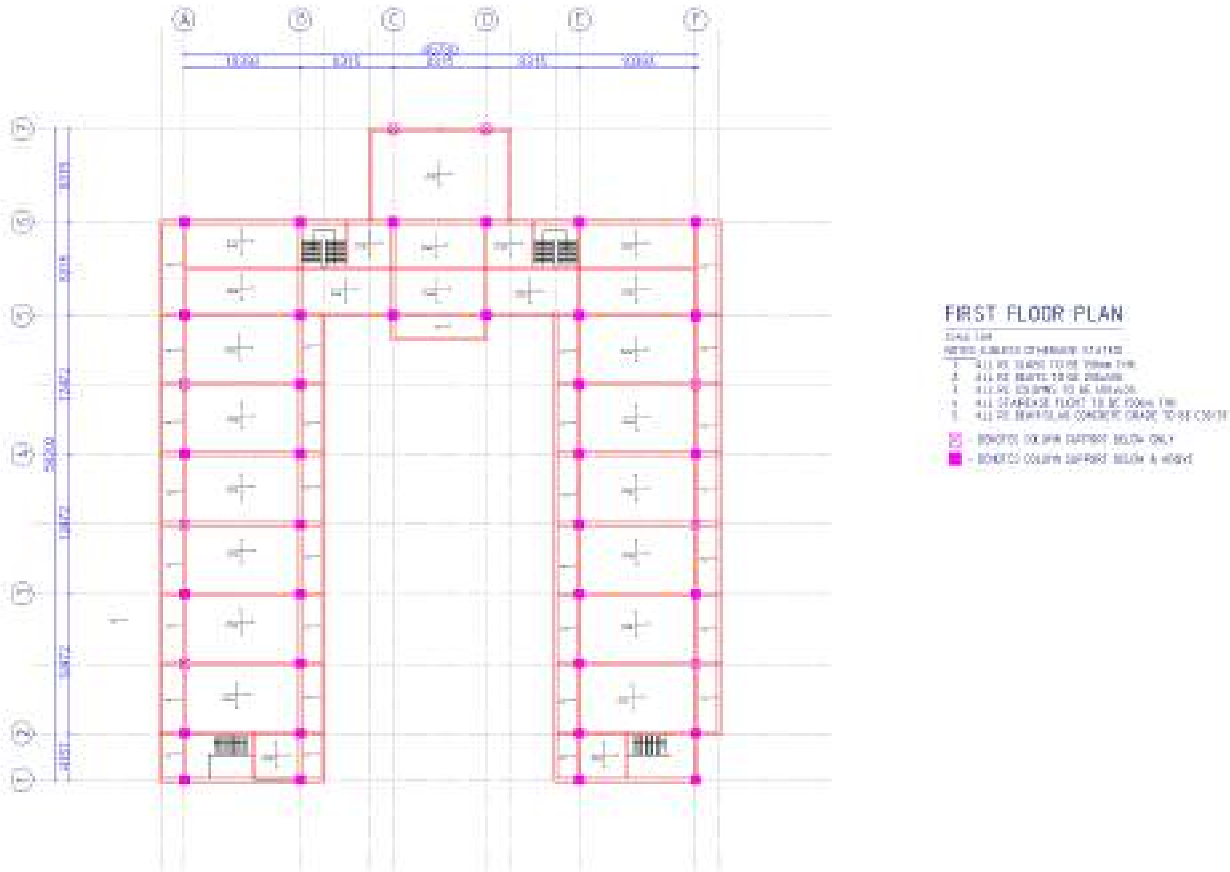
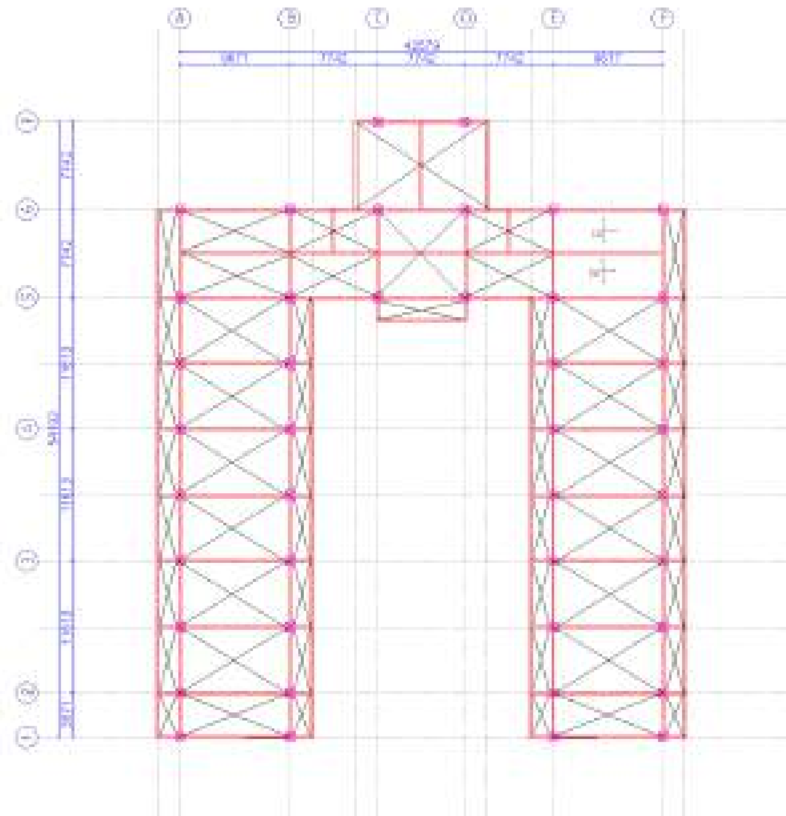
DATE : 11/1/2024

SCALE 1:200

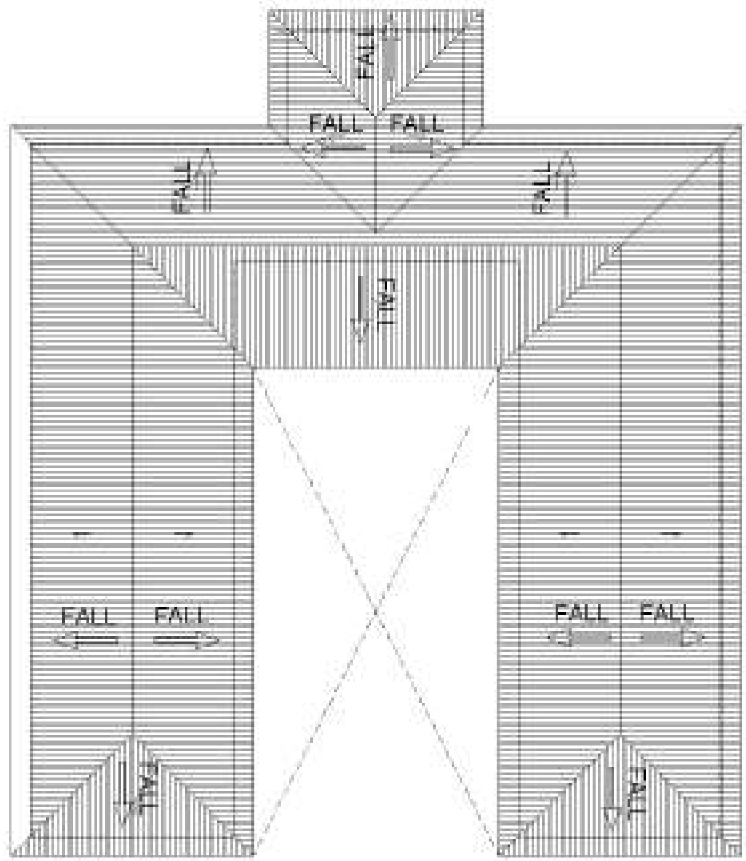


PROJECT: TWO STOREY SCHOOL BUILDING TITLE: FIRST FLOOR PLAN	PREPARED BY: ANAS AHMED ABDULRAFFI BALINDONG	DATE : 11/1/2024 SCALE 1:200



ROOF PLAN

PROJECT: TWO STOREY SCHOOL BUILDING	PREPARED BY:	DATE : 11/1/2024
TITLE: ROOF PLAN	ANAS AHMED ABDULRAFFI BALINDONG	SCALE 1:200



TRUSS LAYOUT

PROJECT: TWO STOREY SCHOOL BUILDING TITLE: TRUSS LAYOUT	PREPARED BY: ANAS AHMED ABDULRAFFI BALINDONG	DATE : 11/1/2024 SCALE 1:200

2.4 Modelling

In order to visualize the 3D representation of the building, Prota Structures was selected for the purpose of analyzing and designing of structural elements, and consequently the building as a whole. Prota Structures is a cutting-edge structural engineering software providing numerous advantages in the design of reinforced concrete (RC) structures. Its integrated platform is one of its strongest points; it provides a unified setting for designing various structural components, including slabs, foundations, columns, and beams along with a predefined code of practice such as Eurocodes, British Standards, American Codes, etc. The Prota Structure's designed structural layout and 3D model views are shown in the figures below.

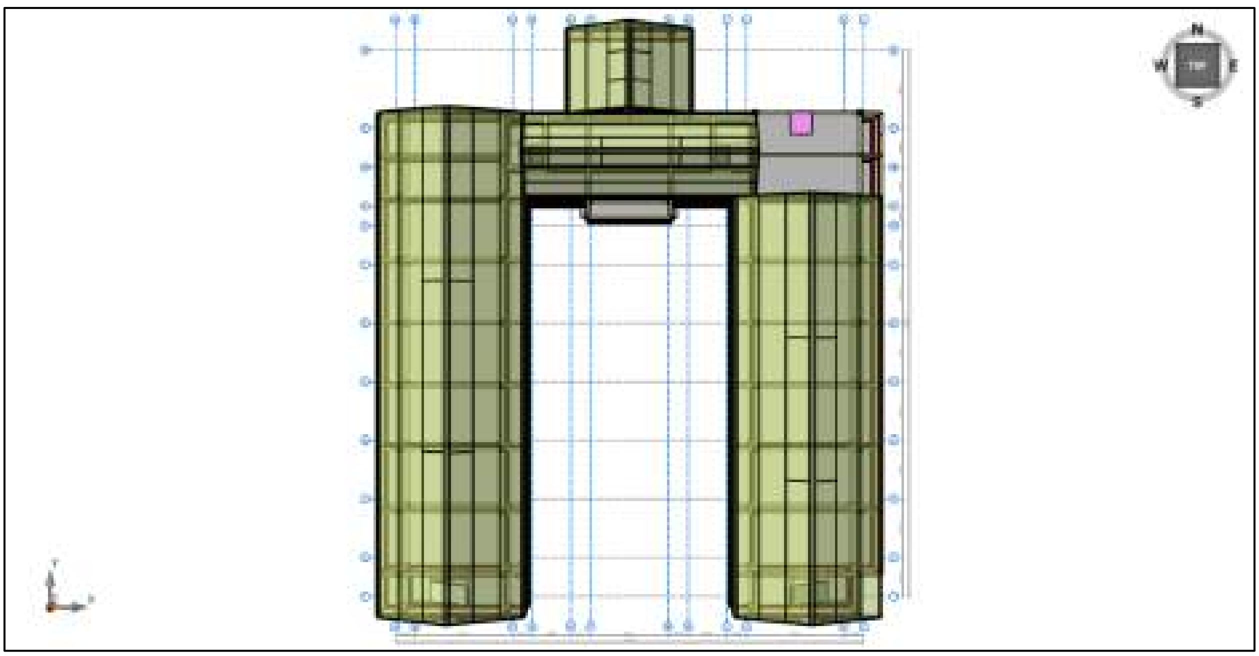


Figure 1 Plan View

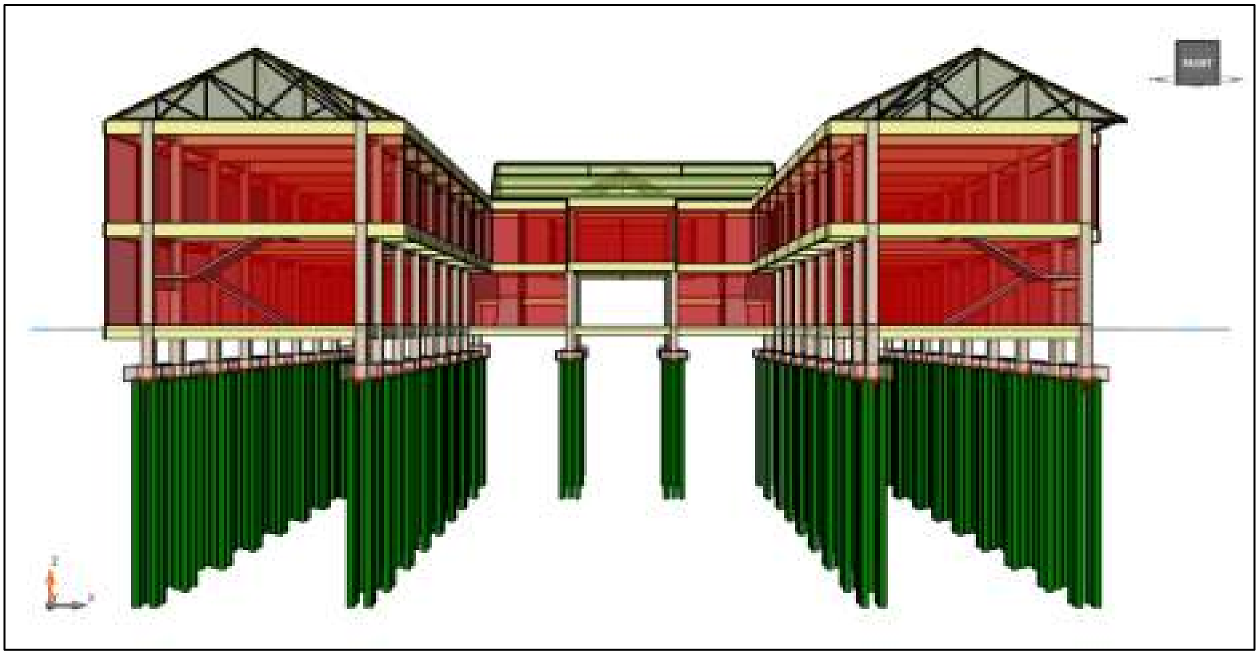


Figure 2 Front View

Figure 3 Isometric View

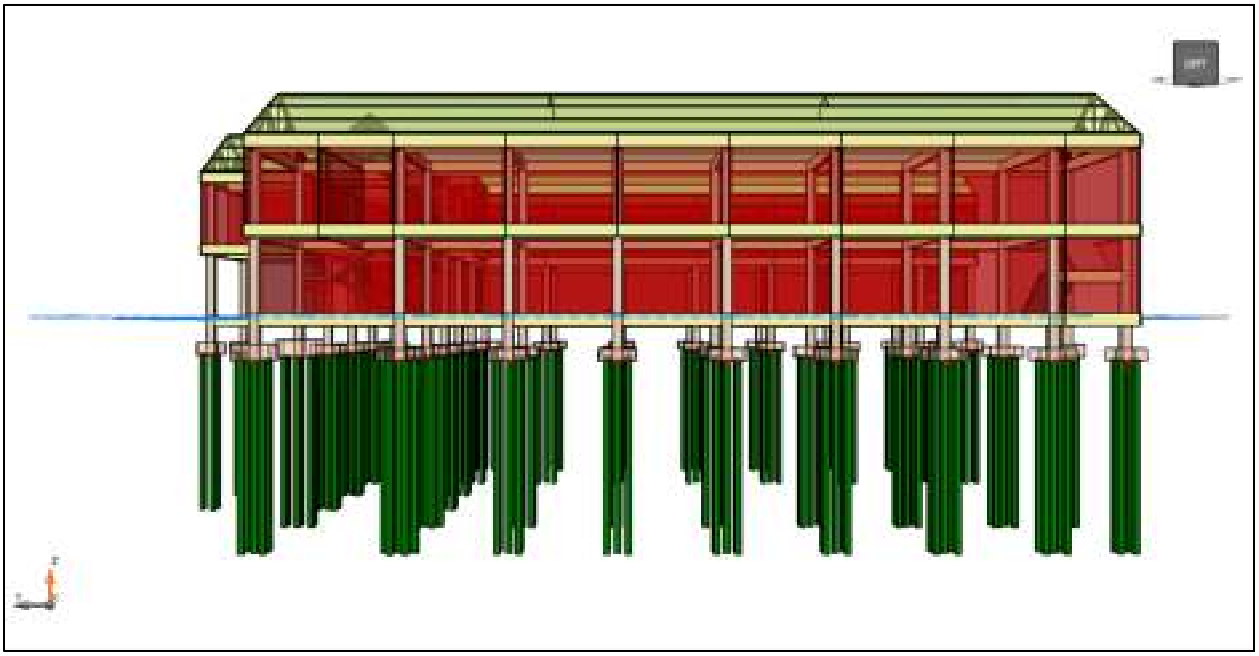


Figure 4 Section Views

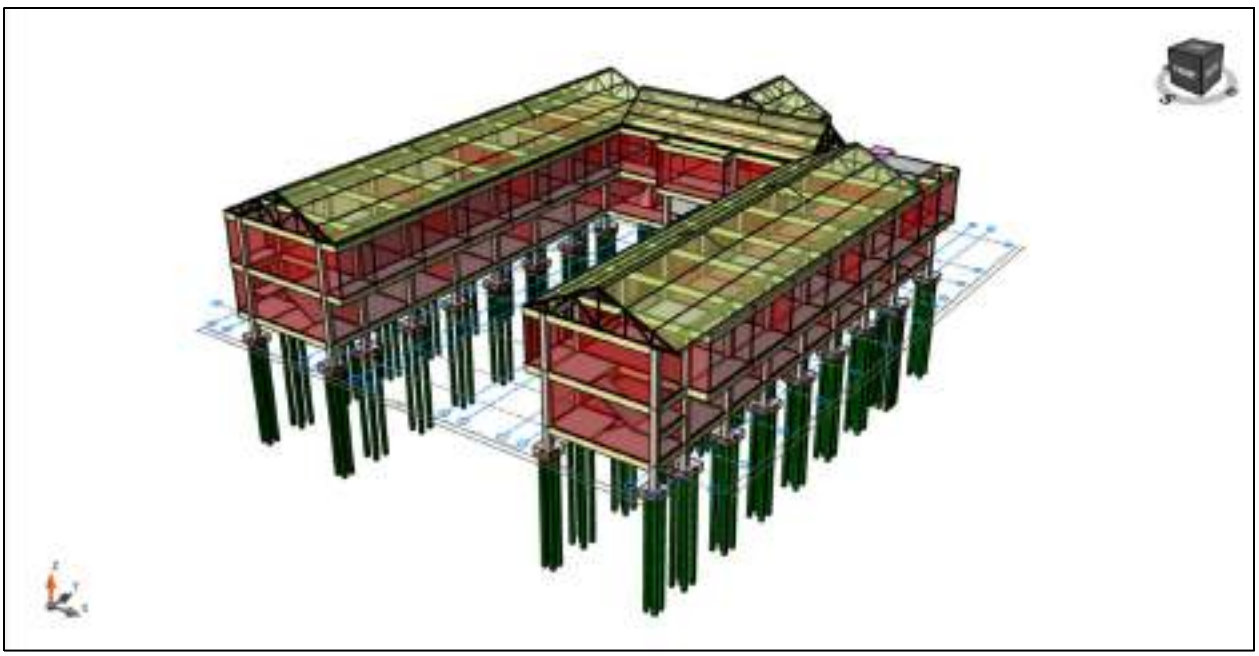
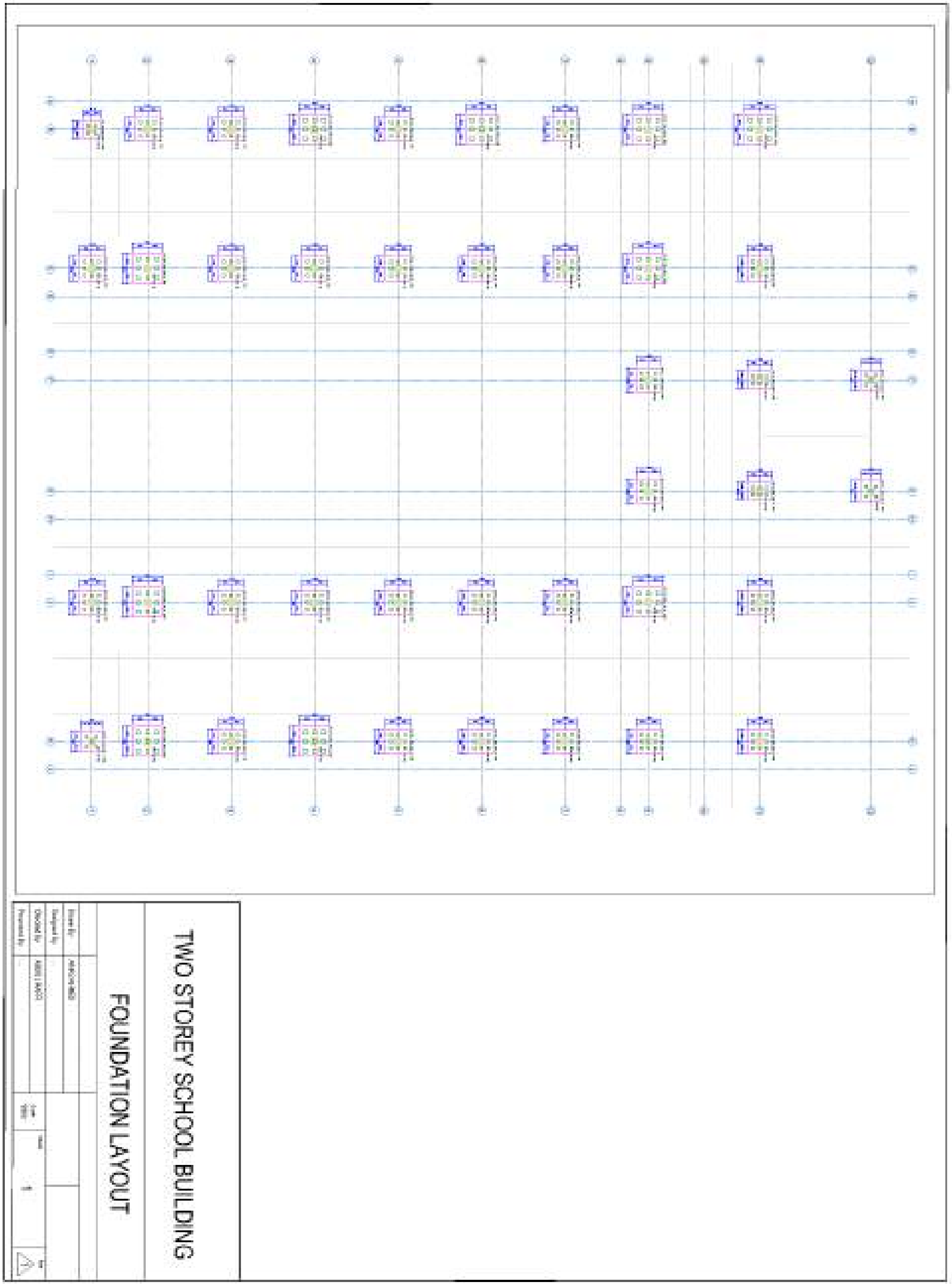
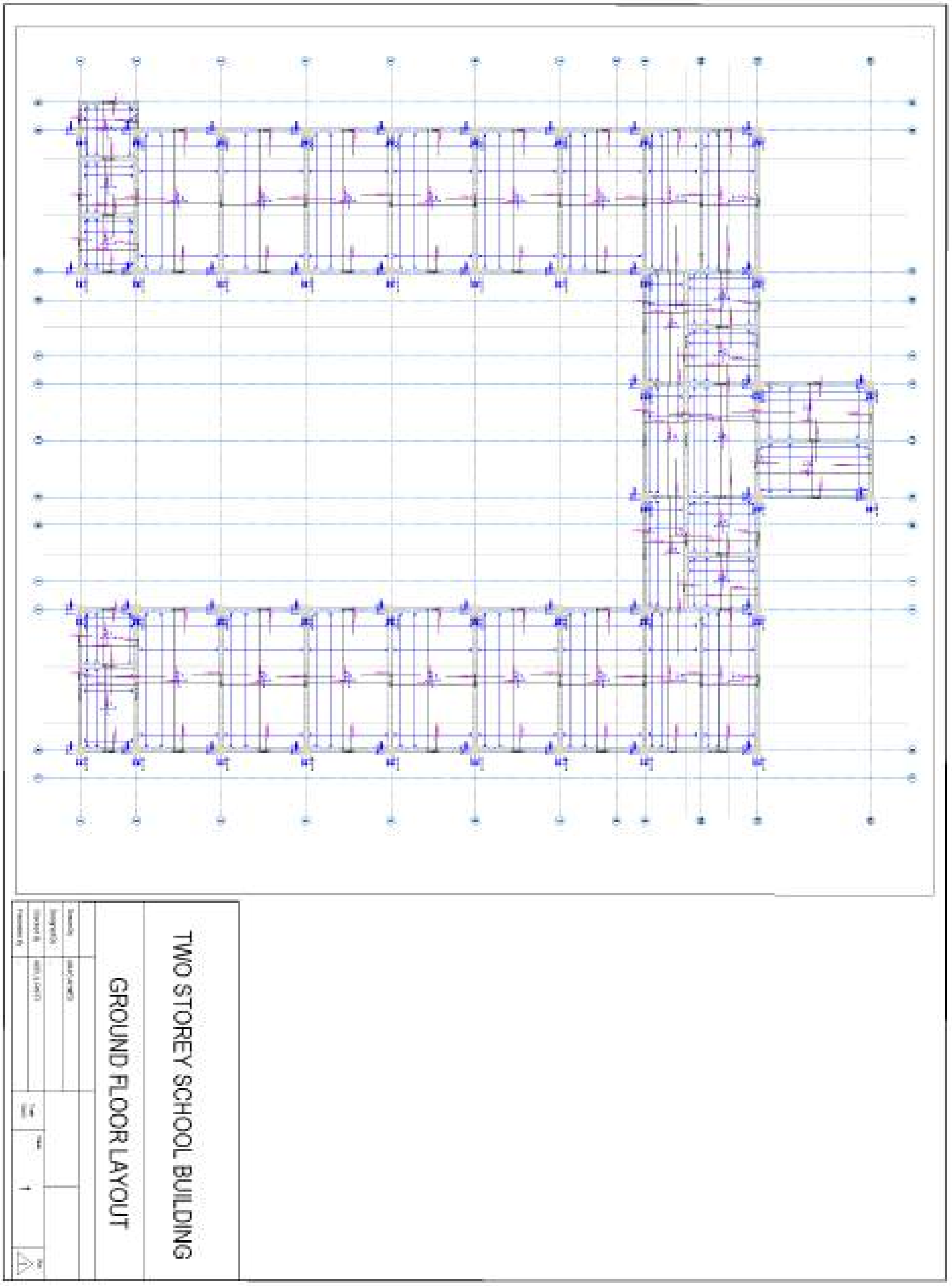
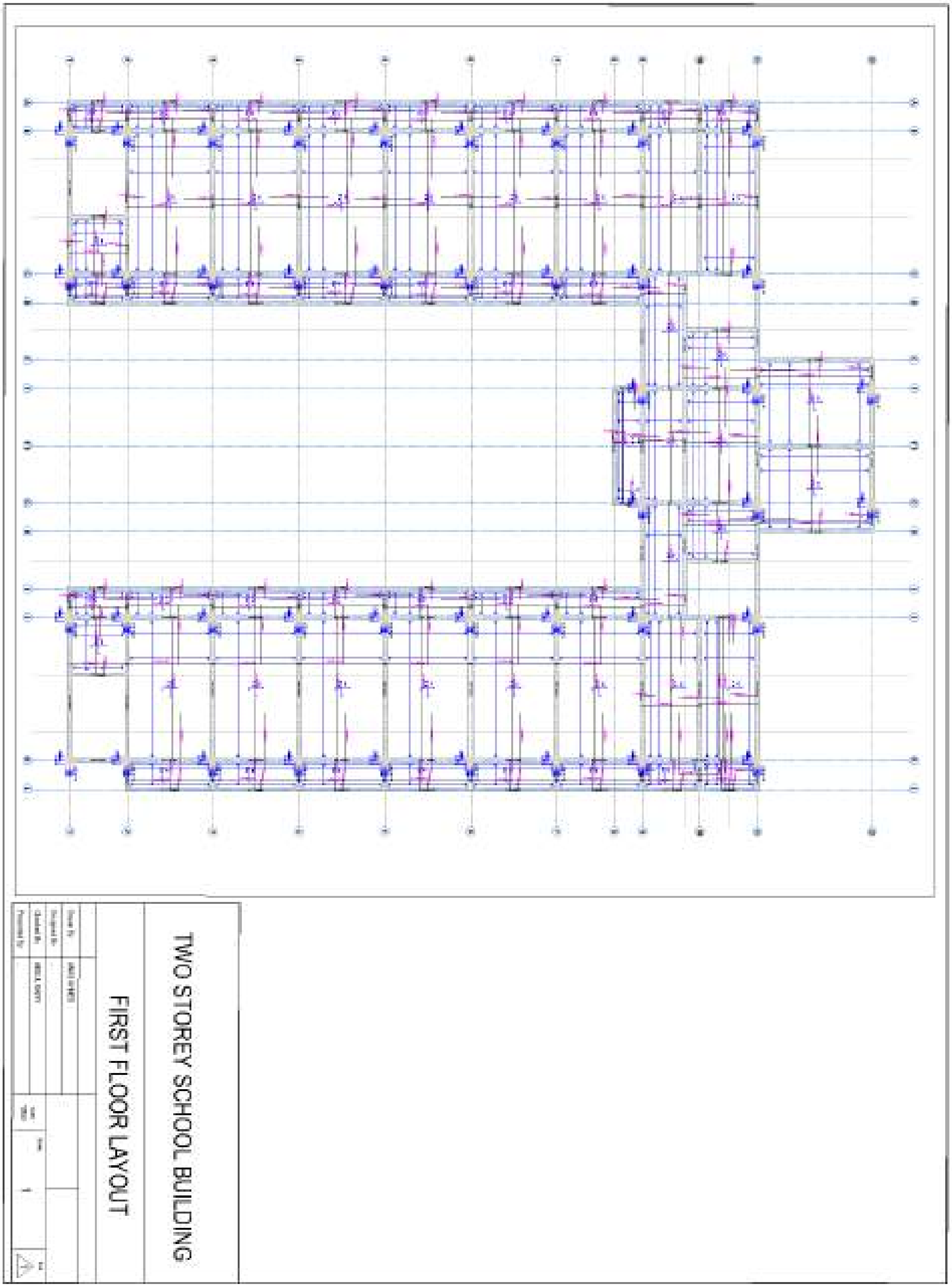


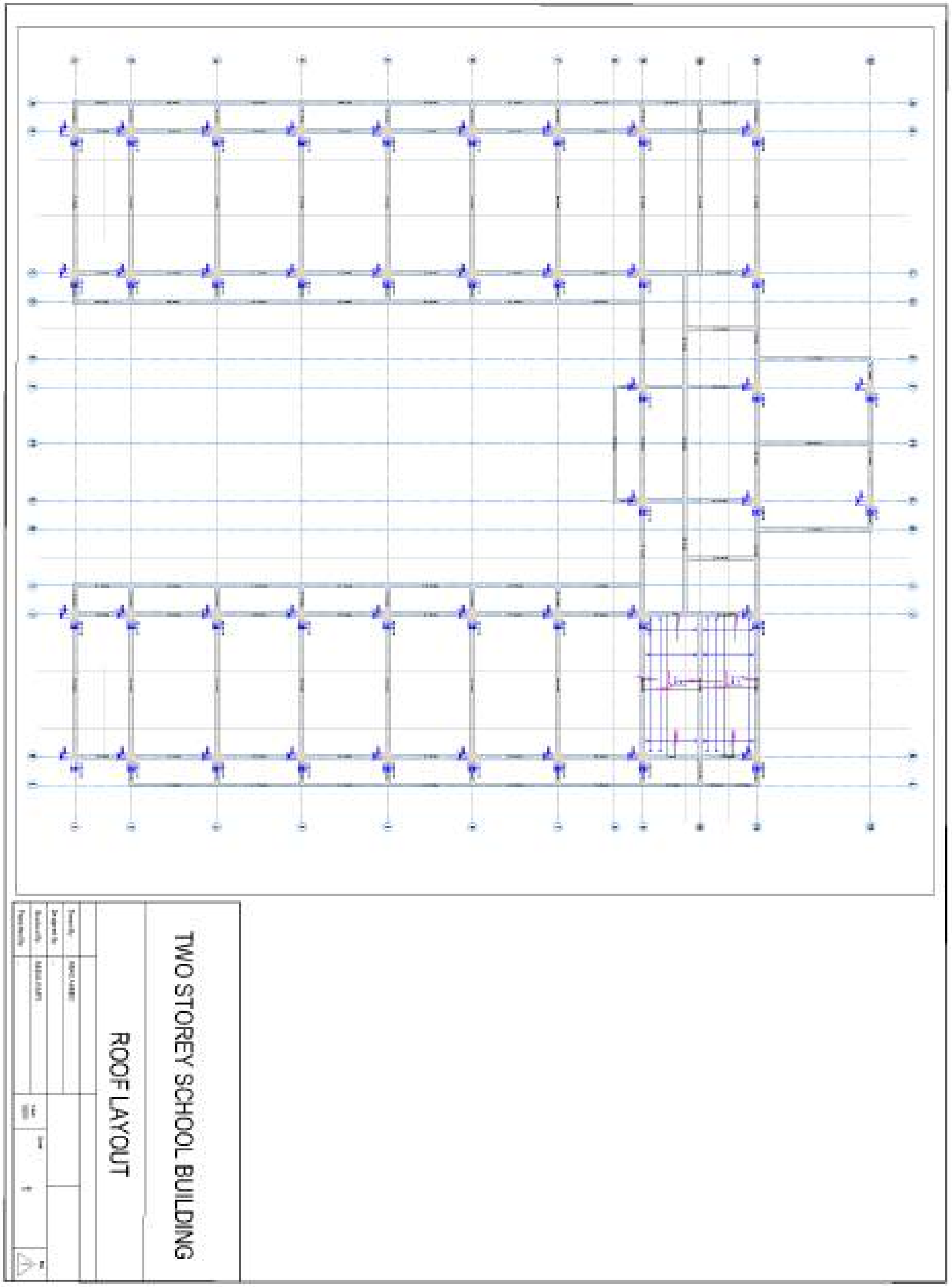
Figure 5 Isometric View


TWO STOREY SCHOOL BUILDING
FOUNDATION LAYOUT


TWO STOREY SCHOOL BUILDING
GROUND FLOOR LAYOUT

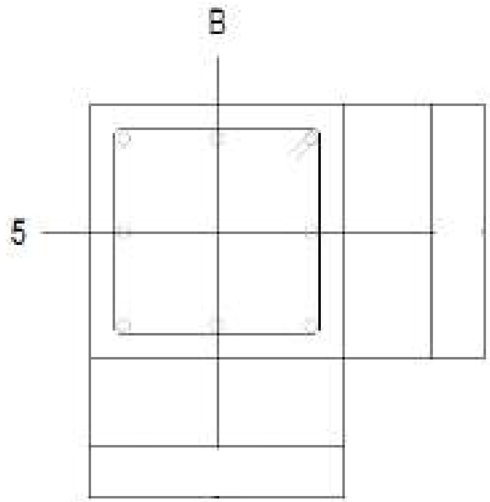


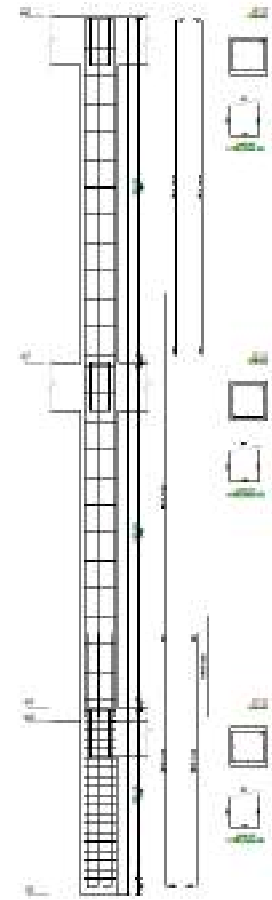
1.


TWO STOREY SCHOOL BUILDING
ROOF LAYOUT

1C13
(400x400)

8H20 L=1050



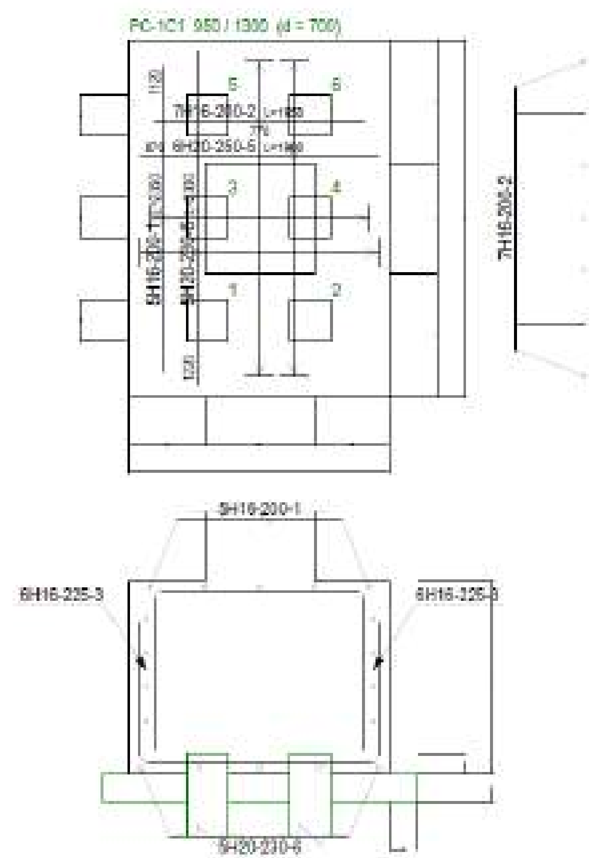


PROJECT: TWO STOREY SCHOOL BUILDING

TITLE: COLUMN ELEVATION SCHEDULE AND DETAILING

PREPARED BY:
ANAS AHMED
ABDULRAFFI BALINDONG

DATE : 11/1/2024

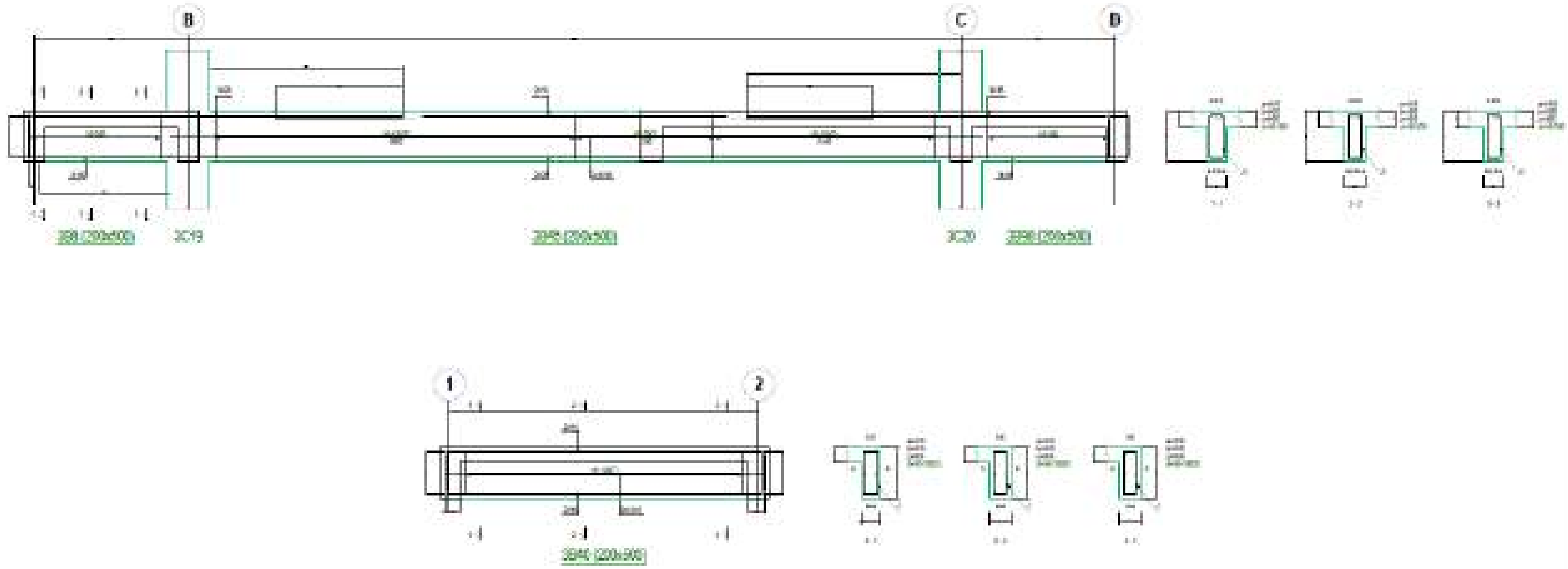


PROJECT: TWO STOREY SCHOOL BUILDING

TITLE: PILE CAP

PREPARED BY:
ANAS AHMED
ABDULRAFFI BALINDONG

DATE : 11/1/2024



PROJECT: TWO STOREY SCHOOL BUILDING

TITLE: BEAM DETAILING

PREPARED BY:
ANAS AHMED
ABDULRAFFI BALINDONG

DATE : 11/1/2024

2.5 Design Specification

Engineers usually design a structure ensuring that it can withstand all the forces acting on it. These forces are either static or dynamic, and they can come from different sources, such as traffic, wind, earthquakes, or human activities. A well-designed structure should be capable of resisting all these loads without collapsing or experiencing any significant damage. For structures to remain durable and withstand a range of loads, specific codes and practices must be followed. Achieving these goals and making sure that potential hazards are adequately addressed during the design process depends heavily on following established codes and recommendations.

The design specifications for the reinforced concrete (RC) structure adhere to European standards, specifically EC3. The structural class is denoted as S4, indicative of the expected performance level. Based on EC2, for a structural class of S4, the recommended design working life spans for 50 years. Thus, the design working life is set at 50 years, as per Table 2.3, ensuring the longevity and durability of the structures. When considering the exposure class, one has to consider the environments in which the structure is exposed to including both chemical and physical conditions. This covers variables including exposure to chemicals, risk of carbonation, moisture content, changes in temperature, and any other pertinent variables unique to the structure's location and purpose.

The exposure class of the structure is identified as XC3, referencing Table 2.4, indicating a moderate risk of corrosion due to environmental conditions.. In terms of fire resistance, the structures are designed to withstand a standard fire for 1 hour (R60). The nominal cover (cnom) for concrete elements is specified at 35mm. The concrete grade employed is C30/37, reflecting a characteristic compressive strength of 30 MPa and 37 MPa for cylinder and cube strengths, respectively. The material strength for other components, such as steel reinforcement, is specified at 500 N/mm^2. The structural elements follow specific dimensions: beams are designed with a cross-section of 200x500mm, columns with 400x400mm, and slabs with a thickness of 150mm. Reinforcement details include main bars with diameters ranging from 16mm to 25mm, secondary bars of 12mm diameter, and links with a diameter of 8mm. These meticulous design specifications ensure compliance with Eurocodes and contribute to the construction of resilient, durable, and code-compliant reinforced concrete structure.

The table below describes the details of the design specifications used during the design process following the codes and recommendations of Eurocodes. These certain codes and guidelines are strictly adhered to during the design process in order for structures to remain durable and able to support a variety of loads.

DESIGN SPECIFICATIONS		
	STRUCTURE Two Storey School Building	
Table 2.1 EN 1992	**DESIGN WORKING LIFE** 50 years	
Table 4.1 EN 1992	**EXPOSURE CLASS** Superstructure & Substructure: (column, beam, slab, wall) XC3 - Moderate humidity : Concrete inside buildings with moderate or high air humidity, External concrete sheltered from rain	
UBBL	**FIRE RESISTANCE** R60 1 hour - School, Max. height < 7.5 m, Floor area = 1382 m^2	
EN 206 Table F1	**MATERIALS** Characteristic strength of concrete, f_{ck} = 30 N/mm^2 Characteristic strength of main reinforcement, f_{yk} = 500 N/mm^2 Characteristic strength of shear reinforcement, f_{ywk} = 500 N/mm^2	
	DIMENSION Diameter of main bar, $\emptyset_{bar}$ = 25 mm Diamter of secondary bar, $\emptyset_{bar}$ = 12 mm Diameter of links, $\emptyset_{link}$ = 8 mm Beam size, b x h (1st flr) = 200 x 500 mm Beam size, b x h (roof) = 200 x 500 mm Column size, b x h = 400 x 400 mm Slab thickness, = 150 mm Concrete cover, C = 35 mm	

Figure 7 Summary of Design Specifications

In Prota Structures, the input parameters, and materials such as concrete grade and steel grade are indicated as follows:

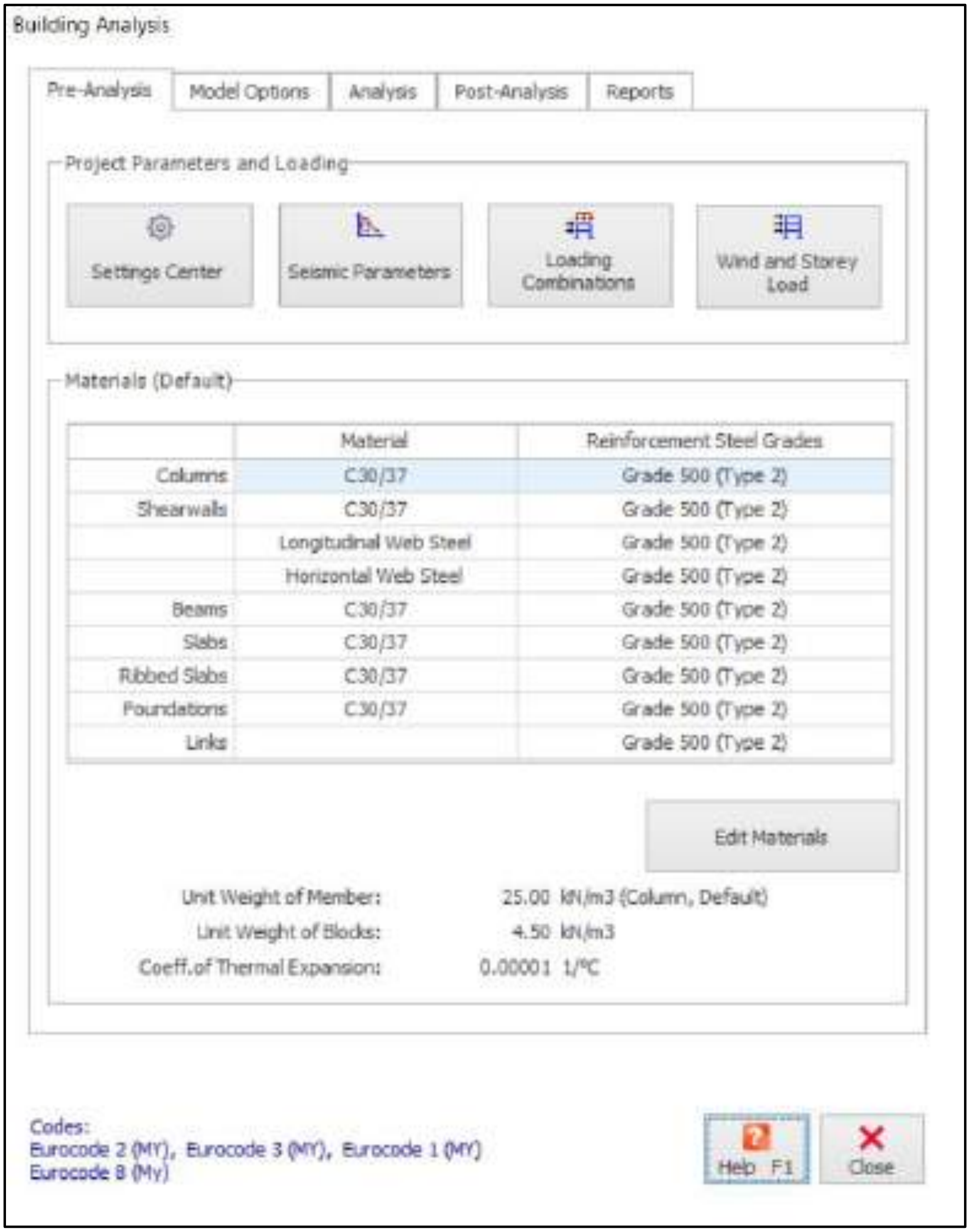


Figure 8 Input Parameters on Prota Structures

2.5.1 Load Assumptions

The assumption of each loading at every floor is based on Goodchild, C.H. et al. "Worked Examples to Eurocodes 2: Volume 1". The loadings are specifically selected for areas unique to the building such as classroom, corridor, staircase, toilets, and utilities.

DESIGN SPECIFICATIONS					
	ACTIONS				
	Permanent actions				
	Unit weight of reinforced concrete	=	25	kN/m^3	EN 1991 Table A1
	Unit weight of water	=	10	kN/m^3	EN 1991 Table A7
	Brickwall : 100 mm thick	=	2.60	kN/m^2	Table 2.13 Ref. [1]
	For Classroom:				
	Floor finishes:				
	Screed (25mm thk)	=	0.60	kN/m^2	Table 2.14 Ref. [1]
	Carpet / flooring	=	0.05	kN/m^2	Table 2.14 Ref. [1]
	Suspended ceiling	=	0.15	kN/m^2	Table 2.14 Ref. [1]
	Services	=	0.20	kN/m^2	Table 2.15 Ref. [1]
	Tiles ceramic floor	=	1.00	kN/m^2	Table 2.15 Ref. [1]
	For Corridors:				
	Floor finishes				
	Screed (25mm thk)	=	0.60	kN/m^2	Table 2.14 Ref. [1]
	Suspended ceiling	=	0.15	kN/m^2	Table 2.14 Ref. [1]
	Services	=	0.20	kN/m^2	Table 2.14 Ref. [1]
	Tiles ceramic floor	=	1.00	kN/m^2	Table 2.15 Ref. [1]
	Roof:				
	Insulated panel	=	0.20	kN/m^2	Table 2.15 Ref. [1]
	Roof tiles	=	0.67	kN/m^2	Table 2.15 Ref. [1]
	Purlins	=	0.10	kN/m^2	Table 2.15 Ref. [1]
	Services	=	0.10	kN/m^2	Table 2.15 Ref. [1]
	Variable actions				
	Imposed load:				
	Roof	=	0.60	kN/m^2	
	Classroom	=	3.00	kN/m^2	EN 1991 Table 6.2
	Corridor	=	4.00	kN/m^2	EN 1991 Table 6.2
	Staircase	=	3.00	kN/m^2	EN 1991 Table 6.2
	Toilet	=	2.00	kN/m^2	EN 1991 Table 6.2
	Reference				
	[1] Goodchild, C.H. et al. "Worked Examples to Eurocodes 2: Volume 1"				
	MS EN 1991: 2010 Eurocode 1 - Actions on structures				
	MS 1553: 2002 Code of practice on wind loading ofr buidling structure				

Figure 9 Summary of Load Assumptions

2.6 Design Input

2.6.1 Slab Design

In both manual and software design, the slab thickness is determined before the slab is designed. For every slab, a thickness of 150 mm has been specified. The permanent load and variable load for Prota Structures need to be manually entered. The software automatically indicates the type of slab, which informs the distribution of load acting on it. The same process applies for manual computations. The distribution of slab actions depends upon the dimensions of the slab, the supporting system, and the boundary conditions.

Figure 10 Slab Design Properties in Prota Structures

2.6.2 Beam Design

The beam design is based on the analysis and understanding of architectural drawings. However, as these drawings lack specific beam placement details, engineers must rely on their knowledge, experience, and judgement to strategically determine the most suitable locations. The dimension of the beam is designed to be 200 x 500 mm for all floor levels. The primary types of beams used in this building are simply supported beams and continuous beams.

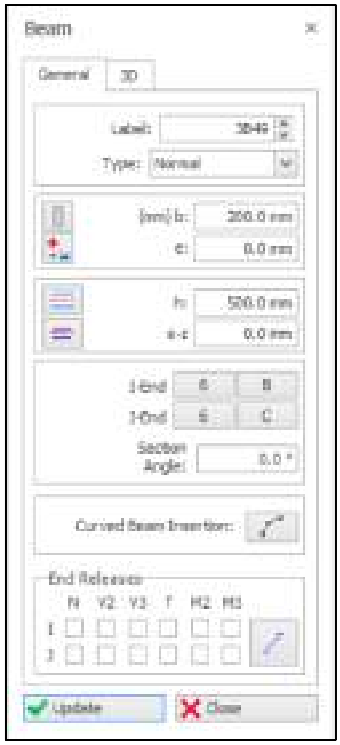


Figure 11 Beam Design Properties in Prota Structures

The majority of the beams are made to withstand brickwall loads. The structural designs specify the beams' alignment and arrangement. When arranging the beams in the plan as illustrated in Figure 2.9, the loading from brickwalls can be input into the software design. Brickwalls are designed to be 100 mm thick, in accordance with the Malaysian standard that is displayed in the software. After subtracting the height of the beam, the brickwall's height is 3.1 meters.

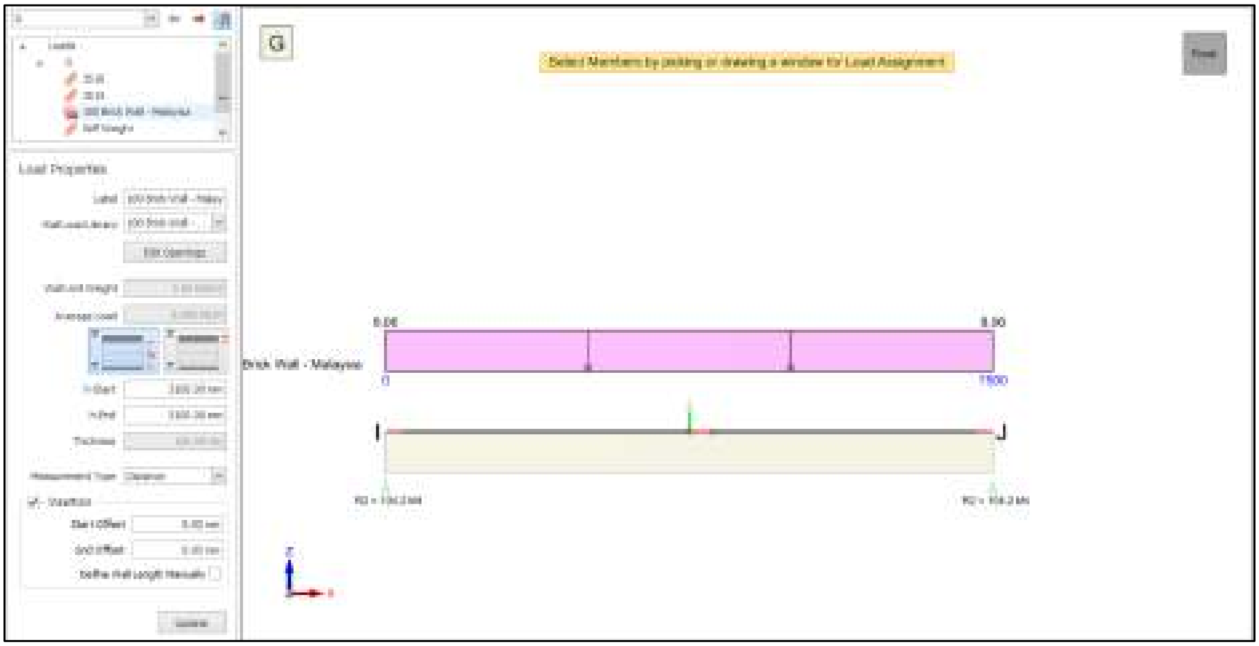


Figure 12 Brickwall Properties

2.6.3 Column Design

The column allocation is based on architectural drawings. Column locations are avoided from openings such as doors and windows. Column dimensions are designed to be 400 x 400 mm. In this project, only vertical load is considered. The columns are designed to sustain the load from column self-weight, truss, beam and slab.

Figure 13 Column Dimension Input

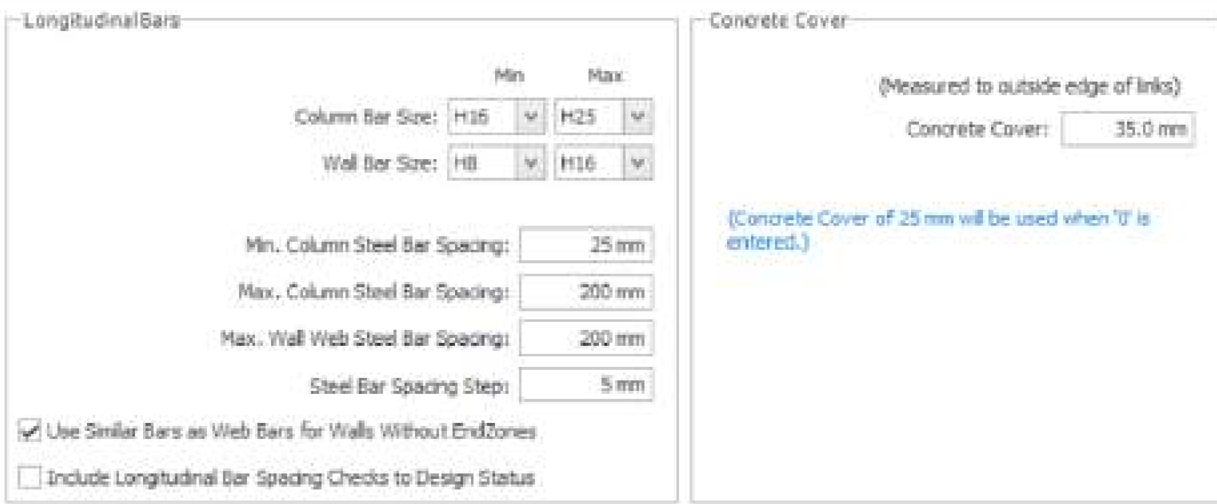


Figure 2.18 Concrete Cover for Column

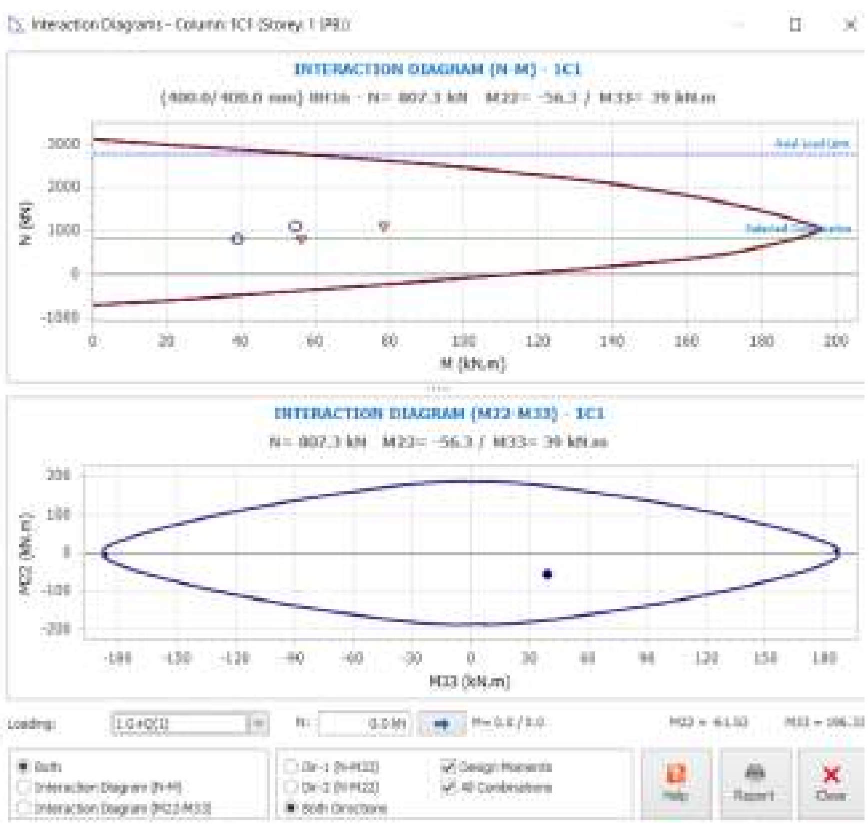


Figure 14 Column Interaction Diagram

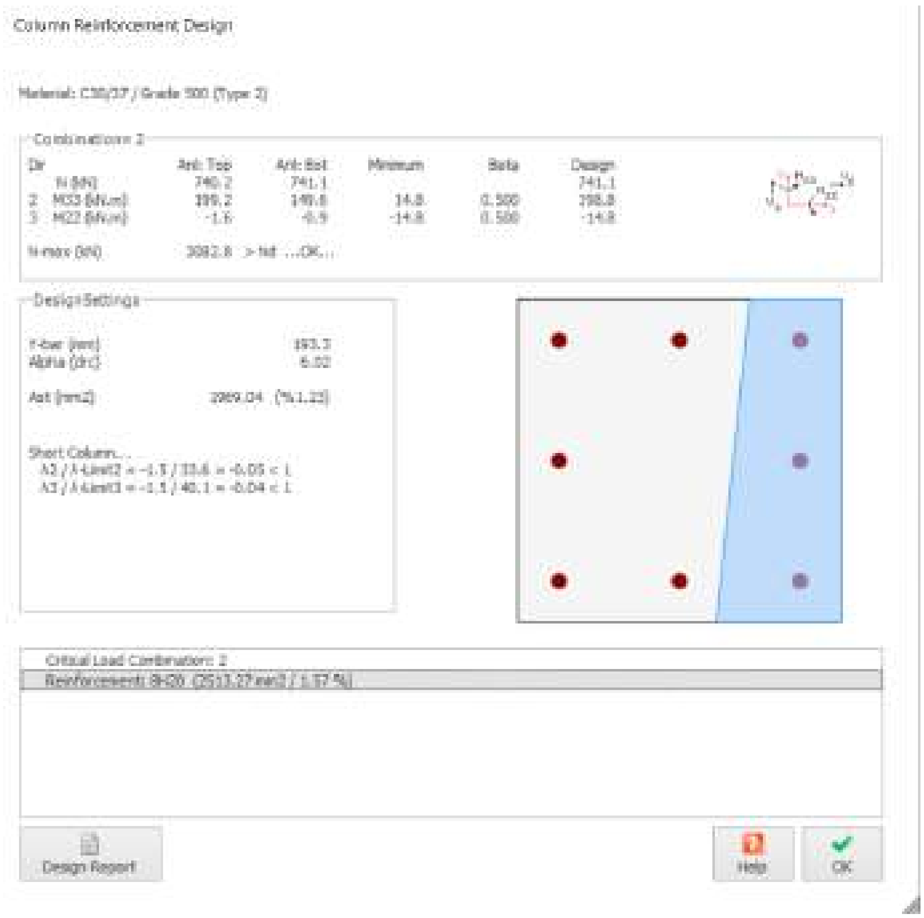


Figure 15 Interactive Column Design

2.6.4 Foundation Design

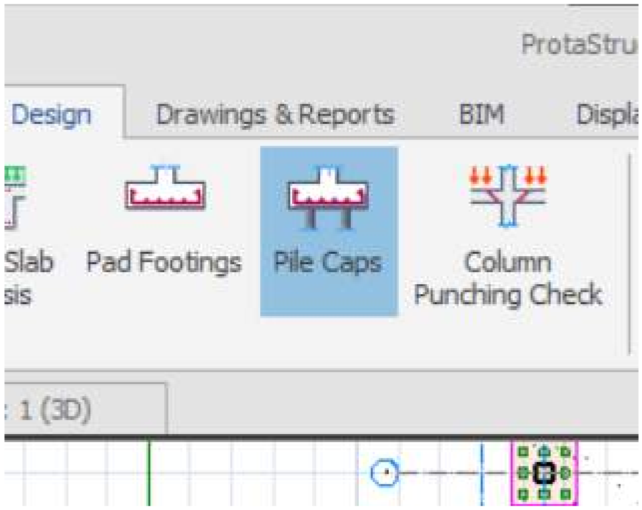


Figure 2.18 Pile cap design button

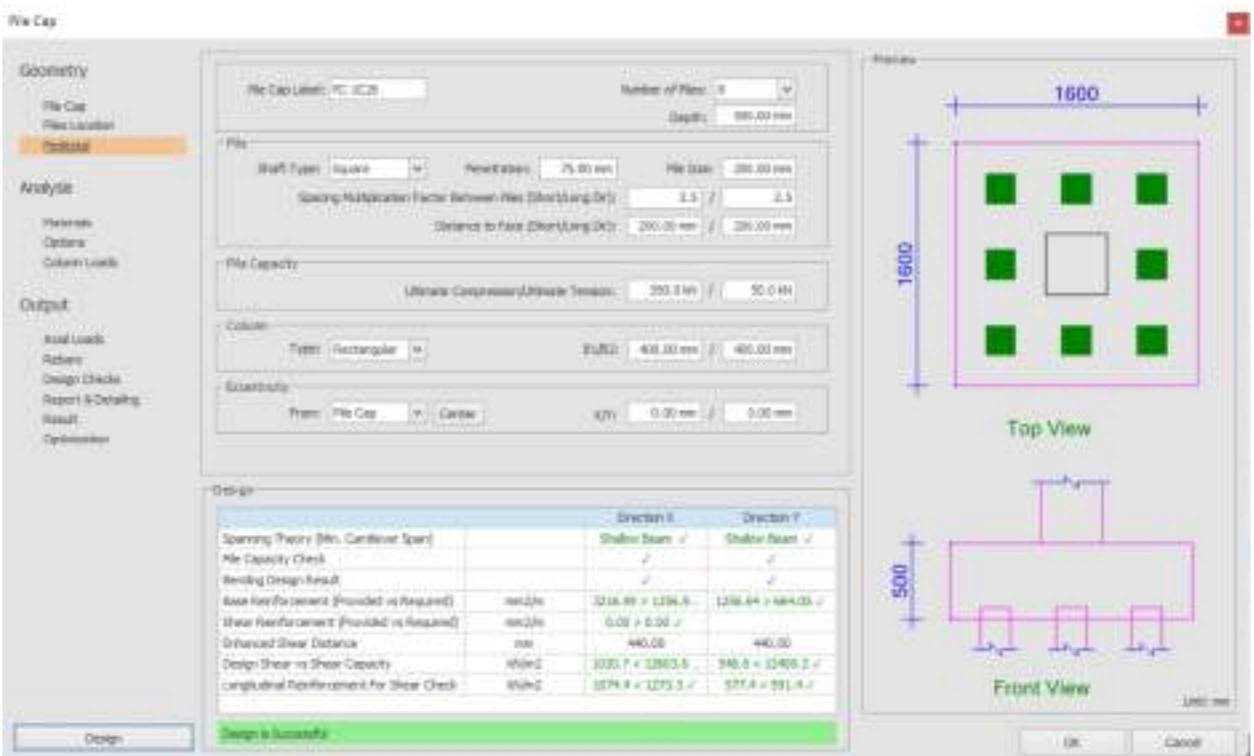


Figure 16 Interactive Pile cap design

2.6.5 Staircase Design

Stairs play a crucial role in multi-storey buildings, facilitating the movement between floors and connecting various levels. They typically comprise a series of steps, often with one or more intermediate landings placed between floor levels. In the case of the two-storey bungalow, the stairs are constructed with two flights of steps and three landings. The specific design details of the stairs are provided in the attached appendix.

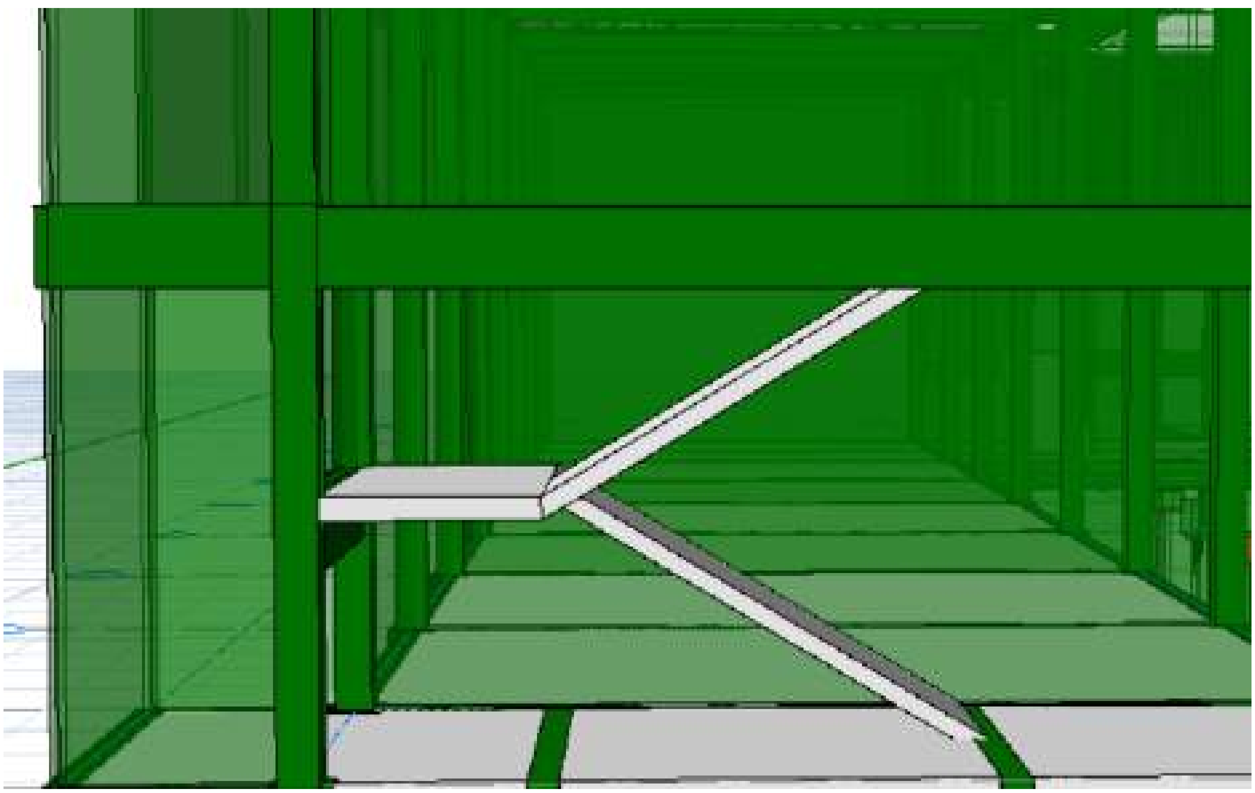


Figure 17 Side 3D view of stair model

2.6.6 Truss Design

A truss is a structural framework composed of interconnected triangular units, commonly employed in engineering and construction for creating stable structures such as bridges and roofs. The distribution of loads in trusses is efficient as they transfer forces along their members, experiencing either compression or tension. These trusses often utilize connections held together by bolts or welds and are typically made of lightweight materials like steel or wood. Various types of trusses exist, each designed with specific optimizations for diverse applications and load requirements. In general, trusses are widely utilized in construction projects due to their ability to provide strength, stability, and effective load distribution. In the case of the two-story school, a king post type truss has been designed.

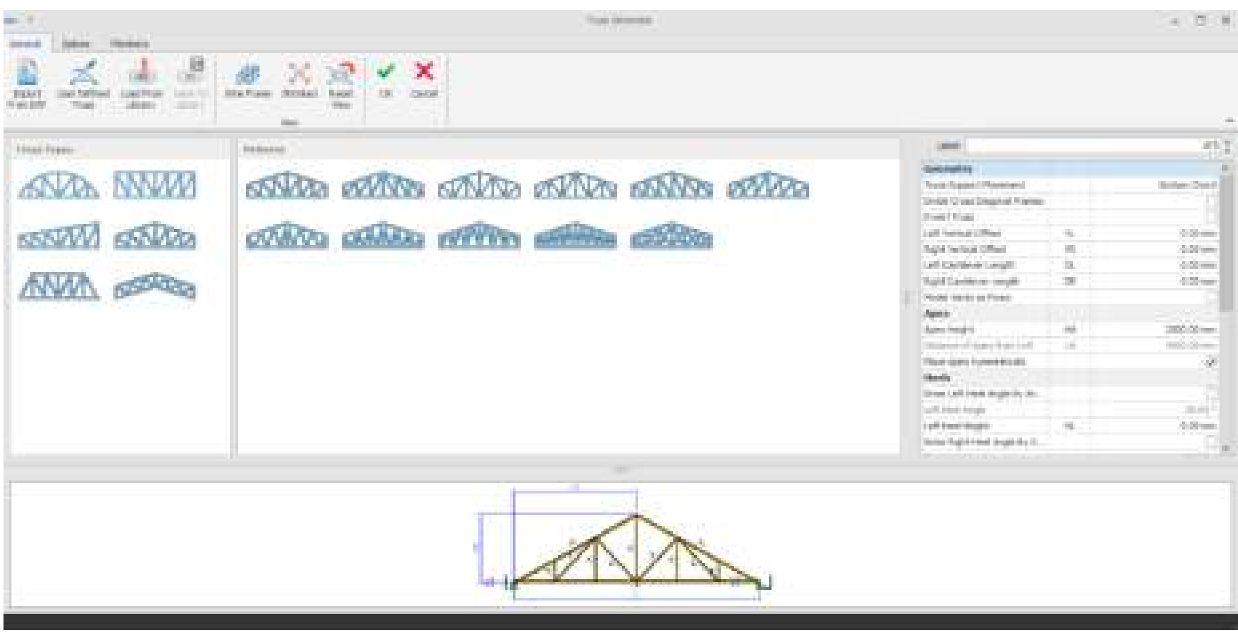


Figure 18 Truss configuration

2.7 Analysis Output

In Prota Structures, after specifying properties and creating a visual design model, a comprehensive layout plans and 3D physical model can be viewed for analysis. This visual inspection helps identify potential flaws in structural elements that may lead to errors or miscalculations in the final structure. To assist with the inspection, under the ‘review’ toolbar, ‘building model check’ can be used to detect and audit the inconsistencies in the model. After the visual inspection is over, the "analysis of the model," the following step, can be carried out (Figure --). To proceed with this process, the ‘Building Analysis’ will be selected under the ‘Analysis Tab’. The user must once again verify the desired concrete grades and steel yield strength mentioned in the design specification (Figure --).

Figure 19 Building Model Check

Figure 20 Pre-Analysis Check

After the pre-analysis is done, the model is ready to be analyzed. To proceed with the next process, select the 'Analysis' tab to run the 'Building Analysis'. All relevant boxes must be ticked before starting the analysis run.

Figure 21 Building Analysis

Before the process of analyzing the model, the software will perform a preliminary analysis check and display the analytical model of the structure. This is to provide a clear and detailed representation of the structural analysis.

Building analysis in Prota Structures is a time-intensive process, involving the thorough examination of each structural element and the overall structure. Once completed, the results are generated and stored for easy access in the "Post-Analysis" tab.

Figure 22 Post-Analysis Tab

The figure displays the analytical model of the structure, illustrating how it behaves under external loads. Using the 'Animation' function, users can visually observe the structure's movement when subjected to different loads. The blue color represents the original position, while the red line indicates the displacement caused by the applied loads.

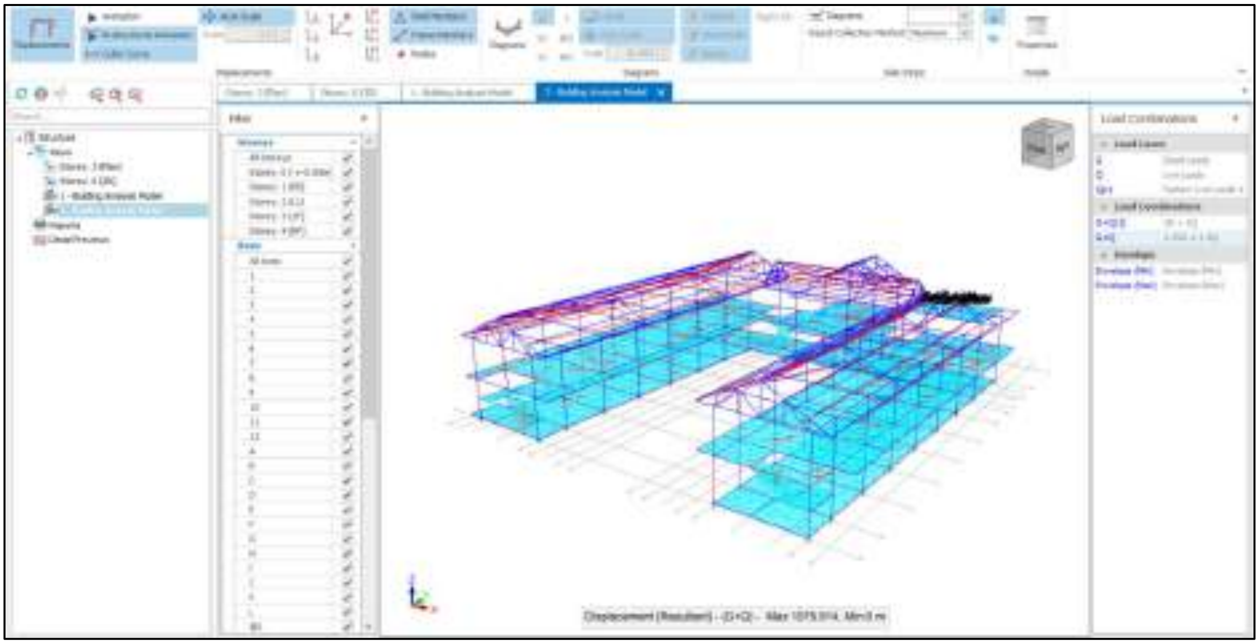


Figure 23 Analytical Model of the Structure

2.8 Design Results

In the analysis of slab, beam and column design, the results are presented within the 'Storey Beam Section Design and Detailing', 'Column Design Reinforcement', and ‘Slab Analysis and Design’ sections, respectively. A 'Green Tick' in the design column signifies that the structural elements, with their section properties, meet the required design standards, ensuring their safety and capacity to withstand applied loads. This visual cue simplifies the identification of elements that pass the design criteria. Additionally, the analysis offers insights into any potential failures, providing detailed information and recommendations for redesigning specific structural elements if needed which can then be modified by the engineer upon addressing any related issues and make necessary corrections. Prota Structures will then recheck the elements to confirm compliance with design standards.

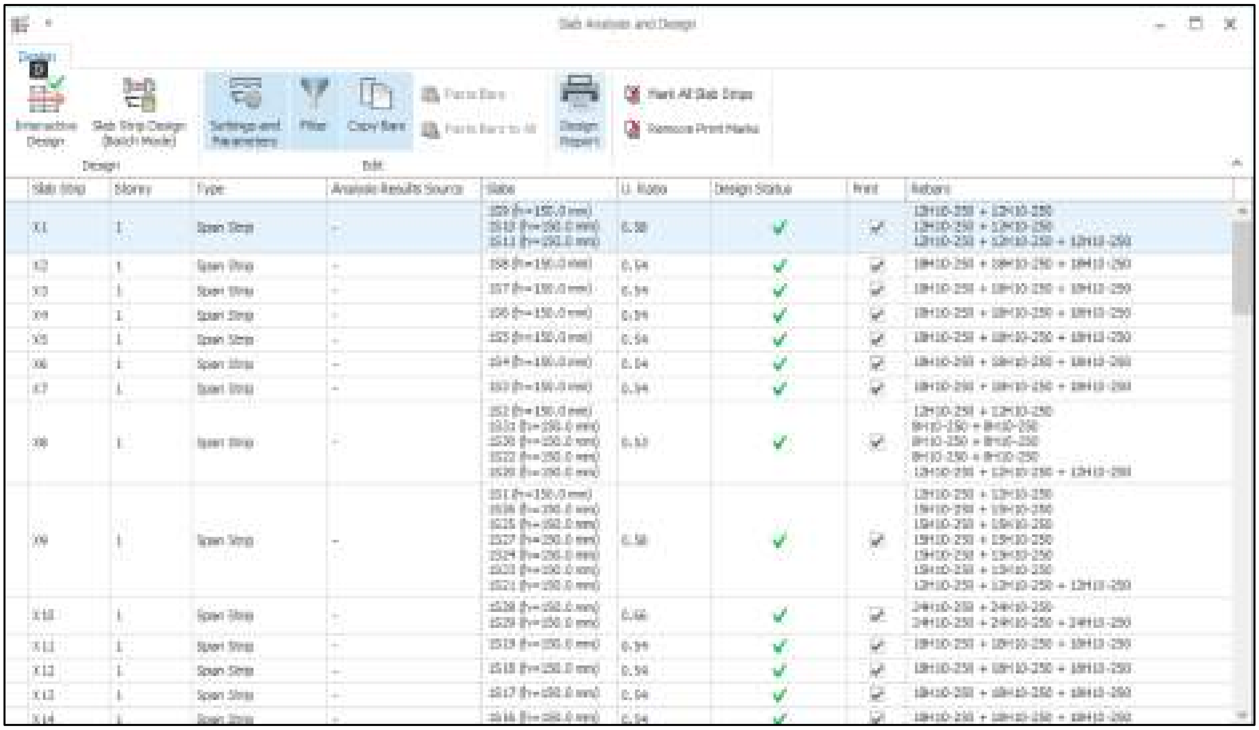


Figure 24   Slab Analysis and Design

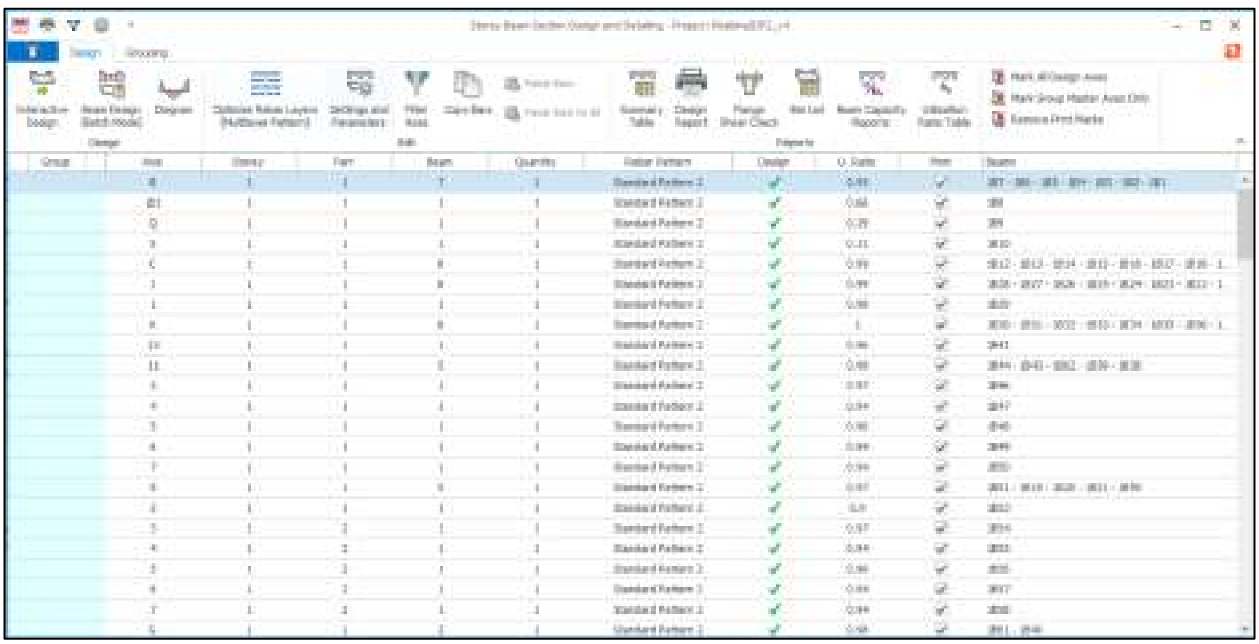


Figure 25   Beam Reinforcement Design

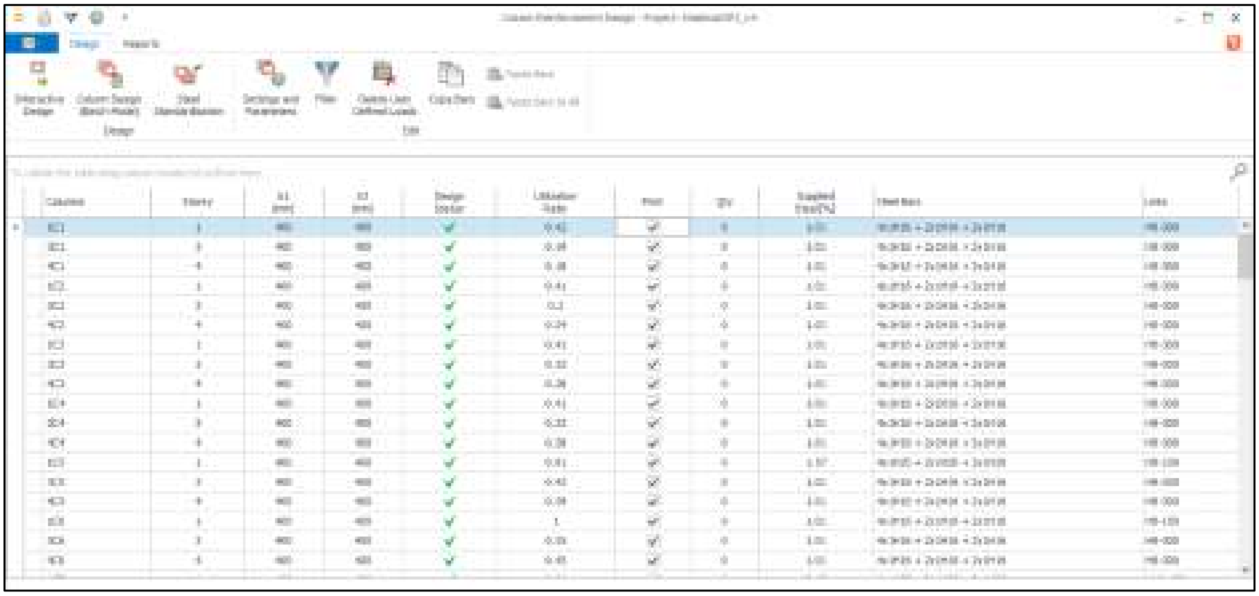


Figure 26 Column Reinforcement Design

A simply supported beam and a continuous beam were analyzed using Prota Structures, which produced thorough results including shear force diagrams, bending moment diagrams, required reinforcing areas, and deflection checks. To verify the validity and accuracy of these results, which are graphically represented in the following diagrams, each one was extensively compared with manual calculations. This comprehensive evaluation validates the software's reliability and precision as well as its capacity to provide realistic design solutions for various beam combinations.

Beam 6/A-D

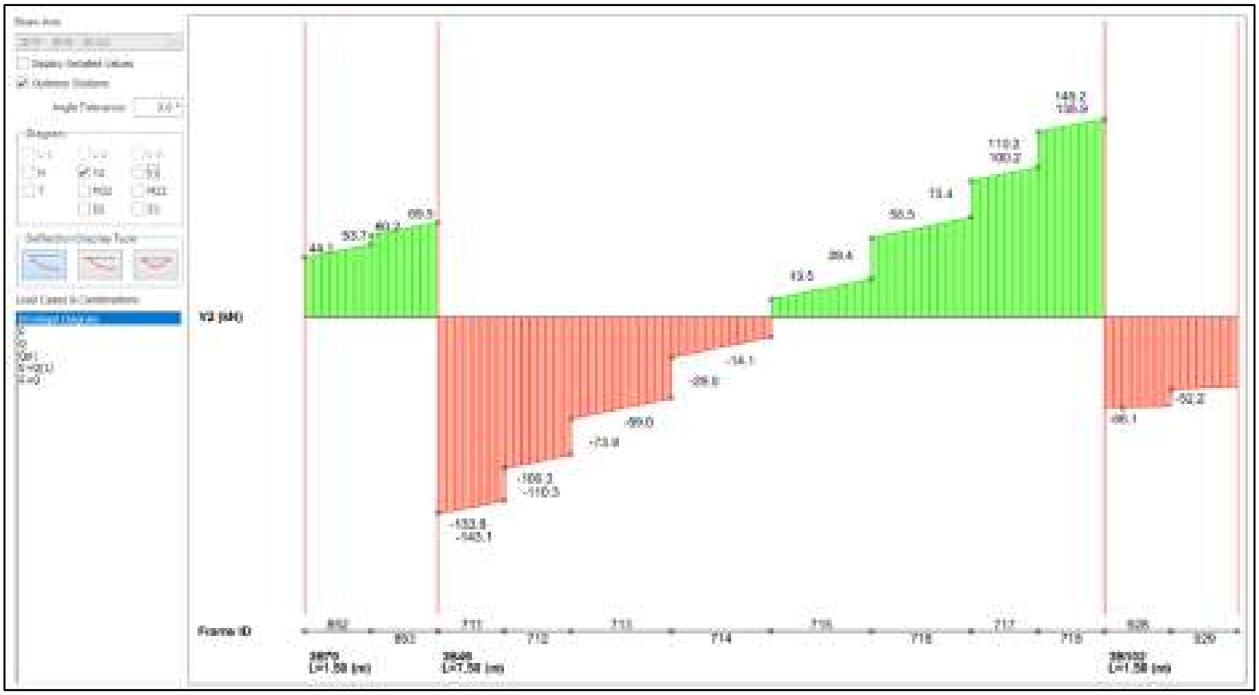


Figure--. Shear Force Diagram of Beam 6/A-D

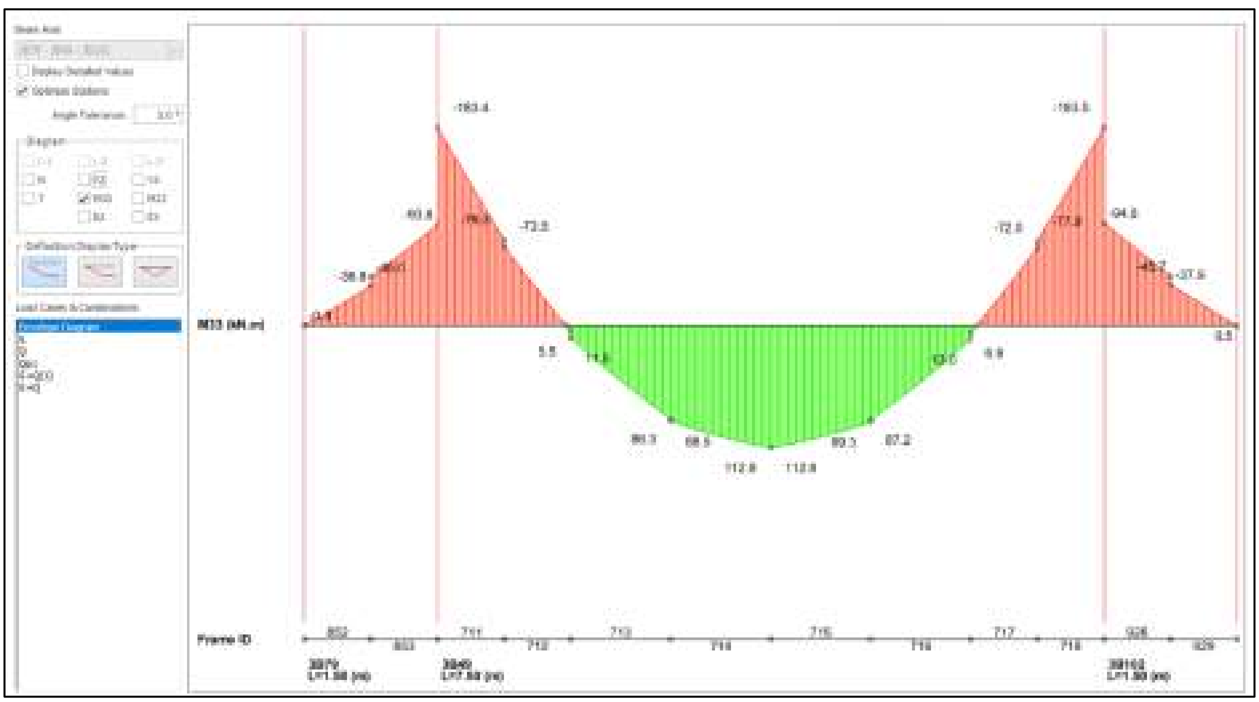


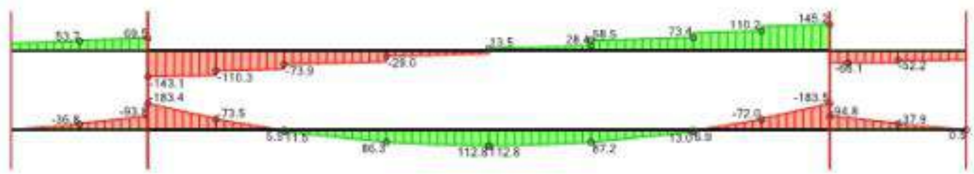
Figure 27 Bending Moment Diagram of Beam 6/A-D

Beam Reinforcement Design

Axis: 6   Storey: 3

Materials: C30/37 / Grade 500 (Type 2) (Links: Grade 500 (Type 2)) Concrete Cover: 35.0 mm

Diagrams



Bending

	3B79		L= 1500mm	3B49		L= 7500mm	3B102		L= 1500mm
B_w x H (mm)		200 x 500			200 x 500			200 x 500	
Flange B_f x H_f (Left) (Right)	---		---		---				
Top Edge									
M (kN.m)	18.9	60.4	93.8	183.4	0.0	183.5	94.8	61.9	19.8
d (mm)	449.0	449.0	447.0	428.0	449.0	428.0	428.0	449.0	449.0
K/K'	0.09	0.30	0.47	1.00	0.00	1.00	0.52	0.31	0.10
x (mm)	56.1	56.1	83.4	191.9	56.1	192.1	88.8	56.1	56.1
A_{sm} (mm^2)	101.66	325.89	521.55	1200.75	0.00	1201.75	555.81	333.93	106.89
A_{sx} (mm^2)	141.92	180.89	197.92	407.25	192.49	413.22	188.10	186.02	146.48
A_s (mm^2)	0.00	0.00	521.55	1200.75	192.49	1201.75	555.81	0.00	0.00
A_s' (mm^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	0.00	0.00	134.65	128.93	135.25	128.93	128.93	0.00	0.00
Bottom Edge									
M (kN.m)	0.0	0.0	0.0	0.0	112.8	0.0	0.0	0.0	0.5
d (mm)	449.0	449.0	449.0	444.5	444.5	444.5	449.0	449.0	449.0
K/K'	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00
x (mm)	56.1	56.1	56.1	55.6	102.8	55.6	56.1	56.1	56.1
A_{sm} (mm^2)	0.00	0.00	0.00	0.00	643.25	0.00	0.00	0.00	2.85
A_{sx} (mm^2)	141.92	180.89	197.92	407.25	192.49	413.22	188.10	186.02	146.48
A_s (mm^2)	0.00	0.00	0.00	407.25	643.25	413.22	0.00	0.00	0.00
A_s' (mm^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	0.00	0.00	135.25	133.90	133.90	133.90	135.25	0.00	0.00

Shear And Torsion Design

V_d (kN)	49.9		69.5	143.1		145.2	66.1		51.5
v (MPa)	0.56		0.78	1.67		1.70	0.77		0.57
v_{Rdc} (MPa)	0.48		0.55	0.72		0.72	0.71		0.48
$v_{Rd,max}$ (MPa)	4.75		4.75	4.75		4.75	4.75		4.75
V_{nom} (kN)		145.7			144.3			145.7	
T_d (kN.m)		0.2 $\leq T_{Min}$			0.4 $\leq T_{Min}$			0.1 $\leq T_{Min}$	
T_{Min} (kN.m)		3.6			3.6			3.6	
$b_{support}$ (mm)	0.0		0.0	0.0		1800.0	0.0		0.0
Links			H8-300	H8-300	H8-300	H8-275	H8-300		

Deflection Check

L/d	3.36 ≤ 9.02 √	16.87 ≤ 42.34 √	3.5 ≤ 10.76 √

Steel Areas (mm^2)

Required							
Top Edge		521.55	1200.75	192.49	1201.75	555.81	
Bottom Edge		0.00	407.25	643.25	413.22	0.00	
Supplied							
Top Edge		628.32	1344.60	402.12	1344.60	1344.60	
Bottom Edge		402.12	981.75	981.75	981.75	402.12	
Steel Bars							
Top Bars				2H16			
Top Sup Bars		2H20	3H20		3H20	3H20	
Top Sup Bars			2H16		2H16	2H16	
Bottom Bars	2H16			2H25			2H16
Bottom Bars							
Bot Sup Bars							
Side Bars							

Figure 28 Analysis of Beam 6/A-D

Beam F1/11-12

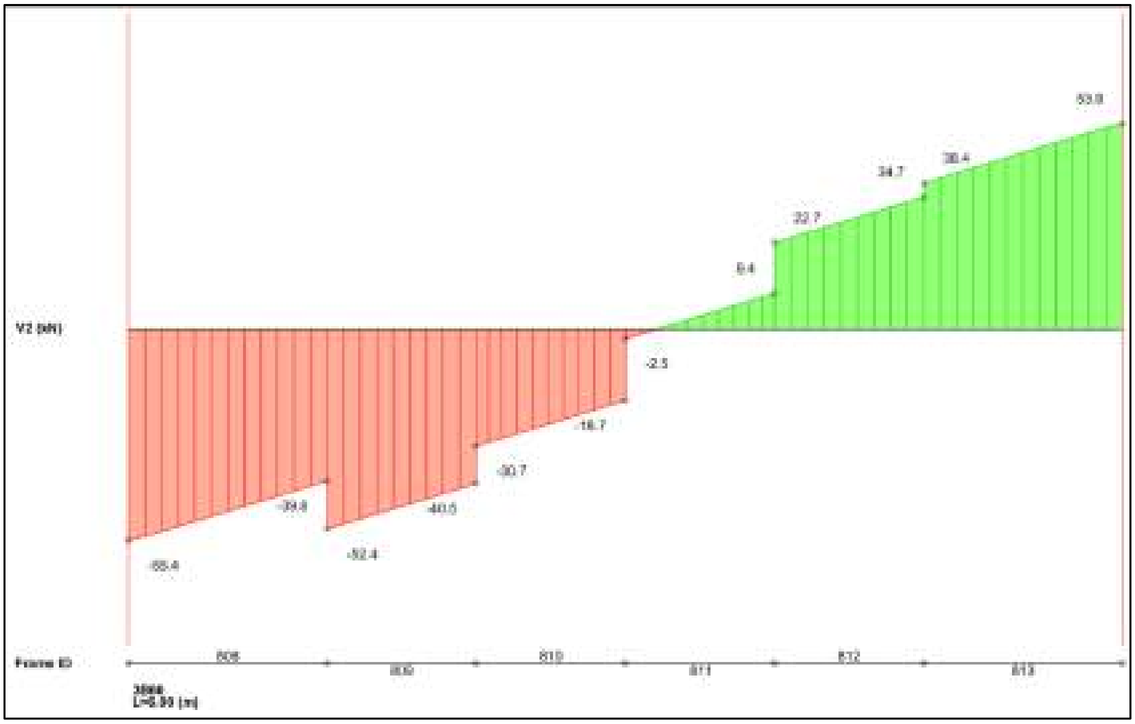


Figure 29 Shear Force Diagram of Beam F1/11-12

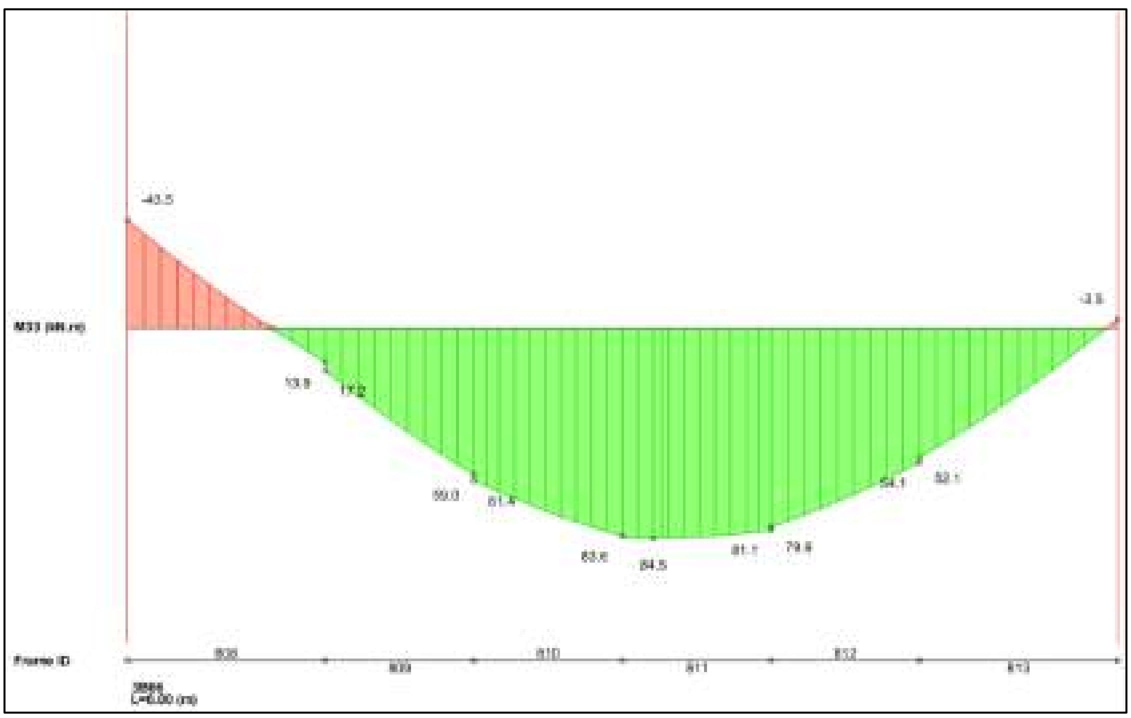


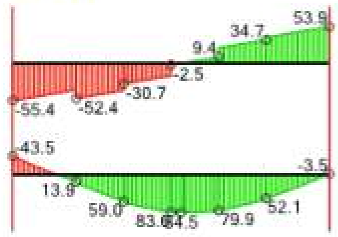
Figure 30 Bending Moment Diagram of Beam F1/11-12

Beam Reinforcement Design

Storey: 3

Materials: C30/37 / Grade 500 (Type 2) (Links: Grade 500 (Type 2)) Concrete Cover: 35.0 mm

Diagrams



Bending

	3B66	L= 6000mm	
B_w x H (mm)		200 x 500	
Flange B_f x H_f (Left) (Right)	---		
Top Edge			
M (kN.m)	43.5	0.0	21.1
d (mm)	449.0	449.0	449.0
K/K'	0.21	0.00	0.10
x (mm)	56.1	56.1	56.1
A_{sm} (mm^2)	234.29	0.00	113.88
A_{sv} (mm^2)	157.69	135.96	153.55
A_s (mm^2)	234.29	135.96	113.88
A_s' (mm^2)	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	135.25	135.25	135.25
Bottom Edge			
M (kN.m)	4.3	84.5	42.9
d (mm)	447.0	447.0	447.0
K/K'	0.02	0.42	0.21
x (mm)	55.9	74.4	55.9
A_{sm} (mm^2)	23.54	465.70	232.27
A_{sv} (mm^2)	157.69	135.96	153.55
A_s (mm^2)	181.22	465.70	385.82
A_s' (mm^2)	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	134.65	134.65	134.65

Shear And Torsion Design

V_d (kN)	55.4		53.9
v (MPa)	0.62		0.60
v_{Rdc} (MPa)	0.55		0.55
$v_{Rd,max}$ (MPa)	4.75		4.75
V_{nom} (kN)		145.1	
T_d (kN.m)		0.1 $\leq T_{Min}$	
T_{Min} (kN.m)		3.6	
$b_{support}$ (mm)	0.0		0.0
Links	**H8-300**	**H8-300**	**H8-300**

Deflection Check

L/d	13.42 ≤ 26.77 ✓

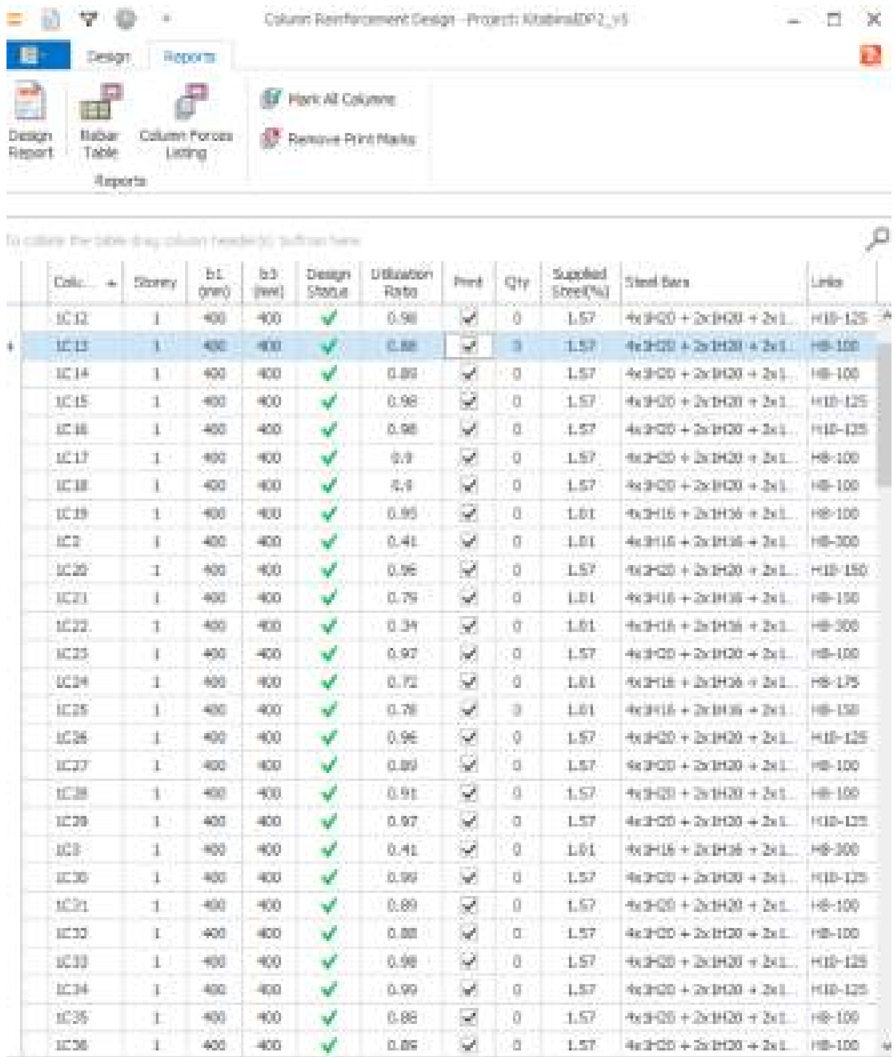
Steel Areas (mm²)

Required			
Top Edge	234.29	135.96	113.88
Bottom Edge	181.22	465.70	385.82
Supplied			
Top Edge	402.12	402.12	402.12
Bottom Edge	628.32	628.32	628.32
Steel Bars			
Top Bars		2H16	
Top.Sup.Bars			
Top.Sup.Bars			
Bottom Bars		2H20	
Bottom Bars			
Bot.Sup.Bars			
Side Bars			

Figure 31 Analysis of Beam F1/11-12

COLUMN

The following results show that all the columns pass the analysis. The column dimensions used are 400 mm x 400 mm for all of the columns. One column was selected to inspect on the results produced by ProtaStructure, namely A/5 The detailed analysis includes shear force diagram, bending moment diagram, required reinforcement area and deflection check as shown in the following diagrams. The results are then compared with manual calculations to ensure that the results obtained are valid.



Colu...	Storey	b1 (mm)	b3 (mm)	Design Status	Utilization Ratio	Print	Qty	Supplied Steel(%)	Steel Bars	Links
1C12	1	400	400	✓	0.98	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C13	1	400	400	✓	0.88	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C14	1	400	400	✓	0.89	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C15	1	400	400	✓	0.98	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C16	1	400	400	✓	0.98	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C17	1	400	400	✓	0.9	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C18	1	400	400	✓	0.9	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C19	1	400	400	✓	0.95	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-100
1C2	1	400	400	✓	0.41	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
1C20	1	400	400	✓	0.96	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-150
1C21	1	400	400	✓	0.79	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-150
1C22	1	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
1C23	1	400	400	✓	0.97	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C24	1	400	400	✓	0.72	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-175
1C25	1	400	400	✓	0.78	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-150
1C26	1	400	400	✓	0.96	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C27	1	400	400	✓	0.89	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C28	1	400	400	✓	0.91	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C29	1	400	400	✓	0.97	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C3	1	400	400	✓	0.41	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
1C30	1	400	400	✓	0.99	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C31	1	400	400	✓	0.89	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C32	1	400	400	✓	0.88	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C33	1	400	400	✓	0.98	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C34	1	400	400	✓	0.99	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H10-125
1C35	1	400	400	✓	0.88	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100
1C36	1	400	400	✓	0.89	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-100

Colu…	Storey	b1 (mm)	b3 (mm)	Design Status	Utilization Ratio	Print	Qty	Supplied Steel(%)	Steel Bars	Links
1C4	1	400	400	✓	0.41	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
1C40	1	400	400	✓	0.88	☑	0	1.57	4x1H20 + 2x1H20 + 2x1…	H8-125
1C41	1	400	400	✓	0.92	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-125
1C42	1	400	400	✓	0.91	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-125
1C5	1	400	400	✓	0.91	☑	0	1.57	4x1H20 + 2x1H20 + 2x1…	H8-100
1C6	1	400	400	✓	1	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-150
1C7	1	400	400	✓	0.84	☑	0	2.45	4x1H25 + 2x1H25 + 2x1…	H10-125
1C8	1	400	400	✓	0.82	☑	0	2.45	4x1H25 + 2x1H25 + 2x1…	H8-125
1C9	1	400	400	✓	0.88	☑	0	1.57	4x1H20 + 2x1H20 + 2x1…	H8-100
3C1	3	400	400	✓	0.19	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C10	3	400	400	✓	0.27	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C11	3	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C12	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C13	3	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C14	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C15	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C16	3	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C17	3	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C18	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C19	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C2	3	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C20	3	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C21	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C22	3	400	400	✓	0.21	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C23	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C24	3	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C25	3	400	400	✓	0.25	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300

Colu…	Storey	b1 (mm)	b3 (mm)	Design Status	Utilization Ratio	Print	Qty	Supplied Steel(%)	Steel Bars	Links
3C26	3	400	400	✓	0.32	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C27	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C28	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C29	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C3	3	400	400	✓	0.32	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C30	3	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C31	3	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C32	3	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C33	3	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C34	3	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C35	3	400	400	✓	0.27	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C36	3	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C37	3	400	400	✓	0.24	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C38	3	400	400	✓	0.26	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C39	3	400	400	✓	0.38	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C4	3	400	400	✓	0.32	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C40	3	400	400	✓	0.22	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C41	3	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C42	3	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C5	3	400	400	✓	0.42	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C6	3	400	400	✓	0.35	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C7	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C8	3	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
3C9	3	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
4C1	4	400	400	✓	0.18	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
4C10	4	400	400	✓	0.26	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300
4C11	4	400	400	✓	0.36	☑	0	1.01	4x1H16 + 2x1H16 + 2x1…	H8-300

Colu...	Storey	b1 (mm)	b2 (mm)	Design Status	Utilization Ratio	Print	Qty	Supplied Steel(%)	Steel Bars	Links
4C12	4	400	400	✓	0.27	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C13	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C14	4	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C15	4	400	400	✓	0.36	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C16	4	400	400	✓	0.37	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C17	4	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C18	4	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C19	4	400	400	✓	0.16	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C2	4	400	400	✓	0.24	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C20	4	400	400	✓	0.27	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C21	4	400	400	✓	0.17	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C22	4	400	400	✓	0.13	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C23	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C24	4	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C25	4	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C26	4	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C27	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C28	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C29	4	400	400	✓	0.35	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C3	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C30	4	400	400	✓	0.37	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C31	4	400	400	✓	0.32	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C32	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C33	4	400	400	✓	0.35	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C34	4	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C35	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C36	4	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300

Colu...	Storey	b1 (mm)	b2 (mm)	Design Status	Utilization Ratio	Print	Qty	Supplied Steel(%)	Steel Bars	Links
4C24	4	400	400	✓	0.31	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C25	4	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C26	4	400	400	✓	0.33	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C27	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C28	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C29	4	400	400	✓	0.35	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C3	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C30	4	400	400	✓	0.37	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C31	4	400	400	✓	0.32	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C32	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C33	4	400	400	✓	0.35	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C34	4	400	400	✓	0.34	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C35	4	400	400	✓	0.3	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C36	4	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C37	4	400	400	✓	0.73	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C38	4	400	400	✓	0.67	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C39	4	400	400	✓	0.6	☑	0	1.57	4x1H20 + 2x1H20 + 2x1...	H8-300
4C4	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C40	4	400	400	✓	0.79	☑	0	2.45	4x1H25 + 2x1H25 + 2x1...	H8-300
4C41	4	400	400	✓	0.4	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C42	4	400	400	✓	0.38	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C5	4	400	400	✓	0.39	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C6	4	400	400	✓	0.45	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C7	4	400	400	✓	0.26	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C8	4	400	400	✓	0.29	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300
4C9	4	400	400	✓	0.28	☑	0	1.01	4x1H16 + 2x1H16 + 2x1...	H8-300

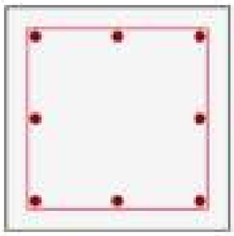
Column A/5 (Foundation to Ground Floor)

Column Reinforcement Design

1C13 (5-B) (400/400)

Materials: C30/37 / Grade 500 (Type 2) (Links: Grade 500 (Type 2))

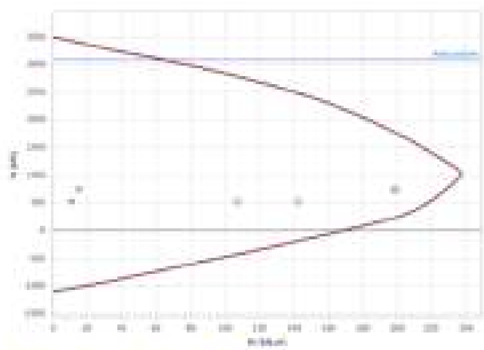
Section



Combinations

No	N_{Top} (kN)	$M_{22\,Top}$ (kN.m)	$M_{33\,Top}$ (kN.m)	N_{Bot} (kN)	$M_{22\,Bot}$ (kN.m)	$M_{33\,Bot}$ (kN.m)
1	534.9	-1.2	142.9	535.5	-0.7	107.3
2	740.2	-1.6	199.2	741.1	-0.9	149.6

Interaction Diagram



Critical Loading: 2 - (G+Q)

		Min	Design	
N	741.1	-	741.1	kN
M_{22}	-1.6	-14.8	-14.8	kN.m
M_{33}	199.2	14.8	198.8	kN.m
N_{Max}	2293.2			

Concrete Cover = 35.0 mm

Neutral Axis: 193.3 mm / 6.02 °

Shear						Rebars		
$V_{Ed\,1/2}$ =	330.6 / 4.6	kN	Short Column...			As (Req):	%1.23	1969.04 mm²
v_{Ed} =	2.16 / 0.03	N/mm²	λ_1/Lim$_1$ =	-1.5 < 33.6	√	As (Sup):	%1.57	2513.27 mm²
v_{Rdc} =	1.23 / 1.23	N/mm²	λ_2/Lim$_2$ =	-1.5 < 40.1	√			
$v_{Rd,max}$ =	0.00 / 0.00	N/mm²	$M_{Add\,1/2}$ =	0.0 / 0.0	kN.m	8H20		
Links = H8-100								

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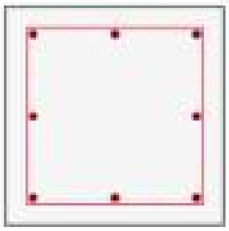
Column A/5 (Ground Floor to 1st Floor)

3C13 (5-B) (400/400)

Materials: C30/37 / Grade 500 (Type 2) (Links: Grade 500 (Type 2))

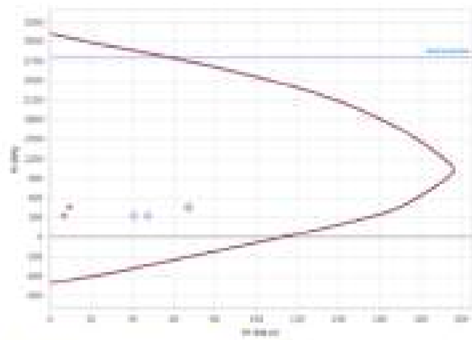
Section



Combinations

No	N_{Top} (kN)	$M_{22\ Top}$ (kN.m)	$M_{33\ Top}$ (kN.m)	N_{Bot} (kN)	$M_{22\ Bot}$ (kN.m)	$M_{33\ Bot}$ (kN.m)
1	319.0	1.4	45.0	333.4	-1.6	-38.2
2	441.2	1.8	64.2	460.6	-2.2	-53.9

Interaction Diagram



Critical Loading: 1 - (G+Q(1))

		Min	Design	
N	333.4	-	333.4	kN
M_{22}	-1.8	-6.7	-6.7	kN.m
M_{33}	45.0	6.7	47.3	kN.m
N_{Max}	2203.2			

Concrete Cover = 35.0 mm

Neutral Axis: 93.5 mm / 4.32 °

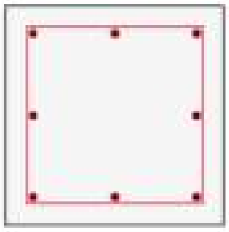
Shear			Short Column...			Rebars		
$V_{Ed(2/3)}$ =	32.8 / 1.1	kN	λ_2/Lim_2 =	22.5 < 116.4	√	As (Req):	%0.20 (min)	320.00 mm²
v_{Ed} =	0.22 / 0.01	N/mm²	λ_3/Lim_3 =	23.8 < 32.0	√	As (Sup):	%1.01	1608.50 mm²
v_{Rdc} =	0.96 / 0.96	N/mm²	$M_{Add1(2)}$ =	0.0 / 0.0	kN.m			
$v_{Rd,Max}$ =	0.00 / 0.00	N/mm²				8H16		
Links = H8-300								

4C13 (5-B) (400/400)

Column A/5 (1st Floor to Roof Floor)

Materials: C30/37 / Grade 500 (Type 2) (Links: Grade 500 (Type 2))

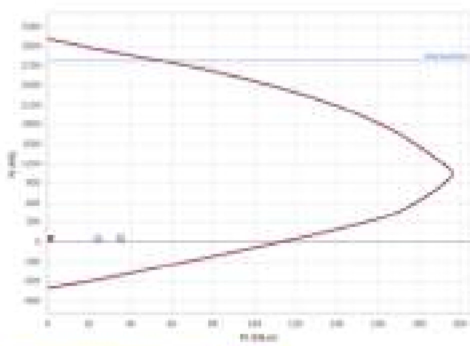
Section



Combinations

No	N_{Top} (kN)	$M_{22\,Top}$ (kN.m)	$M_{33\,Top}$ (kN.m)	N_{Bot} (kN)	$M_{22\,Bot}$ (kN.m)	$M_{33\,Bot}$ (kN.m)
1	33.8	1.0	-2.9	48.2	-0.9	-24.2
2	45.6	1.4	-3.6	65.1	-1.2	-34.9

Interaction Diagram



Critical Loading: 2 - (G+Q)

		Min	Design	
N	65.1	-	65.1	kN
M_{22}	1.4	1.3	1.7	kN.m
M_{33}	-34.9	-1.3	-35.3	kN.m
N_{Max}	2203.2			

Concrete Cover = 35.0 mm

Neutral Axis: 39.5 mm / 0.69 D

Shear						Rebars		
$V_{Ed(2/3)}$ =	8.7 / 0.7	kN	Short Column ...			As (Req):	%0.25 (min)	320.00 mm²
v_{Ed} =	0.06 / 0.00	N/mm²	λ_2/Lim₂ =	18.3 < 164.9	√	As (Sup):	%1.01	1608.50 mm²
$v_{Rd,c}$ =	0.59 / 0.59	N/mm²	λ_3/Lim₃ =	20.3 < 264.4	√			
$v_{Rd,Max}$ =	0.00 / 0.00	N/mm²	$M_{Add(2/3)}$ =	0.0 / 0.0	kN.m	8H16		
Links = H8-300								

2.8 Comparison of Prota and Manual Calculations

Element	Item	Manual	Prota	Remarks
Simply Supported Beam F1/11-12	As required Ved Moment	1021.00 mm^2 125.75 kN 188.63 kNm/m	465.70 mm^2 55.40 kN 84.50 kNm/m	
Continuous Beam 6/A-D	As required (Bottom) Moment	592.00 mm^2 102.58 kNm	521.55 mm^2 93.80 kNm	Span A-B
	As required (Top) As required (Bottom) Ved Moment	1248.10 mm^2 53.30 mm^2 155.30 kN 185.20 kNm	1200.75 mm^2 407.25 mm^2 143.10 kN 183.40 kNm	Support B
	As required (Bottom) Moment	611.00 mm^2 105.90 kNm	643.25 mm^2 4.40 kNm	Span B-C
	As required (Top) As required (Bottom) Ved Moment	1248.10 mm^2 53.30 mm^2 155.30 kN 185.20 kNm	1201.75 mm^2 413.22 mm^2 145.20 kN 183.50 kNm	Support C
	As required (Bottom) Moment	592.00 mm^2 102.58 kNm	555.81 mm^2 94.80 kNm	Span C-D
Column A/5	As required	2400.00 mm^2	1969.00 mm^2	Foundation - Ground Floor
	As required	480.00 mm^2	320.00 mm^2	Ground Floor - First Floor
	As required	315.00 mm^2	320.00 mm^2	First Floor - Roof Floor

2.9 Conclusion

The structural layout was developed based on the architectural drawings provided. Elements like columns and beams are strategically placed to support the loads imposed by the building. The slab thickness for the entire structure is set at 150 mm.

While manual calculations confirm the feasibility of a critical slab, ProtaStructure analysis is employed for the other slabs. The designed brick wall thickness for the building is 130 mm, with a height of 3.6 m. Stair loads are considered in the ProtaStructure modelling to ensure a comprehensive analysis of the associated beams.

For the beams, dimensions of 200 mm x 500 mm are utilized for the ground and first floors, while a dimension of 200 mm x 350 mm is employed for the roof floor. Manual calculations validate the feasibility of critical beams, and ProtaStructure analysis confirms feasibility for the remaining beams.

Column dimensions of 400 mm x 400 mm are implemented throughout the building. Manual calculations confirm feasibility at critical locations, and ProtaStructure analysis supports the feasibility of these dimensions for the entire building. Truss loads are also designed to be applied to columns.

Footings were designed based on the axial load from these columns. A 200 mm x 200 mm square pile was utilized for piling design. Feasibility analysis for the footing is conducted through manual calculations, and ProtaStructure modelling.

2.10 Appendix

The appendix consists of a series of manual calculations including:

i. First Floor Slab
ii. Simply Supported Beam
iii. Continuous Beam
iv. Column
v. Stairs
vi. Foundation

The calculations are attached to below this section.

First Floor Slab S1 J-K/4-5

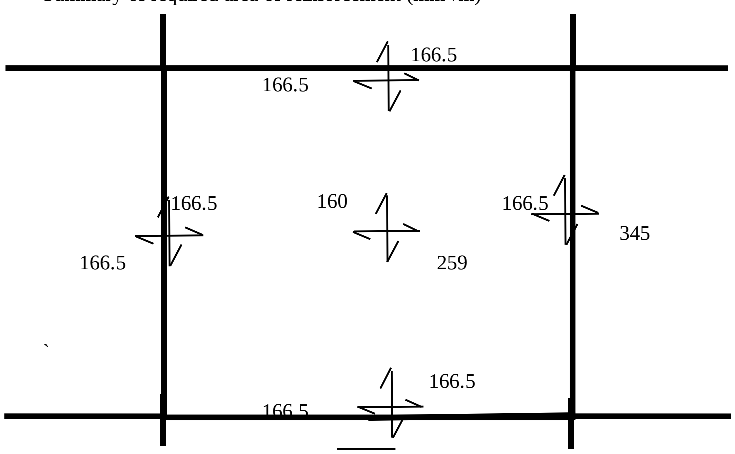
Ref.	Calculations	Output
Project	Two-storey School Building	Designed by: ARB Checked by: AAA Date: Dec-23
Location	First Floor Slab	
	SPECIFICATION Slab panel: 3S42 J-K/4-5 Design Life = 50 Years Fire resistance = 1 hour Exposure Class = XC3 Characteristic Actions: Permanenent, g_k = 2.00 kN/m^2 Variable, q_k = 3.00 kN/m^2 Materials: Characteristic strength of concrete, f_{ck} = 30 N/mm^2	
3.1.2.(3)	Characteristic strength of steel, f_{yk} = 500 N/mm^2 Unit weight of reinforced concrete = 25 kN/m^3 Dimension: Long span, L_y = 7500 mm Short Span, L_x = 4500 mm Thickness, = 150 mm Assumed: $\emptyset_{bar}$ = 8 mm	
	DURABILITY, FIRE AND BOND REQUIREMENTS	
Table 4.2	Min. cover with regard to bond, $c_{min,b}$ = 8 mm	
Table 4.4N	Min. cover with regard to durability, $c_{min,dur}$ = 25 mm	
4.4.1.3	Allowance in design for deviation, Δc_{dev} = 10 mm	
4.4.1.1(2)	Nominal cover with regard to durability and bond, $c_{nom} = c_{min} + \Delta c_{dev}$ = 25 + 10 = 35 mm	
4.4.1.2	Min. required axis distance for 1 hr. fire resistance a = 15 mm Nominal cover with regard to fire $c_{nom} = a - \emptyset_{bar}/2$ = 15 - 0.5(8) = 11 mm Required nominal cover, c_{nom} = 35 mm	
	ACTIONS Slab selfweight = 5.00 kN/m^2 Permanent load (Excluding selfweight) = 2.00 kN/m^2 Characteristic permanent action, g_k = 7.00 kN/m^2 Characteristic variable action, q_k = 3.00 kN/m^2 Design action, $n = 1.35g_k + 1.5q_k$ = 13.95 kN/m^2	
	ANALYSIS l_y / l_x = 7500/4500 = 1.67 < 2.00 Two way Slab Case 1: Four edges continuous	

Ref.	Calculations	Output
	Short span:	
	M_{sx1} = $\beta_{sx1} n_d l_x^2$ = 0.042 x 13.95 x 4.50² = 11.87 kNm/m	
	M_{sx2} = $\beta_{sx2} n_d l_x^2$ = 0.056 x 13.95 x 4.50² = 15.82 kNm/m	
	Long span:	
	M_{sy1} = $\beta_{sy1} n_d l_x^2$ = 0.024 x 13.95 x 4.50² = 6.78 kNm/m	
	M_{sy2} = $\beta_{sy2} n_d l_x^2$ = 0.032 x 13.95 x 4.50² = 9.04 kNm/m	
	<u>MAIN REINFORCEMENTS</u>	
	Effective depth,	
	$d_x = h - c_{nom} - 0.5\varphi_{bar}$ = 150 - 35 - 8/2 = 111 mm	
	$d_y = h - c_{nom} - 1.5\varphi_{bar}$ = 150 - 35 - 1.5(8) = 103 mm	
	Minimum and maximum reinforcement area,	
	$A_{s,min}$ = 0.26 (f_{ctm}/f_{yk})bd $A_{s,max}$ = 0.04Ac	
	= 0.26(2.90/500)bd = 0.04bh	
	= 0.0015bd = 0.04(1000)(150)	
	= 0.0015(1000)(111) = 6000 mm²/m	
9.2.1.1	= 166.5 mm²/m	Secondary bar:
	Short span:	H8- 250
	Midspan, M_{sx} = 11.87 kNm/m	201 mm²/m
	K = M/bd^2f_{ck}	
	= 11.87x1000000/(1000)(111²)(30)	
	= 0.0322 < K_{bal} (0.167)	
	= 0.0322 Compression reinforcement is not required	
6.1	z = d [0.5+√(0.25-K/1.134)]	
	= d[0.5+√(0.25-0.0322/1.134)]	
	= 0.98d ≤ 0.95d	
	= 0.95d	
	= 105.45 mm	
	A_s = $M/0.87f_{yk}z$	
	= 11.87x1000000/(0.87)(500)(105.45)	
	= 259 mm²/m	
	Support, M_{sx} = 15.82 kNm/m	
	K = M/bd^2f_{ck}	Use
	= 15.82x1000000/(1000)(111²)(35 mm)	H8- 175
	= 0.0428 < K_{bal} (0.167)	287 mm²/m
	= 0.0428 Compression reinforcement is not required	bot.
6.1	z = d [0.5+√(0.25-K/1.134)]	
	= d[0.5+√(0.25-0.0428/1.134)]	
	= 0.961d ≤ 0.95d	
	= 0.95d	
	= 105.45 mm	

Ref.	Calculations	Output
	A_s = $M/0.87f_{yk}z$	Use
	= 15.82x1000000/(0.87)(500)(105.45)	H8- 125
	= 345 mm^2/m	402 mm^2/m
		top.
	Long span:	
	Midspan, M_{sy} = 6.78 kNm/m	
6.1	K = M/bd^2f_{ck}	
	= 6.78x1000000/(1000)(103²)(30)	
	= 0.0214 < K_{bal} (0.167)	
	= 0.0214 Compression reinforcement is not required	
	z = d [0.5+√(0.25-K/1.134)]	
	= d[0.5+√(0.25-0.0214/1.134)]	
	= 0.99d ≤ 0.95d	
	= 0.95d	
	= 97.85 mm	
	A_s = $M/0.87f_{yk}z$	Use
	= 6.78x1000000/(0.87)()(97.85)	H8- 250
	= 160 mm^2/m	201 mm^2/m
		bot.
	Support, M_{sy} = 9.04 kNm/m	
6.1	K = M/bd^2f_{ck}	
	= 9.04x1000000/(1000)(111²)(35 mm)	
	= 0.0245 < K_{bal} (0.167)	
	= 0.0245 Compression reinforcement is not required	
	z = d [0.5+√(0.25-K/1.134)]	
	= d[0.5+√(0.25-0.0245/1.134)]	
	= 0.978d ≤ 0.95d	
	= 0.95d	
	= 105.45 mm	
	A_s = $M/0.87f_{yk}z$	Use $A_{s,min}$
	= 9.04x1000000/(0.87)()(105.45)	H8- 225
	= 198 mm^2/m	223 mm^2/m
		top.

Ref.	Calculations	Output
	SHEAR	
	Short span:	
	V_{sx1} = $\beta_{vx1} n_d l_x$ = 0.465 x 13.95 x 4.50 = 29.2 kN/m	Vsx1 0.465
	V_{sx2} = $\beta_{vx2} n_d l_x$ = 0.465 x 13.95 x 4.50 = 29.2 kN/m	Vsx2 0.465
	Long span:	Vsy1 0/33
	V_{sy1} = $\beta_{vy1} n_d l_x$ = 0.33 x 13.95 x 4.50 = 20.72 kN/m	Vsy2 0/33
	V_{sy2} = $\beta_{vy2} n_d l_x$ = 0.33 x 13.95 x 4.50 = 20.72 kN/m	
	Design shear force, V_{Ed} = 29.2 kN/m	
6.2.2	Design shear resistance,	
	$V_{Rd,c}$ = $[0.12k(100\rho_1 f_{ck})^{1/3}]bd$	
	k = $1+(200/d)^{1/2}$	
	= $1+\sqrt{(200/111)}$	
	= 2.35 ≤ 2.00	
	= 2	
	ρ_1 = A_{sl}/bd	
	= 402/(1000)(111)	
	= 0.0037 ≤ 0.02	
	= 0.0037	
	$V_{Rd,c}$ = 0.12(2) $3\sqrt{[100(0.0037)(30)]}$ (1000)(111)	
	= 59.43 kN/m	
	V_{min} = $[0.035k^{3/2}fck^{1/2}]bd$	
	= 60.19 kN/m	
	So, $V_{Rd,c}$ = 60.19 kN/m > V_{Ed}	Ok!
7.4	**DEFLECTION**	
	Percentage of required tension reinforcement,	
	ρ = $A_{s,red}/bd$	
	= 259/(1000)(111)	
	= 0.003	
	Reference reinforcement ratio,	
	ρ_o = $(f_{ck})^{1/2} \times 10^{-3}$	
	= 0.006	
	since $\rho < \rho_o$ use equation (1)	
	$\frac{l}{d} = K[11 + 1.5\sqrt{f_{ck}}\frac{\rho_o}{\rho} + 3.2\sqrt{f_{ck}}(\frac{\rho_o}{\rho} - 1)^{3/2}$ - (1)	
	$\frac{l}{d} = K[11 + 1.5\sqrt{f_{ck}}\frac{\rho_o}{\rho-\rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_o}}$ - (2)	
Table 7.4N	Factor for structural sysyem, K = 1.3	
	Eqn 1, *l/d* = 1.3[11+1.5(√30)(0.006/0.003) +3.2(√30){3√[(0.006/0.003)-1]²}	
	= 1.3(44.96)	
	= 58.4464	
	It is recommended the maximum value in bracket (….....) is 40	
	Hence *l/d* = 52	
	Modification factor for span less than 7m = 1	
	Modification factor for steel area provided = $A_{s,pro} / A_{s,req}$	
	= 287/259	
	= 1.11 ≤ 1.5	

Ref.	Calculations	Output
	Therefore allowable span-effective depth ratio,	
	$(l/d)_{allowable}$ = 52(1)(1.11) = 57.72	
	$(l/d)_{actual}$ = 4500/111 = 40.55	
	$(l/d)_{actual}$ < $(l/d)_{allowable}$	Ok!
	CRACKING	
7.3.3 9.3.1	h = 150 mm < 200mm	
	Main bar:	
	$S_{max,slabs}$ = 3h ≤ 400mm = 400 mm	
	Max bar spacing (mm) = 250 < $S_{max,slabs}$	Ok!
	Secondary bar:	
	$S_{max,slabs}$ = 3.5h ≤ 450mm = 450 mm	
	Max bar spacing (mm) = 250 < $S_{max,slabs}$	Ok!
	DETAILING	
	Dimension:	
	Short span, lx = 4500 mm	
	Long span, l y = 7500 mm	
	Thickness,h = 150 mm	
	Concrete cover = 35 mm mm	
	Summary of required area of reinforcement (mm^2/m)	



Simply Supported Beam F1/11-12

Ref.	Calculations	Output
Project	Two Storey School Building	Designed by: ARB Checked by: AAA Date: Jan-24
Location	1st Floor Beam F1/11-12	

SPECIFICATION

Materials :

Characteristics strength of concrete, fck = 30 N/mm^2

Characteristics strength of steel, f_{yk} = 500 N/mm^2

Characteristics strength of link, f_{yk} = 500 N/mm^2

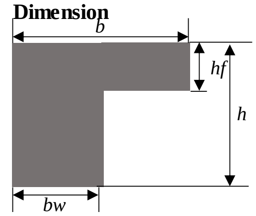
Nominal concrete cover = 35 mm

Assumed: $\emptyset_{bar1}$ = 20 mm b = 2110 mm

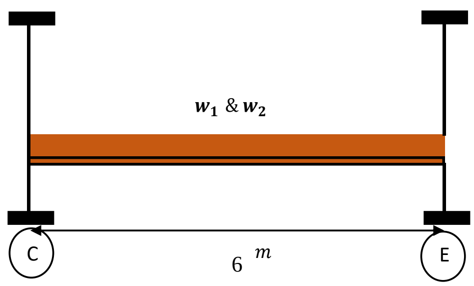
$\emptyset_{link}$ = 8 mm hf = 150 mm

$\emptyset_{bar2}$ = 16 mm h = 500 mm bw = 200 mm

Dimension



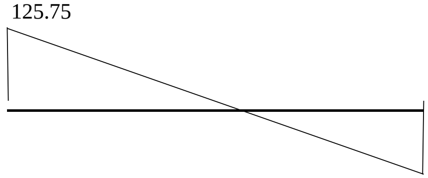
ANALYSIS



Loading

	Gk	Qk	$1.35g_k + 1.5q_k$
w_1	14.05	5.63	27.41
w_2	4.50	5.63	14.51
w	18.55	11.25	41.92

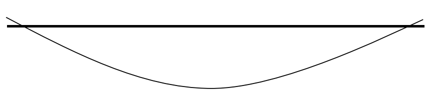
125.75



Shear Force,

V = wL/2

= 125.75 kN



188.63

Bending Moment,

M = $wL^2/8$

= 188.63 kNm/m

6.1 **MAIN REINFORCEMENT**

Effective depth,

$d = h - c_{nom} - \emptyset_{link} - 0.5\,\emptyset_{bar}$ = 447 mm

$d' = c_{nom} + \emptyset_{link} + 0.5\,\emptyset_{bar}$ = 53 mm

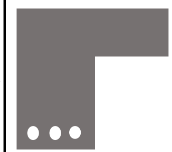
Med = 188.63

Mf = $0.567 f_{ck} b h_f (d - 0.5 h_f)$

= 0.567 x 30 x 2110 x 150 (447 - 75)

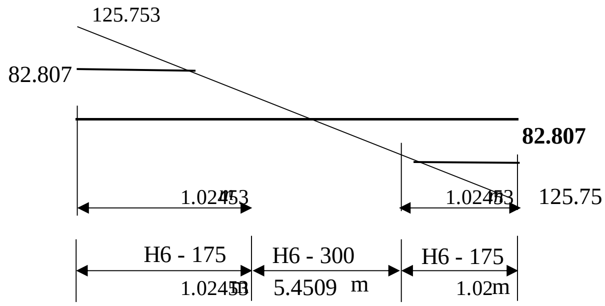
= 2003 kNm

Med < Mf Neutral axis within the flange

Ref.	Calculations	Output
	K = $Med/f_{ck}bd^2$	
	= **188.63** $\times 10^6$ / (30 x 2110 x 447^2) = 0.01491	
	K < Kbal = 0.167, Compression reinforcement is not required	
	z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ **0.9867** d	
	Area of tension reinforcement	Use :
	As = $Med/0.87f_{yk}z$	4H 20
	= 188.63 $\times 10^6$ / (0.87 x 500 x **0.95** x 447)	(1257 mm²)
	= 1021.1 mm²	
9.2.1.1	Minimum and maximum reinforcement area,	
	As,min = $0.26(f_{ctm}/f_{yk})\,bd$	
	= 0.26 (2.9 / 500) bd = 0.00151 bd	
	= 0.00151 x 200 x 447 = 134.815 mm²	
	As,max = $0.04A_c$ = 0.04 x 200 x 500 = 4000 mm²	
	<u>SHEAR REINFORCEMENT</u>	
6.2.3	Design shear force, Ved = 125.75 kN	
	Concrete strut capacity	
	Vrd,max = $0.36b_w df_{ck}(1 - f_{ck}/250)/(\cot\Theta + \tan\Theta)$	
	= 0.36 x 200 x 447 x 30 (1 - 30 / 250) / (cot Θ + tan Θ)	
	= 292.582 kN ⟶ Θ = 22° cot Θ = 2.5	
	= 424.829 kN ⟶ Θ = 45° cot Θ = 1	
	Ved < max cot Θ = 2.5	
	Ved < max cot Θ = 1.0	
	⟶ Therefore angle Θ < < 22°	
	Θ = $0.5\sin^{-1}[Ved/0.18b_w df_{ck}(1 - f_{ck}/250)]$	
	= $0.5\sin^{-1}\left\{\frac{125.75 \times 10^3}{0.18 \times 200 \times 447 \times 30\,(1 - 30/250)\,100}\right\}$	
	= $0.5\sin^{-1}$ (**0.296**) = 10.9°	
	Use : Θ = 22° tan Θ = 0.4 cot Θ = 2.5	
	Shear links	
	Asw/s = $Ved/0.78f_{yk}d\cot\theta$	
	= **125.75** $\times 10^3$ / (0.78 x 500 x 447 x 2.5)	
	= 0.28854	
	Try link H8 Asw = 57 mm²	
	Spacing, S = 57 / 0.28854 = 197.55 mm²	
9.2.2(6)	Max. spacing, Smax = 0.75d = 0.75 x 447 = 335.25 mm²	Use :
9.2.2(5)	Minimum links	H8 - 175
	Asw/s = $0.08f_{ck}^{1/2}b_w/f_{yk}$	
	= 0.08 x 30$^{1/2}$ x 200 / 500 = **0.1753**	
	Try link H6 Asw = 57 mm²	
	Spacing, S = 57 / **0.1753** = 325.21 mm²	Use :
	> 0.75d = 335.25 mm²	H6 - 300
	Shear resistance of minimum links	
	Vmin = $(A_{sw}/s)(0.78f_{yk}d\cot\theta)$	
	= (57 / 300) (0.78 x 500 x 447 x 2.5)	
	= **82.807** kN	

Ref.	Calculations	Output

Links arrangement



6.2.4 **Transverse steel in the flange**

The longitudinal shear stresses are the greatest over a distance Δx measured from the point of zero moment

Δx = 0.5(L/2) = (L/4) = 6000 / 4 = 1500 mm

The change in moment over distance Δx from zero moment,

$\Delta M = (wL/2)(L/4) - (wl/4)(L/8) = 3wL^2/32$

= 3 × 41.9175 × 6 ^{2} / 32 = 141.47 kNm

The change in longitudinal force,

$\Delta Fd = [\Delta M / (d - 0.5h_f)] \times [(b - b_w)/2b]$

$= \dfrac{141.472 \times 10^3}{(447 - 75)} \times \dfrac{(2110 - 200)}{(2 \times 2110)}$ = 172.126 kN

6.2.4(6) Longitudinal shear stress

Ved = $\Delta Fd / (h_f\, \Delta x)$

= 172.126 × 10^3 / (150 × 1500) = 0.765 N/mm²

Ved > $0.27 f_{ctk}$ = 0.27 × 2.03 = 0.5481 N/mm²

Transverse shear reinforcement is required

Concrete strut capacity in flange

$V_{Ed,max} = 0.4\, f_{ck}(1 - f_{ck}/250)/(cot\theta + \tan\theta)$

$= \dfrac{0.4 \times 30 \;(1 - 30 / 250.00)}{(cot\theta + \tan\theta)}$

= 4.2257 N/mm² ⟶ θ = 26.5° cot θ = 2

= 5.28 N/mm² ⟶ θ = 45° cot θ = 1

Ved < $V_{Ed,max}$ $cot\ \theta = 2.0$

Ved < $V_{Ed,max}$ $cot\ \theta = 1.0$

Therefore angle θ < 26.5 °

$\theta = 0.5 sin^{-1}[Ved/0.2 f_{ck}(1 - f_{ck}/250)]$

$= 0.5 sin^{-1} \left\{ \dfrac{0.76501}{0.2 \times 30 (1 - 30 / 250)} \right\}$

$= 0.5 sin^{-1}$ { 0.14489 } = 5.77 °

Use : θ = 26.5 ° tan θ = 0.5 cot θ = 2

Transverse shear reinforcement

$A_{sf} / s_f = V_{Ed} h_f / 0.87 f_{yk} cot\theta$

= **0.765** × 150 / (0.87 × 500.00) × 2 = 0.1319

Try : H10 Asf = 79 mm²

Spacing, s_f = 79 / 0.1319 = 598.95 mm

9.2.1.1 Minimum transverse steel area,

As,min = $0.26(f_{ctm}/f_{yk})\, bh_f$

= 0.26 (2.9 / 500) bh_f

= 0.00151 bh_f ≥ 0.0015 bh_f

= 0.00151 × 1000 × 150 = 226.2 mm²/m

Use :
H10 - 300
(262 mm²/m)

Ref.	Calculations	Output

6.2.3(7)

Additional longitudinal reinforcement

Additional tensile force,

$\Delta F_{td} = 0.5\, V_{Ed} \cot\theta \le M_{Ed,max} / z$

$= 0.5 \times 125.753 \times 2.48$

$= 155.933$ kN

$M_{Ed,max} / z = 188.629 \times 10^6 / 424.65 = 444.198$ kN

$A_{s\,req} = \Delta F_{td} / 0.87 f_{yk}$

$= 155.933 \times 10^3 / (0.87 \times 500)$

$= 358.467$ mm²

Output: To be added to the As near support (after curtailment)

7.40

DEFLECTION

Percentage of required tension reinforcement,

$\rho = A_{s,req} / bd = 1021.15 / (200 \times 447) = 0.01142$

Reference reinforcement ratio,

$\rho_0 = (f_{ck})^{1/2} \times 10^{-3} = (30)^{1/2} \times 10^{3} = 0.00548$

Percentage of required compression reinforcement,

$\rho' = A'_{s,req} / bd = 0 / (200 \times 447) = 0$

Table 7.4N

Factor for structural system, 1

$\rho > \rho_0$

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\,\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho}}\right]$$

$= 1 \times (11 + 3.93969 + 0) = 14.9397$

Modification factor for steel area provided,

$= A_{s,prov} / A_{s,req} = 1257 / 1021.15 = 1.23097 \le 1.5$

Therefore allowable span-effective depth ratio,

$(l/d)_{allowable} = 14.9397 \times 1.23097 = 18.3903$

Actual span-effective depth,

$(l/d)_{actual} = 6000 / 447 = 13.4228 < (l/d)_{allowable}$

Output: Ok

7.3 Table 7.1N

CRACKING

Limiting crack width, $w_{max} = 0.3$ mm

Steel stress,

$$f_s = \frac{f_{yk}}{1.15} \times \frac{G_k + 0.3Q_k}{(1.35G_k + 1.5Q_k)}\frac{1}{\delta}$$

$= (500 / 1.15) \times [\mathbf{18.55} + (0.3 \times 11.25)] / 41.9175 \times 1$

$\times (1021.15 / 1257)$

$= 227.414$ N/mm²

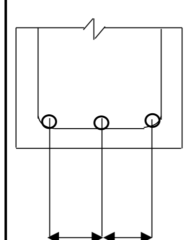


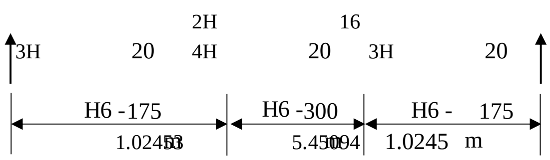
Table 7.3N

Max. allowable bar spacing 230 mm

Bar spacing, s $= [200 - 2(35) - 2(8) - (20)] / 2$

$= 47$ mm < 230 mm

SUMMARY



Note :

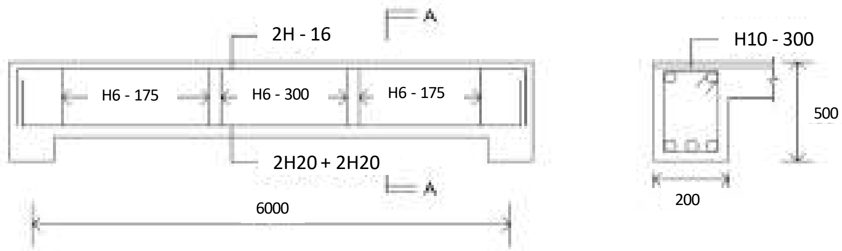
$A_{s\,req}$ near support

$= 0.25 \times 1021.15 = 255.2863$ mm²

Add A_s $= 358.4669$ mm²

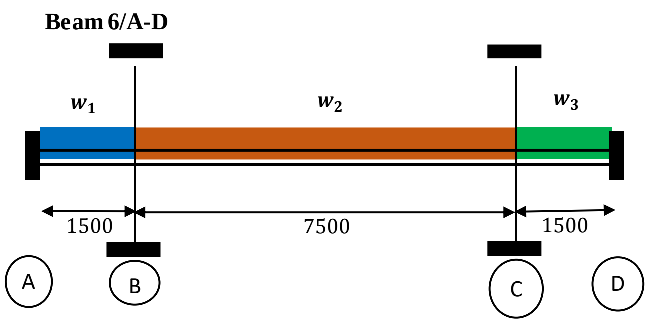
Total $A_{s\,req}$ $= 613.7532$ mm²

3H 20 (982 mm²)

Ref.	Calculations	Output
	DETAILING	
		

Continuous Beam 6/A-D

Ref.	Calculations	Output
Project	Two Storey School Building	Designed by: ARB
Location	1st Floor Continuous Beam 6/A-D	Checked by: AAA Date: Jan-24



Beam : b x h

b		h
200	x	500
200	x	500
200	x	500

Column: b x h

	b		h
upper	400	x	400
lower	400	x	400

Load Cases :

1. Max, Min, Max
2. Min, Max, Min
3. Max, Max, Min
4. Min, Max, Max

	Calculations	Output

Loadings : Load Case : 1

		g_k	q_k								
w1	:	21.65	2.66	kN/m	1.35 g_k	+	1.5	q_k	=	33.2175	L= 1.5 m
w2	:	30.66	4.23	kN/m	1.35 g_k	+	0	q_k	=	41.391	L= 7.5 m
w3	:	21.65	2.66	kN/m	1.35 g_k	+	1.5	q_k	=	33.2175	L= 1.5 m

Loadings : Load Case : 2

		g_k	q_k								
w1	:	21.65	2.66	kN/m	1.35 g_k	+	0	q_k	=	29.2275	L= 1.5 m
w2	:	30.66	4.23	kN/m	1.35 g_k	+	1.5	q_k	=	47.736	L= 7.5 m
w3	:	21.65	2.66	kN/m	1.35 g_k	+	0	q_k	=	29.2275	L= 1.5 m

Loadings : Load Case : 3

		g_k	q_k								
w1	:	21.65	2.66	kN/m	1.35 g_k	+	1.5	q_k	=	33.2175	L= 1.5 m
w2	:	30.66	4.23	kN/m	1.35 g_k	+	1.5	q_k	=	47.736	L= 7.5 m
w3	:	21.65	2.66	kN/m	1.35 g_k	+	0	q_k	=	29.2275	L= 1.5 m

Loadings : Load Case : 4

		g_k	q_k								
w1	:	21.65	2.66	kN/m	1.35 g_k	+	0	q_k	=	29.2275	L= 1.5 m
w2	:	30.66	4.23	kN/m	1.35 g_k	+	1.5	q_k	=	47.736	L= 7.5 m
w3	:	21.65	2.66	kN/m	1.35 g_k	+	1.5	q_k	=	33.2175	L= 1.5 m

	Calculations	Output
	Moment of Inertia	

Moment of Inertia

Column	I_{cu}	=	400 x 400^3 /12	=	2.13 x 10^9
	I_{cl}	=	400 x 400^3 /12	=	2.13 x 10^9
Beam	I_{a-b}	=	200 x 500^3 /12	=	2.08 x 10^9
	I_{b-c}	=	200 x 500^3 /12	=	2.08 x 10^9
	I_{c-d}	=	200 x 500^3 /12	=	2.08 x 10^9

Stiffness: K=I/L

Column $_{Upper}$:	K_{cu}	=	2.13 x 10	=	5.92 x 10^5
Column $_{Lower}$:	K_{cl}	=	2.13 x 10	=	5.92 x 10^5
Beam :	K_{A-B}	=	2.08 x 10^9 / 1500	=	13.9 x 10^5
	K_{B-C}	=	2.08 x 10^9 / 7500	=	2.77 x 10^5
	K_{C-D}	=	2.08 x 10^9 / 1500	=	13.9 x 10^5

Distribution factor

Joint B :	F_{B-A}	=	13.9 /(13.9+5.92 + 5.92 + 2.7	=	0.49
	F_{B-C}	=	2.77 /(13.9+5.92 + 5.92 + 2.7	=	0.09
	F_{cu}	=	5.92 /(13.9+5.92 + 5.92 + 2.7	=	0.21
	F_{cl}	=	5.92 /(13.9+5.92 + 5.92 + 2.7	=	0.21
Joint C :	F_{C-B}	=	2.77 /(13.9+5.92 + 5.92 + 2.7	=	0.09
	F_{C-D}	=	13.9 /(13.9+5.92 + 5.92 + 2.7	=	0.49
	F_{cu}	=	5.92 /(13.9+5.92 + 5.92 + 2.7	=	0.21
	F_{cl}	=	5.92 /(13.9+5.92 + 5.92 + 2.7	=	0.21

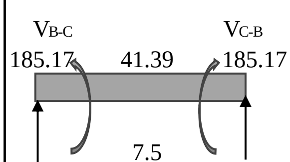
Fixed End Moment **Case : 1**

$\mathbf{M_{A-B}}$	=	wL^2 /12	=	-6.23
$\mathbf{M_{B-A}}$	=	wL^2 /12	=	6.23
$\mathbf{M_{B-C}}$	=	wL^2 /12	=	-194.02
$\mathbf{M_{C-B}}$	=	wL^2 /12	=	194.02
$\mathbf{M_{C-D}}$	=	wL^2 /12	=	-6.23
$\mathbf{M_{D-C}}$	=	wL^2 /12	=	6.23

	Calculations	Output

Case 1

	41.29			-41.29	
	0.00			0.00	
	0.00			0.00	
	0.08			-0.08	
	1.77			-1.77	
	39.44			-39.44	
B	0.21		C	0.21	
0.49	0.21	0.09	0.09	0.21	0.49
6.23		-194.02	194.02		-6.23
92.02	39.44	16.90	-16.90	-39.44	-92.02
0.00		-8.45	8.45		0.00
4.14	1.77	0.76	-0.76	-1.77	-4.14
0.00		-0.38	0.38		0.00
0.19	0.08	0.03	-0.03	-0.08	-0.19
0.00		-0.02	0.02		0.00
0.01	0.00	0.00	0.00	0.00	-0.01
0.00		0.00	0.00		0.00
0.00	0.00	0.00	0.00	0.00	0.00
102.58	41.29	-185.17	185.17	-41.29	-102.58



M @ C = 0

$7.5V_{B-C} + 185.2 - 185.2 - (41.4 \times 7.5 \times 3.75) = 0$

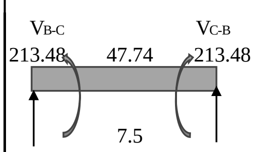
V_{B-C} = 155.22 kN
V_{C-B} = 155.22 kN

	Calculations	Output
	Fixed End Moment **Case : 2**	
	$\mathbf{M}_{\mathbf{A\text{-}B}}$ = wL^2 /12 = -5.48	
	$\mathbf{M}_{\mathbf{B\text{-}A}}$ = wL^2 /12 = 5.48	
	$\mathbf{M}_{\mathbf{B\text{-}C}}$ = wL^2 /12 = -223.76	
	$\mathbf{M}_{\mathbf{C\text{-}B}}$ = wL^2 /12 = 223.76	
	$\mathbf{M}_{\mathbf{C\text{-}D}}$ = wL^2 /12 = -5.48	
	$\mathbf{M}_{\mathbf{D\text{-}C}}$ = wL^2 /12 = 5.48	

	Calculations	Output

Case 2

	48.00			-48.00	
	0.00			0.00	
	0.00			0.00	
	0.09			-0.09	
	2.06			-2.06	
	45.84			-45.84	
B	0.21		C	0.21	
0.49	0.21	0.09	0.09	0.21	0.49
5.48		-223.76	223.76		-5.48
106.96	45.84	19.65	-19.65	-45.84	-106.96
0.00		-9.82	9.82		0.00
4.81	2.06	0.88	-0.88	-2.06	-4.81
0.00		-0.44	0.44		0.00
0.22	0.09	0.04	-0.04	-0.09	-0.22
0.00		-0.02	0.02		0.00
0.01	0.00	0.00	0.00	0.00	-0.01
0.00		0.00	0.00		0.00
0.00	0.00	0.00	0.00	0.00	0.00
117.48	48.00	-213.48	213.48	-48.00	-117.48



M @ C = 0

$7.5V_{B-C} - 213.48 + 213.48 - (47.74 \times 7.5 \times 3.75) = 0$

V_{B-C} = 179.01 kN

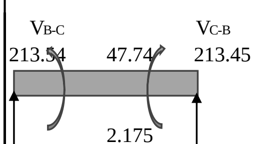
V_{C-B} = 179.01 kN

	Calculations	Output
	Fixed End Moment **Case : 3**	
	M $_{A-B}$ = wL^2 /12 = -6.23	
	M $_{B-A}$ = wL^2 /12 = 6.23	
	M $_{B-C}$ = wL^2 /12 = -223.76	
	M $_{C-B}$ = wL^2 /12 = 223.76	
	M $_{C-D}$ = wL^2 /12 = -5.48	
	M $_{D-C}$ = wL^2 /12 = 5.48	

	Calculations	Output

Case 3

	47.84			-47.99	
	0.00			0.00	
	0.00			0.00	
	0.09			-0.09	
	2.06			-2.06	
	45.68			-45.84	
B	0.21		C	0.21	
0.49	0.21	0.09	0.09	0.21	0.49
6.23		-223.76	223.76		-5.48
106.59	45.68	19.58	-19.65	-45.84	-106.96
0.00		-9.82	9.79		0.00
4.81	2.06	0.88	-0.88	-2.06	-4.80
0.00		-0.44	0.44		0.00
0.22	0.09	0.04	-0.04	-0.09	-0.22
0.00		-0.02	0.02		0.00
0.01	0.00	0.00	0.00	0.00	-0.01
0.00		0.00	0.00		0.00
0.00	0.00	0.00	0.00	0.00	0.00
117.86	47.84	-213.54	213.45	-47.99	-117.46



M @ C = 0

$7.5V_{B\text{-}C} - 213.54 + 213.45 - (41.4 \times 7.5 \times 3.75) = 0$

$V_{B\text{-}C}$ = 51.96 kN

$V_{C\text{-}B}$ = 51.87 kN

	Calculations	Output

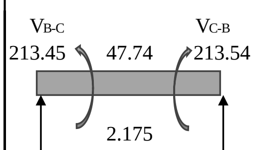
Fixed End Moment **Case : 4**

$M_{A\text{-}B}$	=	wL^2 /12	=	-5.48
$M_{B\text{-}A}$	=	wL^2 /12	=	5.48
$M_{B\text{-}C}$	=	wL^2 /12	=	-223.76
$M_{C\text{-}B}$	=	wL^2 /12	=	223.76
$M_{C\text{-}D}$	=	wL^2 /12	=	-6.23
$M_{D\text{-}C}$	=	wL^2 /12	=	6.23

	Calculations	Output

Case 4

	47.99			-47.84	
	0.00			0.00	
	0.00			0.00	
	0.09			-0.09	
	2.06			-2.06	
	45.84			-45.68	
B	0.21		C	0.21	
0.49	0.21	0.09	0.09	0.21	0.49
5.48		-223.76	223.76		-6.23
106.96	45.84	19.65	-19.58	-45.68	-106.59
0.00		-9.79	9.82		0.00
4.80	2.06	0.88	-0.88	-2.06	-4.81
0.00		-0.44	0.44		0.00
0.22	0.09	0.04	-0.04	-0.09	-0.22
0.00		-0.02	0.02		0.00
0.01	0.00	0.00	0.00	0.00	-0.01
0.00		0.00	0.00		0.00
0.00	0.00	0.00	0.00	0.00	0.00
117.46	47.99	-213.45	213.54	-47.84	-117.86

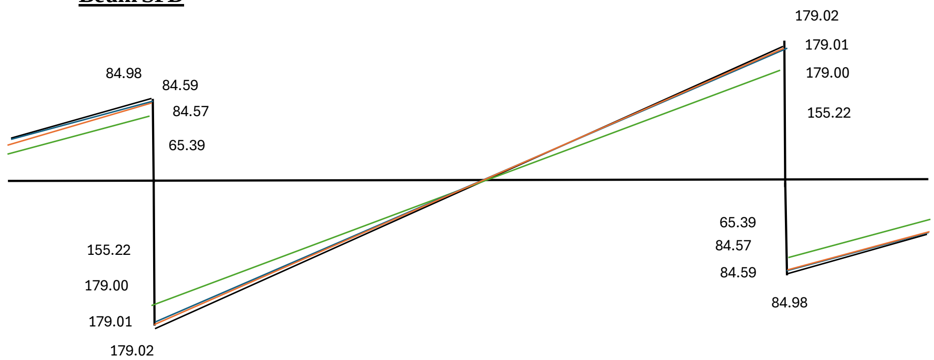
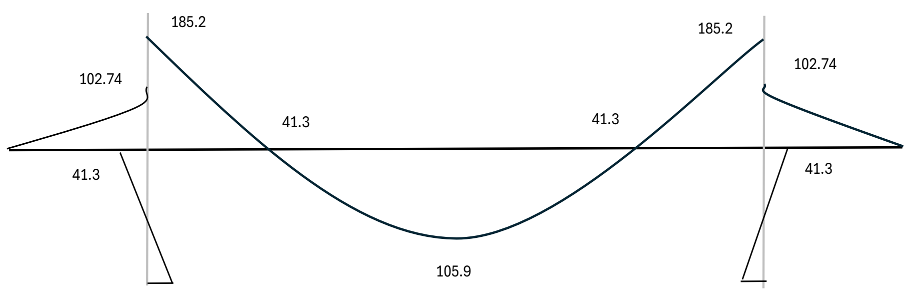


M @ C = 0

$7.5V_{B\text{-}C} - 213.45 + 213.54 - (41.4 \times 7.5 \times 3.75) = 0$

$V_{B\text{-}C}$ = 51.87 kN

$V_{C\text{-}B}$ = 51.96 kN

	Calculations	Output
	Beam SFD  **Beam BMD** 	

Ref	Calculations		Output
Project	Two Storey School Building		Designed by: ARB
Location	1st Floor Continuous Beam	Beam : F1/11-12	Checked by: AAA

SPECIFICATION

Materials :

Characteristics strength of concrete, fck = 30 N/mm^2

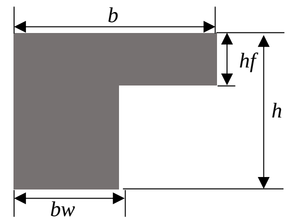
Characteristics strength of steel, f_{yk} = 500 N/mm^2

Characteristics strength of link, f_{yk} = 500 N/mm^2

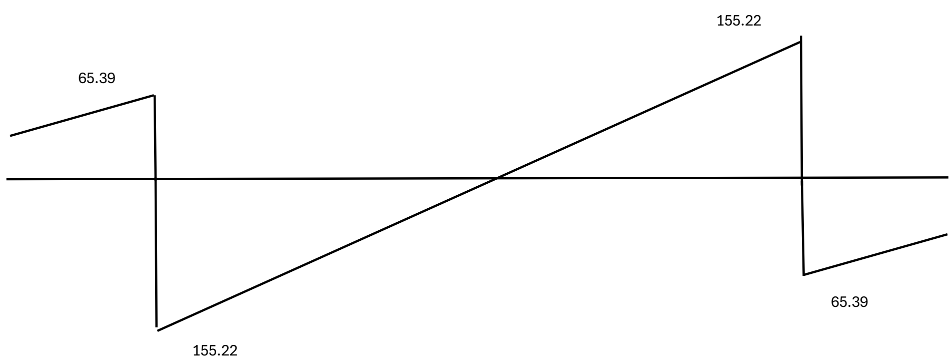
Nominal concrete cover = 35 mm

Assumed:				
$\emptyset_{bar1}$ = 25 mm	b = 2110 mm			
$\emptyset_{\text{link}}$ = 8 mm	hf = 150 mm			
$\emptyset_{bar2}$ = 16 mm	h = 500 mm	bw = 200 mm		

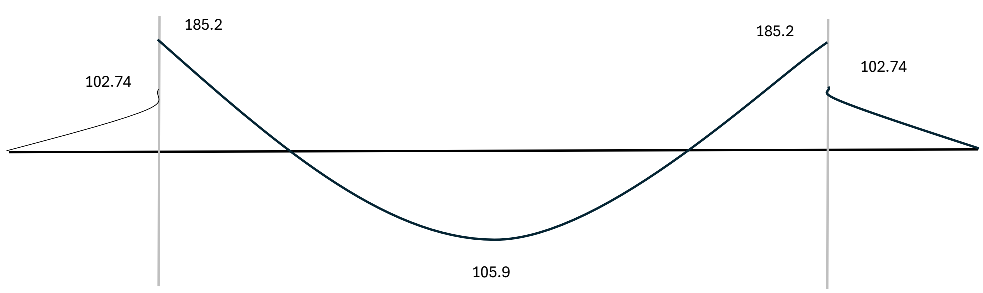
Dimension



SHEAR FORCE



BENDING MOMENT



Ref	Calculations	Output
	MAIN REINFORCEMENT	
	Effective depth,	
	$d = h - c_{nom} - \emptyset_{link} - 1.5\,\emptyset_{bar}$ = 419.5 mm	
	$d' = c_{nom} + \emptyset_{link} + 0.5\,\emptyset_{bar}$ = 55.5 mm	
	Mf = $0.567 f_{ck} b h_f (d - 0.5 h_f)$	
	= 0.567 x 30 x 2110 x 150 (419.5 - 75)	
	= 1855 kNm	
	Support B: Med = 185.17	
	K = $Med/f_{ck}bd^2$	
	= 185.17 × 10^6 / (30 x 200 x 419.5^2) = 0.175	
	K > Kbal = 0.167, Compression reinforcement is not required	
	z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ = 0.81 d	
	= 339.288	
	Area of tension reinforcement	Use : Top
	As = $Med/0.87 f_{yk} z$	3H 25
	= 185.17× 10^6/(0.87 x 500 x 0.95 x 419.5)	(1473 mm²)
	= 1248.1 mm²	Use : Bottom
		2H 25
		(982 mm²)
	Minimum and maximum reinforcement area,	
	As,min = $0.26(f_{ctm}/f_{yk})\,bd$	
	= 0.26 (2.9 / 500) *bd* = 0.0015 *bd*	
	= 0.0015 x 200 x 419.5 = 127 mm²	
	As,max = $0.04A_c$ = 0.04 x 200 x 500 = 4000 mm²	
	Span B-C : Med = 105.90	
	K = $Med/f_{ck}bd^2$	
	= 105.90 × 10^6 / (30 x 2110 x 419.5^2) = 0.010	
	K < Kbal = 0.167, Compression reinforcement is not required	
	z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ = 0.99 d	
	Area of tension reinforcement	Use :
	As = $Med/0.87 f_{yk} z$	2H 25
	= 105.90× 10^6/(0.87 x 500 x 0.95 x 419.5)	(982 mm²)
	= 611 mm²	Bottom

Ref	Calculations	Output
	Support C : Med = 185.17	
	K = $Med/f_{ck}bd^2$	
	= 185.17 × 10^6 / (30 x 200 x 419.5^2) = 0.175	
	K > Kbal = 0.167, Compression reinforcement is required	
	z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ = 0.81 d	
	= 339.288	Use : Top
	Area of tension reinforcement	3H 25
	As = $Med/0.87f_{yk}z$	(1473 mm²)
	= 185.17× 10^6/(0.87 x 500 x 0.95 x 419.5)	Use : Bottom
	= 1248.1 mm² 1068	2H 25
		(982 mm²)
	Span A-B : Med = 102.58	
	K = $Med/f_{ck}bd^2$	
	= 102.58 × 10^6 / (30 x 1250 x 419.5^2) = 0.016	
	K < Kbal = 0.167, Compression reinforcement is not required	
	z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ = 0.99 d	
	Area of tension reinforcement	Use : Bottom
	As = $Med/0.87f_{yk}z$	2H 25
	= 102.58× 10^6/(0.87 x 500 x 0.95 x 419.5)	(982 mm²)
	= 592 mm²	

Ref	Calculations	Output
	Span C-D : Med = 102.58 K = $Med/f_{ck}bd^2$ = $102.58 \times 10^6 / (30 \times 1250 \times 419.5^2)$ = 0.016 K < Kbal = 0.167, Compression reinforcement is not required z = $d\,[0.5 + \sqrt{0.25 - K/1.134}\,]$ = 0.99 d Area of tension reinforcement As = $Med/0.87f_{yk}z$ = $102.58 \times 10^6/(0.87 \times 500 \times 0.95 \times 419.5)$ = 592 mm²	Use : Bottom 2H 25 (982 mm²)

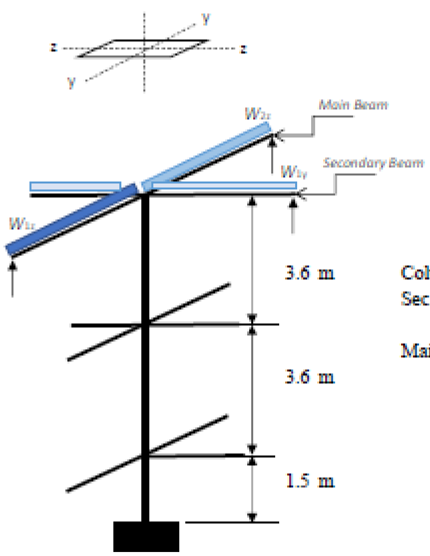
Ref	Calculations	Output
	SHEAR REINFORCEMENT	
6.2.3	**Support B :** Ved = 155.22 kN	
	Design shear force,	
	Concrete strut capacity	
	Vrd,max = $0.36 b_w d f_{ck}(1 - f_{ck}/250)/(\cot \Theta + \tan \Theta)$	
	= 0.36 x 200 x 419.5 x 30 (1 - 30 / 250) / (cot Θ + tan Θ)	
	= 275 kN ⟶ Θ = 22° cot Θ = 2.5	
	= 399 kN ⟶ Θ = 45° cot Θ = 1.0	
	Ved < Vrd,max cot Θ = 2.5	
	Ved < Vrd,max cot Θ = 1.0	
	⟶ Therefore angle Θ < 22°	
	Θ = $0.5 \sin^{-1}[Ved/0.18 b_w d f_{ck}(1 - f_{ck}/250)]$	
	= $0.5 \sin^{-1} \left\{ \dfrac{155.22 \times 10^3}{0.18 \times 200 \times 419.5 \times 30 (1 - 30/250)} \right\}$	
	= $0.5 \sin^{-1}$ { 0.39 } = 4.31°	
	Use : Θ = 22° tan Θ = 0.40 cot Θ = 2.5	
	Shear links	
	Asw/s = $Ved/0.78 f_{yk} d \cot\theta$	
	= 155.22 × 10^3 / (0.78 x 500 x 419.5 x 2.5)	
	= 0.379	
	mm²	
	Try link H6 Asw = 101	
	Spacing, S = 101 / 0.379 = 266 mm²	Use :
9.2.2(6)	Max. spacing, Smax = 0.75d = 0.75 x 419.5 = 315 mm²	H8 -250
	Support C : Ved = 155.22 kN	
	Design shear force,	
	Concrete strut capacity	
	Vrd,max = $0.36 b_w d f_{ck}(1 - f_{ck}/250)/(\cot \Theta + \tan \Theta)$	
	= 0.36 x 200 x 419.5 x 30 (1 - 30 / 250) / (cot Θ + tan Θ)	
	= 275 kN ⟶ Θ = 22° cot Θ = 2.5	
	= 399 kN ⟶ Θ = 45° cot Θ = 1.0	
	Ved < Vrd,max cot Θ = 2.5	
	Ved < Vrd,max cot Θ = 1.0	

Ref	Calculations	Output
	→ Therefore angle Θ < 22° Θ = $0.5sin^{-1}[Ved/0.18b_w df_{ck}(1-f_{ck}/250)]$ = $0.5sin^{-1}\left\{\frac{155.22 \times 10^3}{0.18 \times 200 \times 419.5 \times 30 (1 - 30/250)}\right\}$ = $0.5sin^{-1}$ { 0.39 } = 3.45° Use : Θ = 22° tan Θ = 0.40 cot Θ = 2.5 Shear links Asw/s = $Ved/0.78f_{yk}dcot\theta$ = 155.22 × 10³ / (0.78 x 500 x 419.5 x 2.5) = 0.379 Try link H8 Asw = 101 mm² Spacing, S = 101 / 0.379 = 266 mm² Max. spacing, Smax = 0.75d = 0.75 x 419.5 = 315 mm² Shear resistance of minimum links Vmin = $(A_{sw}/S)(0.78f_{yk}dcot\theta)$ = (101 / 300) (0.78 500 x 419.5 x 2.5) = 137.70 kN	Use : H8 -250

Column A/5

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: A/5	

AXIAL LOAD



Column Size :		400 ×	400	mm
Sec. Beam :	L_{1y} :		7.50	m
	L_{2y} :		1.50	m
Main Beam :	L_{1z} :		4.50	m
	L_{2z} :		4.50	m

Roof	W_{1z}		W_{2z}		W_{1y}		W_{2y}	
G_k	1.8		1.8		1.8		1.8	
Q_k	0.0		0.0		0.0		0.0	
Max.*	2.4		2.4		2.4		2.4	

*Max = $1.35G_k + 1.5Q_k$

1st. Fl	W_{1z}		W_{2z}		W_{1y}		W_{2y}	
G_k	19.8		19.8		28.4		11.1	
Q_k	9.0		9.0		13.5		4.5	
Max.*	40.2		40.2		58.6		21.8	

Gnd. Fl	W_{1z}		W_{2z}		W_{1y}		W_{2y}	
G_k	23.5		23.5		28.4		0.0	
Q_k	6.8		6.8		13.5		0.0	
Max.*	41.9		41.9		58.6		0.0	

First Floor to Roof

Load from roof truss		=	0.00 kN
Main beam =	(2.4 × 4.50 × 0.5) + (0.0 × 0.5)	=	5.32 kN
	(2.4 4.50 × 0.5) + (0.0 × 0.5)	=	5.32 kN
Sec. beam =	(2.4 7.50 × 0.5) + (0.0 × 0.5)	=	8.86 kN
	(2.4 1.50 × 0.5) + (0.0 × 0.5)	=	1.77 kN
Selfweight =	1.35 (0.4 × 0.4 × 3.6 × 25)	=	19.44 kN
	$N_{1\text{-Roof}}$	=	**40.70** kN

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: A/5	

First Floor to Ground Floor

Load from above														=	40.70	kN
Main beam =	(	40.2	×	4.50	×	0.5	)	+	(	0.0	×	0.5	)	=	90.37	kN
	(	40.2		4.50	×	0.5	)	+	(	0.0	×	0.5	)	=	90.37	kN
Sec. beam =	(	58.6		7.50	×	0.5	)	+	(	0.0	×	0.5	)	=	219.61	kN
	(	21.8		1.50	×	0.5	)	+	(	0.0	×	0.5	)	=	16.33	kN
Selfweight =		1.35	(	0.4	×	0.4	×	3.6	×	25	)			=	19.44	kN
												$N_{1\text{-roof}}$		=	**476.82**	kN

Footing to Ground Floor

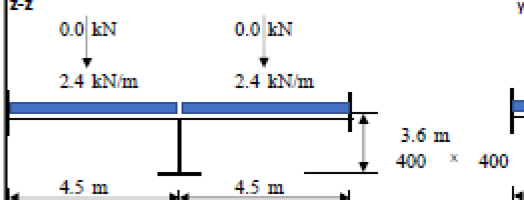
Load from above														=	476.82	kN
Main beam =	(	41.9	×	4.50	×	0.5	)	+	(	0.0	×	0.5	)	=	94.16	kN
	(	41.9		4.50	×	0.5	)	+	(	0.0	×	0.5	)	=	94.16	kN
Sec. beam =	(	58.6		7.50	×	0.5	)	+	(	0.0	×	0.5	)	=	219.61	kN
	(	0.0		1.50	×	0.5	)	+	(	0.0	×	0.5	)	=	0.00	kN
Selfweight =		1.35	(	0.4	×	0.4	×	1.5	×	25	)			=	8.10	kN
												$N_{Gnd\text{-}1}$		=	**892.86**	kN

BENDING MOMENTS

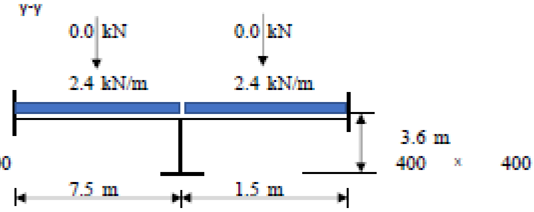
COLUMN = **B/5** **Level :** 1st. Fl to Roof

Level : Roof

z-z



y-y



z-z

Beam size:

200 × 350 200 × 350

Stiffness, $K = bh^3/12L$

Column	Kcl =	5.93 x 10^5	mm^3
Beam	0.5 K_1 =	0.79 x 10^5	mm^3
	0.5 K_2 =	0.79 x 10^5	mm^3

Fixed End Moment :

$M = \frac{wL^2}{12} + \frac{PL}{8}$

M_1 = 3.99 + 0.00 = 3.99 kNm

M_2 = 3.99 + 0.00 = 3.99 kNm

Column Moment

M_c =(K_c/ΣK)x(M_1-M_2)

M_{cL} =(5.93 / 7.51) × 0.00 = 0.00 kNm

y-y

Beam size:

200 × 350 200 × 350

Stiffness, $K = bh^3/12L$

Column	Kcl =	5.93 x 10^5	mm^3
Beam	0.5 K_1 =	0.48 x 10^5	mm^3
	0.5 K_2 =	2.38 x 10^5	mm^3

Fixed End Moment :

$M = \frac{wL^2}{12} + \frac{PL}{8}$

M_1 = 11.07 + 0.00 = 11.07 kNm

M_2 = 0.44 + 0.00 = 0.44 kNm

Column Moment

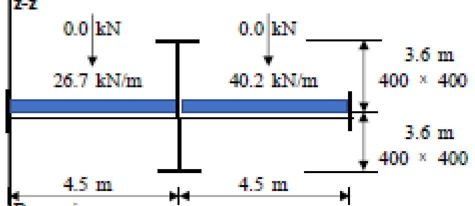
M_c =(K_c/ΣK)x(M_1-M_2)

M_{cL} =(5.93 / 8.78) × 10.63 = 7.17 kNm

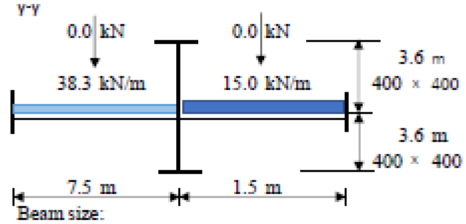
Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: A/5	

Level : First Floor

z-z



y-y



z-z				y-y			
Beam size:				Beam size:			
200 × 500	200 × 500			200 × 500	200 × 500		
Stiffness, $K = bh^3/12L$				Stiffness, $K = bh^3/12L$			
Column	Kcu =	5.93×10^5	mm^3	Column	Kcu =	5.93×10^5	mm^3
	Kcl =	5.93×10^5	mm^3		Kcl =	5.93×10^5	mm^3
Beam	$0.5\,K_1$ =	2.31×10^5	mm^3	Beam	$0.5\,K_1$ =	1.39×10^5	mm^3
	$0.5\,K_2$ =	2.31×10^5	mm^3		$0.5\,K_2$ =	6.94×10^5	mm^3

Fixed End Moment : (z-z)

$M = \frac{wL^2}{12} + \frac{PL}{8}$

$M_1 = 45.11 + 0.00 = 45.11$ kNm

$M_2 = 67.78 + 0.00 = 67.78$ kNm

Column Moment

$M_c = (K_c/\Sigma K) \times (M_1 - M_2)$

$M_{cL} = (5.93 / 16.48) \times 22.67 = 8.15$ kNm

$M_{cL} = (5.93 / 16.48) \times 22.67 = 8.15$ kNm

Fixed End Moment : (y-y)

$M = \frac{wL^2}{12} + \frac{PL}{8}$

$M_1 = 179.59 + 0.00 = 179.59$ kNm

$M_2 = 2.81 + 0.00 = 2.81$ kNm

Column Moment

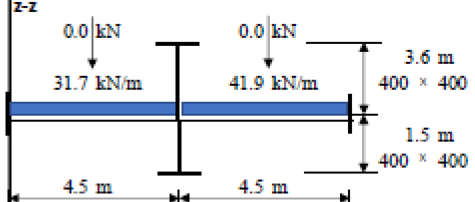
$M_c = (K_c/\Sigma K) \times (M_1 - M_2)$

$M_{cL} = (5.93 / 20.19) \times 176.78 = 51.90$ kNm

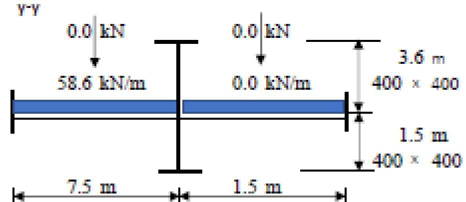
$M_{cL} = (5.93 / 20.19) \times 176.78 = 51.90$ kNm

Level : Gorund Floor

z-z



y-y



z-z				y-y			
Beam size:				Beam size:			
200 × 500	200 × 500			200 × 500	200 × 500		
Stiffness, $K = bh^3/12L$				Stiffness, $K = bh^3/12L$			
Column	Kcu =	5.93×10^5	mm^3	Column	Kcu =	5.93×10^5	mm^3
	Kcl =	14.22×10^5	mm^3		Kcl =	14.22×10^5	mm^3
Beam	$0.5\,K_1$ =	2.31×10^5	mm^3	Beam	$0.5\,K_1$ =	1.39×10^5	mm^3
	$0.5\,K_2$ =	2.31×10^5	mm^3		$0.5\,K_2$ =	6.94×10^5	mm^3

Fixed End Moment : (z-z)

$M = \frac{wL^2}{12} + \frac{PL}{8}$

$M_1 = 53.54 + 0.00 = 53.54$ kNm

$M_2 = 70.62 + 0.00 = 70.62$ kNm

Column Moment

$M_c = (K_c/\Sigma K) \times (M_1 - M_2)$

$M_{cL} = (5.93 / 24.78) \times 17.08 = 4.08$ kNm

$M_{cL} = (14.22 / 24.78) \times 17.08 = 9.80$ kNm

Fixed End Moment : (y-y)

$M = \frac{wL^2}{12} + \frac{PL}{8}$

$M_1 = 274.69 + 0.00 = 274.69$ kNm

$M_2 = 0.00 + 0.00 = 0.00$ kNm

Column Moment

$M_c = (K_c/\Sigma K) \times (M_1 - M_2)$

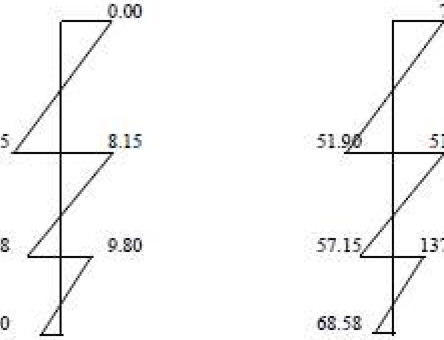
$M_{cL} = (5.93 / 28.48) \times 274.69 = 57.15$ kNm

$M_{cL} = (14.22 / 28.48) \times 274.69 = 137.17$ kNm

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: A/5	

SUMMARY AXIAL LOAD AND BENDING MOMENT

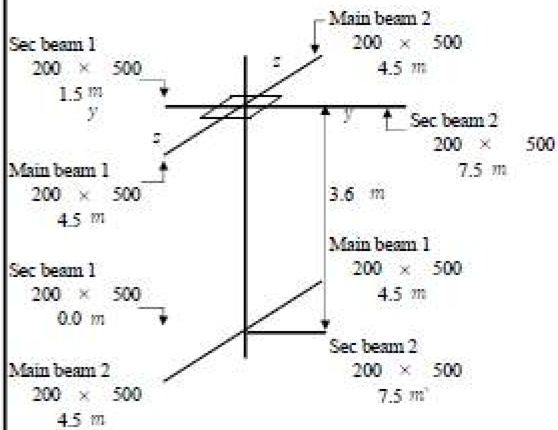
Column **A/5**



Roof		0.00		7.17	
First Floor	8.15	8.15	51.90	51.90	N = 40.70 kN
Gnd. Floor	4.08	9.80	57.15	137.17	N = 476.82 kN
Footing	4.90		68.58		N = 892.86 kN

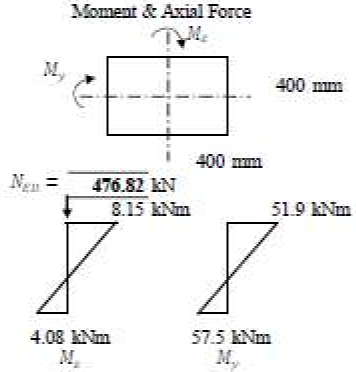
Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN :** **A/5** **Level :** **Gnd. Floor** **to** **1st Floor**	

COLUMN : SLENDER OR NON SLENDER ?



Material
f_{ck} = 30 N/mm^2
f_{yk} = 500 N/mm^2

Moment & Axial Force



Dimension and Size

Column : b x h = 400 × 400 mm

l_z = 3600 − 400 = 3200 mm l_y = 3600 − 400 = 3200 mm * Clear height

Beam :

Top	Main beam : b x h =		200 ×	500	mm
	l_1 =	4500 mm	l_2 =	4500 mm	
	Sec. beam : b x h =		200 ×	500	mm
	l_1 =	7500 mm	l_2 =	1500 mm	
Bottom	Main beam : b x h =		200 ×	500	mm
	l_1 =	4500 mm	l_2 =	4500 mm	
	Sec. beam : b x h =		200 ×	500	mm
	l_1 =	0 mm	l_2 =	7500 mm	

Bottom :
Beam = 1
Footing = 2
1

Moment of Inertia, $I = bh^3/12$

Column :

I_{zz} = 400 × 400^3 / 12 = 2.13 × 10^9 mm^4

I_{yy} = 400 × 400^3 / 12 = 2.13 × 10^9 mm^4

Beam :

Top

Main beam, I = 200 × 500^3 / 12 = 2.08 × 10^9 mm^4

Sec. beam, I = 200 × 500^3 / 12 = 2.08 × 10^9 mm^4

Bottom

Main beam, I = 200 × 500^3 / 12 = 2.08 × 10^9 mm^4

Sec. beam, I = 200 × 500^3 / 12 = 2.08 × 10^9 mm^4

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN : A/5 Level : Gnd. Floor to 1st Floor**	

Stiffness, K = EI / l

Column :

$K_{zz} =$ 2.13 $\times 10^9$ / 3200 = 6.67 $\times 10^5\ mm^4$

$K_{yy} =$ 2.13 $\times 10^9$ / 3200 = 6.67 $\times 10^5\ mm^4$

Beam :

Top

Main $K_{mb1} =$ 2.08 $\times 10^9$ / 4500 = 4.63 $\times 10^5\ mm^4$

$K_{mb2} =$ 2.08 $\times 10^9$ / 4500 = 4.63 $\times 10^5\ mm^4$

Sec. $K_{sb1} =$ 2.08 $\times 10^9$ / 7500 = 2.78 $\times 10^5\ mm^4$

$K_{sb2} =$ 2.08 $\times 10^9$ / 1500 = 13.89 $\times 10^5\ mm^4$

Bottom

Main $K_{mb1} =$ 2.08 $\times 10^9$ / 4500 = 4.63 $\times 10^5\ mm^4$

$K_{mb2} =$ 2.08 $\times 10^9$ / 4500 = 4.63 $\times 10^5\ mm^4$

Sec. $K_{sb1} =$ 2.08 $\times 10^9$ / 0 = 0.00 $\times 10^5\ mm^4$

$K_{sb2} =$ 2.08 $\times 10^9$ / 7500 = 2.78 $\times 10^5\ mm^4$

Relative column stiffness, $k = K_{col}/2(\sum K_{beam})$

z-axis

Top end : $k_2 =$ 6.67 / 2 (4.63 + 4.63)

= 0.36 > 0.10 use : 0.36

Bot. end : $k_1 =$ 6.67 / 2 (4.63 + 4.63)

= 0.36 > 0.10 use : 0.36

Output: Bot. end Beam Use : 0.36

y-axis

Top end : $k_2 =$ 6.67 / 2 (2.78 + 13.89)

= 0.20 > 0.10 use : 0.20

Bot. end : $k_1 =$ 6.67 / 2 (0.00 + 2.78)

= 1.20 > 0.10 use : 1.20

Output: Bot. end Beam Use : 1.20

5.8.3.2 (2)

Effective length of column,

Unbraced = 1 OR Braced = 2 1

Unbraced

$$l_0 = l_{max}\left\{\sqrt{\left(1+10\left(\frac{k_1 k_2}{k_1+k_2}\right)\right)};\left(1+\frac{k_1}{1+k_1}\right)\left(1+\frac{k_2}{1+k_2}\right)\right\}$$

$l_{0z} =$ [1 + 10 (0.36 × 0.36)/(0.36 + 0.36)]$^{1/2}$ = 1.67

[1 + (0.36 / (1 + 0.36)] · [1 + (0.36 / (1 + 0.36)] = 1.60

= 1.67 × 3200 = 5355 mm

$l_{0y} =$ [1 + 10 (0.20 × 1.20)/(0.20 + 1.20)]$^{1/2}$ = 1.65

[1 + (0.20 / (1 + 0.20)] · [1 + (1.20 / (1 + 1.20)] = 1.80

= 1.80 × 3200 = 5770 mm

Braced

$$l_0 = 0.5l\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\cdot\left(1+\frac{k_2}{0.45+k_2}\right)}$$

$l_{0z} =$ $0.5l_z$ [(1 + 0.36 / 0.81)(1 + 0.36 / 0.81)]$^{1/2}$

= 0.72 × 3200 = 2311 mm

$l_{0y} =$ $0.5l_z$ [(1 + 1.20 / 1.65)(1 + 0.20 / 0.65)]$^{1/2}$

0.75 × 3200 = 2405 mm

So, $l_{0z} =$ **5355 mm** $l_{0y} =$ **5770 mm**

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN : A/5 Level : Gnd. Floor to 1st Floor**	
    5.8.3.2 (1) 5.8.3.1 (1)	**Radius of gyration,** $i = (I/A)^{1/2}$ i_z = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm i_y = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm **Slenderness ratio,** $l = l_0/i$ λ_z = 5355 / 115.5 = 46.4 λ_y = 5770 / 115.5 = 50.0 **Slenderness limit,** $\lambda_{lim} = 20.A.B.C / (n^{1/2})$ A = $1/(1+0.2\varphi_{ef})$ = 0.7 (φ_{ef} not known) B = $(1+2\omega)^{1/2}$ = 1.1 (ω not known) C = $1.7 - r_m$ where : r_m = (M_{01}/M_{02}) Unbraced column z axis : r_m = 4.08 / 8.15 = 0.50 C_z = 1.7 − 1.00 = 0.70 y axis : r_m = 57.5 / 51.9 = 1.11 C_z = 1.7 − 1.00 = 0.70 $n = N_{ED} / (A_c f_{cd})$ where : A_c = 400 × 400 = 1.60 × 10^5 mm^4 f_{cd} = 0.85 f_{ck} / γ_c = 0.85 (30 / 1.5) = 17.00 N/mm^2 $n = \dfrac{476.82 \times 10^3}{1.60 \times 10^5 \times 17.00}$ = 0.18 z axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.18 $)^{1/2}$ = 25.7 < λ_z = 46.4 y axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.18 $)^{1/2}$ = 25.7 < λ_y = 50.0	 Column is slender about z-axis Column is slender about y-axis

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: Gnd. FL To 1st Flr	

Leverl:

Classification : Short unbraced column

Material :

Concrete, f_{ck} = 30 N/mm^2

Reinforcment, f_{yk} = 500 N/mm^2

Size, b x h 400 x 400 mm

Effective length l_{ox} = 5.35 m

l_{oy} = 5.77 m

Slenderness ratio λ_z = 46.4

λ_y = 50

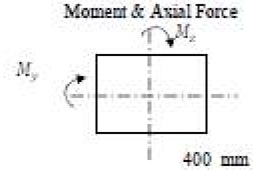
Assumed : link = 6 mm

bar = 12 mm

Nominal cover, C_{nom} = 30 mm

Axial force, N_{Ed} = 476.82

Moment & Axial Force



Bending moment

M_z = 8.15 kNm

M_y = 51.9 kNm

DESIGN MOMENT

The imperfection moment,

M_{imp} = = Ned (lo/400)

$M_{imp,z}$ = 476.82 × (5.35 / 400) = 6.4 kNm

$M_{imp,y}$ = 476.82 × (5.77 / 400) = 6.9 kNm

The design moment including the effect of imperfection,

M_{Edz} = 8.15 + 6.4 = 14.5

M_{Edy} = 51.9 + 6.9 = 58.8

SECOND ORDER MOMENT

The imperfection moment,

M_2 = Ned = 476.82

The design moment including the effect of imperfection,

M_{Edx} = 0 + 0.0 = 0.0

M_{Edy} = 0 + 0.0 = 0.0

c = 10

l_{0x} = 5355 mm

l_{0y} = 5770 mm

k_r = 1

$K\varphi\varphi$ =

= φef = 2.3 x 0.67= 1.54

βz = 0.191

βy = 1.26

$1/r_0$ = 0.87x500/200000/0.45x354 = 1.37×10^{-5}

$1/r$ = $1 \times 1.2 \times 1.37 \times 10^{-5}$ = 1.644×10^{-5}

e_{2z} = $1.644 \times 10^{-5} \times 5355^2/10$ = 47.14

e_{2y} = $1.644 \times 10^{-5} \times 5770^2/10$ = 54.73

The nominal second order moment,

M_2 = 476.82

M_{minz} = 476.82x0.4 = 22.4

M_{miny} = 476.82x0.5 = 25.8

CHECK BIAXIAL BENDING

$e_z = M_{edy} / N_{Ed}$ = $58.8 \times 10^6 / 476.82 \times 10^6$ = 123

$e_z = M_{edy} / N_{Ed}$ = $14.5 \times 10^6 / 476.82 \times 10^6$ = 30

$(e_y/h)/(e_z/b)$ = (30 / 400) / (123 / 400) = 0.25 > 0.2

$(e_z/b)/(e_y/h)$ = (123 / 400) / (30 / 400) = 4.05 > 0.2

==> Check biaxial bending

λ_y/λ_z = 50 / 46.4 = 1.1 < 2

λ_y/λ_z = 46.4 / 50 = 0.9 < 2

==> Ignore biaxial bending

REINFORCEMENT DESIGN

Effective depth, d = h - Cnom - link - 0.5 bar

h' = 400 - 30 - 6 - (0.5 x 12) = 358 mm

b' = 400 - 30 - 6 - (0.5 x 12) = 358 mm

M_z/h' = $36.9 \times 10^6 / 358$ = 103 kN

M_y/h' = $83.1 \times 10^6 / 358$ = 232 kN

M_z/h' < M_y/h'

$M'_x = M_x + \beta\,(h'/b')\,M_y$

Use ==> $M'_y = M_y + \beta\,(h'/b')\,M_x$

N/bhf_{ck} = $476.82 \times 10^3 / (400 \times 400 \times 30)$ = 0.10

$\beta = 1 - N/bh\,f_{ck}$ = 1 - 0.10 = 0.90 ≥ 0.3

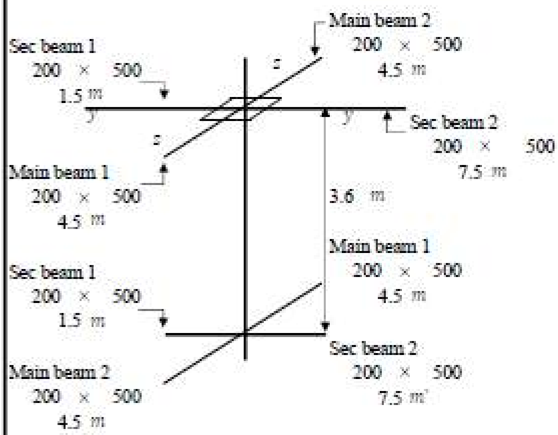
M'y = 58.8 + 0.90 x (358 / 358) x 14.5 = 71.9

Ref.	Calculations	Output
	$d/h = 358 / 400 = 0.90$	
	$N/bh f_{ck} = 476.82 \times 10^3 / (400 \times 400 \times 30) = 0.10$	
	$M/bh^2 f_{ck} = 71.9 \times 10^6 / (400 \times 400^2 \times 30) = 0.04$	
Table 4.12 Reynold's Handbook	$A_s f_{yk} / bh f_{ck} = 0.05$	
	$A_s = f_{yk} / bh f_{ck}$	
	$= 0.05\ (400 \times 400 \times 30) / 500$	
	$= 480\ mm^2$	
9.5.2(2)	$A_{s,min}\ 0.1 N_{Ed} / f_{yd} = 0.1 N_{Ed} / (0.87 f_{yk}) =$	
	$= 0.1\ 476.82 \times 10^3 / (0.87 \times 500)$	
	$= 110\ mm^2$ or $0.002A_c = 315\ mm^2$	Use : 5H 12
9.5.2(3)	$A_{s,max} = 0.04A_c = 0.04 \times 400 \times 400 = 6400\ mm^2$	3H 12 ($905\ mm^2$)
5.8.9(4)	**Check Biaxial Bending**	
	Steel area,	
	All : 5H 12 3H 12 $A_s = 905$	
	z-z : 5H 12 0 12 $A_{sz} = 566$	
	y-y : 5H 12 3H 12 $A_{sy} = 905$	
	$d_{2x}/h = 358 / 400 = 0.90$	
	$d_{2y}/b = 358 / 400 = 0.895$	
	$N/bh f_{ck} = 476.82 \times 10^3 / (400 \times 400 \times 30)$	
	$= 0.10$	
	$A_{sz} f_{yk} / bh f_{ck} = 905 \times 500 / (400 \times 400 \times 30) = 0.09$	
	$M/bh^2 f_{ck} = 0.083$	
	$M_{Rdz} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4\ kNm$	
	$A_{sy} f_{yk} / bh = 905 \times 500 / (400 \times 400 \times 30) = 0.09$	
	$M/bh^2 = 0.083$	
	$M_{Rdy} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4\ kNm$	
	$N_{Rd} = 0.567 f_{ck} A_c + 0.87 f_{ck} A_s$	
	$= (0.567 \times 30 \times 400 \times 400) + (0.87 \times 500 \times 452)$	
	$= 2918\ kN$	
	$N_{Ed} / N_{Rd}\ 476.82 / 2918 = 0.16$	
	$a = 1.06$	
5.8.9(2)	Imperfections need only be taken in one direction - where they have the most unfavourable effect.	
	$M_{Edz} = 14.5\ kNm$	
	$M_{Edy} = 51.9\ kNm$	
	$(M_{Edz}/M_{Rdz})^a + (M_{Edy}/M_{Rdy})^a \leq 1.0$	
	$(14.5 / 159.4)^{1.06} (51.9 / 159.4)^{1.35}$	
	$= 0.08 + 0.22$	
	$= 0.30 < 1$	

Ref.	Calculations	Output
9.5.3	Links, ϕ_{min} = 0.25 x 12 = 3.0 mm ≤ 6 mm $S_{v\,max}$ = the lesser of = 20 x 12 = 240 mm or 350 mm or 400 mm Use : H6 - 200 At section 450 mm below and above beam and at lapped joints $S_{v\,max}$ = 0.6 x 240 = 144 mm Use : H6 - 125	

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN :** **A/5** **Level :** **1st Floor** **to** **Roof**	

COLUMN : SLENDER OR NON SLENDER ?

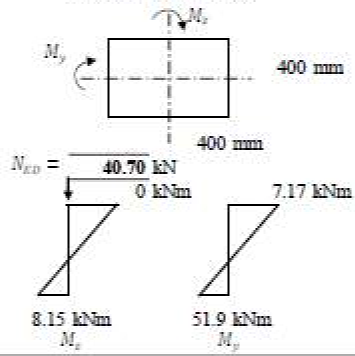


Material

f_{ck} = 30 N/mm^2

f_{yk} = 500 N/mm^2

Moment & Axial Force



Dimension and Size

Column : b x h = 400 × 400 mm

l_z = 3600 − 400 = 3200 mm l_y = 3600 − 400 = 3200 mm   * Clear height

Beam :

Top	Main beam : b x h =		200 × 500	mm		Bottom :
	l_1 =	4500 mm	l_2 =	4500 mm		Beam = 1
	Sec. beam : b x h =		200 × 500	mm		Footing = 2
	l_1 =	7500 mm	l_2 =	1500 mm		1
Bottom	Main beam : b x h =		200 × 500	mm		
	l_1 =	4500 mm	l_2 =	4500 mm		
	Sec. beam : b x h =		200 × 500	mm		
	l_1 =	1500 mm	l_2 =	7500 mm		

Moment of Inertia, $I = bh^3/12$

Column :

I_{zz} = 400 × 400^3/ 12 = 2.13 × $10^9\ mm^4$

I_{yy} = 400 × 400^3/ 12 = 2.13 × $10^9\ mm^4$

Beam :

Top

Main beam, I = 200 × 500^3/ 12 = 2.08 × $10^9\ mm^4$

Sec. beam, I = 200 × 500^3/ 12 = 2.08 × $10^9\ mm^4$

Bottom

Main beam, I = 200 × 500^3/ 12 = 2.08 × $10^9\ mm^4$

Sec. beam, I = 200 × 500^3/ 12 = 2.08 × $10^9\ mm^4$

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN : A/5 Level : 1st Floor to Roof**	

Stiffness, K = EI / l

Column :

$K_{zz} = 2.13 \times 10^9 / 3200 = 6.67 \times 10^5\ mm^4$

$K_{yy} = 2.13 \times 10^9 / 3200 = 6.67 \times 10^5\ mm^4$

Beam :

Top

Main $K_{mb1} = 2.08 \times 10^9 / 4500 = 4.63 \times 10^5\ mm^4$

$K_{mb2} = 2.08 \times 10^9 / 4500 = 4.63 \times 10^5\ mm^4$

Sec. $K_{sb1} = 2.08 \times 10^9 / 7500 = 2.78 \times 10^5\ mm^4$

$K_{sb2} = 2.08 \times 10^9 / 1500 = 13.89 \times 10^5\ mm^4$

Bottom

Main $K_{mb1} = 2.08 \times 10^9 / 4500 = 4.63 \times 10^5\ mm^4$

$K_{mb2} = 2.08 \times 10^9 / 4500 = 4.63 \times 10^5\ mm^4$

Sec. $K_{sb1} = 2.08 \times 10^9 / 1500 = 13.89 \times 10^5\ mm^4$

$K_{sb2} = 2.08 \times 10^9 / 7500 = 2.78 \times 10^5\ mm^4$

Relative column stiffness, $k = K_{col}/2(\sum K_{beam})$

z-axis

Top end : $k_2 = 6.67 / 2 (4.63 + 4.63)$

$= 0.36 > 0.10$ use : 0.36

Bot. end : $k_1 = 6.67 / 2 (4.63 + 4.63)$

$= 0.36 > 0.10$ use : 0.36 — Bot. end Beam Use : 0.36

y-axis

Top end : $k_2 = 6.67 / 2 (2.78 + 13.89)$

$= 0.20 > 0.10$ use : 0.20

Bot. end : $k_1 = 6.67 / 2 (13.89 + 2.78)$

$= 0.20 > 0.10$ use : 0.20 — Bot. end Beam Use : 0.20

5.8.3.2 (2) **Effective length of column,**

Unbraced = 1 OR Braced = 2 — 1

Unbraced

$$l_0 = l_{max}\left\{\sqrt{\left(1+10\left(\frac{k_1 k_2}{k_1+k_2}\right)\right)};\ \left(1+\frac{k_1}{1+k_1}\right)\left(1+\frac{k_2}{1+k_2}\right)\right\}$$

$l_{0z} = [1 + 10 (0.36 \times 0.36)/(0.36 + 0.36)]^{1/2} = 1.67$

$[1 + (0.36 / (1 + 0.36)] \cdot [1 + (0.36 / (1 + 0.36)] = 1.60$

$= 1.67 \times 3200 = 5355$ mm

$l_{0y} = [1 + 10 (0.20 \times 0.20)/(0.20 + 0.20)]^{1/2} = 1.41$

$[1 + (0.20 / (1 + 0.20)] \cdot [1 + (0.20 / (1 + 0.20)] = 1.36$

$= 1.41 \times 3200 = 4525$ mm

Braced

$$l_0 = 0.5l\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\cdot\left(1+\frac{k_2}{0.45+k_2}\right)}$$

$l_{0z} = 0.5l_z [(1 + 0.36 / 0.81)(1 + 0.36 / 0.81)]^{1/2}$

$= 0.72 \times 3200 = 2311$ mm

$l_{0y} = 0.5l_z [(1 + 0.20 / 0.65)(1 + 0.20 / 0.65)]^{1/2}$

$0.65 \times 3200 = 2092$ mm

So, $l_{0z} =$ **5355 mm** $l_{0y} =$ **4525 mm**

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN :** **A/5** **Level :** **1st Floor** **to** **Roof**	
	Radius of gyration, $i = (I/A)^{1/2}$ i_z = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm i_y = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm	
5.8.3.2 (1)	**Slenderness ratio,** $l = l_0/i$ λ_z = 5355 / 115.5 = 46.4 λ_y = 4525 / 115.5 = 39.2	
5.8.3.1 (1)	**Slenderness limit,** $\lambda_{lim} = 20.A.B.C / (n^{1/2})$ A = $1/(1+0.2\varphi_{ef})$ = 0.7 (φ_{ef} *not known*) B = $(1+2\omega)^{1/2}$ = 1.1 (ω *not known*) C = $1.7 - r_m$ where : r_m = (M_{01}/M_{02}) Unbraced column z axis : r_m = 8.15 / 0 = 0.00 C_z = 1.7 − 1.00 = 0.70 y axis : r_m = 51.9 / 7.17 = 7.24 C_z = 1.7 − 1.00 = 0.70 $n = N_{ED} / (A_c f_{cd})$ where : A_c = 400 × 400 = 1.60 × 10^5 mm^4 f_{cd} = 0.85 f_{ck} / γ_c = 0.85 (30 / 1.5) = 17.00 N/mm^2 $n = \dfrac{40.7 \times 10^3}{1.60 \times 10^5 \times 17.00}$ = 0.01	
	z axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.01 $)^{1/2}$ = 88.1 > λ_z = 46.4	Column is non-slender about z-axis
	y axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.01 $)^{1/2}$ = 88.1 > λ_y = 39.2	Column is non-slender about y-axis

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: Footing to Gnd. FL	

Leverl:

classification : Short unbraced column

Material :

Concrete, f_{ck} = 30 N/mm^2

Reinforcement, f_{yk} = 500 N/mm^2

Size, b x h 400 x 400 mm

Effective length l_{0z} = 5.35 m

l_{0y} = 4.50 m

Slenderness ratio λ_z = 46.4

λ_y = 39.2

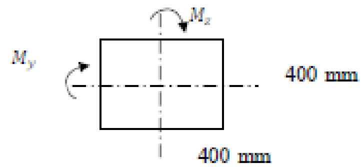
Assumed : link = 6 mm

bar = 12 mm

Nominal cover, C_{nom} = 30 mm

Axial force, N_{Ed} = 40.7

Moment & Axial Force



Bending moment

M_z = 0 kNm

M_y = 7.17 kNm

DESIGN MOMENT

The imperfection moment,

M_{imp} = = Ned (lo/400)

$M_{imp,z}$ = 40.7 x (5.35 / 400) = 0.5 kNm

$M_{imp,y}$ = 40.7 x (4.5 / 400) = 0.5 kNm

The design moment including the effect of imperfection,

M_{Edz} = 0 + 0.5 = 0.5

M_{Edy} = 7.17 + 0.5 = 7.6

CHECK BIAXIAL BENDING

e_z = M_{edy} / N_{Ed} = 7.6 x 10^6 / 40.7 x 10^6 = 187

e_z = M_{edy} / N_{Ed} = 0.5 x 10^6 / 40.7 x 10^6 = 13

$(e_y/h)/(e_z/b)$ = (13 / 400) / (187 / 400) = 0.07 > 0.2

$(e_z/b)/(e_y/h)$ = (187 / 400) / (13 / 400) = 14.01 > 0.2

==> Check biaxial bending

λ_y/λ_z = 39.2 / 46.4 = 0.8 < 2

λ_y/λ_z = 46.4 / 39.2 = 1.2 < 2

==> Ignore biaxial bending

REINFORCEMENT DESIGN

Effective depth, d = h - Cnom - link - 0.5 bar

h' = 400 - 30 - 6 - (0.5 x 12) = 358 mm

b' = 400 - 30 - 6 - (0.5 x 12) = 358 mm

M_z/h' = 0.5 x 10^6 / 358 2 kN

M_y/h' = 7.6 x 10^6 / 358 21 kN

M_z/h' > M_y/h'

Use ==> $M'_z = M_z + \beta\,(h'/b')\,M_y$

$M_y = M_y + \beta\,(h'/b')\,M_z$

N/bhf_{ck} = 40.7 x 10^3 / (400 x 400 x 30) = 0.01

$\beta = 1 - N/bh\,f_{ck}$ = 1 - 0.01 = 0.99 ≥ 0.3

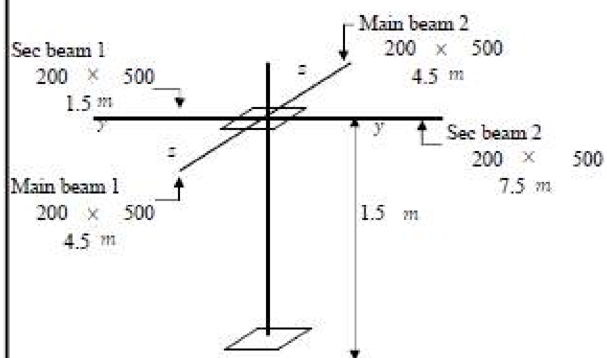
M'_z = 0.5 + 0.99 x (358 / 358) x 7.6 = 8.1

Ref.	Calculations	Output
	$d/h = 358 / 400 = 0.90$	
	$N/bh f_{ck} = 40.7 \times 10^3 / (400 \times 400 \times 30) = 0.01$	
	$M/bh^2 f_{ck} = 8.1 \times 10^6 / (400 \times 400^2 \times 30) = 0.00$	
Table 4.12		
	$A_s f_{yk} / bh f_{ck} = 0$	
Reynold's Handbook	$A_s = f_{yk} / bh f_{ck}$	
	$= 0.00 (400 \times 400 \times 30) / 500$	
	$= 0 \text{ mm}^2$	
9.5.2(2)	$A_{s,min} = 0.1 N_{Ed} / f_{yd} = 0.1 N_{Ed} / (0.87 f_{yk}) =$	
	$= 0.1 \quad 40.7 \times 10^3 / (0.87 \times 500)$	
	$= 9 \text{ mm}^2$ or $0.002A_c = 315 \text{ mm}^2$	Use : 0H 12
9.5.2(3)	$A_{s,max} = 0.04A_c = 0.04 \times 400 \times 400 = 6400 \text{ mm}^2$	4H 12
		(452 mm²)
5.8.9(4)	**Check Biaxial Bending**	
	Steel area,	
	All : 0H 12 4H 12 $A_s = 452$	
	z-z : 0H 12 4H 12 $A_{sz} = 452$	
	y-y : 0H 12 4H 12 $A_{sy} = 452$	
	$d_{2x}/h = 358 / 400 = 0.90$	
	$d_{2y}/b = 358 / 400 = 0.895$	
	$N/bh f_{ck} = 40.7 \times 10^3 / (400 \times 400 \times 30)$	
	$= 0.01$	
	$A_{sz} f_{yk} / bh f_{ck} = 452 \times 500 / (400 \times 400 \times 30) = 0.05$	
	$M/bh^2 f_{ck} = 0.083$	
	$M_{Rdz} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4 \text{ kNm}$	
	$A_{sy} f_{yk} / bh = 452 \times 500 / (400 \times 400 \times 30) = 0.05$	
	$M/bh^2 = 0.083$	
	$M_{Rdy} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4 \text{ kNm}$	
	$N_{Rd} = 0.567 f_{ck} A_c + 0.87 f_{ck} A_s$	
	$= (0.567 \times 30 \times 400 \times 400) + (0.87 \times 500 \times 452)$	
	$= 2918 \text{ kN}$	
	$N_{Ed} / N_{Rd} \quad 40.7 / 2918 = 0.01$	
	$\alpha = 1.35$	
5.8.9(2)	Imperfections need only be taken in one dirextion - where they have the most unfavourable effect.	
	$M_{Edz} = 0.5 \text{ kNm}$	
	$M_{Edy} = 7.17 \text{ kNm}$	
	$(M_{Edz}/M_{Rdz})^a + (M_{Edy}/M_{Rdy})^a \leq 1.0$	
	$(0.5 / 159.4)^{1.35} (7.17 / 159.4)^{1.35}$	
	$= 0.00 + 0.02$	
	$= 0.02 < 1$	

Ref.	Calculations	Output
9.5.3	Links, $\varnothing_{min}$ = 0.25 x 12 = 3.0 mm ≤ 6 mm $S_{v\,max}$ = the lesser of = 20 × 12 = 240 mm or 350 mm or 400 mm Use : H6 - 225 At section 450 mm below and above beam and at lapped joints $S_{v\,max}$ = 0.6 × 240 = 144 mm Use : H6 - 125	

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN : A/5 Level : Footing to Ground**	

COLUMN : SLENDER OR NON SLENDER ?

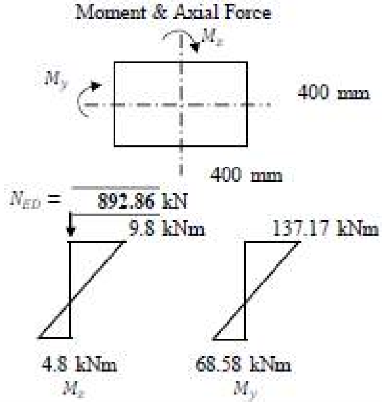


Material

f_{ck} = 30 N/mm^2

f_{yk} = 500 N/mm^2

Moment & Axial Force



Dimension and Size

Column : b x h = 400 × 400 mm

l_z = 1500 − 400 = 1100 mm $\qquad$ l_y = 1500 − 400 = 1100 mm $\qquad$ * Clear height

Beam :

Top $\quad$ Main beam : b x h = 200 × 500 mm

l_1 = 4500 mm $\qquad$ l_2 = 4500 mm

Sec. beam : b x h = 200 × 500 mm

l_1 = 7500 mm $\qquad$ l_2 = 1500 mm

Bottom $\quad$ Main beam : b x h = 0 × 0 mm

l_1 = 0 mm $\qquad$ l_2 = 0 mm

Sec. beam : b x h = 0 × 0 mm

l_1 = 0 mm $\qquad$ l_2 = 0 mm

Output	
Bottom :	
Beam =	1
Footing =	2
	1

Moment of Inertia, $I = bh^3/12$

Column :

I_{zz} = 400 × 400^3/ 12 = 2.13 × 10^9 mm^4

I_{yy} = 400 × 400^3/ 12 = 2.13 × 10^9 mm^4

Beam :

Top

Main beam, I = 200 × 500^3/ 12 = 2.08 × 10^9 mm^4

Sec. beam, I = 200 × 500^3/ 12 = 2.08 × 10^9 mm^4

Bottom

Main beam, I = 0 × 0^3/ 12 = 0.00 × 10^9 mm^4

Sec. beam, I = 0 × 0^3/ 12 = 0.00 × 10^9 mm^4

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN : A/5 Level : Footing to Ground**	

Stiffness, K = EI / l

Column :

$K_{zz} =$ 2.13 × 10^9 / 1100 = 19.39 × $10^5\ mm^4$

$K_{yy} =$ 2.13 × 10^9 / 1100 = 19.39 × $10^5\ mm^4$

Beam :

Top

Main $K_{mb1} =$ 2.08 × 10^9 / 4500 = 4.63 × $10^5\ mm^4$

$K_{mb2} =$ 2.08 × 10^9 / 4500 = 4.63 × $10^5\ mm^4$

Sec. $K_{sb1} =$ 2.08 × 10^9 / 7500 = 2.78 × $10^5\ mm^4$

$K_{sb2} =$ 2.08 × 10^9 / 1500 = 13.89 × $10^5\ mm^4$

Bottom

Main $K_{mb1} =$ 0.00 × 10^9 / 0 = 0.00 × $10^5\ mm^4$

$K_{mb2} =$ 0.00 × 10^9 / 0 = 0.00 × $10^5\ mm^4$

Sec. $K_{sb1} =$ 0.00 × 10^9 / 0 = 0.00 × $10^5\ mm^4$

$K_{sb2} =$ 0.00 × 10^9 / 0 = 0.00 × $10^5\ mm^4$

Relative column stiffness, $k = K_{col}/2(\Sigma K_{beam})$

z-axis

Top end : $k_2 =$ 19.39 / 2 (4.63 + 4.63)

= 1.05 > 0.10 use : 1.05

Bot. end : $k_1 =$ 19.39 / 2 (0.00 + 0.00)

= 0.00 < 0.10 use : 0.10 — *Output:* Bot. end Beam Use : 1.05

y-axis

Top end : $k_2 =$ 19.39 / 2 (2.78 + 13.89)

= 0.58 > 0.10 use : 0.58

Bot. end : $k_1 =$ 19.39 / 2 (0.00 + 0.00)

= 0.00 < 0.10 use : 0.10 — *Output:* Bot. end Beam Use : 0.58

5.8.3.2 (2) **Effective length of column,**

Unbraced = 1 OR Braced = 2 **1**

Unbraced

$$l_0 = l_{max}\left\{\sqrt{\left(1+10\left(\frac{k_1k_2}{k_1+k_2}\right)\right)};\ \left(1+\frac{k_1}{1+k_1}\right)\left(1+\frac{k_2}{1+k_2}\right)\right\}$$

$l_{0z} =$ [1 + 10 (1.05 × 0.10)/(1.05 + 0.10)]$^{1/2}$ = 1.38

[1 + (1.05 / (1 + 1.05)] · [1 + (0.10 / (1 + 0.10)] = 1.65

= 1.65 × 1100 = 1814 mm

$l_{0y} =$ [1 + 10 (0.58 × 0.10)/(0.58 + 0.10)]$^{1/2}$ = 1.36

[1 + (0.58 / (1 + 0.58)] · [1 + (0.10 / (1 + 0.10)] = 1.49

= 1.49 × 1100 = 1641 mm

Braced

$$l_0 = 0.5l\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\cdot\left(1+\frac{k_2}{0.45+k_2}\right)}$$

$l_{0z} = 0.5l_z$ [(1 + 0.10 / 0.55)(1 + 1.05 / 1.50)]$^{1/2}$

= 0.71 × 1100 = 779 mm

$l_{0y} = 0.5l_z$ [(1 + 0.10 / 0.55)(1 + 0.58 / 1.03)]$^{1/2}$

0.68 × 1100 = 748 mm

So, $l_{0z} =$ **1814 mm** $l_{0y} =$ **1641 mm**

Ref.	Calculations	Output
Project	Two Storey Bungalow	Designed by: Anas Checked by: Abdul Raffi
Location	**COLUMN :** **A/5** **Level :** **Footing** **to** **Ground**	
	Radius of gyration, $i = (I/A)^{1/2}$ i_z = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm i_y = (2.13 × 10^9 / 160000 $)^{1/2}$ = 115.5 mm	
5.8.3.2 (1)	**Slenderness ratio,** $l = l_0/i$ λ_z = 1814 / 115.5 = 15.7 λ_y = 1641 / 115.5 = 14.2	
5.8.3.1 (1)	**Slenderness limit,** $\lambda_{lim} = 20.A.B.C\,/\,(n^{1/2})$ A = $1/(1+0.2\varphi_{ef})$ = 0.7 (φ_{ef} *not known*) B = $(1+2\omega)^{1/2}$ = 1.1 (ω *not known*) C = $1.7 - r_m$ where : r_m = (M_{01}/M_{02}) Unbraced column z axis : r_m = 4.8 / 9.8 = 0.00 C_z = 1.7 − 1.00 = 0.70 y axis : r_m = 68.58 / 137.17 = 0.50 C_z = 1.7 − 1.00 = 0.70 $n = N_{ED}\,/\,(A_c f_{cd})$ where : A_c = 400 × 400 = 1.60 × 10^5 mm^4 f_{cd} = 0.85 $f_{ck}\,/\,\gamma_c$ = 0.85 (30 / 1.5) = 17.00 N/mm^2 $n = \dfrac{892.86 \times 10^3}{1.60 \times 10^5 \times 17.00}$ = 0.33	
	z axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.33 $)^{1/2}$ = 18.8 > λ_z = 15.7	Column is non-slender about z-axis
	y axis : λ_{lim} = 20 × 0.7 × 1.1 × 0.70 / (0.33 $)^{1/2}$ = 18.8 > λ_y = 14.2	Column is non-slender about y-axis

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Column: Footing to Gnd. FL	

Leverl:

classification : Short unbraced column

Material :

Concrete, f_{ck} = 30 N/mm^2

Reinforcement, f_{yk} = 500 N/mm^2

Size, b x h 400 x 400 mm

Effective length l_{0z} = 1.9 m

l_{0y} = 1.60 m

Slenderness ratio λ_z = 15.7

λ_y = 14.2

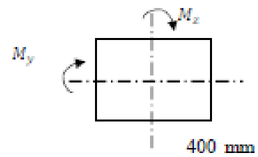
Assumed : link = 6 mm

bar = 25 mm

Nominal cover, C_{nom} = 30 mm

Axial force, N_{Ed} = 892.86

Moment & Axial Force



Bending moment

M_z = 9.8 kNm

M_y = 137.17 kNm

DESIGN MOMENT

The imperfection moment,

M_{imp} = = Ned (lo/400)

$M_{imp,z}$ = 892.86 x (1.9 / 400) = 4.2 kNm

$M_{imp,y}$ = 892.86 x (1.6 / 400) = 3.6 kNm

The design moment including the effect of imperfection,

M_{Edz} = 9.8 + 4.2 = 14.0

M_{Edy} = 137.17 + 3.6 = 140.7

CHECK BIAXIAL BENDING

e_z = M_{Edy} / N_{Ed} = 140.7 x 10^6 / 892.86 x 10^6 = 158

e_z = M_{Edy} / N_{Ed} = 14.0 x 10^6 / 892.86 x 10^6 = 16

$(e_y/h)/(e_z/b)$ = (16 / 400) / (158 / 400) = 0.10 > 0.2

$(e_z/b)/(e_y/h)$ = (158 / 400) / (16 / 400) = 10.02 > 0.2

==> Check biaxial bending

λ_y/λ_z = 14.2 / 15.7 = 0.9 < 2

λ_y/λ_z = 15.7 / 14.2 = 1.1 < 2

==> Ignore biaxial bending

REINFORCEMENT DESIGN

Effective depth, d = h - Cnom - link - 0.5 bar

h' = 400 - 30 - 6 - (0.5 x 25) = 351.5 mm

b' = 400 - 30 - 6 - (0.5 x 25) = 351.5 mm

M_z/h' = 14.0 x 10^6 / 351.5 40 kN

M_y/h' = 140.7 x 10^6 / 351.5 400 kN

M_z/h' < M_y/h'

$M'_z = M_z + \beta$ (h'/b') M_y

Use ==> $M'_y = M_y + \beta$ (h'/b') M_z

N/bhf_{ck} = 892.86 x 10^3 / (400 x 400 x 30) = 0.19

$\beta = 1 - N/bh\, f_{ck}$ = 1 - 0.19 = 0.81 ≥ 0.3

M'_y = 140.7 + 0.81 x 351.5 / 351.5 x 14.0 = 152.2

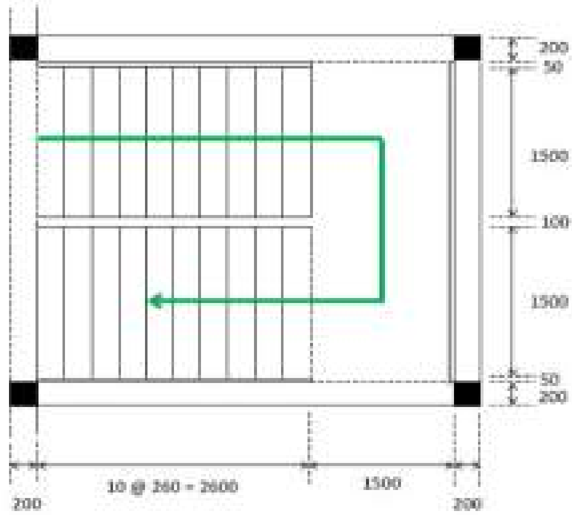
Ref.	Calculations	Output
	$d/h = 351.5 / 400 = 0.88$	
	$N/bhf_{ck} = 892.86 \times 10^3 / (400 \times 400 \times 30) = 0.19$	
	$M/bh^2 f_{ck} = 152.2 \times 10^6 / (400 \times 400^2 \times 30) = 0.08$	
Table 4.12 Reynold's Handbook	$A_s f_{yk} / bh f_{ck} = 0.25$	
	$A_s = f_{yk} / bh f_{ck}$	
	$= 0.25\ (350 \times 450 \times 30) / 500$	
	$= 2400\ mm^2$	
9.5.2(2)	$A_{s,min} = 0.1\ N_{Ed} / f_{yd} = 0.1\ N_{Ed} / (0.87\ f_{yk}) =$	
	$= 0.1\ \ 892.86 \times 10^3 / (0.87 \times 500)$	
	$= 205\ mm^2$ or $0.002A_c = 315\ mm^2$	Use : 6H 25
9.5.2(3)	$A_{s,max} = 0.04A_c = 0.04 \times 400 \times 400 = 6400\ mm^2$	0H 12
		(3398 mm²)
5.8.9(4)	**Check Biaxial Bending**	
	Steel area,	
	All : 6H 25 0H 12 A_s = 3398	
	z-z : 6H 25 0H 12 A_{sz} = 3398	
	y-y : 6H 25 0H 12 A_{sy} = 3398	
	$d_{2x}/h = 351.5 / 400 = 0.88$	
	$d_{2y}/b = 351.5 / 400 = 0.87875$	
	$N/bh f_{ck} = 892.86 \times 10^3 / (400 \times 400 \times 30)$	
	$= 0.19$	
	$A_{sz} f_{yk} / bh f_{ck} = 3398 \times 500 / (400 \times 400 \times 30) = 0.35$	
	$M/bh^2 f_{ck} = 0.083$	
	$M_{Rdz} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4$ kNm	
	$A_{sy} f_{yk} / bh = 3398 \times 500 / (400 \times 400 \times 30) = 0.35$	
	$M/bh^2 = 0.083$	
	$M_{Rdy} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4$ kNm	
	$N_{Rd} = 0.567\ f_{ck}\ A_c + 0.87\ f_{ck}\ A_s$	
	$= (0.567 \times 30 \times 400 \times 400) + (0.87 \times 500 \times 452)$	
	$= 2918$ kN	
	$N_{Ed} / N_{Rd}\ \ 892.86 / 2918 = 0.31$	
	$a = 1.35$	
5.8.9(2)	Imperfections need only be taken in one dirextion - where they have the most unfavourable effect.	
	$M_{Edz} = 14.0$ kNm	
	$M_{Edy} = 137.17$ kNm	
	$(M_{Edz}/M_{Rdz})^a + (M_{Edy}/M_{Rdy})^a \leq 1.0$	
	$(14.0 / 159.4)^{1.35} + (137.17 / 159.4)^{1.35}$	
	$= 0.04 + 0.82$	
	$= 0.85 < 1$	

Ref.	Calculations	Output
	$d/h = 351.5 \;/\; 400 = 0.88$	
	$N/bhf_{ck} = 892.86 \times 10^3 / (400 \times 400 \times 30) = 0.19$	
	$M/bh^2f_{ck} = 152.2 \times 10^6 / (400 \times 400^2 \times 30) = 0.08$	
Table 4.12 Reynold's Handbook	$A_s f_{yk}/bh f_{ck} = 0.25$	
	$A_s = f_{yk}/bh f_{ck}$	
	$= 0.25\ (350 \times 450 \times 30) / 500$	
	$= 2400\ mm^2$	
9.5.2(2)	$A_{s,min} = 0.1 N_{Ed} / f_{yd} = 0.1 N_{Ed} / (0.87 f_{yk}) =$	
	$= 0.1 \quad 892.86 \times 10^3 \;/\; (0.87 \times 500)$	
	$= 205\ mm^2$ or $0.002A_c = 315\ mm^2$	Use : 6H 25
9.5.2(3)	$A_{s,max} = 0.04A_c = 0.04 \times 400 \times 400 = 6400\ mm^2$	0H 12 (3398 mm²)
5.8.9(4)	**Check Biaxial Bending**	
	Steel area,	
	All : 6H 25 0H 12 $A_s = 3398$	
	z-z : 6H 25 0H 12 $A_{sz} = 3398$	
	y-y : 6H 25 0H 12 $A_{sy} = 3398$	
	$d_{2z}/h = 351.5 \;/\; 400 = 0.88$	
	$d_{2y}/b = 351.5 \;/\; 400 = 0.87875$	
	$N/bh f_{ck} = 892.86 \times 10^3 / (400 \times 400 \times 30)$	
	$= 0.19$	
	$A_{sz} f_{yk}/bh f_{ck} = 3398 \times 500 / (400 \times 400 \times 30) = 0.35$	
	$M/bh^2 f_{ck} = 0.083$	
	$M_{Rdz} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4\ kNm$	
	$A_{sy} f_{yk}/bh = 3398 \times 500 / (400 \times 400 \times 30) = 0.35$	
	$M/bh^2 = 0.083$	
	$M_{Rdy} = 0.083 \times 400 \times 400^2 \times 30$	
	$= 159.4\ kNm$	
	$N_{Rd} = 0.567 f_{ck} A_c + 0.87 f_{ck} A_s$	
	$= (0.567 \times 30 \times 400 \times 400) + (0.87 \times 500 \times 452)$	
	$= 2918\ kN$	
	$N_{Ed} / N_{Rd} \quad 892.86 \;/\; 2918 = 0.31$	
	$a = 1.35$	
5.8.9(2)	Imperfections need only be taken in one direxion - where they have the most unfavourable effect.	
	$M_{Edz} = 14.0\ kNm$	
	$M_{Edy} = 137.17\ kNm$	
	$(M_{Edz}/M_{Rdz})^a + (M_{Edy}/M_{Rdy})^a \leq \mathbf{1.0}$	
	$(14.0 \;/\; 159.4)^{1.35} (137.17 \;/\; 159.4)^{1.35}$	
	$= 0.04 + 0.82$	
	$= 0.85 < 1$	

Ref.	Calculations	Output
9.5.3	Links, $Ø_{min}$ = 0.25 x 25 = 6.3 mm ≤ 6 mm $S_{v\,max}$ = the lesser of = 20 x 25 = 500 mm or 350 mm or 400 mm Use : H6 - 75 At section 450 mm below and above beam and at lapped joints $S_{v\,max}$ = 0.6 x 500 = 300 mm Use : H6 - 75	

Stairs

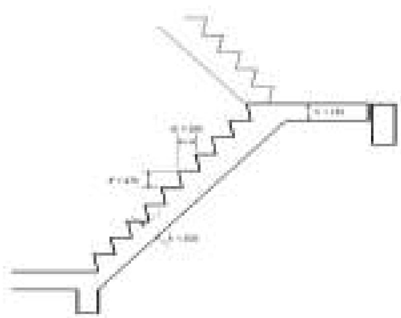
Ref.	Calculations	Output
	SPECIFICATIONS:	Calculated By: Anas Ahmed Checked By: Abdul Raffi



Ref.	Calculations				
	Characteristic Actions:				
	Permanent load, gk	=	1.0 kN/m²		
Table 6.2 EC1	Variable load, qk=	=	3.0 kN/m²		
	Design life	=	50	years	
	Fire resistance	=	R60		
Table 4.1	Exposure classes	=	XC3		

Materials:			
Characteristic strength of concrete, f_{ck}	=	25	kN/m²
Characteristic strength of steel, f_{yk}	=	500	kN/m²
Unit Weight of concrete	=	25	kN/m³

Assumed:	ϕ_{bar}	=	10	mm
	h	=	150	mm
	G	=	260	mm
	R	=	175	mm



Ref.	Calculations	Output
	AVERAGE THICKNESS	
	[illegible]	
	[illegible] [illegible] mm	
	Average thickness	
	[illegible]	
	= [illegible]	
	208 mm	
	ACTIONS	
	Flight	
	Self weight 25 x 0.208 [illegible] kN/m	
	Permanent Load (given) [illegible] kN/m	
	Char. permanent Load, gk [illegible] kN/m	
	Char. variable Load, qk [illegible] kN/m	
	Design action, nd = 1.35gk + 1.5qk [illegible] kN/m	
	Landing	
	Self weight = 25 x 0.15 = 3.75 kN/m	
	Permanent Load (given) 1 kN/m	
	Char. permanent Load, gk 4.75 kN/m	
	Char. variable Load, qk 3 kN/m	
	Design action, nd = 1.35gk + 1.5qk 10.91 kN/m	
	ANALYSIS & DESIGN OF STAIR	
	Consider 1m width	
	Total action	
	F [illegible]	
	92 kN/m	
	Bending Moment	
	M = [illegible]	
	= [illegible]	
	[illegible] kNm	
	Shear Force	
	V F/2	
	92/2	
	46 kN/m	
	MAIN REINFORCEMENT	
	Effective depth	
	d [illegible]	
	[illegible] [illegible] mm	
	Med [illegible] kNm	
	K M/bd²fck	
	[illegible]	
	[illegible] Kbal [illegible]	
	Compression reinforcement is not required	

Ref.	Calculations	Output
	$z = d\,[\,0.5 + (\,0.25 - 0.004 \,/\, 1.134\,)^{1/2}\,]$ = 0.90 d < 0.95d $As = M \,/\, 0.87 f_{yk}\, z$ = 35.55 x 10^6 / (0.87 x 500 x 0.90 x 120) = 757 mm² Minimum and maximum reinforcement area, $As{,}min = 0.26\,(f_{ctm}/f_{yk})\,bd$ = 0.26 x (2.56 / 500) x bd = 0.0013 bd = 0.0013 x 1000 x 120 = 156 mm² $As{,}max = 0.04Ac$ = 0.04 x 1000 x 150 = 6000 mm²	Use: H10 - 50 (1571mm²/m) Secondary bar: H10 - 400 (196mm²)
	SHEAR Ved = 36.83 kN/m Design shear resistance, $VRd{,}c = [\,0.12\,k\,(100\rho l\, fck\,)^{1/3}\,]\,bd$ $k = 1 + [200/d\,]^{1/2} \leq 2.0$ $= 1 + (200/d\,)^{1/2}$ = 2.29 ≤ 2.0 Use 2 $\rho l = As l/bd \leq 0.02$ = 1571 / (1000 x 120) = 0.0131 ≤ 0.02 $VRd{,}c$ = 0.12 x 2.0 x (100 x 0.0131 x 25)⅓ x 1000 x 120 = 92124 N = 92.1 kN $Vmin = [0.035k^{3/2} fck^{1/2}]\,bd$ = 59397 N = 59.4 kN So, $VRdc$ = 92.1 kN > VEd	 Ok !
Table 704N	**DEFLECTION** Percentage of required tension reinforcement, $\rho = A_{s,req} / bd$ = 757 /1000 x 120 = 0.0065 Reference reinforcement ratio, $\rho_0 = (f_{ck})^{1/2} \times 10^{-3}$ = 0.0050 Factor for structural system, K= 1.3 $\rho > \rho_0$ Use equation (1) $\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\,\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right]$ = 1.3 (11 +5.95+ 0) = 22.0 Modification factor for span < 7 m = 1.0 Modification factor for steel area provided, = $A_{s,prov} / A_{s,req}$ = 1571/757 = 2.08 > 1.5 Therefore, allowable span effective depth ratio, $(l/d)_{allowable}$ = 22.0 x 1.0 x 1.5 = 33.1 Actual span - effective depth $(l/d)_{actual}$ = 3850/120 = 32.1 < $(l/d)_{allowable}$	 Ok !

Ref.	Calculations	Output
	$z = d\,[\,0.5 + (\,0.25 - 0.003\ /\ 1.134\,)^{1/2}\,]$ = 0.92 d < 0.95d $As = M\ /\ 0.87\,fyk\,z$ = 46.93 x 10^6 / (0.87 x 500 x 0.92 x 120) = 977 mm² Minimum and maximum reinforcement area, $As,min = 0.26\ (fctm/fyk)\ bd$ = 0.26 x (2.56 / 500) x bd = 0.0013 bd = 0.0013 x 1500 x 120 = 234 mm² $As,max = 0.04Ac$ = 0.04 x 1500 x 120 = 7200 mm²	Use H10 - 750 (1047mm²/m)
	SHEAR Ved = 48.88 kN/m Design shear resistance, VRd,c = [0.12 k (100ρl fck)⅓] bd k = 1 + [200/d]^1/2 ≤ 2.0 = 1 + (200/d)^1/2 = 2.29 ≤ 2.0 Use 2 ρl = Asl/bd ≤ 0.02 = 977 / (1500 x 120) = 0.0054 ≤ 0.02 VRd,c = 0.12 x 2.0 x (100 x 0.0054 x 25)⅓ x 1500 x 120 = 103040 N = 103.0 kN $Vmin$ = [0.035$k^{3/2}$$fck$^1/2] bd = 59397 N = 59.4 kN So, $VRdc$ = 103.0 kN > VEd	Ok !
Table 7.4N	**DEFLECTION** Percentage of required tension reinforcement, $\rho = A_{s,req}\ /\ bd$ = 977 /1500 x 120 = 0.0054 Reference reinforcement ratio, $\rho_0 = (f_{ck})^{1/2} \times 10^{-3}$ = 0.0050 Factor for structural system, K = 1 ρ < ρ_0 Use equation (1) $\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\,\frac{\rho_0}{\rho-\rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right]$ = 1.0 (11 +6.94 + 0) = 17.9 Modification factor for span < 7 m = 1.0 Modification factor for steel area provided, = $A_{s,prov}\ /\ A_{s,req}$ = 1571/977 = 1.61 > 1.5 Therefore, allowable span effective depth ratio, $(l/d)_{allowable}$ = 17.9 x 1.0 x 1.5 = 26.9 Actual span - effective depth $(l/d)_{actual}$ = 3800/120 = 31.7 < $(l/d)_{allowable}$	 Use As,prov= 1571 Ok !

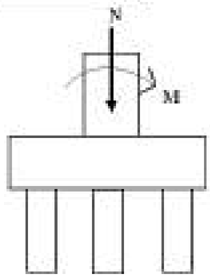
Ref.	Calculations	Output
	CRACKING h = 150mm < 200 mm Main bar: Smax, slabs = 3h = 450 > 400 mm = 400 mm Max. Bar spacing = 50 mm < Smax, slabs Secondary bar: Smax, slabs = 3.5h = 525 > 450 mm = 450 mm Max. Bar spacing = 400 mm < Smax,slabs	Ok !

Ref	Calculations	Output
	CRACKING h [illegible] 150mm [illegible] 200 mm Main bar [illegible] Max. Bar spacing [illegible] Secondary bar [illegible] Max. Bar spacing [illegible]	OK!
	ANALYSIS & DESIGN OF LANDING Consider 1m width Total action, n [illegible] F [illegible] [illegible] kN/m Bending Moment M = [illegible] [illegible] [illegible] kNm/m Shear Force V [illegible] = [illegible] [illegible] kN/m	
	MAIN REINFORCEMENT Effective depth d [illegible] [illegible] mm M_{Ed} [illegible] kNm/m K [illegible] [illegible] [illegible] < K_{bal} = [illegible] Compression reinforcement is not required	

Foundation K/1

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Pile Cap K/1	

SPECIFICATION



Axial Load, N	=	430	kN	
Moment, M	=	8.6	kNm	
Characteristic strength of concrete, f_{ck}	=	30	N/mm^2	f_{ctm} = 2.9 N/mm^2
Characteristic strength of steel, f_{yk}	=	500	N/mm^2	
Bar size, $Ø_{bar}$	=	20	mm	
Nominal concrete cover, c	=	30	mm	
Column size, b x h	=	400 × 400	mm	
Pile : Prestressed Spun Pile	=	200 × 200	mm	
Working Load	=	350	kN	
Safety factor	=	1.4		

SIZE OF PILE CAP

Service load, N = 430 / 1.4 = 308 kN

Selfweight of pilecap, W = 10 % of service load

No. of pile required = $\frac{N + W}{\text{pile capacity}}$

No. of pile required = 308 x 1.1 / 350 = 1

Use : 2

Pile spacing = $k Ø_p$ = 3 $Ø_p$

Width = $Ø_p$ + 300

= 200 300 = 500 mm

Length = $(k + 1) \times Ø_p + 300$

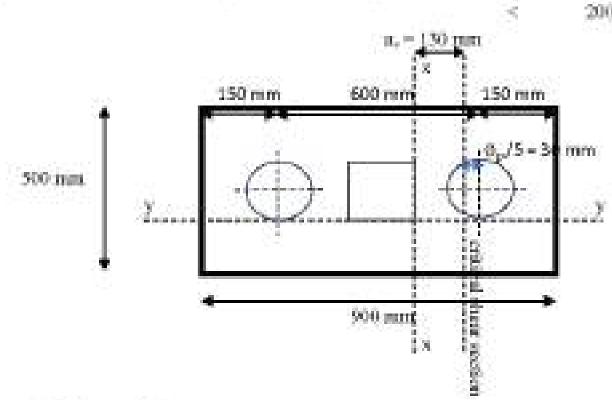
= 3 1 200 300 = 900 mm

Depth, h = $2Ø_p$ + 500 = 2 (200) + 500 = 900 mm

Try size : B x H x h = 500 x 900 x 900 m

Selfweight = 25 x (500 x 900 x 900) = 11 kN

< 200 kN OK!



Max. service load per pile, F = $\frac{(N + W)}{n} + \frac{M_x}{I}$ I = 2 (300)^2 = 0.18 m^2

= [(307.1429 * 11) / 2] + (6.15 × 0.5) / 0.18

= 169.33 kN < 350 kN OK!

Ref.	Calculations	Output
Project	Two Storey School	Designed by [illegible] Checked by [illegible]
Location	Pile cap [illegible]	

Analysis

Ultimate load per pile [illegible]

[illegible] kN

Maximum moment at column face

M = [illegible] kNm

MAIN REINFORCEMENT

Effective depth

d_1 = [illegible] = 894 mm

d_2 = [illegible] = 870 mm

Longitudinal bar

Bending Moment, M = [illegible] kNm

K = M/bd^2f_{ck}

[illegible]

[illegible] < K_{bal} = [illegible]

Compression reinforcement is not required

z = $d[0.5+\sqrt{(0.25-K/1.134)}]$ [illegible] 0.95 d

A_s = $M/0.87f_{yk}z$

[illegible]

[illegible] mm^2

Minimum and maximum reinforcement area

$A_{s,min}$ = $0.26\left(\frac{f_{ctm}}{f_{yk}}\right)bd$ = [illegible] mm^2

$A_{s,max}$ = $0.04A_c$ = [illegible] mm^2

Transverse bar

Bending Moment, M = [illegible] kNm

Minimum and maximum reinforcement area

$A_{s,min}$ = $0.26\left(\frac{f_{ctm}}{f_{yk}}\right)bd$ = [illegible] mm^2

$A_{s,max}$ = $0.04A_c$ = [illegible] mm^2

Ref.	Calculations	Output
Project	[illegible]	Designed by: [illegible] Checked by: [illegible]
Location	Pile Cap [illegible]	

SHEAR

(1) Vertical Shear [illegible]

[illegible]

Shear force, V_{Ed} [illegible]

Pile spacing [illegible]

[illegible]

[illegible]

V_{Ed} [illegible]

[illegible]

Design Shear Resistance

[illegible]

[illegible]

[illegible]

$V_{Rd,c}$ [illegible]

[illegible]

[illegible] OK

(2) Punching Shear [illegible]

Pile spacing [illegible]

No punching shear check is necessary OK

(3) Maximum Punching Shear at column perimeter

$V_{Rd,max}$ [illegible]

[illegible]

[illegible] OK

CRACKING

Assume steel stress under quasi-permanent loading

[illegible]

For design crack width = 0.3 mm

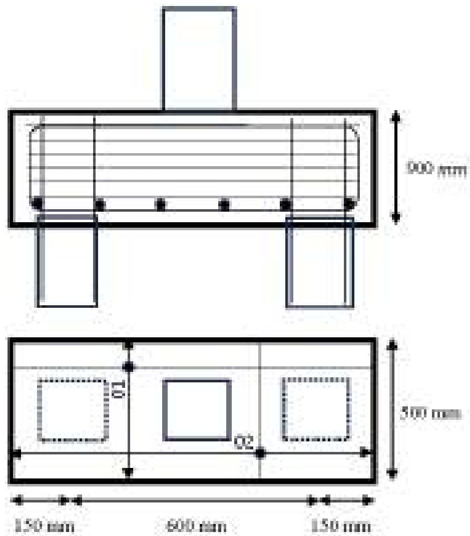
Max allowable bar spacing [illegible]

Max bar spacing 1 [illegible] OK

Max bar spacing 2 [illegible] OK

Ref.	Calculations	Output
Project	Two Storey School	Designed by: Anas Checked by: Abdul Raffi
Location	Pile Cap K/1	

DETAILING



Bar mark: 01 : 2H8

02 : 7H12

Cover : 30 mm

UNIVERSITI TEKNOLOGI MALAYSIA

SEAA4032 | INTEGRATED DESIGN PROJECT 2
SEMESTER SESSION 2023/2024-1

TEAM MEMBERS | GROUP 28

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DRAINAGE DEPARTMENT

PREPARED FOR:

PM. Dr. ZULHILMI BIN ISMAIL

KITABINA SDN BHD
CONSTRUCTION COMPANY

TABLE OF CONTENTS

CHAPTER 3

DRAINAGE DEPARTMENT

3.1 Introduction

In every construction project, one of the most important elements is the design of the drainage system. Designing a drainage system involves considering fluid engineering elements like slope, recommended levels, and streams. The three main objectives of designing the detention pond, culvert, and drainage pipe are to reduce flood risk, minimize erosion, and prevent the structure from losing its bearing capacity. The latter two objectives are achieved by reducing the volume of water gradually released from the upstream to prevent flooding in downstream areas and by allowing the water's pathway from the surface runoff to be evaluated into the closest drain, which lowers the risk of flooding in the upstream area.

The peak discharge estimated over the design life, which is impacted by the frequency and length of rainfall events, determines the size of the drainage system that is built. Rainfall falls on the ground retains its moisture until it is absorbed by vegetation, moves into subterranean flow, and is discharged into the atmosphere, however it can also contribute to surface runoff. Therefore, the drainage system is designed to channel surface runoff from storms and extra rainfall into a nearby creek. The soil, geography, and size of the drainage system all affect how much rainfall actually becomes streamflow.

This study will provide an overview of the drainage system design for The Proposed Housing Complex which connects to Kuantan and is situated in the perfect area of Gambang, Pahang . The Urban Stormwater Management Manual for Malaysia (MSMA 2nd Edition) is cited in the drainage design requirements. Ultimately, it is anticipated that the drainage system will be able to control runoff and stormwater and prevent localized flooding.

3.1.1 Objectives

The purpose of this design is to show the application of the hydrological method in the design of drainage. These are the objectives of this report.

- To determine the stormwater and runoff design
- To propose drainage system design with an effective size
- To determine the appropriate size of culvert
- To determine the volume and suitable size of the detention pond

3.1.2 Scope Of Work

This study of designing the drainage system includes:
● Determine the catchment area.
● Calculate the storm and runoff design by using a rational method.
● Determine the suitable size for the drain.
● Discover the right place to locate and design the culvert.
● Design suitable detention ponds.

3.2 Drainage System Design

3.2.1 Introduction

The 2nd Edition of the Urban Stormwater Management Manual for Malaysia (MSMA) distinguishes between two categories of stormwater systems: minor systems and major systems. Both strategies are used in stormwater runoff management. Small drainage systems, for example, gather, control, and move surface runoff from homes and businesses. They usually handle unforeseen events to avoid flooding. Massive drainage systems are usually built for extreme events, as opposed to a 100-year ARI, which usually concentrates on a vast number of minor drainage systems to efficiently carry and regulate runoff.

As seen in Figure 1.1, the drainage system will be built at Gamang, Pahang in a region that has a well-established housing neighborhood, including Taman Gambang Damai. There will be both small and significant drainage construction. To collect the water within the educational institutional area, minor drainage systems consisting of primary, secondary, and peripheral drainage will be built. Major drainage, however, will overflow the water into the nearby river. Every time a drain and a road cross, culverts are suggested as a river underneath. The lowest level of the educational institutional area is where the detention pond is envisioned and developed in this project.

Figure 3.1 Project location in Gambang, Pahang.

3.2.2 Water Catchment Area

The topography of the region, which includes the surface's level, slope, and pond position, as well as the necessary buildings and accommodations, will be considered during the design phase, according to MSMA. If there is a need to upgrade or modify the drainage system, these items will be required. The water's flow rate and velocity will be monitored while there is water in the drainage system to lessen the chance of flooding. The existing contour in this project, which presupposes that water would flow from the upper to the lower level, determines the direction of water runoff. Sub-catchment areas that supply the canal with water runoff will be formed as a result of the catchment linkages at that time.

Three -catchment regions make up this project, as shown in Figure 3.2 below.
Drainage systems can be measured more precisely by using sub-catchment.
As a result, 36 principal drainage lines—which would be drained into different detention ponds—are suggested for the project's whole area. These retention ponds are situated as close to the river as feasible and at the lowest level. One way to lessen flash flooding during storms is to shorten the primary drainage system.

Figure 3.2 Design Layout Profile and its Catchment Areas

3.2.3 Design Criteria

Flow chart below shows the procedure of stormwater and runoff design procedure using MSMA 2nd Edition and Hydraulic Engineering Textbook as references.

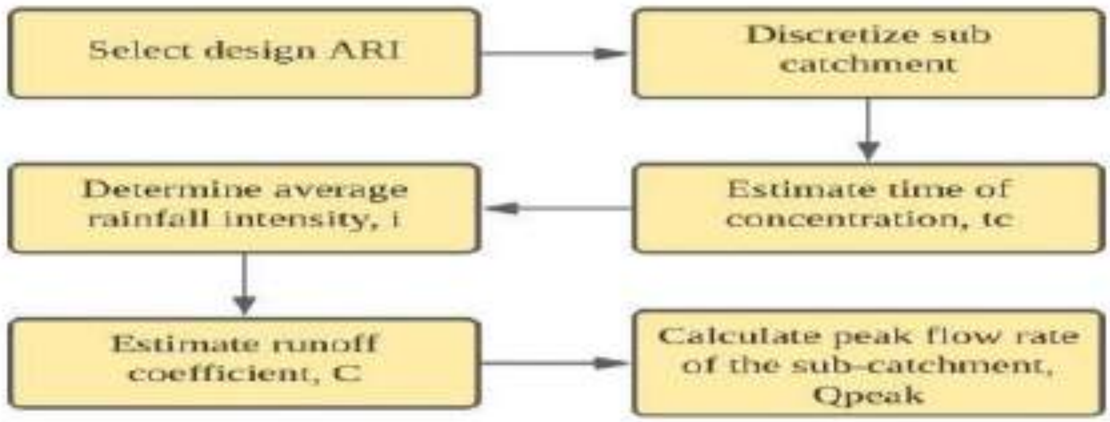


Figure 3.3: Flowchart of drainage design

3.2.3.1 Runoff Coefficient

In Chapter 2 of the Urban Stormwater Management Manual for Malaysia (MSMA 2nd Edition), Table 2.5 states that the type of land use and whether the runoff coefficient is intended for a small or major system determine the runoff coefficient value.

Table 2.5 Recommended Runoff Coefficients for Various Landuses (DID, 1980; Chow et al., 1988; QUDM, 2007 and Darwin Harbour, 2009)

Landuse	Runoff Coefficient (C)	
	For Minor System (≤10 year ARI)	For Major System (> 10 year ARI)
Residential		
Bungalow	0.65	0.70
Semi-detached Bungalow	0.70	0.75
Link and Terrace House	0.80	0.90
Flat and Apartment	0.80	0.85
Condominium	0.75	0.80
Commercial and Business Centres	0.90	0.95
Industrial	0.90	0.95
Sport Fields, Park and Agriculture	0.30	0.40
Open Spaces		
Bare Soil (No Cover)	0.50	0.60
Grass Cover	0.40	0.50
Bush Cover	0.35	0.45
Forest Cover	0.30	0.40
Roads and Highways	0.95	0.95
Water Body (Pond)		
Detention Pond (with outlet)	0.95	0.95
Retention Pond (no outlet)	0.00	0.00

Note: The runoff coefficients in this table are given as a guide for designers. The near-field runoff coefficient for any single or mixed landuse should be determined based on the imperviousness of the area.

3.2.3.2 Time Concentration, Tc (Min)

The time it takes for runoff flows to travel from the hydraulically remotest point upstream in the contributing catchment area to the downstream point under concern is known as the time of concentration (Tc). Table 2.1 (QUDM, 2007) provides the formulas needed to determine the Tc. When determining Tc, the features of the catchment are taken into account, specifically the drainage course's length, slope, and roughness. Since the sheet flow length is longer on mild slopes and shorter on steep slopes, the To can be accurately approximated based on the state of the land surface. Use of this formula is limited to the distances (L) listed in Table 2.1. The catchment's length, slope, and roughness all affect flow velocity, which in turn affects overland flow time. Typical values for Horton's roughness n* for different terrestrial surfaces are given in Table 2.2 (QUDM, 2007). In this project, the paved ground surface is taken into account.

Table 2.1: Equations to Estimate Time of Concentration (QUDM, 2007)

Travel Path	Travel Time	Remark
Overland Flow	$t_o = \frac{107 . n^* . L^{1/3}}{S^{1/5}}$	t_o = Overland sheet flow travel time (minutes) L = Overland sheet flow path length (m) *for Steep Slope (>10%), L ≤ 50 m* *for Moderate Slope (<5%), L ≤ 100 m* *for Mild Slope (<1%), L ≤ 200 m* n^* = Horton's roughness value for the surface (Table 2.2) S = Slope of overland surface (%)
Curb Gutter Flow	$t_g = \frac{L}{40\sqrt{S}}$	t_g = Curb gutter flow time (minutes) L = Length of curb gutter flow (m) S = Longitudinal slope of the curb gutter (%)
Drain Flow	$t_d = \frac{n . L}{60 R^{2/3} S^{1/2}}$	n = Manning's roughness coefficient (Table 2.3) R = Hydraulic radius (m) S = Friction slope (m/m) L = Length of reach (m) t_d = Travel time in the drain (minutes)

Table 2.2: Values of Horton's Roughness n^* (QUDM, 2007)

Land Surface	Horton's Roughness n^*
Paved	0.015
Bare Soil	0.0275
Poorly Grassed	0.035
Average Grassed	0.045
Densely Grassed	0.060

3.2.3.3 Rational Method

Since the rational method is the most widely used approach to predict runoff peak in Malaysia, it is applied in this project. The rational technique of computation makes use of these three assumptions:

(1) Over the whole catchment area, the intensity of the rainfall is constant.

(2) For a duration equal to the time of concentration (tc), the intensity of the rainfall remains constant.

(3) The peak flow occurs when the entire watershed contributes to the flow.

The equation (2.3) utilized in the computation is depicted in Figure 1.4 below, which is in accordance with chapter 2 of the MSMA 2nd edition.

$$Q = \frac{C.i.A}{360}$$

where,

Q = Peak flow (m^3/s);

C = Runoff coefficient (Table 2.5);

i = Average rainfall intensity (mm/hr); and

A = Drainage area (ha).

Figure 3.4 Rational Method Equation

3.2.3.4 Rainfall Intensity

Using an empirical equation to minimize error, rainfall intensity estimation values are obtained using IDF curves. In chapter 2 of the MSMA 2nd edition, this empirical equation is cited as equation (2.2).

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$$

where,

i = Average rainfall intensity (mm/hr);

T = Average recurrence interval - ARI ($0.5 \le T \le 12$ month and $2 \le T \le 100$ year);

d = Storm duration (hours), $0.0833 \le d \le 72$; and

λ, κ, θ *and* η = Fitting constants dependent on the raingauge location (Table 2.B1 in Appendix 2.B).

Referring to Table 2.B1 in Appendix 2.B, value of λ, k, θ, and η for Pintu Kaw Pulau Kertam can be determined.

Pahang	1	2630001	Sungai Pukim	46.577	0.232	0.169	0.687
	2	2634193	Sungai Anak Endau	66.179	0.182	0.081	0.589
	3	2828173	Kg Gambir	47.701	0.182	0.096	0.715
	4	3026156	Pos Iskandar	47.452	0.184	0.071	0.780
	5	3121143	Simpang Pelangai	57.109	0.165	0.190	0.867
	6	3134165	Dispensari Nenasi	61.697	0.152	0.120	0.593
	7	3231163	Kg Unchang	55.568	0.179	0.096	0.649
	8	3424081	JPS Temerloh	73.141	0.173	0.577	0.896
	9	3533102	Rumah Pam Pahang Tua	58.483	0.212	0.197	0.586
	10	3628001	Pintu Kaw. Pulau Kertam	50.024	0.211	0.089	0.716
	11	3818054	Setor JPS Raub	53.115	0.168	0.191	0.833
	12	3924072	Rmh Pam Paya Kangsar	62.301	0.167	0.363	0.868
	13	3930012	Sungai Lembing PCC Mill	45.999	0.210	0.074	0.590
	14	4023001	Kg Sungai Yap	65.914	0.195	0.252	0.817
	15	4127001	Hulu Tekai Kwsn."B"	59.861	0.226	0.213	0.762
	16	4219001	Bukit Bentong	73.676	0.165	0.384	0.879
	17	4223115	Kg Merting	52.731	0.184	0.096	0.805
	18	4513033	Gunung Brinchang	42.004	0.164	0.046	0.802

When an analysis is prepared using a spreadsheet, applying the equation is straightforward. As an alternative, designers can manually apply the Figure 3.5 IDF curves.

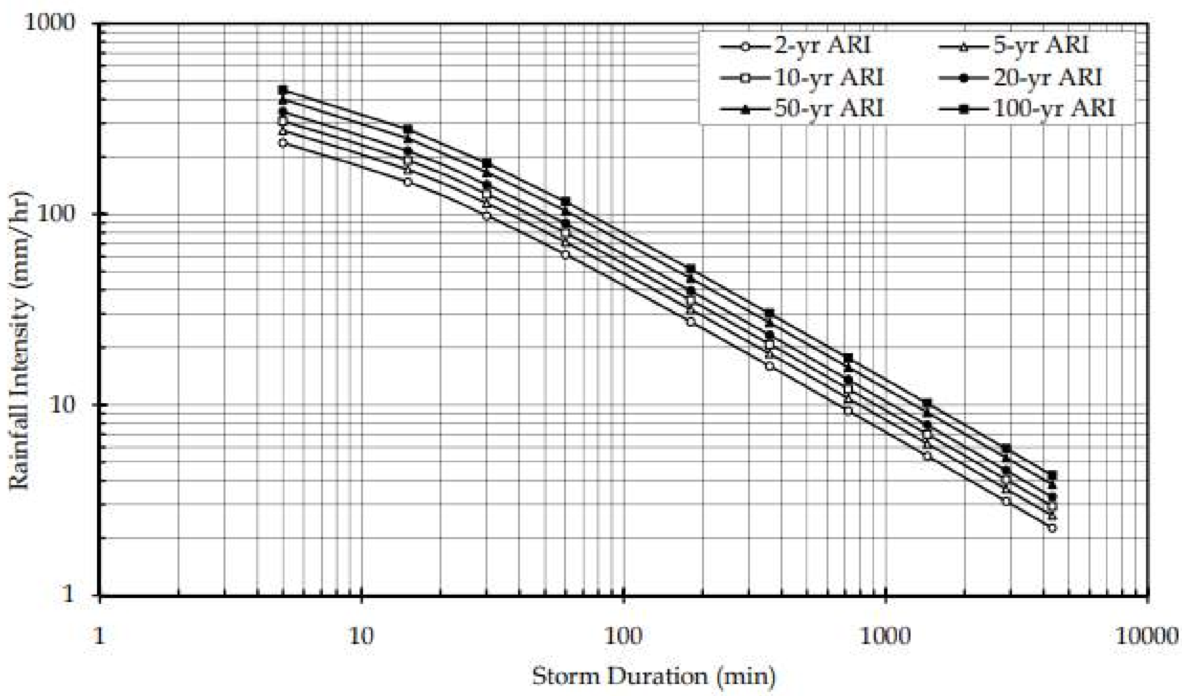


Figure 3.5 Typical IDF Curve

3.2.3.5 Manning’s Equation

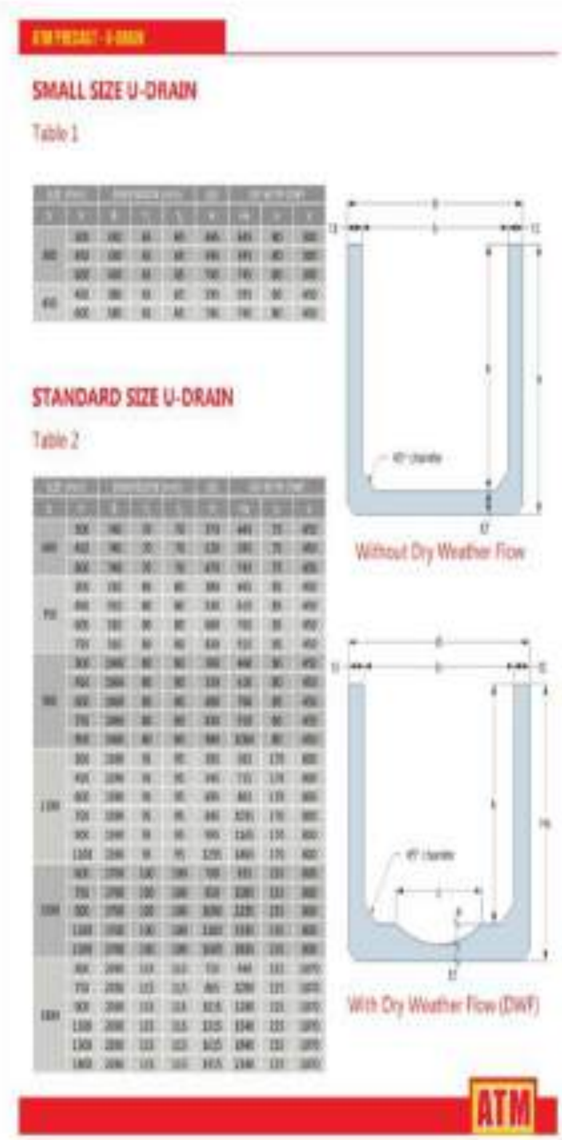
The Mannings' Equation is the most often used formula for open channel flow. The channel velocity, flow area, and slope all affect the Manning's equation, an empirical formula that describes uniform flow in open channels. The following is the Manning's equation:

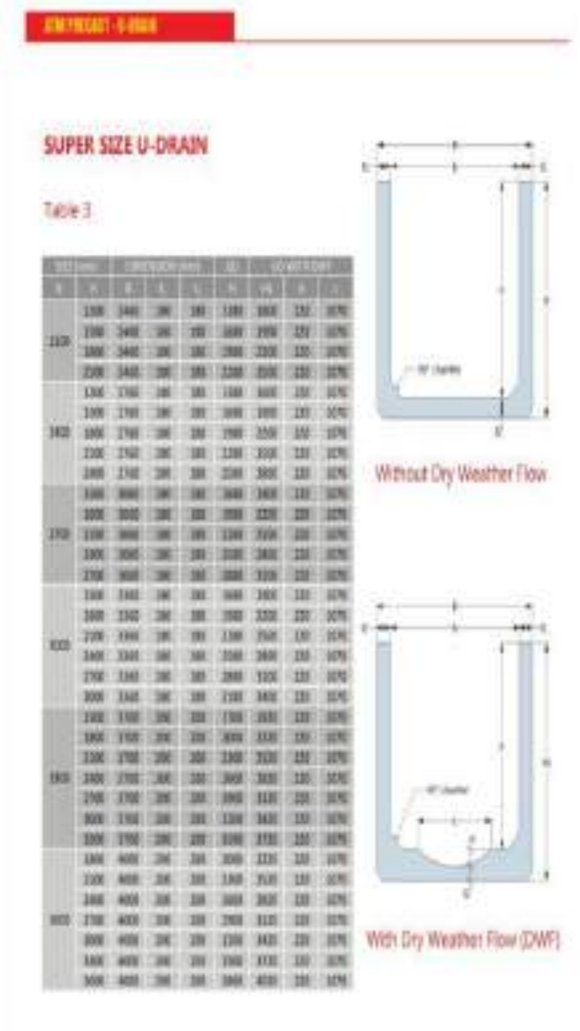
$$Q = \frac{1}{n} A R^{2/3} s^{1/2}$$

Where:
Q = flow rate capacity, m^3 /s
n = manning’s coefficient
A = open drain area, m^2
R = hydraulic radius, m
So = slope of the drain

3.2.4 Open Channel

The concept of a liquid moving through a channel with a free surface is known as open channel flow. Open channels include things like ditches, lakes, rivers, streams, flumes, sewers, and so forth. Inflexible barriers are one kind of open channel. For this reason, ATM Precast Sdn, Bhd’s stiff boundary type of open channel cast, would be used in this project.


SMALL SIZE U-DRAIN
Table 1
STANDARD SIZE U-DRAIN
Table 2
Without Dry Weather Flow
With Dry Weather Flow (DWF)
ATM


SUPER SIZE U-DRAIN
Table 3
Without Dry Weather Flow
With Dry Weather Flow (DWF)

3.2.5 Summary of all Design Calculations

3.2.5.1 Design Calculation Example

References	Calculation
Area	All references are made to Manual Saliran Mesra Alam (MSMA 2nd Edition August 2012 Edited) The Catchment 1 has 4 Main Drainage and 6 Secondary Drainage **M1= 2.169 ha** **M2= 2.324 ha** **M10= 5.445 ha** **M17= 3.334 ha** **S1= 1.030 ha** **S2= 1.139 ha** **S3= 1.335 ha** **S4= 2.229 ha** **S5= 2.031 ha** **S6= 1.185 ha**
Time of Concentration	**For Catchment 1:** M10=5.4445 ha **From Table 2.2, the value for Horton's roughness,** n=0.015
	Length of drainage flow, l= 144.750m
	Length of overland sheet flow,

	Lo= 160.330m
	Height Differences, d= 160-145 = 15m
	Average Surface Slope, S= (Height Difference/ Length of oversheet flow) x 100 = 15/160.330 x100 = 9.3557 %
	Assumed velocity of flow, V= 1.00 m/s
	Time to travel for overland flow, to= $107nL^{(1/3)} / S^{(1/5)}$ = $107 \times 0.015 \times 160.330^{(1/3)} / 9.3557^{(1/5)}$ = 5.575 min
	Time to travel for drain flow, td= l/V = 144.750/60 = 2.4125 min
	Time of concentration, tc= to+td = 5.575+2.4125

	= 7.9875 min
Average Rainfall Intensity (ARI)	**By assuming ARI,** T=100 Years
	The derived IDF parameters are obtained as following: Average rainfall intensity, i= λ(T^k) /(d+θ)^n **Where,** i = Average rainfall intensity (mm/hour) T = Average Recurrence Interval – ARI d = Storm duration (hours) λ ,k,θ,n = Fitting constants dependent on the rain gauge location **Here,** λ= 63.503 k= 0.383 θ= 0.2881 n= 0.8202 **Therefore,** i= 65.47 mm/hr
	The value of runoff coefficient obtained from table 2.B1, C= 0.779
	Peak flow, Qpeak,drain, = CIA/ 360 =(0.779 x 65.4 X 5.445)/ 360 = 0.771 m^(3)/s

	Manning's roughness coefficient (excavated earth drain with no vegetation) n=0.015 Channel longitudinal slope, So= (highest- lowest point of drainage)/length = 0.5
	Assuming: Depth, Y=0.6m Bottom width of the channel, B= 0.75m Therefore, the cross-section of the channel is: Wetted perimeter of the channel, P= B+2Y = 0.75+ 2 x 0.6 = 1.95 m
	Area of the channel, A= B x Y = 0.75 x 0.6 = 0.45 m^(2)
	Hydraulic radius, R=0.23m Freeboard, FB=0.3m Height of the channel, H= Y+FB

	= 0.6+0.3 = 0.9m
	The flow in the channel must not exceed 4.0m/s in order to avoid erosion. **Therefore,** Design peak flow, Qpeak= A(R)^(⅔) (S^(½)) / n =0.45 x (0.23)^(⅔) (0.5)^(½) / 0.015 = 0.7963m^(3)/s > Qpeak, dn=0.771m^(3)/s **(OK)**
	Velocity, V= Q/A = 0.7963/ 0.45 = 1.77m/s < 4m/s **(OK)**
	Froude Number, Fr= V/ (g)^(½) x D = 1.77/ (9.81)^(½) x 0.6 = 1.77/ 1.87 = 0.9465 < 1.0m/s, Subcritical Flow **(OK)**

Runoff coefficient for mixed development:

CATCHMENT	LANDUSE	UNITS	AREA (m^2) Autocad	AREA (ha)	TOTAL AREA (ha)	RUNOFF COEFFICIENT, C	AREA WEIGHTED, Cavg
1	Semi – Detached House	18	10,301.000	1.030	13.657	0.750	0.779
	Semi – Detached House	19	11,387.000	1.139		0.750	
	Semi – Detached House	24	13,546.000	1.355		0.750	
	Semi – Detached House	39	22,294.000	2.229		0.750	
	Semi – Detached House	36	20,305.000	2.031		0.750	
	Semi – Detached House	32	18,550.000	1.855		0.750	
	Roads		40,188.000	4.019		0.950	
	Semi – Detached House	18	10,301.000	1.030	9.639	0.700	0.700
	Semi – Detached House	19	11,387.000	1.139		0.700	
	Semi – Detached House	24	13,546.000	1.355		0.700	
	Semi – Detached House	39	22,294.000	2.229		0.700	
	Semi – Detached House	36	20,305.000	2.031		0.700	
	Semi – Detached House	32	18,550.000	1.855		0.700	
2	Semi – Detached House	22	12,769.000	1.277	10.357	0.750	0.694
	Semi – Detached House	22	12,032.000	1.203		0.750	
	TNB Power Station	1	4,558.000	0.456		0.950	
	Tapak Inja	1	1,996.000	0.200		0.950	
	Tapak Tadika	1	2,200.000	0.220		0.950	
	Tapak Dewan	1	2,267.000	0.227		0.950	
	Tapak Surau	1	4,073.000	0.407		0.950	
	Reservoir A	1	2,979.000	0.298		0.950	
	Kawasan Lapang	1	32,012.000	3.201		0.400	
	PE	1	433.000	0.043		0.950	
	Roads		27,946.000	2.795		0.950	
	Semi – Detached House	22	12,769.000	1.277	4.028	0.700	0.843
	Semi – Detached House	22	12,032.000	1.203		0.700	
	TNB Power Station	1	4,558.000	0.456		0.900	
	Tapak Inja	1	1,996.000	0.200		0.900	
	Tapak Tadika	1	2,200.000	0.220		0.900	
	Tapak Dewan	1	2,267.000	0.227		0.900	
	Tapak Surau	1	4,073.000	0.407		0.900	
3	Semi – Detached House	22	12,992.000	1.299	14.751	0.750	0.757
	Semi – Detached House	22	11,742.000	1.174		0.750	
	Semi – Detached House	20	10,855.000	1.086		0.750	
	Semi – Detached House	10	5,442.000	0.544		0.750	
	Semi – Detached House	10	5,442.000	0.544		0.750	
	Semi – Detached House	14	7,912.000	0.791		0.750	
	Semi – Detached House	12	7,237.000	0.724		0.750	
	Semi – Detached House	5	3,553.000	0.355		0.750	
	Tangki Air	1	9,185.000	0.918		0.950	
	STP	1	275.000	0.028		0.950	
	Reservoir B	1	1,134.000	0.113		0.950	
	Kawasan Lapang 2	1	20,139.000	2.014		0.400	
	Kawasan Lapang 3	1	5,871.000	0.587		0.400	
	Roads		45,837.000	4.584		0.950	
	Semi – Detached House	22	12,992.000	1.299	6.488	0.700	0.700
	Semi – Detached House	22	11,742.000	1.174		0.700	
	Semi – Detached House	20	10,855.000	1.086		0.700	
	Semi – Detached House	10	5,442.000	0.544		0.700	
	Semi – Detached House	10	5,442.000	0.544		0.700	
	Semi – Detached House	14	7,912.000	0.791		0.700	
	Semi – Detached House	12	7,237.000	0.724		0.700	
	Semi – Detached House	5	3,553.000	0.355		0.700	

Length of drain:

	Major System
	Minor System

CATCHMENT	DRAINAGE	LENGTH (m)	TOTAL LENGTH (m)	HEIGHT DIFFERENCE (m)	Lo (m)
1	M1	123.220	617.959	13.000	141.100
	M2	132.403		13.000	102.880
	M10	144.750		15.000	160.330
	M17	217.586		14.000	178.950
	S1	574.720	5010.737	13.000	140.977
	S2	625.274		13.000	140.977
	S3	711.747		13.000	140.977
	S4	1124.445		14.000	127.493
	S5	1028.482		13.000	135.697
	S6	946.069		13.000	209.050
2	M11	72.802	1150.547	5.000	139.700
	M12	224.673		5.000	87.040
	M13	173.349		5.000	139.700
	M14	104.485		5.000	139.700
	M15	258.347		11.000	153.250
	M16	316.889		14.000	178.950
	S7	665.416	1870.258	14.000	178.950
	S8	641.484		13.000	140.400
	S9	80.600		5.000	139.700
	S10	68.406		5.000	139.700
	S11	190.297		5.000	139.700
	S12	224.055		5.000	139.700
3	M3	193.800	1121.512	16.000	136.575
	M4	80.237		18.000	170.270
	M5	85.080		18.000	170.270
	M6	374.412		23.000	210.143
	M7	157.998		26.000	238.610
	M8	119.584		26.000	238.610
	M9	110.401		26.000	221.550
	S13	691.094	3838.818	17.000	165.300
	S14	633.689		17.000	165.300
	S15	585.696		17.000	165.300
	S16	336.020		26.000	221.550
	S17	336.020		26.000	221.550
	S18	455.167		26.000	221.550
	S19	422.578		26.000	230.080
	S20	378.554		26.000	238.610

Time concentration:

OVERLAND FLOW, To (min)					DRAIN FLOW, Td		TIME OF CONCENTRATION, Tc (min)		
CATCHMENT	DRAINAGE	LENGTH OF OVERLAND SHEET, Lo (m)	HORTON'S ROUGHNESS, n*	SURFACE SLOPE, S%	FLOW VELOCITY, V (m/s)	FLOW LENGTH (m)	OVERLAND FLOW, to (min)	DRAIN FLOW, td (min)	TIME OF CONCENTRATION, tc (min)
1	M1	141.10	0.02	9.21	1.00	123.22	5.36	2.05	7.41
	M2	102.88	0.02	12.64	1.00	132.40	4.53	2.21	6.73
	M10	160.33	0.02	9.36	1.00	144.75	5.58	2.41	7.99
	M17	178.95	0.02	7.82	1.00	217.59	5.99	3.63	9.62
	S1	140.98	0.02	9.22	1.00	574.72	5.36	9.58	14.94
	S2	140.98	0.02	9.22	1.00	625.27	5.36	10.42	15.78
	S3	140.98	0.02	9.22	1.00	711.75	5.36	11.86	17.22
	S4	127.49	0.02	10.98	1.00	1124.45	5.00	18.74	23.74
	S5	135.70	0.02	9.58	1.00	1028.48	5.25	17.14	22.39
	S6	209.05	0.02	6.22	1.00	946.07	6.61	15.77	22.38
2	M11	139.70	0.02	3.58	1.00	72.80	6.45	1.21	7.67
	M12	87.04	0.02	5.74	1.00	224.68	5.01	3.74	8.76
	M13	139.70	0.02	3.58	1.00	173.35	6.45	2.89	9.34
	M14	139.70	0.02	3.58	1.00	104.49	6.45	1.74	8.19
	M15	153.25	0.02	7.18	1.00	258.35	5.79	4.31	10.10
	M16	178.95	0.02	7.82	1.00	316.89	5.99	5.28	11.28
	S7	178.95	0.02	7.82		665.42	5.99	11.09	17.08
	S8	140.40	0.02	9.26	1.00	641.48	5.35	10.69	16.04
	S9	139.70	0.02	3.58	1.00	80.60	6.45	1.34	7.80
	S10	139.70	0.02	3.58	1.00	68.41	6.45	1.14	7.59
	S11	139.70	0.02	3.58	1.00	190.30	6.45	3.17	9.62
	S12	139.70	0.02	3.58	1.00	224.06	6.45	3.73	10.19

	M3	136.58	0.02	11.72	1.00	193.80	5.05	3.23	8.28
	M4	170.27	0.02	10.57	1.00	80.24	5.55	1.34	6.89
	M5	170.27	0.02	10.57	1.00	85.08	5.55	1.42	6.97
	M6	210.14	0.02	10.94	1.00	374.41	5.91	6.24	12.15
	M7	238.61	0.02	10.90	1.00	158.00	6.17	2.63	8.81
	M8	238.61	0.02	10.90	1.00	119.58	6.17	1.99	8.17
	M9	221.55	0.02	11.74	1.00	110.40	5.93	1.84	7.77
3	S13	165.30	0.02	10.28	1.00	691.09	5.53	11.52	17.04
	S14	165.30	0.02	10.28	1.00	633.69	5.53	10.56	16.09
	S15	165.30	0.02	10.28	1.00	585.70	5.53	9.76	15.29
	S16	221.55	0.02	11.74	1.00	336.02	5.93	5.60	11.54
	S17	221.55	0.02	11.74	1.00	336.02	5.93	5.60	11.54
	S18	221.55	0.02	11.74	1.00	455.17	5.93	7.59	13.52
	S19	230.08	0.02	11.30	1.00	422.58	6.06	7.04	13.10
	S20	238.61	0.02	10.90	1.00	378.55	6.17	6.31	12.48

Intensity And Peak Flow:

CATCHMENT	DRAINAGE	STORM DURATION, d (min)	ARI (Year)	λ	K	θ	η	I (mm/hr)	Cavg	AREA (ha)	FLOW, Q (m3 /s)
1	M1	7.413	100.000	63.507	0.383	0.288	0.820	69.451	0.779	2.169	0.326
	M2	6.735	100.000	63.507	0.383	0.288	0.820	74.904	0.779	2.324	0.377
	M10	7.988	100.000	63.507	0.383	0.288	0.820	65.469	0.779	5.445	0.771
	M17	9.620	100.000	63.507	0.383	0.288	0.820	56.481	0.779	0.334	0.041
	S1	14.935	5.000	63.507	0.383	0.288	0.820	12.608	0.700	1.030	0.025
	S2	15.778	5.000	63.507	0.383	0.288	0.820	12.063	0.700	1.139	0.027
	S3	17.219	5.000	63.507	0.383	0.288	0.820	11.242	0.700	1.335	0.029
	S4	23.743	5.000	63.507	0.383	0.288	0.820	8.670	0.700	2.229	0.038
	S5	22.390	5.000	63.507	0.383	0.288	0.820	9.092	0.700	2.031	0.036
	S6	22.377	5.000	63.507	0.383	0.288	0.820	9.096	0.700	1.185	0.021
2	M11	7.667	100.000	63.507	0.383	0.288	0.820	67.628	0.864	2.430	0.394
	M12	8.759	100.000	63.507	0.383	0.288	0.820	60.856	0.864	1.540	0.225
	M13	9.343	100.000	63.507	0.383	0.288	0.820	57.814	0.864	1.054	0.146
	M14	8.195	100.000	63.507	0.383	0.288	0.820	64.155	0.864	5.510	0.848
	M15	10.097	100.000	63.507	0.383	0.288	0.820	54.347	0.864	5.510	0.719
	M16	11.275	100.000	63.507	0.383	0.288	0.820	49.760	0.864	0.808	0.096
	S7	17.084	5.000	63.507	0.383	0.288	0.820	11.314	0.843	1.227	0.033
	S8	16.036	5.000	63.507	0.383	0.288	0.820	11.906	0.843	1.203	0.034

	S9	7.797	10.000	63.507	0.383	0.288	0.820	27.628	0.843	0.486	0.031
	S10	7.593	10.000	63.507	0.383	0.288	0.820	28.211	0.843	0.486	0.032
	S11	9.625	10.000	63.507	0.383	0.288	0.820	23.374	0.843	1.054	0.058
	S12	10.188	10.000	63.507	0.383	0.288	0.820	22.339	0.843	1.054	0.055
3	M3	8.283	100.000	63.507	0.383	0.288	0.820	63.616	0.757	2.014	0.269
	M4	6.888	100.000	63.507	0.383	0.288	0.820	73.590	0.757	2.014	0.312
	M5	6.969	100.000	63.507	0.383	0.288	0.820	72.918	0.757	2.014	0.309
	M6	12.153	100.000	63.507	0.383	0.288	0.820	46.862	0.757	0.919	0.091
	M7	8.808	100.000	63.507	0.383	0.288	0.820	60.588	0.757	1.870	0.238
	M8	8.167	100.000	63.507	0.383	0.288	0.820	64.326	0.757	1.079	0.146
	M9	7.775	100.000	63.507	0.383	0.288	0.820	66.884	0.757	4.627	0.651
	S13	17.045	100.000	63.507	0.383	0.288	0.820	35.703	0.700	1.299	0.090
	S14	16.088	100.000	63.507	0.383	0.288	0.820	37.405	0.700	1.174	0.085
	S15	15.288	100.000	63.507	0.383	0.288	0.820	38.973	0.700	1.066	0.081
	S16	11.535	100.000	63.507	0.383	0.288	0.820	48.862	0.700	0.544	0.052
	S17	11.535	100.000	63.507	0.383	0.288	0.820	48.862	0.700	0.544	0.052
	S18	13.521	100.000	63.507	0.383	0.288	0.820	43.019	0.700	0.791	0.066
	S19	13.098	100.000	63.507	0.383	0.288	0.820	44.130	0.700	0.724	0.062

	S20	12.483	100.000	63.507	0.383	0.288	0.820	45.865	0.700	0.355	0.032

Drain Size:

CATCHMENT	DRAIN	MANNING'S (n)	SLOPE, So	WIDTH, B(m)	DEPTH, D(m)	AREA, A (m2)	WETTED PERIMETER	HYDRAULIC RADIUS, R(m)	DRAINAGE VELOCITY (m/s)	DRAINAGE CAPACITY, Qprov (m3 /s)	Qreq (m3 /s)	Qprov>Qreq
1	M1	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.32597	OK
	M2	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.37668	OK
	M10	0.015	0.5	0.75	0.6	0.45	1.95	0.23	1.76962	0.79633	0.77138	OK
	M17	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.04082	OK
	S1	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.02525	OK
	S2	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.02672	OK
	S3	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.02918	OK
	S4	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03758	OK
	S5	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03591	OK
	S6	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.02096	OK
2	M11	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.39441	OK
	M12	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.22492	OK
	M13	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.14625	OK
	M14	0.015	0.5	0.75	0.75	0.5625	2.25	0.25	1.87077	1.05231	0.84839	OK
	M15	0.015	0.5	0.75	0.6	0.45	1.95	0.23	1.76962	0.79633	0.71868	OK
	M16	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.09649	OK
	S7	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03251	OK
	S8	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03354	OK

	S9	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03144	OK
	S10	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03211	OK
	S11	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.05769	OK
	S12	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.05514	OK
3	M3	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.26941	OK
	M4	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.31165	OK
	M5	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.30881	OK
	M6	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.09056	OK
	M7	0.015	0.5	0.6	0.6	0.36	1.8	0.2	1.61218	0.58039	0.23825	OK
	M8	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.14595	OK
	M9	0.015	0.5	0.75	0.6	0.45	1.95	0.23	1.76962	0.79633	0.65075	OK
	S13	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.09018	OK
	S14	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.08539	OK
	S15	0.015	0.5	0.45	0.3	0.135	1.05	0.13	1.20973	0.16331	0.08078	OK
	S16	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.05168	OK
	S17	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.05168	OK
	S18	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.06617	OK
	S19	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.06212	OK
	S20	0.015	0.5	0.3	0.3	0.09	0.9	0.1	1.01561	0.09140	0.03166	OK

Summary of Drainage size:

MAIN DRAIN					
CATCHMENT	DRAINAGE	WIDTH, B(m)	DEPTH, D(m)	DRAINAGE VELOCITY (m/s)	0.6 m/s <Vreq< 2m/s
1	M1	0.6	0.6	1.612180783	**OK**
	M2	0.6	0.6	1.612180783	**OK**
	M10	0.75	0.6	1.769615718	**OK**
	M17	0.45	0.3	1.209732397	**OK**
2	M11	0.6	0.6	1.612180783	**OK**
	M12	0.6	0.6	1.612180783	**OK**
	M13	0.45	0.3	1.209732397	**OK**
	M14	0.75	0.75	1.870770081	**OK**
	M15	0.75	0.6	1.769615718	**OK**
	M16	0.45	0.3	1.209732397	**OK**
3	M3	0.6	0.6	1.612180783	**OK**
	M4	0.6	0.6	1.612180783	**OK**
	M5	0.6	0.6	1.612180783	**OK**
	M6	0.45	0.3	1.209732397	**OK**
	M7	0.6	0.6	1.612180783	**OK**
	M8	0.45	0.3	1.209732397	**OK**
	M9	0.75	0.6	1.769615718	**OK**

SECONDARY DRAIN					
CATCHMENT	DRAINAGE	WIDTH, B(m)	DEPTH, D(m)	DRAINAGE VELOCITY (m/s)	0.6 m/s <Vreq< 2m/s
1	S1	0.3	0.3	1.015610253	**OK**
	S2	0.3	0.3	1.015610253	**OK**
	S3	0.3	0.3	1.015610253	**OK**
	S4	0.3	0.3	1.015610253	**OK**
	S5	0.3	0.3	1.015610253	**OK**
	S6	0.3	0.3	1.015610253	**OK**
2	S7	0.3	0.3	1.015610253	**OK**
	S8	0.3	0.3	1.015610253	**OK**
	S9	0.3	0.3	1.015610253	**OK**
	S10	0.3	0.3	1.015610253	**OK**
	S11	0.45	0.3	1.209732397	**OK**
	S12	0.45	0.3	1.209732397	**OK**
3	S13	0.45	0.3	1.209732397	**OK**
	S14	0.45	0.3	1.209732397	**OK**
	S15	0.45	0.3	1.209732397	**OK**
	S16	0.3	0.3	1.015610253	**OK**
	S17	0.3	0.3	1.015610253	**OK**
	S18	0.3	0.3	1.015610253	**OK**
	S19	0.3	0.3	1.015610253	**OK**
	S20	0.3	0.3	1.015610253	**OK**

3.3 Culvert Design

3.3.1 Introduction

A culvert is an enclosed channel that is positioned beneath a road or embankment to preserve the flow from a natural channel or drainage ditch. A culvert-carrying flow cannot cause an unsafe backwater, excessive flow restriction, or excessive outlet velocities. It is not enough to just calculate the design flows and related hydraulic performance of a particular culvert; other factors could also affect the final design of the culvert. These factors could include the cost-effectiveness of different pipe materials and sizes, alignment challenges both vertically and horizontally, environmental concerns, and necessary culvert end treatments. The hydraulic capacity may not always be the determining factor in the size of the culvert aperture. For fish passage, a different type of bridge is often needed than what is usually used for hydraulic capacity. Wetland areas may require the enlargement of existing culverts or the replacement of them with bridges. If there is a high chance of debris, a larger culvert might be required.

3.3.2 Design Criteria

The flow velocity is one of the many factors that need to be taken into account, according to the MSMA 2nd edition. When the culvert is operating at maximum flow, its flow velocity is taken into account to prevent erosion. There are a few items that should be examined:

(1) Control of the inlet

The Colebrook-White equation, Design Chart 18.A12, Appendix 18.A, states that the exit velocity of a pipe culvert flowing with inlet control can be computed with pipe roughness of k=0.5. For various pipe materials, charts should utilize the appropriate k values. Charts 18.A5 and 18.A6, for box and circular culverts, respectively, show the velocity for a part-full flow. The idea behind this approach is that uniform flow happens at the output.

Design Charts 18.A7 and 18.A8, correspondingly, for box and circular culverts show the essential depth that needs to be compared to the flow depth.

(2) Control of outlets

The average outlet velocity can be calculated by dividing the discharge by the flow cross sections.

(3) The conduit's erosion

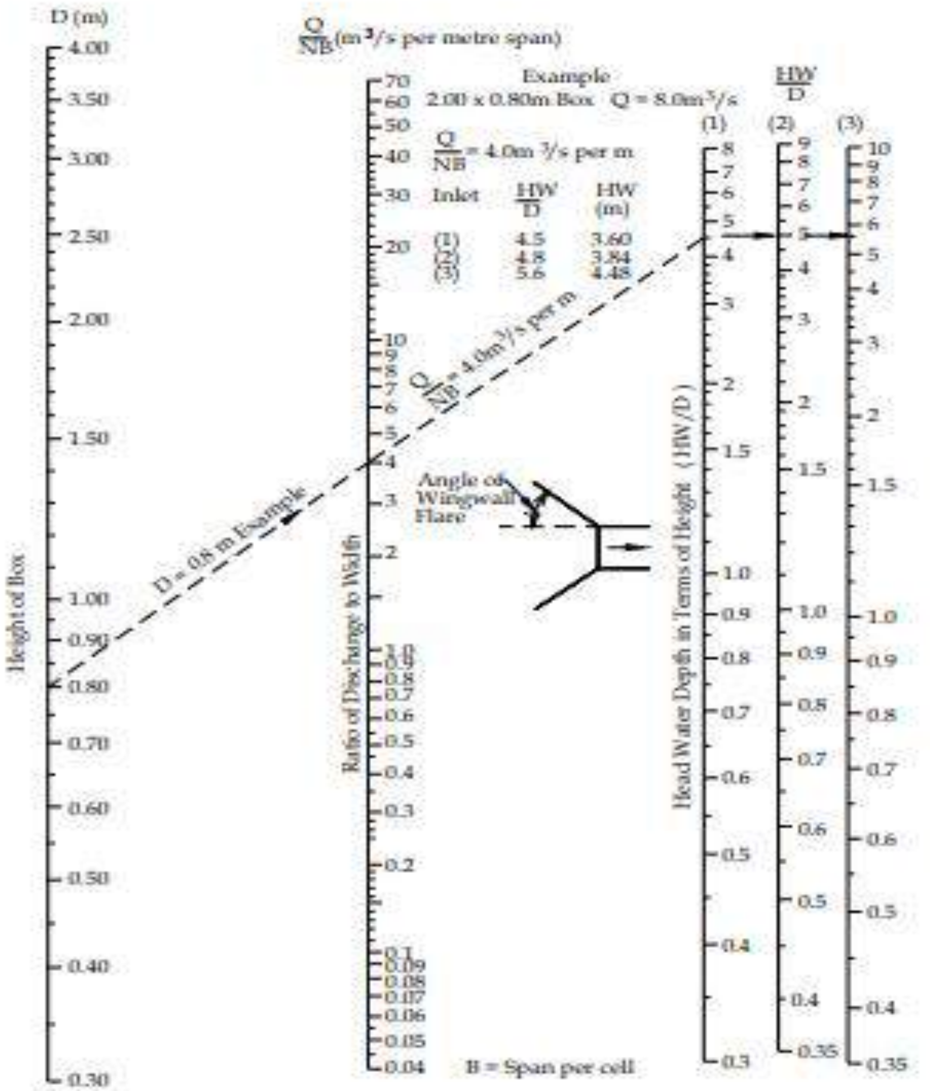
Excessive flow rates of 12 m/s in open channels and more than 7.5 m/s in full flow pipes have the potential to cause cavitation and conduit damage. The highest acceptable flow rates for precast concrete pipes and precast box culverts are 8.0 m/s, whereas the minimum recommended rates for hard packed rock and in-situ concrete are 6.0 m/s.

(4) Scour around the exit and inlet

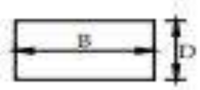
Scour may develop upstream of the culvert due to the flow's high acceleration and velocity when it leaves the natural channel and enters the culvert. Wing walls, aprons, cut-off walls, and embankment paving at the upstream end of a culvert help to maintain the embankment and stream bed. The high velocity flow coming out of the culvert could cause erosion and scour in the bed directly downstream. Concrete apron, rock riprap, rock mattresses, and concrete-filled mattresses are all taken into account for scour protection.

(5) The Siltation

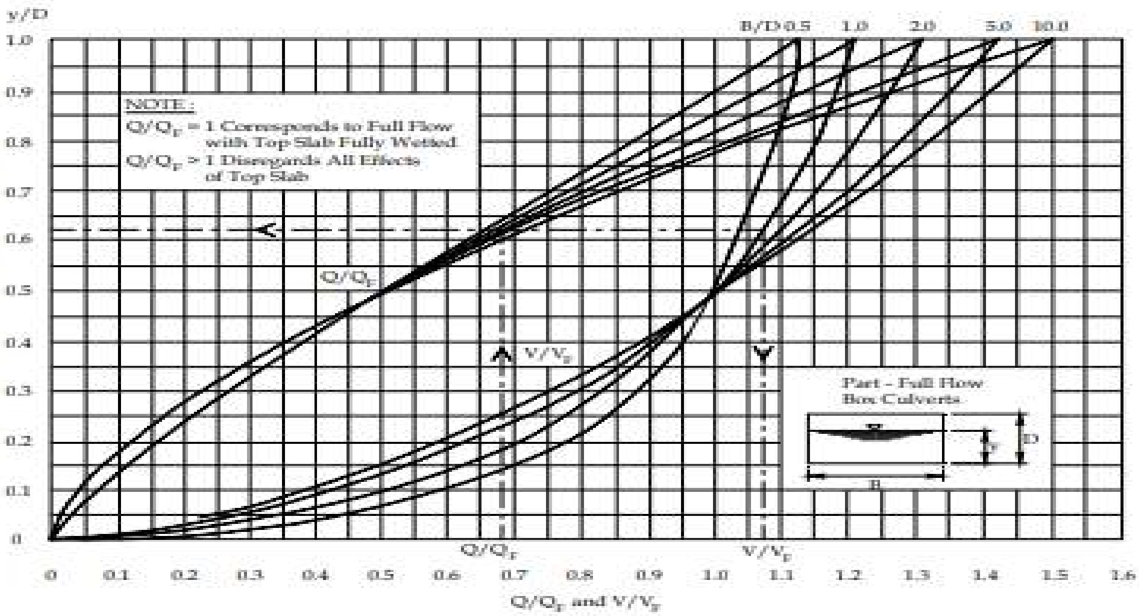
At flow velocities less than 0.5 m/s, siltation takes place as fine to medium sized sand particles settle. Higher slopes have the potential to increase velocity and have self-cleaning qualities. Self-cleaning graded culverts can also be achieved by matching the average grade of the water course above and downstream of the culvert; however, the levels must equal the average stream levels before the culvert was built.



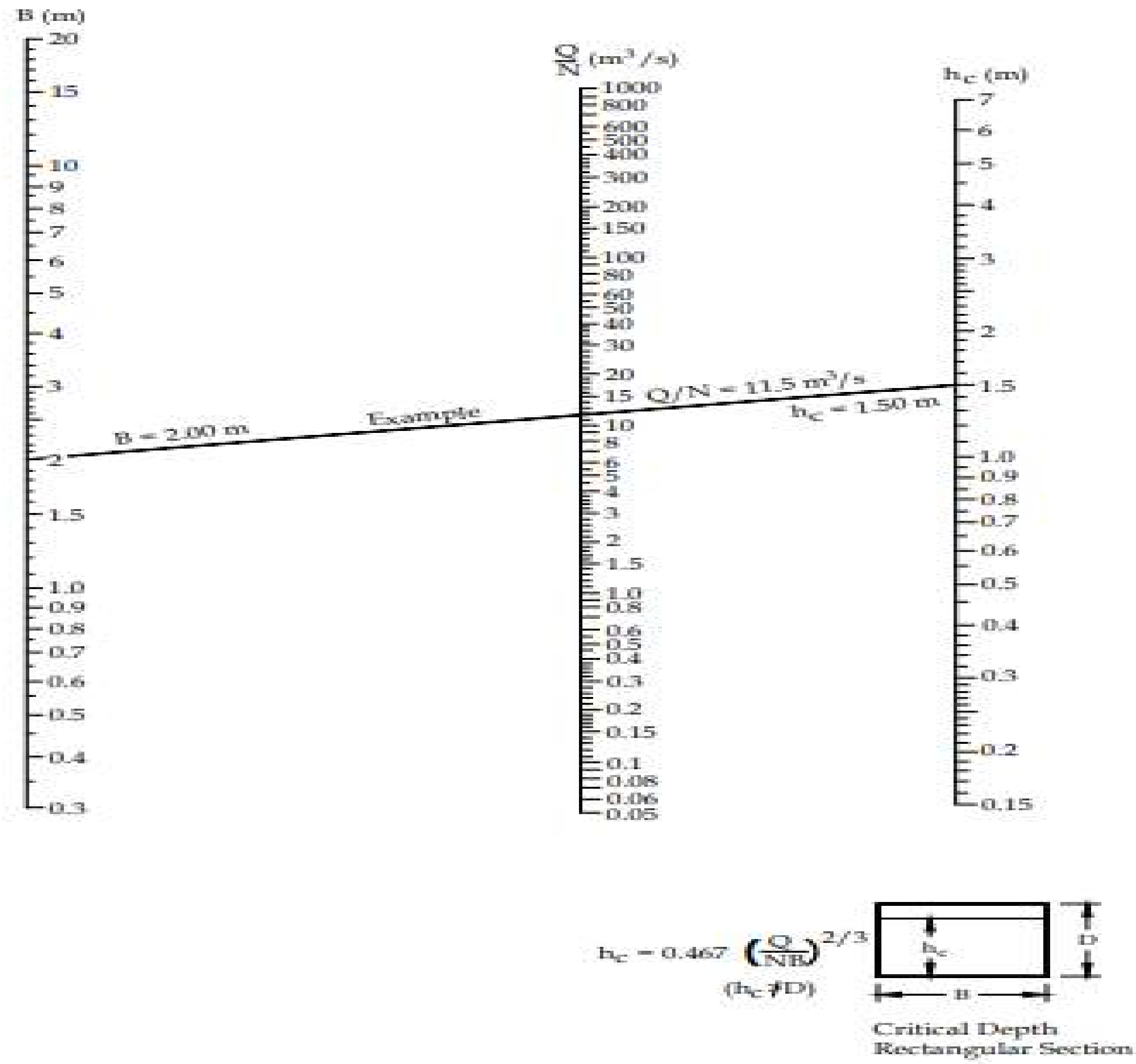
Wingwall Flare	HW/D Scale
30° - 75°	1
90° (headwall)	2
0° (parallel)	3



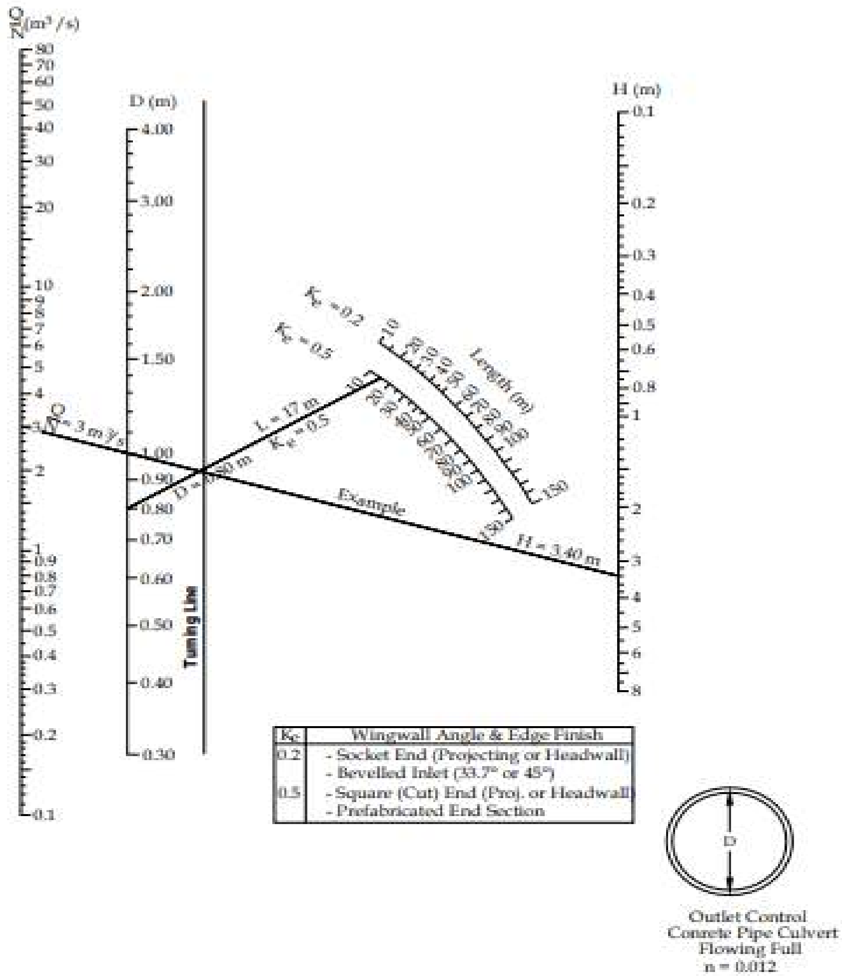
Design Chart 18.A3: Inlet Control Nomograph - Box Culvert



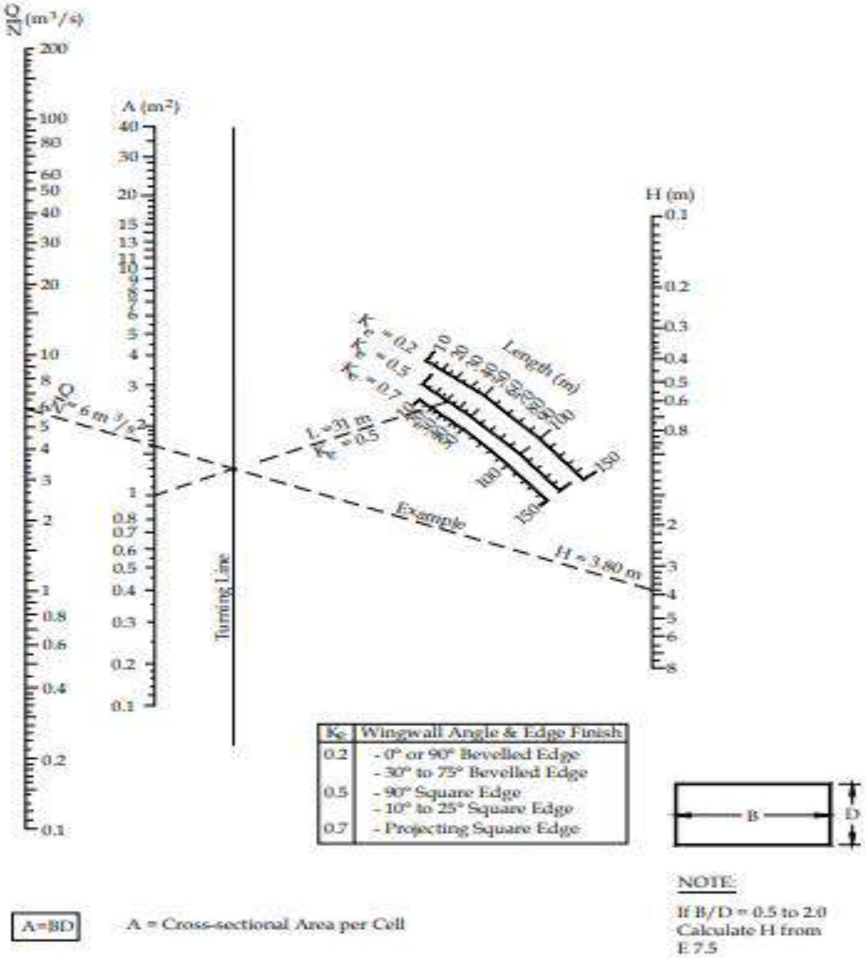
Design Chart 18.A6: Relative Discharge, Velocity and Hydraulic Radius in Part-full Box Culvert Flow



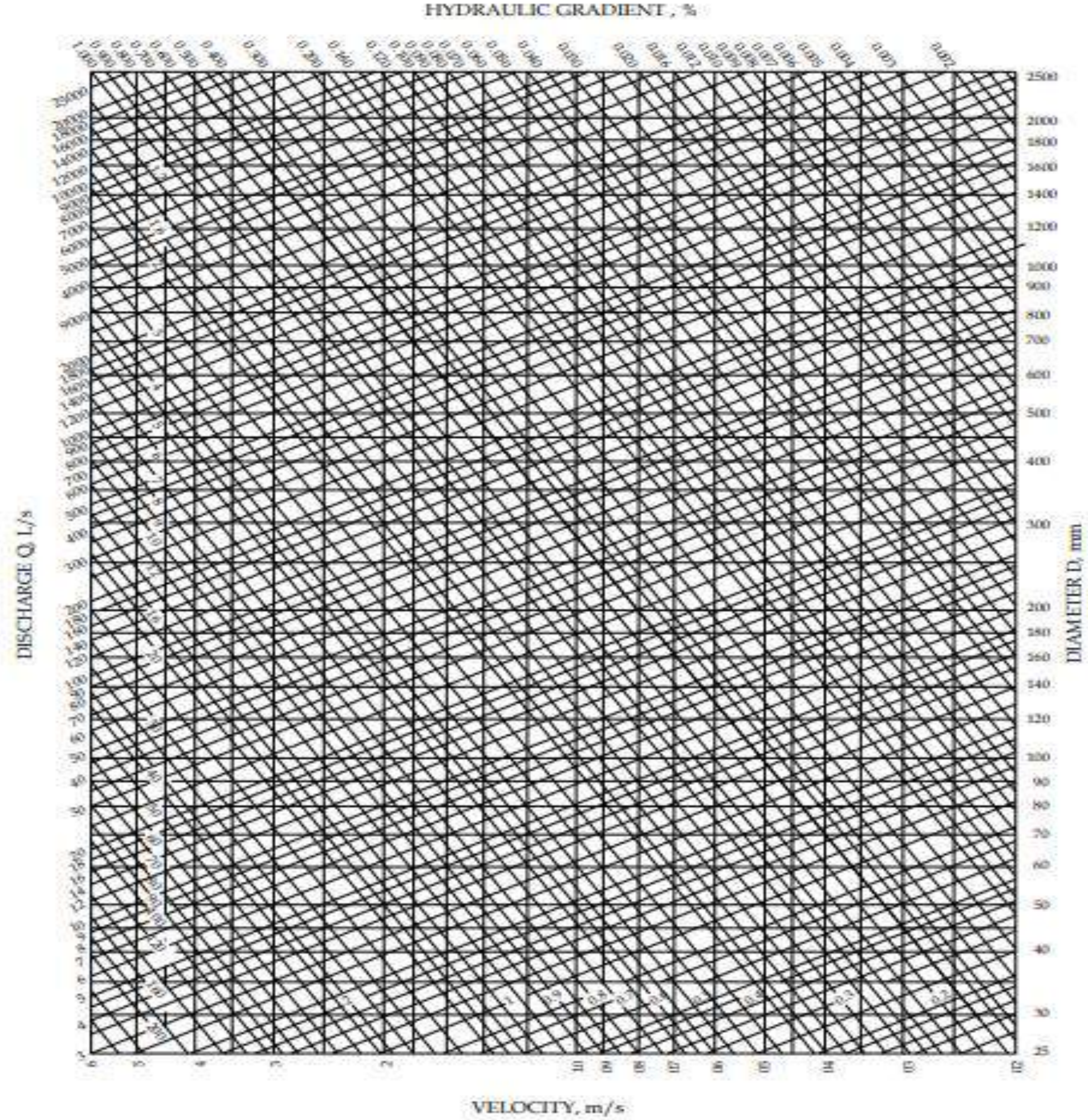
Design Chart 18.A8: Critical Depth in a Rectangular (Box) Section



Design Chart 18.A9: Outlet Control Nomograph - Concrete Pipe Culvert Flowing Full with n = 0.012



Design Chart 18.A10: Outlet Control Nomograph Concrete Box Culvert Flowing Full with n = 0.012



Design Chart 18.A12: Hydraulic Design of Pipes – Colebrook-White Formula – k = 0.60 mm

3.3.3 Results And Calculation

Culvert Design Output:

							ALLOW UPSTREAM	PROPOSED	MIN.	DOWNSTREAM TAIL					
CATCHMENT	CULVERT	FLOW, Q (m3 /s)	LENGTH (m)	INLET (m)	OUTLET (m)	Vh	FLOOD LEVEL (ASSUMED)	ROAD LEVEL	FREEBOARD	-WATER LEVEL (m)	HW1 (m)	HW2 (m)	HWmax (m)	V (m/s)	A (m2)
1	C1	0.670	15.619	43.5	43.42	0.08	44	45	0.3	44.3	1.2	0.5	0.5	2	0.335
	C2	0.180	26.059	43.5	43.42	0.08	44	45	0.3	44.3	1.2	0.5	0.5	2	0.09
	C3	0.180	21.281	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
	C4	0.180	21.336	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
	C5	0.180	19.446	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
	C6	0.890	20.672	39.5	39.42	0.08	40	41	0.3	40.3	1.2	0.5	0.5	2	0.445
	C7	0.180	22.259	39.5	39.42	0.08	40	41	0.3	40.3	1.2	0.5	0.5	2	0.09
	C8	0.180	21.817	39.5	39.42	0.08	40	41	0.3	40.3	1.2	0.5	0.5	2	0.09
	C9	0.180	24.387	43.5	43.42	0.08	44	45	0.3	44.3	1.2	0.5	0.5	2	0.09
	C10	0.180	21.635	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
	C11	0.180	21.338	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
	C12	0.180	24.387	41.5	41.42	0.08	42	43	0.3	42.3	1.2	0.5	0.5	2	0.09
2	C13	0.180	21.338	37.5	37.42	0.08	38	39	0.3	38.3	1.2	0.5	0.5	2	0.09
	C14	0.580	21.338	37.5	37.42	0.08	38	39	0.3	38.3	1.2	0.5	0.5	2	0.29
	C15	0.250	20.017	37.5	37.42	0.08	38	39	0.3	38.3	1.2	0.5	0.5	2	0.125
	C16	0.250	20.248	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	0.125
	C17	0.250	19.812	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	0.125
	C18	1.210	19.843	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	0.605
	C19	2.420	21.522	37.5	37.42	0.08	38	39	0.3	38.3	1.2	0.5	0.5	2	1.21
	C20	2.420	22.102	37.5	37.42	0.08	38	39	0.3	38.3	1.2	0.5	0.5	2	1.21
	C21	2.220	56.730	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.11
	C22	2.810	19.812	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.405
3	C23	2.810	19.826	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.405
	C24	2.020	12.692	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.01
	C25	2.020	12.280	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.01
	C26	2.610	12.166	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.305
	C27	2.220	19.820	36.5	36.42	0.08	37	38	0.3	37.3	1.2	0.5	0.5	2	1.11

Inlet & Outlet Control:

INLET & OUTLET CONTROL																
CULVERT	SIZE	LENGTH	IL	OUT	D/S TW LEVEL	HW (max)	N	D (m)	B (m)	AREA (m2)	P (m)	R	FLOW, Q (m3 /s)	Q/NB	Q/N
C1	1200 x 1200	15.619	43.5	43.42	44.3	0.5	1	1.2	1.2	1.44	3.6	0.3	0.670	0.804	0.67
C2	1200 x 1200	26.059	43.5	43.42	44.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C3	1200 x 1200	21.281	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C4	1200 x 1200	21.336	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C5	1200 x 1200	19.446	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C6	1200 x 1200	20.672	39.5	39.42	40.3	0.5	1	1.2	1.2	1.44	3.6	0.33	0.890	1.068	0.89
C7	1200x 1200	22.259	39.5	39.42	40.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C8	1200 x 1200	21.817	39.5	39.42	40.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C9	1200 x 1200	24.387	43.5	43.42	44.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C10	1200 x 1200	21.635	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C11	1200 x 1200	21.338	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C12	1200x 1200	24.387	41.5	41.42	42.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C13	1200 x 1200	21.338	37.5	37.42	38.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.180	0.216	0.18
C14	1200 x 1200	21.338	37.5	37.42	38.3	0.5	1	1.2	1.2	1.44	3.6	0.2	0.580	0.696	0.58
C15	1200 x 1200	20.017	37.5	37.42	38.3	0.5	1	1.2	1.2	1.44	3.6	0.33	0.250	0.3	0.25
C16	1200 x 1200	20.248	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.33	0.250	0.3	0.25
C17	1200 x 1200	19.812	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.33	0.250	0.3	0.25
C18	1200 x 1200	19.843	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.26	1.210	1.452	1.21

C19	1200 x 1200	21.522	37.5	37.42	38.3	0.5	1	1.2	1.2	1.44	3.6	0.26	2.420	2.904	2.42
C20	1200 x 1200	22.102	37.5	37.42	38.3	0.5	1	1.2	1.2	1.44	3.6	0.33	2.420	2.904	2.42
C21	1200 x 1200	56.730	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.23	2.220	2.664	2.22
C22	1200 x 1200	19.812	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.33	2.810	3.372	2.81
C23	1200 x 1200	19.826	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.33	2.810	3.372	2.81
C24	1200x 1200	12.692	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.2	2.020	2.424	2.02
C25	1200 x 1200	12.280	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.2	2.020	2.424	2.02
C26	1200 x 1200	12.166	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.3	2.610	3.132	2.61
C27	1200 x 1200	19.820	36.5	36.42	37.3	0.5	1	1.2	1.2	1.44	3.6	0.23	2.220	2.664	2.22

Headwater Computation:

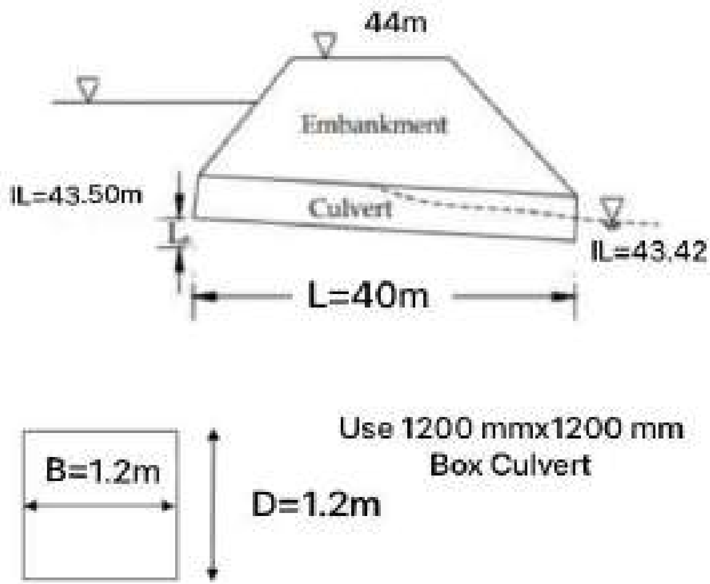
HEADWATER COMPUTATION												CONTROLLING HWc
INLET CONTROL			OUTLET CONTROL, HWo= (hc+D)/2+H-LS									
HWi/D	HWi						TW					
	HWi	STATUS	Ke	H	Hc	(hc+D)/2	TW	STATUS	LS	HWo		
0.95	1.14	OK	0.5	0.2	0.5	0.85	0.8	OK	0.08	0.97	0.97
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
1	1.2	OK	0.5	0.2	0.5	0.85	0.8	OK	0.08	0.97	0.97
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.7	0.84	OK	0.5	0.6	0.5	0.85	0.8	OK	0.08	1.37	1.37
0.9	1.08	OK	0.5	0.35	0.5	0.85	0.8	OK	0.08	1.12	1.12
0.75	0.9	OK	0.5	0.4	0.5	0.85	0.8	OK	0.08	1.17	1.17
0.75	0.9	OK	0.5	0.4	0.5	0.85	0.8	OK	0.08	1.17	1.17
0.75	0.9	OK	0.5	0.4	0.5	0.85	0.8	OK	0.08	1.17	1.17
1.1	1.32	OK	0.5	6	0.5	0.85	0.8	OK	0.08	6.77	6.77
1.5	1.8	OK	0.5	4	0.5	0.85	0.8	OK	0.08	4.77	4.77
1.5	1.8	OK	0.5	4	0.5	0.85	0.8	OK	0.08	4.77	4.77
1.45	1.74	OK	0.5	7	0.5	0.85	0.8	OK	0.08	7.77	7.77
2	2.4	OK	0.5	3.5	0.5	0.85	0.8	OK	0.08	4.27	4.27
2	2.4	OK	0.5	3.5	0.5	0.85	0.8	OK	0.08	4.27	4.27
1.25	1.5	OK	0.5	7.5	0.5	0.85	0.8	OK	0.08	8.27	8.27

1.25	1.5	OK	0.5	7.5	0.5	0.85	0.8	OK	0.08	8.27	8.27
1.75	2.1	OK	0.5	5	0.5	0.85	0.8	OK	0.08	5.77	5.77
1.45	1.74	OK	0.5	4.5	0.5	0.85	0.8	OK	0.08	5.27	5.27

Design Calculation Example:

References	**Calculation**	**Outlet**
Table 1.1	**CULVERT DESIGN (BOX TYPE)** Based on the design at storm catchment 1, and for the economical and optimize the cost, Minor system was selected for Quantity Storm ARIs. Assemble site data Determine Design Storm Discharge From Design Storm Catchment 1: **Culvert 1** **STEP 1 :Data** Flow, Qdrain = 0.670 m^(3)/s Culvert Culvert length, L = 15.619 m Natural waterway inverts level: Inlet = 43.5 m (PL-Culvert h 1.2m- FB 0.3) Outlet = 43.42 m Acceptable upstream flood level (assumed) = 37.00 m Proposed pavement level = 44.00 m Minimum freeboard (assumed) = 0.300 m Estimated downstream tailwater level (assumed) = 44.30 m (IL+0.8m)	**HWmax=0.5m**

	Maximum headwater height HWmax, is : (PL-FB-IL) = 44 – 0.3-43.5 = 0.2 m (Acceptable upstream- IL) = 44– 43.5 = 0.5 m	
Use Design Chart 18.A2	**STEP 2: Assume Inlet Control** Estimate required waterway flow area by assuming flow velocity, V = 2.0 m/s. Estimated flow area, A = Q/V = 0.335 m2 Use box culvert with 1.2 m ($wide$) × 1.2 m ($h$eight) Enter Design Chart 18.A2 with D = 1.20m , Q/NB = 0.335/(1x1.2) =0.804 m^(3)/s/m Inlet Type (1) HWi / D obtained = 0.95 HWi = 1.14 m < 1.2 m	**HWi<HWmax (OK)**
Use Design Chart A18.A8 **Use Design Chart 18.A10**	**STEP 3: Check Outlet Control** TW = 43.42– 42.62= 0.8 m < D (1.2 m) Enter Design Chart A18.A8 with B = 1.2 m , Q/N = 0.67/1 = 0.67 m^(3)/s hc obtained = 0.5 m < B (1.2m) (hc + D)/2 = (0.5 + 1.2)/2 = 0.85 m > TW = 0.8 m Calculate HWo for outlet control Enter Design Chart A18.A10 with A = 1.4 m^(2) Q/N = 0.67 m^(3)/s Ke = 0.5 L = 40 m H = 0.20 m Fall of culvert invert, Ls = 43.5-43.42 = 0.08 m, HWo = (hc + D)/2 + H – Ls = (0.5 + 1.2)/2+0.2-0.08 = 0.97 m HWi = 1.14 m > HWo = 0.97 m	

	Therefore, inlet control governs. **Summary:** Use a single 1200mm x 1200 mm (b x h) concrete box with square edges entrance. The culvert will flow with outlet control with headwater height of 1.20 m and headwater at RL 44m. The possibility of scour or the formation of a hydraulic jump at the outlet must be checked	**Inlet Control HWi<HWmax, OK**
		

3.4 Detention Ponds

3.4.1 Introduction

These days, the detention pond is regarded as the most important part of stormwater management. In order to lessen the amount of stormwater impacts caused by larger urbanizing catchments, retention ponds are utilized. The facilities are usually positioned in open areas by creating an embankment across a stream or channel or by digging a potential storage area. It is possible to build "wet" or "dry" ponds. The wet pond's catchment area spans more than 10 hectares. This ensures that the area generates sufficient baseflow to replenish and maintain the level of the permanent pool. The pond lowers the peak discharge of floodwaters downstream by temporarily retaining water and releasing it gradually through a control outlet—typically an ungated structure, riser, or culvert—located at the base of the embankment. An overflow spillway needs to be positioned towards the top of the embankment in order to safely pass storms that are bigger than the pond's capacity. The spillway protects against the embankment failing and putting resources and life downstream in jeopardy.

3.4.2 Design Criteria

3.4.2.1 General

When studying various stormwater management facilities, it is crucial to take into account an ideal release schedule in order to ensure that the desired outcome is achieved for design usage. This includes the behavior of the pond storage. The outflow hydrograph release time, also known as the empty time, of a detention pond should ideally occur within a day. In order to avoid worst-case scenarios like catastrophic floods, it is also necessary to analyze a variety of design storms, including minimum dam height, pool surface size, flow velocities, storage volume, and overtopping depth. Historically, the primary safety concern has been the potential for drowning incidents in detention ponds. In order to prevent overuse by the public, dry ponds should be fenced off at a depth of 1.2 or 1.5 meters.

3.4.2.2 Detention Pond Design Procedure

There are steps that must be taken to plan and design a detention pond or stormwater management system for a general new development area. The flowchart of the typical procedure is as portrayed in Chart 1 and Chart 2

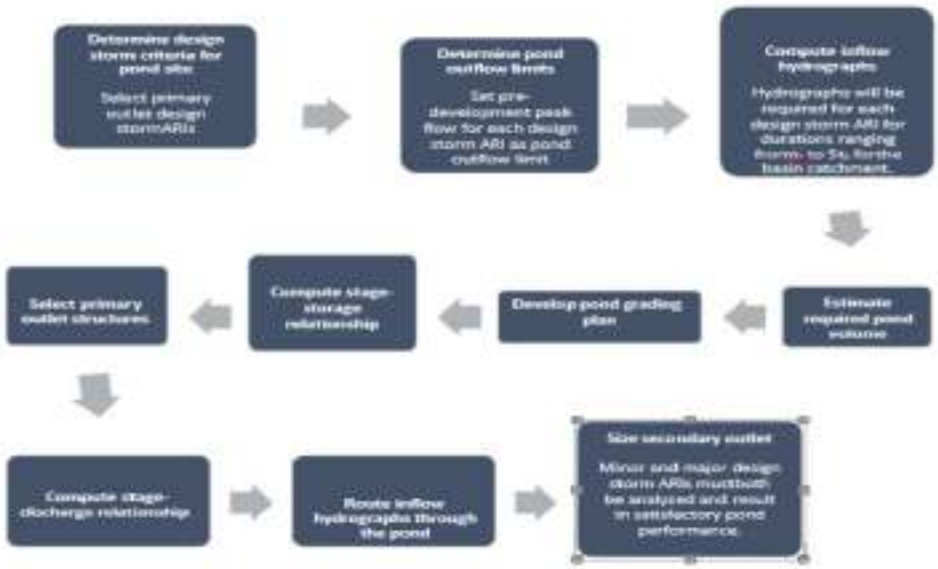


Chart 1: Detention Pond sizing Procedure for Volume and Primary Outlets

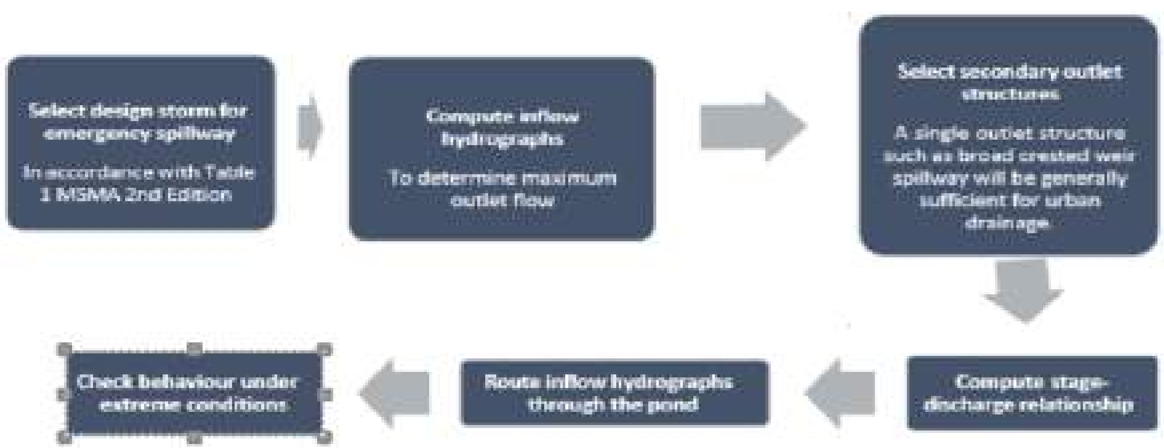


Chart 2: Detention Pond sizing Procedure for Secondary Outlets

3.4.2.3 Inlet

The approach channel's design capacity should be met or surpassed when selecting the inlet's size. The pond's invert level ought to be at least as high as the inflow channel's. The wings of the intake structures need to be protected from erosion using concrete walls, gabions, and other materials. To capture particles and dissolved contaminants prior to their entry into the detention pond, wetlands, sediment forebays, and water quality ponds are commonly utilized methods. Occasionally, the amount required by the system is approximately 30% of the capacity of the detention pond.

3.4.2.4 Outlet

The two types of outlets are the primary outlet and the secondary outlet, often known as the emergency spillway. Primary outlets are made in order to control and discharge water from a detention pond in a prearranged manner. Every stream that was taken into account when
It is the outlet conduit's responsibility to design the riser construction. To accomplish peak flows for pre development of the main and minor systems design storm ARI, primary
Detention pond outflows need to be made. Owing to the requirement for a two-stage output arrangement—one to control the minor system design's flow and the other to manage the main system design's flow. However, the pipe downstream of the outlet works must be large enough to pass the major design flow without developing hydraulic surcharge pressure inside of it in order to prevent a piping-related embankment failure.

When flows exceed the maximum design storm ARI of the storage facility, a controlled overflow is provided by an emergency spillway, or auxiliary exit. Extensive research is frequently not required to evaluate the spillway capacity of stormwater retention structures. Although there is a significant chance of harm from a failure, the catastrophic risk of a major reservoir being overtopped or breached usually outweighs the possible damage. Because of their small catchment areas, only extremely brief, intense thunderstorms are expected to pose a risk of overtopping or embankment failure at numerous locations. Furthermore, the buildings' capacities are usually insufficient to produce a flood wave. The secondary exits of all non-hazardous small detention ponds must be built to allow a design storm with a minimum duration of 100 years ARI to pass through the pond safely. According to the authorized requirements, they must be made for hazard ponds (MSMA 2nd Edition).

3.4.2.5 Storage zone and Embankment

The drawdown time is controlled by the primary and secondary outlets' appropriate sizes. It is recommended that a dry pond be drained within 12 hours of the rain stopping, while the water level in a wet pond should return to normal 24 hours after the rain stops. It should be feasible to avoid low flows across or around a dry detention pond by using a low flow canal or pipe. This is necessary to avoid small storms flooding the pond bottom, especially if it is grassy, or baseflow wetting the floor frequently during dry periods. The minimum bypass flow rate should be computed using a 10 mm depth of runoff from the contributing catchment.

Dry detention ponds are irregular water-retaining structures, and their embankments don't need to be carefully built as dams unless they are exceptionally tall or have special soil problems. A dam is defined as an embankment that raises the water level by a predetermined amount, as decided by the applicable dam safety group. This is typically measured along the downstream embankment toe to the emergency spillway crest and is 1.5 to 3 meters above the mean low water height. These embankments have to be constructed, maintained, and engineered in compliance with any relevant State or Federal dam safety laws.

3.4.2.6 Safety and Erosion

Once the size of the detention pond and outlet structures have been established, maximum departure velocities and the need to prevent erosion of the downstream bed and banks should be considered.Public safety must be considered in the construction of a detention pond both during operation and during the times in between storms when the facility is being emptied. During these times, appropriate measures must be taken to dissuade and prevent the public from being exposed to high-hazard regions.

3.4.3 Sizing Design Flow

An overview of how to size a detention pond is provided below with diagrams.

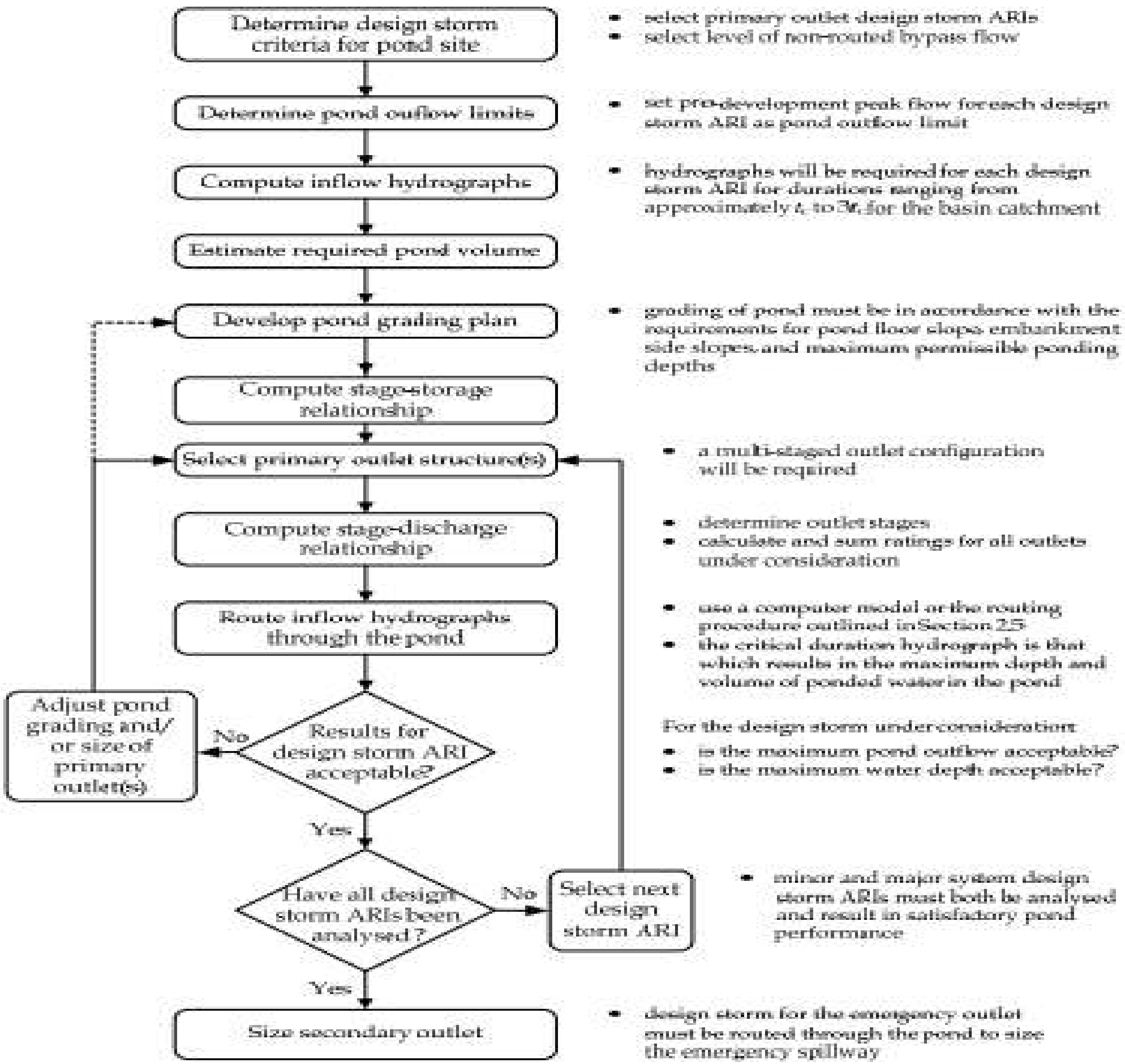


Figure 7.8: Detention Pond Sizing Procedure for Volume and Primary Outlets (DID, 2000)

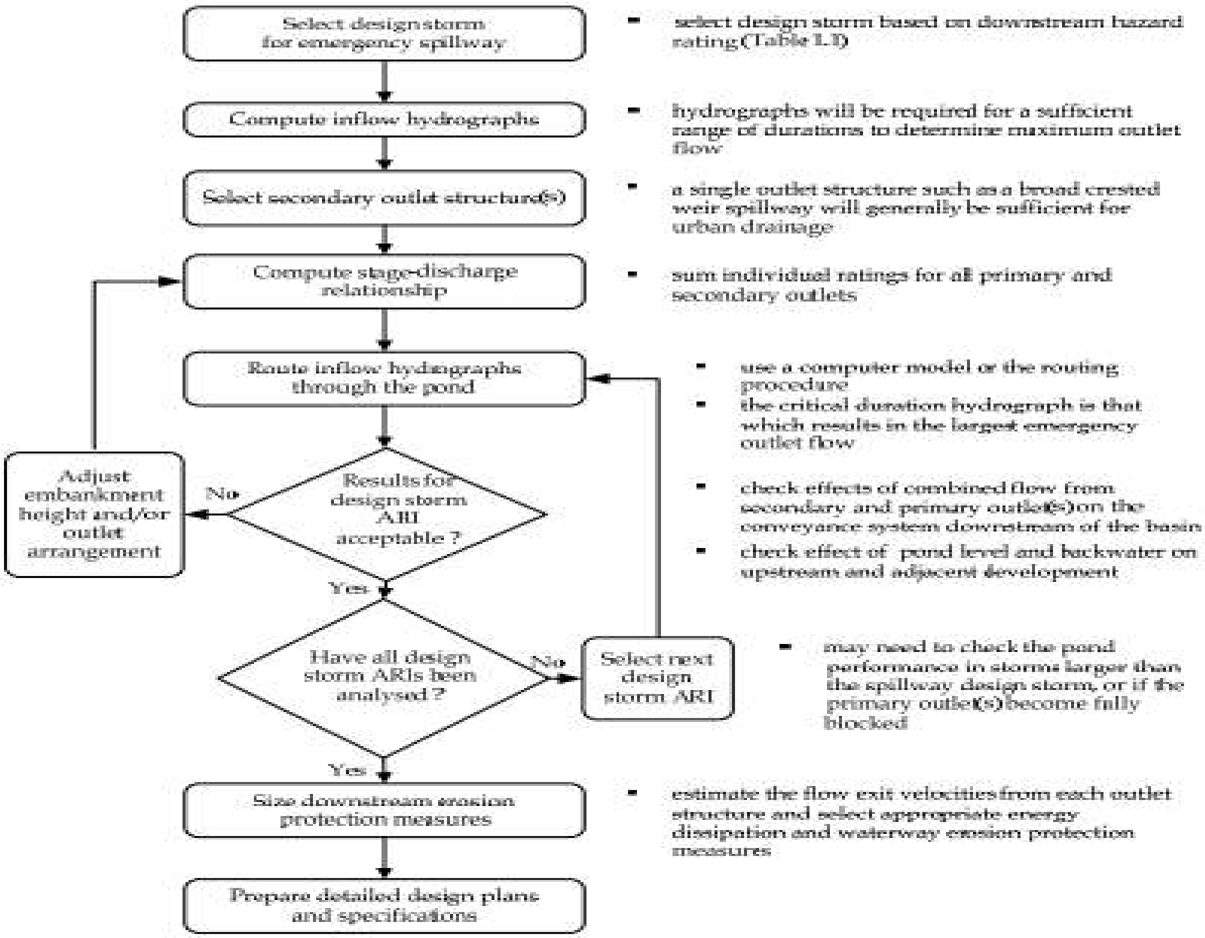


Figure 7.9: Detention Pond Sizing Procedure for Secondary Outlet (DID, 2000)

3.4.4 Results And Calculation

Step 1: Setting the design storm criteria for the pond

The minor and major design storms for primary outlet are 5 and 50 year ARI, while the secondary outlet is 100 year ARI (in accordance with Table 1.1, Section 7.2.3 and 7.2.4).

Step 2: Compute Pond Inflow Hydrograph.

RESERVOIR	PRE- DEVELOPMENT CATCHMENT AND STREAM PROPERTIES							
A	REACH	OVERLAND			NATURAL STREAM			
		Lo (m)	n*	So (%)	Ld (m)	n	Sd (mm)	R (m)
	-	139.7	0.045	3.58	222	0.05	0.023	0.338
	to (min)	td (min)	tc (min)					
	19.36	2.51	21.87					
	POST- DEVELOPMENT CATCHMENT AND STREAM PROPERTIES							
	REACH	OVERLAND			DRAIN FLOW			
		Lo (m)	n*	So (%)	Ld (m)	n	Sd (mm)	R (m)
	-	139.7	0.035	3.58	222	0.015	0.023	0.2
	to (min)	td (min)	tc (min)					
	15.06	1.07	16.13					

	PRE- DEVELOPMENT CATCHMENT AND STREAM PROPERTIES							
	REACH	OVERLAND			NATURAL STREAM			
		Lo (m)	n*	So (%)	Ld (m)	n	Sd (mm)	R (m)
	-	160.33	0.045	9.36	166	0.05	0.09	0.338
	to (min)	td (min)	tc (min)					
	16.72	0.95	17.67					
B	**POST- DEVELOPMENT CATCHMENT AND STREAM PROPERTIES**							
	REACH	OVERLAND			DRAIN FLOW			
		Lo (m)	n*	So (%)	Ld (m)	n	Sd (mm)	R (m)
	-	160.33	0.035	9.36	166	0.015	0.09	0.2
	to (min)	td (min)	tc (min)					
	13.01	0.29	13.3					

Step 3: Determine the pond outflow limits

The nearest rainfal station is Pintu Kaw Pulau Kertam obtained from Table 2.B2

λ	κ	θ	η
63.5073	0.383	0.2881	0.8202

POND OUTFLOW LIMITS

RESERVOIR	PRE- DEVELOPMENT DISCHARGE						
	ARI (yrs)	Storm Duration, d(m)	tc (min)	i (mm/hr)	Cpre	A (ha)	Qpre (m3/s)
	5.00	tc	21.87	9.27	0.50	14.39	0.19
	50.00	tc	21.87	22.38	0.50	14.39	0.45
	100.00	tc	21.87	29.19	0.50	14.39	0.58
	POST- DEVELOPMENT DISCHARGE						
	ARI (yrs)	Storm Duration, d(m)	tc (min)	i (mm/hr)	Cpost	A (ha)	Qpost (m3/s)
A	5.00	tc	16.13	11.85	0.90	14.39	0.43
		1.5tc	24.20	8.54	0.90	14.39	0.31
		2.0tc	32.26	6.76	0.90	14.39	0.24
		2.5tc	40.33	5.64	0.90	14.39	0.20
	50.00	tc	16.13	28.62	0.95	14.39	1.09
		1.5tc	24.20	20.62	0.95	14.39	0.78
		2.0tc	32.26	16.33	0.95	14.39	0.62
		2.5tc	40.33	13.62	0.95	14.39	0.52
	100.00	tc	16.13	37.33	0.95	14.39	1.42
		1.5tc	24.20	26.90	0.95	14.39	1.02
		2.0tc	32.26	21.29	0.95	14.39	0.81
		2.5tc	40.33	17.76	0.95	14.39	0.67

	PRE- DEVELOPMENT DISCHARGE						
	ARI (yrs)	Storm Duration, d(m)	tc (min)	i (mm/hr)	Cpre	A (ha)	Qpre (m3/s)
	5.00	tc	17.67	11.01	0.50	21.25	0.32
	50.00	tc	17.67	26.59	0.50	21.25	0.78
	100.00	tc	17.67	34.68	0.50	21.25	1.02
	POST- DEVELOPMENT DISCHARGE						
	ARI (yrs)	Storm Duration, d(m)	tc (min)	i (mm/hr)	Cpost	A (ha)	Qpost (m3/s)
B	5.00	tc	13.30	13.84	0.90	21.25	0.74
		1.5tc	19.95	9.98	0.90	21.25	0.53
		2.0tc	26.60	7.91	0.90	21.25	0.42
		2.5tc	33.25	6.60	0.90	21.25	0.35
	50.00	tc	13.30	33.43	0.95	21.25	1.87
		1.5tc	19.95	24.11	0.95	21.25	1.35
		2.0tc	26.60	19.10	0.95	21.25	1.07
		2.5tc	33.25	15.93	0.95	21.25	0.89
	100.00	tc	13.30	43.59	0.95	21.25	2.44
		1.5tc	19.95	31.44	0.95	21.25	1.76
		2.0tc	26.60	24.91	0.95	21.25	1.40
		2.5tc	33.25	20.78	0.95	21.25	1.17

The pre-development flows for this duration will become the post-development flow limits in the channel immediately downstream of the pond. The pond outflow limits for 5, 50 and 100 year ARI are 0.19 m¾, 0.45 m⅜ and 0.58 m¾ respectively.

Step 4: Estimate required pond volume using Rational Hydrograph Method:

<table>
<tr><td rowspan="12">A</td><td colspan="7">For 50 years ARI, the inflow hydrograph is obtained based on post developlent pond</td></tr>
<tr><th>ARI (yrs)</th><th>Storm Duration, d(m)</th><th>tc (min)</th><th>ti (min)</th><th>Qi (m3/s)</th><th>Qo (m3/s)</th><th>Vs (m3)</th></tr>
<tr><td rowspan="4">50.00</td><td>tc</td><td>16.13</td><td>32.26</td><td>1.09</td><td>0.45</td><td>618.99</td></tr>
<tr><td>1.5tc</td><td>24.20</td><td>40.33</td><td>0.78</td><td>0.45</td><td>595.76</td></tr>
<tr><td>2.0tc</td><td>32.26</td><td>56.46</td><td>0.62</td><td>0.45</td><td>442.54</td></tr>
<tr><td>2.5tc</td><td>40.33</td><td>72.59</td><td>0.52</td><td>0.45</td><td>277.01</td></tr>
<tr><td colspan="7">For 50 years ARI, the inflow hydrograph is obtained based on post developlent pond</td></tr>
<tr><td rowspan="4">100.00</td><td>tc</td><td>16.13</td><td>32.26</td><td>1.42</td><td>0.58</td><td>807.19</td></tr>
<tr><td>1.5tc</td><td>24.20</td><td>40.33</td><td>1.02</td><td>0.58</td><td>776.90</td></tr>
<tr><td>2.0tc</td><td>32.26</td><td>56.46</td><td>0.81</td><td>0.58</td><td>577.09</td></tr>
<tr><td>2.5tc</td><td>40.33</td><td>72.59</td><td>0.67</td><td>0.58</td><td>361.24</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="8">B</td><td colspan="7">For 50 years ARI, the inflow hydrograph is obtained based on post developlent pond</td></tr>
<tr><th>ARI (yrs)</th><th>Storm Duration, d(m)</th><th>tc (min)</th><th>ti (min)</th><th>Qi (m3/s)</th><th>Qo (m3/s)</th><th>Vs (m3)</th></tr>
<tr><td rowspan="4">50.00</td><td>tc</td><td>13.30</td><td>26.60</td><td>1.87</td><td>0.78</td><td>869.53</td></tr>
<tr><td>1.5tc</td><td>19.95</td><td>33.25</td><td>1.35</td><td>0.78</td><td>835.46</td></tr>
<tr><td>2.0tc</td><td>26.60</td><td>46.55</td><td>1.07</td><td>0.78</td><td>613.19</td></tr>
<tr><td>2.5tc</td><td>33.25</td><td>59.85</td><td>0.89</td><td>0.78</td><td>373.12</td></tr>
<tr><td colspan="7">For 50 years ARI, the inflow hydrograph is obtained based on post developlent pond</td></tr>
<tr><td>100.00</td><td>tc</td><td>13.30</td><td>26.60</td><td>2.44</td><td>1.02</td><td>1133.91</td></tr>
</table>

		1.5tc	19.95	33.25	1.76	1.02	1089.48
		2.0tc	26.60	46.55	1.40	1.02	799.63
		2.5tc	33.25	59.85	1.17	1.02	486.57

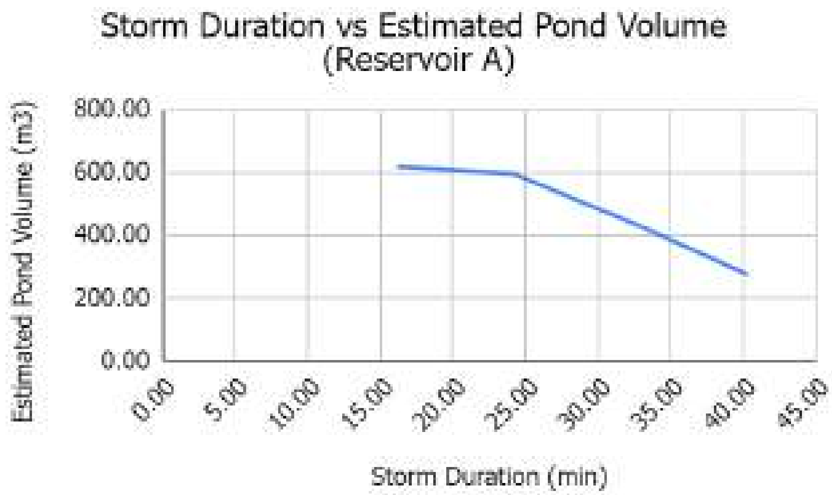
Make a preliminary estimate of the required pond volume, Vs storm duration (based on 50 yr ARI design storm) using Rational Hydrograph Method (RHM)

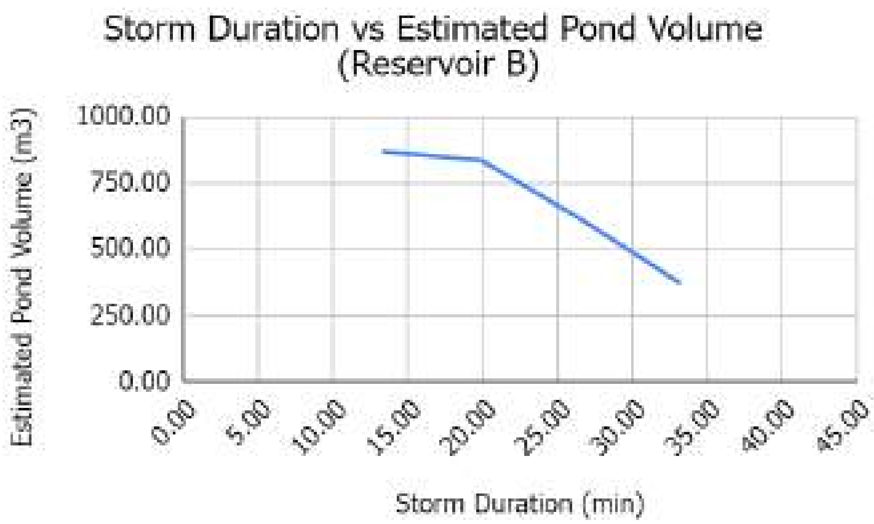
For Type 2 hydrograph (storm duration d is equal to tc),

Vs = 0.5t; (Qi - Qo)

For 50 year ARI, the estimated pond volumes for various storm durations are:

For storm duration d=t = 16.13 min, ti=33.26 min,
For storm duration d=1.5 t. = 24.20 min, ti=40.33 min,
For storm duration d=2.0 tc = 32.26 min, ti=56.58 min,
For storm duration =2.5 tc = 40.33 min, ti=72.59 min,





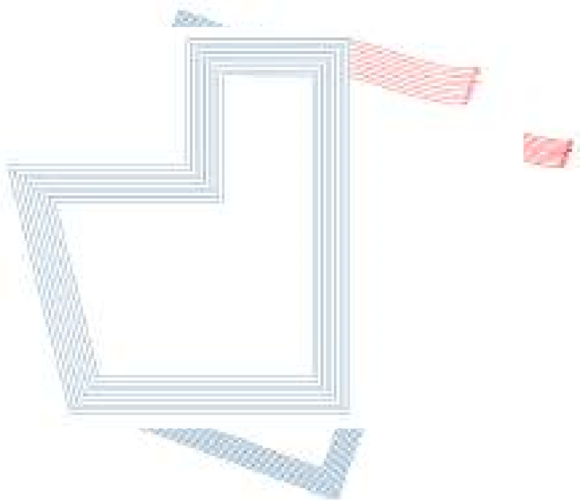
Therefore the estimated pond volume for Reservoir A is 620m3 and for Reservoir B is 1140m3

Step 5: Develop a pond grading plan

The location and grading of the pond embankment and storage area is selected by trial and error so that at least the preliminary estimated volume for Reservoir A of 619m3 and for Reservoir B of 869m3, is available in the pond to cater for the critical 50 year ARI design storm event.

Pond A grading plan

Pond B grading plan



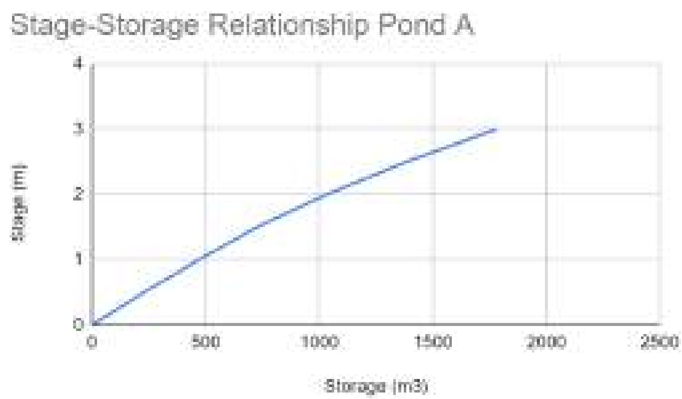
As observed the maximum area for Reservoir A is 623m2 and 754m2 for Reservoir B.

Step 6: Compute stage-storage relationship

The maximum allowable elevation is 37.7m for Reservoir A and 25.7m for Reservoir B These values are obtained by subtracting 300mm freeboard.

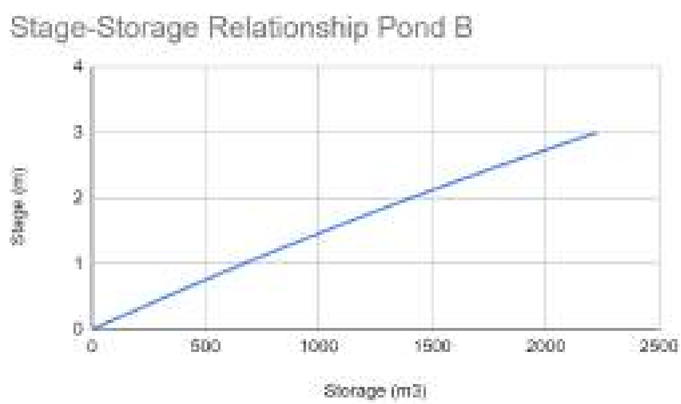
Stage-Storage Relationship Pond A

Stage (m)	Elevation (m)	Area (m2)	Storage Volume (m3)
0	35	451	0
0.5	35.5	463	228.5
1	36	478	470.5
1.5	36.5	492	727.5
2	37	543	1035
2.5	37.5	565	1385
3	38	623	1782



Stage-Storage Relationship Pond B

Stage (m)	Elevation (m)	Area (m2)	Storage Volume (m3)
0	23	646	0
0.5	23.5	658	326
1	24	674	666
1.5	24.5	695	1026.75
2	25	711	1406
2.5	25.5	732	1803.75
3	26	754	2229



Step 7: Size the minor design storm primary outlet

The invert level of the upstream end of the culvert was set at the stage 35.00 m LSD in the pond.

Rectangular orifice measuring 0.5 m (width) x 0.5 m (depth) was chosen.

Stage-Discharge Relation and Storage Indicator Number (5 year ARI 1st Trial)

Co=0.6(Orifice)

A = 1.44m2

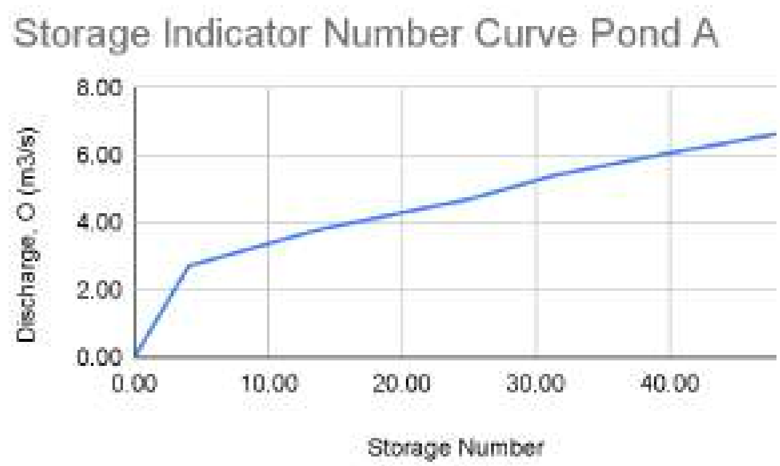
Invert level = 35 m

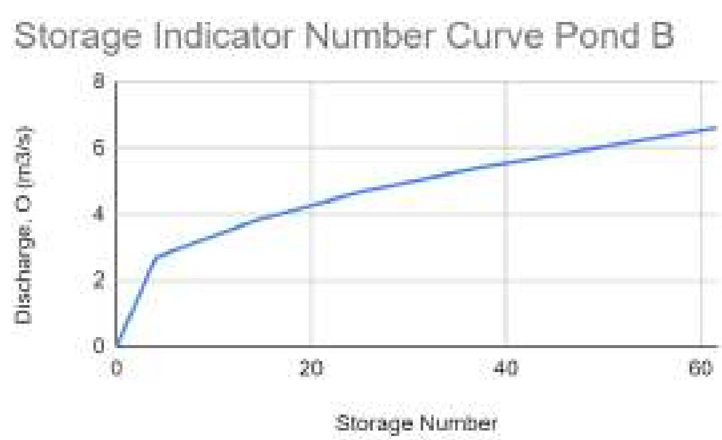
Dt=1min

H (m)	O (m3/s)	S (m3)	Area	t (s)	change in t	S/DT+O/2
0.00	0.00	0.00	451.00	0.00	0.00	0.00
0.50	2.71	228.50	463.00	84.44	84.44	4.06
1.00	3.83	470.50	478.00	122.94	38.50	14.13
1.50	4.69	727.50	492.00	155.21	32.27	24.89
2.00	5.41	1035.00	543.00	191.23	36.02	31.44
2.50	6.05	1385.00	565.00	228.88	37.65	39.81
3.00	6.63	1782.00	623.00	268.83	39.95	47.92

Stage-Storage Relationship Pond B

H(m)	O (m3/s)	S (m3)	Area	t (s)	change in t	S/DT+O/2
0	0	0	646	0.00	0	0
0.50	2.71	326.00	658.00	120.47	120.47	4.06
1.00	3.83	666.00	674.00	174.02	53.56	14.35
1.50	4.69	1026.75	695.00	219.06	45.03	25.14
2.00	5.41	1406.00	711.00	259.78	40.72	37.23
2.50	6.05	1803.75	732.00	298.09	38.31	50.11
3.00	6.63	2229.00	754.00	336.27	38.18	61.69


Storage Indicator Number Curve Pond A
8.00
6.00
4.00
2.00
0.00
Discharge, O (m3/s)
0.00
10.00
20.00
30.00
40.00
Storage Number


Storage Indicator Number Curve Pond B
8
6
4
2
0
Discharge, O (m3/s)
0
20
40
60
Storage Number

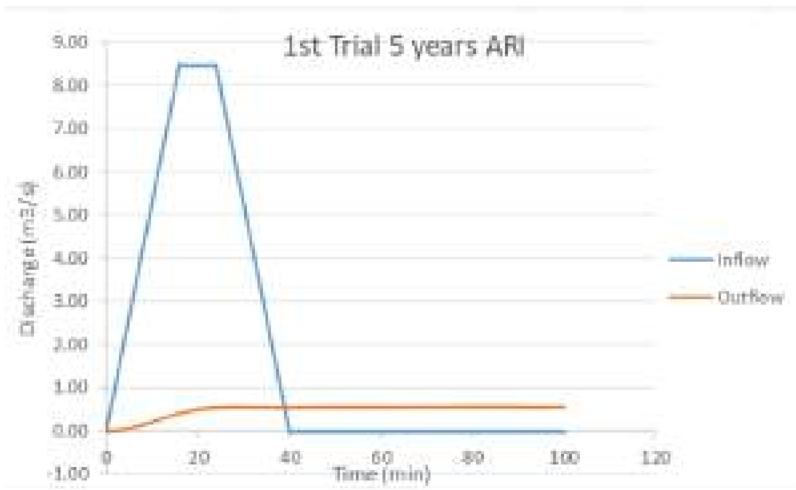
Using a routing time step of 1 minute,
Routing Table for Reservoir A, 5 yr ARI (1st Trial), Take d = 1.5 tc, tc = 16.13 minutes

Time (min)	I (m3/s)	(I1 +I2)/2	S1/Dt +O1/2 (m3/s)	O1 (m3/s)	S2/Dt +O2/2 (m3/s)	O2 (m3/s)
0	0	0	0	0.00	0	0
1	0.1	0.05	0	0.00	0.05	0
2	0.2	0.15	0.05	0.00	0.20	0.01
3	0.74	0.47	0.2	0.01	0.68	0.02
4	1.28	1.01	0.68	0.02	1.71	0.03
5	1.82	1.55	1.71	0.03	3.29	0.05
6	2.36	2.09	3.29	0.05	5.43	0.07
7	2.9	2.63	5.43	0.07	8.13	0.09
8	3.44	3.17	8.13	0.09	11.39	0.11
9	3.98	3.71	11.39	0.11	15.21	0.12
10	4.52	4.25	15.21	0.12	19.58	0.12
11	5.06	4.79	19.58	0.12	24.49	0.12
12	5.6	5.33	24.49	0.12	29.95	0.13
13	6.14	5.87	29.95	0.13	35.95	0.13
14	6.68	6.41	35.95	0.13	42.49	0.13
15	7.22	6.95	42.49	0.13	49.57	0.13
16	7.76	7.49	49.57	0.13	57.19	0.13
17	7.76	7.76	57.19	0.13	65.08	0.13
18	7.76	7.76	65.08	0.13	72.97	0.14
19	7.76	7.76	72.97	0.14	80.87	0.14
20	7.76	7.76	80.87	0.14	88.77	0.14
21	7.76	7.76	88.77	0.14	96.67	0.14
22	7.76	7.76	96.67	0.14	104.58	0.14
23	7.76	7.76	104.58	0.14	112.48	0.14
24	7.76	7.76	112.48	0.14	120.38	0.14
25	7.22	7.49	120.38	0.14	128.01	0.16
26	6.68	6.95	128.01	0.16	135.12	0.16

27	6.14	6.41	135.12	0.16	141.69	0.16
28	5.6	5.87	141.69	0.16	147.72	0.16
29	5.06	5.33	147.72	0.16	153.21	0.16
30	4.52	4.79	153.21	0.16	158.16	0.16
31	3.98	4.25	158.16	0.16	162.57	0.16
32	3.44	3.71	162.57	0.16	166.44	0.16
33	2.9	3.17	166.44	0.16	169.77	0.16
34	2.36	2.63	169.77	0.16	172.56	0.16
35	1.82	2.09	172.56	0.16	174.81	0.16
36	1.28	1.55	174.81	0.16	176.52	0.16
37	0.74	1.01	176.52	0.16	177.69	0.16
38	0.2	0.47	177.69	0.16	178.32	0.16
39	0	0.1	178.32	0.16	178.58	0.16
40	0	0	178.58	0.16	178.74	0.16
41	0	0	178.74	0.16	178.90	0.16
42	0	0	178.90	0.16	179.06	0.16
43	0	0	179.06	0.16	179.22	0.16
44	0	0	179.22	0.16	179.38	0.16
45	0	0	179.38	0.16	179.54	0.16
46	0	0	179.54	0.16	179.70	0.16
47	0	0	179.70	0.16	179.86	0.16
48	0	0	179.86	0.16	180.02	0.16
49	0	0	180.02	0.16	180.18	0.16
50	0	0	180.18	0.16	180.34	0.16
51	0	0	180.34	0.16	180.50	0.16
52	0	0	180.50	0.16	180.66	0.16
53	0	0	180.66	0.16	180.82	0.16
54	0	0	180.82	0.16	180.98	0.16
55	0	0	180.98	0.16	181.14	0.16
56	0	0	181.14	0.16	181.30	0.16
57	0	0	181.30	0.16	181.46	0.16
58	0	0	181.46	0.16	181.62	0.16
59	0	0	181.62	0.16	181.78	0.16

60	0	0	181.78	0.16	181.94	0.16
61	0	0	181.94	0.16	182.10	0.16
62	0	0	182.10	0.16	182.26	0.16
63	0	0	182.26	0.16	182.42	0.16
64	0	0	182.42	0.16	182.58	0.16
65	0	0	182.58	0.16	182.74	0.16
66	0	0	182.74	0.16	182.90	0.16
67	0	0	182.90	0.16	183.06	0.16
68	0	0	183.06	0.16	183.22	0.16
69	0	0	183.22	0.16	183.38	0.16
70	0	0	183.38	0.16	183.54	0.17
71	0	0	183.54	0.17	183.71	0.17
72	0	0	183.71	0.17	183.88	0.17
73	0	0	183.88	0.17	184.05	0.17
74	0	0	184.05	0.17	184.22	0.17
75	0	0	184.22	0.17	184.39	0.17
76	0	0	184.39	0.17	184.56	0.17
77	0	0	184.56	0.17	184.73	0.17
78	0	0	184.73	0.17	184.90	0.17
79	0	0	184.90	0.17	185.07	0.17
80	0	0	185.07	0.17	185.24	0.17
81	0	0	185.24	0.17	185.41	0.17
82	0	0	185.41	0.17	185.58	0.17
83	0	0	185.58	0.17	185.75	0.17
84	0	0	185.75	0.17	185.92	0.17
85	0	0	185.92	0.17	186.09	0.17
86	0	0	186.09	0.17	186.26	0.17
87	0	0	186.26	0.17	186.43	0.17
88	0	0	186.43	0.17	186.60	0.17
89	0	0	186.60	0.17	186.77	0.17
90	0	0	186.77	0.17	186.94	0.17
91	0	0	186.94	0.17	187.11	0.16
92	0	0	187.11	0.16	187.27	0.16

93	0	0	187.27	0.16	187.43	0.16
94	0	0	187.43	0.16	187.59	0.16
95	0	0	187.59	0.16	187.75	0.16
96	0	0	187.75	0.16	187.91	0.16
97	0	0	187.91	0.16	188.07	0.16
98	0	0	188.07	0.16	188.23	0.16
99	0	0	188.23	0.16	188.39	0.16
100	0	0	188.39	0.16		



Using a routing time step of 1.0 minutes, the 5 yr ARI orifice produced a maximum discharge of 0.42 m3/s which is acceptable as it is less than the outflow limit of 0.19 m3/s. 2nd Trial is not needed.

Step 9: Size the secondary outlet arrangement

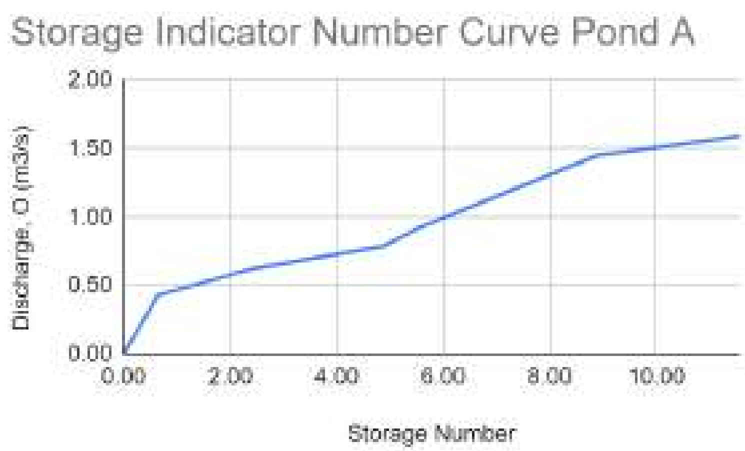
A 10 m wide broad-crested weir spillway with O(H): 1(V) side slopes was selected for the pond secondary outlet.
The spillway was set at the side of embankment with a height of 36.5 m (50 year ARI maximum water level)

Combined Stage-Discharge - 5 yr and 50 yr ARI orifice with 100 yr ARI Weir
Co =1.7 (Weir)
0.6 (Orifice)
B= 10m (For broad crested weir)
Dt = 1min

H (m)	5 yr ARI Orifice	50yr ARI Weir	total Discharge
0.00	0.00	0.00	0.00
0.50	0.48	0.00	0.48
1.00	0.66	0.00	0.66
1.50	0.82	0.00	0.82
2.00	0.94	0.00	0.94
2.50	1.06	0.52	1.58
3.00	1.15	0.54	1.69

Combined Storage indicator Number.

Stage-Storage Relationship Pond A						
H (m)	O (m3/s)	S (m3)	Area	t (s)	change in t	S/DT+O/2
0.00	0.00	0.00	451.00	0.00	0.00	0.00
0.50	0.43	228.50	463.00	531.40	531.40	0.65
1.00	0.62	470.50	478.00	758.87	227.48	2.38
1.50	0.79	727.50	492.00	920.89	162.02	4.89
2.00	0.92	1035.00	543.00	1125.00	204.11	5.53
2.50	1.45	1385.00	565.00	955.17	169.83	8.88
3.00	1.59	1782.00	623.00	1120.75	165.58	11.56



Using a routing time step of 1 minute,
Routing Table for Reservoir , 5 yr and 50 yr ARI Orifice and 100 yr Weir (1st Trial), Take d = 1.5 tc, tc = 16.13 minutes

Time (min)	I (m3/s)	(I1 +I2)/2	S1/Dt +O1/2 (m3/s)	O1 (m3/s)	S2/Dt +O2/2 (m3/s)	O2 (m3/s)
0	0	0	0	0.00	0	0
1	0.54	0.27	0	0.00	0.27	0
2	1.08	0.81	0.27	0.00	1.08	0.01
3	1.62	1.35	1.08	0.01	2.44	0.02
4	2.16	1.89	2.44	0.02	4.35	0.03
5	2.7	2.43	4.35	0.03	6.81	0.05
6	3.24	2.97	6.81	0.05	9.83	0.07
7	3.78	3.51	9.83	0.07	13.41	0.09
8	4.32	4.05	13.41	0.09	17.55	0.11
9	4.86	4.59	17.55	0.11	22.25	0.12
10	5.4	5.13	22.25	0.12	27.50	0.14
11	5.94	5.67	27.50	0.14	33.31	0.16
12	6.48	6.21	33.31	0.16	39.68	0.18
13	7.02	6.75	39.68	0.18	46.61	0.20
14	7.56	7.29	46.61	0.20	54.10	0.21
15	8.1	7.83	54.10	0.21	62.14	0.23
16	8.64	8.37	62.14	0.23	70.74	0.25
17	8.64	8.64	70.74	0.25	79.63	0.27
18	8.64	8.64	79.63	0.27	88.54	0.29
19	8.64	8.64	88.54	0.29	97.47	0.30
20	8.64	8.64	97.47	0.30	106.41	0.32
21	8.64	8.64	106.41	0.32	115.37	0.34
22	8.64	8.64	115.37	0.34	124.35	0.36
23	8.64	8.64	124.35	0.36	133.35	0.38
24	8.64	8.64	133.35	0.38	142.37	0.39
25	8.1	8.37	142.37	0.39	151.13	0.41
26	7.56	7.83	151.13	0.41	159.37	0.41

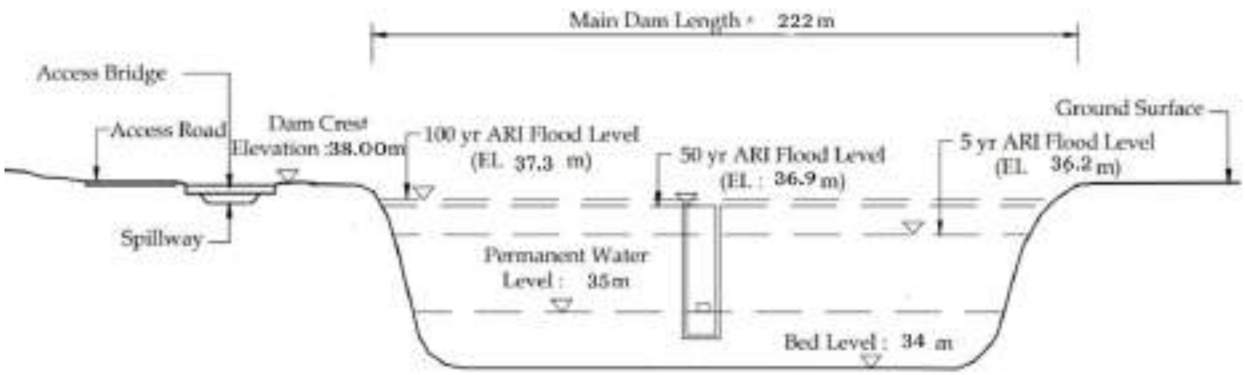
27	7.02	7.29	159.37	0.41	167.07	0.41
28	6.48	6.75	167.07	0.41	174.24	0.41
29	5.94	6.21	174.24	0.41	180.86	0.41
30	5.4	5.67	180.86	0.41	186.94	0.41
31	4.86	5.13	186.94	0.41	192.48	0.41
32	4.32	4.59	192.48	0.41	197.48	0.41
33	3.78	4.05	197.48	0.41	201.95	0.41
34	3.24	3.51	201.95	0.41	205.87	0.41
35	2.7	2.97	205.87	0.41	209.25	0.41
36	2.16	2.43	209.25	0.41	212.09	0.41
37	1.62	1.89	212.09	0.41	214.39	0.41
38	1.08	1.35	214.39	0.41	216.16	0.41
39	0.54	0.81	216.16	0.41	217.38	0.41
40	0	0.27	217.38	0.41	218.06	0.41
41	0	0	218.06	0.41	218.47	0.41
42	0	0	218.47	0.41	218.88	0.41
43	0	0	218.88	0.41	219.30	0.41
44	0	0	219.30	0.41	219.71	0.41
45	0	0	219.71	0.41	220.12	0.41
46	0	0	220.12	0.41	220.53	0.41
47	0	0	220.53	0.41	220.94	0.41
48	0	0	220.94	0.41	221.36	0.41
49	0	0	221.36	0.41	221.77	0.41
50	0	0	221.77	0.41	222.18	0.41
51	0	0	222.18	0.41	222.59	0.41
52	0	0	222.59	0.41	223.00	0.41
53	0	0	223.00	0.41	223.42	0.41
54	0	0	223.42	0.41	223.83	0.41
55	0	0	223.83	0.41	224.24	0.41
56	0	0	224.24	0.41	224.65	0.41
57	0	0	224.65	0.41	225.06	0.41
58	0	0	225.06	0.41	225.48	0.41
59	0	0	225.48	0.41	225.89	0.41

60	0	0	225.89	0.41	226.30	0.41
61	0	0	226.30	0.41	226.71	0.41
62	0	0	226.71	0.41	227.12	0.41
63	0	0	227.12	0.41	227.54	0.41
64	0	0	227.54	0.41	227.95	0.41
65	0	0	227.95	0.41	228.36	0.41
66	0	0	228.36	0.41	228.77	0.41
67	0	0	228.77	0.41	229.18	0.41
68	0	0	229.18	0.41	229.60	0.41
69	0	0	229.60	0.41	230.01	0.41
70	0	0	230.01	0.41	230.42	0.42
71	0	0	230.42	0.42	230.84	0.42
72	0	0	230.84	0.42	231.26	0.42
73	0	0	231.26	0.42	231.68	0.42
74	0	0	231.68	0.42	232.10	0.42
75	0	0	232.10	0.42	232.52	0.42
76	0	0	232.52	0.42	232.94	0.42
77	0	0	232.94	0.42	233.36	0.42
78	0	0	233.36	0.42	233.78	0.42
79	0	0	233.78	0.42	234.20	0.42
80	0	0	234.20	0.42	234.62	0.42
81	0	0	234.62	0.42	235.04	0.42
82	0	0	235.04	0.42	235.46	0.42
83	0	0	235.46	0.42	235.88	0.42
84	0	0	235.88	0.42	236.30	0.42
85	0	0	236.30	0.42	236.72	0.42
86	0	0	236.72	0.42	237.14	0.42
87	0	0	237.14	0.42	237.56	0.42
88	0	0	237.56	0.42	237.98	0.42
89	0	0	237.98	0.42	238.40	0.42
90	0	0	238.40	0.42	238.82	0.42
91	0	0	238.82	0.42	239.24	0.41
92	0	0	239.24	0.41	239.65	0.41

93	0	0	239.65	0.41	240.06	0.41
94	0	0	240.06	0.41	240.47	0.41
95	0	0	240.47	0.41	240.88	0.41
96	0	0	240.88	0.41	241.29	0.41
97	0	0	241.29	0.41	241.70	0.41
98	0	0	241.70	0.41	242.11	0.41
99	0	0	242.11	0.41	242.52	0.41
100	0	0	242.52	0.41		

Using a routing time step of 1.0 minutes, the 5 yr ARI orifice produced a maximum discharge of 0.42 m3/s which is acceptable as it is less than the outflow limit of 0.49 m3/s. 2nd Trial is not needed.
The maximum water elevation in the pond is 36.2m, LSD. It is ok since it is less than the maximum allowable elevation (37.7m.)

DETENTION POND LAYOUT



3.5 Conclusion and Recommendations

Since the project is being implemented, the drainage system is crucial to every development since it offers an effective drainage system that can control rainfall and handle discharge volumes. We now have a better grasp of the drainage system overall thanks to this project, especially with regard to the design of the detention pond, culvert, and drainage works. To calculate the discharge and rainfall intensity values based on the site's location, the peak discharge estimation and rainfall intensity data must be gathered for all catchment areas. The drainage system can be designed using the values that were acquired. The manufacturer's handbook was consulted to determine the drain's dimensions and design.

Following the drainage design, the culvert design for each sub-catchment was determined by its specific location. Information on the concentration peak and peak flow was obtained by calculations carried out during the drainage design phase. The measurements of the culvert were ascertained by consulting the manufacturer's catalog subsequent to the completion of its design. Lastly, certain characteristics have to be taken out of the provided design requirements in order to construct the detention pond. It is necessary to design the detention pond using the 5-year, 50-year, and 100-year ARI. The construction was followed in the pond routing.
hydrograph with the numbers that were computed.

3.6 References

1. Urban Stormwater Management Manual for Malaysia (MSMA) 2nd Edition
2. Department of Irrigation and Drainage or DID (2000). Urban Stormwater Management Manual for Malaysia Ministry of Natural Resources and Environment, Malaysia.

UNIVERSITI TEKNOLOGI MALAYSIA

SEAA4032 | INTEGRATED DESIGN PROJECT 2
SEMESTER SESSION 2023/2024-1

ROADWORK DEPARTMENT

TEAM MEMBERS | GROUP 28

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KITABINA SDN BHD
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CHAPTER 4

ROAD DEPARTMENT

4.1 Introduction

4.1.1 General

The origins of road transportation in Malaysia may be traced back to the pre-colonial era, during which the indigenous population relied on trails and pathways for inter-settlement movement and trade. In the colonial era, the British established a system of roads to link their settlements and ports, particularly with the intention of exploiting resources such as rubber and tin. Following attaining independence in 1957, Malaysia made significant advancements in the development and enhancement of its road infrastructure, notably during the post-independence era. During the 1970s and 1980s, Malaysia initiated ambitious infrastructure initiatives to enhance the interconnectivity and accessibility among various locations within the country through extensive road development projects. These projects encompassed the development of the North-South Expressway, facilitating the connection between the northern and southern areas of Peninsular Malaysia, as well as the East Coast Expressway, linking the east coast states of Peninsular Malaysia.

In the 21st century, Malaysia is making ongoing enhancements to its road infrastructure through various initiatives. One notable project is the Pan-Borneo Highway, a 2,325 km long highway that links Sabah and Sarawak to the rest of Peninsular Malaysia. Additionally, Malaysia is constructing new expressways like the Klang Valley Expressway (KVE) and the West Coast Expressway (WCE). Hence, it is imperative to establish an appropriate road network classification in order to guarantee that the road is adequate for its intended purpose, while also adhering to safety and environmental requirements.

Road design involves planning, designing, and building safe, efficient, and effective roads for their intended purpose. The process includes planning, design, building, and maintenance. Planning entails determining the need for new or improved roads, considering traffic volume, land use, and environmental impact. Road design involves determining the layout, alignment, width, and gradient of the road. It also involves designing junctions, bridges, and drainage systems. During construction, the road is built by excavating the roadbed, applying foundation and pavement, and installing drainage, lighting, and signage.

4.1.2 Background

In general, the road network is an important aspect of our daily lives, facilitating movement from one location to another. Kitabina prioritizes efforts to ensure the smooth and safe operation of the road network. To be consistent and safe for all users, such as the general public, cyclists, and pedestrians, it is important that road development follows general ethical standards.

The proposed housing complex is conveniently close to the E coast Epoxy (Toll Road), which connects to Kuantan, and is situated in the perfect area of Gambang, Pahang. The project area offers quick access to key services including educational institutions like SMK Gambang and Pahang Matriculation College as it is flanked by well-established housing neighborhoods, including Taman Gambang Damai.

The region is further enhanced by its closeness to Jalan Gambang, a vital road system that links the project area to other settlements and amenities., providing a gorgeous and tranquil environment that is ideal for a good quality of life.

Figure 4.1 Key map of project site

The project's approximate latitude and longitude is
3°41'50.42"N, 103° 2'34.97"E

4.1.3 Objectives

There are a few objectives that should be achieved in this project:

i. To design and construct a road system that prioritizes safety, efficiency, cost-effectiveness, and usability.
ii. Our objective is to install an affordable, long-lasting, and comfortable pavement in the newly developed area.
iii. To ensure that traffic flows smoothly throughout the development area.

4.1.4 Scope of Work

The following are included in the scope of work:

a. Consider an internal traffic circulation system and road network to access the development site.
b. Design and estimation of mean daily traffic.
c. Assign distribution of trips in and out from the proposed development.
d. Calculation and design of structural pavement in accordance with the ATJ Manual on Pavement (5/85)
e. Perform horizontal and vertical alignment calculations and designs.
f. Determine and plan junctions and intersections.

4.1.5 Design Standards

In our project, we will be referring to these standards:

i. ATJ 5/85
ii. ATJ 8/86 (2015)
iii. ATJ 13/87 (pindaan 2017)
iv. HCM 2000
v. RTVM 2021
vi. Malaysian Trip Generation Manual 2010

4.1.6 Data Collection

The traffic information of the site has been gathered from the Road Traffic Volume Malaysia (RTVM 2021). The census station CR403 was chosen since it is the closest station to the development area, as determined by the coordinates in the RTVM 2021. The image depicted below illustrates the census station situated in the vicinity of the development region, which served as the basis for the selection of CR403.

Figure 4.2 Location of the nearest census station from the site

Based on the RTVM 2021, the data related to the type of the carriageway and traffic volume from census station CR403 can be obtained.

KUANTAN

Station ID	Survey Type	Route Number	KM	Location Description	GPS Coordinate (WGS84)		Type of Carriageway
					Latitude	Longitude	
CR403	0	2		Kuantan-Maran	3.711452	103.127868	K2-2

Station ID	Data Collected During MCO												Projected 16-hr Volume
	16-hr Volume	Peak Hour Volume	Peak Hour Time	Traffic Composition (%)						V (pcu/hr)	C (pcu/hr)	Level of Service (LOS)	
				Cars & Taxis	Vans & Utilities	Medium Lorries	Heavy Lorries	Busses	Motorcycles				
CR403	19,103	1,675	16:00-17:00	70.93	10.01	4.97	5.13	1.03	7.94	2,174	6,479	A	26,977

Figure 4.3 Location description and 16 hr traffic volume details for CR403

Page 139 of the RTVM 2021 report shows that the Kuantan region experienced an annual growth rate of 2.91% and the predicted 16-hour volume for the CR403 station is expected to reach 26,977.

Figure 4.4 Geometric classification of road for CR403

4.2 Proposed Project Area and Road Network

The figure 4.5 shows the study site and proposed road network design made based on Integrated Design Project (IDP) 1.

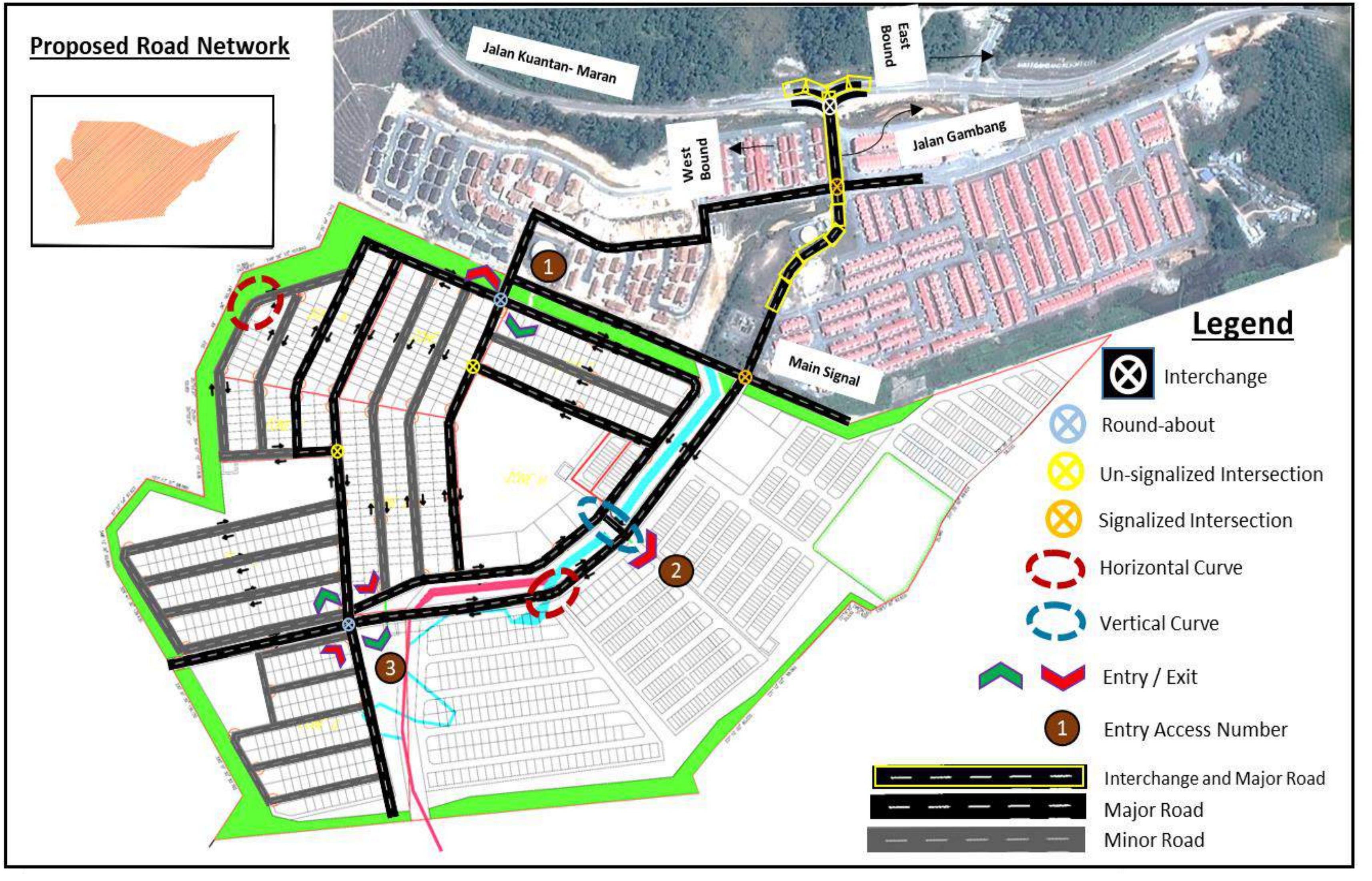


Figure 4.5 Project site along with proposed road network

Figure 4.6 Proposed Level for Residence Area and Road based on IDP 1.

Figure 4.7 Zoom 1: Proposed Road Level along with Entrance 1

Figure 4.8 Zoom 2: Proposed Road Level along with Entrance 2 (Exit only) and Entrance 3

Note that the orange circles show the entrances to the study area, the green lines show the major roads, and the red lines show the minor roads.

4.2.1 Proposed Road Network with Contour

Figure 4.9 shows the proposed road network along with the existing contour .

Figure 4.9 Proposed Road Level with Existing Contour

4.2.2 Internal Circulation Plan

Figure 4.10 shows the circulation plan within the development with trip distribution assumptions at the entry/exit points present in the study area.

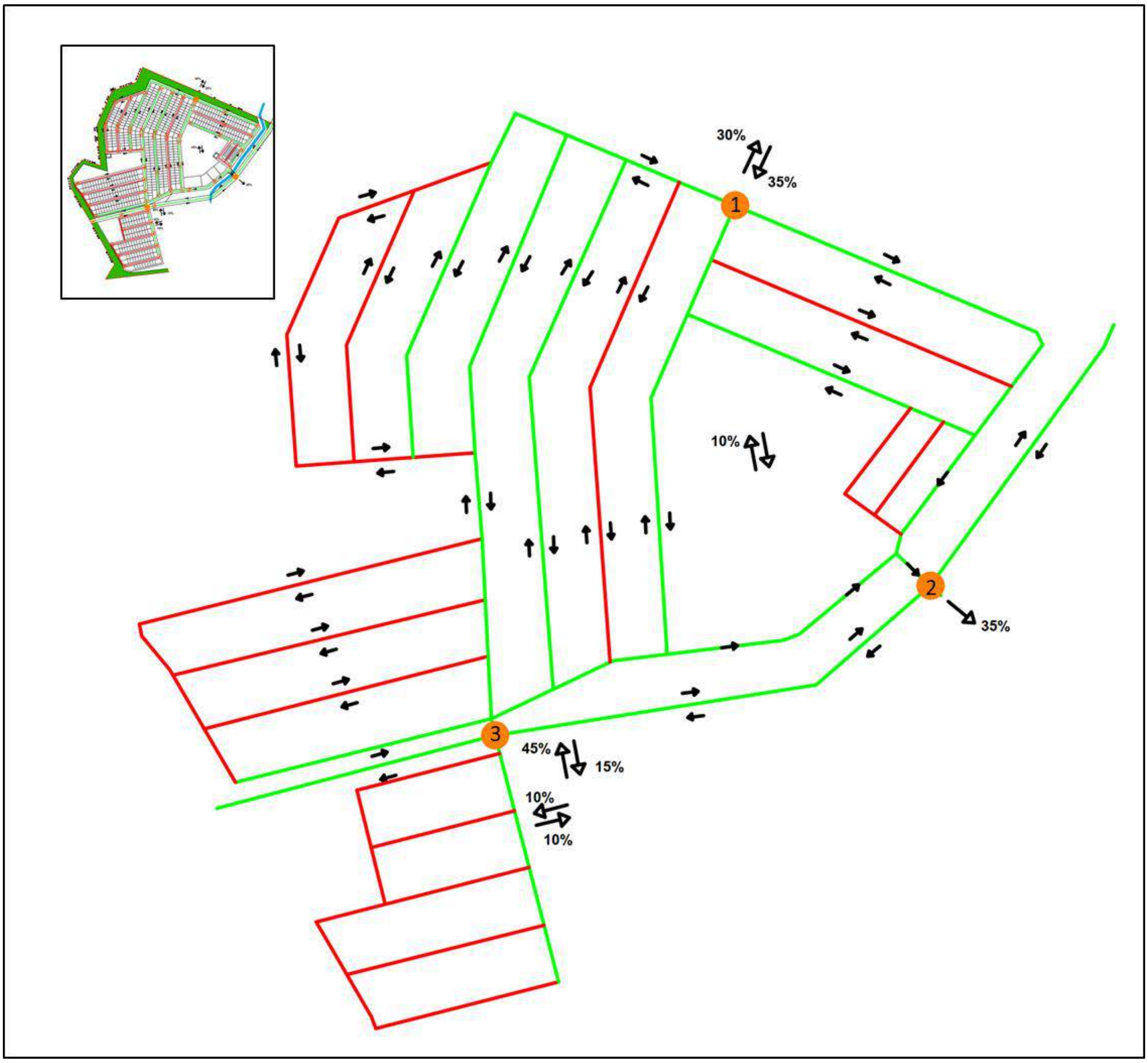


Figure 4.10 Circulation Plan with trip distribution assumptions

4.3 Road Classification and Design Standards

4.3.1 Introduction

Establishing a hierarchical system for roads can provide clarity regarding the specific highway requirements that apply to properties served by each road. This hierarchy makes it possible to create intricate planning standards that are specific to various types of highways. Road width, pedestrian control, intersections, design speed, frontage access, and other factors are all included in these criteria. Policies connected to growth control and traffic management can be reinforced by outlining the planning objectives at each level of the road hierarchy, and vice versa. This strategy makes sure that each planning decision complies with the necessary roadway criteria.

To do this, a flow chart is employed to depict the design criteria (see to Figure 4.11). This flow chart serves as a visual representation of the design process and guides the implementation of the appropriate standards based on the route hierarchy. This systematic approach enables the effective clarification and enforcement of the regulations that control the highway requirements for each property along the route.

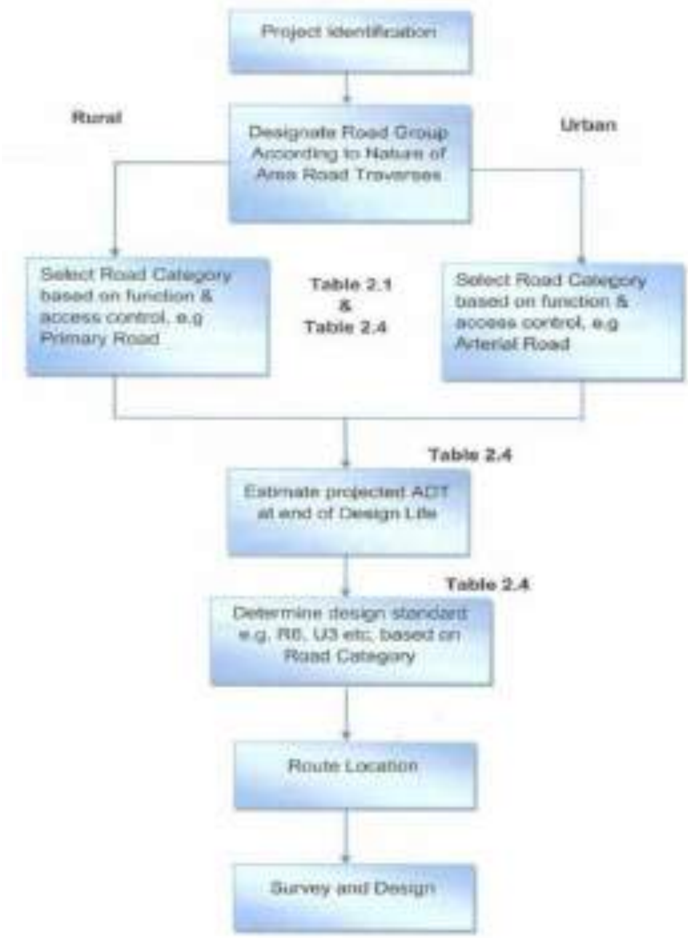


Figure 4.11 Flow Chart for Design Standards (Extracted from Figure 2.2 in ATJ 8/86 (2015))

4.3.2 Traffic Volume

4.3.2.1 Estimation of Average Daily Traffic (ADT)

Average daily traffic (ADT) is a metric employed in the fields of transportation planning and transportation engineering. The average daily traffic (ADT) is calculated by dividing the total annual vehicle volume on a road by 365 days. It is frequently employed to measure the volume of vehicles on a specific stretch of road and is commonly utilized as an indicator of traffic congestion or the attractiveness of a place. Additionally, it can be utilized to assess the necessity for new infrastructure or enhancements to current infrastructure.

The ADT concept is defined as the total traffic volume for one year divided by the number of days in the year, in accordance with ATJ Guide 8/86 on Geometric Design of Roads. RTVM 2021 recorded that for the Kuantan section (CR403), the traffic volume in 2021 for 16 hours reached 26,977 vehicles. This data is useful for estimating ADT for the next 20 year period, with applications in expenditure projections, road structural planning, and setting road standards.

For the calculation of ADT at the end of design period (Vx), we can use the following formula:

$$V_x = V_0\,(1 + r)^{x}$$

Where,

V_x = Volume of Daily Traffic after (x) Years in One Direction

V_0 = Initial Daily Traffic in One Direction

x = Design Period (years)

4.3.2.2 Design Hourly Volume (DHV)

Based on hourly flow, the patterns of traffic on the roads show clear changes in traffic levels during the day and at different times of the year. It's hard to decide which hourly traffic numbers to use during the planning process. If you base your design decisions on the busiest hour of the year and normal hourly traffic, you might end up with designs that are too expensive and don't work well. To fix this, a curve that shows how hourly traffic numbers change over the course of the year is used to find the best hourly traffic value for design. In this case, the hourly number is a better way to figure out how much traffic the route needs to handle. If you look at the hourly flow, which better shows changes in traffic demand, you can get a better idea of how much capacity the road needs.

That way, the road standard will take into account how changing traffic trends are, and the geometry will be able to work well with the way traffic really flows. In this case, it might make sense to set a design hourly volume that is expected to happen during a few peak hours of the design year (usually 15 to 20), and that volume should make up about half of the hourly volumes. If you look at the exact hourly traffic levels that show how traffic changes throughout the year and take into account the data's limitations, you can come up with a better and more efficient plan. This method makes sure that the design takes peak-hour traffic trends and different traffic needs into account. This makes the road better prepared to handle the expected traffic load.

4.3.2.3 Calculation of ADT and DHV

Ref	Calculations	Output/Remark
RTVM 2021	**<u>Location Description for Traffic Census Station</u>** State : Pahang Location : Kuantan – Maran Census Station Number : CR403 Number of Lanes : 4 (Divided) Type of Carriageway : K2-2 Design Period : 20 years **<u>Traffic Volume & 16 hr Traffic Composition and LOS</u>** 16 hour Traffic Volume : 26,977 veh/16hr Peak Hour Traffic : 1,675 veh/hr (16:00 -17:00) LOS : A **<u>ADT of existing main road</u>** ➔ <u>Annual Traffic Growth Rate for Year 2021</u> Normal Growth, r : 2.91%	
HCM 2010	➔ <u>ADT in 2021</u> V_{2021} = 26,977 x 1.2 = 32,372 veh/day	*1.2 is the factor used to convert 16 hrs survey data to 24 hrs
RTVM 2019 Equation 3.0 (page 15)	**<u>Projected ADT:</u>** $V_x = V_1 (1 + r)^x$	

	➔ ADT in 2023 $V_{2023} = V_{2021}\ (1+0.0291)^2$ $= 32{,}372\ (1+0.0291)^2$ $= 34{,}283$ veh/day	
ATJ 8/86 '15 Table 2.4	**Existing Classification of Road Category - 2023** Since, **V_{2023} =** 34,283 veh/day {> 10,000} Therefore, existing main road category is, **R5 (Highway)**	Existing Road: R5 (Highway)
	Projected ADT – Year 2043 (n = 20 Years) **V_{2023}** = 34,283 veh/day **V_{2043}** $=(34{,}283)\ (1 + 0.0291)^{20} = 60{,}846$ veh/day	
ATJ 8/86 '15 Table 2.4	**Projected Classification of Road Category -2043** Since, **V_{2043} =** 60,846 veh/day {> 10,000} Therefore, projected main road, Jalan Kuantan-Maran remains in the same category as, **R5 (Highway)**	Projected Road: R5 (Highway)
ATJ 8/86 '15 Cl 3.2.3	**Design Hourly Volume Ratio (DHV)** DHV ratio, K (urban areas) = 12 % **V_{2043} =** 60,846 veh/day **DHV_{2043} =** (0.12) (60,846) = 7,302 veh/hr	DHV is used to determine the hourly traffic best fitted for design. However, In the absence of information for projected year, K = 12% for rural roads can be used.
	One direction: DHV_{2043} = 0.65 x 7,302 = **4,746 veh/hr**	In the absence of field data for year 2043, the directional distribution ratio (D) for rural areas is 65%.

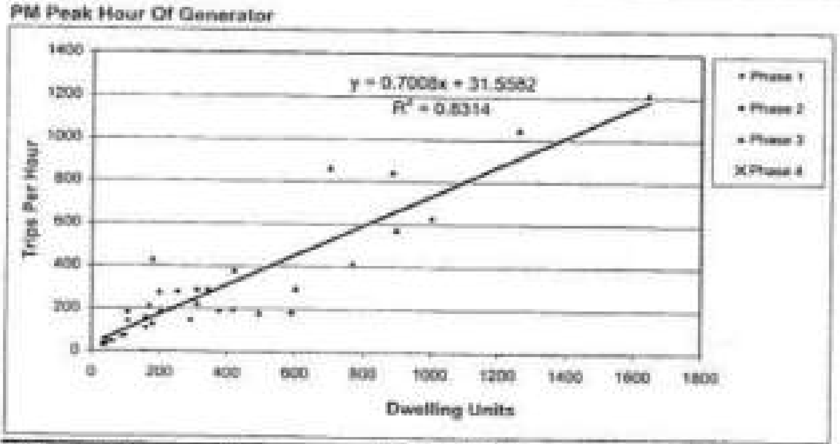
4.3.2.4 Trip Generation

The total number of vehicle movements entering and exiting a facility during a certain period is referred to as the Trip Generation. Generator peaks refer to the clock with the highest traffic flow, both for vehicles entering and exiting a location, and this does not always correspond to the busiest time on the nearest road. AM Peak Hour of Generator is defined as the clock with the highest traffic generation before noon for the proposed project, while PM Peak Hour of Generator is defined as the hour with the highest traffic generation in the afternoon or evening.

The steps in estimating the generation of travel are as follows:

1. Determine the appropriate land use category.
2. Select the most appropriate independent variable predictor of trip generations for that land use.
3. From a selection of categories such as AM Generator, PM Generator, and Daily, look for levels or equations that reflect the number of trips required.
4. Make a travel calculation by multiplying the travel rate by independent variables, such as floor area, number of employees, number of residential units, etc. Or, input these values into the relevant travel level equation.
5. Convert vehicle estimates into trips by calculating PCU (Passenger Car Unit) trips.

PM Peak Hour Of Generator



Number Of Sites :	38	Percent In/Out :	59 / 41
Average Rate :	0.92	Regression Equation :	y = 0.7008x + 31.5582
Minimum Rate :	0.32	(T = Trips; X = Independent Variable)	
Maximum Rate :	2.36	R-squared :	0.8314
Standard Deviation :	0.4128		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	61.68	1.00	0.62
Motorcycle	29.66	0.33	0.10
Small Lorry	7.00	1.75	0.12
Big Lorry	0.23	2.25	0.01
Bus	1.44	2.25	0.03
Total	100.00%		0.87

Figure 4.12 Sample PM Peak Hour of Generator for Residential (Extracted from MTGM 2010 – page 1)

The appendix part contains trip generation graphs for all land uses found in the study development.

4.3.2.4.1 Calculation of Trip Generation

Ref	Calculations	Output/ Remark
MTGM 2010	(see below)	Average Rate is calculated based on an interpolated value between the regression from the curve (which usually gave lower trips) and the average value provided in MTGM2010 for each land use type (generally high values).

<u>Land Use Details of Study Area</u>

Land Use Details

Land Use	GFA (m²)	Unit	Quantity
Semi-Detached House	--	Dwelling Units	648
Kindergarten	3960	TSF	42.625
Community Hall	4081	Units	10
Market Place	1987	Units	12
Recreational Park	55,513	Acre	13.72
Substation	2096	Acre	0.518
Surau	7331	TSF	78.91

<u>Trip Generation rates & distribution - AM & PM Peak</u>

Trip Generation Details - AM Peak

Land Use	Unit	Average Rate	In %	Out %
Semi-Detached House	Dwelling Units	1.79	35%	65%
Kindergarten	TSF	1.98	52%	48%
Community Hall	Units	2.02	51%	49%
Market Place	Units	7.39	53%	47%
Recreational Park	Acre	8.44	42%	58%
Substation	Acre	17.19	81%	19%
Surau	TSF	0.81	59%	41%

Trip Generation Details - PM Peak

Land Use	Unit	Average Rate	In %	Out %
Semi-Detached House	Dwelling Units	1.78	55%	45%
Kindergarten	TSF	1.13	51%	49%
Community Hall	Units	2.43	52%	48%
Market Place	Units	11.2	49%	51%
Recreational Park	Acre	12.5	43%	57%
Substation	Acre	11.51	27%	73%
Surau	TSF	0.94	44%	56%

Trip Generation Calculation – Existing 2023

Land Use	Unit	Quantity	AM Peak			PM Peak		
			Total	In	Out	Total	In	Out
Semi-Detached House	Dwelling Units	648	1160	406	754	1153	634	519
Kindergarten	TSF	42.625	84	44	40	48	24	24
Community Hall	Units	10	20	10	10	24	12	12
Market Place	Units	12	89	47	42	134	66	68
Recreational Park	Acre	13.72	116	49	67	172	74	98
Substation	Acre	0.518	9	7	2	6	2	4
Surau	TSF	78.91	64	38	26	74	33	41
Total			**1542**	**601**	**941**	**1611**	**845**	**766**

Highlighted cell shows that the PM Peak is the worst peak based on highest total number of trips generated.

Trip Generation– Projected 2043 (n = 20 years , growth rate = 2.91%)

Land Use	Unit	Quantity	AM Peak			PM Peak		
			Total	In	Out	Total	In	Out
Semi-Detached House	Dwelling Units	648	2059	721	1338	2046	1125	921
Kindergarten	TSF	42.625	149	78	72	85	43	42
Community Hall	Units	10	35	18	17	43	22	20
Market Place	Units	12	158	84	74	238	117	121
Recreational Park	Acre	13.72	206	86	119	305	131	174
Substation	Acre	0.518	16	13	3	11	3	8
Surau	TSF	78.91	114	67	47	131	58	74
Total			**2737**	**1066**	**1670**	**2859**	**1500**	**1360**

Therefore, considering the ultimate life of the road after 20 years, the trip distribution and road classification will be carried out based on the uplifted 2043 trip generation values along with the DHV from the projected ADT on the main expressway that serves as the main entry/exit point to our development.

4.3.2.5 Trip Distribution

Trip distribution is the second phase of the four-step transportation planning process in traffic engineering, which comes after trip generation. Trip distribution is the analysis of the patterns and destinations of trips that are generated within a specific area of study. It entails identifying the entry and exit points of trips and creating an initial estimation of the movement of travel between various zones in a transportation network.

During trip distribution, planners evaluate the spatial dispersion of trip destinations (such as residential, commercial, or industrial districts) and origins (often residential areas). Diverse models and procedures are utilised to approximate the quantity of journeys made between distinct zones or traffic analysis zones. These models consider variables such as land use, socio-economic attributes, and transportation infrastructure.

In the end, trip distribution helps engineers and planners figure out how people travel within an area, which makes it easier to plan good transport routing plans, intersection controls and infrastructure improvements.

4.3.2.5.1 Calculation of Trip Distribution

Ref	Calculations	Output/ Remark

<u>Trip Distribution considerations for Existing scenario - 2023</u>

Jalan Gambang					
Trip Distribution PM Peak - Existing 2023 (After Development)					
Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak		
			Total	In	Out
Study area Zone A	Entrance 1	35% / 30%	526	296	230
	Entrance 2	0% / 35%	268	0	268
	Entrance 3 - North Bound	45% / 15%	495	380	115
	Entrance 3 - South Bound	10% / 10%	161	84	77
Internal Circulation (10% IN & OUT)		10% / 10%	162	85	77
Grand Total Excluding Internal Circulation		90%	1450	760	689
Proposed Zone B	Main Road	90%	1400	734	666
Existing Development	Main Road	70%	1120	587	533
Total			3,970	2,081	1,889

Trip Distribution considerations for Interim scenario - 2033

Jalan Gambang					
Trip Distribution PM Peak - Interim 2033 (n = 10 years, 2.91% growth rate)					
Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak		
			Total	In	Out
Study area Zone A	Entrance 1	35% / 30%	700	394	306
	Entrance 2	0% / 35%	357	0	357
	Entrance 3 - North Bound	45% / 15%	660	507	153
	Entrance 3 - South Bound	10% / 10%	215	113	102
	Internal Circulation (10% IN & OUT)	10% / 10%	216	113	103
	Grand Total Excluding Internal Circulation	90%	1932	1013	919
Proposed Zone B	Main Road	90%	1865	978	887
Existing Development	Main Road	70%	1492	782	710
Total			5,289	2,773	2,516

Trip Distribution considerations for Ultimate scenario - 2043

Jalan Gambang					
Trip Distribution PM Peak - Ultimate 2043 (n = 20 years, 2.91% growth rate)					
Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak		
			Total	In	Out
Study area Zone A	Entrance 1	35% / 30%	933	525	408
	Entrance 2	0% / 35%	476	0	476
	Entrance 3 - North Bound	45% / 15%	879	675	204
	Entrance 3 - South Bound	10% / 10%	286	150	136
	Internal Circulation (10% IN & OUT)	10% / 10%	288	151	137
	Grand Total Excluding Internal Circulation	90%	2573	1350	1224
Proposed Zone B	Main Road	90%	2485	1302	1182
Existing Development	Main Road	70%	1988	1042	946
Total			7,046	3,694	3,352

Trip distribution is a phase in transportation planning and traffic engineering that involves determining the patterns of movement of trips (journeys) between different origin-destination pairs in a transportation network.

Following are the assumptions considered based on existing condition of the site:-

- Only 70% of Existing Development's traffic is considered because there's an exclusive entry / exit access point shared only by the existing development to cater traffic for the remaining 30%.
- 100% of trips to Proposed Zone B have been considered to share the same main road along with 100% of trips generated for Study Zone A.
- Trips generated by Existing Development, Study Zone A and B have been uplifted with the growth rate of 2.91% to estimate the projected DHV generated from these three zones.

- The uplifted DHV obtained from nearest ADT station is inclusive of Existing Development's traffic, whereas Trips generated for Study zone A and B were added on top of the existing background DHV.

- Entrance 1 and 3 have been allocated for Entry to development whereas Entrance 1,2 and 3 facilitate Exit from the Proposed Study Zone A.

<u>DHV obtained from nearest Census Station on the main road.</u>

DHV/direction	Main Intersection	veh/hr
2023	East bound (35%)	1440
	West bound (65%)	2674
2033	East bound (35%)	1919
	West bound (65%)	3562
2043	East bound (35%)	2556
	West bound (65%)	4746

The following assumption has been considered based on live traffic observed from google maps and high commercial activities present towards the east bound from the main street of proposed development.

<u>Assumptions on directional split to and from the Main Street 23 to Expressway Intersection.</u>

Main Street 23	Main Intersection	Percentage split
Entry to Main Street 23	East bound	20%
	West bound	80%
Exit from Main Street 23	East bound	80%
	West bound	20%

In the absence of field data for year 2043, the directional distribution ratio (D) for urban areas is 60%.

<u>Sample Calculations – Vehicles approaching West Bound Intersection in 2043 (Jalan Kuantan - Maran)</u>

DHV_{2043} = 7,302 veh/hr
Directional split = 65/35%
= 7,302 x 0.65 = 4,746 veh/hr

Trips generated for Study Zones A and B (IN) = 2,652 veh/hr
Assume 80% of IN trips arriving from West Bound approach,
= 0.8 x 2,652 = 2,122 veh/hr

Total vehicles travelling West Bound approach = 4,746 + 2,122 = 6,868 veh/hr

30% of Existing development's traffic enters through exclusive access.
Therefore, remaining vehicles traveling towards West Bound,
= 6,868 – 448 (30%) = 6,420 veh/hr

	<u>Sample Calculations – Vehicles approaching East Bound Intersection in 2043 (Jalan Kuantan - Maran)</u> DHV_{2043} = 7,302 veh/hr Directional split = 35/65% = 7,302 x 0.35 = 2,556 veh/hr Trips generated for Study Zones A and B (IN) = 2,652 veh/hr Assume 20% of IN trips arriving from East Bound approach, = 0.2 x 2,652 = 532 veh/hr Total vehicles travelling West Bound approach = 2,556 + 531 = 3,087 veh/hr	The total DHV_{2043} projected from nearest census station is inclusive of 100% trips entering the existing development.

4.3.2.5.2 Trip Distribution Layout

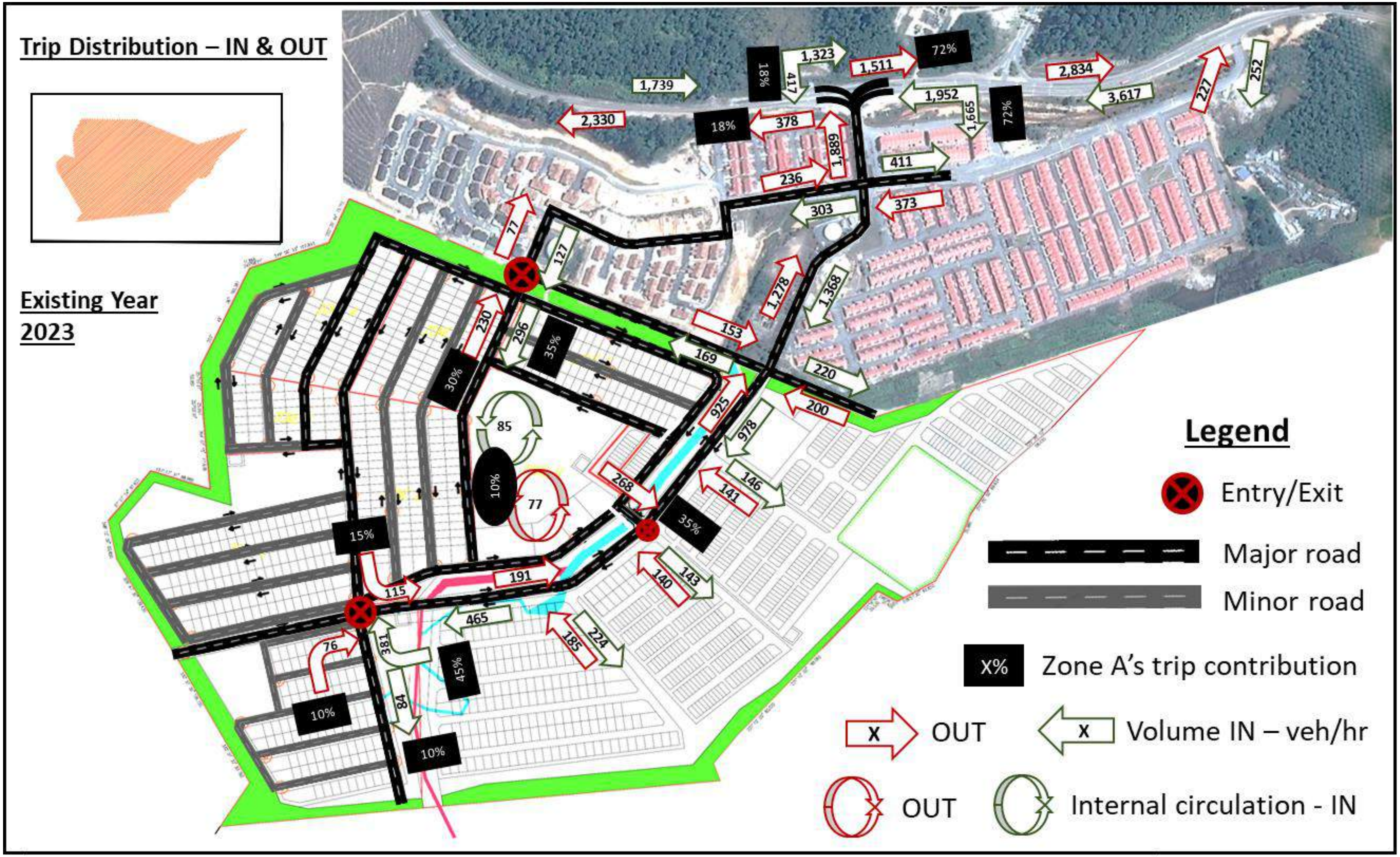


Figure 4.13 Proposed road network with distributed traffic flow during 2043 – Existing scenario

Interim 2033

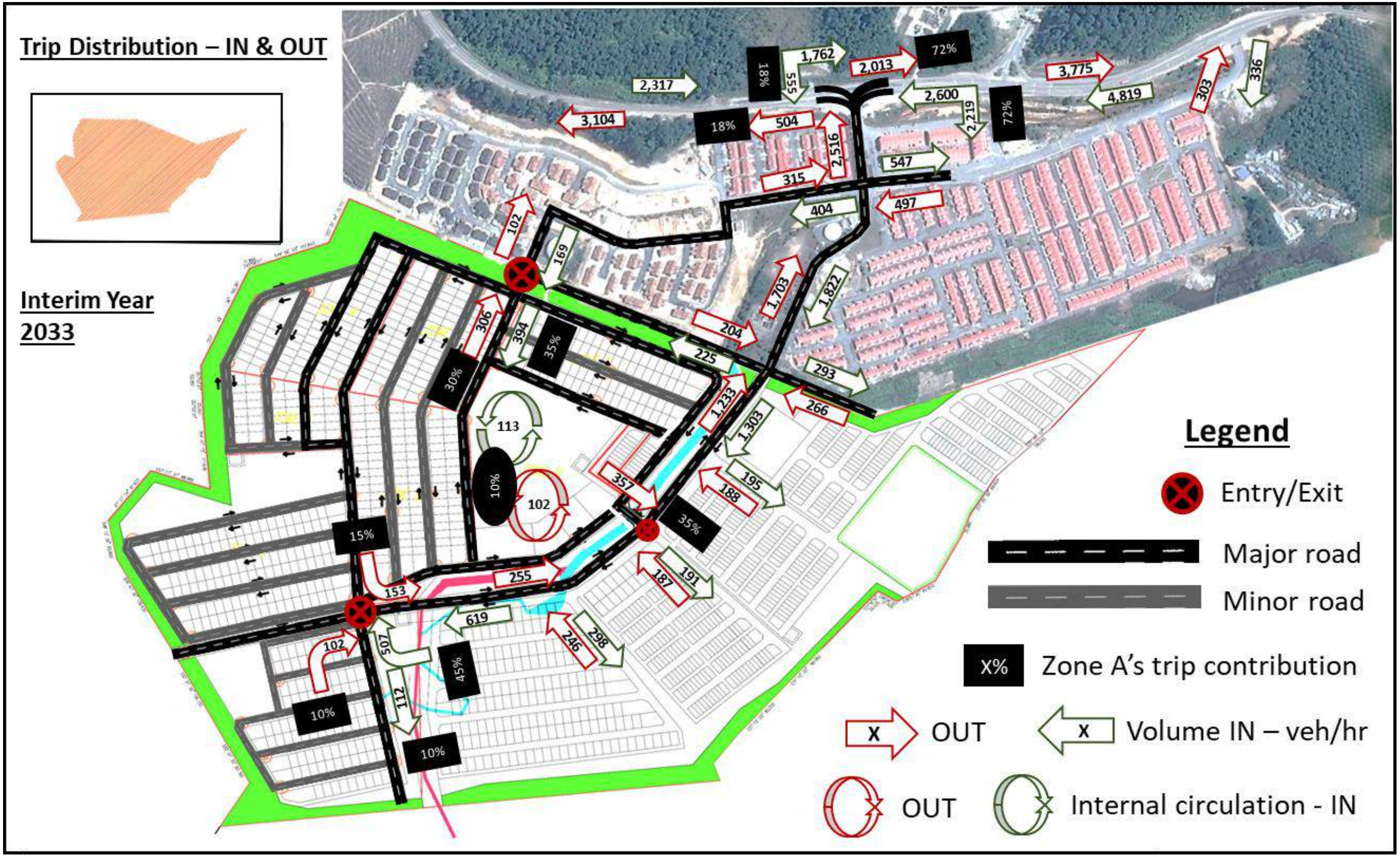


Figure 4.14 Proposed road network with distributed traffic flow during 2033 – Interim scenario

Ultimate 2043

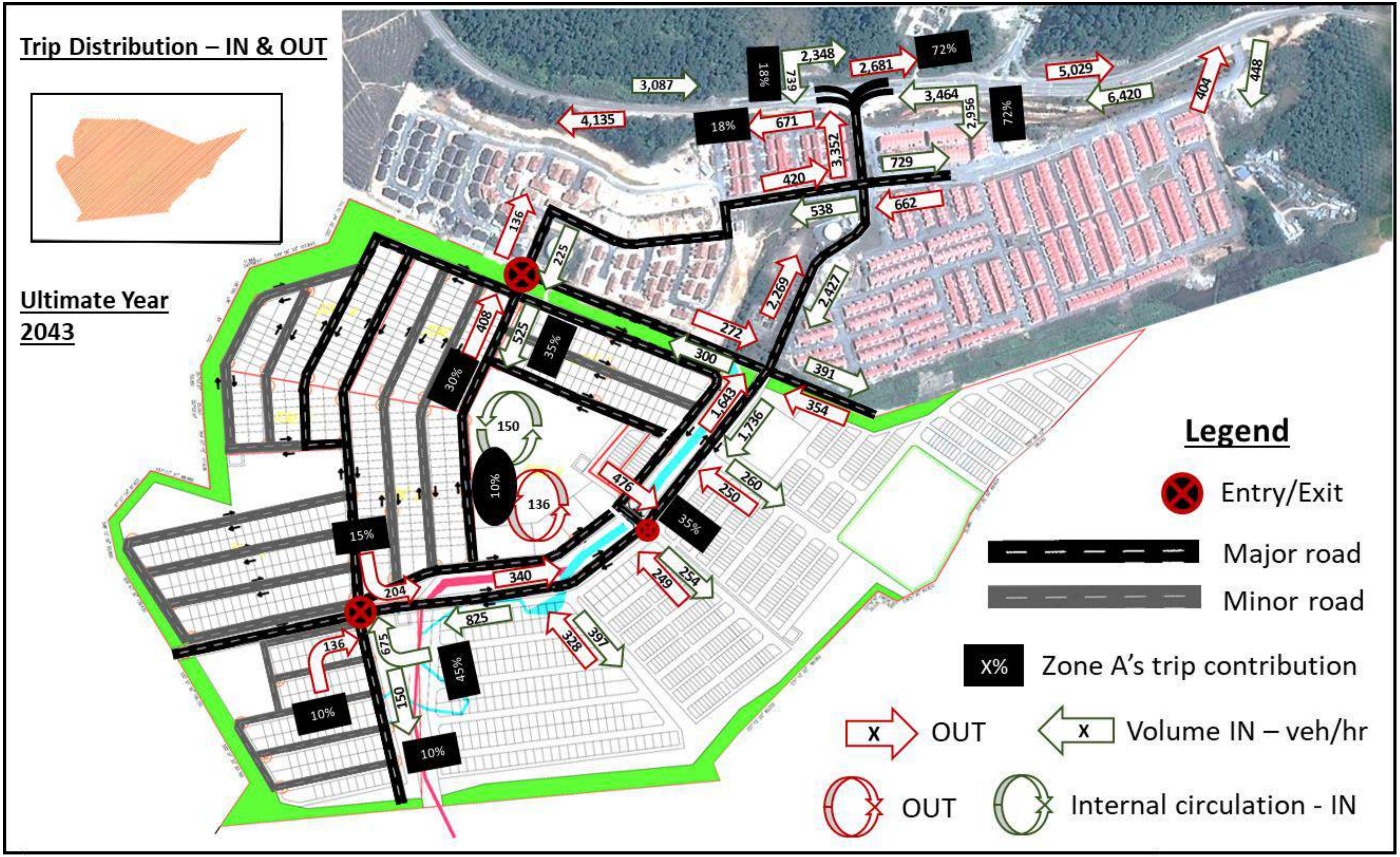


Figure 4.15 Proposed road network with distributed traffic flow during 2043 – Ultimate scenario

4.3.3 Road Category & Classification

The road network in rural areas is generally divided into several categories, including toll roads, highways, main roads, secondary roads, and minor roads. Meanwhile, in metropolitan areas, highways are classified into four main types: toll roads, arterials, collectors and local roads. This classification is designed to create a sequence that reduces mobility levels as accessibility decreases.

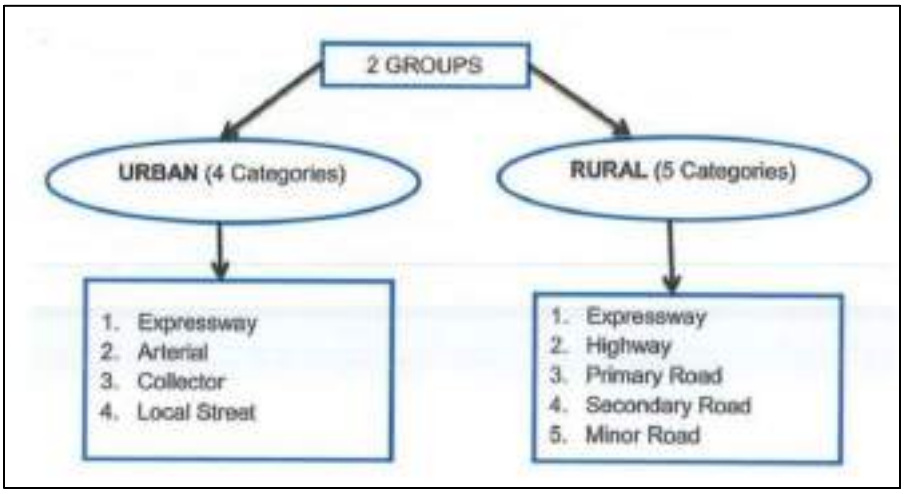


Figure 4.16 Road categories (Extracted from Clause 2.1.3 in ATJ 8/86 (2015))

Categories of roads in Malaysia are defined by their general functions, namely as follows:

i) Expressway

A divided highway for through traffic with comprehensive access control and grade separations at every intersection is known as an expressway. For through traffic in rural areas, they use the interstates, which serve as the foundation of the nation's fast-traveling road system. They facilitate lengthy journeys and offer enhanced comfort and speed of travel. They are entirely access limited and designed to the finest standards to preserve this. For metropolitan regions they provide the main structure for through traffic in the road transportation system additionally, they give relatively lengthy journeys, smooth traffic flow, complete access management, and they complement the Rural Expressway.

ii) Highway

The interstate highways form an across-the-nation network that handles high traffic volumes in the central areas and provides additional support to the expressway system. Usually, they provide connections between the country's capital, state capitals, prominent urban areas, and entrance and departure points, either by direct or indirect routes. While not as crucial as on an expressway, high to medium speed is still necessary. Implementing limited access restrictions facilitates uninterrupted movement. They cater to trips of varying durations, ranging from long to intermediate.

iii) Primary Roads

Primary roads, also known as main roads, are a comprehensive system of highways that play a vital role in linking major cities, significant regions, and other strategically important points within a given area or country. The main attributes are a large storage capability, strict restrictions on entry, and a structure that enables fast performance. Main highways enable the smooth movement of a significant amount of traffic and serve as the fundamental structure of the transportation system, playing a crucial part in connecting cities and promoting regional economic growth.

iv) Secondary Roads

Secondary roads, also known as local roads, are integral components of the transportation infrastructure that serve as links between small towns, settlements, or sparsely populated regions. They serve to gather traffic from nearby roads and assist in the movement of cars towards the main or principal road. Secondary roads are often smaller in size compared to main roads, although they play a crucial role in facilitating local connections and traffic distribution within urban and rural regions.

v) Minor Roads

Minor roads are portions of the highway network that tend to be smaller and have a local purpose. These roads are often found in rural regions or within small towns. Minor roads operate as local access, enabling connectivity between residences, small enterprises, and other key areas in a region. Even though they are smaller in size compared to main highways or secondary roads, minor roads are nonetheless crucial in supporting daily mobility at the local level.

vi) Arterials

Arterial roads are primary routes that efficiently manage heavy traffic flow, linking urban cores, commercial hubs, and other densely populated locations. They facilitate high velocities, possess restricted access control, and function as the primary conduits in a city's or region's transportation network.

vii) Collectors

Roads that collect and distribute traffic within an area. Typically, they are greater in size compared to local roads but less in size compared to arterial highways. Collector roads serve as a connection between local roads and arterial roads, facilitating the flow of traffic from residential or commercial districts to the wider road network. Collector roads provide property access and manage traffic in urban or residential areas.

viii) Local Streets

Small roads within residential areas that are used for direct access to homes and small businesses. These roads are specifically intended for use by local vehicles, with limited speeds, and serve a crucial function in enabling everyday transportation inside the community.

When it comes to ensuring that transportation infrastructure is both safe and efficient, road design standards are an extremely important factor. At present, there are six primary road design standards that are being chosen, and they are as follows: R1/U1, R2/U2, R3/U3, R4/U4, R5/U5, and R6/U6:

Road Design standards, namely as follows:

i) Standard R6/U6

Provides superior quality in geometric design for urban and rural areas. Long-distance travel is usually facilitated by roads in this classification, which offer high travel speeds (90 km/h or more), comfort, and safety. In order to enhance both comfort and safety, the design always incorporates segregated lanes and comprehensive access control measures. This standard is applicable to both rural and urban expressways.

ii) Standard R5/U5

Exhibits superior geometric criteria and often operates at high to moderate travel velocities (80 km/h or greater) for extended to intermediate distances. Typically, limited access restriction is employed. This standard is applicable to the Highway, Primary Road, and Arterial. At times, it is constructed as divided lanes with limited entry.

iii) Standard R4/U4

Provides moderate geometric specifications and accommodates excursions of various durations, with travel velocities of 70 km/h or higher. It often involves limited access control. The Primary Road, Secondary Road, Minor Arterial, and Major Collector are encompassed under this standard.

iv) Standard R3/U3

The primary function of this modest geometric standard is to provide support for local traffic. There may be minimal or no access control. These standards apply to secondary roads, collector roads, and main local streets. Journeying at an average speed of 60 km/h.

v) Standard R2/U2

` Provided are minimal geometrical requirements for two-way flow. It is applicable solely to local traffic, with minimal commercial traffic. This stipulation is applicable to local streets and minor roads. A 50 km/h average pace of travel is observed.

vi) Standard R1/U1

Contains the fewest geometric requirements and is implemented on roads where the volume of commercial vehicles is negligible in comparison to that of passengers. The speed limit is reduced to 40 km/h. In situations where commercial traffic is not expected, such as on a private access road in an affordable housing neighborhood, the design standards could possibly be adjusted with respect to the lane width and gradient.

Table 1 Selection of Design Standard (Extracted from Table 2.4 in ATJ 8/86 (2015))

Area	Road Category \ Projected ADT	All Traffic Volume	≥ 10,001	3,001 To 10,000	1,001 To 3,000	151 To 1,000	≤150
RURAL	Expressway	R6	-	-	-	-	-
	Highway	R5	-	-	-	-	-
	Primary Road	-	R5	R4	-	-	-
	Secondary Road	-	-	R4	R3	-	-
	Minor Road	-	-	-	-	R2	R1
URBAN	Expressway	U6	-	-	-	-	-
	Arterials	-	U5	U4	-	-	-
	Collector	-	U5	U4	U3	-	-
	Local Street	-	-	U4	U3	U2	U1

In summary, several types of project- and context-specific factors would play a role in the decision to construct a U4 (Arterial) road as opposed to a U5. Large-width, high-capacity highways and motorways are frequently built to U5 and U6 road standards. These standards often call for more restrictive access control and have tougher geometric design requirements. Constructing roads that meet the U5 standard may cost more due to the extra requirements. The U4 road standard is better appropriate for our project's environment, which comprises an industrial region inside the project and surrounding residential, commercial, and educational sectors.

The U4 standard is suitable for highways with intermediate trip durations and medium speeds, and it offers medium geometric standards and partial access management. This choice finds a middle ground between the need for effective mobility inside the project area and the effects on the environment. This option may result in cheaper development costs as compared to the higher U5 standard since it achieves a compromise between the need for effective transit inside the project area and the surrounding land uses. To reach a well-informed decision, however, based on the specific needs and objectives of the project, a thorough investigation and consultation with transportation specialists and interested parties are necessary.

4.3.3.1 Classification of Road Categories

Ref	Calculations	Output/ Remark
ATJ 8/86 2015	**<u>Road Classification – Expressway Road (Jalan Kuantan – Maran)</u>** Total Volume entering the expressway projected to 20 years from operation with a growth rate of 2.91% DHV_{2043} = Existing projected volume + Projected Trip Generation of Study Zone A and B. = 7,302 + 2,573 + 2,485 = **12,360 veh/hr** ADT_{2043} = 12,360/0.12 = 103,000 veh/day ADT > 10,001 Therefore, Major Road can be classified as R5, Highway	**Road Category:** R5 (Highway)
ATJ 8/86 2015	**<u>Road Classification – Major Road (Jalan Gambang)</u>** Total Volume entering and exiting Major Road (In and Out – Considering Both directions), DHV_{2043} = 70% of Existing development's projected volume + Projected Trip Generation of Study Zone A and B. = 1,988 + 2,573 + 2,485 = **7,046 veh/hr** ADT_{2043} = 7,046/0.12 = 58,717 veh/day ADT > 10,001 Therefore, Major Road can be classified as U5, Arterial Road	**Road Category:** U5 (Arterial Road)

Based on Trip Distribution	**<u>Road Classification – Major Road Inside Development</u>** **<u>(From Entrance 1 to Entrance 3)</u>** Total Volume entering and exiting Major Road (In and Out – Considering Both directions), DHV_{2043} = 45% of Projected Trip Generation of Study Zone A (In) + 30% of Projected Trip Generation of Study Zone A (Out). = 0.5 x (1,500) + 0.3 x (1,360) = **1,158 veh/hr** ADT_{2043} = 1,158/0.12 = 9,650 veh/day 3000 > ADT > 1,001 Therefore, Major Road can be classified as U4, Collector Road	**Road Category:** U4 (Collector Road)
Based on Trip Distribution	**<u>Road Classification – Minor Road Inside Development</u>** **<u>(Worst Case Scenario)</u>** Assume 15% of traffic from Major Road entering Minor Road: DHV_{2043} = 15% DHV_{major} = 0.15 x (1,812) = **272 veh/hr** ADT_{2043} = 272 /0.12 = 2,267 veh/day 3000 > ADT > 1,001 Therefore, Major Road can be classified as U3, Local Street	**Road Category:** U3 (Local Street)

4.3.3.2 Access Control

Access control is often categorized into three groups based on the level of control: full control, partial control, and no-control. To ensure the road's original capacity and enhance safety for all road users, it is essential to select the proper degree of management. Two crucial elements to consider are the management of future construction access after road construction and the consideration of access to existing projects during the design phase. The level of access control adopted is influenced by factors such as the volume of traffic, the intended use of the road, and the overall road network in the vicinity.

According to ATJ 8/86 (2015), it is possible to determine the access control of a proposed road. As per the previous design, the main road Jalan Kuantan-Maran is categorised as an R5 Highway. The main road, Jalan Gambang, has been classified as an Arterial road according to the U5 road classification. The main road within the development was designated as a U4 Collector Road. The above three roads indicate that access is only partially controlled. Whereas the minor road within the development serves as a local street U3, however it does not have any access control measures in place.

TABLE 2.3A: SELECTION OF ACCESS CONTROL (RURAL)

Design Standard / Road Category	R6	R5	R4	R3	R2	R1
Expressway	F	-	-	-	-	-
Highway	-	P	-	-	-	-
Primary Road	-	P	P	-	-	-
Secondary Road	-	-	P	P	-	-
Road	-	-	-	-	N	N

TABLE 2.3B: SELECTION OF ACCESS CONTROL (URBAN)

Design Standard / Road Category	U6	U5	U4	U3	U2	U1
Expressway	F	-	-	-	-	-
Arterial	-	P	P	-	-	-
Collector	-	P	P	P	-	-
Local Street	-	-	N	N	N	N

Note: F = Full Control of Access
P = Partial Control of Access
N = No Control of Access

Jalan Kuantan – Maran, Jalan Gambang, Major Road
Minor road (Inside Development)

Figure 4.17 Selection of Access Control (Extracted from Table 2.3 in ATJ 8/86 (2015))

4.4 Geometric Design

4.4.1 Introduction

The geometric layout of roadways is influenced by various factors, such as topography, land use, vehicle design, speed, and road capacity. These aspects are crucial to ensure that the road design can accommodate the expected traffic loads. The geometric arrangement adheres to the guidelines outlined in ATJ 8/86 (2015).

4.4.2 Topography

The topography of an area directly influences the way roads are designed. Therefore, it is crucial to choose a suitable terrain for the roads in order to achieve the desired design. There are three distinct topographical classifications based on road grade:

a) Flat Terrain

In level terrain, the incline of the ground that runs parallel to the contours of the natural landscape is typically approximately 3 %.

b) Rolling Terrain

Within a sloping landscape, the natural ground cross-slopes generally vary between 3 and 25 %.

c) Mountainous Terrain

In mountainous terrain, the incline of the natural ground is generally greater than 25%.

In general, the topography of the region has a direct impact on the design considerations and decisions that are taken throughout the process of geometrically designing roadways.

4.4.2.1 Calculation of Topography

Ref	Calculations	Output/ Remark
	<u>Gradient:</u> $G\% = \frac{Vertical\ height, \Delta y}{Horizontal\ distance}\ x\ 100\%$	
ATJ 8/86 2015 (Page 15)	**a) Expressway road (Jalan Kuantan-Maran)** G% = $\frac{49-37}{552}$ x 100% = 2.17 % < 3%	Terrain is flat
ATJ 8/86 2015 (Page 15)	**b) Major road (Jalan Gambang)** G% = $\frac{40-35}{245}$ x 100% = 2.04 % < 3%	Terrain is flat
ATJ 8/86 2015 (Page 15)	**c) Major road (Inside development)** G% = $\frac{45-38}{385}$ x 100% = 1.82 % < 3%	Terrain is flat
ATJ 8/86 2015 (Page 15)	**d) Minor road (Inside Development)** G% = $\frac{43-41}{237.5}$ x 100% = 0.84 % < 3%	Terrain is flat

4.4.3 Design Vehicle

The physical characteristics of cars and the proportions of various vehicle sizes on the road will have an impact on the geometric design of the roadways. Highway design regulations are created to accommodate cars of a particular type using the weight, dimensions, and operating characteristics of a design vehicle. For geometric design purposes, the design vehicle should be larger than almost every other vehicle in its class in both dimensions and minimum turning radius. An overview of the design vehicle specs and features from ATJ 8/86 (2015) is shown in Table 2 below.

Table 2 Design Vehicle Dimensions (Extracted from Table 3.1 in ATJ 8/86 (2015))

TABLE 3.1: DESIGN VEHICLE DIMENSIONS

Design Vehicle		Dimension in meter (m)						Turning Radius (m)
Type	Symbol	Wheel Base (m)	Overhang (m) Front*	Overhang (m) Rear **	Overall Length (m)	Overall Width (m)	Height (m)	
Passenger Car	P	3.35	0.91	1.52	5.79	2.13	1.3	7.26
Single Unit Truck	SU	6.10	1.22	1.83	9.12	2.44	3.4-4.1	12.73
Truck Combination	WB-15	WB1: 4.45 WB2: 10.79	0.91	0.6	16.77	2.59	4.1	13.72

Note:

a) Maximum allowable overall lengths under current Malaysian Legislation are 16m, or 25 m, if with special approval.

b) Maximum allowable overall width under current Malaysian Legislation is 2.5 m.

c) Maximum overall height control under current Malaysian Legislation is 4.2 m.

* This is the length of the front overhang from the front axle
**This is the length of the rear overhang from the back axle of the tandem axle assembly

4.4.4 Speed

Design speed is the maximum safe speed that can be driven on a specific stretch of road under perfect conditions. differing road categories will have differing design speeds in order to handle a range of traffic loads.

Table 3 Design Speed (Urban) (Extracted from Table 3.2B in ATJ 8/86 (2015))

TABLE 3.2B: DESIGN SPEED (URBAN)

Design Standard	Design Speed (km/ hr)		
	Area Type		
	I	II	III
U6	100	80	60
U5	80	60	50
U4	70	60	50
U3	60	50	40
U2	50	40	30
U1	40	30	20

Note:

Type I - Relatively free in road location with very little problems as regards land acquisition, affected buildings or other socially sensitive areas.

Type II - Intermediate between I and III.

Type III - Very restrictive in road location with problems as regards to land acquisition, affected buildings and other sensitive areas.

Major road

Minor road

The road design for the development area, which is categorized as type III based on its location, adheres to the guidelines outlined in ATJ 8/86 (2015). The main road, U5 (Collectors), is engineered with a speed limit of 50 km/h to facilitate smooth traffic flow, whereas the secondary route, U4 (Collector), has the same design speed of 50 km/h. These design considerations take into account the distinct characteristics and demands of each road category, guaranteeing secure and suitable travel speeds for the specified traffic volumes and conditions in the development region. Whereas the minor road, U3 (Local Street), has a lower design speed of 40 km/h.

4.4.5 Road Capacity

The maximum number of vehicles that may travel through a particular section of a lane or roadway in a given amount of time, taking into account current traffic and highway conditions is known as the road's capacity. The amount of traffic that a planned route can accommodate, up to the capacity allocated for the design hour, without experiencing levels of congestion that obstruct operational conditions is known as the service volume.

The diagram below displays the level of service (LOS) category for various traffic volumes, sourced from ATJ 8/86 (2015).

Table 4 Level of Service (LOS) (Extracted from Table 3.3 in ATJ 8/86 (2015))

Level of Service	Remarks
A	Free Flow with individual users virtually unaffected by the presence of other vehicles in the traffic stream. This is a condition of free flow with low volume and high speed of vehicle travel on the highways.
B	Stable traffic flow with a high degree of freedom to select speed and operating condition but with some influence from the other users.
C	Restricted flow that remains stable but with significant interaction with others in the traffic stream. The general level of comfort and convenience decline noticeable at this level. Speed and maneuverability are closely controlled by the higher volume. Most of the drivers are restricted in their freedom to select their own speed, change lane or pass.
D	High density flow in which speed and freedom to maneuver are severely restricted and comfort and convenience have decline even though flow remains stable. This level represents unstable flow with operating speed being maintained, though considerably affected by changes in operating condition.
E	Unstable flow at or near capacity levels with poor level of comfort and convenience. This level represents operation at lower operating speed with volume at or near the capacity of the highways. Flow is unstable and stoppage may occur for a momentary duration.
F	Forced traffic flow in which the amount of traffic approaching a point exceeds the amount that can be served. LOS F is characterized by poor time travel with low comfort, convenience and increase accident exposure. This condition describes a forced flow operation at low speed where volumes are below the capacity. Speed is reduced substantially and stoppage may occur for short or long periods of time because of the downstream traffic condition.

The Level of Service (LOS) is a qualitative measure used to evaluate the degree to which transport infrastructure satisfies the requirements of users. The analysis considers multiple elements, including speed, travel time, traffic congestion, manoeuvrability, safety, comfort, and operational expenses. Table 5 depicts the standard design for levels of service (LOS) in urban environments, classified according to the kind of route.

Table 5 Design Level of Service (LOS) (Urban) (Extracted from Table 3.4B in ATJ 8/86 (2015))

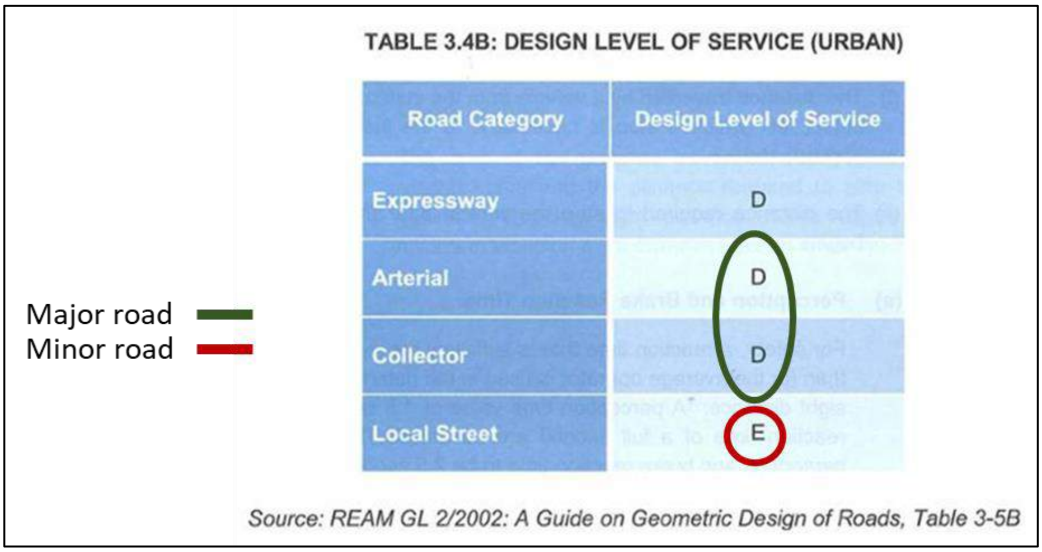


TABLE 3.4B: DESIGN LEVEL OF SERVICE (URBAN)

Road Category	Design Level of Service
Expressway	D
Arterial	D
Collector	D
Local Street	E

Major road
Minor road

Source: REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 3-5B

In ATJ 8/86 (2015), the design LOS for major roads, specifically U5 (Arterial) and U4 (Collector) are determined to be LOS D. On the other hand, the design LOS is designated also as LOS E for roads classed as U3 (Local Street). For assessing road capacity and figuring out the Level of Service (LOS) for various kinds of road infrastructure, the Highway Capacity Manual (HCM) 2000 was used as a reference.

An assessment is conducted to compare the design level of service (LOS) with the calculated level of service. This is done to determine the required number of lanes needed to accommodate the traffic volume on a particular route. In order to calculate the flow rate comparable to a passenger car, denoted as Vp, the initial step is to utilise the following equation:

$$Vp = \frac{V}{PHF \times N \times Fhv \times Fp}$$

Where,

V = Hourly Volume, Veh/h

PHF = Peak Hour Factor

N = Number of Lane

Fhv = Heavy Vehicle Adjustment

Fp = Driver Population Factor

4.4.5.1 Design for Jalan Kuantan-Maran highway

To ensure that the LOS obtained is the same as or better than the designated LOS as stated in ATJ 8/86, the below equation is performed to determine the most appropriate number of lanes (2015). Free flow speed, or FFS, is an additional parameter that must be obtained to compute LOS;

$$FFS = BFFS - f_{LW} - f_{LC} - f_{M} - f_{A}$$

Where,

BFFS = Base Free Flow Speed, (km/h);

FFS = Estimated Free Flow Speed, (km/h);

f_{LW} = Adjustment for Lane Width, from Exhibit 21-4 (km/h);

f_{LC} = Adjustment for Lateral Clearance, from Exhibit 21-5 (km/h);

f_{M} = Adjustment for Median Type, from Exhibit 21-6 (km/h); and

f_{A} = Adjustment for Access Points, from Exhibit 21-7 (km/h).

The equation is used to find the ideal number of lanes for achieving a design Level of Service (LOS) that is the same as or better than the stated LOS according to ATJ 8/86 (2015). Using the Volume-to-Capacity ratio (Vp) and Free Flow Speed (FFS) from the Highway Capacity Manual (HCM) 2000, you can determine the Level of Service (LOS) and compare it to the LOS limits present in the Speed-Flow curve.

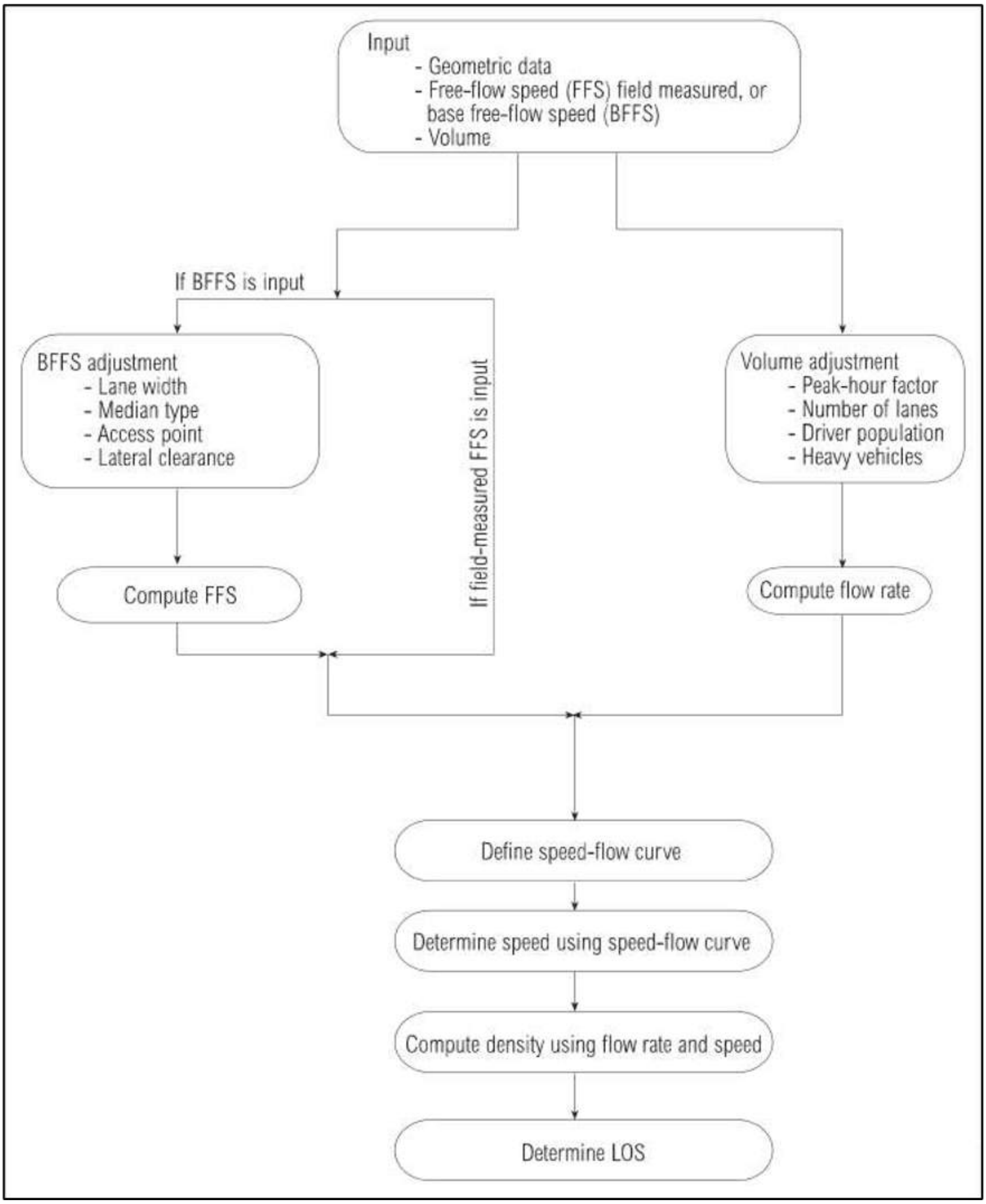


Figure 4.18 Flowchart: Design of Multilane Highways (Extracted from Exhibit 21, HCM 2000)

Table 6 LOS Criteria (Extracted from Exhibit 21-2, HCM 2000)

Free–Flow Speed	Criteria	LOS				
		A	B	C	D	E
100 km/h	Maximum density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h)	100.0	100.0	98.4	91.5	88.0
	Maximum volume to capacity ratio (v/c)	0.32	0.50	0.72	0.92	1.00
	Maximum service flow rate (pc/h/ln)	700	1100	1575	2015	2200
90 km/h	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	90.0	90.0	89.8	84.7	80.8
	Maximum volume to capacity ratio (v/c)	0.30	0.47	0.68	0.89	1.00
	Maximum service flow rate (pc/h/ln)	630	990	1435	1860	2100
80 km/h	Maximum density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h)	80.0	80.0	80.0	77.6	74.1
	Maximum volume to capacity ratio (v/c)	0.28	0.44	0.64	0.85	1.00
	Maximum service flow rate (pc/h/ln)	560	880	1280	1705	2000
70 km/h	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	70.0	70.0	70.0	69.6	67.9
	Maximum volume to capacity ratio (v/c)	0.26	0.41	0.59	0.81	1.00
	Maximum service flow rate (pc/h/ln)	490	770	1120	1530	1900

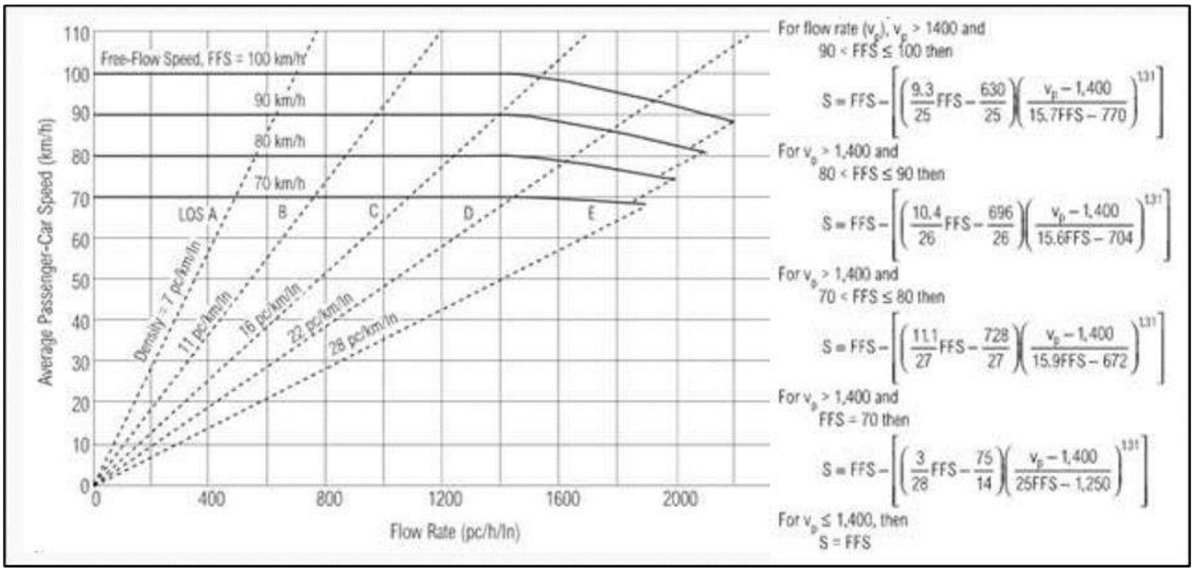


Figure 4.19 Speed-Flow curves and LOS (Extracted from Exhibit 21-3, HCM 2000)

Table 7 Adjustments for Lane Width (Extracted from Exhibit 21-4, HCM 2000)

Lane Width (m)	Reduction in FFS (km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Table 8 Adjustments for Lateral Clearance (Extracted from Exhibit 21-5 in HCM 2000)

Four–Lane Highways		Six–Lane Highways	
Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)	Total Lateral Clearance[a] (m)	Reduction in FFS (km/h)
3.6	0.0	3.6	0.0
3.0	0.6	3.0	0.6
2.4	1.5	2.4	1.5
1.8	2.1	1.8	2.1
1.2	3.0	1.2	2.7
0.6	5.8	0.6	4.5
0.0	8.7	0.0	6.3

Table 9 Adjustments for Median Type (Extracted from Exhibit 21-6 in HCM 2000

Median Type	Reduction in FFS (km/h)
Undivided highways	2.6
Divided highways (including TWRTLs)	0.0

Table 10 Adjustments for Access-Point Density (Extracted from Exhibit 21-7 in HCM 2000)

Access Points per km	Reduction in FFS (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
≥ 24	16.0

Number of Lane and Level of Service (LOS) Calculation for Jalan Kuantan - Maran

Ref	Calculations	Output/ Remark
HCM 2000 (Page 23-1) **HCM 2000** (Page 23-10)	**Traffic & road characteristics: (Jalan Kuantan-Maran)** • Percentage of trucks (goods vehicles) and buses = 8.1% • Percentage of recreational vehicles = 6% • E_T = 1.5 , E_R = 1.2 (Passenger Car Equivalent from Exhibit 21-8) Based on the topography calculation, the development area can be considered as level terrain Passenger car-equivalent flow rate, V_P: $v_p = \frac{V}{PHF \ x \ N \ x \ f_{HV} x \ f_p}$ • Peak Hour Factor, PHF = 0.88 (Rural Area) • Driver Population Factor, f_p = 1.0 • Heavy Vehicle Adjustment, f_{HV}: $f_{HV} = \frac{1}{1 + PT \ x \ (ET - 1) + PR \ x \ (ER - 1)}$ $f_{HV} = \frac{1}{1 + 0.05 \ x \ (1.5-1) + 0.01 \ x \ (1.2-1)}$ f_{HV} = 0.95	Interpolation between (From RTVM 2021 for CR403 station) and (Trip Generation Assumptions) According to **HCM 2000**, fp is in the range from 0.85 – 1.00. fp = 1.0 for commuter traffic

HCM 2000 (Exhibit 21)	**<u>Design calculation for the Jalan Kuantan – Maran Highway | 2023 Scenario</u>** Road Category = R5 (Highway - Divided) Design LOS = D Hourly volume, V = 6,451 veh/hr Directional Design Hourly Volume, D DHV = 3,617 veh/hr	Based on Trip Distribution Layout 2023
	<u>Compute Free-flow speed,</u> $FFS = BFFS - f_{Lw} - f_{LC} - f_{M} - f_{A}$ FFS = 100 – 1.0 – 0.0 – 0.0 – 1.0 = 98 km/hr	using Exhibits 21-4, 21-5, 21-6 and 21-7
	<u>Compute Vp using existing N = 2,</u> **Vp =** $\frac{3,617}{0.88\ x\ 2\ x\ 0.95\ x\ 1.0}$ **= 2,163 pc/h/ln**	
	Since Vp = 2,163 pc/h/ln < the existing limit of Speed-Flow curve graph, therefore N=2 is adequate.	Vp = 2400 pc/h/ ln(1800+5FFS), is the maximum Limit.

Density = $\dfrac{Vp}{S}$

$$S = FFS - \left[\left(\frac{9.3}{25} FFS - \frac{630}{25} \right) \left(\frac{v_p - 1{,}400}{15.7FFS - 770} \right)^{1.31} \right]$$

Using the above equation,

S = 94km/h (< FFS = 98 km/ h)

Density $= \dfrac{2{,}163}{94}$

= **20.80 pc/km/ln**

<u>Determine LOS</u>

LOS D

Therefore, LOS D is obtained from the Exhibit 21-3 chart while using 2 number of lanes which is critical and in par with the design standard, LOS D.

Thus, the capacity of road is acceptable.

using Exhibit 21-3

HCM 2000 (Exhibit 21)	**Design calculation for the Jalan Kuantan – Maran Highway | 2033 Scenario** Road Category = R5 (Highway - Divided) Design LOS = D Hourly volume, V = 8,594 veh/hr Directional Design Hourly Volume, D DHV = 4,819 veh/hr **Compute Free-flow speed,** $FFS = BFFS - f_{Lw} - f_{LC} - f_{\mathrm{M}} - f_{\mathrm{A}}$ FFS = 120 – 1.0 – 0.0 – 0.0 – 1.0 = 118 km/hr **Compute Vp using existing N = 2,** **Vp =** $\frac{4,819}{0.88\ x\ 2\ x\ 0.95\ x\ 1.0}$ **= 2,882 pc/h/ln** **Since Vp = 2,882 pc/h/ln > the existing limit** of Speed-Flow curve graph, therefore N=2 is inadequate. **Compute Vp using N = 3,** **Vp =** $\frac{4,819}{0.88\ x\ 3\ x\ 0.95\ x\ 1.0}$ **= 1,922 pc/h/ln**	Based on Trip Distribution Layout 2033 using Exhibits 21-4, 21-5, 21-6 and 21-7 Vp = 2400 pc/h/ ln(1800+5FFS), is the maximum Limit.

Density = $\frac{Vp}{S}$

$$S = FFS - \left[\left(\frac{9.3}{25} FFS - \frac{630}{25} \right) \left(\frac{v_p - 1{,}400}{15.7FFS - 770} \right)^{1.31} \right]$$

Using the above equation,

S = 88 km/h (< FFS = 98 km/ h)

Density $= \frac{1{,}922}{88}$

$=$ **21.84 pc/km/ln**

<u>Determine LOS</u>

LOS D

Therefore, LOS D is obtained from the Exhibit 21-3 chart while using 3 number of lanes which is critical and in par with the design standard, LOS D.

using Exhibit 21-3

Thus, the capacity of road is acceptable.

HCM 2000 (Exhibit 21)	**<u>Design calculation for the Jalan Kuantan – Maran Highway | 2043 Scenario</u>** Road Category = R5 (Highway - Divided) Design LOS = D Hourly volume, V = 11,449 veh/hr Directional Design Hourly Volume, D DHV = 6,420 veh/hr **<u>Compute Free-flow speed,</u>** $FFS = BFFS - f_{Lw} - f_{LC} - f_{M} - f_{A}$ FFS = 120 – 1.0 – 0.0 – 0.0 – 1.0 = 118 km/hr **<u>Compute Vp using existing N = 2,</u>** **Vp =** $\dfrac{6{,}420}{0.88\ x\ 2\ x\ 0.95\ x\ 1.0}$ **= 3,840 pc/h/ln** **Since Vp = 3,340 pc/h/ln > the existing limit** of Speed-Flow curve graph, therefore N=2 is inadequate. **<u>Compute Vp using N = 4,</u>** **Vp =** $\dfrac{6{,}420}{0.88\ x\ 4\ x\ 0.95\ x\ 1.0}$ **= 1,920 pc/h/ln**	Based on Trip Distribution using Exhibits 21-4, 21-5, 21-6 and 21-7 Vp = 2400 pc/h/ ln(1800+5FFS), is the maximum Limit.

Density = $\frac{Vp}{S}$

$$S = FFS - \left[\left(\frac{9.3}{25}FFS - \frac{630}{25}\right)\left(\frac{v_p - 1{,}400}{15.7FFS - 770}\right)^{1.31}\right]$$

Using the above equation,

S = 88 km/h (< FFS = 98 km/ h)

Density = $\frac{1{,}920}{88}$

= **21.81 pc/km/ln**

<u>Determine LOS</u>

LOS D

Therefore, LOS D is obtained from the Exhibit 21-3 chart while using 4 number of lanes which is critical and in par with the design standard, LOS D.

Thus, the capacity of road is acceptable.

using Exhibit 21-3

4.4.5.2 Design for Jalan Gambang, Major Road and Minor Road (Inside the development)

According to ATJ 8/86 (2015) in Clause 2.2.2, urban areas are defined as roads within a gazetted Municipality limit or township having a population of at least 10 000, where buildings and houses are gathered, and business activity is prevalent. Thus, throughout the entire design process, the road category urban is applied.

a) For Jalan Gambang

To ensure that the LOS obtained is the same as or better than the designated LOS as stated in HCM 2000 Exhibit 10-19 for Urban Street influenced by signal, the below equation is performed to determine the most appropriate number of lanes (2015).

$$c = N \times s \times \frac{g}{C}$$

where
c = capacity of the through lane (veh/h),
N = number of through lanes at the intersection,
s = adjusted saturation flow per through lane (veh/h), and
g/C = effective green time per cycle for the through movement at the intersection.

Table 11 Adjusted Saturation Flow Rate by Area type – Urban Streets (Extracted from Exhibit 10-19, HCM 2000)

Area Type	Default Value (veh/h/ln)	Range (veh/h/ln)
CBD	1700	1600–1800
Other	1800	1700–1950

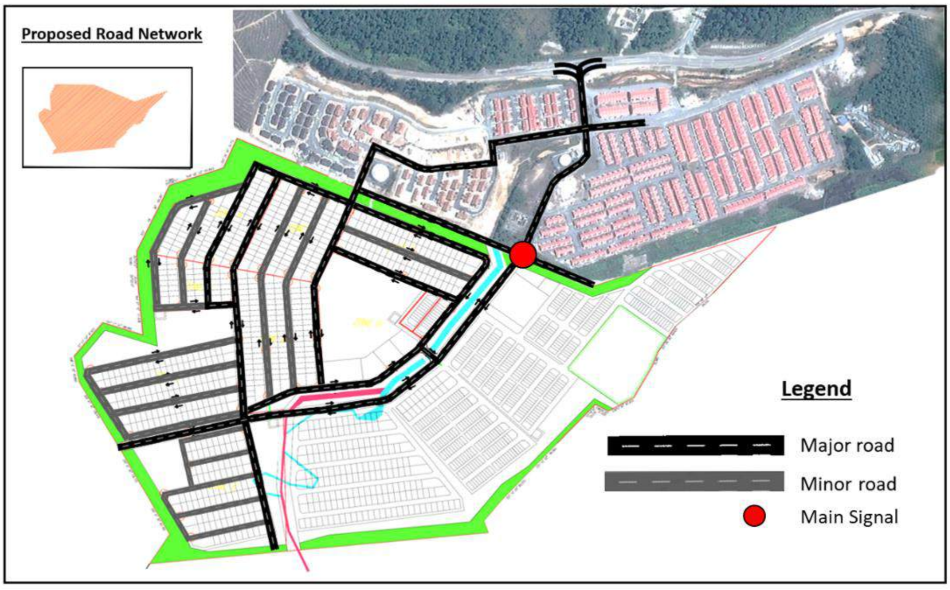


Figure 4.20 Location of main traffic signal

b) For Major and Minor road inside the development (Study Zone A)

To ensure that the LOS obtained is the same as or better than the designated LOS as stated in ATJ 8/86, the below equation is performed to determine the most appropriate number of lanes (2015). Free flow speed, or FFS, is an additional parameter that must be obtained to compute LOS;

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A$$

Where,

BFFS = Base Free Flow Speed, (km/h);

FFS = Estimated Free Flow Speed, (km/h);

f_{LW} = Adjustment for Lane Width, from Exhibit 21-4 (km/h);

f_{LC} = Adjustment for Lateral Clearance, from Exhibit 21-5 (km/h);

f_M = Adjustment for Median Type, from Exhibit 21-6 (km/h); and

f_A = Adjustment for Access Points, from Exhibit 21-7 (km/h).

The equation is used to find the ideal number of lanes for achieving a design Level of Service (LOS) that is the same as or better than the stated LOS according to ATJ 8/86 (2015). Using the Volume-to-Capacity ratio (Vp) and Free Flow Speed (FFS) from the Highway Capacity Manual (HCM) 2000, you can determine the Level of Service (LOS) and compare it to the LOS limits present in the Speed-Flow curve.

Table 12 V/C ratio range of values (Extracted from RTVM 2021, Table 5)

LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
V/C Ratio < 0.6	V/C Ratio 0.60 - 069	V/C Ratio 0.70 - 0.79	V/C Ratio 0.8 - 0.89	V/C Ratio 0.90 - 0.99	V/C Ratio > 1.0
Free Flow	Stable flow with slight delay	Stable flow with acceptable delay	Approaching unstable flow with tolerable delay	Unstable flow	Force flow

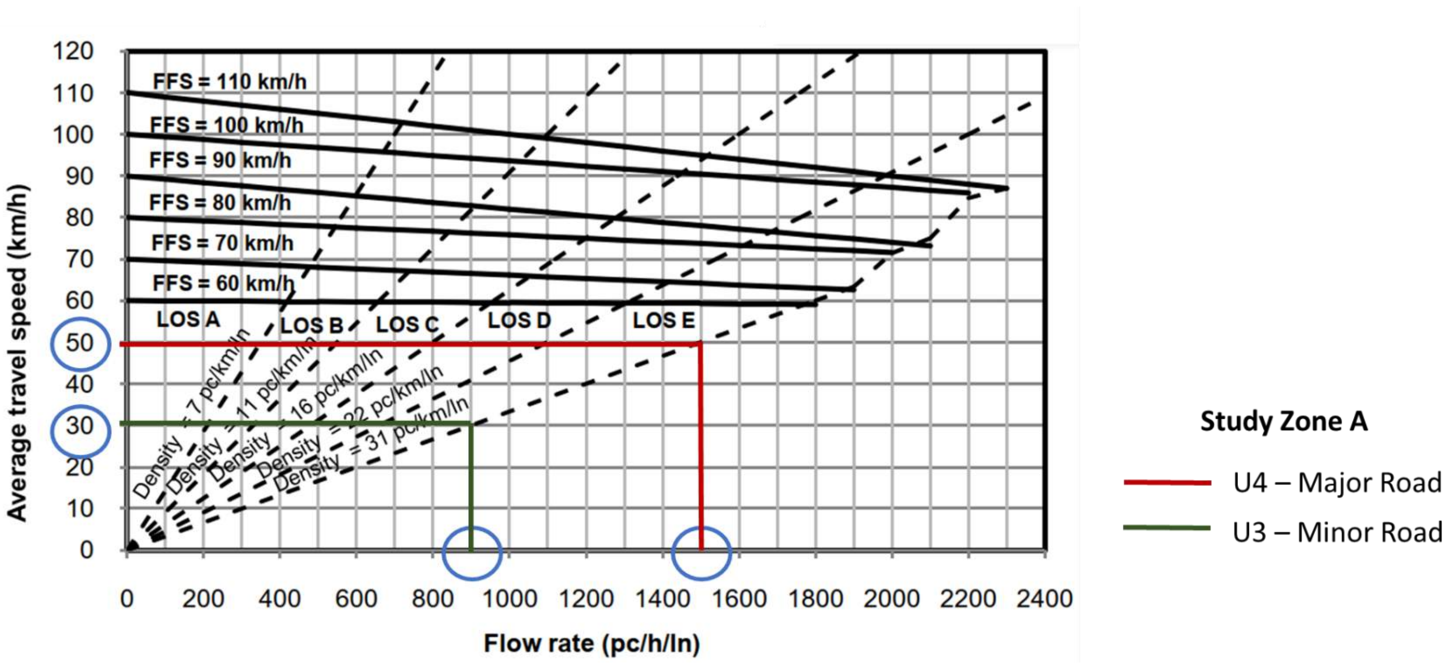


Figure 4.21 Maximum Capacity for U4 and U3 to obtain LOS E (v/c ratio = 1)

Number of Lane and Level of Service (LOS) Calculation

Ref	Calculations	Output/ Remark
	<u>Traffic & road characteristics: (Inside Development)</u>	
HCM 2000 (Exhibit 21)	• Percentage of trucks (goods vehicles) and buses = 5%	(Assumed)
	• Percentage of recreational vehicles = 1%	
HCM 2000 (Exhibit 21)	• E_T = 1.5 , E_R = 1.2 (Passenger Car Equivalent from Exhibit 21-8)	
	Based on the topography calculation, the development area can be considered as level terrain Passenger car-equivalent flow rate, V_P:	
	$$v_p = \frac{V}{PHF\ x\ N\ x\ f_{HV}\ x\ f_p}$$	According to **HCM 2000**, fp is in the range from 0.85 – 1.00.
	• Peak Hour Factor, PHF = 0.92 (Urban Area)	
	• Driver Population Factor, f_p = 1.0	fp = 1.0 for commuter traffic
	• Heavy Vehicle Adjustment, f_{HV}:	
	$$f_{HV} = \frac{1}{1 + PT\ x\ (ET - 1) + PR\ x\ (ER - 1)}$$	
	$$f_{HV} = \frac{1}{1 + 0.05\ x\ (1.5 - 1) + 0.01\ x\ (1.2 - 1)}$$	
	f_{HV} = 0.97	

HCM 2000 (Exhibit 10)	**a) Jalan Gambang** Road Category = U5 (Arterial Road - Divided) Design LOS = D Hourly volume, V = 4,696 veh/hr Directional Design Hourly Volume, D DHV = 2,427 veh/hr Area type = Non – CBD (Max saturation flow rate = 1950 veh/h/ln)	Based on Trip Distribution
	<u>**Compute Maximum Capacity (Un-mitigated Signal),**</u> c = N x s x g/C c = 2 x 1950 x 69/182 = 1,479 veh/hr	Refer to fixed time signal design calculation
	<u>**Determine v/c ratio (Un-mitigated Signal)**</u> v/c = 2,427/1,479 = **1.64 (LOS F)** Therefore, mitigation of geometry and cycle time of signal was carried out. Extra acceleration and deceleration lanes were added)	V/C Ratio **LOS F**
	<u>**Compute Maximum Capacity (Mitigated Signal),**</u> c = N x s x g/C c = 3 x 1950 x 67/144 = 2,723 veh/hr	Refer to appendix for signal timing diagram of mitigated signal using SIDRA
	<u>**Determine v/c ratio (Mitigated Signal)**</u> v/c = 2,427/2,723 = **0.89 (LOS D)**	V/C Ratio **LOS D**

HCM 2000 (Exhibit 21)	**Determine LOS** LOS D Therefore, LOS D is obtained from table 5 of RTVM 2021 which is critical and in par with the design standard, LOS D. Thus, the capacity of road is acceptable. **b) Major road (Inside Development)** Road Category = U4 (Collector Road - Divided) Design LOS = D Hourly volume, V = 1,812 veh/hr Directional Design Hourly Volume, D DHV = 1,200 veh/hr Maximum Capacity (LOS E) = 1,500 pc/h/ln **Compute Free-flow speed,** $FFS = BFFS - f_{Lw} - f_{LC} - f_{M} - f_{A}$ FFS = 61 – 4.4 – 1.5 – 2.6 – 2.0 = 50.5 km/hr **Determine maximum Vp** vp = 1,025 pc/h/ln (i.e. maximum flow rate for LOS D and average FFS = 50 km/h)	Using **RTVM 2021** Based on Trip Distribution using Exhibits 21-4, 21-5, 21-6 and 21-7 using Exhibit 21-3

Determine minimum number of lanes, N, required

$$N = \frac{DDHV}{PHF \times v_p \times f_{HV} \times f_p}$$

$$N = \frac{1{,}200}{0.92x1{,}025x0.97x1.0} = 1.31$$

Therefore 2 lanes are required.

Compute Vp using minimum N required,

$$\mathbf{Vp} = \frac{1{,}200}{0.92\ x\ 2\ x\ 0.97\ x\ 1.0}$$

= 672 pc/h/ln

Determine v/c ratio

v/c = 672/1500 = **0.45 (< 0.89 OK!)**

Determine LOS

LOS A

Therefore, LOS A is obtained from RTVM 2021 while using 2 number of lane which is the best level of service that can be obtained and is in par with the design standard, LOS D.

using RTVM 2021

Thus, the capacity of road is adequate.

HCM 2000
(Exhibit 21)

b) Minor Road (Inside the development)

Road Category = U3 (Local Street - Divided)

Design LOS = E

Hourly volume, V = 413 veh/hr

Directional Design Hourly Volume, D DHV = 272 veh/hr

Based on Trip Distribution

Compute Free-flow speed,

$FFS = BFFS - f_{Lw} - f_{LC} - f_{M} - f_{A}$

FFS = 51 – 4.4 – 3 – 2.9 – 2.0

= 38.7 km/hr

using Exhibits 21-4, 21-5, 21-6 and 21-7

Determine maximum Vp

vp = 900 pc/h/ln (i.e. maximum flow rate for LOS E and average FFS = 30km/h)

using Exhibits 21-2 or 21-3

Determine minimum number of lanes, N, required

$$N = \frac{D\,DHV}{PHF \times v_p \times f_{HV} \times f_p}$$

$$N = \frac{272}{0.92x900x0.97x1.0} = 0.34$$

Therefore 1 lane is sufficient.

	Compute Vp using minimum N required, **Vp =** $\frac{272}{0.92\ x\ 1\ x\ 0.97\ x\ 1.0}$ **= 305 pc/h/ln** **Determine v/c ratio** v/c = 305/900 = **0.34 (< 0.89 OK!)** **Determine LOS** LOS A Therefore, LOS A is obtained from RTVM 2021 while using 1 number of lanes which is one of the best level that can be obtained. It satisfies the minimum design standard, LOS E. Thus, capacity of road is adequate.	using RTVM 2021

4.5 Structural Pavement Design

A road pavement structure is composed of many layers of different materials that are compressed and stacked together. Vehicle loads on the road are mostly supported by pavement, which also offers a comfortable ride. The pavement's materials, composition, and thickness all affect how well it performs. According to ATJ 5/85 (2013), the pavement is designed. The pavement was made up of these layers:

I. Sub-Grade

The subgrade layer, which is typically located one meter below the formation level, may consist of either natural soil or be constructed into an embankment structure. The uppermost 50 cm layer of the subgrade soil has a high degree of compaction and possesses optimal moisture levels. It facilitates the provision of subgrade support for the pavement. the strength of soil is influenced by various factors such as soil type, moisture level, dry density, internal structure, and method of stress application.

II. Sub-Base

The layer located between the road base and subgrade is commonly referred to as the intermediate layer. The load-distributing layer acts to minimize the infiltration of fines from the subgrade into the pavement structure while also improving drainage. The material typically consists of crushed aggregate that is of lower quality compared to the road base but nevertheless better than the subgrade soils. The presence of a sub-base course within a pavement is uncertain. (Mohd Rosli Hainin et al., 2000)

III. Road Base

Fundamental structural layer that balances traffic loads to prevent overstressing of the sub-base and sub-grade.

IV. Binder Course

The binder course needs to have high resistance to shear-induced strain since the highest shear stress occurs at a depth of approximately 0.9 times the radius of the contact area of a wheel load. This depth is typically around 8 to 12 cm below the surface of the pavement for most commercial vehicles.

V. Wearing Course

In order to ensure a comforting driving experience, the wearing course of the road must feature adequate structural integrity, sufficient durability, optimal frictional characteristics, and a smooth surface.

The selection of pavement type is influenced by factors such as the volume and composition of traffic, soil characteristics, weather conditions, availability of materials, initial cost, and the long-term maintenance and service life expenses. ATJ 8/86 (2015) states that the pavement surface type is decided based on the road design category.

Table 13 Pavement Surface Type (Extracted from Table 5.1 in ATJ 8/86 (2015))

TABLE 5.1: PAVEMENT SURFACE TYPE

Design Standard	Description
R6 / U6	Asphaltic Concrete / Concrete / Specialty Mix
R5 / U5	Asphaltic Concrete / Concrete / Specialty Mix
R4 / U4	Asphaltic Concrete / Specialty Mix
R3 / U3	Concrete / Specialty Mix / Asphaltic Concrete
R2 / U2	Surface Treatment / Semigrout / Asphaltic Concrete
R1 / U1	Gravel / Surface Treatment

Source: Adapted from REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-1

4.5.1 Equivalent Standard Axle Load (ESALs)

The load-bearing capacity of the pavement is partly determined by traffic statistics. The traffic volume is calculated based on the axle load spectrum and the known or expected volume of commercial vehicles (CV). The traffic counts and axle load spectrum utilised for pavement design are derived from the volume and categories of commercial vehicles, as the axle loads of passenger cars are insufficient to induce significant damage.

The formula shown below can be utilised to ascertain the design traffic for the design lane and base year Y1, which represents the initial year of the design period:

$$ESAL_{y1} = ADT \times 365 \times PCV \times 3.7 \times L \times T$$

Where.

ADT = Average Daily Traffic

PCV = Percentage of CV (Un-Laden Weight > 1.5 ton)

L = Lane Distribution Factor

T = Terrain Factor

Table 14 Lane Distribution Factors (Extracted from Table 2.2 in ATJ 5/85 (2013))

Number of Lanes (in One Direction)	Lane Distribution Factor, L
One	1.0
Two	0.9
Three or more	0.7

Table 15 Terrain Factors (Extracted from Table 2.3 in ATJ 5/85 (2013))

Type of Terrain	Terrain Factor, L
Flat	1.0
Rolling	1.1
Mountainous/Steep	1.3

The design traffic for the projected year is determined using the given formula:

$$\boxed{ESAL_{Des} = ESAL_{y1} \times \frac{(1+r)^n - 1}{r}}$$

Where,

$ESAL_{y1}$ = Number of ESALs for the Base Year

r = Average Annual Traffic Growth Factor for Design Period

n = Number of Years in Design Period

4.5.2 Traffic Category

The anticipated traffic, quantified in terms of Equivalent Single Axle Loads (ESALs) over the design period (2013), can be classified into various categories based on ATJ 5/85.

Table 16 Traffic Categories (Extracted from Table 2.5 in ATJ 5/85 (2013))

Traffic Category	Design Traffic (ESAL x 10^6)	Probability (Precentile) Applied to Proporties of Sub-Grade Materials
T1	≤ 1.0	≥ 60%
T2	1.1 to 2.0	≥ 70%
T3	2.1 to 10.0	≥ 85%
T4	10.1 to 30.0	≥ 85%
T5	> 30.0	≥ 85%

4.5.3 Sub-Grade Properties

Providing the strength of the sub-grade is crucial for achieving the best possible pavement performance, especially with regard to thickness and composition. The elastic modulus and the California Bearing Ratio (CBR) are important markers for determining the sub-grade category. In the absence of field evidence, ATJ 5/85 (2013) states that pavements serving traffic levels equivalent to Traffic Classes T1 through T5 should have a minimum CBR of 5%. In order to satisfy this requirement, at least 300 mm of inappropriate sub-grade soil must be replaced or stabilised, with consideration given to pertinent moisture conditions and the likelihood of achieving the design input value. It is recommended that road pavements designed to accommodate heavy traffic, such as Traffic Classes T4 and T5, have a minimum sub-grade strength of 12 percent CBR.

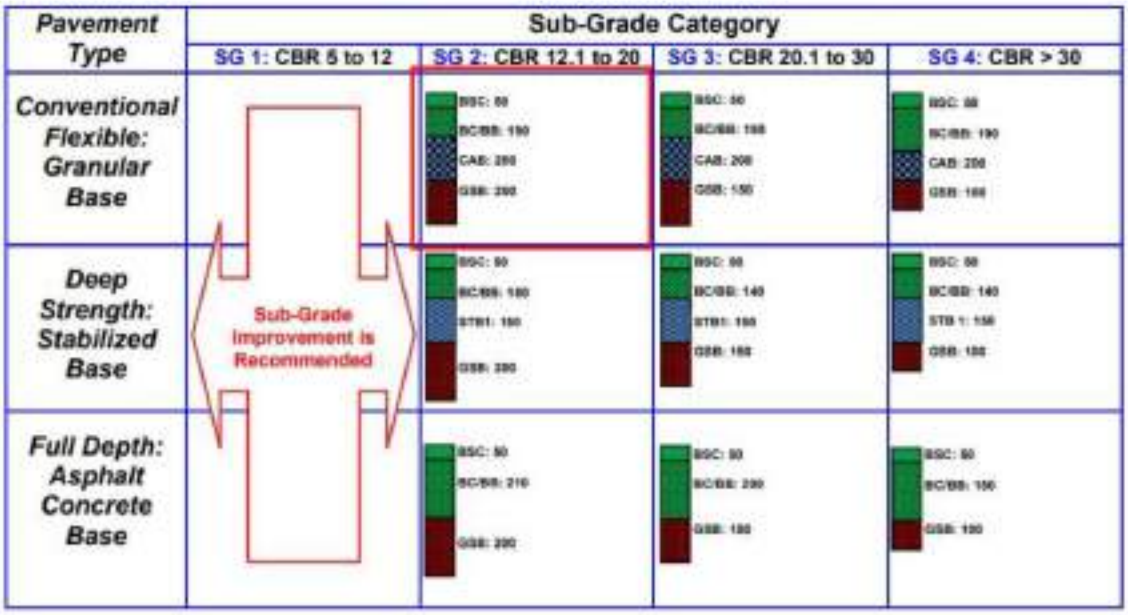
Table 17 Classes of Sub-Grade Strength (Extracted from Table 2.6 in ATJ 5/85 (2013))

Sub-Grade Category	CBR (%)	Elastic Modulus (Mpa)	
		Range	Design Input Value
SG 1	5 to 12	50 to 120	60
SG 2	12.1 to 20	80 to 140	120
SG 3	20.1 to 30.0	100 to 140	140
SG 4	> 30.0	120 to 180	180

4.5.4 Pavement Structures

A catalogue of pavement options based on the sub-grade strength and design traffic category is based on ATJ 5/85 (2013) guidelines. These pavement cross-sections have been specially designed to meet the demands of roads and motorways in Malaysia.

Table 18 Pavement Structures for Category T5: >30.0 million ESALs (80 kN)
(Extracted from Figure 3.5 in ATJ 5/85 (2013))



4.5.5 Calculation of Structural Thickness Pavement Design

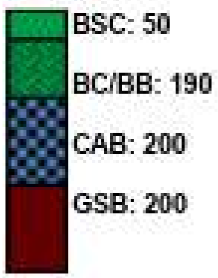
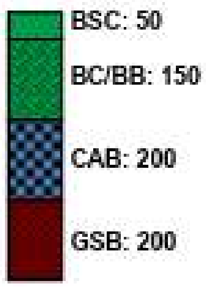
References	Calculation Design	Remarks
ATJ 5/85 - 2013 Table 2.2 Table 2.3	**Pavement Design** The Equivalent Standard Axle Load, ESAL: $ESAL_{y1}$ = ADT x 365 x PCV x 3.7 x L x T Percentage of Commercial Vehicles, PCV = 11.13% Annual Traffic Growth Rate, r = 2.91% Lane Distribution Factor, L: One Lane, L = 1.0 Two Lane, L = 0.9 Three Lane or More, L = 0.7 Terrain Factor, T = 1.0 (Flat)	Annual Traffic Growth Rate is obtained from **RTVM 2021**
	a) Jalan Kuantan – Maran • **Class R5** ADT_{2023} = 103,000 veh/day One Direction ADT_{2023} = 0.60 x 103,000 = 61,800 veh/day	ADT is obtained from **RVTM 2021**
ATJ 5/85 – 2013 Equation 2	**Design ESAL Year 2023** No. of Lanes = 4 Lanes (One Direction) $ESAL_{2023}$ = 61,800 x 365 x 0.1113 x 3.7 x 0.7 x 1 = 6.50 x 10^6 (Millions)	

Equation 3	Design Traffic for the Design Lane in One Direction: $ESAL_{des} = ESAL_{y1} \text{ x } \frac{(1+r)^n-1}{r}$ Year 2023 (n = 2) $ESAL_{des} = 6.50 \text{ x } 10^6 \text{ x } \frac{(1+0.0291)^2-1}{0.0291}$ $= 13.19 \text{ x } 10^6$ Year 2043 (n = 20) $ESAL_{des} = 13.196 \text{ x } 10^6 \text{ x } \frac{(1+0.0291)^{20}-1}{0.0291}$ $= 351.19 \text{ x } 10^6$	
ATJ 5/85-2013 Table 2.5	Since, Design Traffic is > 30 x 10^6 Therefore, Traffic Category = T5 Such that Probability (Percentile) Applied to Properties of Sub-Grade Materials is ≥ 85%	
Table 2.6	<u>Sub-Grade Properties</u> For T5, Min. CBR = 12% Assume CBR = 15% Sub-Grade Category = SG 2	Clause 2.4 recommends a minimum sub-grade strength relative CBR of 12% for Road Category T5.
	b) Jalan Gambang • **Class U5** ADT_{2023} = 58,717 veh/day One Direction ADT_{2023} = 0.60 x 58,717 =35,230 veh/day	

	Design ESAL Year 2023	
ATJ 5/85 – 2013	No. of Lanes = 2 Lanes (One Direction)	
	$ESAL_{2023}$ = 35,230 x 365 x 0.1113 x 3.7 x 0.9 x 1	
Equation 2	= 4.77 x 10^6 (Millions)	
	Design Traffic for the Design Lane in One Direction:	
Equation 3	$ESAL_{des} = ESAL_{y1} \times \frac{(1+r)^n-1}{r}$	
	Year 2023 (n = 2)	
	$ESAL_{des} = 4.77 \times 10^6 \times \frac{(1+0.0291)^2-1}{0.0291}$	
	$=9.68 \times 10^6$	
	Year 2043 (n = 20)	
	$ESAL_{des} = 9.68 \times 10^6 \times \frac{(1+0.0291)^{20}-1}{0.0291}$	
ATJ 5/85-2013	$= 257.74 \times 10^6$	
	Since, Design Traffic is > 30 x 10^6	
Table 2.5	Therefore, Traffic Category = T5	
	Such that Probability (Percentile) Applied to Properties of Sub-Grade Materials is ≥ 85%	
	<u>Sub-Grade Properties</u>	
Table 2.6	For T5,	**ATJ 5/85 - 2013** Table 2.6 recommends a minimum sub-grade strength relative CBR of 12% for Road Category T5.
	Min. CBR = 12%	
	Assume CBR = 15%	
	Sub-Grade Category = SG 2	

	c) Major Road (Inside Development)	
ATJ 5/85 – 2013	• **Class U4**	
	ADT_{2023} = 9,560 veh/day	
	One Direction	
	ADT_{2023} = 0.60 x 9,560	
	= 5,736 veh/day	
	Design ESAL Year 2023	
	No. of Lanes = 2 Lanes (One Direction)	
	Assume PCV for Inside Development Area = 8%	
	$ESAL_{2023}$ = 5,736 x 365 x 0.08 x 3.7 x 0.9 x 1	
Equation 2	= 0.56×10^6 (Millions)	
	Design Traffic for the Design Lane in One Direction:	
	$ESAL_{des} = ESAL_{y1} \times \frac{(1+r)^n-1}{r}$	
Equation 3	Year 2023 (n = 2)	
	$ESAL_{des} = 0.56 \times 10^6 \times \frac{(1+0.0291)^2-1}{0.0291}$	
	$=1.14 \times 10^6$	
	Year 2043 (n = 20)	
	$ESAL_{des} = 1.14 \times 10^6 \times \frac{(1+0.0291)^{20}-1}{0.0291}$	
	$= 29.85 \times 10^6$	
ATJ 5/85-2013	Since, Design Traffic is $> 10.1 \times 10^6$ & $< 30 \times 10^6$	
Table 2.5	Therefore, Traffic Category = T4	
	Such that Probability (Percentile) Applied to Properties of Sub-Grade Materials is $\geq$ 85%	

Table 2.6	<u>Sub-Grade Properties</u> For T4, Min. CBR = 12% Assume CBR = 15% Sub-Grade Category = SG 2	**ATJ 5/85 - 2013** Table 2.6 recommends a minimum sub-grade strength relative CBR of 12% for Road Category T4.
	d) Minor Road (Inside Development) (Class U3) ADT_{2023} = 2,267 veh/day One Direction ADT_{2023} = 0.60 x 2,267 = 1,360 veh/day **Design ESAL Year 2023**	
ATJ 5/85 – 2013 Equation 2	No. of Lanes = 2 Lanes (One Direction) $ESAL_{2023}$ = 1,360 x 365 x 0.08 x 3.7 x 0.9 x 1 = 0.13×10^6 (Millions) Design Traffic for the Design Lane in One Direction:	
Equation 3	$ESAL_{des} = ESAL_{y1} \times \frac{(1+r)^n-1}{r}$ Year 2023 (n = 2) $ESAL_{des} = 0.13 \times 10^6 \times \frac{(1+0.0291)^2-1}{0.0291}$ $= 0.26 \times 10^6$ Year 2043 (n = 20) $ESAL_{des} = 0.26 \times 10^6 \times \frac{(1+0.0291)^{20}-1}{0.0291}$ $= 6.92 \times 10^6$ Since, Design Traffic is $> 2.1 \times 10^6$ & $< 10 \times 10^6$	**ATJ 5/85 - 2013**

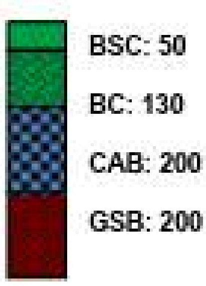
ATJ 5/85-2013 Table 2.5 Table 2.6	Therefore, Traffic Category = T3 Such that Probability (Percentile) Applied to Properties of Sub-Grade Materials is ≥ 85% <u>Sub-Grade Properties</u> For T3, Min. CBR = 12% Assume CBR = 15% Sub-Grade Category = SG 2	Table 2.6 recommends a minimum sub-grade strength relative CBR of 12% for Road Category T3.
References	**Pavement Structural Thickness**	**Remarks**
ATJ 5/85 - 2013 Fig. 3.5 **ATJ 5/85 - 2013** Fig. 3.4	**For Jalan Kuantan – Maran and Jalan Gambang** For Pavement Type T5 with SG 2, We choose conventional flexible: Granular Base.  **For Major Road (Inside Development)** For Pavement Type T4 with SG 2 We choose conventional flexible: Granular Base 	

<table>
<tr>
<td>ATJ 5/85 - 2013

Fig. 3.3</td>
<td>For Minor Road (Inside Development)

For Pavement Type T3 with SG 2

We choose conventional Flexible: Granular Base.



<table>
<tr><th>Abbreviation</th><th>Description</th></tr>
<tr><td>BSC</td><td>Medium to fine bituminous mix (AC10 or AC14)</td></tr>
<tr><td>BC/BB</td><td>Coarse bituminous mix (AC28)</td></tr>
<tr><td>CAB</td><td>Crushed granular material with max. 10% fine</td></tr>
<tr><td>GSB</td><td>Crushed or natural granular material with max 10% fine</td></tr>
</table>
</td>
<td>ATJ 8/86 – 2015

Table 5.1

Standard design pavement surface for both R5, U5, U4, and U3 is Asphaltic Concrete</td>
</tr>
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4.5.6 Pavement Structural Thickness Layout

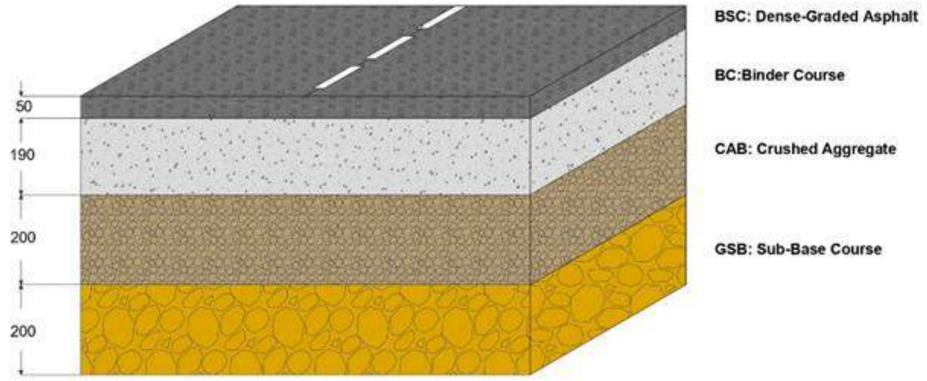


Figure 4.22 a) Pavement Structural Thickness Layout for T5

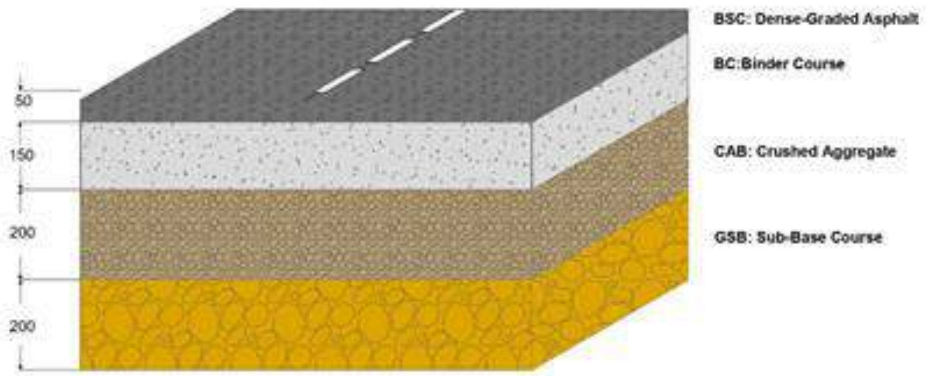


Figure 4.22 b) Pavement Structural Thickness Layout for T4

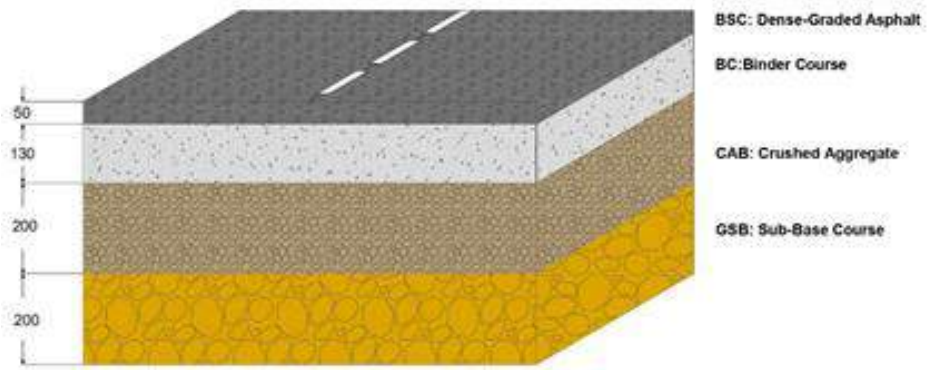


Figure 4.22 c) Pavement Structural Thickness Layout for T3

4.6 Cross Section Design

4.6.1 Introduction

The cross-section design determines road features like lane width, shoulders, medians, and the marginal strip. The comfort and safety of riders hinge on an adequate and appropriate cross-section design.

4.6.2 Lane Width and Marginal Strip

The width of the lane affects the road's capacity and service level. The effective width of the travelled path is further decreased when lateral clearance is restricted by fixtures like parked cars, bridge piers, and retaining walls. A marginal strip is a narrow strip of pavement that runs the length of a carriageway and is built to the same exacting standards as the main pavement. Marginal strips are present on both sides of divided roads in both directions. The marginal strip, which is a portion of the shoulder width, and the through lane are distinguished from one another by lane edge markings. Standard lane widths and marginal strip lengths for various road standards are provided by ATJ 8/86 (2015).

Table 19 Lane and Marginal Strip Widths (Extracted from Table 5.2 in ATJ 8/86 (2015))

TABLE 5.2: LANE & MARGINAL STRIP WIDTHS

Design Standard	Lane Width (m)	Marginal Strip Width (m)
R6 / U6	3.65	0.50
R5 / U5	3.50	0.50
R4 / U4	3.50	0.25
R3 / U3	3.25	0.25
R2 / U2	3.00	0.25
R1 / U1	5.00*	0.00
Interchange Ramps		
Single Lane	4.50	Lt 1.50 Rt 0.50
Multi Lanes	3.50	Lt 0.50 Rt 0.50
Single Lane Loop	4.50	Lt 1.50 Rt 0.50

Source: Adapted from REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-2

Note: * denotes the total two-way width

4.6.3 Shoulders

A shoulder is an integral part of the road that extends from the traveled way, providing designated space for stationary vehicles, emergency use, and lateral support for the pavement. In urban settings, ATJ 8/86 defines a standard width for paved shoulders (2015).

Table 20 Paved Shoulder Width (Urban) (Extracted from Table 5.3b in ATJ 8/86 (2015))

TABLE 5.3B: PAVED SHOULDER WIDTH (URBAN)

Design Standard	Paved Shoulder Width (m)		
	Area Type *		
	I	II **	III **
U6	3.00	3.00	2.50
U5	3.00	3.00	2.50
U4	3.00	2.50	2.00
U3	2.50	2.00	1.50
U2	2.00	1.50	1.50
U1	1.50	1.50	1.50

Source: REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-3B

Notes:
* For Area Type definition, see Table 3-2B
** For Areas Type II & III, U1 to U4, shoulder may be replaced by sidewalk

4.6.4 Road Median

A median is a crucial feature for all roads with four or more lanes and should be incorporated whenever feasible. Its main functions are to maintain the appropriate distance from oncoming traffic, provide a recovery area for cars that have lost control, allow for speed adjustments, store cars that are making right or U turns, and make room for additional lanes. For optimal efficiency, the median needs to be easily observable in both daylight and dark conditions, with a distinct appearance from the through traffic lanes.

Median should have a width that is adequate for the other elements of the cross-section and can be flush, raised, or depressed against the pavement surface. It is advised that the median width be at least 1.5 metres in Type III urban areas and ideally 10 metres on rural motorways. It is crucial to incorporate a swale or depressed centre for drainage in wider medians.

The suggested and ideal widths as well as the kinds of median appropriate for various road standards in urban areas is shown in Tables 5.5B. The median widths that are given are the separations between the through-lane edges and include any right shoulders that may be present.

Table 21 Median Width and Type (Urban) (Extracted from Table 5.5b in ATJ 8/86 (2015))

TABLE 5.5B: MEDIAN WIDTH AND TYPES (URBAN)

Design Standard	Median Width (m) Area Type I		II		III		Median Type
	Min.	Des.	Min.	Des.	Min.	Des.	
U6	4.0	9.0	3.5	6.0	2.0	4.0	B,C,E,F
U5	3.0	6.5	2.5	4.0	2.0	3.0	B,C,E
U4	2.5	5.0	2.0	3.0	1.5	2.0	A,B,C,D
U3	2.0	4.0	1.5	2.0	1.5	2.0	A,B,D

Source: Adapted from REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-5B

Note:
Min. - Minimum
Des. - Desirable (for consideration of landscaping or other aesthetic features)

4.6.5 Reserve Width

A sufficient width for the road reserve is crucial to accommodate not just current traffic needs but also future requirements, especially considering potential challenges in acquiring additional land. The minimum reserve widths for different road standards are shown in Table 5.8, with modifications required for regions with deep fills or cuts.

Table 22 Minimum Reserved Width (Extracted from Table 5.8 in ATJ 8/86 (2015))

TABLE 5.8: MINIMUM RESERVE WIDTH

Area	Road Category	Design Standard	Minimum Reserve Width (m)
RURAL	Expressway	R6	60
	Highway	R5	60
	Primary Road	R5 R4	50 40
	Secondary Road	R4 R3	30 25
	Minor Road	R2 R1	20 20
URBAN	Expressway	U6	65
	Arterials	U5 U4	65 40
	Collector	U4 U3	40 40
	Local Street	U3 U2 U1	40 30 25

4.6.6 Calculation of Road Cross Section

<table>
<tr><th>References</th><th>Calculation Design</th><th>Remarks</th></tr>
<tr><td>

ATJ 8/86 - 2015

Table 3.2A

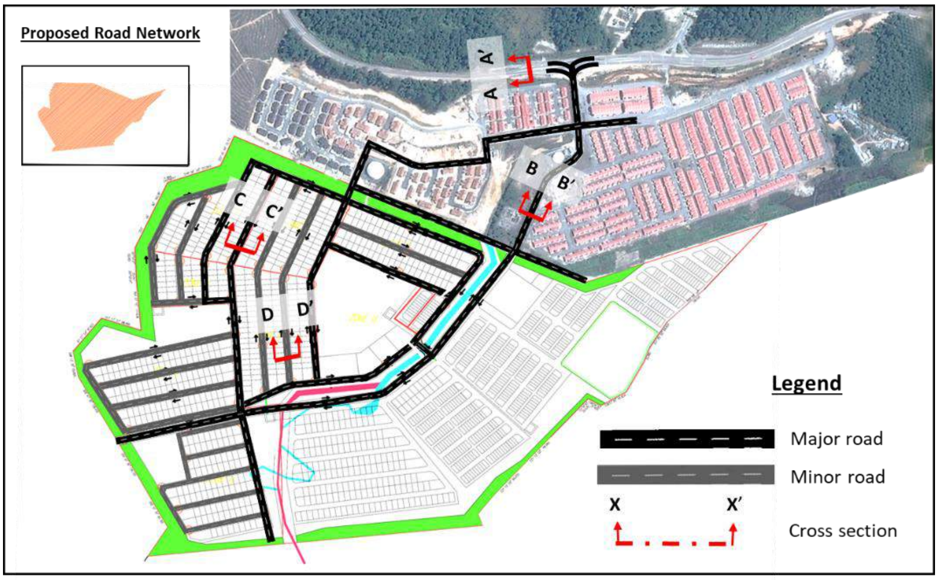
Table 5.2

Table 5.3A

Table 5.8</td><td>

Roads Cross-Section Design

Key Map:



a) Jalan Kuantan - Maran

A-A'

Design Standard = R5

Area Type = II

Number of Lanes (One Direction) = 4 Lanes

Lane Width = 3.50 m

Marginal Strip Width = 0.50 m

Paved Shoulder Width = 3.0 m

Shoulder Cross Slope = 3% (Assumed)

Minimum Median Width = 4.0 m

Desirable Median Width = 4.0 m

Minimum Reserved Width = 60 m

</td><td>

Bituminous and Concrete Surface Shoulders should to be sloped from 2% to 6%.</td></tr>
</table>

ATJ 8/86 - 2015 Table 3.2B Table 5.2 Table 5.3B Table 5.8	**b) Jalan Gambang** **B-B'** Design Standard = U5 Area Type = III Number of Lanes (One Direction) = 2 Lanes Lane Width = 3.50 m Marginal Strip Width = 0.50 m Paved Shoulder Width = 2.5 m Shoulder Cross Slope = 3% (Assumed) Minimum Median Width = 2.0 m Desirable Median Width = 2.0 m Minimum Reserved Width = 65 m	
ATJ 8/86 - 2015 Table 3.2B Table 5.2 Table 5.3A Table 5.8	**c) Major Road (Inside Development Area)** **C-C'** Design Standard = U3 Area Type = III Number of Lanes (One Direction) = 2 Lanes Lane Width = 3.25 m Marginal Strip Width = 0.25 m Paved Shoulder Width = 1.5 m Shoulder Cross Slope = 3% (Assumed) Minimum Median Width = 1.50 m Desirable Median Width = 1.50 m Minimum Reserved Width = 40 m	Bituminous and Concrete Surface Shoulders should to be sloped from 2% to 6%.

ATJ 8/86 - 2015 Table 3.2B Table 5.2 Table 5.3A Table 5.8	**d) Minor Road (Inside Development Area)** **D-D’** Design Standard = U3 Area Type = III Number of Lanes (One Direction) = 1 Lanes Lane Width = 1.50 m Marginal Strip Width = 0.25 m Paved Shoulder Width = 1.5 m Shoulder Cross Slope = 3% (Assumed) Minimum Median Width = 1.5 m Desirable Median Width = 1.5 m Minimum Reserved Width = 40 m	

4.6.7 Cross Section Layouts

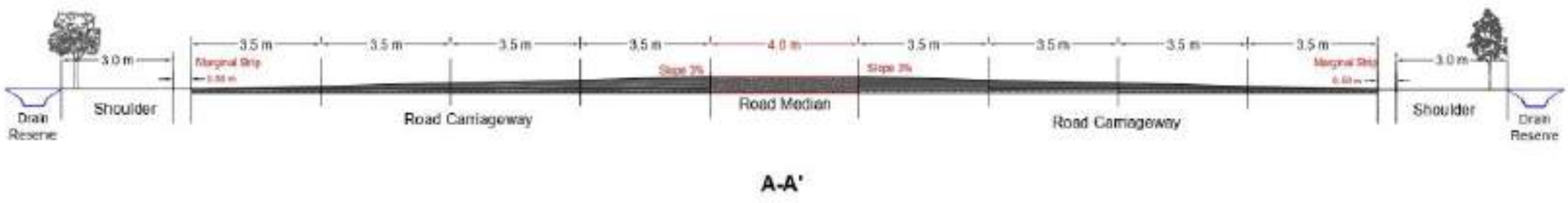


Figure 4.23 Cross Section of Jalan Kuantan-Maran Highway

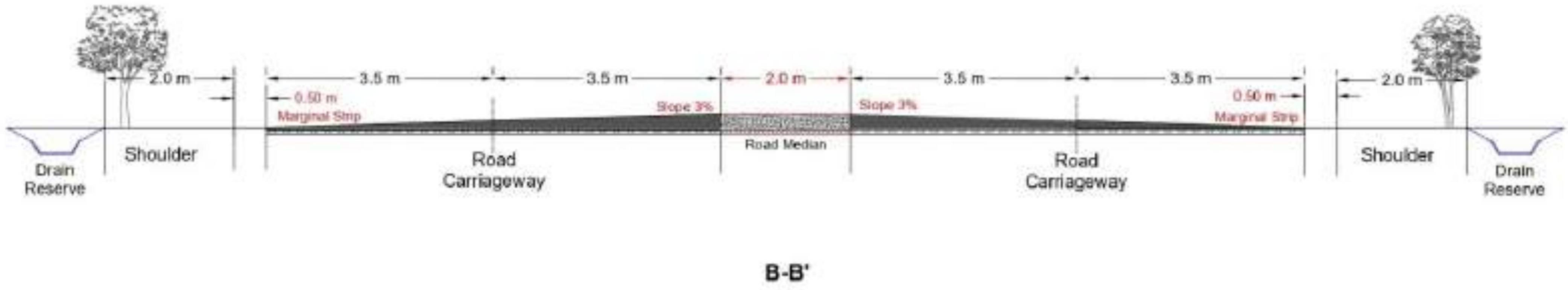


Figure 4.24 Cross Section of Jalan Gambang

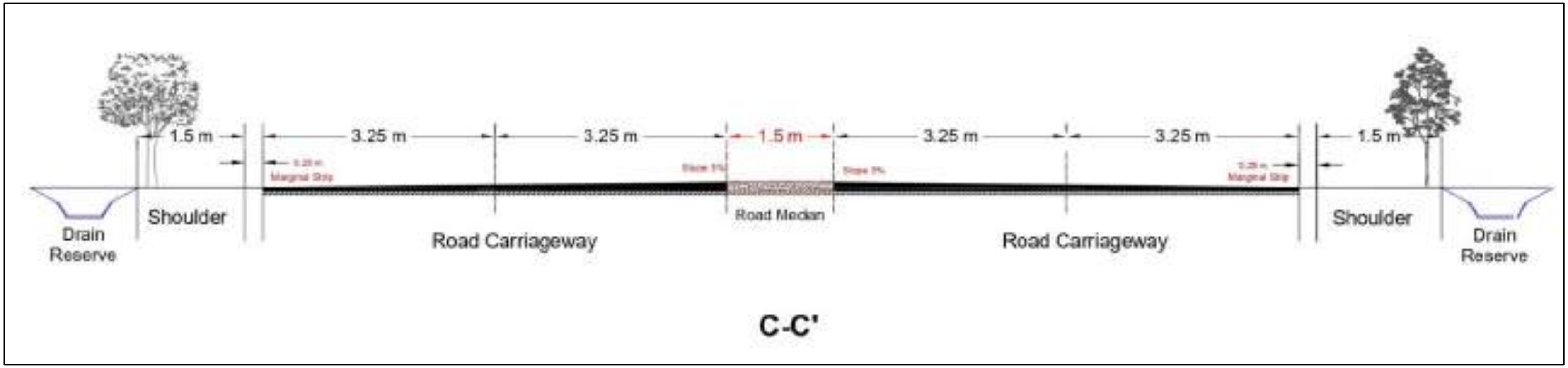


Figure 4.25 Cross Section of Major Road (Inside Study Zone A)

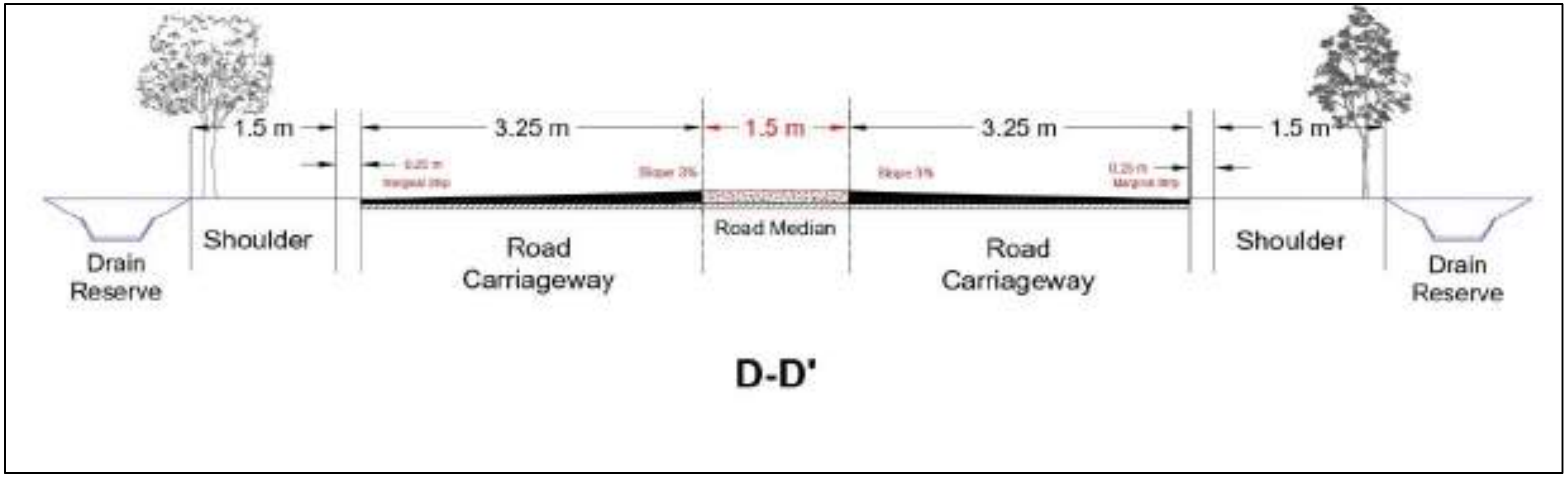


Figure 4.26 Cross Section of Minor Road (Inside Study Zone A)

4.7 Intersection Design

4.7.1 Type of Junction Control

ATJ 11/87 (2016) states that the regulated priority of an at-grade intersection usually has sufficient capacity to accommodate the expected traffic flow at most intersections. Alternative types of intersections are necessary in locations where the projected traffic volume exceeds the available area. These are examples of different types of intersections: roundabouts, signal-controlled intersections, and grade separated intersections or interchanges.

Table 23 Selection of Intersection Type (Extracted from ATJ 11/87 Revision 2017)

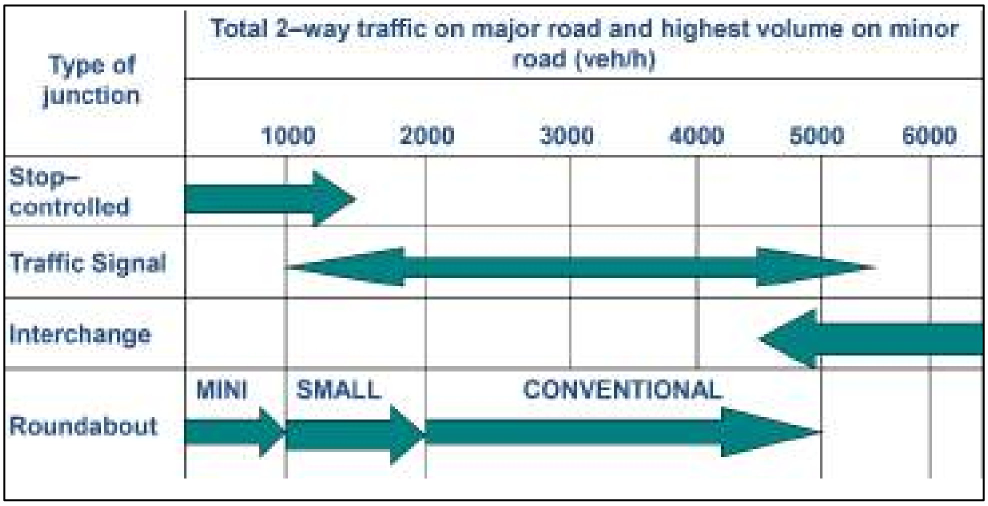


Table 24 General Selection Criteria of Intersection Type (Extracted from ATJ 11/87 Revision 2017)

Table of general selection criteria (2a): Urban Area

Expressway	Arterial	Collector	Local Street	
Interchange	Interchange	---	---	Expressway
	Interchange / Signalised Intersection	Signalised Intersection	Signalised Intersection / Stop Control	Arterial
		Signalised Intersection	Stop Control	Collector
			Stop Control	Local Street

4.7.1.1 Roundabouts

- Roundabouts are suitable for a total traffic volume of up to 6000 cars per hour, considering all directions. If the layout can be freely specified, roundabouts can be constructed to accommodate any distribution of turning traffic

- Nevertheless, the design of roundabouts necessitates a greater amount of land in order to accommodate the approach of each intersection. However, the intersection can contain more than four legs due to the presence of free-flow unsignalized approaches.

- The roundabout can be signalized once it exceeds the capacity per leg (6000 veh/hr) if it is so required.

- If any of the approaches of a roundabout exceeds its saturation capacity level, the design can be modified to accommodate future growth. This can be done by changing the roundabout into an interchange, such as a flyover or ramp, to alleviate traffic congestion for that specific approach.7.0 Structural Pavement Design.

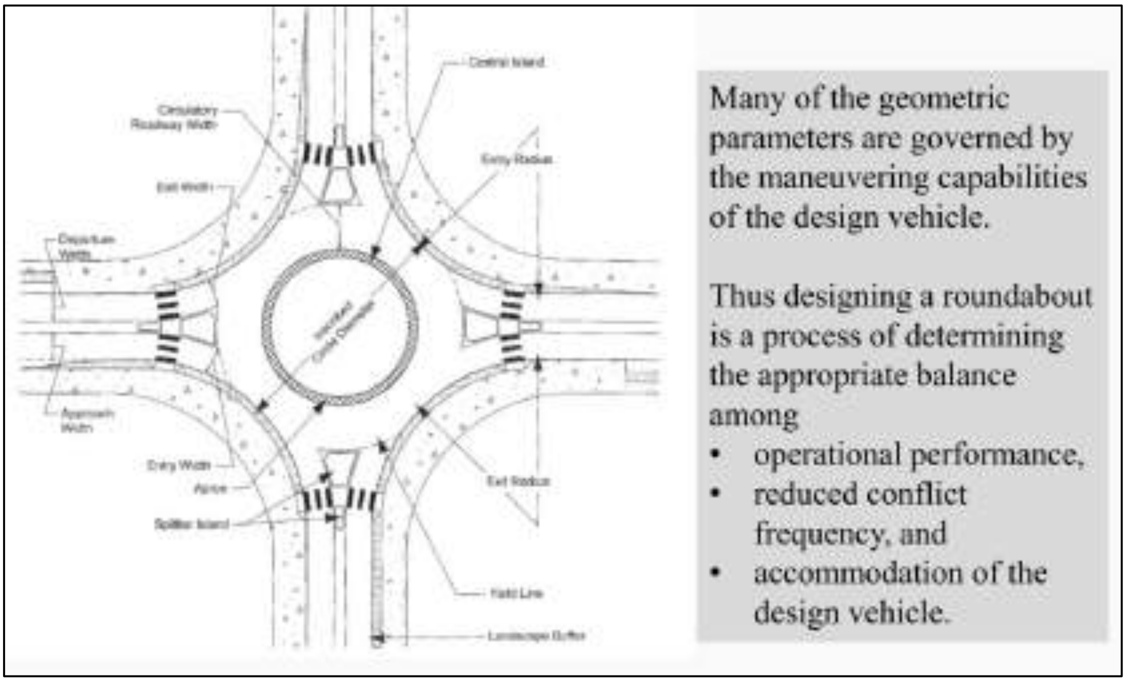


Figure 4.27 Components of Roundabout

Types of Roundabouts

ATJ 11/87:

Type	Diameter of Inscribed Circle (m)	Diameter of Centre Circle (m)
Conventional	$D_I > 50$	$D_C > 25$
Small	$50 > D_I > 20$	$25 > D_C > 4$
Mini	$D_I < 20$	$D_C < 4$

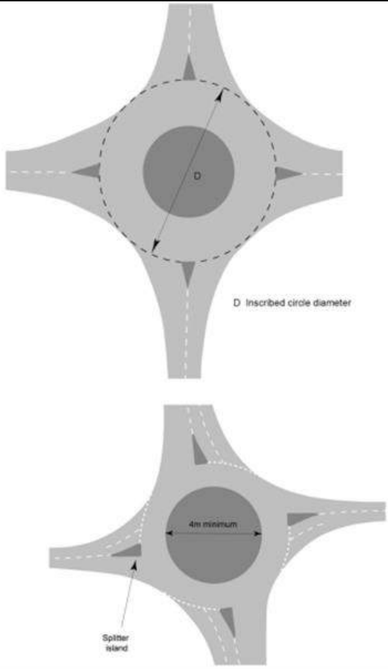


Figure 4.28 Types of Roundabouts based on ATJ 11/87

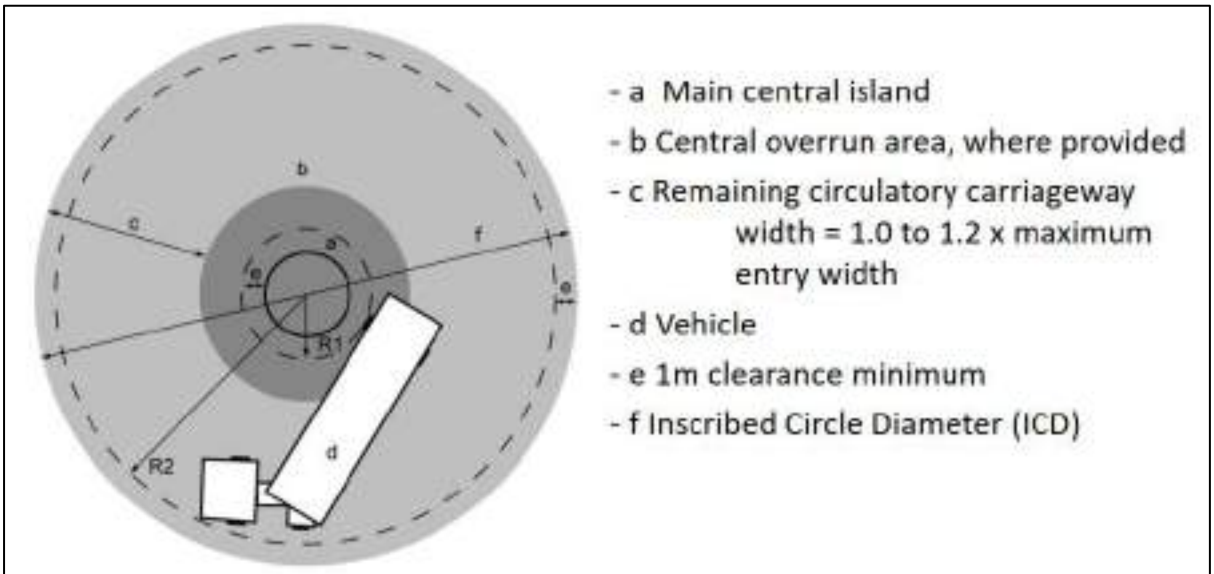


Figure 4.29 Geometric Parameters of Roundabouts

Table 25 Design values for geometric variables

Central Island Dia. (m)	R1 (m)	R2(m)	Minimum ICD (m)
4.0	3	13.0	28.0
6.0	4	13.4	28.8
8.0	5	13.9	29.8
10.0	6	14.4	30.8
12.0	7	15.0	32.0
14.0	8	15.6	33.2
16.0	9	16.3	34.6
18.0	10	17.0	36.0

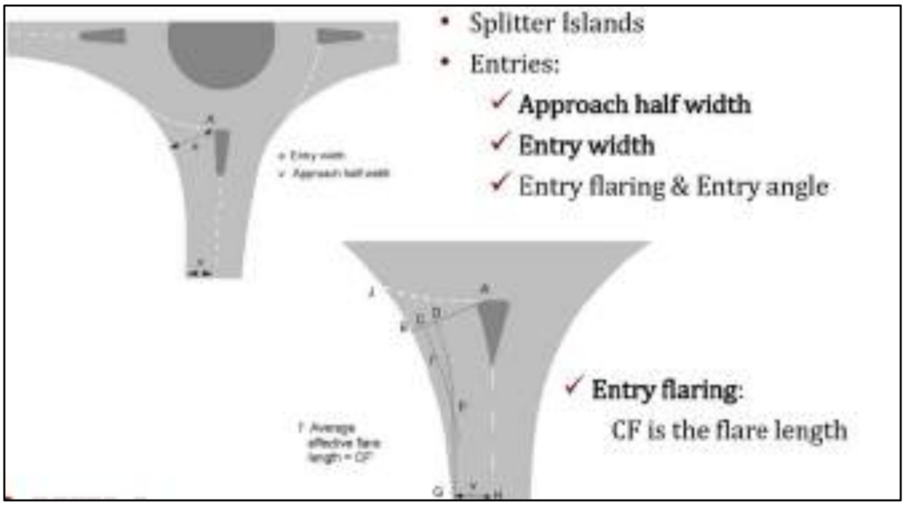


Figure 4.30 Other Important Design Parameters

Table 26 LOS Criteria for Roundabouts

Performance of roundabouts in terms of LOS is also based on control delays per vehicle:

LOS	Criteria: Control Delay per vehicle (sec/veh)
A	≤ 10
B	> 10 to 20
C	> 20 to 35
D	> 35 to 50
E	> 55 to 70
F	> 70

4.7.1.2 Signal Controlled Intersections

- Signal controlled junctions are suitable for managing extremely high traffic volumes of 8,000 vehicles per hour.
- Signalized junctions may effectively manage high volumes of traffic when equipped with a sufficient number of approach lanes.
- Nevertheless, the wide road necessitates a lengthier clearance period for cars to traverse, resulting in reduced efficiency in traffic management.

The primary purpose of installing a traffic light at a junction is to allocate right-of-way to vehicles approaching from each direction, so enhancing the efficiency of traffic handling. This leads to more efficient traffic flow, improved safety, a lower incidence of conflict between vehicles, and reduced traffic delays.

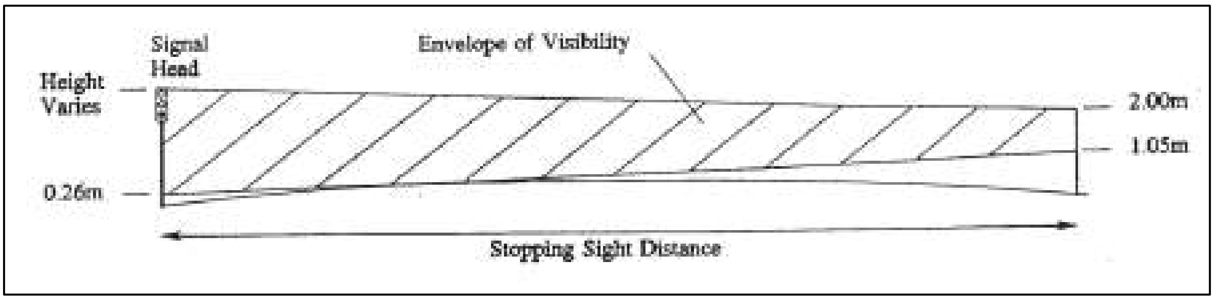


Figure 4.31 Visibility envelope of Signalized Intersection (Extracted from ATJ 13/87)

Minimum Visibility distances as suggested by ATJ 13/87

85th percentile speed (km/h)	Minimum Visibility Distance (m)	Desirable Distance (m)
32	53	81
40	66	99
48	82	123
56	99	140
64	119	174
72	140	201
80	165	232
88	190	265
97	218	299

Adjustments for Grade:

85th percentile speed (km/h)	Add for downgrade, m		Subtract for upgrade, m	
	5%	10%	5%	10%
32	2	5	2	3
40	3	6	3	5
48	5	9	3	6
56	6	14	5	8
64	9	20	6	11
72	12	27	9	15
80	15	37	11	20
88	18	46	14	24
97	21	58	17	29

Figure 4.32 Minimum Visibility distances and Adjustments for Grade (Extracted from ATJ 13/87)

4.7.1.2.1 Design of Four-leg Signal Controlled Intersection

Figure 4.33 depicts an instance of a larger and more complex signal-controlled intersection connecting two major dual carriageways.

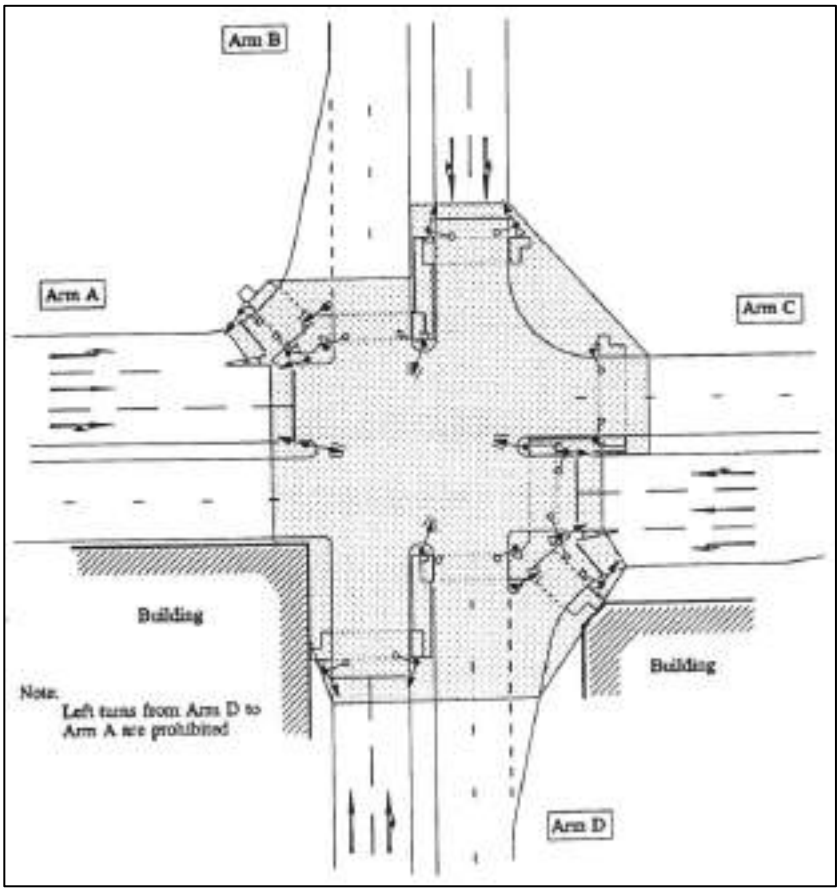


Figure 4.33 Example of a 4 leg Signal-Controlled at grade Intersection (Extracted from ATJ 13/87)

The following design features are incorporated into the example :

a) uncontrolled left turn slip lane (A to B), circular radius without tapers (Arm B to C), controlled left turn slip lane (C to D) and left turn ban (Arm D to A);

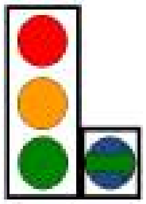
b) due to the constraints imposed by the separation island, the staggered pedestrian crossing on Arm C is not the preferred orientation;

c) the staggered pedestrian crossing on Arm D indicates the preferred orientation.

4.7.1.2.2 Design of fixed-time traffic signal control system

Terminologies & Definitions

- **SIGNAL ASPECTS (OR INDICATIONS):**



RED: → STOP (DON'T GO)

AMBER: → (i) Drivers approaching the stop–line must slow down and ready to stop as the right–of–way is about to end, and

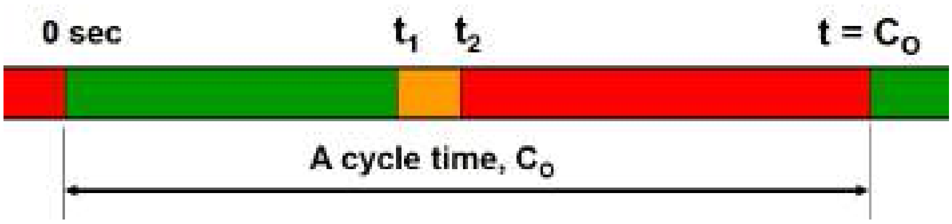
(ii) Drivers who have already crossed the stop–line must proceed and clear the junction quickly.

GREEN: → Drivers have the right–of–way.

GREEN ARROW: → Proceed to follow the indicated direction.

- **CYCLE TIME (C_O)**

A period for a complete sequence of signal indications (aspects), i.e., green followed with amber, and followed with red period.



- **TRAFFIC (SIGNAL) PHASES**

The portion of a signal cycle time allocated to any single combination of one or more traffic movements simultaneously receiving the right-of-way during one or more intervals.

<u>Phase Sequence:</u>

A predetermined order in which the phases of a cycle occur.

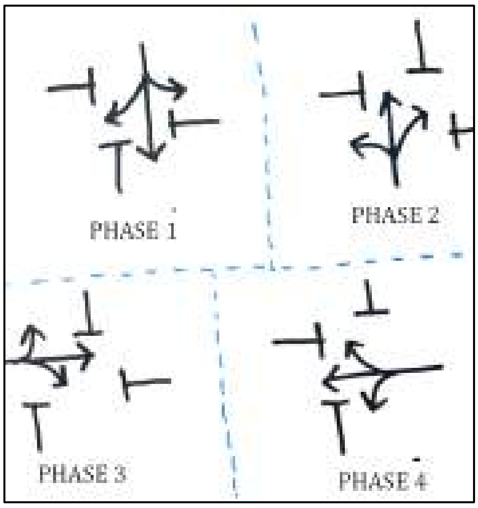


Figure 4.34 Example of phase diagram for 4 leg signal.

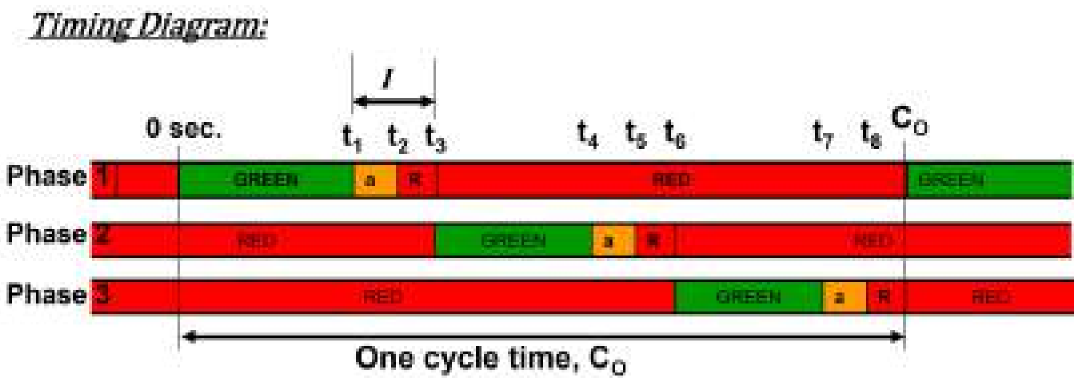
- **ALL–RED PERIOD (R)**

The part or parts of the signal cycle time during which the signal indications do not change. This short period of time is to ensure all vehicles/pedestrians have cleared the junction before the next traffic phase is given right-of-way.

- **INTERGREEN PERIOD (I)**

A period of time from end of the green indication of a phase to the beginning of green indication for the next phase.

$$I = a + R$$



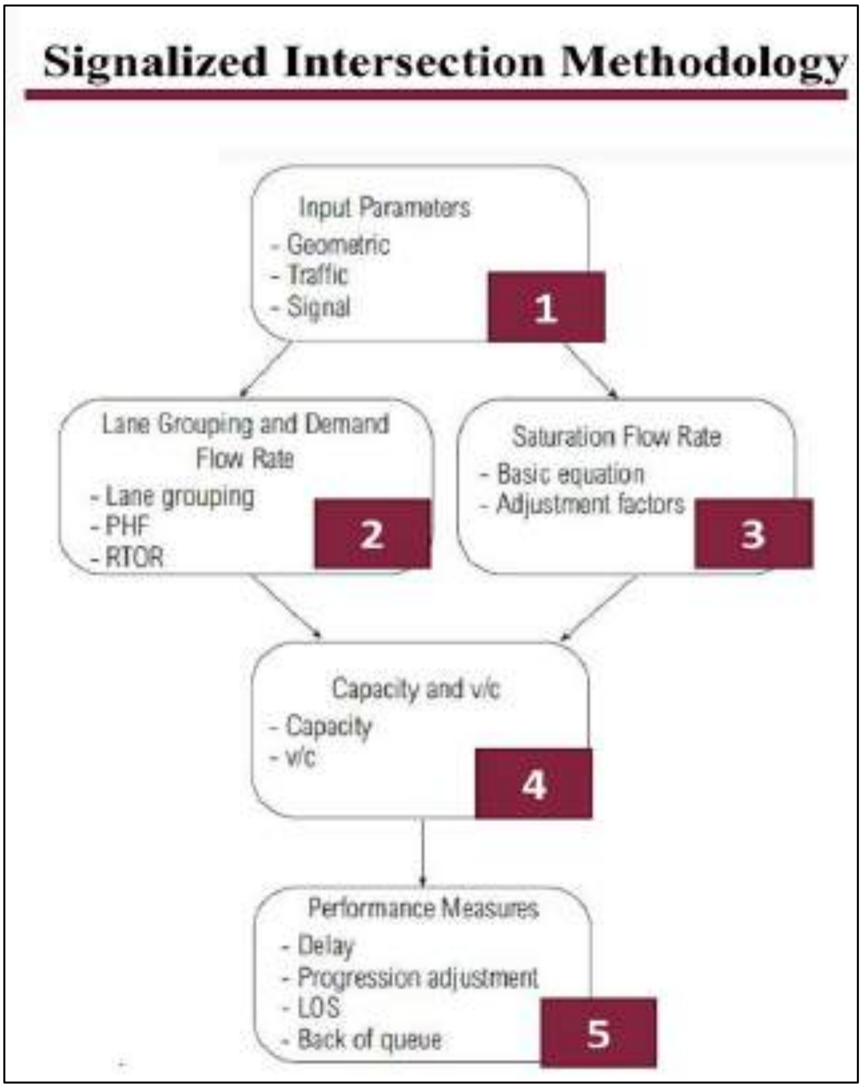


Figure 4.35 Design Flowchart of Signalized Intersection (Adopted from notes by Dr. Sitti Asmah)

4.7.1.3 Grade Seperated Intersections or Interchanges

- Grade separated intersections efficiently accommodate heavy traffic flow while minimising disruptions to the continuous movement of vehicles.

- They are mandatory for all fully access-controlled roadways and should be taken into account for roads with design speeds above 90 km/hr.

- Grade separation is advised when each road crossing consists of four or more through lanes.

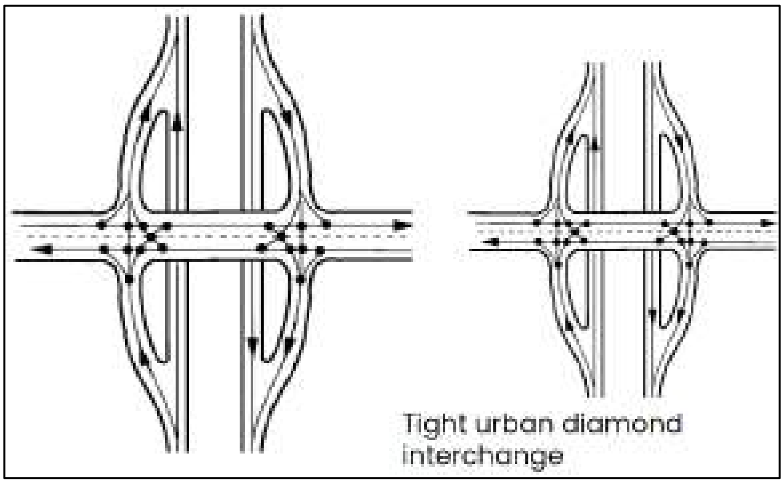


Figure 4.36 Example of Conflict points in an interchange

Traffic volume is the primary determinant of the kind of intersection. Additional considerations, such as the road class and lane arrangement, should be taken into account, particularly as the traffic volume approaches the limit of an intersection type.

Signalization may be necessary due to factors such as high pedestrian volume and frequent accidents, in addition to traffic volume. The selection of the intersection type along an arterial may be influenced by coordinated traffic control and the type of nearby intersections.

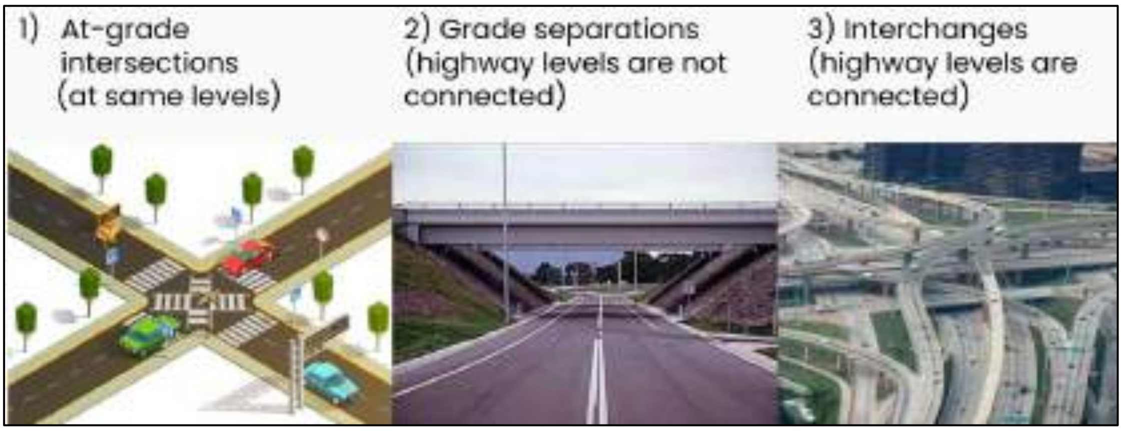
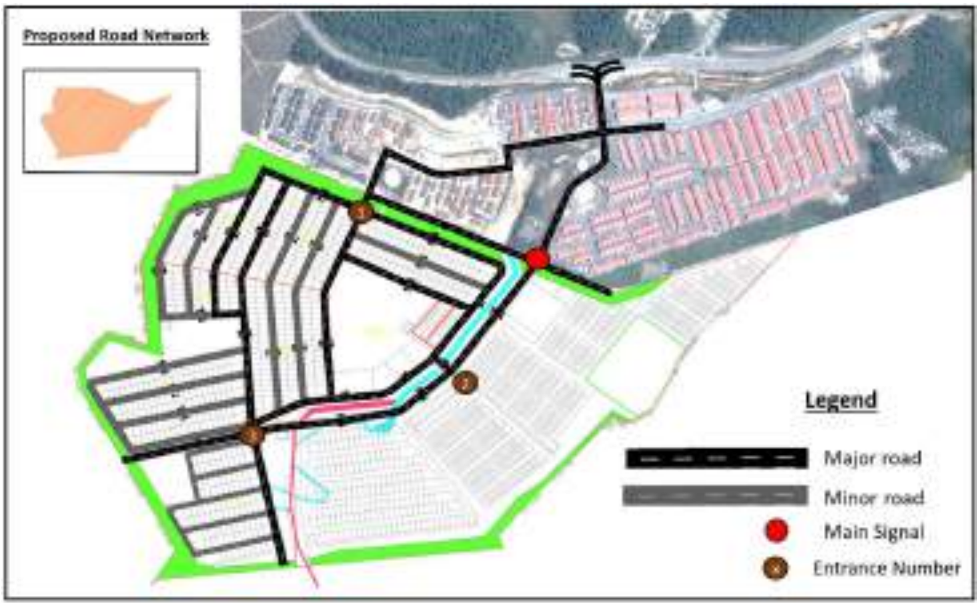


Figure 4.37 Types of Intersections based on proposed grades.

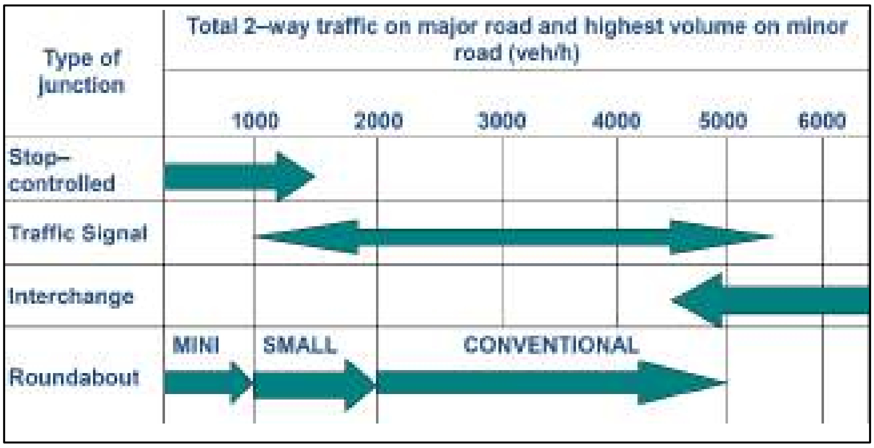
4.7.2 Design of Junction Control

<table>
<tr><th>Ref</th><th>Calculations</th><th>Output/
Remark</th></tr>
<tr><td>ATJ 11/87
Rev. 2017</td><td>

<u>Type of Junction Control:</u>



Criteria for Selection of Control Type



a) Main Intersection (Between Study Development A & B)

- Total 2-way traffic on Major road = 3,736 veh/hr
- Highest minor road volume = 346 veh/hr

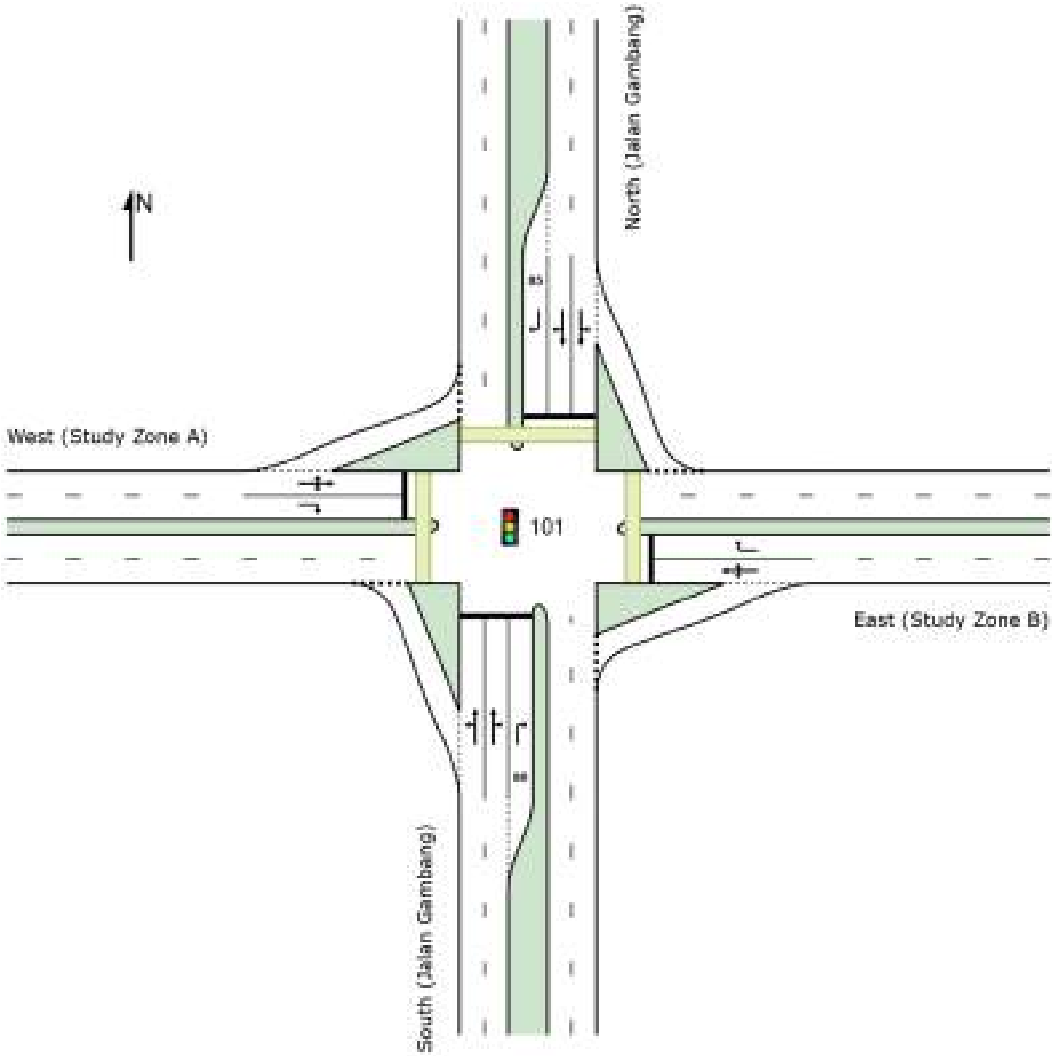
Total Volume = **4,082 veh/hr**

</td><td></td></tr>
</table>

A traffic signal is appropriate for this intersection because to the significant amount of traffic, as well as the constraints in terms of the geometry and size of the area.

Control Type
Traffic Signal

Proposed Layout of Signalized Intersection



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ATJ 11/87
Rev. 2017

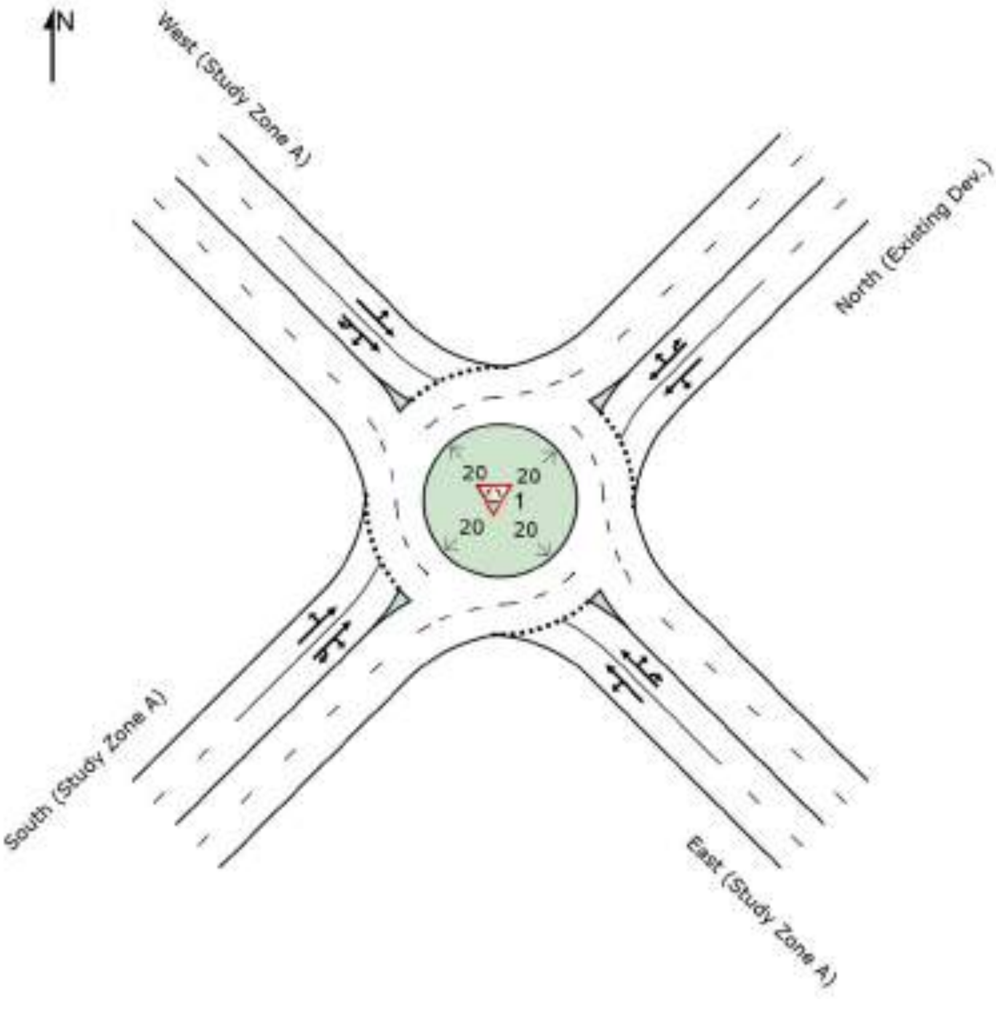
b) Entrance 1 (Study Zone A)

- Total 2-way traffic on Major road = 891 veh/hr
- Highest minor road volume = 126 veh/hr

Total Volume = **1,017 veh/hr**

Roundabouts are typically more effective in handling uninterrupted traffic flow, particularly in regions with modest traffic loads. They support for a continuous, cyclical motion that has the potential to reduce delays and enhance the overall flow of traffic.

Proposed Layout of Roundabout



Control Type
Roundabout

<table>
<tr>
<td>ATJ 11/87
Rev. 2017</td>
<td>

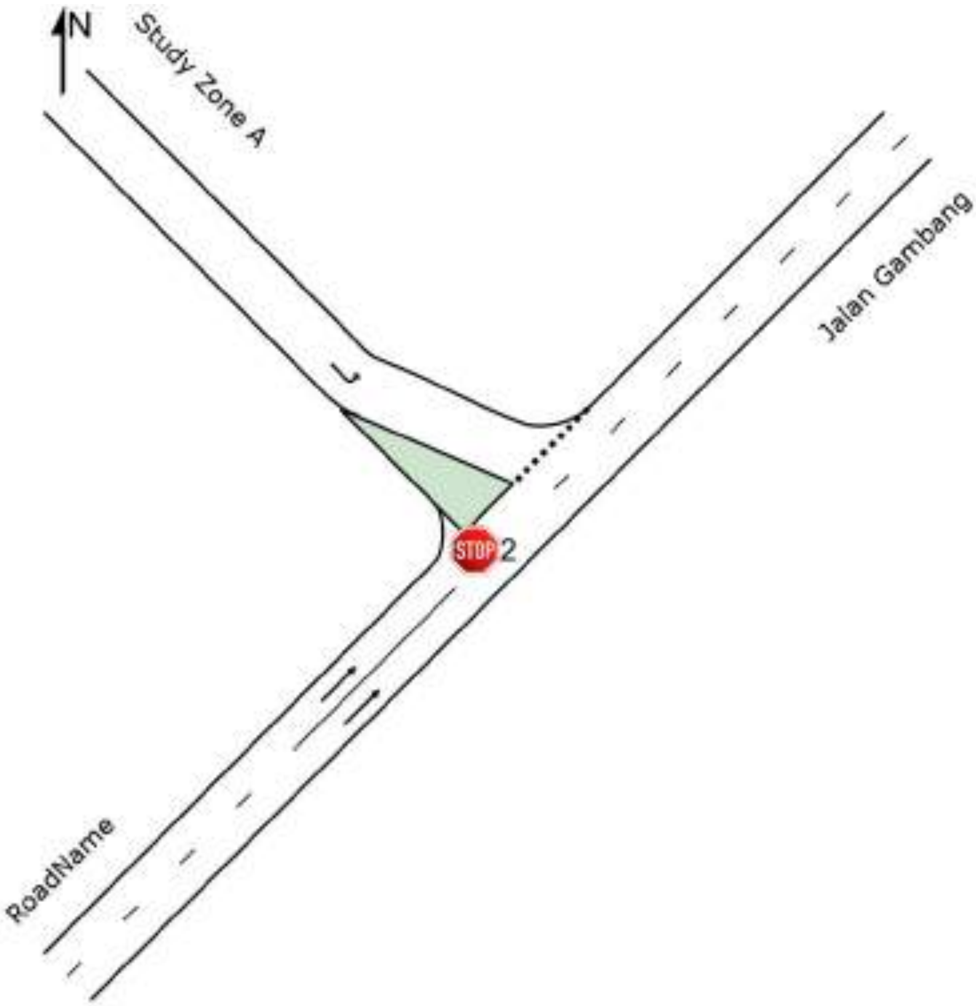
c) Entrance 2 (Exit only – Study Zone A)

- Total 2-way traffic on Major road = 358 veh/hr
- Left (Out) volume = 501 veh/hr

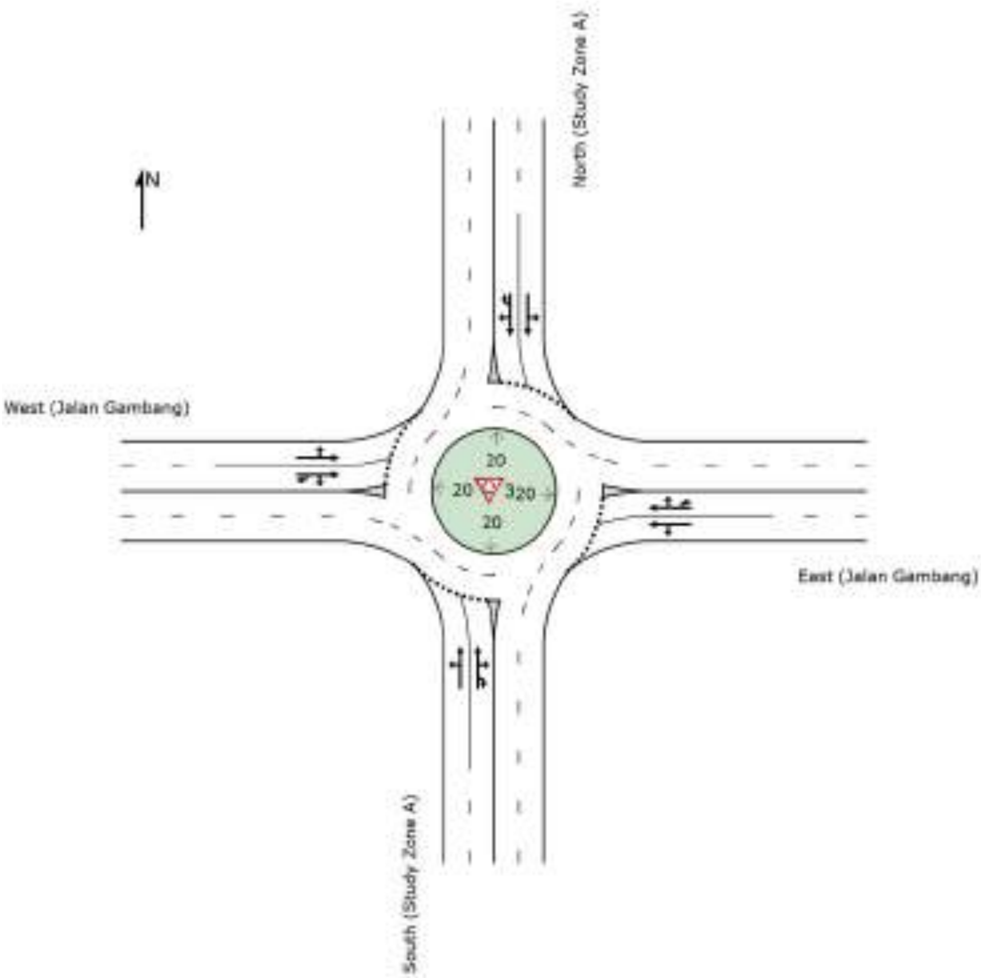
Total Volume = **859 veh/hr**

Since total volume is lower than 1000 veh/hr, the left out option is feasible. Therefore, left-turning vehicles typically need to yield to oncoming traffic.

<u>Proposed Layout of Left Out</u>

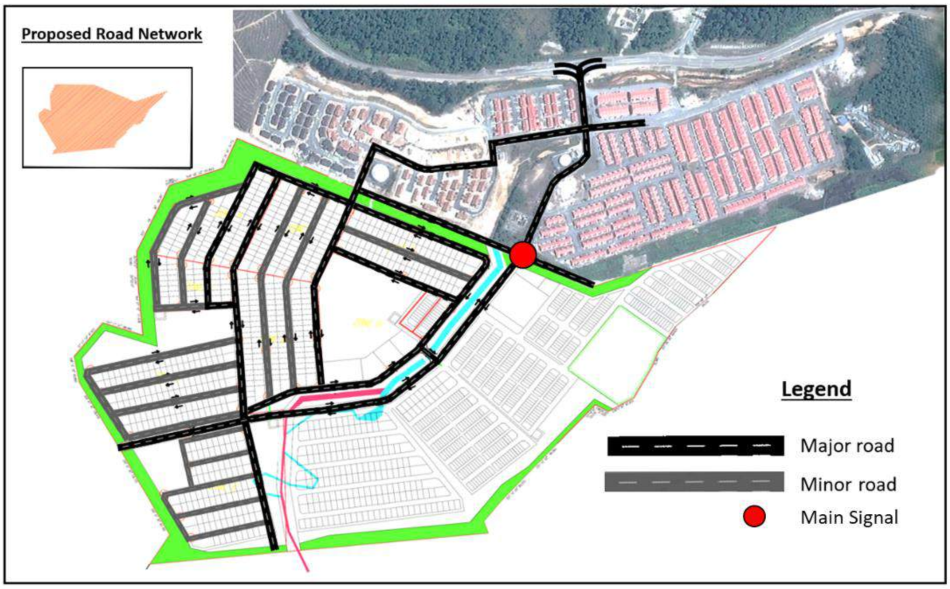


</td>
<td>Control Type
Stop Controlled</td>
</tr>
</table>

ATJ 11/87 Rev. 2017	**d) Entrance 3 (Study Zone A)** • Total 2-way traffic on Major road = 891 veh/hr • Highest minor road volume = 126 veh/hr Total Volume = 1,017 veh/hr Roundabouts are typically more effective in handling uninterrupted traffic flow, particularly in regions with modest traffic loads. They support for a continuous, cyclical motion that has the potential to reduce delays and enhance the overall flow of traffic. **<u>Proposed Layout of Roundabout</u>**  Refer to the next section for the design of signal phases and timings, as well as intersection performance.	Control Type **Roundabout**

4.7.3 Design Calculation of fixed-time Signal Control System

Ref	Calculations	Output/ Remark
	Location of Main Signal:	



General Details of the Intersection

Location:	Gambang, Pahang
No. of approaches:	4
Nearest Census station:	CR403, (Jalan Kuantan-Maran)
Annual growth rate:	2.91%
Approach lanes:	2 lanes each per direction
Lane width:	3.5 m each
Grade:	North Bound: -3% South Bound: +3% East Bound : +1% West Bound : -1%
Area:	Non - CBD

Warrant Analysis

ATJ 13/87 Rev. 2017

a) **Warrant #1 – Vehicular Operation (Traffic volume for each of any 8 hour)**

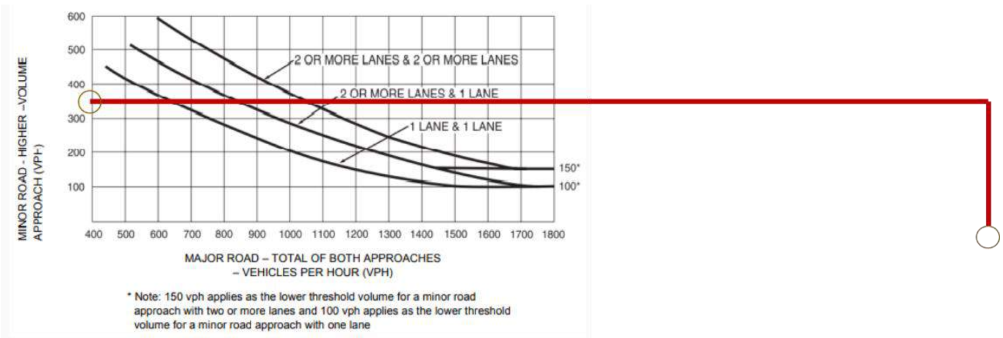
No records are attained which are related to the hour wise breakdown of volume of the area thus this analysis could not be performed.

ATJ 13/87 Rev. 2017

b) **Warrant #2 – Peak hour Volume – Urban Roads**

- Total 2-way traffic on Major road = 3,736 veh/hr
- Highest minor road volume = 346 veh/hr

Total Volume = **4,082 veh/hr**



Therefore, by using the major-minor road veh/hr limit curve extracted from Figure 4C-3, Manual on Uniform Traffic Control Devices (MUTCD), 2003 & Arahan Teknik Jalan 13/87 (Pindaan 2017), considering 2 lanes for all approaches, the red line drawn is above the curve indicating that **traffic signal must be warranted.**

Traffic Signal must be warranted.

ATJ 13/87 Rev. 2017

c) **Warrant #3 – Coordinated Signal System**

No records are attained which are related to the nearby signals and co-ordination of them. Thus this analysis could not be performed.

ATJ 13/87 Rev. 2017

d) **Warrant #4 – Pedestrian Safety**

No records are attained which are related to the pedestrian safety of the area thus this analysis could not be performed.

ATJ 13/87
Rev. 2017

e) Warrant #5 – Pedestrian Safety

No records are attained which are related to the pedestrian safety of the area thus this analysis could not be performed.

Therefore, a traffic signal must be designed and warranted as it satisfies the requirements present in Warrant 2.

Traffic Data

From	North				South		
To	LT	ST	RT		LT	ST	RT
Q (vph)	591	1229	430		173	1153	160

From	West				East		
To	LT	ST	RT		LT	ST	RT
Q (vph)	220	53	25		24	20	302

Guidelines for Separate Right Turn Phase Requirement

ATJ 13/87
Rev. 2017

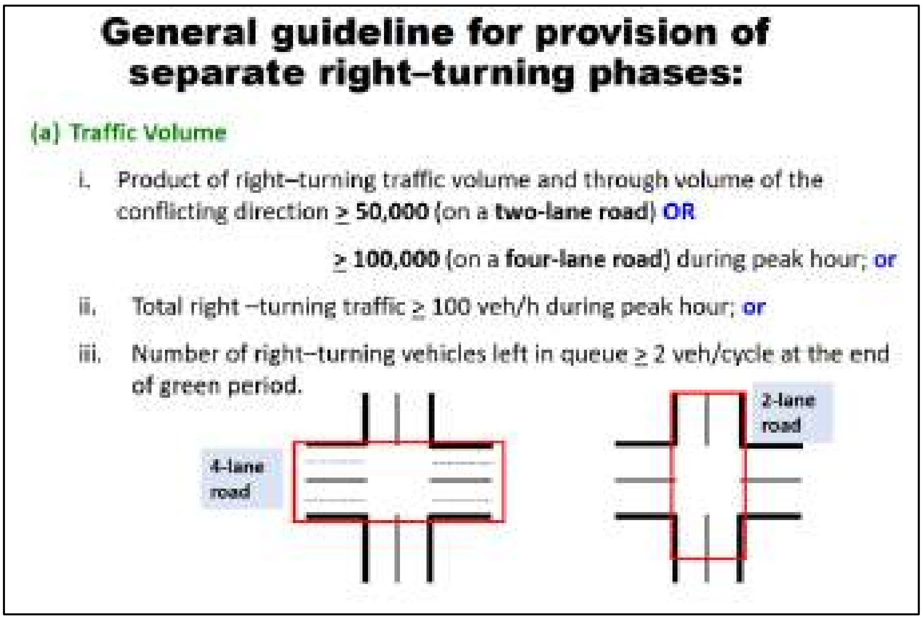


Figure 4.38 General Requirement for separate right turn (Extracted from ATJ 13/87, Adopted from notes of Ts. Che Ros bin Ismail)

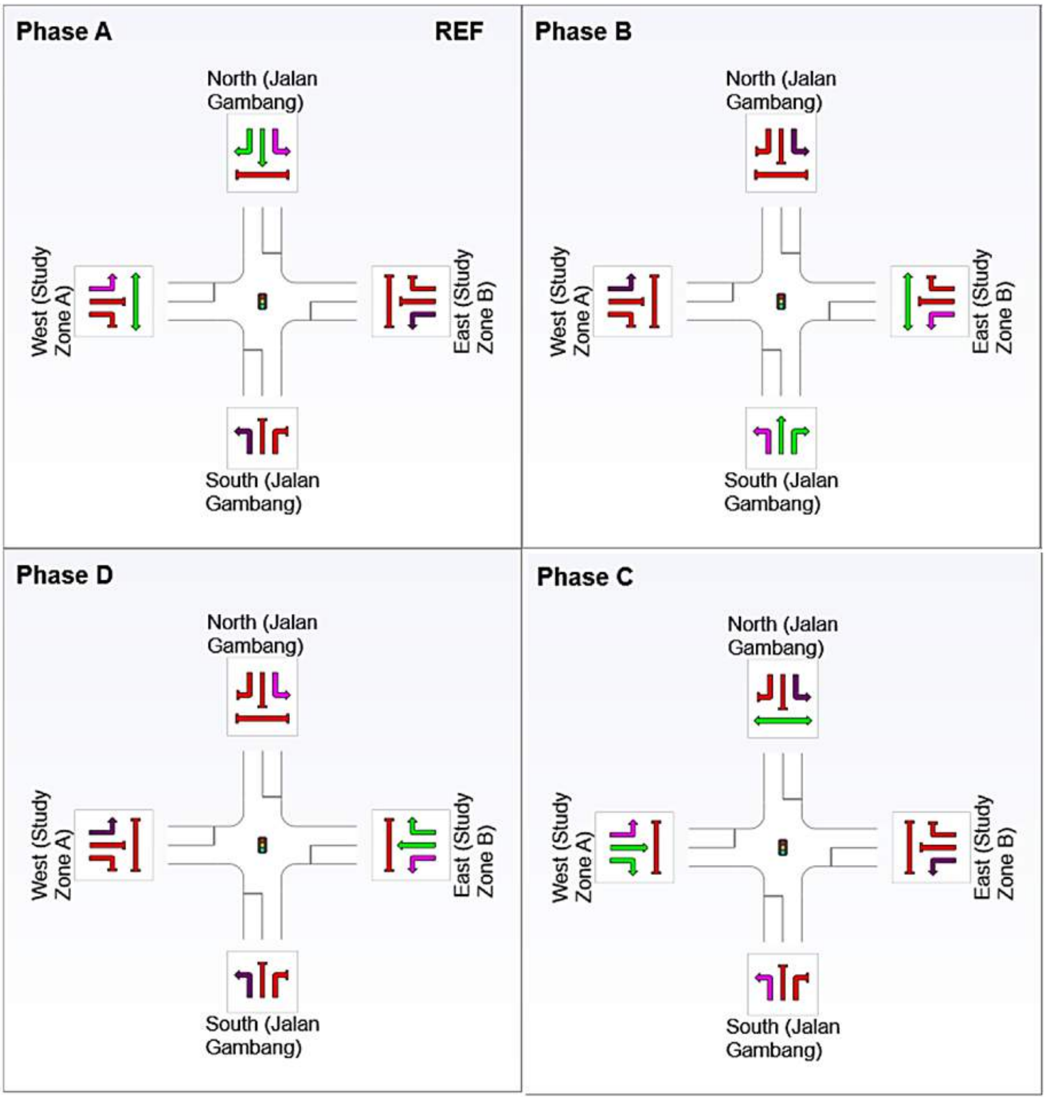
ATJ 13/87 Rev. 2017	**<u>Checking for Separate Right Turn Phase Requirement</u>** ➔ Assume using 2-phase system: • Phase 1 - Combination movement between North (N) and South (S). • Phase 2 - Combination movement between East (E) and West (W). ➔ **Phase 1:** <u>Conflict point between: N–S & S–E</u> = 1,229 x 160 = 196,640 > 100,000 **(for 4-lane road NOT OK!)** <u>Turning Volume</u> = 160 > 100 **(NOT OK!)** <u>Conflict point between: S–N & N–W</u> = 1,153 x 430 = 495,790 > 100,000 **(for 4-lane road NOT OK!)** <u>Turning Volume</u> = 430 > 100 **(NOT OK!)** • Therefore, combination movement between N and S is not suitable in a single phase.	Requirement **Split phasing**
	➔ **Phase 2:** <u>Conflict point between: E–W & W–S</u> = 20 x 25 = 500 < 100,000 **(for 4-lane road OK!)** <u>Turning Volume</u> = 25 < 100 **(OK!)** <u>Conflict point between: W–E & E–N</u> = 53 x 302 = 16,006 < 100,000 **(for 4-lane road OK!)** <u>Turning Volume</u> = 302 > 100 **(NOT OK!)** • Therefore, combination movement between E and W is not suitable in a single phase.	Requirement **Split phasing**

Hence, it requires at least a 4 phase system.

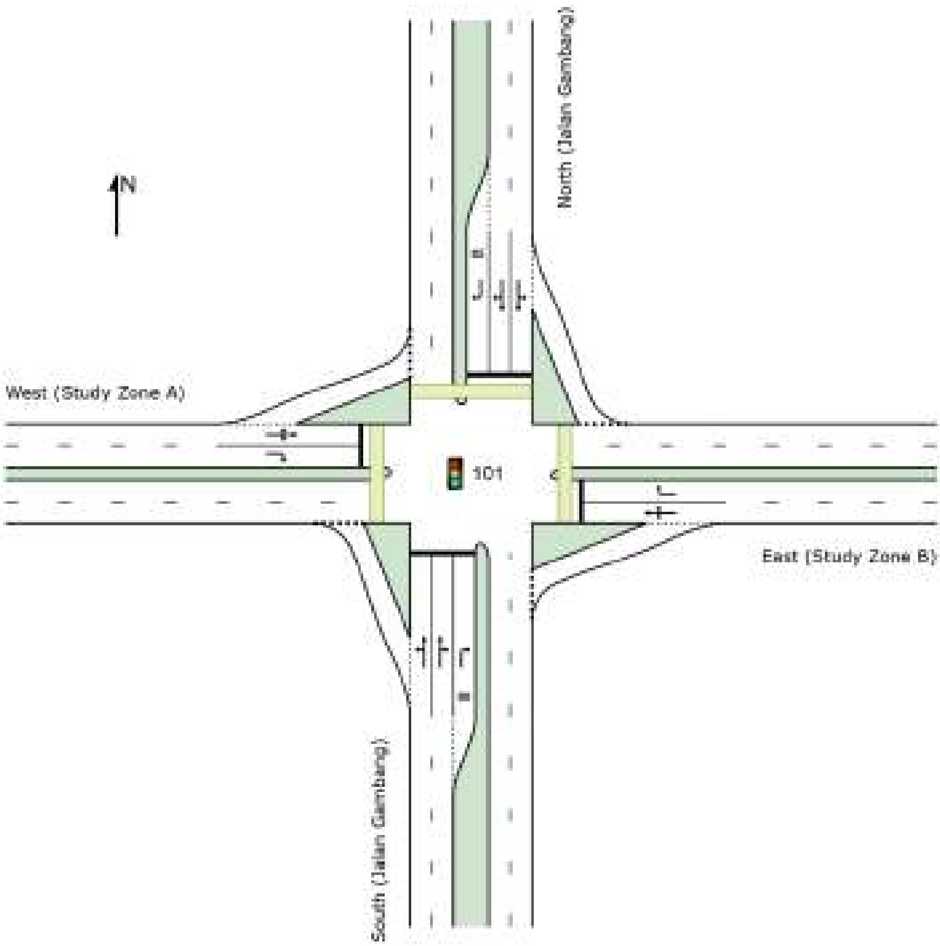
Phase A: All movements from North Approach
Phase B: All movements from South Approach
Phase C: All movements from West Approach
Phase D: All movements from East Approach

Total no. of phases **4 phases**

Phasing Diagram



Proposed Layout of Signalized Intersection



Critical flow ratio for each phase and for the intersection

Phase	Phase A				Phase B		
From		North				South	
To	LT	ST	RT		LT	ST	RT
Q (vph)	591	1229	430		173	1153	160
Saturation flow, So		1930				1930	
No of lanes		2	1			2	1
fw		0.96	0.96			0.96	0.96
fg		1.001	1.001			0.998	0.998
fa		1	1			1	1
flt		1.000	1.000			1.000	1.000
frt		1.000	0.840			1.000	0.840
1/fc	Yield	0.909	0.909		Yield	0.909	0.909
Adjusted S'		3372	1416			3362	1412
y=q/S'		0.38	0.32			0.36	0.12
		0.38				0.36	

DESIGN BASED ON ATJ 13/87 (Pindaan 2017) (MHCM 2006 – the Malaysia version of U.S. HCM) & U.S. HCM2010 (i.e., for the Cycle Time & Signal Setting)

Phase	Phase C				Phase D		
From		West				East	
To	LT	ST	RT		LT	ST	RT
Q (vph)	220	53	25		24	20	302
Saturation flow, So		1930				1930	
No of lanes		2				2	
fw		0.96				0.96	
fg		0.999				1.000	
fa		1				1	
flt		1.000				1.000	
frt		0.895				0.845	
1/fc	Yield	0.909			Yield	0.909	
Adjusted S'		3013				2849	
y=q/S'		0.03				0.12	
		0.03				0.12	

Y_{max} = 0.38 + 0.36 + 0.03 + 0.12 = **0.89 < 1.00 OK!**

Selection design criteria & lost time

- Initial delay, l = 2 sec/phase
- Amber period, a = 3 sec
- All-red period, R = 2 sec/phase
- End gain, e = 2 sec/phase

➔ **Lost time per phase** = l + a + R – e

t_L = 2 + 3 +2 – 2 = **5 sec/phase**

➔ **Total Lost time per cycle** = $t_{L1} + t_{L2} + t_{L3} + t_{L4}$

L = 5 + 5 + 5 + 5 = **20 sec**

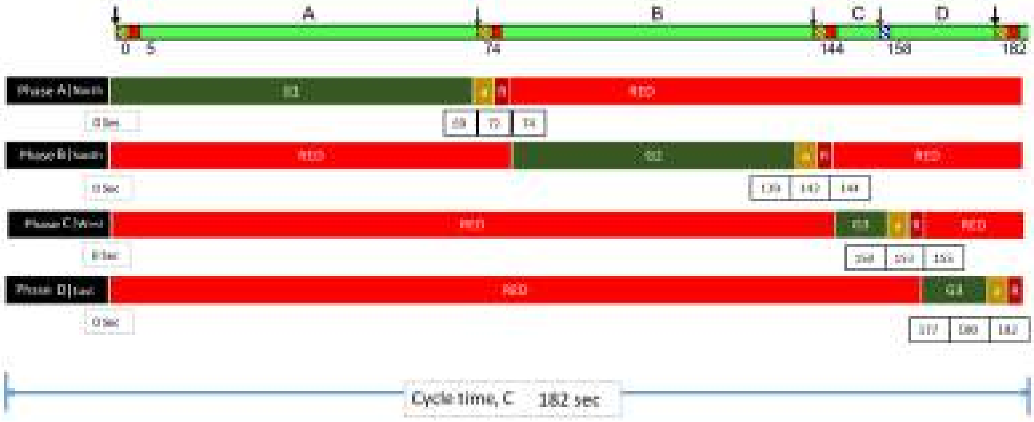
Y_{max} = 0.89

Total lost time per cycle,

L = 20 sec

	Cycle time & timing setting using U.S. HCM 2010 formula **C =** $\frac{L\,(Xc)}{Xc - \sum yc,i}$ sec **L :** Cycle lost time **Xc:** Critical Junction flow ratio **yc,i:** Critical flow ratio for phase i targeted Xc = 1.0 $\therefore$ **Cycle time, C** $= \frac{20\,(1.0)}{1.0 - 0.89} = \mathbf{182\ sec}$ **Effective Green Period, gi** gi = yi ($\frac{C}{Xc}$) • **Phase A:** $g_A = \frac{0.38\,(182)}{1.0}$ = 69 sec • **Phase B:** $g_B = \frac{0.36\,(182)}{1.0}$ = 65 sec • **Phase C:** $g_C = \frac{0.03\,(182)}{1.0}$ = 6 sec • **Phase D:** $g_D = \frac{0.12\,(182)}{1.0}$ = 22 sec **Check: $g_A + g_B + g_C + g_D + L = C$** : 69 + 65 + 6 +22 + 20 = **182 sec** Therefore, the design is arithmetically correct. **Actual Green or Displayed Green Period, Gi = gi – a – R + t_L** • G_A = 69 sec • G_B = 65 sec • G_C = 6 sec • G_D = 22 sec	(Adopted from notes of Dr. Che Othman, Cycle time formula provided in ATJ 13/87 Revision 2017 is incorrect) Total cycle time, **C = 182 sec**

Timing Diagram



4.7.4 Operational Performance Assessment

Ref	Calculations	Output/ Remark

<u>Capacity and Level of Service</u>

The idea of level of service is frequently employed to define the operational conditions for various categories of road infrastructure. The service volume refers to the highest capacity of traffic that may be handled while still meeting the specified operating requirements for a certain level of service.

The tables below provides definitions for the various levels contained in the Level of Service as well as different range of values for control ddelay per vehicle specified by HCM 2000 as the criteria for unsignalized and signalized intersection.

HCM 2000

LOS	Typical operating conditions	
	Roadways	*Intersections*
A	Free flowing traffic conditions	Little or no delay
B	Still free flowing traffic conditions	Short traffic delays
C	Traffic flow is still under stable conditions	Average traffic delays
D	Approaching unstable flow and vehicle movements are constrained by high volume of traffic	Long traffic delays
E	Unstable flow	Very long traffic delays
F	Congested flow	Extremely long traffic delays

HCM 2000

Definitions of levels of service for signalized intersections

LOS	Criteria: Control Delay per vehicle (sec/veh)
A	≤ 10
B	> 10 to 20
C	> 20 to 35
D	> 35 to 55
E	> 55 to 80
F	> 80

HCM 2000

Definitions of levels of service for unsignalized intersections		
LOS	**Criteria: Control Delay (sec/veh)**	**Expected delay to minor road traffic**
A	≤ 10	Little or no delay
B	> 10 to 15	Short traffic delays
C	> 15 to 25	Average traffic delays
D	> 25 to 35	Long traffic delays
E	> 35 to 50	Very long traffic delays
F	> 50	Extremely long traffic delays

Operational Performance Assessment Tool

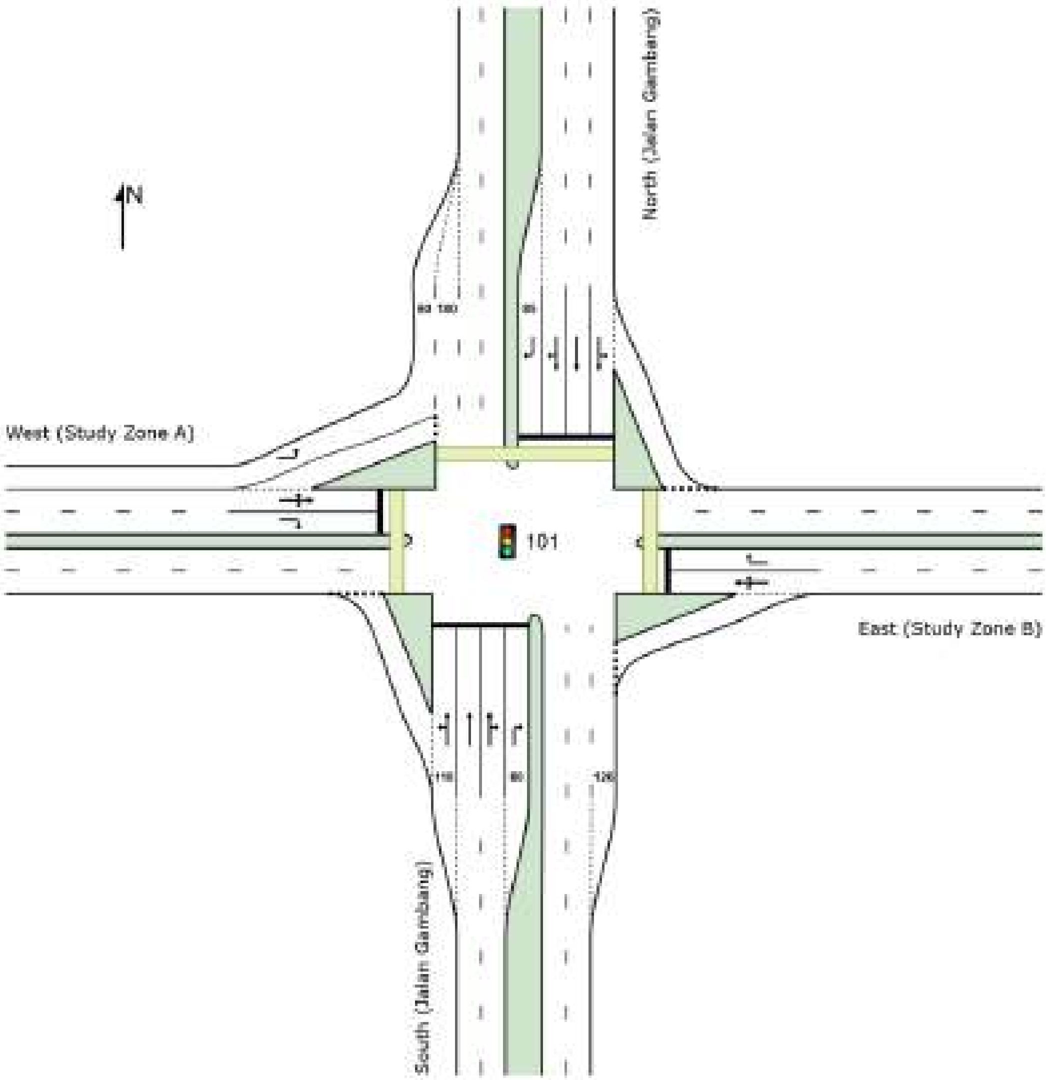
The Sidra Intersection software is renowned for its ability was used to accurately simulate and model the operational performance of intersections with traffic signals as well as those without signals. This tool is extensively utilized by transportation engineers, urban planners, and researchers to assess the efficiency and efficacy of intersection designs, signal timings, and other traffic management.

SIDRA software

a) Main Signalized Intersection (Between Study Development A & B)

Level of Service - Unmitigated

Vehicle Movement Performance																
Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
South: South (Jalan Gambang)																
1	L2	All MCs	173	2.0	173	2.0	1.037	52.8	LOS D	74.8	532.4	1.00	1.10	1.23	20.1
2	T1	All MCs	1153	2.0	1153	2.0	* 1.037	100.6	LOS F	74.8	532.4	1.00	1.14	1.24	21.3
3	R2	All MCs	160	2.0	160	2.0	0.245	84.8	LOS F	9.8	69.8	0.75	0.77	0.75	32.5
Approach			1486	2.0	1486	2.0	1.037	93.4	LOS F	74.8	532.4	0.97	1.10	1.19	21.9
East: East (Study Zone B)																
4	L2	All MCs	24	2.0	24	2.0	0.774	32.2	LOS C	15.4	109.6	1.00	0.90	1.07	22.2
5	T1	All MCs	20	2.0	20	2.0	* 0.774	108.4	LOS F	15.4	109.6	1.00	0.90	1.07	22.5
6	R2	All MCs	302	2.0	302	2.0	0.774	102.2	LOS F	15.4	109.6	1.00	0.88	1.07	22.9
Approach			346	2.0	346	2.0	0.774	97.7	LOS F	15.4	109.6	1.00	0.89	1.07	22.8
North: North (Jalan Gambang)																
7	L2	All MCs	591	2.0	591	2.0	1.418	204.7	LOS F	129.1	919.2	1.00	1.33	1.76	11.4
8	T1	All MCs	1229	2.0	1229	2.0	* 1.418	300.0	LOS F	129.1	919.2	1.00	1.50	1.77	11.5
9	R2	All MCs	430	2.0	430	2.0	1.063	163.5	LOS F	47.4	337.6	1.00	1.13	1.33	19.6
Approach			2250	2.0	2250	2.0	1.418	248.9	LOS F	129.1	919.2	1.00	1.39	1.68	12.4
West: West (Study Zone A)																
10	L2	All MCs	232	2.0	232	2.0	1.656	334.6	LOS F	32.4	230.5	1.00	1.45	2.03	8.0
11	T1	All MCs	56	2.0	56	2.0	* 1.656	423.6	LOS F	32.4	230.5	1.00	1.45	2.03	8.0
12	R2	All MCs	26	2.0	26	2.0	0.291	99.2	LOS F	2.4	16.7	1.00	0.72	1.00	22.6
Approach			314	2.0	314	2.0	1.656	330.7	LOS F	32.4	230.5	1.00	1.39	1.95	8.4
All Vehicles			4396	2.0	4396	2.0	1.656	190.3	LOS F	129.1	919.2	0.99	1.25	1.49	14.6

	Therefore, LOS F is obtained from Sidra Analysis which is critically showing failure of intersection in comparison to the minimum design standard of LOS D. Hence, the signal requires mitigation to improve the level of service. **<u>Layout of Mitigated Signalized Intersection</u>**  The current design underwent geometrical enhancement whereby one additional storage lane was added to South, North and West approaches. This resulted in a reduction of total cycle time by 26 secs from 182 secs to 156 secs.	Average Delay **LOS F**

SIDRA software

Level of Service - Mitigated

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
South: South (Jalan Gambang)															
1	L2	All MCs	173	2.0	173	2.0	0.460	12.4	LOS B	18.9	134.8	0.79	0.75	0.79	35.4
2	T1	All MCs	1153	2.0	1153	2.0	*0.790	63.1	LOS E	33.4	237.9	0.94	0.84	0.94	34.1
3	R2	All MCs	160	2.0	160	2.0	0.237	58.8	LOS E	8.3	59.2	0.74	0.76	0.74	34.8
Approach			1486	2.0	1486	2.0	0.790	56.7	LOS E	33.4	237.9	0.90	0.82	0.90	34.3
East: East (Study Zone B)															
4	L2	All MCs	24	2.0	24	2.0	0.970	43.7	LOS D	15.8	112.6	1.00	1.02	1.32	22.0
5	T1	All MCs	20	2.0	20	2.0	*0.970	108.7	LOS F	15.8	112.6	1.00	1.02	1.32	22.3
6	R2	All MCs	302	2.0	302	2.0	0.970	108.8	LOS F	15.8	112.6	1.00	1.01	1.32	22.0
Approach			346	2.0	346	2.0	0.970	104.2	LOS F	15.8	112.6	1.00	1.01	1.32	22.0
North: North (Jalan Gambang)															
7	L2	All MCs	591	2.0	591	2.0	0.608	10.5	LOS B	20.8	148.3	0.70	0.79	0.70	45.2
8	T1	All MCs	1229	2.0	1229	2.0	*0.889	63.2	LOS E	51.5	367.0	0.99	0.96	1.07	32.0
9	R2	All MCs	430	2.0	430	2.0	0.758	63.1	LOS E	27.8	198.3	0.93	0.86	0.93	32.9
Approach			2250	2.0	2250	2.0	0.889	49.3	LOS D	51.5	367.0	0.90	0.90	0.94	34.8
West: West (Study Zone A)															
10	L2	All MCs	232	2.0	232	2.0	0.126	8.1	LOS A	0.0	0.0	0.00	0.53	0.00	53.3
11	T1	All MCs	56	2.0	56	2.0	*0.754	87.7	LOS F	4.6	32.7	1.00	0.83	1.17	24.8
12	R2	All MCs	26	2.0	26	2.0	0.374	89.8	LOS F	2.1	14.9	1.00	0.72	1.00	24.0
Approach			314	2.0	314	2.0	0.754	29.1	LOS C	4.6	32.7	0.26	0.60	0.29	40.8
All Vehicles			4396	2.0	4396	2.0	0.970	54.7	LOS D	51.5	367.0	0.86	0.86	0.91	33.5

Therefore, LOS D is based on an average delay of 54.7 secs is obtained from Sidra Analysis which is in par with the minimum design standard of LOS D.

Hence, the mitigated signal set up is acceptable.

Average Delay
54.7 secs
LOS D

SIDRA software	**b) Roundabout at Entrance 1 (Study Zone A)** <u>Level of Service - Unmitigated</u>	

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
SouthEast: East (Study Zone A)															
21	L2	All MCs	25	2.0	25	2.0	0.051	5.4	LOS A	0.1	1.0	0.40	0.35	0.40	50.5
22	T1	All MCs	13	0.0	13	0.0	0.051	5.2	LOS A	0.1	1.0	0.40	0.35	0.40	51.1
23	R2	All MCs	77	2.0	77	2.0	0.116	5.9	LOS A	0.3	2.3	0.40	0.35	0.40	47.0
23u	U	All MCs	12	2.0	12	2.0	0.116	5.9	LOS A	0.3	2.3	0.40	0.35	0.40	47.0
Approach			126	1.8	126	1.8	0.116	5.8	LOS A	0.3	2.3	0.40	0.35	0.40	48.1
NorthEast: North (Existing Dev.)															
24	L2	All MCs	111	2.0	111	2.0	0.278	6.2	LOS A	0.9	6.6	0.23	0.12	0.23	50.0
25	T1	All MCs	385	2.0	385	2.0	0.278	6.2	LOS A	1.0	7.0	0.24	0.13	0.24	50.1
26	R2	All MCs	56	0.0	56	0.0	0.278	6.2	LOS A	1.0	7.0	0.25	0.13	0.25	49.0
26u	U	All MCs	13	2.0	13	2.0	0.278	6.3	LOS A	1.0	7.0	0.25	0.13	0.25	49.0
Approach			564	1.8	564	1.8	0.278	6.2	LOS A	1.0	7.0	0.24	0.13	0.24	49.9
NorthWest: West (Study Zone A)															
27	L2	All MCs	69	2.0	69	2.0	0.083	5.1	LOS A	0.2	1.6	0.35	0.27	0.35	50.6
28	T1	All MCs	16	2.0	16	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	49.0
29	R2	All MCs	23	2.0	23	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	48.2
29u	U	All MCs	14	2.0	14	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	48.2
Approach			122	2.0	122	2.0	0.083	5.1	LOS A	0.2	1.6	0.35	0.28	0.35	49.6
SouthWest: South (Study Zone A)															
30	L2	All MCs	35	2.0	35	2.0	0.169	5.3	LOS A	0.5	3.6	0.25	0.15	0.25	50.7
31	T1	All MCs	227	2.0	227	2.0	0.169	5.3	LOS A	0.5	3.8	0.26	0.16	0.26	50.6
32	R2	All MCs	48	2.0	48	2.0	0.169	5.3	LOS A	0.5	3.8	0.27	0.16	0.27	49.1
32u	U	All MCs	17	2.0	17	2.0	0.169	5.3	LOS A	0.5	3.8	0.27	0.16	0.27	49.1
Approach			327	2.0	327	2.0	0.169	5.3	LOS A	0.5	3.8	0.26	0.16	0.26	50.3
All Vehicles			1140	1.9	1140	1.9	0.278	5.8	LOS A	1.0	7.0	0.28	0.18	0.28	49.8

	Therefore, LOS A based on average delay of 5.8 is obtained from Sidra Analysis which is the best level that can be obtained and is in par with the minimum design standard of LOS D. Hence, the original design of the roundabout is acceptable.	Average Delay **5.8 secs** **LOS A**

SIDRA software

c) Left OUT at Entrance 2 (Study Zone A)

<u>Level of Service - Unmitigated</u>

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
NorthWest: Study Zone A															
7	L2	All MCs	501	2.0	501	2.0	0.362	6.5	LOS A	1.9	13.6	0.35	0.57	0.35	51.9
Approach			501	2.0	501	2.0	0.362	6.5	LOS A	1.9	13.6	0.35	0.57	0.35	51.9
SouthWest: RoadName															
11	T1	All MCs	358	2.0	358	2.0	0.093	0.0	LOS A	0.0	0.0	0.00	0.00	0.00	60.0
Approach			358	2.0	358	2.0	0.093	0.0	NA	0.0	0.0	0.00	0.00	0.00	60.0
All Vehicles			859	2.0	859	2.0	0.362	3.8	NA	1.9	13.6	0.21	0.33	0.21	55.0

Therefore, LOS A is based on an average delay of 3.8 secs that is obtained from Sidra Analysis which is the best level that can be obtained and is in par with the minimum design standard of LOS D.

Hence, the original design of the left OUT is acceptable.

Average Delay
3.8 secs
LOS A

SIDRA software

d) Roundabout at Entrance 3 (Study Zone A)

Level of Service - Unmitigated

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total	HV]	Arrival Flows [Total	HV]	Deg. Satn	Aver. Delay	Level of Service	95% Back Of Queue [Veh.	Dist]	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed
			veh/h	%	veh/h	%	v/c	sec		veh	m				km/h
South: South (Study Zone A)															
21	L2	All MCs	11	2.0	11	2.0	0.041	6.9	LOS A	0.1	0.8	0.51	0.49	0.51	49.5
2	T1	All MCs	13	2.0	13	2.0	0.041	6.9	LOS A	0.1	0.8	0.51	0.49	0.51	50.0
23	R2	All MCs	143	2.0	143	2.0	0.264	9.6	LOS A	0.8	5.9	0.56	0.55	0.56	45.0
23u	U	All MCs	12	2.0	12	2.0	0.264	9.6	LOS A	0.8	5.9	0.56	0.55	0.56	45.0
Approach			178	2.0	178	2.0	0.264	9.3	LOS A	0.8	5.9	0.55	0.54	0.55	45.6
East: East (Jalan Gambang)															
24	L2	All MCs	158	2.0	158	2.0	0.161	4.8	LOS A	0.5	3.6	0.17	0.07	0.17	50.8
25	T1	All MCs	11	2.0	11	2.0	0.161	4.8	LOS A	0.5	3.6	0.17	0.07	0.17	51.3
6	R2	All MCs	711	2.0	711	2.0	0.688	13.0	LOS B	4.9	34.8	0.38	0.17	0.38	43.3
26u	U	All MCs	13	2.0	13	2.0	0.688	13.0	LOS B	4.9	34.8	0.38	0.17	0.38	43.3
Approach			892	2.0	892	2.0	0.688	11.5	LOS B	4.9	34.8	0.34	0.15	0.34	44.5
North: North (Study Zone A)															
7	L2	All MCs	215	2.0	215	2.0	0.226	6.0	LOS A	0.8	5.4	0.30	0.19	0.30	50.0
8	T1	All MCs	16	2.0	16	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	49.3
9	R2	All MCs	11	2.0	11	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	48.5
9u	U	All MCs	22	2.0	22	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	48.5
Approach			263	2.0	263	2.0	0.226	5.7	LOS A	0.8	5.4	0.30	0.18	0.30	49.8
West: West (Jalan Gambang)															
10	L2	All MCs	11	2.0	11	2.0	0.040	7.3	LOS A	0.1	0.8	0.54	0.54	0.54	49.2
31	T1	All MCs	11	2.0	11	2.0	0.040	7.3	LOS A	0.1	0.8	0.54	0.54	0.54	49.7
32	R2	All MCs	11	2.0	11	2.0	0.042	7.7	LOS A	0.1	0.8	0.56	0.56	0.56	45.7
32u	U	All MCs	11	2.0	11	2.0	0.042	7.7	LOS A	0.1	0.8	0.56	0.56	0.56	45.7
Approach			42	2.0	42	2.0	0.042	7.5	LOS A	0.1	0.8	0.55	0.55	0.55	47.5
All Vehicles			1375	2.0	1375	2.0	0.688	10.0	LOS A	4.9	34.8	0.37	0.22	0.37	45.7

Therefore, LOS A is based on an average delay of 10.0 secs is obtained from Sidra Analysis which is the best level that can be obtained and is in par with the minimum design standard of LOS D.

Hence, the original design of the roundabout is acceptable.

Average Delay
10.0 secs
LOS A

4.8 Horizontal Alignment

4.8.1 Introduction

Horizontal alignment relates to establishing a linkage in the horizontal dimension of a road layout, encompassing the relationship between design speed and curve, as well as superelevation and side friction.

4.8.2 Superelevation Rate

According to ATJ 8/86, a superelevation rate ranging from 6% to 10% can be utilized as a design criterion for horizontal alignment design (2015). In regions where weather conditions often result in slick road surfaces and slow vehicle speeds, the superelevation should not exceed eight percent.

4.8.3 Minimum Radius

The minimum radius for the given speed is calculated using the maximum superelevation rate and the maximum permissible side friction factor. The ATJ 8/86 (2015) standard curve formula can be utilized for determining the minimum safe radius.

$$\boxed{R_{min} = \frac{V^2}{127(e + f)}}$$

where, R_{min} = Minimum radius of circular curve, m

V = Design Speed, km/h

e = Maximum superelevation rate

f = Maximum allowable side friction factor

Table 27 Minimum Radius (Extracted from Table 4.5 in ATJ 8/86 (2015))

Design Speed (kph)	Minimum Radius (m)		
	e = 0.06	e = 0.08	e = 0.10
120	755	665	595
110	560	500	455
100	435	395	360
90	335	305	275
80	250	230	210
70	195	175	160
60	135	125	115
50	90	80	75
40	55	50	45
30	30	30	25

The design standard of the major road is U5 (Arterial) with design speed of 60 km/h and minor road is U3 (Local Street) with design speed of 40 km/h. Assumption is made for superelevation rate value, which is e = 0.08. Hence, the design minimum radius obtained is 125 m and 50 m respectively.

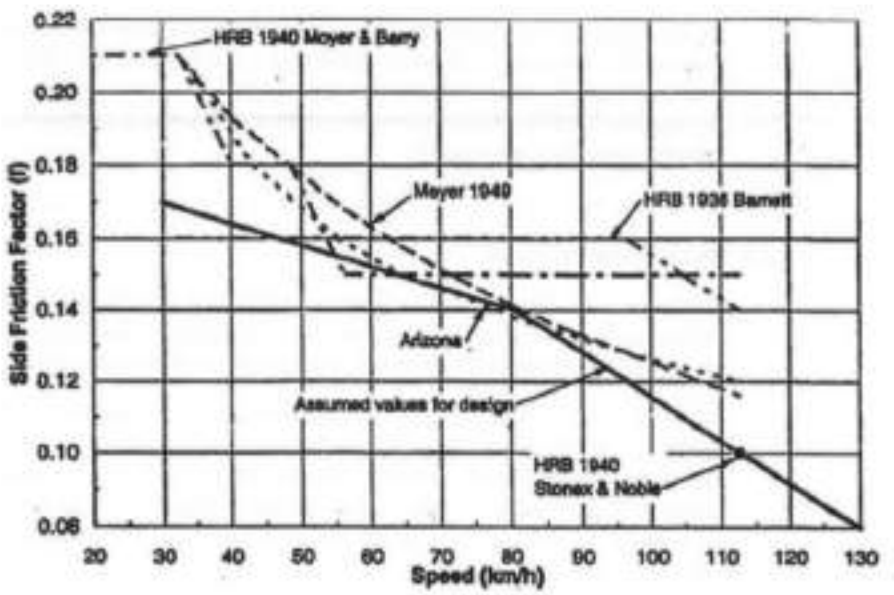


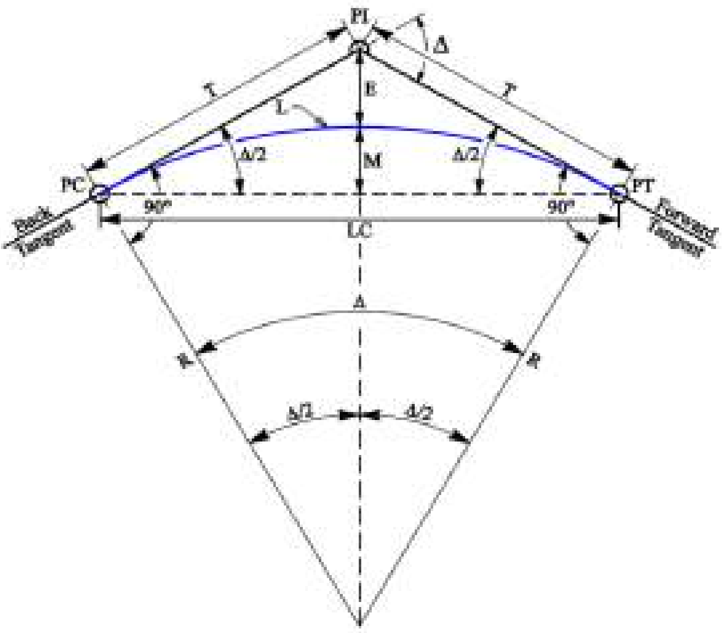
Figure 4.39 The maximum allowable friction graph

The maximum allowable friction is obtained f = 0.16 from the assumed value for design line from the graph plotted above.

4.8.4 Design of Horizontal Curve

In order to ensure the comfort and safety of interacting with other road users, it is essential to have a horizontal alignment design. The calculation and design of the horizontal curve in the area adhere to the specifications outlined in ATJ 8/86 (2015) and Chapter 4: Highway Geometric Design from Traffic Engineering as well as Chapter 2: Horizontal Alignment from Highway Infrastructure Design Notes.

4.8.4.1 Circular Curve Components



R = Radius

PC = Point of Curvature (point at which the curve begins)

PT = Point of Tangent (point at which the curve ends)

PI = Point of Intersection (point at which the two tangents intersect)

T = Tangent Length (distance from PC to PI or PI to PT)

LC = Long Chord Length (straight line between PC and PT)

L = Curve Length (distance from PC to PT measured along the curve)

M = Middle Ordinate (distance from midpoint of LC to midpoint of the curve)

E = External Distance (distance from vertex to curve)

Δ = Deflection Angle (change in direction of two tangents)

4.8.4.2 General Cicular Curve Formula

Since the horizontal is represented by a circular curve, it is crucial to build the alignment with the appropriate radius of curvature. Since the minimum radius is a limiting value of curvature, every attempt should be made to design the horizontal curves with a radius bigger than the necessary minimum values for increased comfort and safety.

The following formula needs to be used to compute a number of requirements for a complete circular curve design.

- **Length of curve**

$$L = R \times \frac{2\pi\Delta}{360^o}$$

- **Length of the long chord**

$$LC = 2R \sin\left(\frac{\Delta}{2}\right)$$

- **Length of the tangent**

$$T = R \tan\left(\frac{\Delta}{2}\right)$$

- **Length of the external distance**

$$E = T \tan\left(\frac{\Delta}{4}\right) = R\left(\frac{1}{cos\frac{1}{2}\Delta} - 1\right)$$

- **Length of the middle ordinate**

$$M = E \cos\left(\frac{\Delta}{2}\right) = R\left(1 - cos\frac{1}{2}\Delta\right)$$

Where,

R = **Radius of Curve, m**

Δ = **Deflection Angle of Curve**

4.8.4.3 Location of Horizontal Alignment

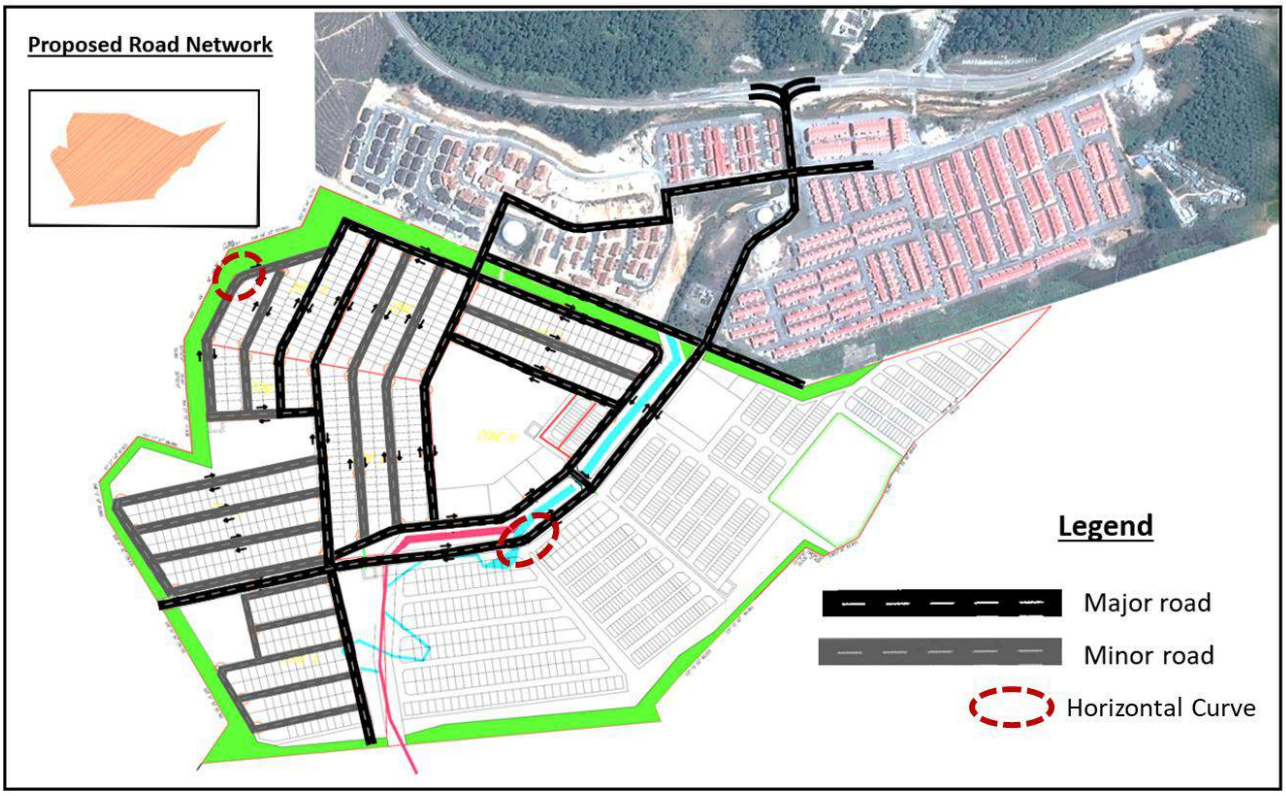


Figure 4.40 Proposed Layout of Road Network with points of Horizontal alignment

4.8.4.4 Calculation of Horizontal Alignment

Ref	Calculations	Output/ Remark
ATJ 8/86 2015 **ATJ 8/86 2015** (Page 15)	a) **<u>Circular Curve @ Jalan Gambang (South)</u>** Design Standard = U5 (Arterial Road) Design Speed, v = 60 km/hr Superelevation , e = 8% Minimum Radius = 125 m Side friction factor, f = 0.16 <u>Radius of Curve, R</u> R = $\frac{V^2}{127\ (e+f)}$	According to ATJ 8/86 (2015), e between 6% – 10% can be used. Since there is no field data, e is assumed to be 8%.

	$R = \frac{60^2}{127\ (0.08+0.16)}$ R = 118 m < 125 m (Use minimum radius = 125 m) **Length of circular curve** Angle, Δ = 32° (Angle between two tangents) • <u>Length of tangent, T</u> $T = R \times \tan\left(\frac{\Delta}{2}\right)$ $= 125 \times \tan\left(\frac{32}{2}\right)$ = 35.8 m • <u>Length of long cord, Lc</u> $Lc = 2R \times \sin\left(\frac{\Delta}{2}\right)$ $= 2 \times 125 \times \sin\left(\frac{32}{2}\right)$ = 68.91 m • <u>Length of curve, L</u> $L = R \times \left(\frac{2\pi\Delta}{360}\right)$ $= 125 \times \left(\frac{2\pi(32)}{360}\right)$ = 69.81 m • <u>Length of external distance, E</u> $E = T \times \tan\left(\frac{\Delta}{4}\right)$ $= 35.8 \times \tan\left(\frac{32}{4}\right)$ = 5.03 m	Obtained from CAD drawing.

	• <u>Length of middle ordinate, M</u> M = E x cos $(\frac{\Delta}{2})$ = 5.03 x cos $(\frac{32}{2})$ = 4.84 m	
ATJ 8/86 2015	b) **<u>Circular Curve @ Study Zone A (Minor road)</u>** Design Standard = U3 (Local Street) Design Speed, v = 40 km/hr Superelevation , e = 8% Minimum Radius = 50 m Side friction factor, f = 0.16	
ATJ 8/86 2015 (Page 15)	<u>Radius of Curve, R</u> R = $\frac{V^2}{127\ (e+f)}$ R = $\frac{40^2}{127\ (0.08+0.16)}$ R = 53 m > 50 m (OK!)	
	Length of circular curve Angle, Δ = 46° (Angle between two tangents)	Obtained from CAD drawing
	• <u>Length of tangent, T</u> T = R x tan $(\frac{\Delta}{2})$ = 53 x tan $(\frac{46}{2})$ = 22.5 m	

- <u>Length of long cord, Lc</u>

$$Lc = 2R \times \sin\left(\frac{\Delta}{2}\right)$$

$$= 2 \times 53 \times \sin\left(\frac{46}{2}\right)$$

$$= 41.42 \text{ m}$$

- <u>Length of curve, L</u>

$$L = R \times \left(\frac{2\pi\Delta}{360}\right)$$

$$= 53 \times \left(\frac{2\pi(46)}{360}\right)$$

$$= 42.55 \text{ m}$$

- <u>Length of external distance, E</u>

$$E = T \times \tan\left(\frac{\Delta}{4}\right)$$

$$= 22.5 \times \tan\left(\frac{46}{4}\right)$$

$$= 4.58 \text{ m}$$

- <u>Length of middle ordinate, M</u>

$$M = E \times \cos\left(\frac{\Delta}{2}\right)$$

$$= 4.58 \times \cos\left(\frac{46}{2}\right)$$

$$= 4.22 \text{ m}$$

4.8.4.5 Proposed Horizontal Alignment

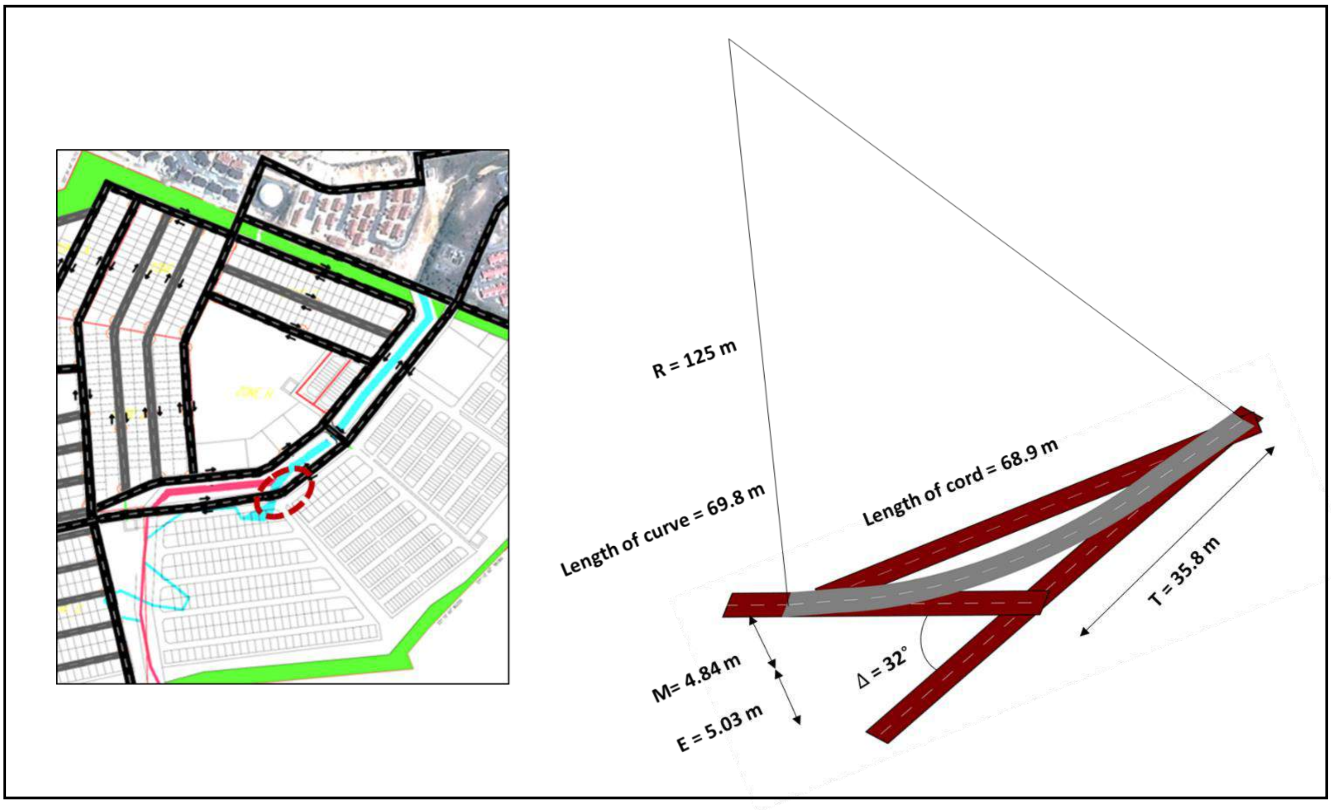


Figure 4.41 Proposed Horizontal Alignment at Jalan Gambang (South)

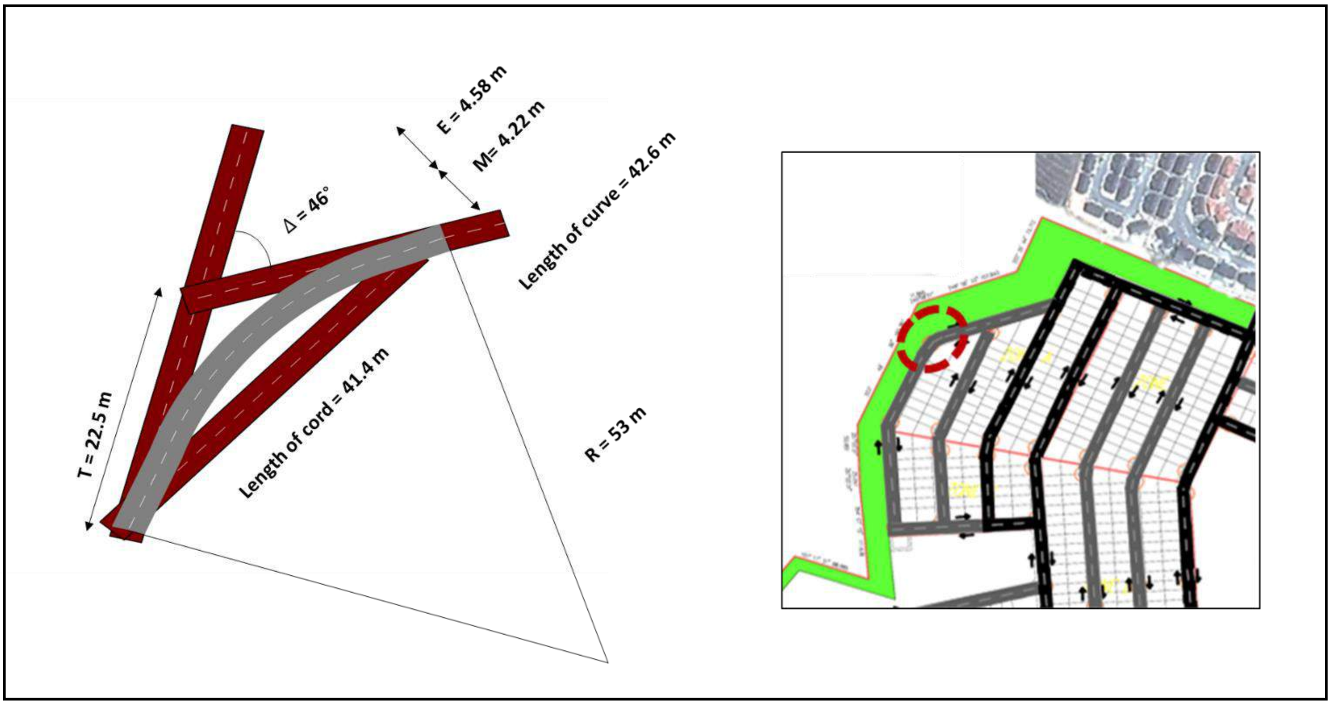


Figure 4.42 Proposed Horizontal Alignment at Study Zone A (Minor Road)

4.9 Vertical Alignment

4.9.1 Introduction

Vertical alignment is a crucial part of highway design which refers to the layout and arrangement of the road along its vertical axis, including the gradients, slopes, and curves. Having proper vertical alignment helps in ensuring safety, comfort, and efficient drainage on highways. The design of vertical alignment involves carefully planning the slopes or grades of the road, incorporating sag and crest grades to cater for proper drainage and enhance visibility. The implementation of summit and sag curves aids in ensuring optimal sight distances, particularly at the summits and depressions of hills. Gradual grade transitions through vertical curves are essential for providing a smooth and comfortable driving experience, minimizing abrupt changes in slope. stopping sight distances, allowing drivers ample time to react to potential obstacles.

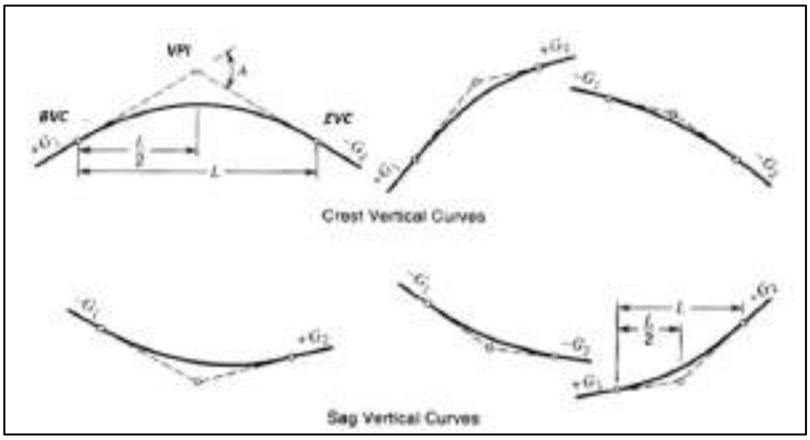


Figure 4.43 Types of Vertical Curves

4.9.2 Maximum and Minimum Grade

Vehicle performance is impacted by the road's vertical profile. A standard maximum grade control in terms of design speed has been established for ATJ 8/86 (2015). The area is included in the U4 (Collector) design standard for the major road, in Class III. Therefore, at 50 km/h design speed, the highest grade that may be achieved for the Eleven percent is design.

ATJ 8/86 (2015) states that a required minimum grade for design is 0.5 percent. Meanwhile, a high type pavement with an acceptable crown may be designed using a grade of 0.35 percent.

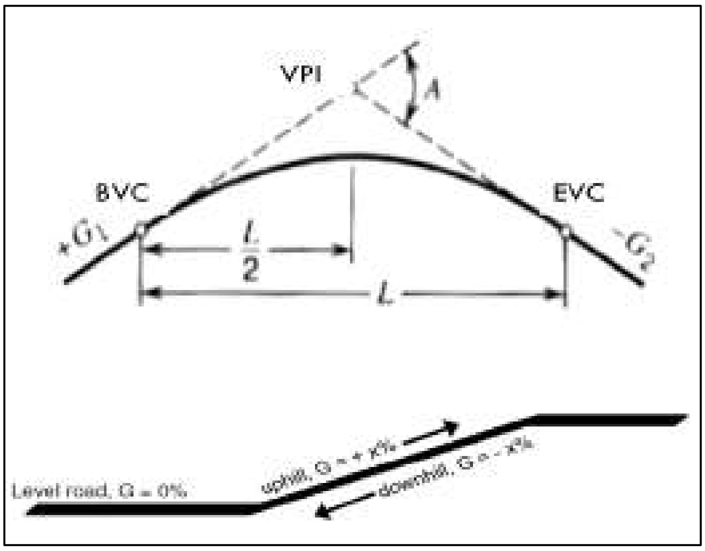
Table 28: Maximum Grades for U4 Standard Roads (extracted from Table 4.10C in ATJ 8/86 (2015))

Area Type	Design Speed (kph)				
	40	50	60	70	80
Type I (%)	9	9	9	8	7
Type II (%)	12	11	10	9	8
Type III (%)	13	12	12	11	10

4.9.3 Design of Vertical Curve

Vertical alignment is essential for ensuring a smooth and safe experience for other individuals using the road. The calculations and design of the vertical curve in the area are conducted in accordance with ATJ 8/86 (2015) and Chapter 4: Highway Geometry Design from Traffic Engineering Notes. The terrain in our development region is predominantly flat, with an average slope grade of less than 3 percent. However, there exists a small bridge over the natural channel of water that is flowing near the exit only at entrance 2 of study zone A.

4.9.3.1 Vertical Curve Components



VPI = Vertical point of intersection (point where the grade lines intersect one another)

G_1 = The slope of the first grade line (typically given in percent)

G_2 = The slope of the second grade line (typically given in percent)

Note: When the grade rises along the alignment, G is positive, when the grade falls or slopes downward, G is negative.

A = The algebraic difference of grades

BVC = Point where the vertical curve begins

EVC = Point where the vertical curve ends

L = Length of the vertical curve is the projection of the curve onto a horizontal surface. In most cases, the vertical curve will have equal-tangent lengths (i.e. the VPI is located midway between the BVC and the EVC).

4.9.3.2 Location of Vertical Alignment

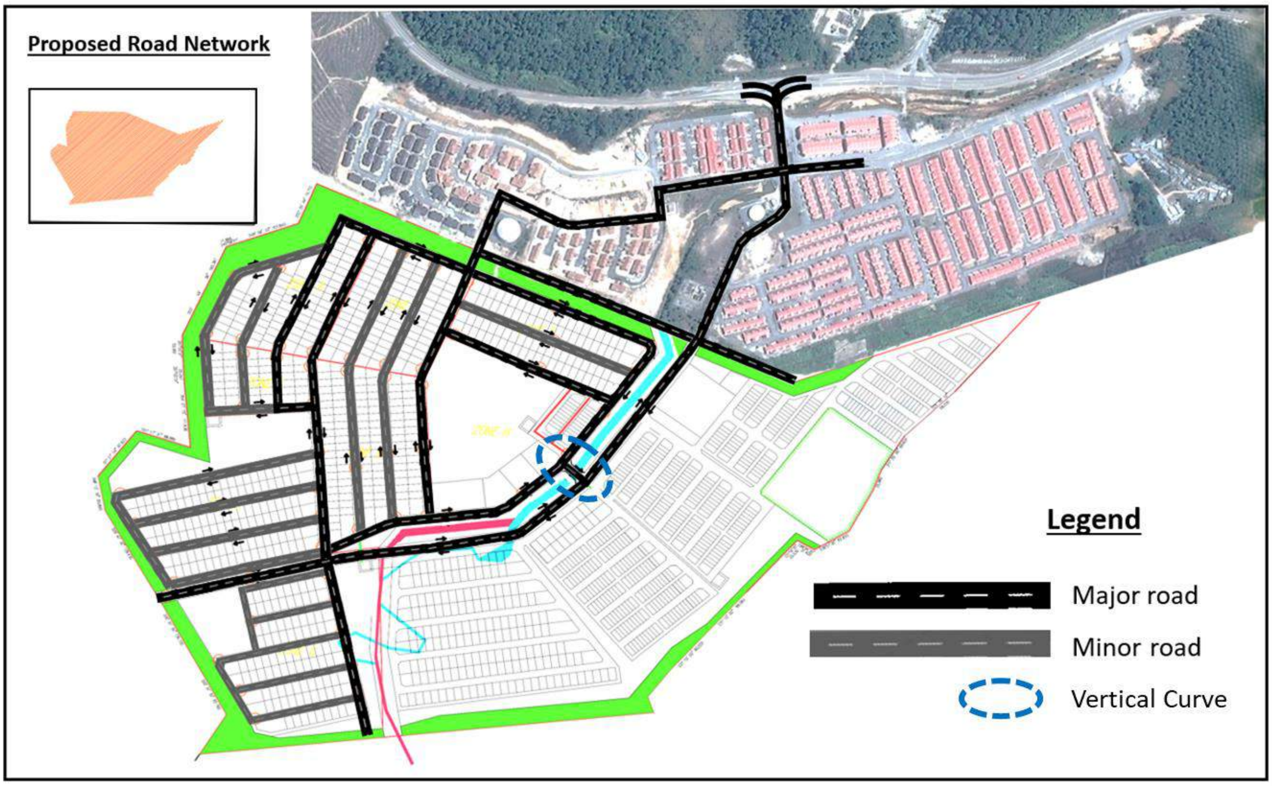


Figure 4.44 Proposed Layout of Road Network with location of Vertical alignment

4.9.3.3 Calculation of Vertical Alignment

Ref	Calculations	Output/ Remark
ATJ 8/86 2015	**<u>Small bridge @ Study Zone A (Entrance 2)</u>** Design speed = 50 km/h Length of curve = 50 m $ELEV_{BVC}$ = 38 m $ELEV_{EVC}$ = 31 m G_1 = +5% G_2 = -8% $A = G_2 – G_1$ = -8-5 = -13% VPI is located in the middle at a 25 m distance away from BVC and from EVC, and since $ELEV_{BVC}$ is known, therefore using the formula of determining Y_{BVC} we can determine the elevation at VPI by making $ELEV_{VPI}$ the subject of the equation: $ELEV_{BVC} = G_1(x) + ELEV_{VPI}$ x (VPI horizontal distance from BVC/EVC) : 25 m ➔ $ELEV_{VPI} = ELEV_{BVC} – G_1(x)$ ➔ $ELEV_{VPI} = 38 – 0.05(-25)$ ➔ $ELEV_{VPI}$ = 39.25 m **<u>Point of Vertical Alignment</u>** <u>Formula for determining highest point along the curve:</u> $x = -G_1(L)/A = -0.05(50)/-0.13$ = 19.23 m The highest point along the curve lies at a distance of 19.23 m from the BVC.	Obtained from CAD drawing.

	<u>Determining the elevation of the highest point:</u> $y = Ax^2/2L + G_1x + ELEV_{BVC}$ $y = -0.13(19.23)^2/2(50) + 0.05(19.23) + 38 = 38.5$ m Therefore, the elevation of the highest point along the curve is 38.5 m.	Highest Elev. **38.5 m**

4.9.3.4 Proposed Vertical Alignment

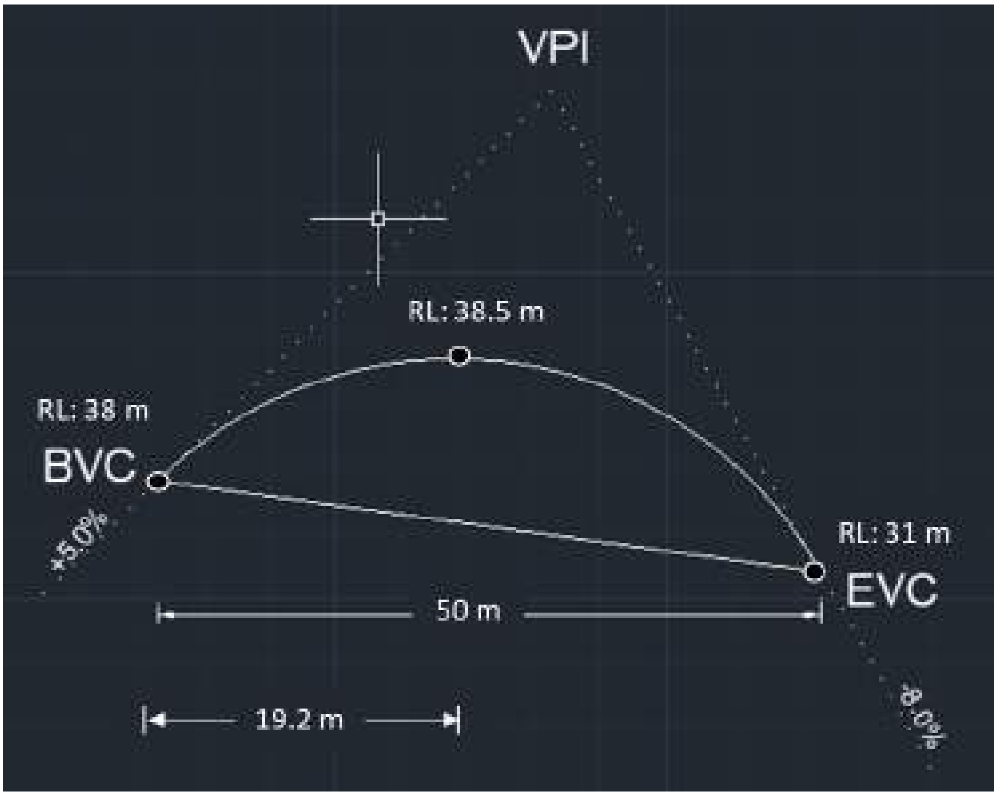


Figure 4.45 Proposed Vertical Alignment at Study Zone A (Entrance 2)

4.10 Road Furniture

4.10.1 Introduction

Road furniture includes many elements such as traffic lights, street signs, guardrails, and median barriers that are strategically positioned beside roadways and highways. They offer guidance, regulate traffic, and ensure the safety of motorists, pedestrians, and cyclists, among other responsibilities.

4.10.2 Kerbs

The configuration and positioning of Kerbs exert a substantial influence on driver conduct, traffic safety, and overall road utilisation. Kerbs have multiple functions, such as regulating drainage, marking the boundary of the pavement, improving visual appeal, outlining pedestrian pathways, and encouraging organised development along roadsides. Kerbs are frequently utilised on roadways in urban areas, but their utilisation is restricted to regions with largely urban features in rural environments, and they are generally avoided elsewhere.

ATJ 8/86 (2015) classifies kerbs into three primary categories: barrier kerbs, mountable/semi-mountable kerbs, and channel kerbs. These kerb types can be installed either individually or as components of the pavement design. In addition, they can be utilised to construct kerb and gutter sections in combination with gutters. Each type of curb possesses distinct characteristics and applications that contribute to the overall effectiveness and safety of the road infrastructure.

The careful choice and design of kerbs are essential factors in road planning and construction. They have a crucial function in ensuring efficient water drainage, providing visual indicators for cars, delineating pedestrian zones, and maintaining the integrity of the roadside. Transportation authorities can enhance the movement of vehicles, enhance road safety, and promote a calm and organised environment for road users by implementing appropriate kerb designs.

There are three distinct categories of Kerbs:

- Barrier Kerbs

Barrier kerbs are specifically engineered with steep inclines and increased heights to efficiently obstruct or discourage cars from deviating off the route. They are particularly suitable for deployment in densely populated areas with high pedestrian activity. It is necessary to refrain from using barrier kerbs together with traffic barriers or on roads with design speeds exceeding 70 km/h. These kerbs are not advised for use on motorways due to their specific design and intended use. In densely populated areas, B1 barrier kerbs are the recommended choice, however in areas with lower pedestrian activity, Type B2 semi-barrier kerbs may offer greater benefits. The careful selection and strategic placement of barrier kerbs play a crucial role in promoting road safety. They help restrict vehicles within defined travel paths, so improving the protection of pedestrians and guaranteeing smooth traffic flow.

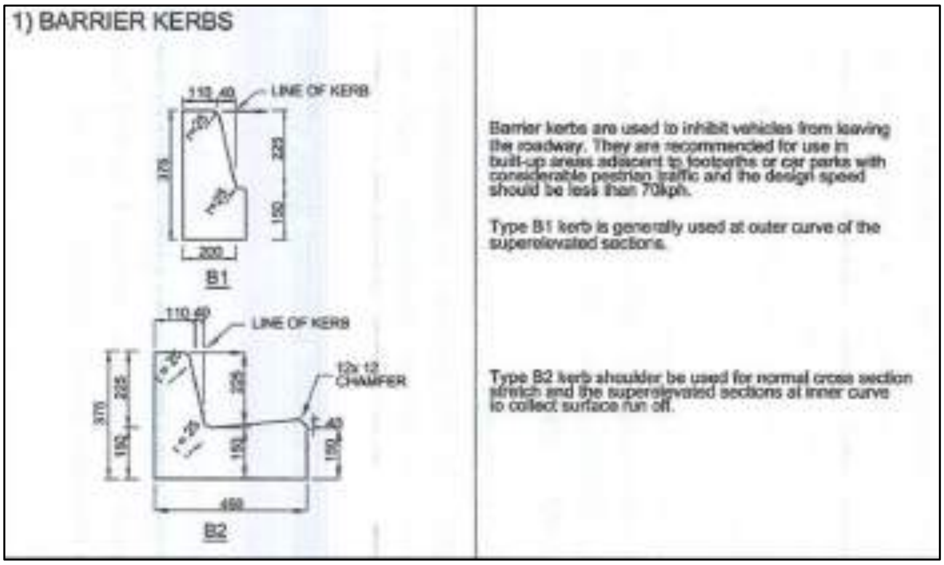


Figure 4.46 Road Barrier Kerb Details (Extracted from Figure 5.3a in ATJ 8/86 (2015))

- Mountable Kerbs

Mountable kerbs, especially type M1 and M2, play a crucial role in defining the boundaries of traffic lanes on roads. They play a crucial role in outlining the road surface and establishing clear demarcations for vehicles. The Type SM1 and SM2 kerbs are designed to be partially mounted and can be used in many ways inside the roadway, such as creating channelization islands, medians, outer separators, and other demarcation requirements. Type M2 kerbs have the added advantage of effectively capturing surface runoff while simultaneously ensuring free passage of vehicles. Additionally, they provide a designated zone for emergency parking that is situated away from the primary roadway. Road planners can enhance the accuracy of marking and optimise the control of traffic movement, hence enhancing road safety and maximising transportation systems, with the incorporation of both mountable and semi-mountable kerbs.

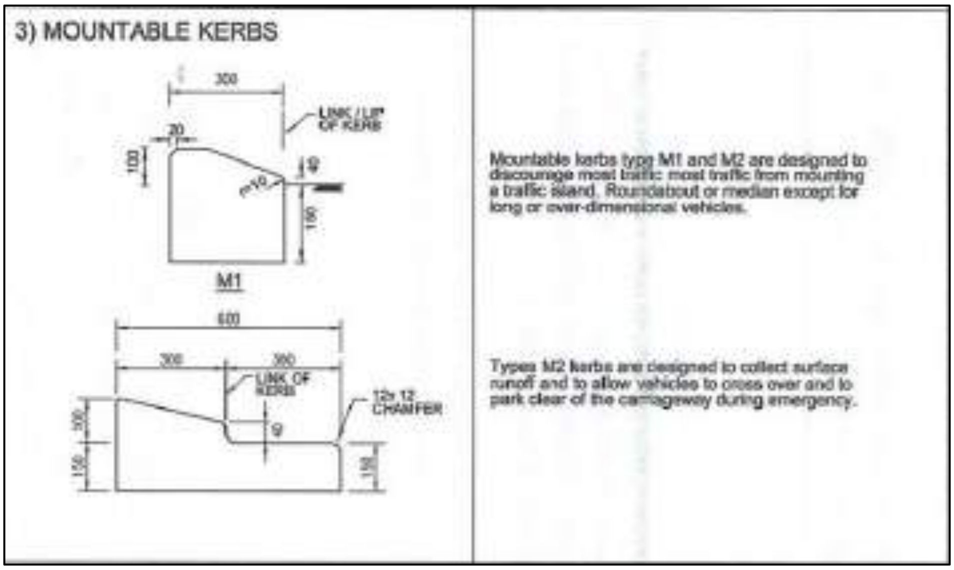


Figure 4.47 Road Mountable Kerb Details (Extracted from Figure 5.3a in ATJ 8/86 (2015))

- Channel Kerbs

Channel kerbs are crucial in highway scenarios since they effectively control road surface runoff and serve as a visual boundary. Channel kerbs are essential for effective drainage and to regulate water flow at intersections and on motorways, particularly on roads with expansive roadways and steep embankments. Their design aims to minimise the adverse impact of channels on steering, ensuring secure navigation through these areas. Road designers can mitigate drainage concerns and minimise the hazards associated with water pooling by using channel kerbs. The gutter section of drainage kerbs can be seen as a component of the marginal strip, while kerbs are regarded as a cross-sectional feature located outside the width of the traffic lane. In order to achieve accurate positioning, it is necessary to have a minimum offset of 0.25 metres for kerbs when there is no shoulder on the roadside. In general, channel kerbs serve as a crucial solution for efficient drainage and demarcation in particular highway layouts, hence enhancing the safety and productivity of road networks.

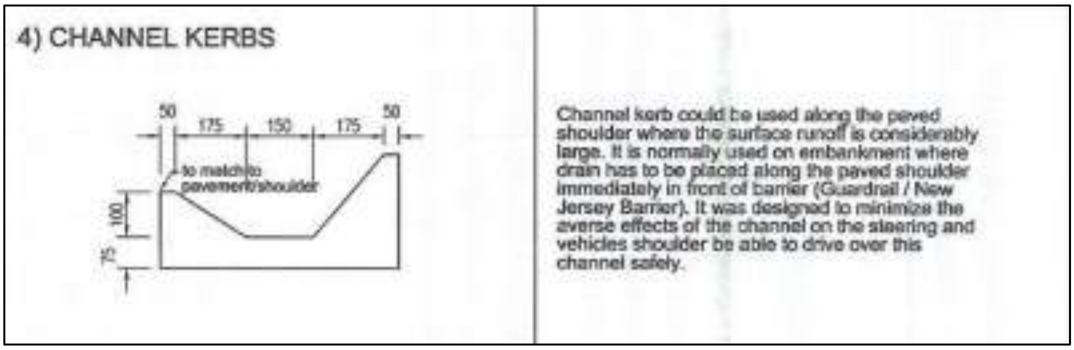


Figure 4.48 Road Channel Kerb Details (Extracted from Figure 5.3a in ATJ 8/86 (2015))

4.10.3 Turning Lane

When designing intersections, the inclusion of both right-turn and left-turn lanes is determined according to the individual requirements. Additional turning lanes may be utilised based on the circumstances and traffic patterns. However, the presence of traffic lights at signalised crossings eliminates the need for an extra turning lane at major intersections. Traffic lights effectively regulate the movement of vehicles. Conversely, a direct left-turn lane is commonly utilised at less significant crossroads. To enable accurate turning manoeuvres, it is essential to comply with the minimum curb radius requirement of 6 metres for urban areas. Incorporating appropriate turning lanes into junction design can enhance and optimise traffic patterns, resulting in improved flow and safety at crossings.

4.10.4 Median

It is strongly advised to have a median in roads that have four or more lanes, and it should be included whenever it is feasible. Medians provide several essential functions, including dividing traffic lanes, serving as a space for vehicles that have skidded, accommodating future lane expansions, regulating speed fluctuations, and providing storage for vehicles making right turns or U-turns. To maximise effectiveness, a median should possess high visibility throughout both daytime and nighttime, clearly distinguishing itself from the lanes used for through traffic.

Various configurations of medians can be implemented, such as sunken, elevated, or aligned with the pavement's surface. To ensure proportionality with the other elements of the road cross-section, it is advisable to maximise the width of the median. In order to provide effective drainage in the case of wide medians, it is necessary to incorporate a depressed centre or swale.

Roadways can benefit from enhanced safety, improved traffic flow management, and potential future development by incorporating well-designed medians. Thoughtful deliberation on median design enables the establishment of a cohesive and efficient mobility system.

Table 29: Median Width and Types (Urban) (Extracted from Table 5.5B in ATJ 8/86 (2015))

TABLE 5.5B: MEDIAN WIDTH AND TYPES (URBAN)

Design Standard	Median Width (m) Area Type						Median Type
	I		II		III		
	Min.	Des.	Min.	Des.	Min.	Des.	
U6	4.0	9.0	3.5	6.0	2.0	4.0	B,C,E,F
U5	3.0	6.5	2.5	4.0	2.0	3.0	B,C,E
U4	2.5	5.0	2.0	3.0	1.5	2.0	A,B,C,D
U3	2.0	4.0	1.5	2.0	1.5	2.0	A,B,D

Source: Adapted from REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-5B

Note:
Min. - Minimum
Des. - Desirable (for consideration of landscaping or other aesthetic features)

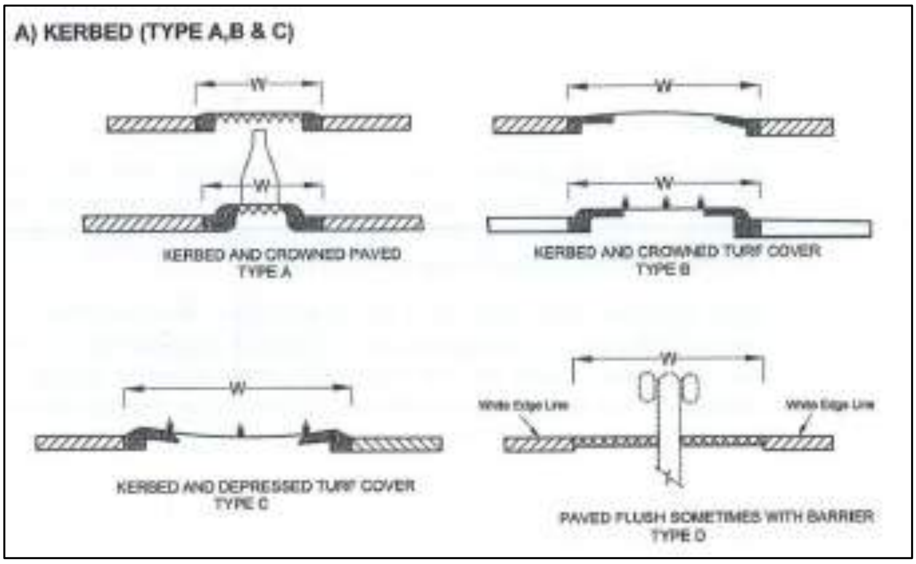


Figure 4.49 Median Types (Extracted from Table 5.4 in ATJ 8/86 (2015))

4.10.5 Road Signage

As per ATJ 2E/87, the main objective of traffic signs is to guarantee the secure and well-informed functioning of all individuals using the road. Regulation, warning, and direction are among the several purposes they provide. They are particularly vital in situations when specific limitations are only in effect at specific periods or when dangers are not immediately evident. In addition, traffic signs properly highlight highway routes, directions, destinations, and areas of interest. Vertical alignment is essential to ensure a smooth and safe ride for other road users. The calculations and design of the vertical curve in the area are conducted in accordance with ATJ 8/86 (2015) and Chapter 4: Highway Geometry Design from Traffic Engineering Notes. The topography of our development zone is predominantly flat, with an average slope grade of less than 3 percent.

When creating traffic signs, it is important to consider many essential parameters in order to achieve optimal effectiveness. Prior to installation, the signs must be specifically tailored to accommodate the projected levels of traffic and speeds on the respective roadways. Furthermore, they must possess a high level of visibility, effectively capturing the attention of drivers from a considerable distance, and easily recognised as traffic signs. Traffic signs should possess clarity and conciseness in conveying essential information to drivers, enabling them to comprehend the signs promptly without being distracted from their primary task of driving.

Legibility is a crucial aspect, as signs should be constructed to be easily legible from a fair distance without necessitating excessive movement of the head. Optimal positioning is essential to reduce obstruction caused by automobiles and other obstacles. Furthermore, the signs should be designed in a manner that allows motorists sufficient time to respond safely upon hearing the message. The efficacy of traffic signs should be taken into account both during daylight hours and at night, as factors such as colour, shape, size, text, symbol sizes, arrangement, position, and illumination or reflectorization significantly impact their functionality.

Adhering to these standards can significantly enhance road safety and facilitate organised and efficient traffic movement through the use of traffic signs.

Traffic signs can be categorised into five distinct types:

a) Regulatory Sign
b) Warning Sign
c) Temporary Sign
d) Guide Sign:
    1. Destination Sign
    2. Directional Sign
    3. Distance Sign
    4. Information Sign
    5. Route number markers
    6. Kilometer Posts

e) Other Traffic Signs:
    1. Gantry Sign

4.10.6 Road Marking

Road markings and delineations are essential for traffic regulation and driver guidance. They can be utilised independently or in combination with other methods of traffic control. In order to ensure quick and clear recognition by all individuals using the road, it is necessary for all road markings and delineators to follow standardised designs, applications, and placements. Any unnecessary delineations or markers that have the potential to cause confusion should be promptly removed. Similarly, in the absence of traffic limitations or conditions that necessitate special markings, those markings should be removed.

Markers in well-lit areas still require reflective materials for visibility during nighttime. Reflective evening visibility markings have become increasingly prevalent in order to enhance safety. Road studs are suitable for areas with inadequate alignment or hazardous conditions, such as critical intersections and crossroads, in addition to reflective lines. Pavement markers, meanwhile, encounter specific challenges. In humid conditions, they may be less conspicuous and less resistant to heavy foot traffic. Therefore, regular maintenance is necessary to ensure their effectiveness. Slip resistance should be taken into account while selecting pavement marking materials. It is imperative to bear in mind that pavement markings must not be applied on roads that are not paved.

Hence, to enhance overall road safety, it is crucial to create and maintain consistent road markings and delineations. This will improve traffic control by providing unambiguous communication with drivers.

The various categories of road marking are as follows:

- Longitudinal lines
  a. Center line
  b. Lane line
  c. No passing zone marking.
  d. Warning arrows
  e. Climbing lanes
  f. Pavement edge lines

- Continuity lines

- Transverse lines
  a. Stops lines.
  b. Holding lines or give way lines.
  c. Pedestrian crossing marking

- Other marking
  a. Diagonal and chevron markings
  b. Message on
  c. Arrows
  d. Approaches to railway crossing marking.
  e. Parking space limits
  f. Paved shoulder markings
  g. yellow boxes
  h. Kerb markings

4.10.7 Design of T-junction

This section covers the design of road kerbs, markings, and traffic signs specifically for T intersections within study zone A. The designs adhere to the requirements specified in the ATJ 8-86 Pindaan 2015.

4.10.7.1 Location of T-junctions

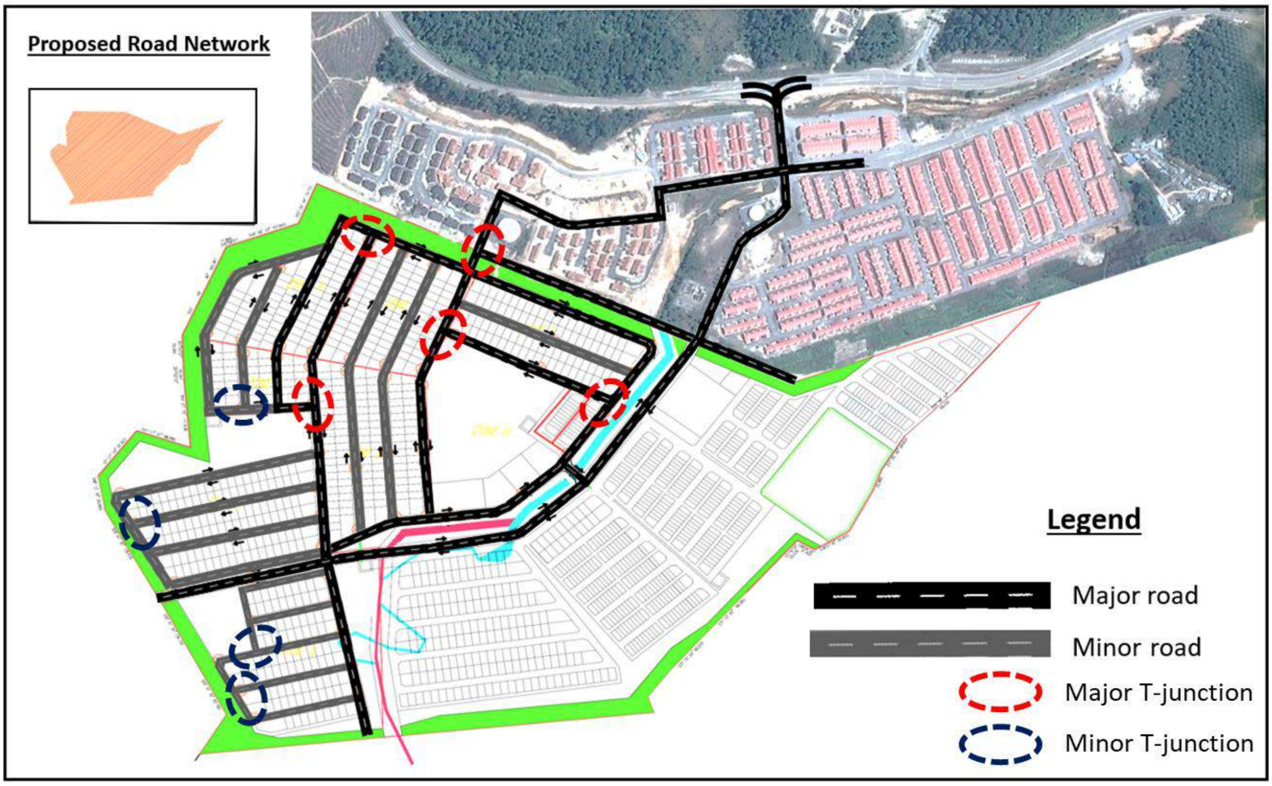


Figure 4.50 Proposed Layout of Road Network with location of T-junctions

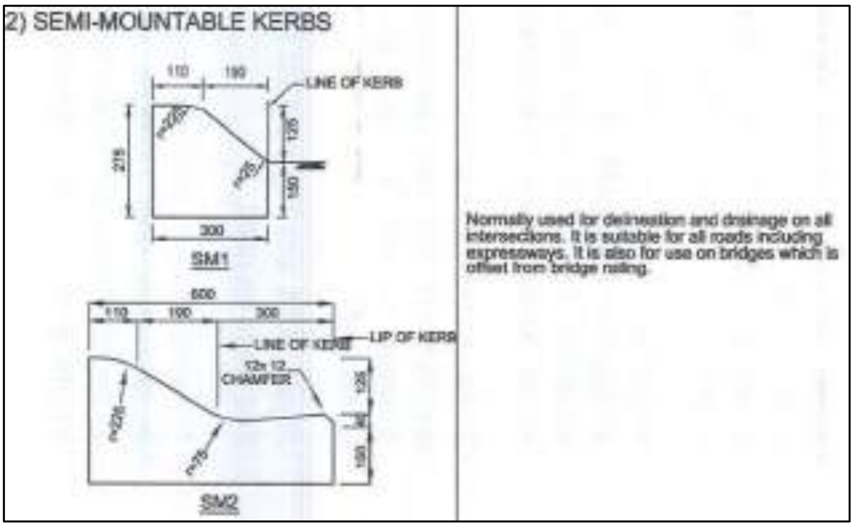
4.10.7.2 Design of Road Furniture – Major T-junction

Reference	Design/Calculation

ATJ 8/86
(Page 85)

Design of Kerbs (T-Junction)

- Semi Mountable Kerb



ATJ 8/86
(Page 90)

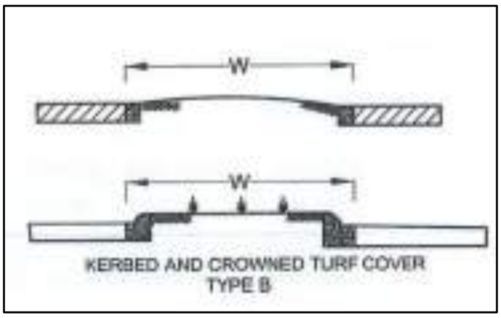
TABLE 5.5B: MEDIAN WIDTH AND TYPES (URBAN)

Design Standard	Median Width (m) Area Type I Min.	I Des.	II Min.	II Des.	III Min.	III Des.	Median Type
U6	4.0	9.0	3.5	6.0	2.0	4.0	B,C,E,F
U5	3.0	6.5	2.5	4.0	2.0	3.0	B,C,E
U4	2.5	5.0	2.0	3.0	1.5	2.0	A,B,C,D
U3	2.0	4.0	1.5	2.0	1.5	2.0	A,B,D

Source: Adapted from REAM GL 2/2002: A Guide on Geometric Design of Roads, Table 5-5B

Note:
Min. - Minimum
Des. - Desirable (for consideration of landscaping or other aesthetic features)

For major roads, median type B (kerbed and crowned turf cover) with a width of three metres is used.

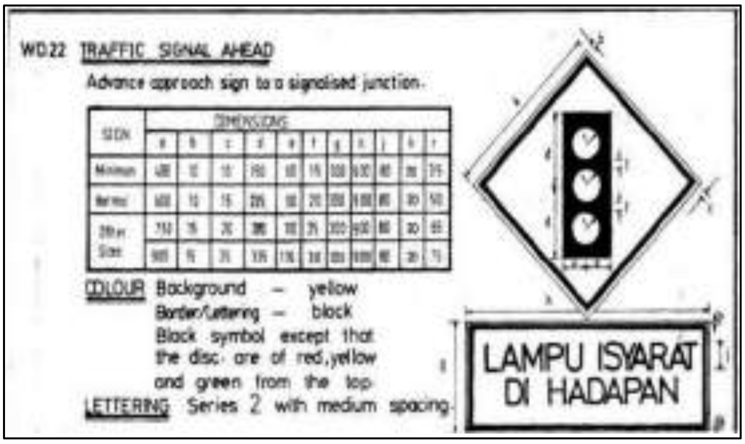
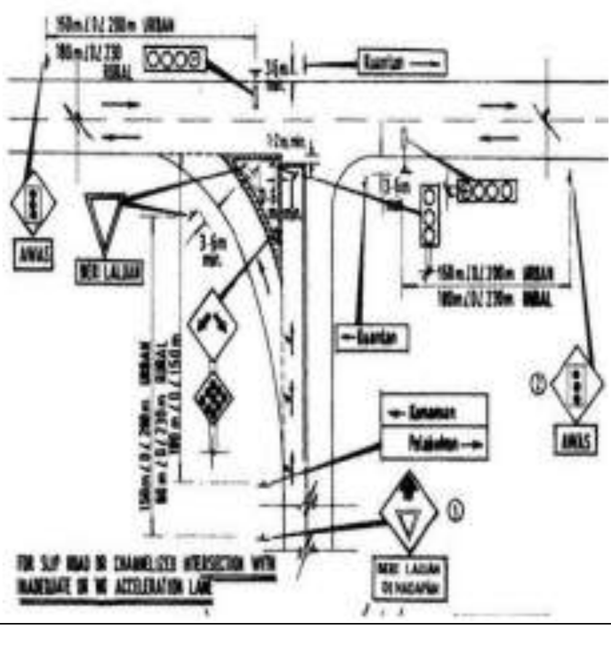


ATJ 2B/85	**Design Road Markings** 1) Longitudinal Lines: i) Lane line on urban streets - Lane line shall be broken lines - 100mm width - Use a gap or stroke length of 1.7m and 1m ii) Pavement edge lines: - Edge lines are used anywhere it is desirable to deter vehicles from using the shoulder of the road and to improve safety and comfort when driving, especially at night, by giving drivers a constant guidance. - Also, they serve as a pathfinder for objects that are dangerously close to the pavement's edge. If a pavement does not have a marginal strip, its edge line should be at least 150 mm from the pavement's edge. - Pavement edge lines may be placed on the right-hand margin of each pavement on split roadways if the median is not clearly defined. - When there are no marginal strips present, it is recommended that the pavement edge line be at least 150 mm away from the edge of the pavement. 2) Transverse lines: i) Stop lines: - Straight and unbroken lines - 300mm wide - They shall extend across the traffic lanes approaching traffic signals or at STOP sign. - It is placed not more than 10 m nor less than 1.2 m for the nearest edge of intersecting roadway (since there are no crosswalk line). 3) Markings: i) Arrows: - Arrows are used to ensure correct lane usage at approaches to intersections, exit ramps and other control points. - A spacing of 15 to 30m should be used between repeater arrows according to the size of the arrow, larger arrows being used for higher speed roads. ii) Yellow Box - This yellow box is painted at the intersection to indicate the area that parking, and waiting are prohibited. ii) Kerb Marking: - If deemed essential, the kerbs of medians and traffic islands might be painted and fitted with reflectors to enhance visibility.

<table>
<tr><td></td><td>- Kerbs that might present a risk to through traffic may be painted in segments of black and white no longer than 1.5 metres.

-There should be a white segment that can also be reflectorized at the start and finish of these treated kerbs.

- Kerbs may not need to be marked in the case of openings in a continuous median island unless a specific assessment has identified the requirement for such markings.</td></tr>
<tr><td>ATJ 2A/85</td><td>Table of road signage for major road

<table>
<tr><th>Type</th><th>Description</th></tr>
<tr><td>Traffic Signal Ahead</td><td>
</td></tr>
</table></td></tr>
<tr><td>ATJ 2B/85
(Figure 9)</td><td>FIG 9 TYPICAL LOCATIONS FOR YIELD SIGN

</td></tr>
</table>

4.10.7.3 Design of Road Furniture – Minor T-junction

<table>
<tr><th>Reference</th><th>Design/Calculation</th></tr>
<tr><td>ATJ 2D/85
(Pages 5-9)</td><td>

Design Road Markings

1. Centre lines:

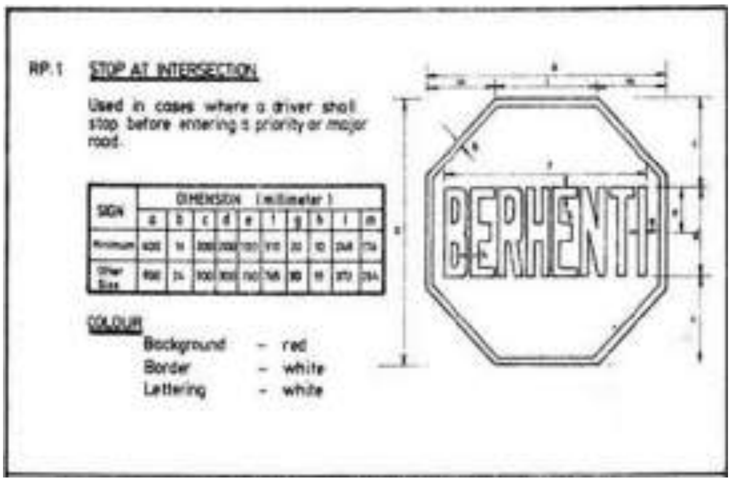
   - No passing zones
   - Double continuous white lines with width 100mm
   - Distance between adjacent lines is 125mm.

2. Pavement Edge Lines:
   - Width = 150m

3. STOP Lines:
   - Straight line
   - Width(300mm)
   - Position it at the closest intersection's edge, not more than 10 m nor less than 1.2 m

4. Yellow Box
   - To indicate the area where parking and waiting are forbidden, a yellow box is painted at the intersection.

</td></tr>
<tr><td>ATJ 2A/85
(Pages
4,24,25)</td><td>
<table>
<tr><th>Types</th><th>Description</th></tr>
<tr><td>Stop at Intersection</td><td>



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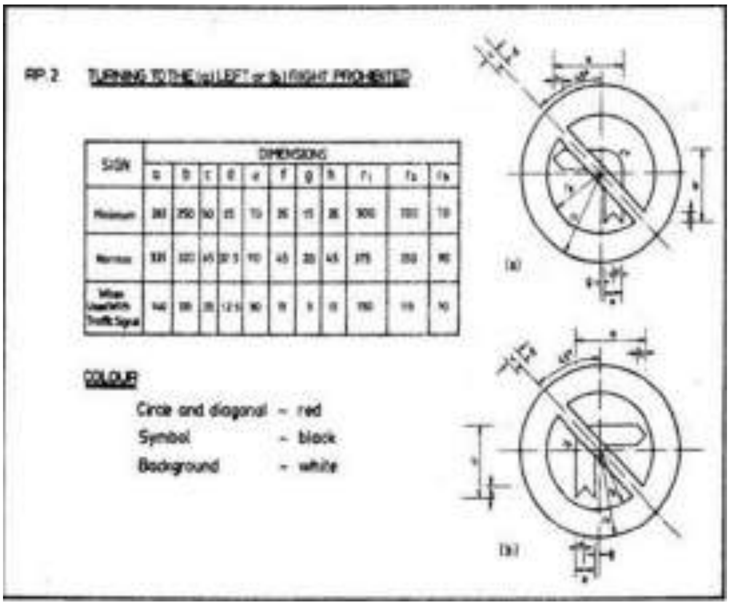
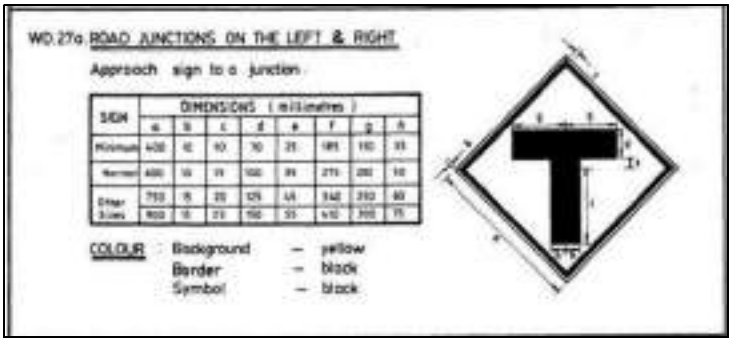
</table>
</td></tr>
</table>

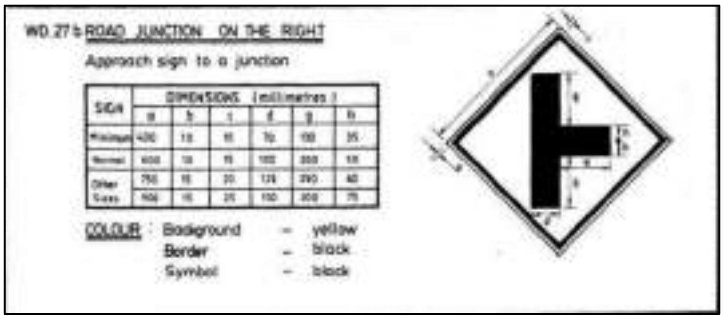
Turning of a movement is prohibited.



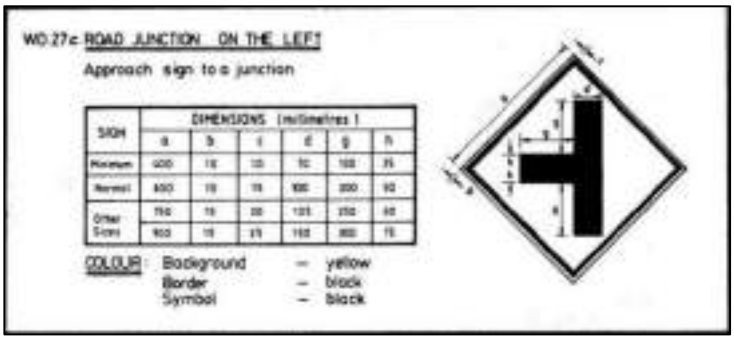
Road junction on the left and right

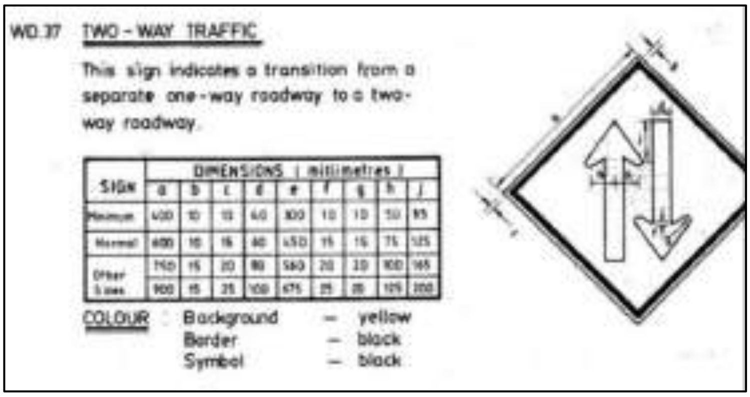
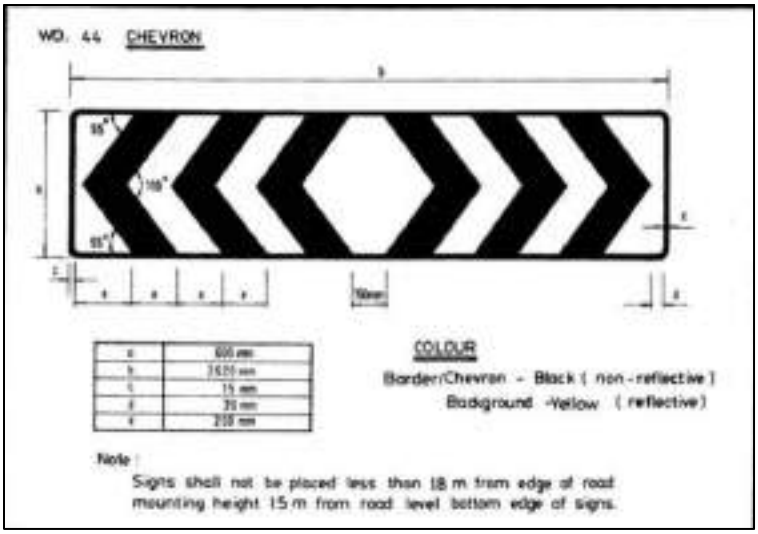


Road junction on the right



Road junction on the left



	Two-way Traffic	
	Chevron	

4.10.8 Traffic Signs

Traffic signs are crucial visual indicators positioned on or alongside roads to control, caution, and direct traffic. The many classifications encompass regulatory signs (such as stop, yield, and speed limit signs), cautionary signs (such as steep bends and construction zones), and informative signs (such as directional and destination signs). These signs employ a diverse range of colours, shapes, and symbols to promptly convey their intended message and ensure that drivers can readily comprehend and respond to them.

Furthermore, medians, which can have varying heights relative to the road surface, are essential components of road design. Wide medians often incorporate a central depression or swale to ensure effective drainage while maintaining a cohesive appearance with other components of the road. Strategically designed crossings with medians can create environments that are more secure, well-organized, and facilitate smooth traffic flow.

4.10.8.1 Proposed Traffic Signs

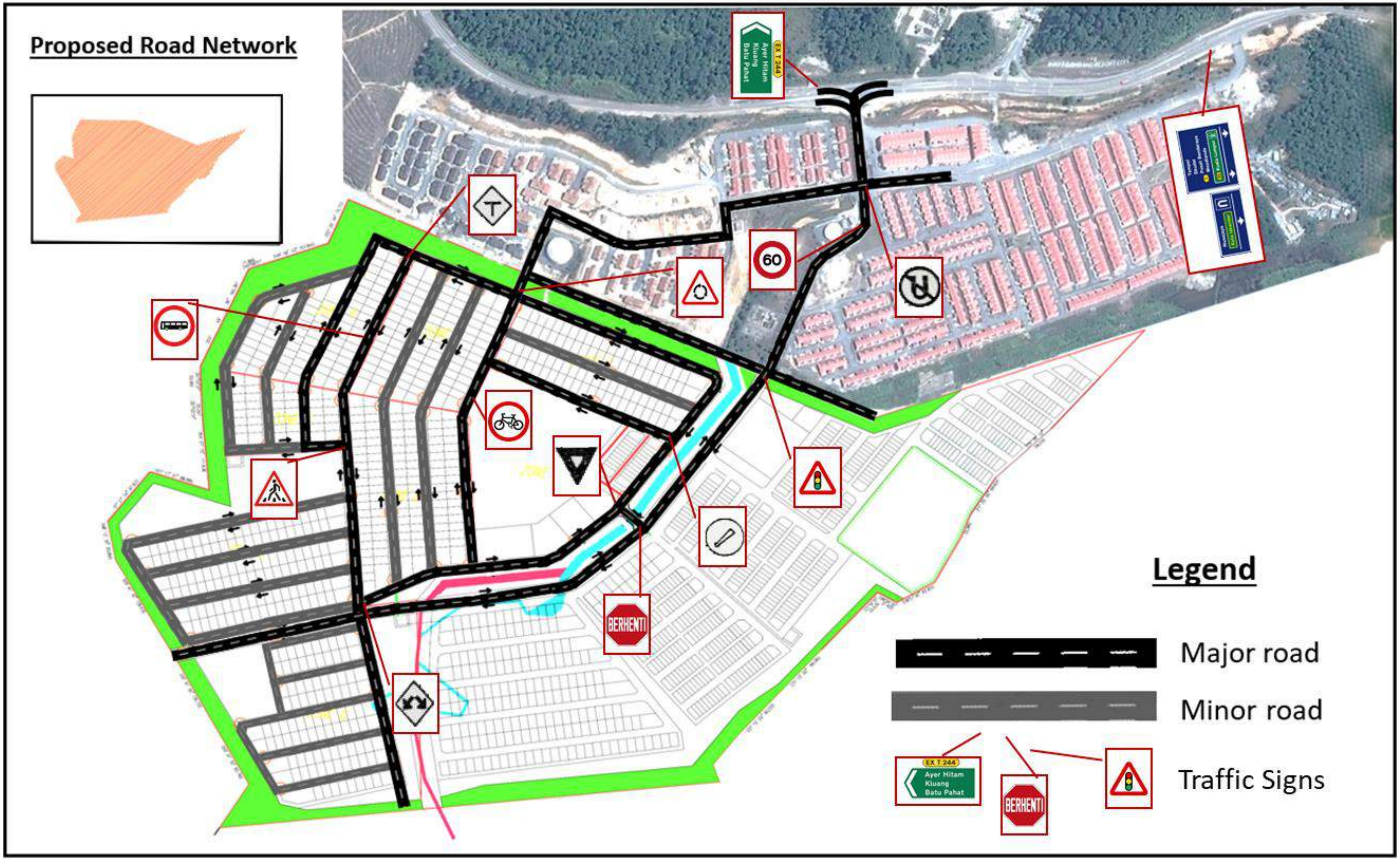


Figure 4.51 Proposed road network with traffic signs (one location displayed for different traffic signs)

4.11 Road Infrastructure

4.11.1 General

The ongoing expansion of urban populations and the associated increase in the need for efficient transportation necessitate the careful consideration and implementation of highway infrastructure development and maintenance. These efforts are of paramount importance in ensuring the provision of safe and convenient mobility for all individuals. Within this sub chapter we try to integrate pedestrian crossings/walkways, bicycle lanes, and strategically positioned bus stops within the proposed development area.

The highway infrastructure, being a critical component of the transportation network, plays a pivotal role in facilitating economic growth and enhancing the interconnectivity among various communities, commercial enterprises, and vital amenities. The historical purpose of highways has predominantly revolved around catering to the requirements of motor vehicles. However, over time, these roadways have undergone modifications to incorporate the diverse needs of various users, encompassing pedestrians, cyclists, and individuals utilizing public transportation systems. The seamless incorporation of pedestrian walkways, bicycle lanes, and thoughtfully engineered bus stops serves to promote equal accessibility and improve the comprehensive operability of the transportation infrastructure.

4.11.2 Road Crossings

Crossing a street or road from one side to the other is referred to as a street crossing. It is a crucial component of urban mobility because it makes it possible for pedestrians to get where they need to go quickly and safely. Street crossings are intended to give pedestrians a defined location to cross the street with the least amount of risk of accidents and conflicts with moving automobiles.

Along the minor roads it may not be necessary to provide detailed crossings as there are not many cars going past and it should be okay to cross at any point along the road, but along the major roads we suggest having crossings at every junction.

	FUNCTIONAL CLASS / LEGAL CLASS				
	Expressway	Primary Arterial	Secondary Arterial	Collector Road	Local Road
TYPE OF PEDESTRIAN FACILITY	Expressway	Federal Highway	State Highways & Major Municipal Routes	Municipal and FELDA Routes	Municipal and FELDA Routes
Uncontrolled Crossing	C	B	B	B	B
School Children's Crossing	C	B	B	A	A
Pedestrian (Zebra) Crossing	C	B	A	A	A
Signalised Pedestrian Crossing*	C	A	B	B	C
Grade Separated Pedestrian Crossing	A	B	B	C	C

Notes: 'A' Indicates a treatment which is most likely to be the appropriate treatment

'B' Indicates a treatment which may be an appropriate treatment

'C' Indicates a treatment which is most likely not the appropriate treatment

Indicates facilities which may incorporate speed control humps.

* Not at an Intersection. Includes 'Pelicon' and 'Puffin' type crossings .

FIGURE 1. GUIDE FOR SELECTING THE MOST APPROPRIATE TYPE OF PEDESTRIAN CROSSING FACILITY

Figure 4.52 Selection Criteria for most appropriate pedestrian crossing facility (Extracted from ATJ 18-97)

4.11.2.1 Design Standard for Road Crossings (General)

Pedestrian mobility is a fundamental aspect of nearly every journey taken on the road system, making pedestrians a crucial element of the traffic system. The susceptibility of pedestrians when navigating through automobile traffic is clearly highlighted by the significant number of traffic accident fatalities involving pedestrians.The inadequate infrastructure for pedestrians to safely cross or walk along roads is a significant factor in the elevated number of pedestrian casualties on Malaysian roads.

It is imperative to incorporate the distinct requirements of pedestrians as a fundamental aspect in the planning, design, building, maintenance, and operation of any roads or road projects. These guidelines based on AUSTROADS: Guide To Traffic Engineering Practice Part 13 – Pedestrians (1995) and ATJ 18-97: Basic guidelines on pedestrian facilities should be utilised to attain enhanced and uniform norms and practices in order to establish a road environment that is more user-friendly and secure for pedestrians.

4.11.2.1.1 Installation of pedestrian crossing facilities - Warrants

- **Uncontrolled Pedestrian Crossings:**

There are no formal criteria established for uncontrolled crossings. However, they can be implemented in areas with significant traffic volume on arterial routes (excluding motorways), especially when traffic is congested owing to neighbouring traffic lights. Each case should be evaluated based on its own merits, taking into account elements such as: the width of the road to be crossed, whether it is a one-way or two-way road, the number of pedestrians, the rate of traffic flow, the speed of traffic, and the available sight distance.Unregulated pedestrian crossings are frequently paired with Local Area Traffic Management Devices and Traffic Calming Techniques.

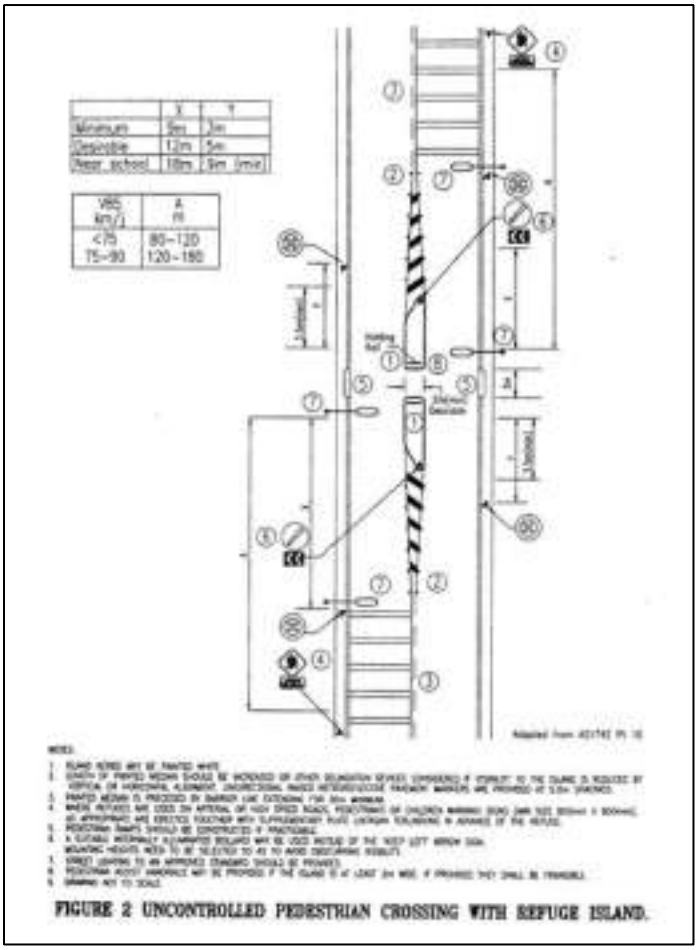


Figure 4.53 Design Standard for Uncontrolled Pedestrian Crossing (Extracted from ATJ 18-97)

- **Zebra Pedestrian Crossings:**

'Zebra' type pedestrian crossings are suitable when the average speed of traffic, as shown by the 85th percentile traffic speed, is below 70 km/h. However, certain criterias must be followed for this to be applicable:

- The minimum number of pedestrians seeking to cross the road is 60 per hour. The overall volume of vehicular traffic on the road at the site is larger than 600 vehicles per hour for at least 2 different one-hour periods of a typical weekday. Additionally, the product of the number of pedestrians and the volume of vehicular traffic, PxV, is greater than 90,000.
- Pedestrians are only required to cross a maximum of four traffic lanes in one stride, which corresponds to a carriageway width of no more than 15 metres.
- The visibility is sufficient for both vehicle drivers to see the crossing and pedestrians to see vehicles approaching the crossing. Therefore, it is crucial to thoroughly evaluate the operational speed of traffic.

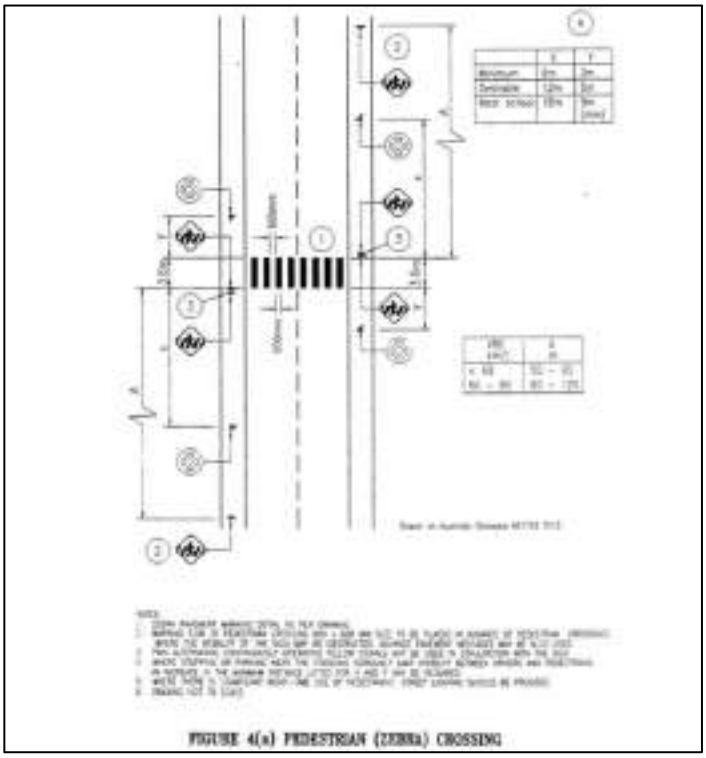


Figure 4.54 Design Standard for Pedestrian with Zebra Crossing (Extracted from ATJ 18-97)

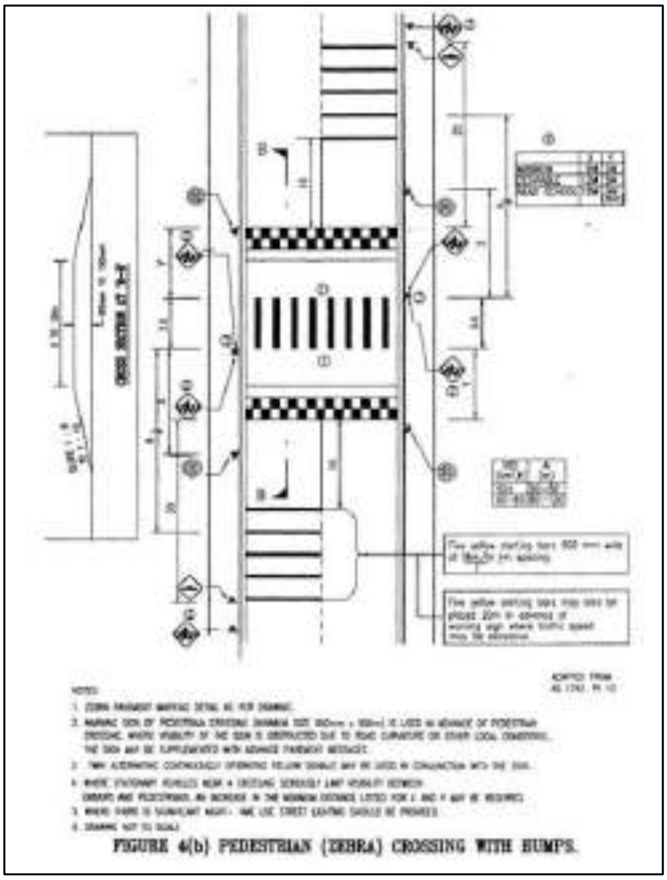


Figure 4.55 Design Standard for Pedestrian with Zebra Crossing and Humps (Extracted from ATJ 18-97)

- **Signalized Pedestrian Crossing:**

  A signalized pedestrian crossing may be installed if any of the following criteria are met:

  - If the average daily demand exceeds 350 passengers per hour (pph) for any of three one-hour intervals, or if it exceeds 175 pph for each of any eight one-hour periods and:
    - In areas without a central median or pedestrian refuge island, the vehicular traffic flow must exceed 600 vehicles per hour in both directions during the same hours.
    - In areas where there is a central median or pedestrian refuge island, the volume of vehicular traffic, V, exceeds 1000 vehicles per hour (combined for both directions) during the same time period.

      Provided that there are no alternative pedestrian crossings, including an elevated crossing, within a reasonable proximity of the location, such as around 200 metres away.

  - A signalised pedestrian crossing may be installed as a replacement for a school Children's Crossing in the following circumstances:
    - Given that P is greater than 50 pedestriana per hour (pph) for each of two one-hour periods, and V is greater than 600 vehicles per hour (vph).
    - The result of product PxV is greater than 40,000.

  - A signalised pedestrian crossing can be considered at any point along an arterial road if the criteria for a pedestrian (zebra) crossing are met. However, it may not be suitable to install a zebra crossing in cases where the traffic speed is high, the road width exceeds 15m, or there is a constant heavy flow of pedestrians that would cause significant delays to vehicles at a zebra crossing.

  - A signalized pedestrian crossing may be warranted to replace an existing pedestrian (Zebra) crossing if there have been two or more pedestrian-related accidents in the past three (3) years that might be prevented by installing traffic signals.

  - In cases where a location is part of a coordinated traffic signal system, or is in close proximity to a signalized crossroads or railway level crossing, it may be more appropriate to install a signalized pedestrian crossing instead of a pedestrian (zebra) crossing. This is particularly necessary where there is a risk of vehicles posing a danger.

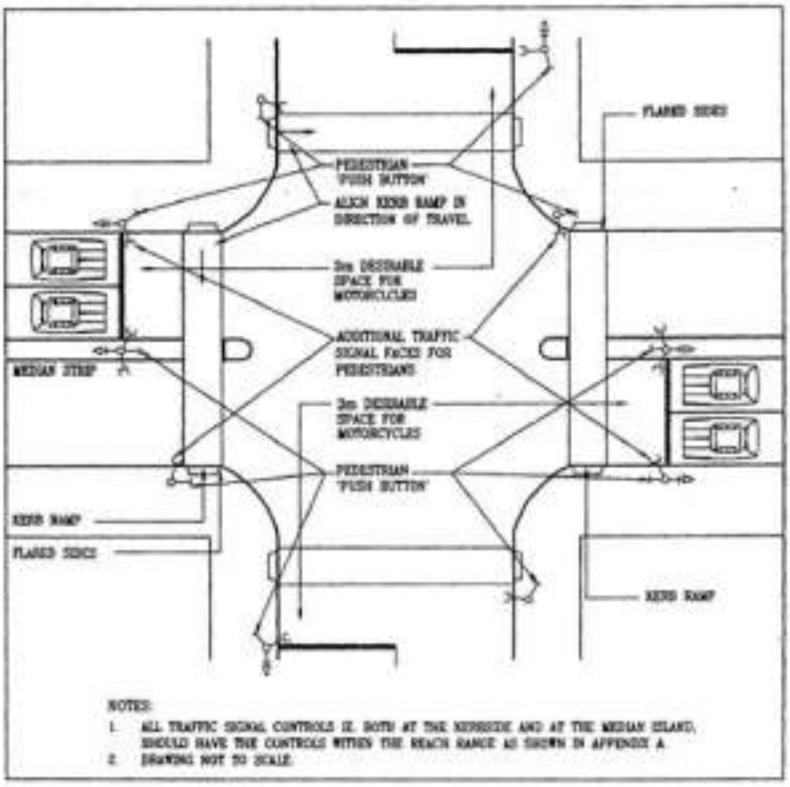


Figure 4.56 Design Standard for Pedestrian at Signalized Intersection (Extracted from ATJ 18-97)

4.11.2.2 Design Standard for Road Crossings (In front of kindergarten)

Kindergarten children's crossings can be constructed at any area where children require regular access to cross a road. Provided that proper arrangements are made, the Children's Crossing Flags will be placed (or the flashing lights will be activated) during the times of day when children are expected to be crossing the road. The flags will be removed (or the flashing lights will be deactivated) outside of these designated crossing periods. This arrangement often involves the presence of an appropriately authorised, instructed, and uniformed "Crossing Supervisor" whose responsibility is to operate the crossing equipment and safely guide the children over the road.

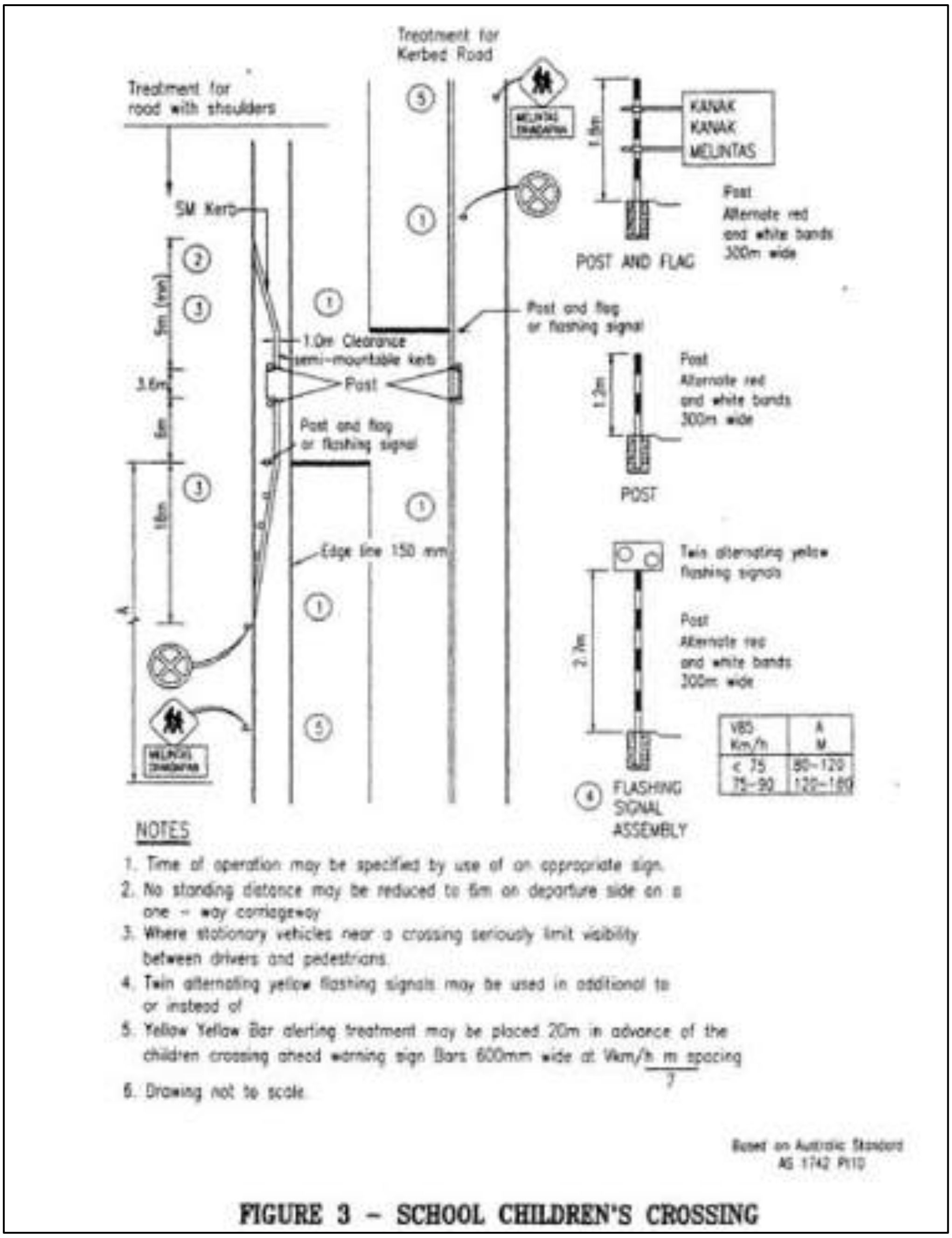


Figure 4.57 Design Standard for Children's crossing at Signalized Intersection (Extracted from ATJ 18-97)

4.11.3 Pedestrian Walkway

Sidewalks near or along highways in rural and suburban areas are usually needed where there are a lot of people walking, like near homes, schools, businesses, and industrial plants. Sidewalks are a crucial component of urban infrastructure that improves how livable and walkable cities and towns are overall. They improve accessibility and inclusivity of public areas, enable pedestrian mobility, and encourage physical activity. Depending on the area, expected foot traffic, and particular urban planning factors, sidewalk width can vary.

The average pedestrian won't walk more than 1.5 km to work or more than 1.0 km to catch a bus, and about 80% of the lengths they walk will be less than 1.0 km which provides a base guideline for design of pedestrian walkways.

We propose for there to be walkways as per guidelines stated in AUSTROADS, available throughout each minor road within our area, we believe for a state of the art and modern design a pedestrian walkway is a necessity throughout the whole neighborhood. In in accordance with the American Association of State Highway and Transportation Officials - Geometric design 6th edition, it is stated that in residential places, sidewalks can be anywhere from 1.2 to 2.4 m wide and if a sidewalk is less than 1.5 m wide, a passing area needs to be added every 60 m for access. Therefore, due to the low population density of our area we shall propose a sidewalk of width 1.2 m to be provided along each minor road in our area.

Figure 4.37: Urban border

Table 4.28: Typical urban border widths

Border function	Desirable minimum width (m)
Footpath Light volume Disabilities Bus stop At shops	General min.1.2 Absolute min. 0.9 1.0 – 1.8 3.4 2.4
Pedestrians plus public utility services Local road or service road Collector Arterial with service road Arterial	Measured to line of kerb 4.6 5.1 7.3 4.3
Pedestrians plus fully indented bays	5.4

Figure 4.58 Design Standard for Urban border width (Extracted from AUSTROADS)

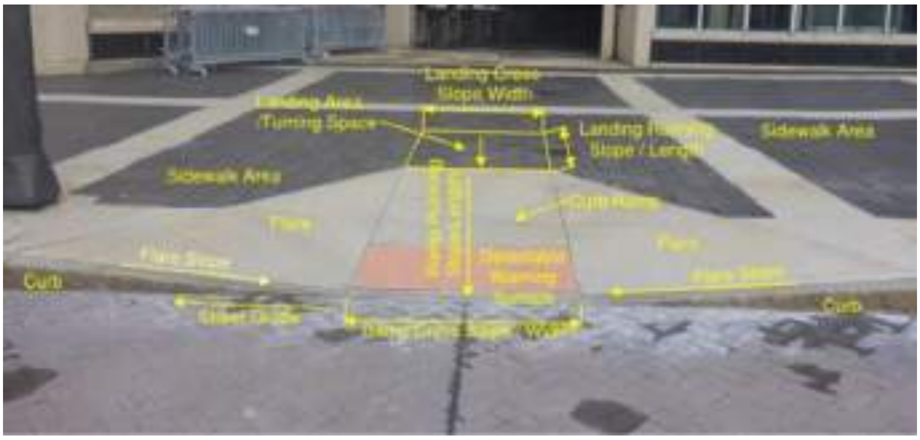


Figure 4.59 Kerb cut out design elements

4.11.4 Bicycle Lane

A bicycle lane is a designated part of a roadway that is specifically marked and reserved for the exclusive use of bicycles. These lanes are intended to provide a safer and more accessible space for cyclists, encouraging alternative and sustainable modes of transportation.

Sustrans Design Manual Handbook for cycle-friendly design

The width required by cyclist is based of factors such as:

- 'Dynamic width' of the cyclist: The dynamic width of the cyclist refers to the slight movements a cyclist may need as they are not always in a stationary sitting state during motion, it is noted to be 1m in accordance with the design manual.
- Clearance when passing fixed objects: this is the space needed in order to safely maneuver around objects such as fire hydrants and wheel stoppers. We shall add a kerb of 150mm between cyclists and edge of the road, this therefore leads to an additional width of 200mm.
- Traffic flow of cyclists: This design shall be a single lane design due to the low traffic flow of cyclists
- Speed of vehicles on the street: speed limit along segment 2 and 4 is 50km/h and speed along segment 3 is 30 km/h
- Distance from other traffic (both cyclist and motor vehicles): Addition due to distance from cyclists shall be ignored since it is a single lane track, for motor vehicles, the road shall be of a total width 5.6m, this is due to bus/HGV traveling at 30mph (48kph).

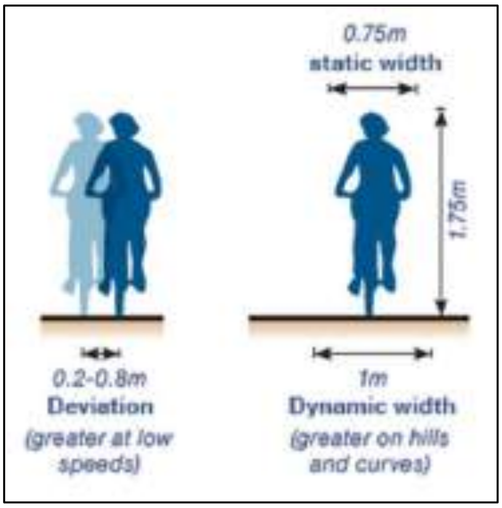


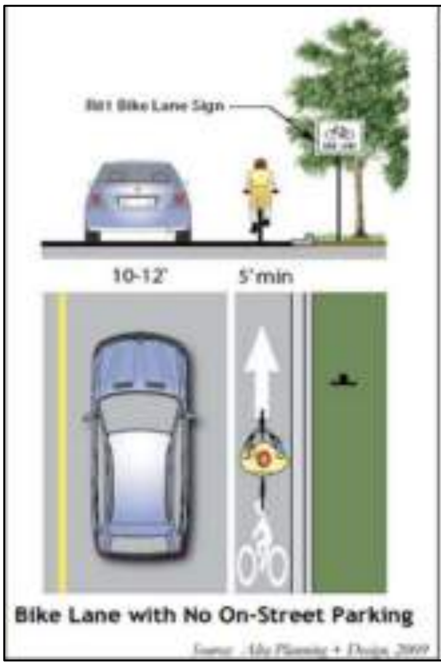
Figure 4.60 Dynamic and Static width

Table 30: Design Parameters for Cycle lane width.

Table H.1 **Overtaking by motor vehicles**	
Minimum passing distance	
20mph	1m
30mph	1.5 m
Total width required for overtaking cyclist in secondary riding position (see figure below)	
Car passing at 20 mph	4.3m
Car passing at 30 mph	4.8m
Bus/HGV passing at 20 mph	5.1m
Bus/HGV passing at 30 mph	5.6m

Table H.2 **Additional clearances to maintain effective widths for cyclists** (see figure below)	
Type of edge constraint	**Additional width required (mm)**
Flush or near-flush surface (including shallow angled battered kerbs - see photo below)	Nil
Kerb up to 150 mm high	Add 200
Vertical feature from 150 to 600 mm high	Add 250
Vertical feature above 600 mm high	Add 500

Table H.3 **Calculation of minimum width required:** minimum width = a+b+c+d	
a	dynamic width
b	minimum passing distance from other users (Table H.1)
c	clearance for edge constraints (Table H.2)
d	additional width for high cycle/pedestrian volumes, steep gradients, curves



General Guidelines

The width of the bike lanes vary according to parking and street conditions. Note that these dimensions are for reference only, and are subject to engineering design review.

- 4 feet (1.2 m) minimum width if no gutter exists, measured from edge of pavement;
- 5 feet (1.5 m) minimum width with normal gutter, measured from curb face; or 3' (0.9 m) measured from the gutter pan seam;
- 5 feet (1.5 m) minimum width when parking stalls are marked; and
- 11 feet (3.4 m) minimum width for a shared bike/parking lane where parking is permitted but not marked on streets without curbs; or 12 feet (3.7 m) for a shared lane adjacent to a curb face.
- Bicycle lanes shall be comprised of a 6 inch solid white stripe on the outside of the lane, and a 4 inch solid white stripe on the inside of the lane.
- Where on-street parking is allowed, bicycle lanes must be striped between the parking area and the travel lanes.
- In cases where there is insufficient space for a bike lane, cities may recommend removing a traffic lane, narrowing traffic lanes, or prohibiting parking.
- The R81 (CA) bicycle lane sign shall be placed at the beginning of all bicycle lanes, on the far side of arterial street intersections, at all changes in direction and at a maximum of .6 mile intervals. All standard signage is shown in Chapter 9 of the 2006 *California MUTCD*.

Figure 4.61 General guidelines for Bicycle lane (Extracted from Alta Planning and California Highway Design Manual)

In a residential area such as ours, it is necessary to provide a bicycle lane because there will be cyclists and children within the neighborhood who will benefit from this. In accordance with the California Highway Design Manual, it is suggested to have a minimum width of 1.2 m for bicycle lane, but due to the lack of space we propose to join the bicycle lane and pedestrian lane and have a joint width of 2.0 m along every minor road within the proposed area.

4.11.5 Bus Stop

A bus stop is a designated location where buses pick up and drop off passengers. These stops are strategically placed along bus routes to facilitate efficient and convenient public transportation. Generally, the design of a bus stop requires a lot of area to be taken from a road segment, therefore it shall not be suitable for use in the minor roads and its only sensible to place the bus stops along the major roads. We suggest there be 5 bus stops location as we feel like this is suitable and can be well distributed throughout the area, the choices made are at a focal point whereas residents from the different designated areas can have quick and easy access to the stop.

The bus stop is designed in accordance to Translink Bus Infrastructure Design Guidelines (2013) and State Transit Bus Infrastructure Guide Australia (2012).

The following were implemented in the design;

- A minimum 3-m wide bus stop next to a bike lane is desirable so a stopped bus does not impact the bike lane.

- A bus stop in a bus bay adjacent to a bike lane requires longer pull-in and pull-out distances than a bus bay adjacent to a vehicle travel lane due to the additional bike-lane width that a bus needs to cross to enter or exit the bus stop. The taper ratio requirements should conform to those shown in Table 31 below.

Table 31: Bus Stop Taper Lengths (adapted from Translink BIDG).

Roadway Posted Speed	Pull-in Taper	Pull-out Taper
<=50 km/hr	1:6	1:3.3
>=60 km/hr	1:8.3	1:8.3

- Passenger pad that covers all potential bus doors locations. It is worthy to note that this bus stop has been designed to have 1 bus only using the facility at a time. This is because the bus stop is found on a route not served by many bus companies and the buses that pass through there have a schedule of 1 each 30 minutes.

- A wheelchair pad is present at the bus stop for wheelchair accessibility.

- For simple bus stops, night-time conditions should be considered but standard street lighting conditions are acceptable as is the case here.

- The existing open drain should be covered as the minimum reserve to leave it open no longer exists. Drainage grates and utility covers are potential safety hazards for boarding and alighting passengers at bus stops, therefore near the landing, it is fully concrete covered drain.

- As for the kerbs, barrier kerbs are used as there is pedestrian access. This is shown in figure 4.62

Figure 4.62 Barrier Kerb

- All bus stops and routes should have a clear zone of 800mm across the footpath from the face of the kerb and 4.3m (the allowable height for medium rigid vehicles) above pavement level as in figure 4.63.

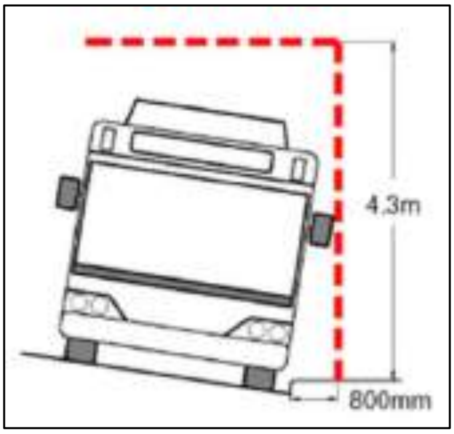


Figure 4.63 Clear zone

4.11.6 Design of Road Infrastructure Elements

This section covers the design of pedestrian crossing, bicycle lane, and bus stops present within study zone A. The designs adhere to the requirements specified in the AUSTROADS Part 13, California Highway Design Manual and Translink Bus Infrastructure Design Guidelines

4.11.6.1 Location of Road Infrastructure Elements

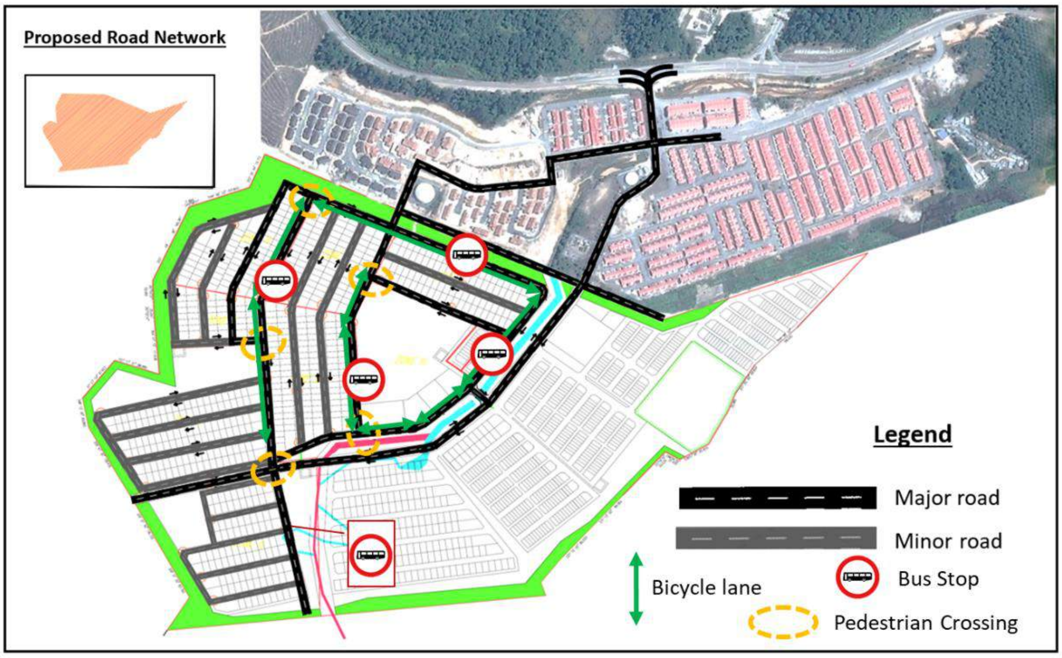


Figure 4.64 Proposed Layout of Road Network with location of Road Infrastructure Elements

4.11.6.2 Proposed Design of Road Infrastructure Elements

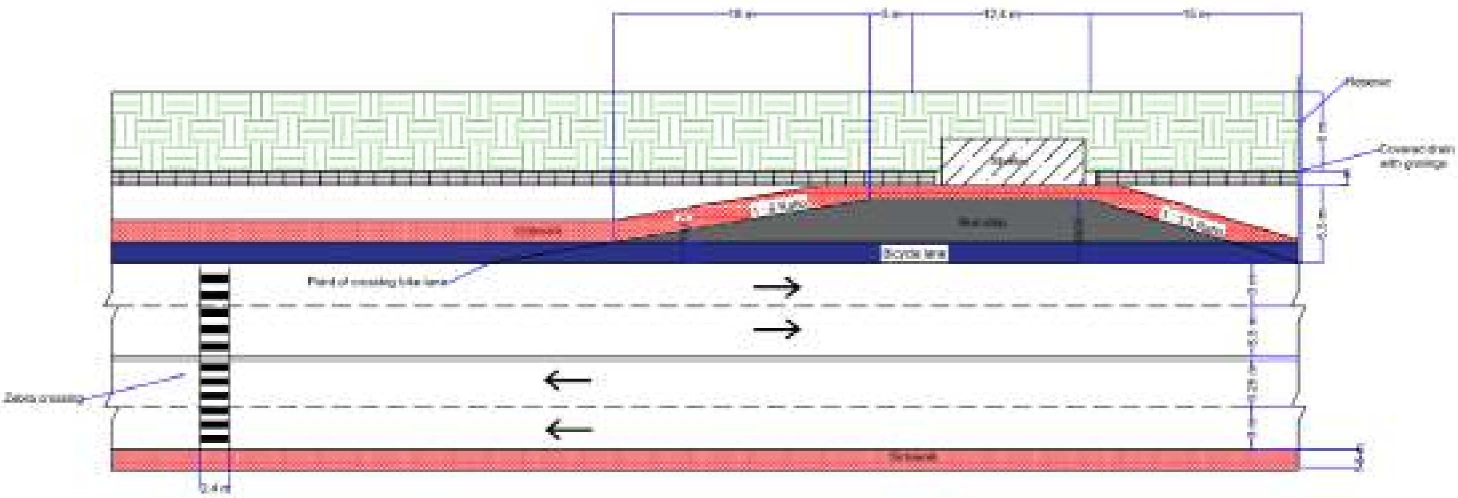


Figure 4.65 Proposed Road Infrastructure design at Study Zone A (South)

References

Arahan Teknik Jalan (ATJ) 8/86– Pindaan 2015: A Guide on Geometric Design of Roads

Arahan Teknik Jalan (ATJ) 5/85: Manual on Pavement Design

Arahan Teknik Jalan (ATJ) 13/87: A Guide to the Design of Traffic Signals

Arahan Teknik Jalan (ATJ) 11/87– Pindaan 2016: A Guide to The Design of At-Grade Intersections

Arahan Teknik Jalan (ATJ) 2A/85: Standard Traffic Signs

Arahan Teknik Jalan (ATJ) 2B/85: Traffic Signs Application

Arahan Teknik Jalan (ATJ) 2D/85: Manual on Traffic Control Devices (Road Marking and Delineation)

Arahan Teknik Jalan (ATJ) 2E/87– Pindaan 2015: Guide Signs Design and Applications

Arahan Teknik Jalan (ATJ) 18/97– Basic Guidelines on Pedestrian Facilities

Chapter 4: Highway Geometry Design from Traffic Engineering Notes

Chapter 1 & 2: Vertical and Horizontal Alignment from Highway Infrastructure Design Notes

Highway Capacity Manual (HCM) 2000

Chapter 3: Design of fixed-time Signal from Traffic Management & Analysis Notes - MHCM 2006 – the Malaysia version of U.S. HCM) & U.S. HCM2010 and ATJ 13/87 Pindaan 2017

Malaysia Traffic Generation Manual (MTGM) 2010 12. Road Traffic Volume Malaysia (RTVM) 2021

AUSTROADS: Guide To Traffic Engineering Practice Part 13 – Pedestrians (1995)

Sustrans Design Manual Handbook for cycle-friendly design

California Highway Design Manual 2016

Translink Bus Infrastructure Design Guidelines (2013)

State Transit Bus Infrastructure Guide Australia (2012).

Appendix A | Trip Generation

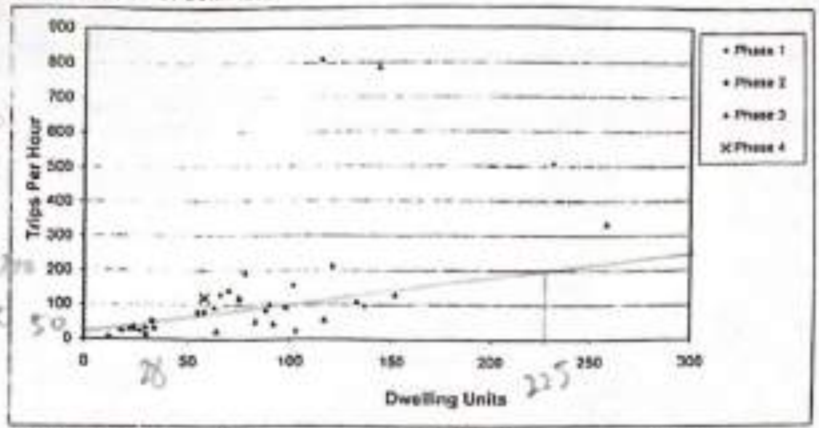
Malaysian Trip Generation Manual

Highway Planning Unit
Ministry of Works Malaysia

Residential
Semi-Detached, Detached
Trips per Dwelling Units

CODE
01 01 03/04

AM Peak Hour Of Commuter

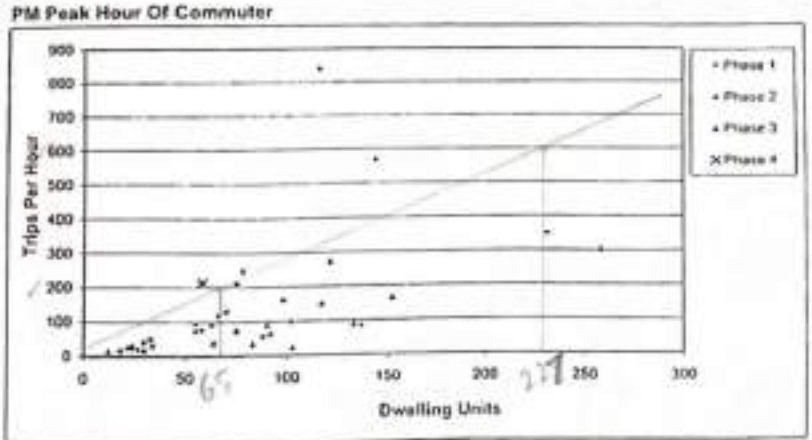


m = 0.76

Number Of Sites :	37	Percent In/Out :	35 / 65
Average Rate :	1.51	Use Trip Rates	
Minimum Rate :	0.25		
Maximum Rate :	6.96		
Standard Deviation	1.2732		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	76.94	1.00	0.77
Motorcycle	15.11	0.33	0.05
Small Lorry	6.68	1.75	0.12
Big Lorry	0.02	2.25	0.00
Bus	1.24	2.25	0.03
Total	100.00%		0.96

PM Peak Hour Of Commuter



m = (600 - 200) / (225 - 65)

m = 2.45

600 = 2.45(225) + c

C = 41.4

Number Of Sites :	37	Percent In/Out :	53 / 47
Average Rate :	1.54	Use Trip Rates	
Minimum Rate :	0.24		
Maximum Rate :	7.23		
Standard Deviation	1.2817		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	67.41	1.00	0.67
Motorcycle	22.85	0.33	0.08
Small Lorry	8.45	1.75	0.15
Big Lorry	0.12	2.25	0.00
Bus	0.76	2.25	0.02
Total	100.00%		0.92

CODE
03 01 02

Religious
Surau, Madrasah
Trips per TSF

AM Peak Hour Of Generator

$m = \frac{12.5 - 5.5}{62 - 1}$

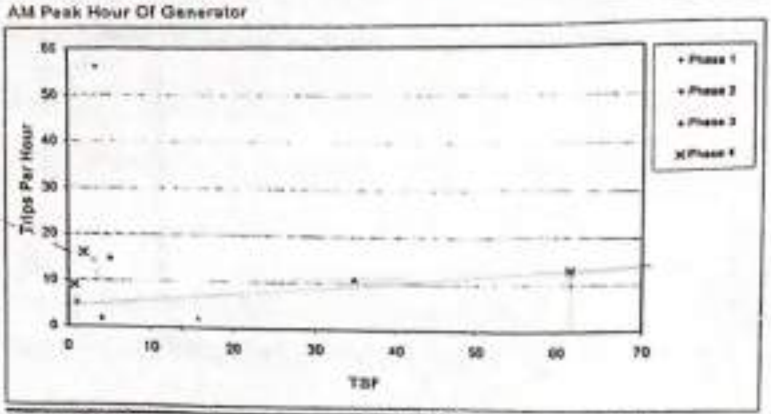
$m = 0.11$

$y = mx + c$

$12.5 = 0.11(62) + c$

$c = 5.68$

$y = 0.11x + 5.68$



Number Of Sites :	8	Percent In/Out :	59 / 41
Average Rate :	5.46	Use Trip Rates	
Minimum Rate :	0.21		
Maximum Rate :	16.00		
Standard Deviation :	5.8628		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	40.18	1.00	0.40
Motorcycle	59.82	0.33	0.20
Small Lorry	0.00	1.75	0.00
Big Lorry	0.00	2.25	0.00
Bus	0.00	2.25	0.00
Total	100.00%		0.60

PM Peak Hour Of Generator

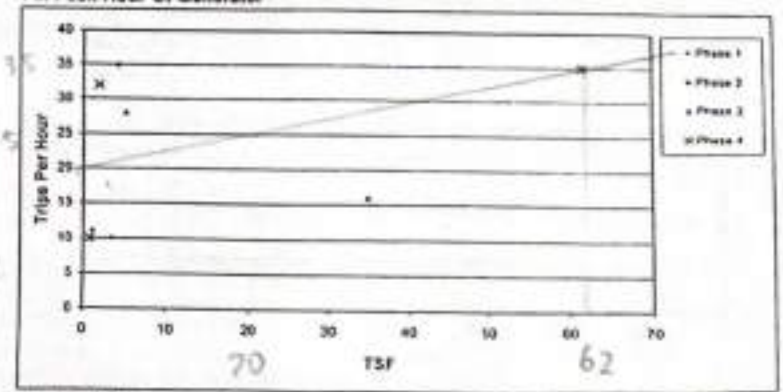
$m = \frac{35 - 25}{62 - 10}$

$m = 0.24$

$y = mx + c$

$35 = 0.24(62) + c$

$c = 20.2$



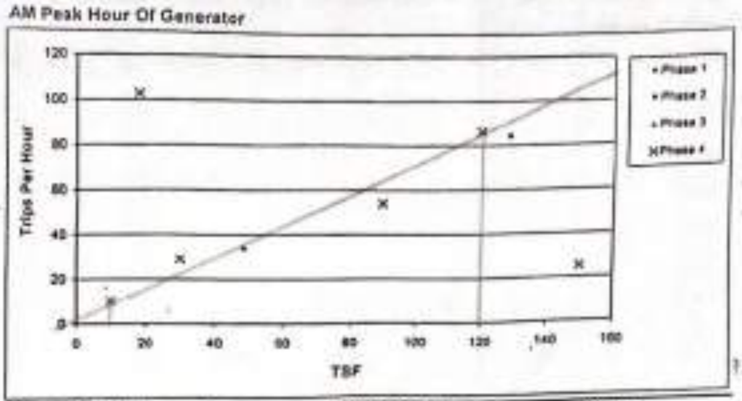
Number Of Sites :	8	Percent In/Out :	44 / 56
Average Rate :	7.01	Use Trip Rates	
Minimum Rate :	0.46		
Maximum Rate :	16.64		
Standard Deviation :	5.8259		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	40.68	1.00	0.41
Motorcycle	59.32	0.33	0.20
Small Lorry	0.00	1.75	0.00
Big Lorry	0.00	2.25	0.00
Bus	0.00	2.25	0.00
Total	100.00%		0.60

Institutional
Telecommunications, Power Supply,
Gas Distribution Centre, Environmental Services
Trips per TSF

CODE
02.09
01/02/03/04

AM Peak Hour Of Generator



$m = \frac{86-12}{119-9}$

$m = 0.67$

$y = mx + c$

$y = 0.67x + c$

$12 = 0.67(9) + c$

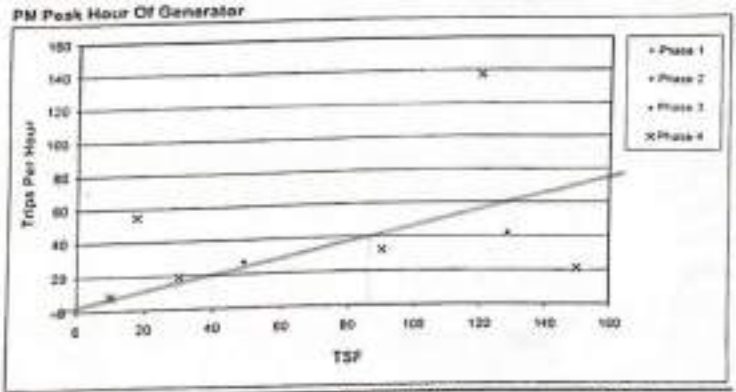
$c = 5.97$

$y = 0.67x + 5.97$

Number Of Sites :	8	Percent In/Out :	69 / 31
Average Rate :	1.34	Use Trip Rates	
Minimum Rate :	0.17		
Maximum Rate :	5.89		
Standard Deviation :	1.8560		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	46.82	1.00	0.47
Motorcycle	25.88	0.33	0.09
Small Lorry	26.12	1.75	0.46
Big Lorry	1.18	2.25	0.03
Bus	0.00	2.25	0.00
Total	**100.00%**		**1.04**

PM Peak Hour Of Generator



$m = \frac{40-20}{86-40}$

$m = 0.43$

$y = mx + c$

$y = 0.43x + c$

$40 = 0.43(86) + c$

$c = 3$

$y = 0.43x + 3$

Number Of Sites :	8	Percent In/Out :	31 / 69
Average Rate :	0.89	Use Trip Rates	
Minimum Rate :	0.14		
Maximum Rate :	3.14		
Standard Deviation :	0.9629		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	42.52	1.00	0.43
Motorcycle	29.62	0.33	0.10
Small Lorry	25.81	1.75	0.45
Big Lorry	2.05	2.25	0.05
Bus	0.00	2.25	0.00
Total	**100.00%**		**1.02**

Community
Public Park, Botanical Parks, Open Space, Playground, Recreational Forest
Trips per Acre

CODE
06 01
02/03/04/05/06

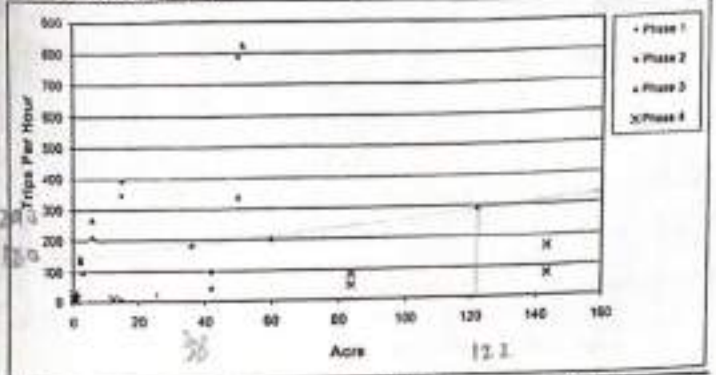
$m = \frac{290-150}{122-38}$

$m = 1.31$

$290 = 1.31(122) + c$

$c = 130.18$

AM Peak Hour Of Generator



Number Of Sites :	28	Percent In/Out :	42 / 58
Average Rate :	20.44	Use Trip Rates	
Minimum Rate	0.27		
Maximum Rate	75.00		
Standard Deviation :	23.0869		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	67.25	1.00	0.67
Motorcycle	27.63	0.33	0.09
Small Lorry	4.02	1.75	0.07
Big Lorry	0.02	2.25	0.00
Bus	1.08	2.25	0.02
Total	100.00%		0.86

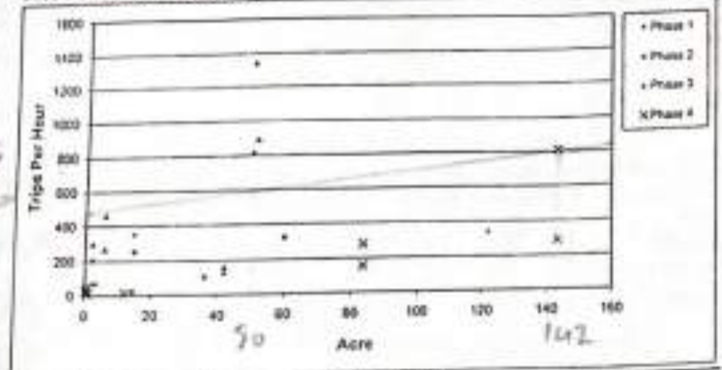
$m = \frac{815-600}{142-50}$

$m = 2.34$

$815 = 2.34(142) + c$

$c = 482.72$

PM Peak Hour Of Generator

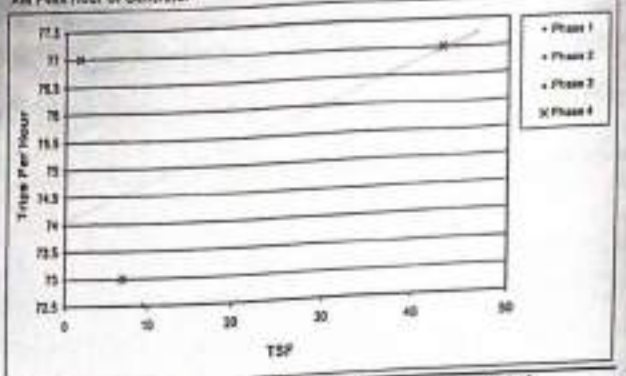


Number Of Sites :	28	Percent In/Out :	43 / 57
Average Rate :	32.50	Use Trip Rates	
Minimum Rate :	0.81		
Maximum Rate :	150.00		
Standard Deviation :	41.2002		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	57.04	1.00	0.57
Motorcycle	38.80	0.33	0.13
Small Lorry	3.87	1.75	0.07
Big Lorry	0.00	2.25	0.00
Bus	0.28	2.25	0.01
Total	100.00%		0.77

Educational
Kindergarten
Trips per TSF

AM Peak Hour Of Generator

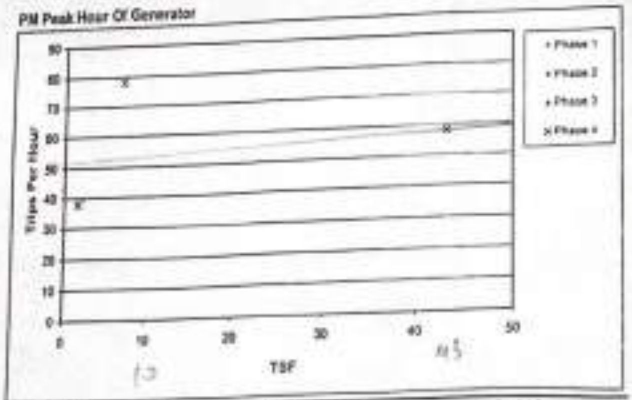


$m = \frac{77-74}{43-10}$

Number Of Sites :	3	Percent In/Out :	52 / 48
Average Rate :	10.35	Use Trip Rates	
Minimum Rate :	1.78		
Maximum Rate :	45.83		
Standard Deviation :	23.3400		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	80.18	1.00	0.80
Motorcycle	12.78	0.33	0.04
Small Lorry	7.05	1.75	0.12
Big Lorry	0.00	2.25	0.00
Bus	0.00	2.25	0.00
Total	100.00%		0.97

PM Peak Hour Of Generator



$m = \frac{59-53}{43-10}$

$m = 0.182$

$59 = 0.182(43) + c$

$c = 51.17$

Number Of Sites :	3	Percent In/Out	51 / 49
Average Rate :	11.70	Use Trip Rates	
Minimum Rate :	1.34		
Maximum Rate :	22.62		
Standard Deviation :	10.6485		

Vehicle Type	Vehicle Composition	PCU Factor	PCU Conversion Factor
Car/Taxi	78.74	1.00	0.79
Motorcycle	17.24	0.33	0.06
Small Lorry	4.02	1.75	0.07
Big Lorry	0.00	2.25	0.00
Bus	0.00	2.25	0.00
Total	100.00%		0.91

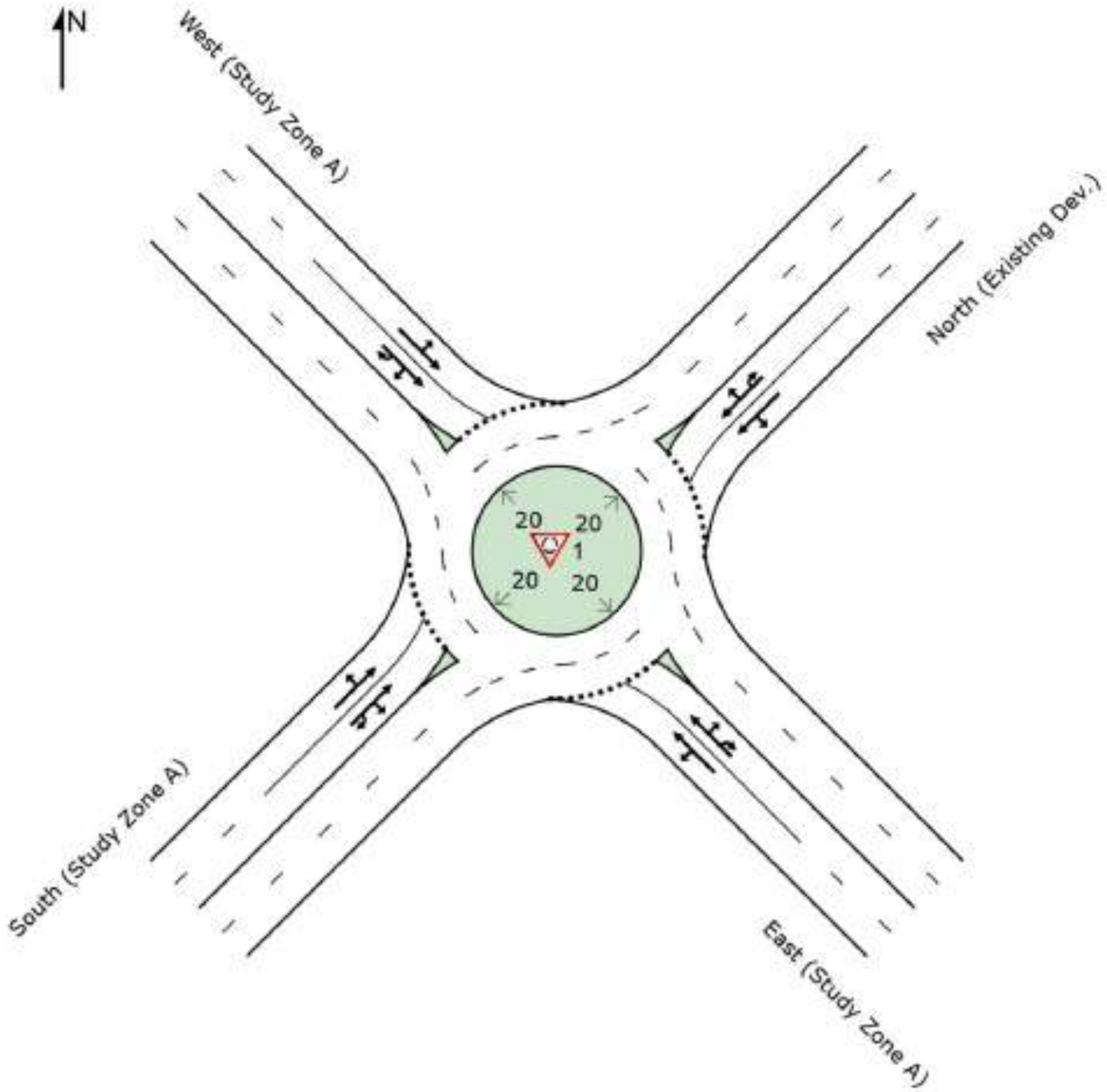
Appendix B | SIDRA Results

SITE LAYOUT

Site: 1 [Entrance 1 (Site Folder: General)]

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Layout pictures are schematic functional drawings reflecting input data. They are not design drawings.



INPUT VOLUMES

Vehicles and pedestrians per 60 minutes

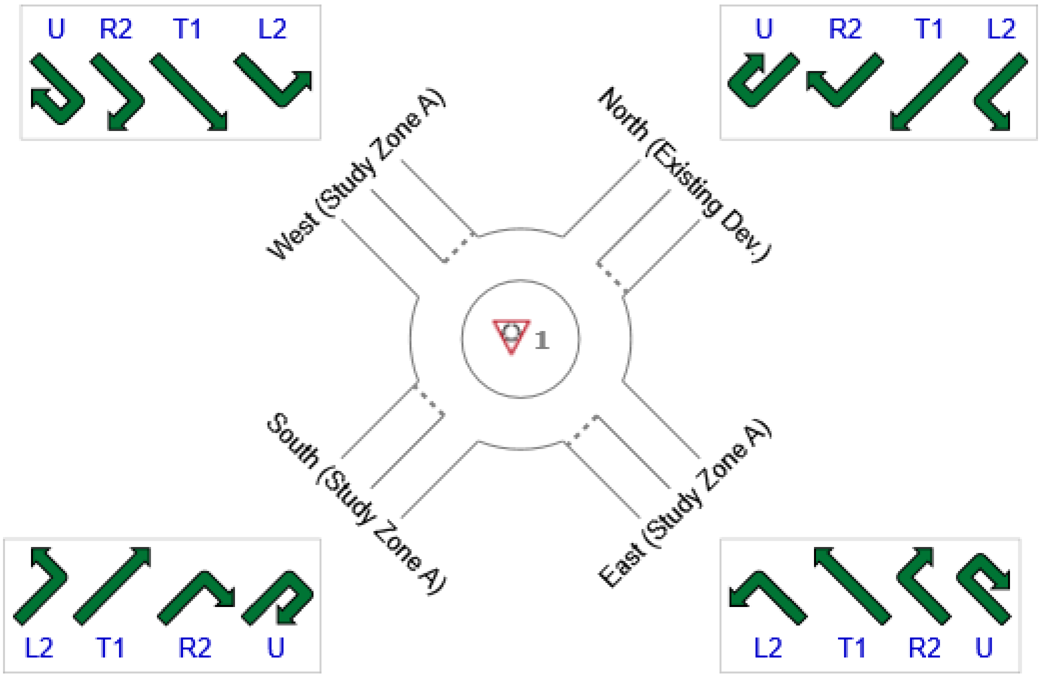
Site: 1 [Entrance 1 (Site Folder: General)]

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Volume Display Method: Total and %

	U	R2	T1	L2
Tot	13	22	15	66
LV	98%	98%	98%	98%
HV	2%	2%	2%	2%

	U	R2	T1	L2
Tot	12	53	366	105
LV	98%	100%	98%	98%
HV	2%	0%	2%	2%



	L2	T1	R2	U
Tot	33	216	46	16
LV	98%	98%	98%	98%
HV	2%	2%	2%	2%

	L2	T1	R2	U
Tot	24	12	73	11
LV	98%	100%	98%	98%
HV	2%	0%	2%	2%

	All MCs	Light Vehicles (LV)	Heavy Vehicles (HV)
SE: East (Study Zone A)	120	118	2
NE: North (Existing Dev.)	536	526	10
NW: West (Study Zone A)	116	114	2
SW: South (Study Zone A)	311	305	6
Total	1083	1063	20

MOVEMENT SUMMARY

Site: 1 [Entrance 1 (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
SouthEast: East (Study Zone A)															
21	L2	All MCs	25	2.0	25	2.0	0.051	5.4	LOS A	0.1	1.0	0.40	0.35	0.40	50.5
22	T1	All MCs	13	0.0	13	0.0	0.051	5.2	LOS A	0.1	1.0	0.40	0.35	0.40	51.1
23	R2	All MCs	77	2.0	77	2.0	0.116	5.9	LOS A	0.3	2.3	0.40	0.35	0.40	47.0
23u	U	All MCs	12	2.0	12	2.0	0.116	5.9	LOS A	0.3	2.3	0.40	0.35	0.40	47.0
Approach			126	1.8	126	1.8	0.116	5.8	LOS A	0.3	2.3	0.40	0.35	0.40	48.1
NorthEast: North (Existing Dev.)															
24	L2	All MCs	111	2.0	111	2.0	0.278	6.2	LOS A	0.9	6.6	0.23	0.12	0.23	50.0
25	T1	All MCs	385	2.0	385	2.0	0.278	6.2	LOS A	1.0	7.0	0.24	0.13	0.24	50.1
26	R2	All MCs	56	0.0	56	0.0	0.278	6.2	LOS A	1.0	7.0	0.25	0.13	0.25	49.0
26u	U	All MCs	13	2.0	13	2.0	0.278	6.3	LOS A	1.0	7.0	0.25	0.13	0.25	49.0
Approach			564	1.8	564	1.8	0.278	6.2	LOS A	1.0	7.0	0.24	0.13	0.24	49.9
NorthWest: West (Study Zone A)															
27	L2	All MCs	69	2.0	69	2.0	0.083	5.1	LOS A	0.2	1.6	0.35	0.27	0.35	50.6
28	T1	All MCs	16	2.0	16	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	49.0
29	R2	All MCs	23	2.0	23	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	48.2
29u	U	All MCs	14	2.0	14	2.0	0.065	5.0	LOS A	0.2	1.3	0.36	0.28	0.36	48.2
Approach			122	2.0	122	2.0	0.083	5.1	LOS A	0.2	1.6	0.35	0.28	0.35	49.6
SouthWest: South (Study Zone A)															
30	L2	All MCs	35	2.0	35	2.0	0.169	5.3	LOS A	0.5	3.6	0.25	0.15	0.25	50.7
31	T1	All MCs	227	2.0	227	2.0	0.169	5.3	LOS A	0.5	3.8	0.26	0.16	0.26	50.6
32	R2	All MCs	48	2.0	48	2.0	0.169	5.3	LOS A	0.5	3.8	0.27	0.16	0.27	49.1
32u	U	All MCs	17	2.0	17	2.0	0.169	5.3	LOS A	0.5	3.8	0.27	0.16	0.27	49.1
Approach			327	2.0	327	2.0	0.169	5.3	LOS A	0.5	3.8	0.26	0.16	0.26	50.3
All Vehicles			1140	1.9	1140	1.9	0.278	5.8	LOS A	1.0	7.0	0.28	0.18	0.28	49.8

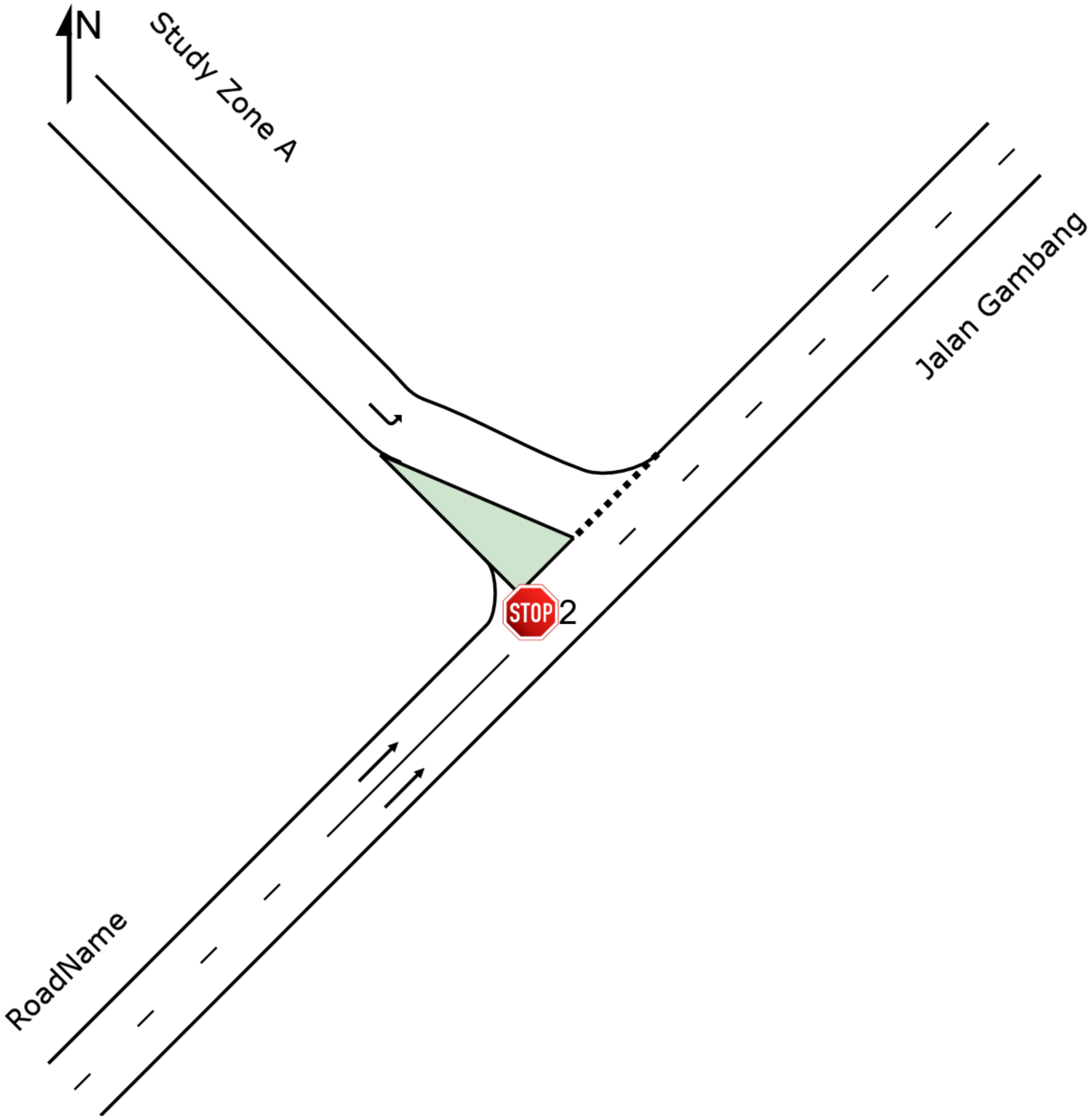
Site Level of Service (LOS) Method: Delay & v/c (HCM 2010). Site LOS Method is specified in the Parameter Settings dialog (Options tab).
Roundabout LOS Method: SIDRA Roundabout LOS.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement.
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
Delay Model: HCM Delay Formula (Stopline Delay: Geometric Delay is not included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Gap.
Gap-Acceptance Capacity Formula: Siegloch M1 implied by US HCM 2010 Roundabout Capacity Model.
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

SITE LAYOUT

Site: 2 [Entrance 2 (Site Folder: General)]

New Site
Site Category: (None)
Stop (Two-Way)

Layout pictures are schematic functional drawings reflecting input data. They are not design drawings.



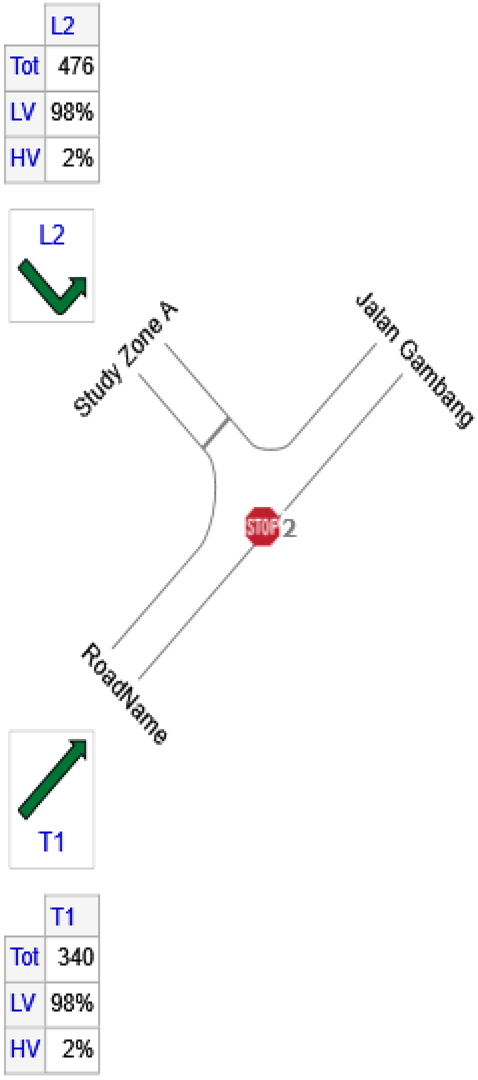
INPUT VOLUMES

Vehicles and pedestrians per 60 minutes

Site: 2 [Entrance 2 (Site Folder: General)]

New Site
Site Category: (None)
Stop (Two-Way)

Volume Display Method: Total and %



	All MCs	Light Vehicles (LV)	Heavy Vehicles (HV)
NW: Study Zone A	476	466	10
SW: RoadName	340	333	7
Total	816	800	16

MOVEMENT SUMMARY

Site: 2 [Entrance 2 (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

New Site
Site Category: (None)
Stop (Two-Way)

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
NorthWest: Study Zone A															
7	L2	All MCs	501	2.0	501	2.0	0.362	6.5	LOS A	1.9	13.6	0.35	0.57	0.35	51.9
Approach			501	2.0	501	2.0	0.362	6.5	LOS A	1.9	13.6	0.35	0.57	0.35	51.9
SouthWest: RoadName															
11	T1	All MCs	358	2.0	358	2.0	0.093	0.0	LOS A	0.0	0.0	0.00	0.00	0.00	60.0
Approach			358	2.0	358	2.0	0.093	0.0	NA	0.0	0.0	0.00	0.00	0.00	60.0
All Vehicles			859	2.0	859	2.0	0.362	3.8	NA	1.9	13.6	0.21	0.33	0.21	55.0

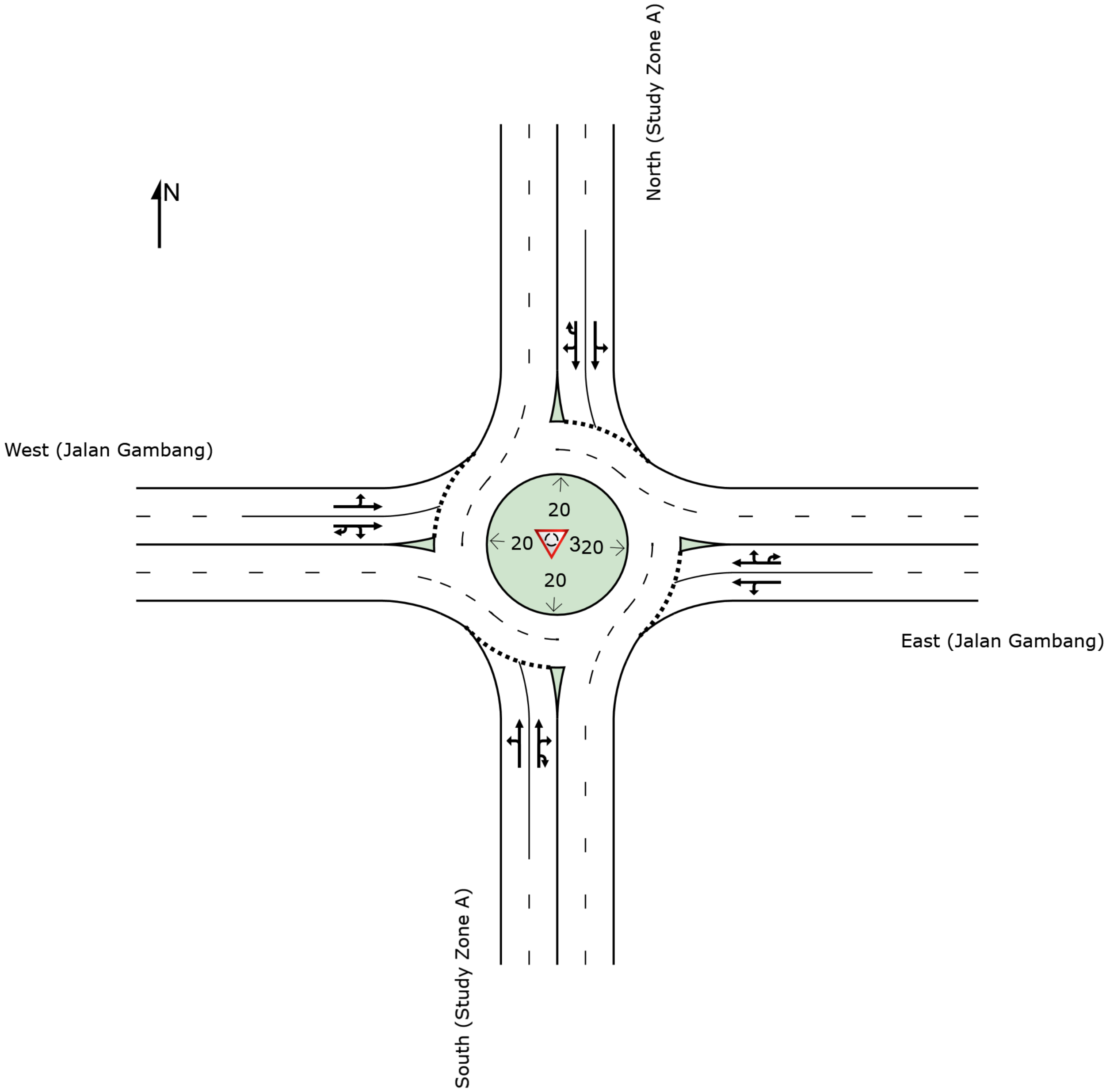
Site Level of Service (LOS) Method: Delay & v/c (HCM 2010). Site LOS Method is specified in the Parameter Settings dialog (Options tab).
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement.
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Minor Road Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
NA (TWSC): Level of Service is not defined for major road approaches or the intersection as a whole for Two-Way Sign Control (HCM LOS rule).
Two-Way Sign Control Capacity Model: SIDRA Standard.
Delay Model: SIDRA Standard (Control Delay: Geometric Delay is included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Gap.
Gap-Acceptance Capacity Formula: SIDRA Standard (Akçelik M3D).
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

SITE LAYOUT

Site: 3 [Entrance 3 (Site Folder: General)]

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Layout pictures are schematic functional drawings reflecting input data. They are not design drawings.



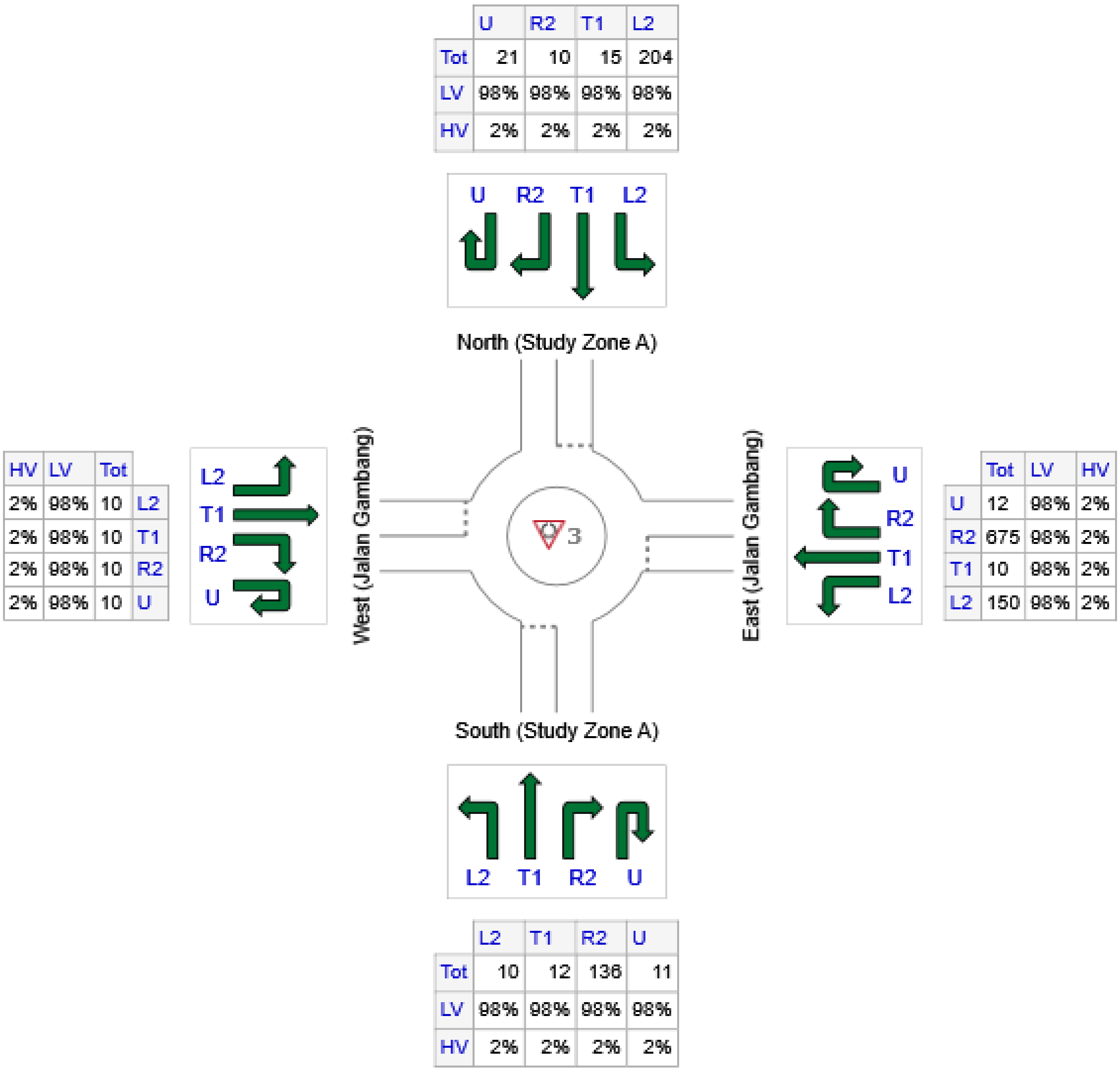
INPUT VOLUMES

Vehicles and pedestrians per 60 minutes

Site: 3 [Entrance 3 (Site Folder: General)]

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Volume Display Method: Total and %



	All MCs	Light Vehicles (LV)	Heavy Vehicles (HV)
S: South (Study Zone A)	169	166	3
E: East (Jalan Gambang)	847	830	17
N: North (Study Zone A)	250	245	5
W: West (Jalan Gambang)	40	39	1
Total	1306	1280	26

MOVEMENT SUMMARY

Site: 3 [Entrance 3 (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

Study Development A - Gambang, Pahang
Site Category: (None)
Roundabout

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Deg. Satn v/c	Aver. Delay sec	Level of Service	95% Back Of Queue [Veh. veh	Dist] m	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed km/h
South: South (Study Zone A)															
21	L2	All MCs	11	2.0	11	2.0	0.041	6.9	LOS A	0.1	0.8	0.51	0.49	0.51	49.5
2	T1	All MCs	13	2.0	13	2.0	0.041	6.9	LOS A	0.1	0.8	0.51	0.49	0.51	50.0
23	R2	All MCs	143	2.0	143	2.0	0.264	9.6	LOS A	0.8	5.9	0.56	0.55	0.56	45.0
23u	U	All MCs	12	2.0	12	2.0	0.264	9.6	LOS A	0.8	5.9	0.56	0.55	0.56	45.0
Approach			178	2.0	178	2.0	0.264	9.3	LOS A	0.8	5.9	0.55	0.54	0.55	45.6
East: East (Jalan Gambang)															
24	L2	All MCs	158	2.0	158	2.0	0.161	4.8	LOS A	0.5	3.6	0.17	0.07	0.17	50.8
25	T1	All MCs	11	2.0	11	2.0	0.161	4.8	LOS A	0.5	3.6	0.17	0.07	0.17	51.3
6	R2	All MCs	711	2.0	711	2.0	0.688	13.0	LOS B	4.9	34.8	0.38	0.17	0.38	43.3
26u	U	All MCs	13	2.0	13	2.0	0.688	13.0	LOS B	4.9	34.8	0.38	0.17	0.38	43.3
Approach			892	2.0	892	2.0	0.688	11.5	LOS B	4.9	34.8	0.34	0.15	0.34	44.5
North: North (Study Zone A)															
7	L2	All MCs	215	2.0	215	2.0	0.226	6.0	LOS A	0.8	5.4	0.30	0.19	0.30	50.0
8	T1	All MCs	16	2.0	16	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	49.3
9	R2	All MCs	11	2.0	11	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	48.5
9u	U	All MCs	22	2.0	22	2.0	0.052	4.3	LOS A	0.2	1.1	0.27	0.17	0.27	48.5
Approach			263	2.0	263	2.0	0.226	5.7	LOS A	0.8	5.4	0.30	0.18	0.30	49.8
West: West (Jalan Gambang)															
10	L2	All MCs	11	2.0	11	2.0	0.040	7.3	LOS A	0.1	0.8	0.54	0.54	0.54	49.2
31	T1	All MCs	11	2.0	11	2.0	0.040	7.3	LOS A	0.1	0.8	0.54	0.54	0.54	49.7
32	R2	All MCs	11	2.0	11	2.0	0.042	7.7	LOS A	0.1	0.8	0.56	0.56	0.56	45.7
32u	U	All MCs	11	2.0	11	2.0	0.042	7.7	LOS A	0.1	0.8	0.56	0.56	0.56	45.7
Approach			42	2.0	42	2.0	0.042	7.5	LOS A	0.1	0.8	0.55	0.55	0.55	47.5
All Vehicles			1375	2.0	1375	2.0	0.688	10.0	LOS A	4.9	34.8	0.37	0.22	0.37	45.7

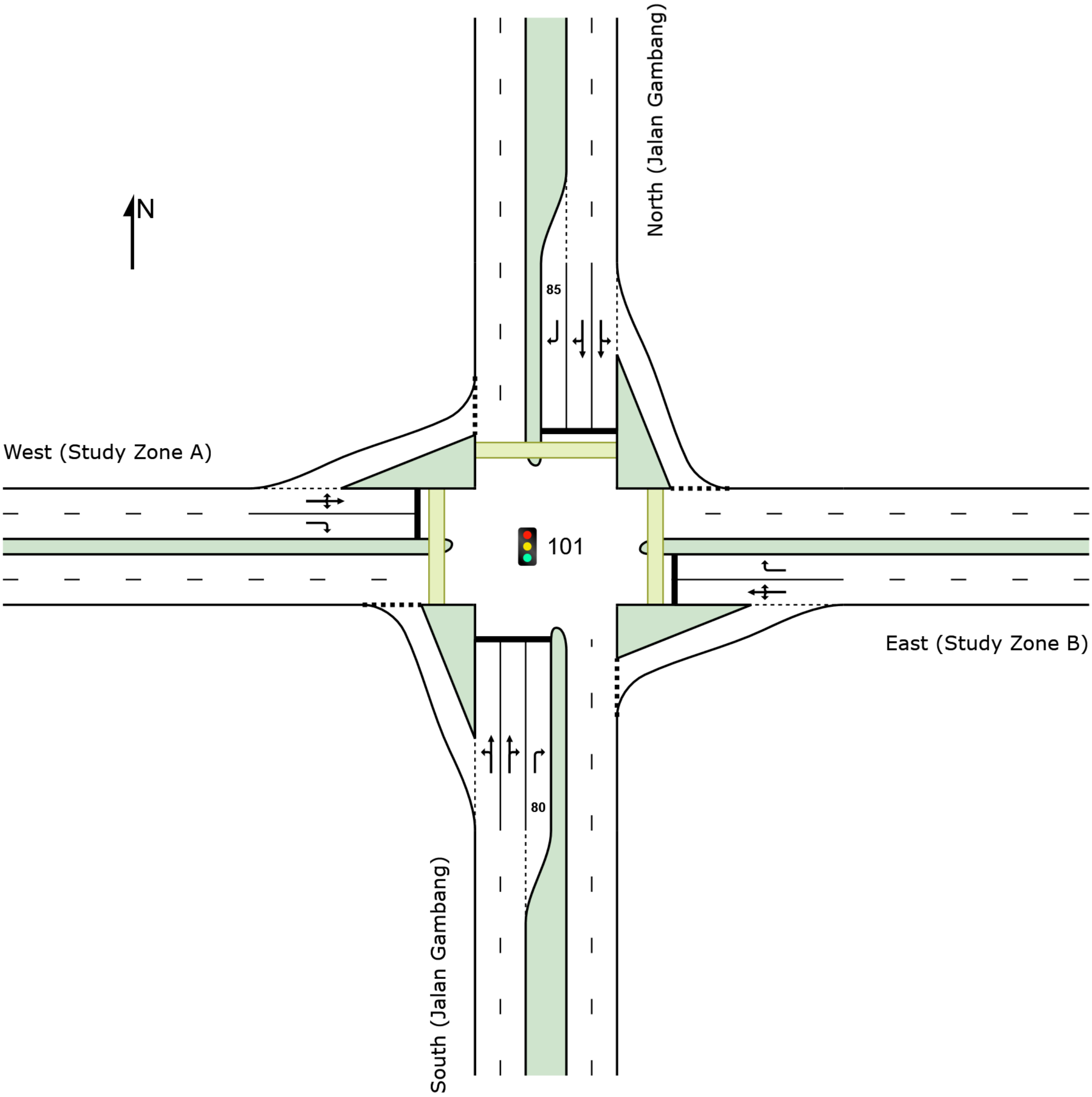
Site Level of Service (LOS) Method: Delay & v/c (HCM 2010). Site LOS Method is specified in the Parameter Settings dialog (Options tab).
Roundabout LOS Method: SIDRA Roundabout LOS.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement.
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
Delay Model: HCM Delay Formula (Stopline Delay: Geometric Delay is not included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Gap.
Gap-Acceptance Capacity Formula: Siegloch M1 implied by US HCM 2010 Roundabout Capacity Model.
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

SITE LAYOUT

Site: 101 [Un-mitigated (Site Folder: General)]

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated

Layout pictures are schematic functional drawings reflecting input data. They are not design drawings.



INPUT PHASE SEQUENCE

All Movement Classes

Site: 101 [Un-mitigated (Site Folder: General)]

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated

Phase Sequence: Four-Phase Split Phasing
Reference Phase: Phase A
Input Phase Sequence: A, B, C, D

REF: Reference Phase
VAR: Variable Phase

MOVEMENT TIMING

All Movement Classes

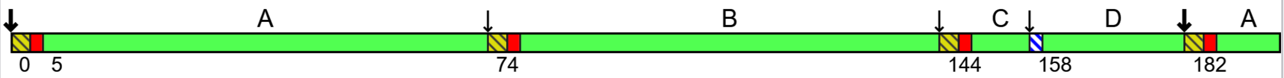
Site: 101 [Un-mitigated (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

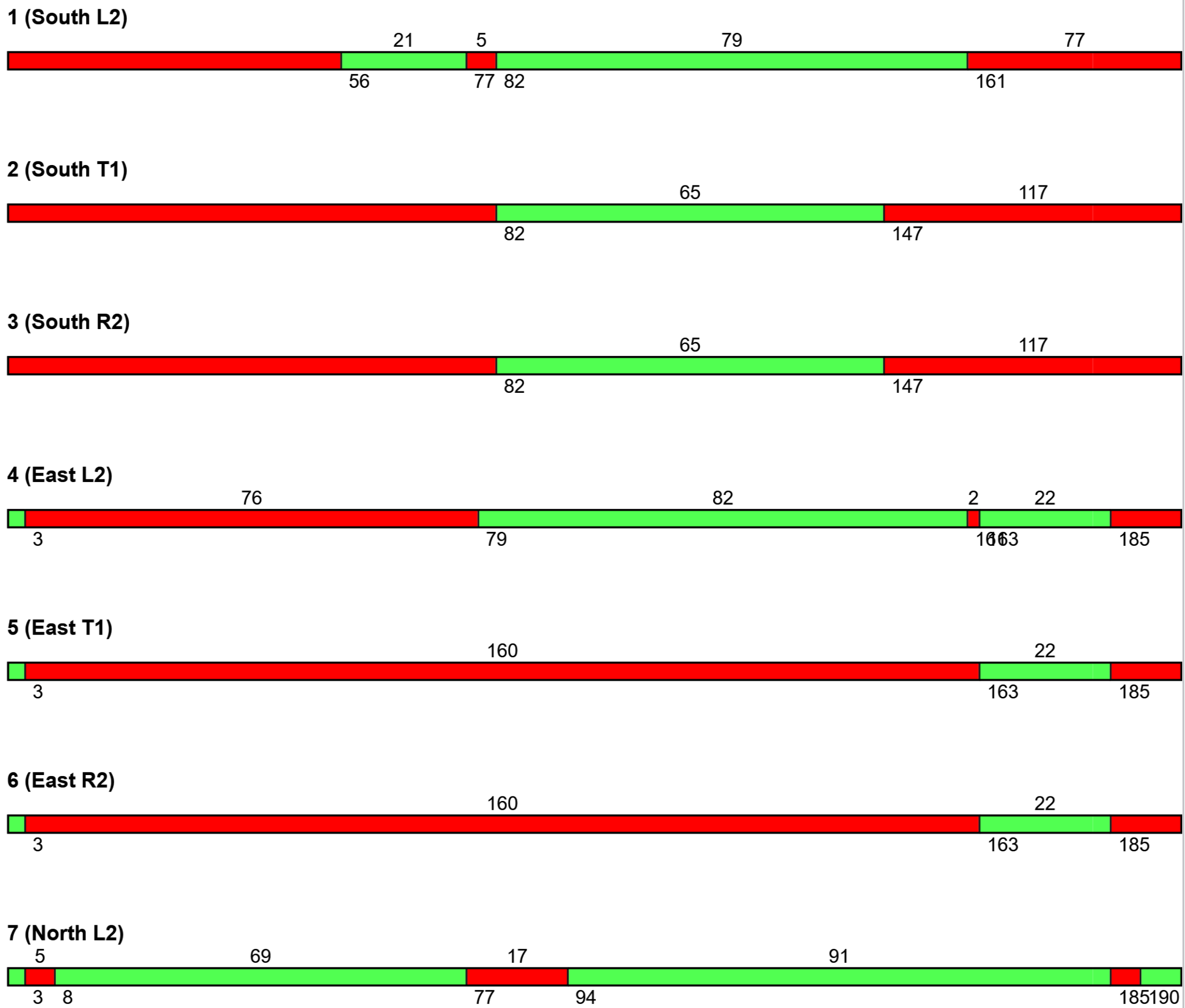
Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 182 seconds (Site User-Given Phase Times)

Timings based on settings in the Site Phasing & Timing dialog
Phase Times specified by the user
Phase Sequence: Four-Phase Split Phasing
Input Phase Sequence: A, B, C, D
Output Phase Sequence: A, B, C, D
Reference Phase: Phase A

Displayed Signal Timing - Phases



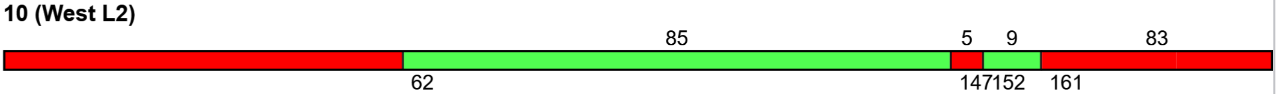
Effective Signal Timing - Movements



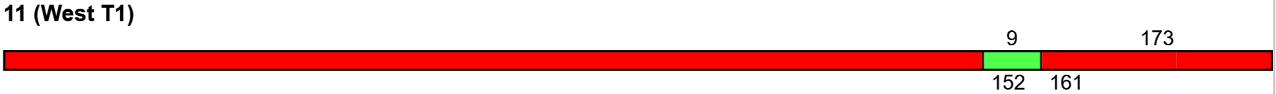
8 (North T1)

9 (North R2)

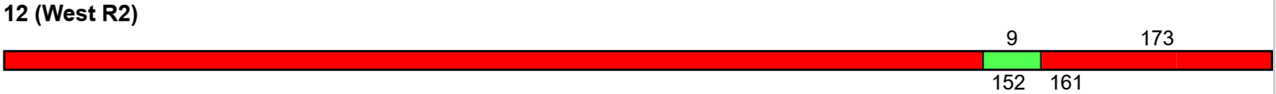
10 (West L2)



11 (West T1)



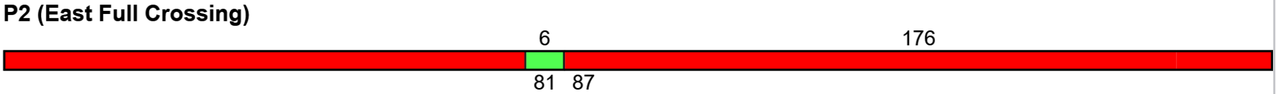
12 (West R2)



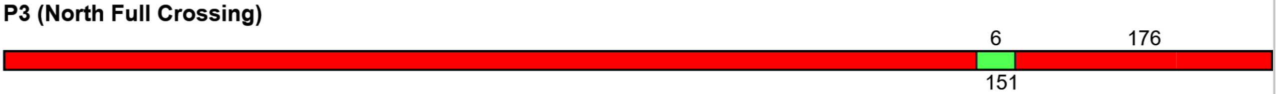
Green Interval
Red Interval

Pedestrian Signal Timing

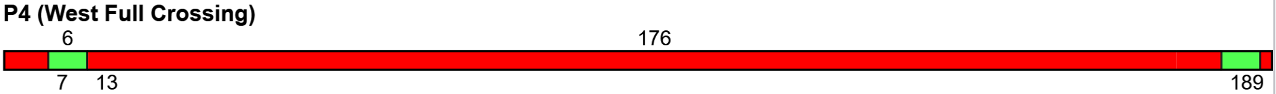
P2 (East Full Crossing)



P3 (North Full Crossing)



P4 (West Full Crossing)



Green Interval
Red Interval

MOVEMENT SUMMARY

Site: 101 [Un-mitigated (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 182 seconds (Site User-Given Phase Times)

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total	HV]	Arrival Flows [Total	HV]	Deg. Satn	Aver. Delay	Level of Service	95% Back Of Queue [Veh.	Dist]	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed
			veh/h	%	veh/h	%	v/c	sec		veh	m				km/h
South: South (Jalan Gambang)															
1	L2	All MCs	173	2.0	173	2.0	1.037	52.8	LOS D	74.8	532.4	1.00	1.10	1.23	20.1
2	T1	All MCs	1153	2.0	1153	2.0	* 1.037	100.6	LOS F	74.8	532.4	1.00	1.14	1.24	21.3
3	R2	All MCs	160	2.0	160	2.0	0.245	84.8	LOS F	9.8	69.8	0.75	0.77	0.75	32.5
Approach			1486	2.0	1486	2.0	1.037	93.4	LOS F	74.8	532.4	0.97	1.10	1.19	21.9
East: East (Study Zone B)															
4	L2	All MCs	24	2.0	24	2.0	0.774	32.2	LOS C	15.4	109.6	1.00	0.90	1.07	22.2
5	T1	All MCs	20	2.0	20	2.0	* 0.774	108.4	LOS F	15.4	109.6	1.00	0.90	1.07	22.5
6	R2	All MCs	302	2.0	302	2.0	0.774	102.2	LOS F	15.4	109.6	1.00	0.88	1.07	22.9
Approach			346	2.0	346	2.0	0.774	97.7	LOS F	15.4	109.6	1.00	0.89	1.07	22.8
North: North (Jalan Gambang)															
7	L2	All MCs	591	2.0	591	2.0	1.418	204.7	LOS F	129.1	919.2	1.00	1.33	1.76	11.4
8	T1	All MCs	1229	2.0	1229	2.0	* 1.418	300.0	LOS F	129.1	919.2	1.00	1.50	1.77	11.5
9	R2	All MCs	430	2.0	430	2.0	1.063	163.5	LOS F	47.4	337.6	1.00	1.13	1.33	19.6
Approach			2250	2.0	2250	2.0	1.418	248.9	LOS F	129.1	919.2	1.00	1.39	1.68	12.4
West: West (Study Zone A)															
10	L2	All MCs	232	2.0	232	2.0	1.656	334.6	LOS F	32.4	230.5	1.00	1.45	2.03	8.0
11	T1	All MCs	56	2.0	56	2.0	* 1.656	423.6	LOS F	32.4	230.5	1.00	1.45	2.03	8.0
12	R2	All MCs	26	2.0	26	2.0	0.291	99.2	LOS F	2.4	16.7	1.00	0.72	1.00	22.6
Approach			314	2.0	314	2.0	1.656	330.7	LOS F	32.4	230.5	1.00	1.39	1.95	8.4
All Vehicles			4396	2.0	4396	2.0	1.656	190.3	LOS F	129.1	919.2	0.99	1.25	1.49	14.6

Site Level of Service (LOS) Method: Delay (SIDRA). Site LOS Method is specified in the Parameter Settings dialog (Options tab).
Vehicle movement LOS values are based on average delay per movement.
Intersection and Approach LOS values are based on average delay for all vehicle movements.
Delay Model: SIDRA Standard (Control Delay: Geometric Delay is included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Green.
Gap-Acceptance Capacity Formula: SIDRA Standard (Akçelik M3D).
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

* Critical Movement (Signal Timing)

Pedestrian Movement Performance

Mov ID	Crossing	Input Vol.	Dem. Flow	Aver. Delay	Level of Service	AVERAGE BACK OF QUEUE [Ped	Dist]	Prop. Que	Eff. Stop Rate	Travel Time	Travel Dist.	Aver. Speed
		ped/h	ped/h	sec		ped	m			sec	m	m/sec
East: East (Study Zone B)												
P2	Full	50	53	85.3	LOS F	0.3	0.3	0.97	0.97	239.1	200.0	0.84
North: North (Jalan Gambang)												
P3	Full	50	53	85.3	LOS F	0.3	0.3	0.97	0.97	239.1	200.0	0.84

West: West (Study Zone A)											
P4 Full	50	53	85.3	LOS F	0.3	0.3	0.97	0.97	239.1	200.0	0.84
All Pedestrians	150	158	85.3	LOS F	0.3	0.3	0.97	0.97	239.1	200.0	0.84

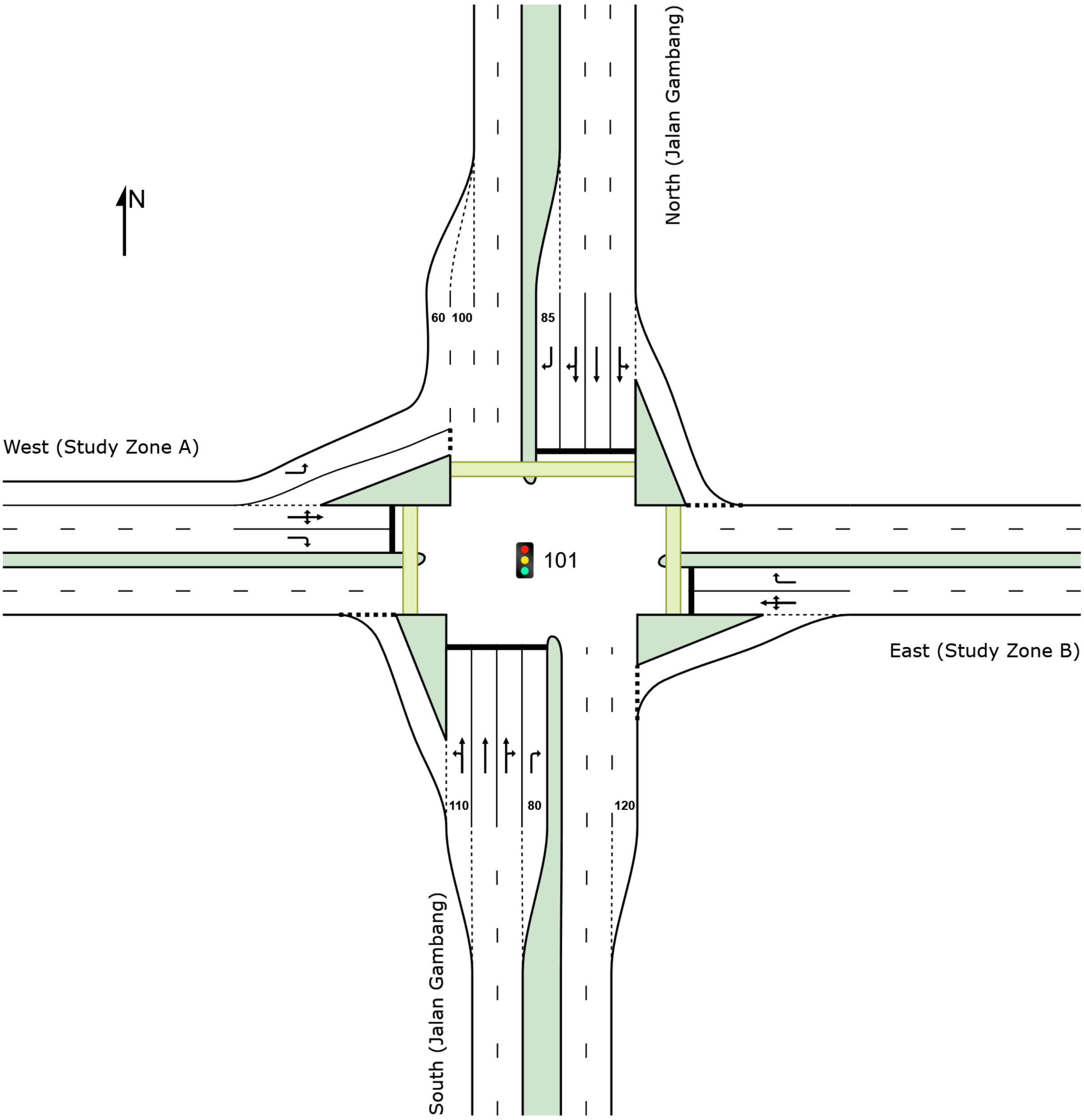
Level of Service (LOS) Method: SIDRA Pedestrian LOS Method (Based on Average Delay)
Pedestrian movement LOS values are based on average delay per pedestrian movement.
Intersection LOS value for Pedestrians is based on average delay for all pedestrian movements.

SITE LAYOUT

Site: 101 [Mitigated (Site Folder: General)]

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated

Layout pictures are schematic functional drawings reflecting input data. They are not design drawings.



INPUT PHASE SEQUENCE

All Movement Classes

Site: 101 [Mitigated (Site Folder: General)]

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated

Phase Sequence: Four-Phase Split Phasing
Reference Phase: Phase A
Input Phase Sequence: A, B, C, D

REF: Reference Phase
VAR: Variable Phase

MOVEMENT TIMING

All Movement Classes

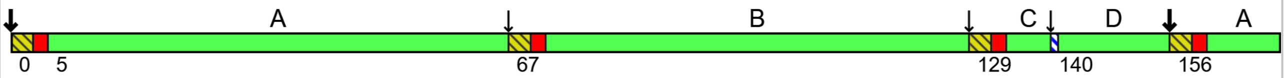
Site: 101 [Mitigated (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 156 seconds (Site User-Given Phase Times)

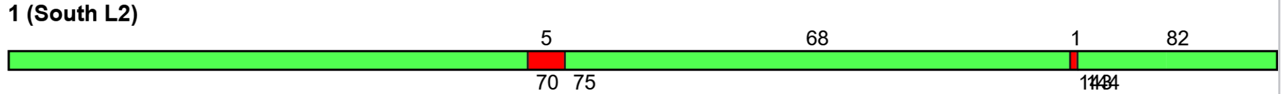
Timings based on settings in the Site Phasing & Timing dialog
Phase Times specified by the user
Phase Sequence: Four-Phase Split Phasing
Input Phase Sequence: A, B, C, D
Output Phase Sequence: A, B, C, D
Reference Phase: Phase A

Displayed Signal Timing - Phases

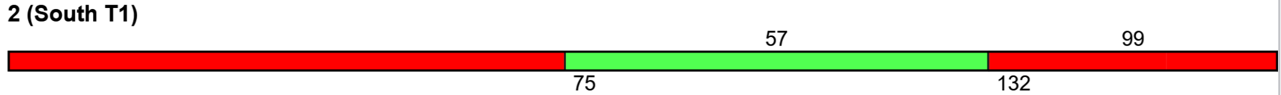


Effective Signal Timing - Movements

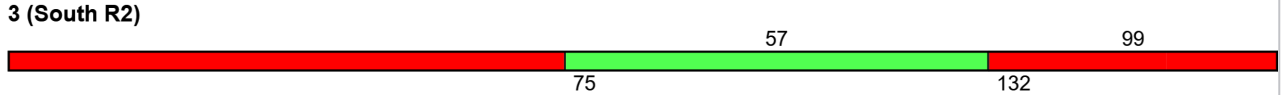
1 (South L2)



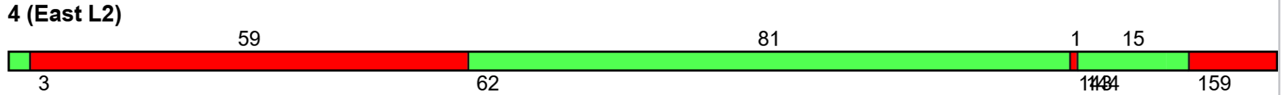
2 (South T1)



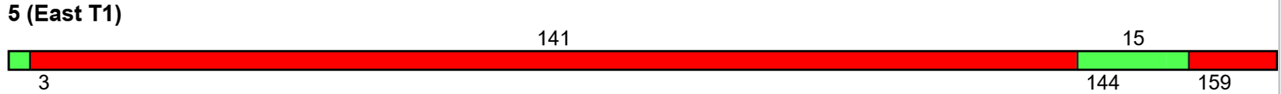
3 (South R2)



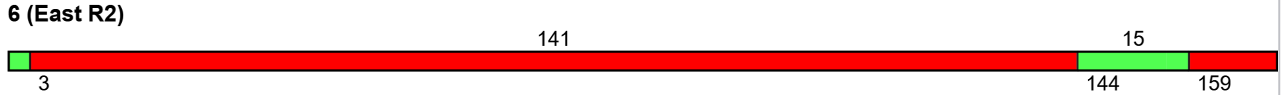
4 (East L2)



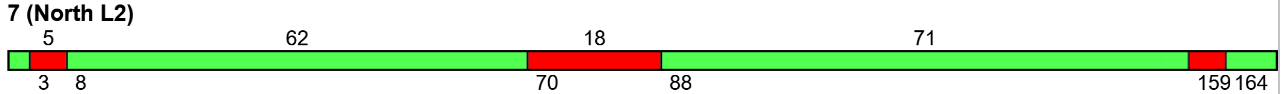
5 (East T1)

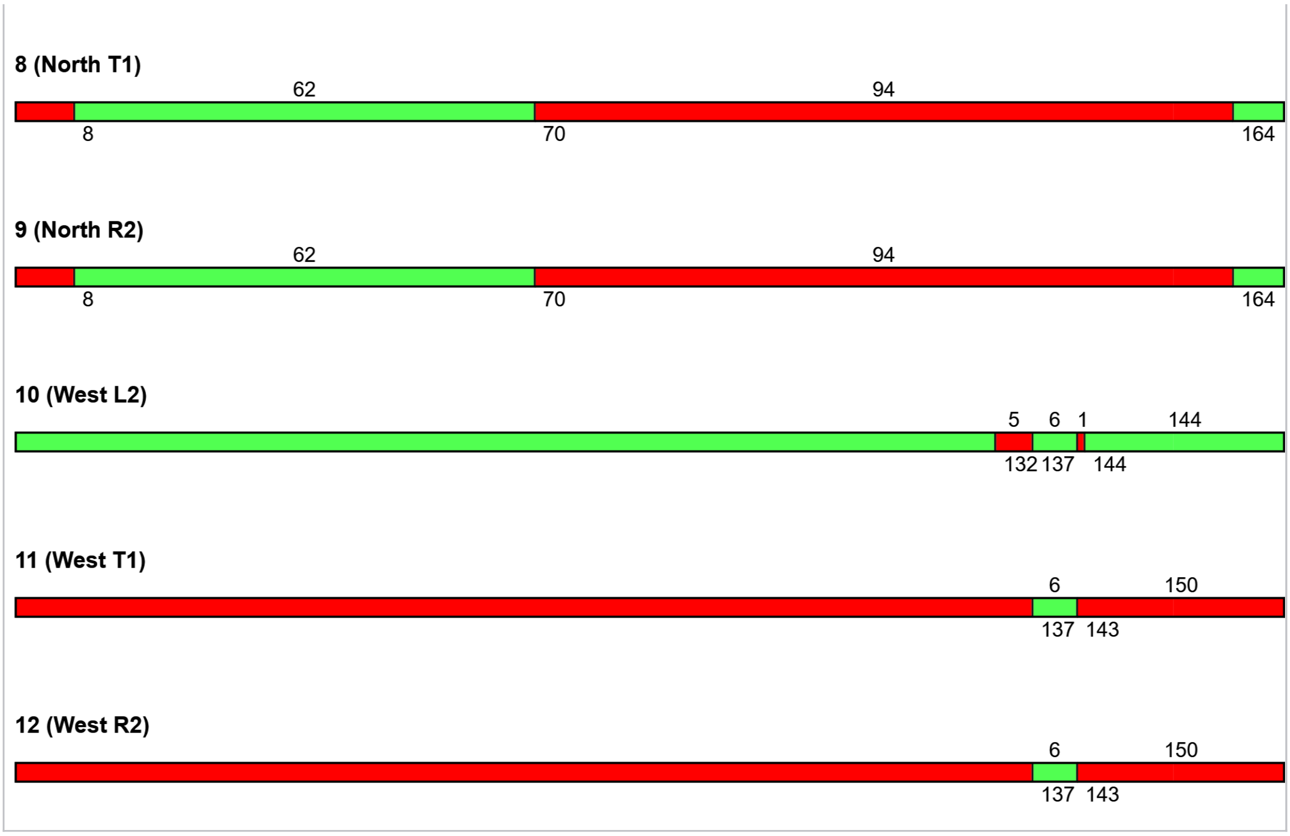


6 (East R2)



7 (North L2)





Green Interval
Red Interval

Pedestrian Signal Timing

Green Interval
Red Interval

MOVEMENT SUMMARY

Site: 101 [Mitigated (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.1.200

Main Signal (Between Study zone A & B)
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 156 seconds (Site User-Given Phase Times)

Vehicle Movement Performance

Mov ID	Turn	Mov Class	Demand Flows [Total	HV]	Arrival Flows [Total	HV]	Deg. Satn	Aver. Delay	Level of Service	95% Back Of Queue [Veh.	Dist]	Prop. Que	Eff. Stop Rate	Aver. No. of Cycles	Aver. Speed
			veh/h	%	veh/h	%	v/c	sec		veh	m				km/h
South: South (Jalan Gambang)															
1	L2	All MCs	173	2.0	173	2.0	0.460	12.4	LOS B	18.9	134.8	0.79	0.75	0.79	35.4
2	T1	All MCs	1153	2.0	1153	2.0	* 0.790	63.1	LOS E	33.4	237.9	0.94	0.84	0.94	34.1
3	R2	All MCs	160	2.0	160	2.0	0.237	58.8	LOS E	8.3	59.2	0.74	0.76	0.74	34.8
Approach			1486	2.0	1486	2.0	0.790	56.7	LOS E	33.4	237.9	0.90	0.82	0.90	34.3
East: East (Study Zone B)															
4	L2	All MCs	24	2.0	24	2.0	0.970	43.7	LOS D	15.8	112.6	1.00	1.02	1.32	22.0
5	T1	All MCs	20	2.0	20	2.0	* 0.970	108.7	LOS F	15.8	112.6	1.00	1.02	1.32	22.3
6	R2	All MCs	302	2.0	302	2.0	0.970	108.8	LOS F	15.8	112.6	1.00	1.01	1.32	22.0
Approach			346	2.0	346	2.0	0.970	104.2	LOS F	15.8	112.6	1.00	1.01	1.32	22.0
North: North (Jalan Gambang)															
7	L2	All MCs	591	2.0	591	2.0	0.608	10.5	LOS B	20.8	148.3	0.70	0.79	0.70	45.2
8	T1	All MCs	1229	2.0	1229	2.0	* 0.889	63.2	LOS E	51.5	367.0	0.99	0.96	1.07	32.0
9	R2	All MCs	430	2.0	430	2.0	0.758	63.1	LOS E	27.8	198.3	0.93	0.86	0.93	32.9
Approach			2250	2.0	2250	2.0	0.889	49.3	LOS D	51.5	367.0	0.90	0.90	0.94	34.8
West: West (Study Zone A)															
10	L2	All MCs	232	2.0	232	2.0	0.126	8.1	LOS A	0.0	0.0	0.00	0.53	0.00	53.3
11	T1	All MCs	56	2.0	56	2.0	* 0.754	87.7	LOS F	4.6	32.7	1.00	0.83	1.17	24.8
12	R2	All MCs	26	2.0	26	2.0	0.374	89.8	LOS F	2.1	14.9	1.00	0.72	1.00	24.0
Approach			314	2.0	314	2.0	0.754	29.1	LOS C	4.6	32.7	0.26	0.60	0.29	40.8
All Vehicles			4396	2.0	4396	2.0	0.970	54.7	LOS D	51.5	367.0	0.86	0.86	0.91	33.5

Site Level of Service (LOS) Method: Delay (SIDRA). Site LOS Method is specified in the Parameter Settings dialog (Options tab).
Vehicle movement LOS values are based on average delay per movement.
Intersection and Approach LOS values are based on average delay for all vehicle movements.
Delay Model: SIDRA Standard (Control Delay: Geometric Delay is included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Green.
Gap-Acceptance Capacity Formula: SIDRA Standard (Akçelik M3D).
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

* Critical Movement (Signal Timing)

Pedestrian Movement Performance

Mov ID	Crossing	Input Vol.	Dem. Flow	Aver. Delay	Level of Service	AVERAGE BACK OF QUEUE [Ped	Dist]	Prop. Que	Eff. Stop Rate	Travel Time	Travel Dist.	Aver. Speed
		ped/h	ped/h	sec		ped	m			sec	m	m/sec
East: East (Study Zone B)												
P2	Full	50	53	72.3	LOS F	0.2	0.2	0.96	0.96	226.1	200.0	0.88
North: North (Jalan Gambang)												
P3	Full	50	53	72.3	LOS F	0.2	0.2	0.96	0.96	226.1	200.0	0.88

West: West (Study Zone A)											
P4	Full	50	53	72.3	LOS F	0.2	0.2	0.96	0.96	226.1	200.0	0.88
All Pedestrians		150	158	72.3	LOS F	0.2	0.2	0.96	0.96	226.1	200.0	0.88

Level of Service (LOS) Method: SIDRA Pedestrian LOS Method (Based on Average Delay)
Pedestrian movement LOS values are based on average delay per pedestrian movement.
Intersection LOS value for Pedestrians is based on average delay for all pedestrian movements.

Appendix C | Comparison between Existing, Interim and Ultimate year Design

Jalan Kuantan – Maran | 2023

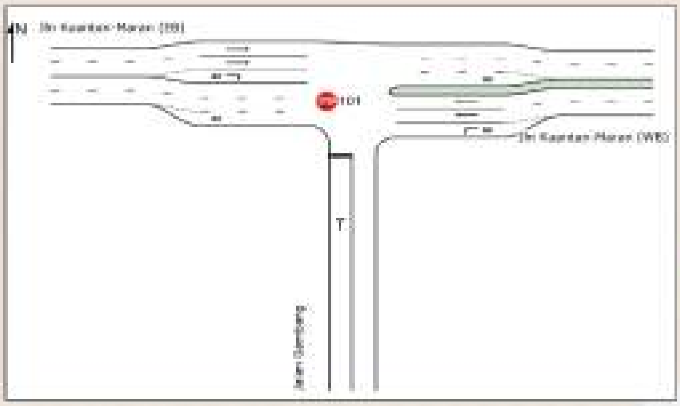
Peak hour traffic volume & LOS | Existing (Before Development) - 2023

Jalan Kuantan-Maran

Trip Distribution PM Peak - Existing 2023 (Before Development)

Plot	Source	Percentage (IN/OUT)	PM Peak [illegible]		PM Peak [illegible]	
			East Bound	West Bound	East Bound	West Bound
Study area Zone A	Trip Generation	[illegible]	0	0	0	0
Study area Zone B	Trip Generation	[illegible]	0	0	0	0
Total		0%	0	0	0	0
Existing Background traffic + Existing Development	RTVM 2021 | CR403	100%	1440	2422	1977	2058
		Grand Total	1,440	2,422	1,977	2,058

Class: R5, Highway
ADT_{2023} = 34,283 veh/day
D DHV_{2023} = 2,422 veh/hr
No of lanes = 2
LOS = C



Jalan Gambang

Trip Distribution PM Peak - Existing 2023 (Before Development)

Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak		
			Total	In	Out
Study area Zone A	Entrance 1	35% / 30%	0	0	0
	Entrance 2	0% / 30%	0	0	0
	Entrance 3 - North Bound	45% / 15%	0	0	0
	Entrance 3 - South Bound	10% / 10%	0	0	0
	Internal Circulation (10% IN & OUT)	10% / 10%	0	0	0
	Grand Total	0%	0	0	0
Proposed Zone B	Main Road	0%	0	0	0
Existing Development	Main Road	70%	1,120	587	533
	Total		1,120	587	533

Jalan Kuantan – Maran | 2023

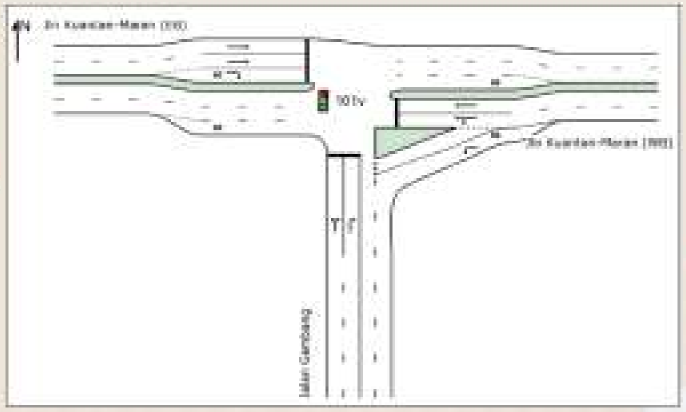
Peak hour traffic volume & LOS | Existing (After Development) - 2023

Jalan Kuantan-Maran

Trip Distribution PM Peak - Existing 2023 (After Development)

Plot	Source	Percentage (IN/OUT)	PM Peak [illegible]		PM Peak [illegible]	
			East Bound	West Bound	East Bound	West Bound
Study area Zone A	Trip Generation	[illegible]	152	608	553	136
Study area Zone B	Trip Generation	[illegible]	147	587	531	136
Total		90%	299	1195	1084	272
Existing Background traffic + Existing Development	RTVM 2021 | CR403	100%	1440	2422	1977	2058
		Grand Total	1,739	3,617	3,061	2,330

Class: R5, Highway
ADT_{2023} = 43,007 veh/day
D DHV_{2023} = 3,617 veh/hr
No of lanes = 2
LOS = D



Jalan Gambang

Trip Distribution PM Peak - Existing 2023 (After Development)

Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak		
			Total	In	Out
Study area Zone A	Entrance 1	35% / 30%	526	296	230
	Entrance 2	0% / 30%	260	0	260
	Entrance 3 - North Bound	40% / 15%	495	360	135
	Entrance 3 - South Bound	10% / 10%	161	84	77
	Internal Circulation (10% IN & OUT)	10% / 10%	162	81	77
	Grand Total Excluding Internal Circulation	90%	1458	760	689
Proposed Zone B	Main Road	30%	1400	734	666
Existing Development	Main Road	70%	1120	587	533
	Total		3,970	2,081	1,889

Appendix C | Comparison between Existing, Interim and Ultimate year Design

Jalan Kuantan – Maran | 2033

Peak hour traffic volume & LOS | Interim Scenario - 2033

Jalan Kuantan-Maran

Trip Distribution PM Peak - Interim 2033 (n = 10 years, 2.91% growth rate)

Plot	Source	Percentage IN/OUT	PM Peak (Before IN) East Bound	PM Peak (Before IN) West Bound	PM Peak (After OUT) East Bound	PM Peak (After OUT) West Bound
Study area Zone A	Trip Generation	[illegible]	203	850	775	189
Study area Zone B	Trip Generation	[illegible]	146	787	732	177
Total		90%	339	1501	1485	841
Existing Background traffic + Existing Development	ETVM 2022 | C8800	100%	2929	3227	2631	2153
		Grand Total	3,267	4,813	4,076	3,194

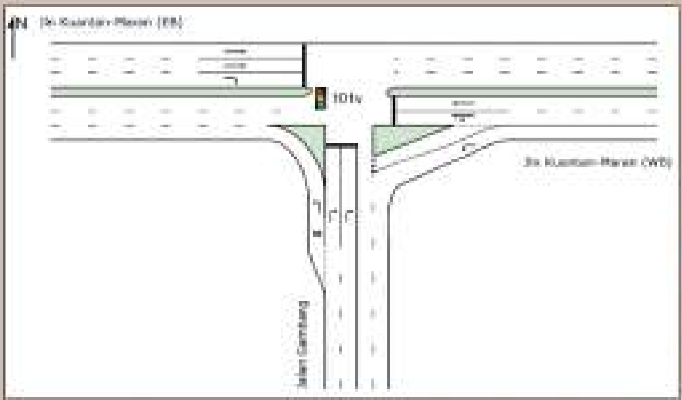
Class: R5, Highway

ADT_{2033} = 57,293 veh/day

$DDHV_{2033}$ = 4,819 veh/hr

No of lanes = 3

LOS = D



Jalan Gambang

Trip Distribution PM Peak - Interim 2033 (n = 10 years, 2.91% growth rate)

Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak Total	PM Peak In	PM Peak Out
Study area Zone A	Entrance 1	30% / 30%	700	394	306
	Entrance 2	0% / 35%	357	8	357
	Entrance 3 - North Bound	45% / 15%	660	507	153
	Entrance 4 - South Bound	10% / 12%	255	118	102
Internal Circulation (10% IN & OUT)		10% / 10%	236	133	103
Grand Total Excluding Internal Circulation		90%	1932	1013	919
Proposed Zone B	Main Road	30%	1805	978	887
Existing Development	Main Road	70%	1492	782	730
Total			5,299	2,773	2,536

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Jalan Kuantan – Maran | 2043

Peak hour traffic volume & LOS | Ultimate Scenario - 2043

Jalan Kuantan-Maran

Trip Distribution PM Peak - Ultimate 2043 (n = 20 years, 2.31% growth rate)

Plot	Source	Percentage IN/OUT	PM Peak (Before IN) East Bound	PM Peak (Before IN) West Bound	PM Peak (After OUT) East Bound	PM Peak (After OUT) West Bound
Study area Zone A	Trip Generation	[illegible]	179	1080	979	245
Study area Zone B	Trip Generation	[illegible]	159	1042	546	236
Total		90%	338	2122	2323	481
Existing Background traffic + Existing Development	ETVM 2021 | C0483	100%	2556	4256	3508	5654
		Grand Total	3,087	[illegible]	5,831	6,135

Class: R5, Highway

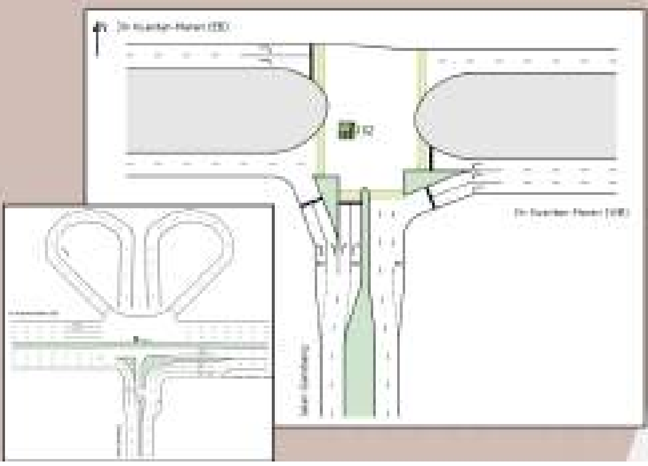
ADT_{2043} = 76,327 veh/day

$DDHV_{2043}$ = 6,420 veh/hr

No of lanes = 4

LOS = D

Either flyover for through movement in Major road or Ramp to minor road from East bound.



Jalan Gambang

Trip Distribution PM Peak - Ultimate 2043 (n = 20 years, 2.31% growth rate)

Plot	Ingress/ Egress Points	Percentage IN/OUT	PM Peak Total	PM Peak In	PM Peak Out
Study area Zone A	Entrance 1	35% / 30%	915	525	408
	Entrance 2	0% / 25%	176	8	176
	Entrance 3 - North Bound	40% / 15%	879	675	204
	Entrance 4 - South Bound	10% / 10%	280	150	130
Internal Circulation (10% IN & OUT)		10% / 10%	288	151	137
Grand Total Excluding Internal Circulation		90%	2579	1050	1238
Proposed Zone B	Main Road	80%	2083	1000	1182
Existing Development	Main Road	70%	1958	1042	946
Total			[illegible]	[illegible]	[illegible]

UTM

UNIVERSITI TEKNOLOGI MALAYSIA

SEAA4032 | INTEGRATED DESIGN PROJECT 2
SEMESTER SESSION 2023/2024-1

GEOTECHNICAL DEPARTMENT

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TABLE OF CONTENT

CHAPTER 5

GEOTECHNICAL DEPARTMENT

5.1. Introduction

This report is prepared by Geotechnical Department of Group 28. This report highlights the thorough examination of the provided bore log data and the subsequent determination of soil parameters. The primary focus of the project centres on boreholes 3 and 5, with Team 28 undertaking the responsibility of analysing the associated bore log information.

By utilizing the derived parameters from the bore log data, the department has crafted a comprehensive soil profile, aiming to facilitate the design of appropriate foundations, including shallow, single pile, and group pile foundations. Furthermore, the report explores the identification of optimal soil support measures to mitigate potential earth movement. Through careful research and analysis, the geotechnical department has successfully determined the soil's bearing capacity, preventing structural damage and settlement resulting from soil failure. The document offers a succinct overview of the design for foundations and retaining walls, supplemented with essential calculations crucial for the proposed development.

5.2. Objectives

The purpose of this report is outlined as follows:

(a) Analyzing the bore log information given to create a detailed soil profile.

(b) Suggesting the appropriate foundation type and design based on the soil properties while ensuring compliance with settlement criteria.

(c) Recommending an efficient design for a retaining wall that ensures stability against sliding, overturning, and settling.

5.3. Soil Profile

Creating a soil profile holds great significance in geotechnical engineering, especially in the context of foundation design. The soil profile is a key source of information regarding the properties and behaviour of the soil, enabling engineers to precisely identify soil parameters and make well-informed decisions. Through a thorough analysis of the soil profile, engineers can evaluate factors like bearing capacity, settlement characteristics, and potential risks. This critical information plays a crucial role in the selection of suitable foundation types, dimensions, and reinforcement strategies, ensuring effective support for the structure and guaranteeing its long-term stability and safety. Ultimately, a comprehensive soil profile forms the basis for a successful and dependable foundation design.

Figure 5.1 shows the soil profile from borehole 3 and borehole 5. The groundwater exists at 5.5m below ground for borehole 3 while for borehole 5 is at 3.8 m. Furthermore, the termination depth for borehole 3 and borehole 5 are 69.45m and 60.45m respectively. Both soil profiles consist of silty clayey/clayey silty sand that ranged from loose to medium dense and soft to firm sandy clay.

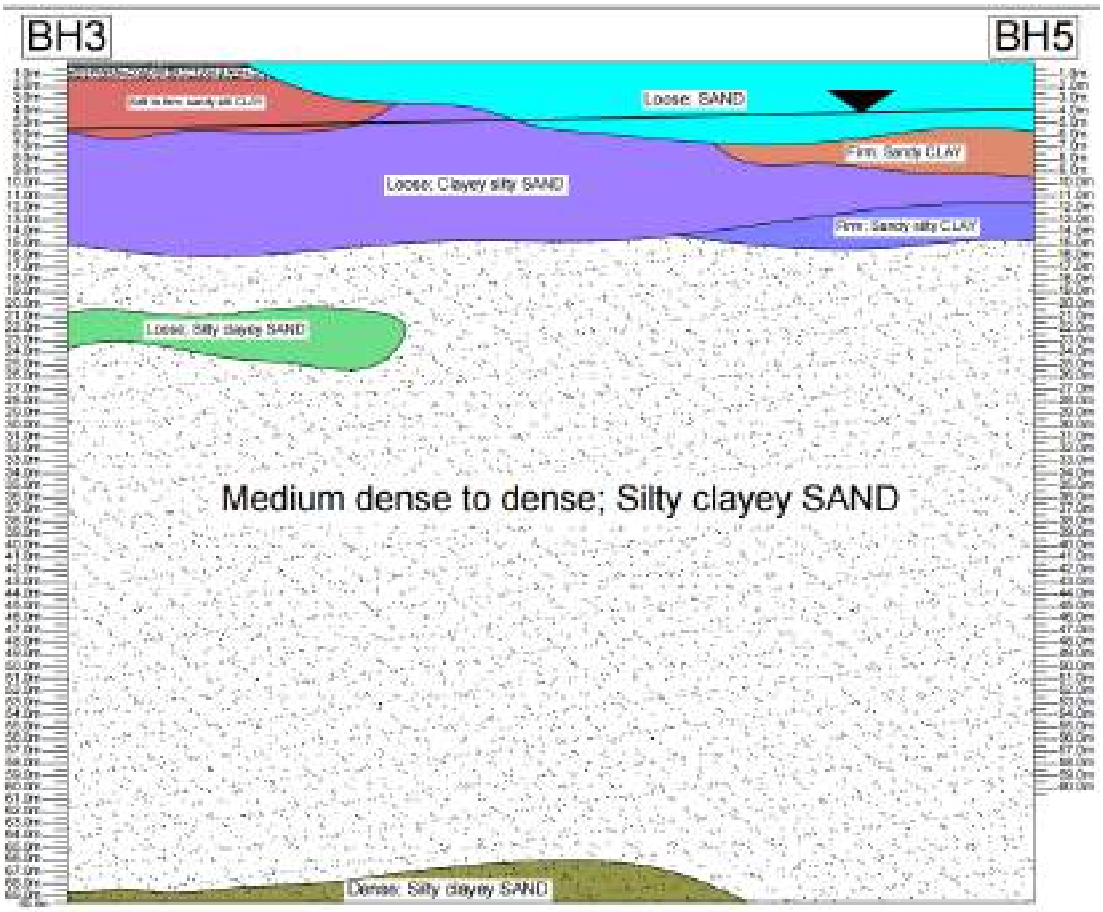


Figure 5.1 Soil profile

5.4. Soil Parameter

Soil parameters encompass specific characteristics or properties of soil that are utilized to articulate and categorize various soil types. These parameters hold significant importance in geotechnical engineering, serving as valuable indicators of the soil's behaviour and properties. Several key geotechnical parameters, such as bulk unit weight density, angle of internal friction, and undrained shear strength, are established by considering the soil's consistency and the SPT-N value obtained from the bore log. Table 5.1 provides a summary of soil parameters pertaining to BH 3 and BH 5.

Table 5.1 Soil parameters of Borehole 3 and Borehole 5

Borehole 3 (GWT = 5.5m)									
Upper depth (m)	**Level Depth (m)**	**Height, H (m)**	**Soil Description**	**SPT-N**	**Bulk Unit Weight, kN/m³**	**Saturated Unit weight**	**Internal Friction angle**	**Adhesion Factor**	**Cohesion of soil (c)**
0	1.5	1.5	Soft to Firm; sandy silt CLAY	0	16	15.7	-	1	-
1.5	3	1.5	Soft to Firm; sandy silt CLAY	3	17	16	-	1	17.25
3	4.5	1.5	Soft to Firm; sandy silt CLAY	7	19	18	-	0.77	88.5
4.5	6	1.5	Soft to Firm; sandy silt CLAY	8	20	19	-	0.71	100
6	7.5	1.5	Loose; clayey silty SAND	8	17	18	29	-	-
7.5	9	1.5	Loose; clayey silty SAND	7	16	17	29	-	-
9	10.5	1.5	Loose; clayey silty SAND	9	17	18	30	-	-
10.5	12	1.5	Loose; clayey silty SAND	9	17	18	30	-	-
12	13.5	1.5	Loose; clayey silty SAND	8	17	18	29	-	-
13.5	15	1.5	Loose; clayey silty SAND	9	17	18	30	-	-
15	16.5	1.5	Loose; clayey silty SAND	10	18	19	30	-	-
16.5	18	1.5	Medium dense to dense; Silty clayey SAND	10	20	19	30	-	-

18	19.5	1.5	Medium dense to dense; Silty clayey SAND	9	20	19	30	-	-
19.5	21	1.5	Medium dense to dense; Silty clayey SAND	10	20	19	30	-	-
21	22.5	1.5	Loose; Silty clayey SAND	9	17	18	30	-	-
22.5	24	1.5	Loose; Silty clayey SAND	11	18	18	31	-	-
24	25.5	1.5	Medium dense to dense; Silty clayey SAND	10	19	18	30	-	-
25.5	27	1.5	Medium dense to dense; Silty clayey SAND	11	19	18	31	-	-
27	28.5	1.5	Medium dense to dense; Silty clayey SAND	13	19	18	31	-	-
28.5	30	1.5	Medium dense to dense; Silty clayey SAND	16	19	18	32	-	-
30	31.5	1.5	Medium dense to dense; Silty clayey SAND	21	20	19	33	-	-
31.5	33	1.5	Medium dense to dense; Silty clayey SAND	18	19	18	32	-	-
33	34.5	1.5	Medium dense to dense; Silty clayey SAND	16	19	18	31	-	-
34.5	36	1.5	Medium dense to dense; Silty clayey SAND	18	19	18	32	-	-

36	37.5	1.5	Medium dense to dense; Silty clayey SAND	23	20	19	33	-	-
37.5	39	1.5	Medium dense to dense; Silty clayey SAND	20	20	19	33	-	-
39	40.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	33	-	-
40.5	42	1.5	Medium dense to dense; Silty clayey SAND	21	20	19	33	-	-
42	43.5	1.5	Medium dense to dense; Silty clayey SAND	19	19	18	32	-	-
43.5	45	1.5	Medium dense to dense; Silty clayey SAND	30	20	19	36	-	-
45	46.5	1.5	Medium dense to dense; Silty clayey SAND	36	21	19	37	-	-
46.5	48	1.5	Medium dense to dense; Silty clayey SAND	28	20	19	36	-	-
48	49.5	1.5	Medium dense to dense; Silty clayey SAND	27	20	19	35	-	-
49.5	51	1.5	Medium dense to dense; Silty clayey SAND	24	20	19	33	-	-
51	52.5	1.5	Medium dense to dense; Silty clayey SAND	21	20	19	33	-	-

52.5	54	1.5	Medium dense to dense; Silty clayey SAND	21	20	19	33	-	-
54	55.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	33	-	-
55.5	57	1.5	Medium dense to dense; Silty clayey SAND	25	20	19	34	-	-
57	58.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	33	-	-
58.5	60	1.5	Medium dense to dense; Silty clayey SAND	24	20	19	34	-	-
60	61.5	1.5	Medium dense to dense; Silty clayey SAND	28	20	19	36	-	-
61.5	63	1.5	Medium dense to dense; Silty clayey SAND	28	20	19	36	-	-
63	64.5	1.5	Medium dense to dense; Silty clayey SAND	29	20	19	36	-	-
64.5	66	1.5	Medium dense to dense; Silty clayey SAND	25	20	19	34	-	-
66	67.5	1.5	Medium dense to dense; Silty clayey SAND	43	22	20	38	-	-
67.5	69	1.5	Medium dense to dense; Silty clayey SAND	38	22	20	36	-	-

69	69.45	0.45	Medium dense to dense; Silty clayey SAND	50	22	20	41	-	-

Borehole 5 (GWT = 3.8m)									
Upper depth (m)	**Level Depth (m)**	**Height, H (m)**	**Soil Description**	**SPT -N**	**Bulk Unit Weight, kN/m³**	**Saturated Unit weight, kN/m³**	**Internal Friction angle**	**Adhesion Factor**	**Cohesion of soil (c)**
0	1.5	1.5	Loose; SAND	0	11	13	0	-	-
1.5	3	1.5	Loose; SAND	7	17	15.5	29	-	-
3	4.5	1.5	Loose; SAND	6	17	15.3	28	-	-
4.5	6	1.5	Loose; SAND	5	16	15	28	-	-
6	7.5	1.5	Firm; Sandy CLAY	4	17	18	-	0.99	25
7.5	9	1.5	Firm; Sandy CLAY	5	18	18	-	0.91	25
9	10.5	1.5	Loose; Clayey silty SAND	6	17	15.3	28	-	-
10.5	12	1.5	Loose; Clayey silty SAND	5	16	15	28	-	-
12	13.5	1.5	Firm; Sandy silty CLAY	6	19	19	-	0.84	37.5
13.5	15	1.5	Firm; Sandy silty CLAY	7	19	19	-	0.77	31.25

15	16.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	34	-	-
16.5	18	1.5	Medium dense to dense; Silty clayey SAND	23	20	19	34.5	-	-
18	19.5	1.5	Medium dense to dense; Silty clayey SAND	23	20	19	34.5	-	-
19.5	21	1.5	Medium dense to dense; Silty clayey SAND	23	20	19	34.5	-	-
21	22.5	1.5	Medium dense to dense; Silty clayey SAND	28	21	19	36	-	-
22.5	24	1.5	Medium dense to dense; Silty clayey SAND	26	21	19	35.5	-	-
24	25.5	1.5	Medium dense to dense; Silty clayey SAND	20	19	19	34	-	-
25.5	27	1.5	Medium dense to dense; Silty clayey SAND	19	19	18.8	38	-	-
27	28.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	34	-	-
28.5	30	1.5	Medium dense to dense; Silty clayey SAND	20	20	19	34	-	-
30	31.5	1.5	Medium dense to dense; Silty clayey SAND	21	19	18.8	34	-	-

31.5	33	1.5	Medium dense to dense; Silty clayey SAND	16	18	17.9	32	-	-
33	34.5	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	34	-	-
34.5	36	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	34	-	-
36	37.5	1.5	Medium dense to dense; Silty clayey SAND	18	19	18.5	33	-	-
37.5	39	1.5	Medium dense to dense; Silty clayey SAND	18	19	18.5	33	-	-
39	40.5	1.5	Medium dense to dense; Silty clayey SAND	17	18	18.5	33	-	-
40.5	42	1.5	Medium dense to dense; Silty clayey SAND	20	19	19	34	-	-
42	43.5	1.5	Medium dense to dense; Silty clayey SAND	16	18	17.9	32	-	-
43.5	45	1.5	Medium dense to dense; Silty clayey SAND	20	19	19	34	-	-
45	46.5	1.5	Medium dense to dense; Silty clayey SAND	20	19	19	34	-	-
46.5	48	1.5	Medium dense to dense; Silty clayey SAND	22	20	19	34	-	-

48	49.5	1.5	Medium dense to dense; Silty clayey SAND	20	19	19	34	-	-
49.5	51	1.5	Medium dense to dense; Silty clayey SAND	23	20	19	34.5	-	-
51	52.5	1.5	Medium dense to dense; Silty clayey SAND	24	20	19	35	-	-
52.5	54	1.5	Medium dense to dense; Silty clayey SAND	24	20	19	35	-	-
54	55.5	1.5	Medium dense to dense; Silty clayey SAND	27	21	19	35.5	-	-
55.5	57	1.5	Medium dense to dense; Silty clayey SAND	26	21	19	35.5	-	-
57	58.5	1.5	Medium dense to dense; Silty clayey SAND	24	20	19	35	-	-
58.5	60	1.5	Medium dense to dense; Silty clayey SAND	29	21	20.4	36	-	-
60	60.45	0.45	Medium dense to dense; Silty clayey SAND	30	21	20.4	37	-	-

The subsequent discussion will provide further details regarding the references and sources utilized in determining the soil parameters.

5.4.1 Bulk Unit Weight

Soil bulk unit weight, also known as soil density, is a measure of the mass of soil per unit volume. It represents the weight of soil in its natural, uncompressed state. Table 5.2 and Table 5.3 shows the relationship between SPT, JKR/ Mackintosh Probe and densities of both cohesive and cohesionless soil.

Table 5.2 Relationship between SPT, JKR or Mackintosh Probe and Unconfined Compressive Strength of Clay (after Terzaghi and Peck (1953) in Public Works Department, (2016))

SPT-N Value	Soil Consistency	Bulk Unit Weight, γ, (kN/m³)	Unconfined Compressive Strength, q_u (kPa)	JKR Probe (Blow/ft)
0-2	Very Soft CLAY	16-19	0-25	0-10
2-4	Soft CLAY		25-50	10-20
4-8	Medium (Firm) CLAY	17-21	50-100	20-40
8-15	Stiff CLAY	19-22	100-200	40-70
15-30	Very Stiff CLAY		200-400	70-100
> 30	Hard CLAY	≥ 21	400	100

Table 5.3 Relationship between SPT, JKR/ Mackintosh Probe and densities of Cohesionless Soil (after Karol (1960) in Public Works Department (2016))

SPT-N Value	Soil Consistency	Bulk Unit Weight, γ, (kN/m³)	Internal Friction Angle, ϕ°	Allowable Soil Pressure (kPa)	JKR Probe (Blow/ft)
0-4	Very Loose	< 16	0-28	Not Suitable	0-10
4-10	Loose	15-20	28-30	0-80	10-30
10-30	Medium	17-21	30-36	80-280	30-80
30-50	Dense	17-22	36-41	280-470	80-110
> 50	Very Dense	> 21	≥ 41	≥ 470	≥ 110

5.4.2 Saturated Unit Weight

Soil saturated unit weight, also known as saturated density, refers to the weight of saturated soil per unit volume. It represents the mass of soil when all pore spaces are filled with water.

Table 5.4 Penetration Resistance and Soil Properties on the Basis of SPT (Cohesive Soil: Fairly reliable) (Peck et. al. 1974; Bowles, 1977; BNBC 2015 Table 6.D.6)

SPT N-value		**0 to 4**	**4 to 10**	**10 to 30**	**30 to 50**	**>50**
Compactness		**very loose**	**loose**	**medium**	**dense**	**very dense**
Relative Density, D_r (%)		0 to 15	15 to 35	35 to 65	65 to 85	85 to 100
Angle of Internal Friction, φ(°)		<28	28 to 30	30 to 36	36 to 41	>41
Unit Weight (moist)	**pcf**	<100	95 to 125	110 to 130	110 to 140	>130
	kN/m³	<15.7	14.9 to 19.6	17.3 to 20.4	17.3 to 22.0	>20.4
Submerged unit weight	**pcf**	<60	55 to 65	60 to 70	65 to 85	>75
	kN/m³	<9.4	8.6-10.2	9.4 to 11.0	10.5 to 13.4	>11.8

Table 5.5 Penetration Resistance and Soil Properties on the Basis of SPT (Cohesionless Soil: rather unreliable) (Peck et. al. 1974; Bowles, 1977; BNBC 2015 Table 6.D.6)

SPT N-value		**0 to 2**	**2 to 4**	**4 to 8**	**8 to 16**	**16 to 32**	**>32**
Consistency		**very soft**	**soft**	**medium**	**stiff**	**very stiff**	**hard**
Unconfined Comp. Test	**lb/ft²**	0 to 250	250 to 500	500 to 1000	1000 to 2000	2000 to 4000	>4000
	kPa	0 to 25	25 to 50	50 to 100	100 to 200	200 to 400	>400
Unit Weight (Saturated)	**pcf**	<100	100 to120	110 to 125	115 to130	120 to 140	>130
	kN/m³	<15.7	15.7 to 18.8	17.3 to 19.6	18.1 to 20.4	18.8 to 22.0	>20.4

5.4.3 Internal Friction Angle

Soil friction angle, also known as angle of internal friction, is a measure of the resistance of soil to shearing forces. It represents the angle at which soil particles begin to slide or deform when subjected to external loads or stresses.

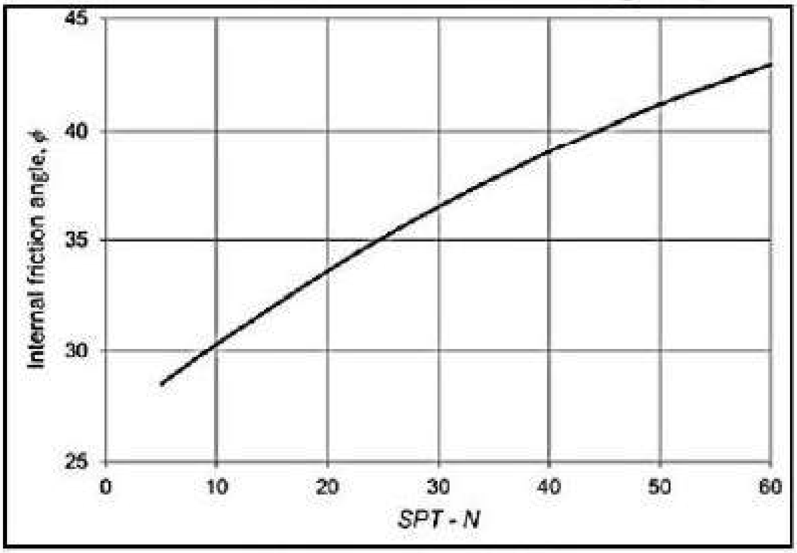


Figure 5.2 From SPT-N to soil friction angle (Peck et. al. 1974)

5.4.4 Adhesion Factor

Soil adhesion factor, also known as cohesion or adhesive strength, is a measure of the internal attraction between soil particles. It represents the ability of soil particles to stick together and resist shear forces.

Table 5.6 Values of undrained shear strength c_u and adhesion factor α for clay based on SPT-N (Public Work Department, 2016)

SPT-N	c_u kN/m²	α	SPT-N	c_u kN/m²	α
0	0	1	16	102.14	0.31
1	5.99	1	17	108.53	0.30
2	11.97	1	18	114.91	0.28
3	17.96	1	19	121.30	0.27
4	23.94	0.99	20	127.68	0.26
5	29.93	0.91	21	134.06	0.26
6	35.91	0.84	22	140.45	0.26
7	41.90	0.77	23	146.83	0.25
8	47.88	0.71	24	153.22	0.25
9	54.71	0.64	25	159.60	0.25
10	61.55	0.58	26	165.98	0.25
11	68.39	0.53	27	172.37	0.25
12	75.23	0.48	28	178.75	0.25
13	82.07	0.43	29	185.13	0.25
14	88.91	0.39	30	191.52	0.25
15	95.76	0.36	>30	191.52	0.25

5.4.5 Cohesion of Soil

Cohesion of soil, also known as cohesive strength, refers to the internal attraction or bonding between soil particles. It represents the ability of cohesive soils, such as clay, to resist shear forces without the need for external confining pressure.

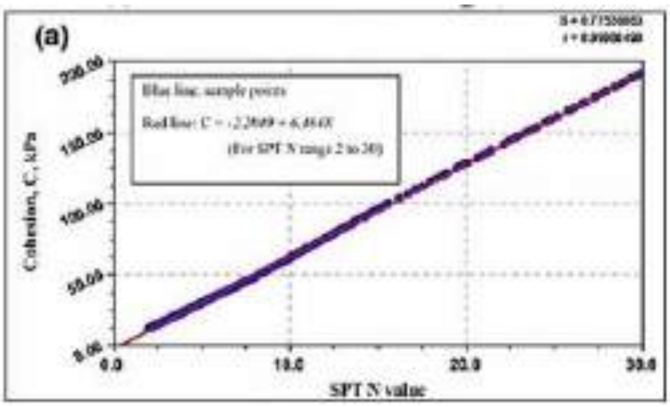


Figure 5.3 From SPT-N to cohesive strength, c_u (Karol, 1960)

5.5. Foundation Design

The primary function of a foundation is to serve as a substructure that transfers loads from the superstructure to the underlying soil. Two critical considerations in foundation design are ensuring that the applied load does not lead to shear failure in the supporting soil and preventing excessive settlement of the foundation. In most cases, settlement emerges as the predominant factor influencing foundation design.

The design process for a foundation begins with a comprehensive site investigation to evaluate soil conditions, followed by an analysis of structural loads. Based on these assessments, the most suitable foundation type is chosen, such as shallow foundations for stable soil or deep foundations for challenging soil conditions. Design parameters, including allowable settlement and bearing capacity, are taken into account to ensure stability and structural integrity. The structural design of foundation elements, encompassing dimensions and reinforcement, is optimized to withstand both the loads and prevailing soil conditions.

Construction considerations and quality control measures are implemented to guarantee that the foundation is constructed in accordance with design specifications. This meticulous approach results in the creation of a stable and secure base for the structure, addressing both load transmission and settlement concerns.

5.5.1 Shallow Foundation

A shallow foundation is a specific type of foundation designed to transmit the weight and load of a structure to the ground, typically situated near the surface. This foundation type is commonly utilized in scenarios where the immediate soil conditions beneath the structure offer sufficient strength and stability to bear the intended load without experiencing significant settlement or structural challenges. Shallow foundations are often considered a more cost-effective option compared to deep foundations, as they necessitate less excavation and construction materials, leading to project cost savings. Moreover, the construction of shallow foundations is generally simpler and faster, making them a practical choice for a variety of structures. Figure 5.4 illustrates some common types of shallow foundations.

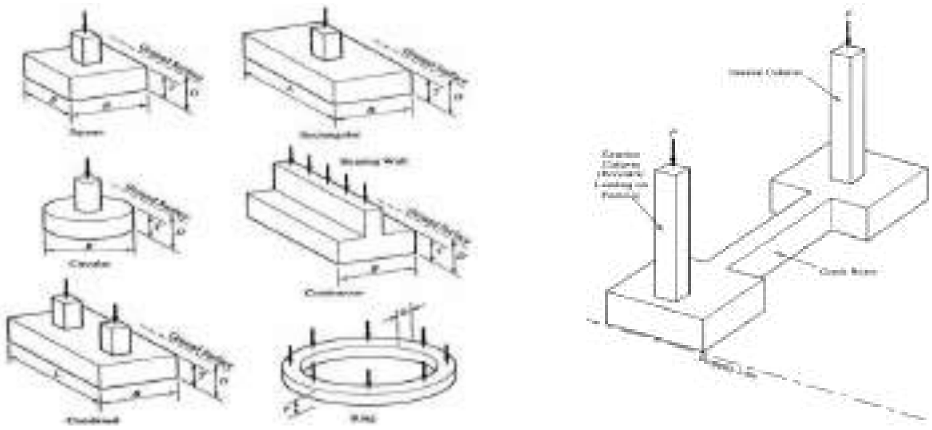


Figure 5.4 Example of shallow foundation types

5.5.1.1 Bearing Capacity of Shallow Foundation

The bearing capacity of a shallow foundation denotes the maximum load that the underlying soil can sustain without causing excessive settlement or failure, making it a critical factor in geotechnical engineering for the design of safe and stable foundations. The bearing capacity is influenced by various factors, including soil type, strength, stiffness properties, as well as the dimensions and shape of the foundation.

Several methods, such as Terzaghi's method and Meyerhof's method, are employed to estimate the ultimate bearing capacity. These methods consider factors like soil cohesion, friction angle, surcharge, and footing geometry. They are empirical in nature, grounded in extensive research and observations, and provide simplified equations that establish a relationship between the ultimate bearing capacity and soil parameters, along with footing geometry.

When assessing the bearing capacity of soil, there are different modes of failure that can occur. These failure modes indicate the various ways in which the soil may fail under load. Here are three common types of bearing capacity failures:

General Shear Failure, as depicted in Figure 5.5 below, is the entire soil mass beneath the foundation fails simultaneously, often seen in cohesive soils like clays. It results in overall settlement or tilting of the foundation.

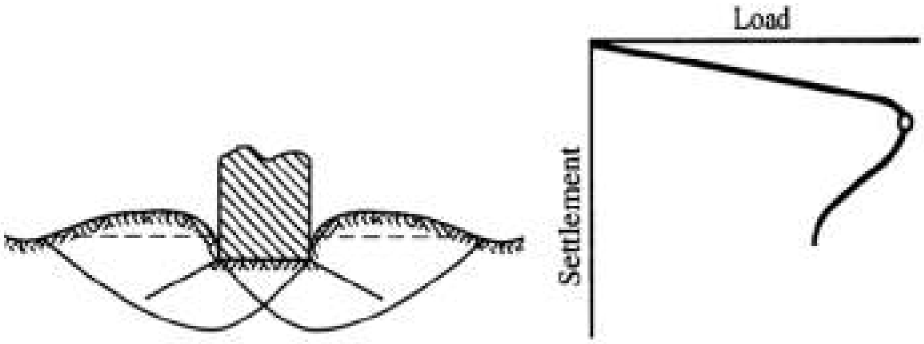


Figure 5.5 Shallow Foundation Bearing Capacity Failure (General Shear Failure)

Local Shear Failure, as depicted in Figure 5.6 below, is the soil immediately below the footing fails in a localized manner, commonly observed in granular soils like sands or gravels. It leads to localized shear surfaces and can cause excessive settlement or tilting.

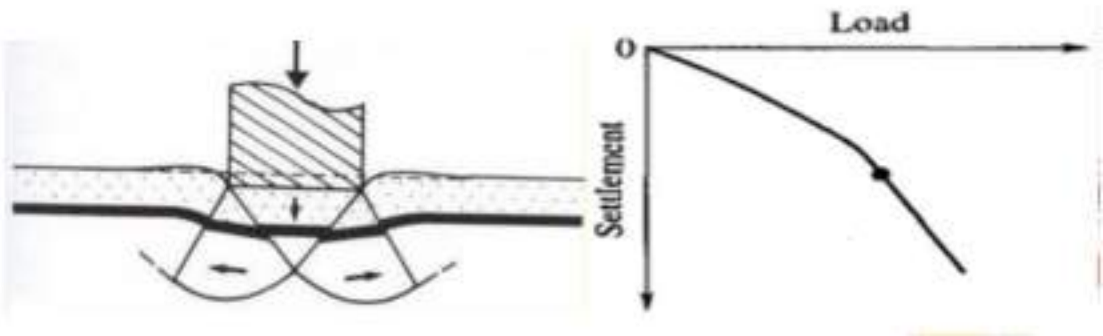


Figure 5.6 Shallow Foundation Bearing Capacity Failure (Local Shear Failure)

Punching Shear Failure, as depicted in Figure 5.7 below, this failure occurs when a concentrated load is applied to a footing with inadequate support. It results in the formation of a shear cone around the load area, causing soil failure beneath the footing. This is more common in weak or soft soils.

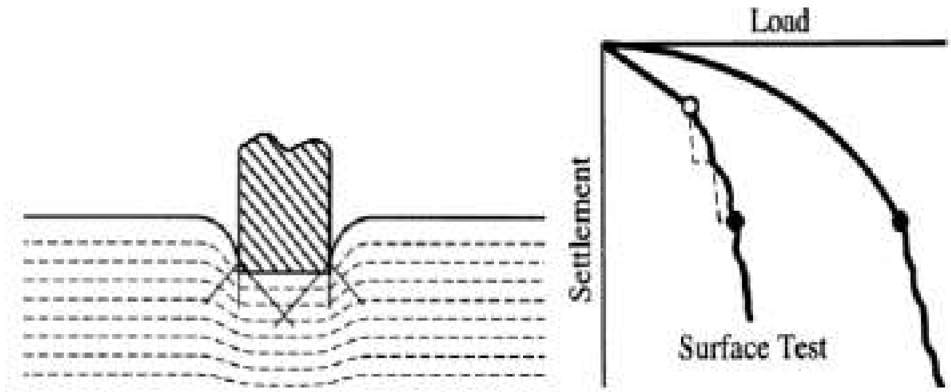


Figure 5.7 Shallow Foundation Bearing Capacity Failure (Punching Shear Failure)

Terzaghi Method

For the calculation of the ultimate bearing capacity of the shallow foundation in this project, we have opted to employ the Terzaghi method, which will be presented in the subsequent sections. The ultimate bearing capacity of the footing is computed for interval of 0.5 m, up until 3 m below the ground. In Terzaghi's bearing capacity theory, several assumptions are made to simplify the analysis and estimation of the ultimate bearing capacity of shallow foundations. These assumptions include:

1. General shear failure assumed.
2. Depth of foundation ≤ Width of foundation ($D_f \leq B$)
3. Rough base of the footing
4. No shear strength considered above the bottom of the foundation.
5. Footing is assumed to be very rigid compared to the soil.

6. Surcharge load considered up to the base of the footing (represented as equivalent surcharge, ($q = \gamma D_f$)

7. Load applied vertically and non-eccentrically.

8. Homogeneous and isotropic soil assumed.

9. L/B ratio assumed to be infinite.

For Square Footing, Terzaghi's Equation is as follows:

$$\mathbf{q_{ult} = 1.3c'N_c + qN_q + 0.4\,\gamma' B N_\gamma}$$

where,

qu = ultimate bearing capacity

c = cohesion of soil

q = stress at base of footing = γDf

γ = unit weight of soil

Df = depth of footing

B = width of footing

L = length of Footing

Nc, Nq, Nγ = bearing capacity factors (Table 4.7)

Table 5.7 Terzaghi Bearing Capacity Spreadsheet (CivilWeb Spreadsheets, 2020)

ϕ'	N_c	N_q	N_γ^*	ϕ'	N_c	N_q	N_γ^*
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

Effect of Groundwater Table on Bearing Capacity

The bearing capacity of a footing is significantly influenced by the presence of a groundwater table. The existence of groundwater reduces the density of the soil due to buoyancy effects. Consequently, when groundwater is present, adjustments to the soil density are necessary. In this scenario, where the computation of the bearing capacity of a shallow foundation is considered up to a depth of 3 meters, two cases of groundwater are taken into account: Case B, where the groundwater table is situated above the foundation base, and Case D, where the groundwater table is at a depth (D) below the foundation base, with D being less than B. This is illustrated in Figure 5.8.

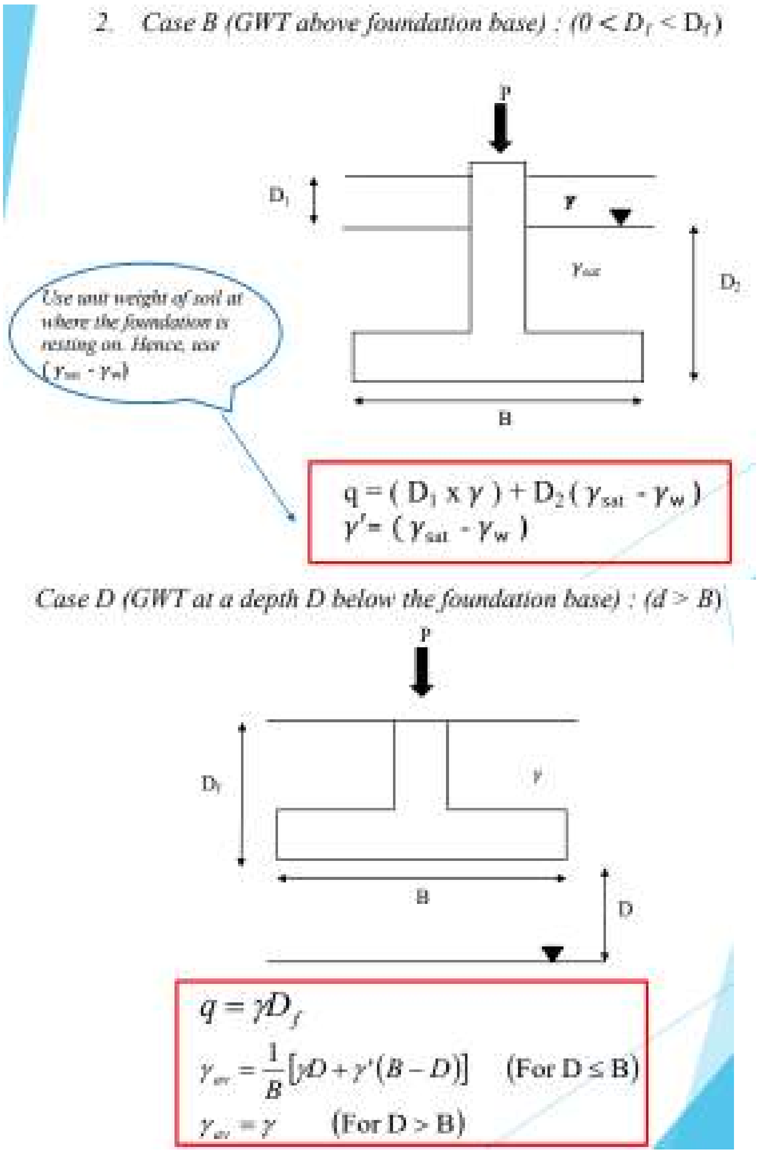


Figure 5.8 Case B and Case D of Groundwater Table Effects

Factor of Safety

Selection of appropriate factor of safety depends on various factors which include, the type of soil, level of uncertainty in soil strength, importance of structure and consequences of failure and likelihood of design load occurrence. Considering the superstructure in this project is a school, the factor of safety to be 3.0 is choosen. The list of minimum factors of safety is demonstrated in Table 5.8.

Table 5.8 Minimum Factor of Safety (Shahrin, 2021)

Category	Typical Structures	Characteristics of the Category	Design Factor of Safety: Thorough and Complete Soil Exploration	Design Factor of Safety: Limited Soil Exploration
A	Railway bridges, warehouses, blast furnaces, hydraulic, retaining walls, silos	Maximum design load likely to occur often; consequences of failure disastrous	3.0	4.0
B	Highway bridges, light industrial and public buildings	Maximum design loads may occur occasionally, consequences of failure serious	2.5	3.5
C	Apartment and office buildings	Maximum design load unlikely to occur	2.0	3.0

Result for Allowable Bearing Capacity

Upon obtaining the allowable bearing capacity values presented in Table 5.9, a comparison with the unconfined compressive strength of the soil based on its SPT-N number is conducted, as detailed in Table 5.10. The expectation is that the Allowable Bearing Capacity (ABC) should align within the range of the Unconfined Compressive Strength (UCS) for a foundation design that is consistent and reliable.

The determination of the ABC value typically considers the UCS value along with other pertinent factors. The goal is to establish an ABC value within a range that is either in line with or slightly below the UCS value. This approach ensures that the foundation can safely bear anticipated loads without surpassing the strength limitations of the soil or rock material.

Table 5.9 Allowable bearing capacity of shallow foundation at every 1.5 m up to 3m below the ground

Borehole 3

Level Depth, D_f	Soil Classification	SPT-N	Allowable bearing capacity, q_{all} (kN/m^2)
0	-	0	-
0.5	SAND	0	-
1	Concrete	0	-
1.5	CLAY	3	34.20
2	CLAY	3	34.20
2.5	CLAY	3	34.20
3	CLAY	3	34.20

Borehole 5

Level Depth, D_f	Soil Classification	SPT-N	Allowable bearing capacity, q_{all} (kN/m^2)
0	-	0	-
0.5	SAND	0	0.00
1	SAND	0	0.00
1.5	SAND	7	40.00
2	SAND	7	40.00
2.5	SAND	7	40.00
3	SAND	6	26.67

Table 5.10 Relationships between SPT-N, JKR or Mackintosh Probes and Unconfined Compressive Strength of Clay

N (Blows per 300 mm)	Consistency	Unconfined compressive strength (kPa)	JKR or Mackintosh Probe (Blows / 300 mm)
0 – 2	Very soft	0 – 25	0 – 10
2 – 4	Soft	25 – 50	10 – 20
4 – 8	Medium (Firm)	50 – 100	20 – 40
8 – 15	Stiff	100 – 200	40 – 70
15 – 30	Very stiff	200 – 400	70 – 100
Over 30	Hard	400	100

Determination of Suitable Footing Size

At BH 3,
Load from superstructure, Q = 1629.8 kN
Mx = 117.1 kNm, My = 148.2 kNm
At depth of 2.5 m,
SPT-N = 7
q_{all} = 34.20 kN/m^2

$$A = \frac{Q}{q} = \frac{1629.8}{34.2} = 47.655m^2$$

B x L = $\sqrt{48} = 7.4$m

Therefore, proposed foundation size is,
B x L = 7.4 m x 7.4 m

At BH 5,
Load from superstructure, Q = 1629.8 kN
Mx = 117.1 kNm, My = 148.2 kNm
At depth of 3.0 m,
SPT-N = 6
q_{all} = 26.67 kN/m^2

$$A = \frac{Q}{q} = \frac{1629.8}{26.67} = 61m^2$$

B x L = $\sqrt{61} = 8$m

Therefore, proposed foundation size is,
B x L = 8.3 m x 8.3 m

Example Calculation for Determination of Ultimate Bearing Capacity

At BH 3,

GWT = 5.5m below ground, Depth of foundation, Df, = 2.5 m

q_{al} = 34.2 kN/m^2

Q_{all} = 34.2 x 7.4 x 7.4 = 1872.79 kN OK!

At BH 5,

GWT = 3.8m below ground, Depth of foundation, Df, = 3 m

q_{all} = 26.67 kN/m^2

Q_{all} = 26.67 x 8.3 x 8.3 = 1837.30 kN OK!

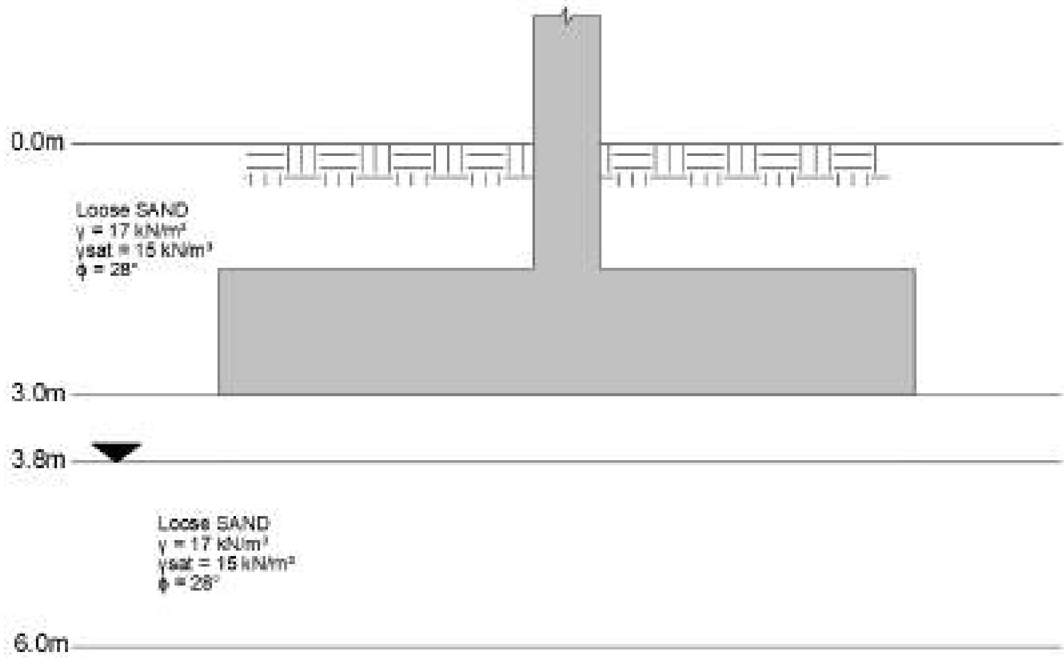


Figure 5.9 Shallow Foundation of BH5

5.5.1.2 Eccentricity of Shallow Foundation

The term "eccentricity" in the context of a shallow foundation refers to the horizontal displacement between the applied load and the centerline of the footing. It signifies the offset or shift of the load from the center of the foundation. The introduction of eccentricity brings about additional bending moments, shearing forces, and bearing pressures in both the foundation and the underlying soil. This aspect is of paramount importance in geotechnical engineering to ensure the stability and optimal performance of the foundation system. To mitigate the effects of eccentricity and guarantee that the foundation can securely bear the applied loads and moments, appropriate design measures may be implemented, such as enlarging the foundation size, incorporating reinforcement, or utilizing pile foundations.

Based on data provided by the Reinforced Concrete Design Department, an analysis of the superstructure was conducted to determine the load and moments resulting from it. The extreme load is recorded as 1629.8 kN, with moments about the x and y axes measuring 117.1 kNm and 148.2 kNm, respectively, on the other hand, the lowest load is recorded as 430.3kN, with moments about the x and y axes measuring 8.6 kNm and -118.2 kNm, respectively In situations where a shallow foundation is subjected to two-way eccentric moments, it implies that the applied loads do not pass through the centroid of the foundation, resulting in bending moments in two perpendicular directions. A visual representation of this scenario, depicting two-way eccentric moments applied to a shallow foundation, is illustrated in Figure 5.10.

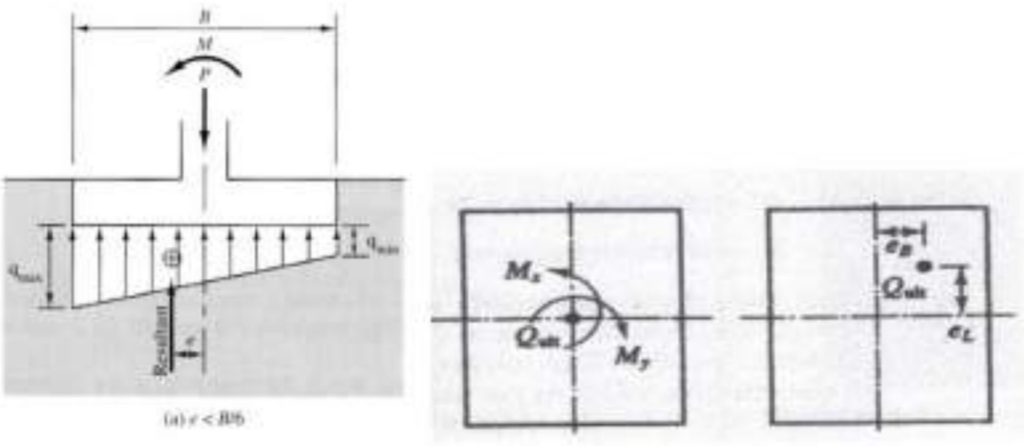


Figure 5.10 Two eccentric moments on shallow foundation

Example Calculation of the Shallow Foundation's Eccentricity

At BH 3,

Depth = 2.5 m

Size of footing (B x L) = 7.4 m x 7.4 m

Load from Superstructure, Q = 1629.8 kN

Mx = 117.1 kNm, My = 148.2 kNm,

Eccentricity: *B/6 = 7.4/6 = 1.2333

e_B = Mx /Q = 117.1/ 1629.8 = 0.071849 (< B/6) OK!

e_L = My /Q = 148.2/ 1629.8 = 0.090931 (< B/6) OK!

Effective dimensions:

B' = B - 2e_B = 7.4 – 2*0.071849 = 7.25 m

L' = B - 2e_L = 7.4 – 2*0.090931 = 7.21 m

$$q_{max,B} = \left(\frac{P+w_f}{A'}\right) + \left(1+6\frac{e_B}{B'}\right) \qquad W_f = M_x/B'$$

$$q_{max,B} = \left(\frac{1629.8+\frac{117.1}{7.25}}{7.25\ x\ 7.21}\right) + \left(1+6\frac{0.071849}{7.25}\right)$$

= 33.292 kN/m²

$$q_{max,L} = \left(\frac{P+w_f}{A'}\right) + \left(1+6\frac{e_L}{L'}\right) \qquad W_f = M_y/L'$$

$$q_{max,L} = \left(\frac{1629.8+\frac{148.2}{7.21}}{7.25\ x\ 7.21}\right) + \left(1+6\frac{0.090931}{7.25}\right)$$

= 33.880 kN/m²

For contact pressure to remain (+)ve everywhere,

$$\frac{6e_B}{B} + \frac{6e_L}{L} \le 1$$

$$\frac{6(0.071849)}{7.4} + \frac{6(0.090931)}{7.4} = 0.131984359 \leq 1$$

$q_{max,L} > q_{max,B}$ ∴ q_{max},= 33.880 kN/m^2

At BH 5,

Depth = 3 m

Size of footing (B x L) = 8.3 m x 8.3 m

Load from Superstructure, Q = 1629.8 kN

Mx = 117.1 kNm, My = 148.2 kNm,

Eccentricity: *B/6 = 8.3/6 = 1.383

e_B = Mx /Q = 117.1/ 1629.8 = 0.071849 (< B/6) OK!

e_L = My /Q = 148.2/ 1629.8 = 0.090931 (< B/6) OK!

Effective dimensions:

B' = B - 2e_B = 8.3 – 2*0.071849 = 8.16 m

L' = B - 2e_L = 8.3 – 2*0.090931 = 8.12 m

$$q_{max,B} = \left(\frac{P+w_f}{A'}\right) + \left(1 + 6\frac{e_B}{B'}\right) \qquad W_f = M_x/B'$$

$$q_{max,B} = \left(\frac{1629.8 + \frac{117.1}{8.16}}{8.16\, x\, 8.12}\right) + \left(1 + 6\frac{0.071849}{8.16}\right)$$

= 26.143 kN/m²

$$q_{max,L} = \left(\frac{P+w_f}{A'}\right) + \left(1 + 6\frac{e_L}{L'}\right) \qquad W_f = M_y/L'$$

$$q_{max,L} = \left(\frac{1629.8 + \frac{148.2}{8.12}}{8.16\, x\, 8.12}\right) + \left(1 + 6\frac{0.090931}{8.12}\right)$$

= 26.556 kN/m²

For contact pressure to remain (+)ve everywhere,

$$\frac{6e_B}{B} + \frac{6e_L}{L} \leq 1$$

$$\frac{6(0.071849)}{8.3} + \frac{6(0.090931)}{8.3} = 0.117673 \leq 1$$

$q_{max,L} > q_{max,B} \therefore q_{max,} = 26.556$ kN/m^2

$q_{max} = 33.880$ kN/m^2 < q_{all} for BH 3 = 34.20 kN/m^2

$q_{max} = 26.556$ kN/m^2 < q_{all} for BH 5 = 26.67 kN/m^2

∴ bearing capacity of shallow foundation with two-way eccentricity is OK!

5.5.1.3 Settlement of Shallow Foundation

Settlement in shallow foundations refers to the downward movement or deformation of both the foundation and the supported structure. This phenomenon arises from various factors, including the structural weight, characteristics of the underlying soil, and processes involved in construction and loading. Settlement has implications for the stability, functionality, and structural integrity of both the foundation and the supported structure.

A rigid foundation settlement assumption is opted rather than a flexible one for several reasons. Firstly, this choice ensures a conservative design approach, providing an additional margin of safety to accommodate potential settlements and uncertainties. Secondly, it simplifies the analysis and design procedures, given that the behavior of a rigid foundation is more straightforward to model and analyze compared to a flexible foundation. Thirdly, by assuming a rigid foundation, we can minimize the occurrence of differential settlements, fostering uniform settlements across the structure and preserving its overall performance. The representation of flexible and rigid foundation settlement is depicted in Figure 5.11.

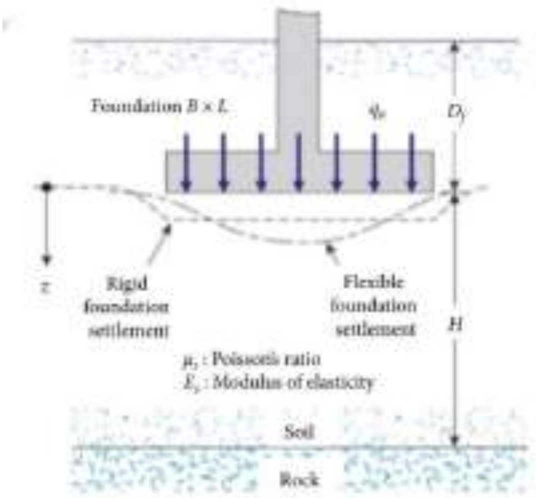


Figure 5.11 Rigid and flexible foundation settlement

Intermediate Settlement

Immediate settlement, also referred to as elastic settlement or primary settlement, pertains to the initial vertical displacement that takes place immediately after the construction and loading of a shallow foundation. This type of settlement is mainly influenced by the elastic deformation of the soil and results from the redistribution of stresses within the soil mass. Immediate settlement is characterized by its rapid occurrence and reversibility, typically happening over a short timeframe, ranging from days to weeks

In the computation of elastic settlement, we have employed the equation proposed by Harr (1966), as depicted below:

$$S_e = \frac{Bq_0}{E}(1 - \mu_s^2)\alpha$$

where:

B = width of footing

q_0 = nett pressure from footing, kN/m^2

Es = modulus of elasticity of soil, kN/m^2

μ = poisson's ratio

α = factor depend on footing flexibility (Figure 5.12)

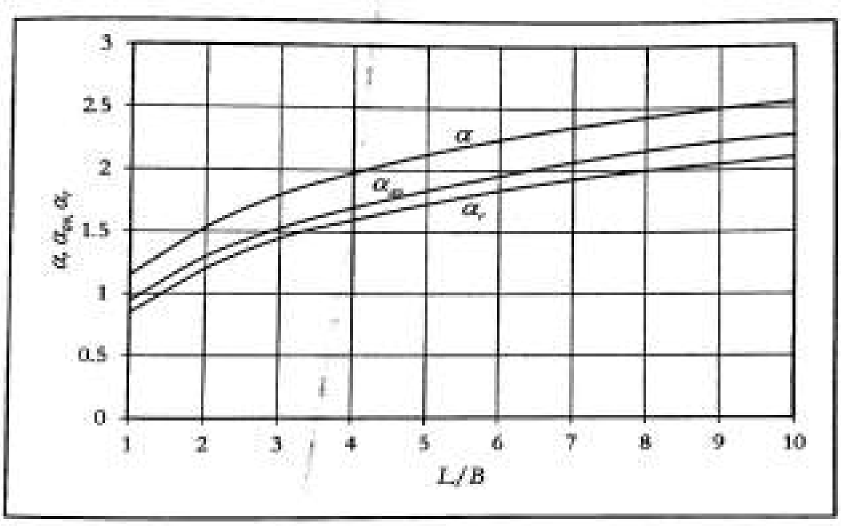


Figure 5.12 Values of α, α_r and α_{av} (redrawn from Das, 1990)

- Modulus of Elasticity of Soil, E_s

The modulus of elasticity of soil, also known as soil stiffness or Young's modulus, refers to the measure of the soil's ability to deform elastically under the application of stress. It represents the relationship between stress and strain in the soil.

- Poisson's Ratio

Poisson's ratio refers to the ratio of the transverse strain (lateral contraction or expansion) to the axial strain (compression or extension) under an applied load. It describes how the soil volume changes in response to loading. We referred the values for the elastic modulus and Poisson's ratio of soil from Table 5.11 and Table 5.12 below

Table 5.11 The correlation between the consistency of soil with Young's modulus, E_s (Meyerhoff, 1956)

Type of Soil	Young's Modulus, E_s		Poisson's Ratio
	MN/m²	lb/in.²	
Loose Sand	10.35 - 24.15	1500 - 3500	0.20 - 0.40
Medium Dense Sand	17.25 - 27.60	2500 - 4000	0.25 - 0.40
Dense Sand	34.50 - 55.20	5000 - 8000	0.30 - 0.45
Silty Sand	10.35 - 17.25	1500 - 2500	0.20 - 0.40
Sand and Gravel	69.00 - 172.50	10000 - 25000	0.15 - 0.35
Soft Clay	2.07 - 5.18	300 - 750	
Medium Clay	5.18 - 10.35	750 - 1500	0.20 - 0.50
Stiff Clay	10.35 - 24.15	1500 - 3500	

Table 5.12 Typical Poisson's Ratio Values for Common Soil Types, (StructX.com, n.d.)

Description	Poisson's Ratio
Sand	0.15 - 0.4
Dense	0.2 - 0.4
Course	0.15
Fine	0.25
Silt	0.3 - 0.35
Clay	0.1 - 0.5
Saturated	0.4 - 0.5
Unsaturated	0.1 - 0.3
Sandy Clay	0.2 - 0.3

To account for the presence of different soil layers beneath the foundation, it is necessary to consider that the modulus of elasticity (E_s) will vary from layer to layer. In such cases, it is recommended to use a weighted average of the E_s values for calculations, as suggested by Bowles (1987). The calculation of E_s can be performed using the following equation and the calculations are shown in Table 5.13 and Table 5.14.

$$E_s = \frac{\left[\sum E_{s(i)} \cdot \Delta z\right]}{z_0}$$

where,

Es(i) = soil modulus elasticity within a depth Δz

z0 = H or 5B, whichever is smaller

At BH 3,

GWT at 5.5m

Total Load, Q = 1835.15 kN

Pressure from footing, $q = \frac{Q}{A} = \frac{1835.15}{7.4 \ x \ 7.4}$ = 34.51 kN/m²

5B = 37m

Total height of SAND, H = 63.45m

∴ z0 = 37 m

Table 5.13 Soil modulus elasticity of BH 3

Upper depth (m)	Level Depth, Df (m)	Height, H (m)	Soil Description	SPT-N	Poisson's Ratio, μ	$E_{s(i)}$ (kPa)	$E_{s(i)}.\ \Delta z$ (kPa)
3	4.5	1.5	Soft to Firm; sandy silt CLAY	7	-	-	-
4.5	6	1.5	Soft to Firm; sandy silt CLAY	8	-	-	-
6	7.5	1.5	Loose; clayey silty SAND	8	0.25	13800	20700
7.5	9	1.5	Loose; clayey silty SAND	7	0.25	13800	20700
9	10.5	1.5	Loose; clayey silty SAND	9	0.26	14500	21750
10.5	12	1.5	Loose; clayey silty SAND	9	0.26	14500	21750
12	13.5	1.5	Loose; clayey silty SAND	8	0.25	13800	20700
13.5	15	1.5	Loose; clayey silty SAND	9	0.26	14500	21750
15	16.5	1.5	Loose; clayey silty SAND	10	0.28	15870	23805
16.5	18	1.5	Medium dense to dense; Silty clayey SAND	10	0.28	13110	19665
18	19.5	1.5	Medium dense to dense; Silty clayey SAND	9	0.27	12765	19147.5
19.5	21	1.5	Medium dense to dense; Silty clayey SAND	10	0.28	13110	19665
21	22.5	1.5	Loose; Silty clayey SAND	9	0.27	15180	22770
22.5	24	1.5	Loose; Silty clayey SAND	11	0.29	16500	24750
24	25.5	1.5	Medium dense to dense; Silty clayey SAND	10	0.28	13110	19665

25.5	27	1.5	Medium dense to dense; Silty clayey SAND	11	0.29	13455	20182.5
27	28.5	1.5	Medium dense to dense; Silty clayey SAND	13	0.3	13799	20698.5
28.5	30	1.5	Medium dense to dense; Silty clayey SAND	16	0.35	15525	23287.5
30	31.5	1.5	Medium dense to dense; Silty clayey SAND	21	0.36	15870	23805
31.5	33	1.5	Medium dense to dense; Silty clayey SAND	18	0.35	15525	23287.5
33	34.5	1.5	Medium dense to dense; Silty clayey SAND	16	0.35	15525	23287.5
34.5	36	1.5	Medium dense to dense; Silty clayey SAND	18	0.35	15525	23287.5
36	37.5	1.5	Medium dense to dense; Silty clayey SAND	23	0.36	15870	23805
37.5	39	1.5	Medium dense to dense; Silty clayey SAND	20	0.36	15870	23805
39	40.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.36	15870	23805
40.5	42	1.5	Medium dense to dense; Silty clayey SAND	21	0.36	15870	23805
42	43.5	1.5	Medium dense to dense; Silty clayey SAND	19	0.35	15525	23287.5
43.5	45	1.5	Medium dense to dense; Silty clayey SAND	30	0.37	16215	24322.5
45	46.5	1.5	Medium dense to dense; Silty clayey SAND	36	0.37	16215	24322.5

46.5	48	1.5	Medium dense to dense; Silty clayey SAND	28	0.36	15870	23805
48	49.5	1.5	Medium dense to dense; Silty clayey SAND	27	0.36	15870	23805
49.5	51	1.5	Medium dense to dense; Silty clayey SAND	24	0.36	15870	23805
51	52.5	1.5	Medium dense to dense; Silty clayey SAND	21	0.36	15870	23805
52.5	54	1.5	Medium dense to dense; Silty clayey SAND	21	0.36	15870	23805
54	55.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.36	15870	23805
55.5	57	1.5	Medium dense to dense; Silty clayey SAND	25	0.36	15870	23805
57	58.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.36	15870	23805
58.5	60	1.5	Medium dense to dense; Silty clayey SAND	24	0.36	15870	23805
60	61.5	1.5	Medium dense to dense; Silty clayey SAND	28	0.36	15870	23805
61.5	63	1.5	Medium dense to dense; Silty clayey SAND	28	0.36	15870	23805
63	64.5	1.5	Medium dense to dense; Silty clayey SAND	29	0.36	15870	23805
64.5	66	1.5	Medium dense to dense; Silty clayey SAND	25	0.36	15870	23805
66	67.5	1.5	Medium dense to dense; Silty clayey SAND	43	0.39	16905	25357.5

67.5	68.7	1.2	Medium dense to dense; Silty clayey SAND	38	0.38	16560	19872
68.7	69.45	0.75	Medium dense to dense; Silty clayey SAND	50	0.4	17250	12937.5
				μ_{avg}	0.33	**$\sum E_{s(i)}.\Delta z$**	969438

$$E_s = \frac{[\sum E_{s(i)} \cdot \Delta z]}{z_0} = \frac{969438}{37} = 26201\ kPa$$

L/B = 7.4/7.4 = 1 ; α = 1.25

$$S_e = \frac{Bq_0}{E}(1 - \mu_s^2)\alpha$$

$$S_e = \frac{6(29.22)}{26201}(1 - 0.33^2)1.25$$

$S_e =$ 0.00427m = 4.27mm

At BH 5,

GWT at 3.8m

Total Load, Q = 1888.14 kN

Pressure from footing, $q = \frac{Q}{A} = \frac{1888.14}{8.3\ x\ 8.3}$ = 27.41 kN/m²

5B = 41.5m

Total height of SAND, H = 52.5m

∴ z0 = 41.5 m

Table 5.14 Soil modulus elasticity of BH 5

Upper depth (m)	Level Depth, D_f (m)	Height, H (m)	Soil Description	SPT-N	Poisson's Ratio, μ	$E_{s(i)}$ (kPa)	$E_{s(i)}.\Delta z$ (kPa)
3	4.5	1.5	Loose; SAND	6	0.2	10350	15525
4.5	6	1.5	Loose; SAND	5	0.2	10350	15525
6	7.5	1.5	Firm; Sandy CLAY	4	-	-	-
7.5	9	1.5	Firm; Sandy CLAY	5	-	-	-
9	10.5	1.5	Loose; Clayey silty SAND	6	0.2	10350	15525
10.5	12	1.5	Loose; Clayey silty SAND	5	0.2	10350	15525
12	13.5	1.5	Firm; Sandy silty CLAY	6	-	-	-
13.5	15	1.5	Firm; Sandy silty CLAY	7	-	-	-
15	16.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.35	24150	36225
16.5	18	1.5	Medium dense to dense; Silty clayey SAND	23	0.35	24150	36225
18	19.5	1.5	Medium dense to dense; Silty clayey SAND	23	0.35	24150	36225
19.5	21	1.5	Medium dense to dense; Silty clayey SAND	23	0.35	24150	36225
21	22.5	1.5	Medium dense to dense; Silty clayey SAND	28	0.35	24150	36225
22.5	24	1.5	Medium dense to dense; Silty clayey SAND	26	0.35	24150	36225
24	25.5	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225

25.5	27	1.5	Medium dense to dense; Silty clayey SAND	19	0.35	24150	36225
27	28.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.35	24150	36225
28.5	30	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225
30	31.5	1.5	Medium dense to dense; Silty clayey SAND	21	0.35	24150	36225
31.5	33	1.5	Medium dense to dense; Silty clayey SAND	16	0.35	24150	36225
33	34.5	1.5	Medium dense to dense; Silty clayey SAND	22	0.35	24150	36225
34.5	36	1.5	Medium dense to dense; Silty clayey SAND	22	0.35	24150	36225
36	37.5	1.5	Medium dense to dense; Silty clayey SAND	18	0.35	24150	36225
37.5	39	1.5	Medium dense to dense; Silty clayey SAND	18	0.35	24150	36225
39	40.5	1.5	Medium dense to dense; Silty clayey SAND	17	0.35	24150	36225
40.5	42	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225
42	43.5	1.5	Medium dense to dense; Silty clayey SAND	16	0.35	24150	36225
43.5	45	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225
45	46.5	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225

46.5	48	1.5	Medium dense to dense; Silty clayey SAND	22	0.35	24150	36225
48	49.5	1.5	Medium dense to dense; Silty clayey SAND	20	0.35	24150	36225
49.5	51	1.5	Medium dense to dense; Silty clayey SAND	23	0.35	24150	36225
51	52.5	1.5	Medium dense to dense; Silty clayey SAND	24	0.35	24150	36225
52.5	54	1.5	Medium dense to dense; Silty clayey SAND	24	0.35	24150	36225
54	55.5	1.5	Medium dense to dense; Silty clayey SAND	27	0.35	24150	36225
55.5	57	1.5	Medium dense to dense; Silty clayey SAND	26	0.35	24150	36225
57	58.5	1.5	Medium dense to dense; Silty clayey SAND	24	0.35	24150	36225
58.5	60	1.5	Medium dense to dense; Silty clayey SAND	29	0.35	24150	36225
60	61.5	1.5	Medium dense to dense; Silty clayey SAND	30	0.35	24150	36225
				μ_{avg}	0.33	**$\sum E_{s(i)}.\Delta z$**	1185075

$$E_s = \frac{\left[\sum E_{s(i)} \cdot \Delta z\right]}{z_0} = \frac{1185075}{41.5} = 28556\ kPa$$

L/B = 8.3/8.3 = 1 ; α = 1.25

$$S_e = \frac{Bq_0}{E}(1 - \mu_s^2)\alpha$$

$$S_e = \frac{8.3(27.41)}{28556}(1 - 0.33^2)1.25$$

$S_e =$ 0.00885m = 8.85mm

Consolidation Settlement

Consolidation settlement is a long-term settlement process that occurs due to the compression and consolidation of saturated soils. It takes place over an extended period of time, often months or even years. Consolidation settlement is caused by the drainage of excess pore water from the soil layers, resulting in the rearrangement and compaction of soil particles. It is typically a slower process compared to immediate settlement and can cause significant long-term vertical deformations in the foundation. For the calculation of consolidation settlement, the equation is shown below:

$$S_C = \frac{C_c H_0}{1 + e_0} log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right)$$

where:

Cc = compression index

H0 = soil thickness

e0 = initial void ratio

σ’0 = effective vertical stress

Δσ = stress increment

- Compression Index

The compression index of soil, also known as the coefficient of compression or C_c, is a geotechnical parameter that quantifies the compressibility or consolidation characteristics of soil. It represents the rate at which a soil specimen consolidates under an applied load over time. Soil Consolidation and Oedometer Test. (n.d.). findings indicate that the compression index (C_c) typically varies from 0.1 to 10 and is dimensionless. In the case of normally consolidated clays, C_c is commonly observed within the range of 0.20 to 0.50, while for silts, it falls between 0.16 and 0.24. Sands, however, exhibit a narrower range for C_c, typically ranging from 0.01 to 0.06. It is important to note that the compression index is not considered a particularly meaningful parameter for sands due to their specific granular characteristics

- Initial Void Ratio

Void ratio is a fundamental geotechnical parameter that characterizes the relationship between the volume of voids and the volume of solid particles in a soil sample. It is defined as the ratio of the volume of voids to the volume of solids within the soil mass.

Table 5.15 Initial void ratio of soils

Description	USCS	Void ratio [-]			Reference
		min	max	Specific value	
Well graded gravel, sandy gravel, with little or no fines	GW	0.26	0.46		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Poorly graded gravel, sandy gravel, with little or no fines	GP	0.26	0.46		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road

					and Traffic Engineers
Silty gravels, silty sandy gravels	GM	0.18	0.28		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Gravel	(GW-GP)	0.30	0.60		Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.
Clayey gravels, clayey sandy gravels	GC	0.21	0.37		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Glatial till, very mixed grained	(GC)	-	-	0.25	Terzaghi, K., Peck, R., and Mesri, G., Soil Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. &

					Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012
Well graded sands, gravelly sands, with little or no fines	SW	0.29	0.74		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers; Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.
Coarse sand	(SW)	0.35	0.75		Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.
Fine sand	(SW)	0.40	0.85		Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.

Poorly graded sands, gravelly sands, with little or no fines	SP	0.30	0.75		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers; Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.
Silty sands	SM	0.33	0.98		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers; Das, B., Advanced Soil Mechanics. Taylor & Francis, London & New York, 2008.
Clayey sands	SC	0.17	0.59		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers

Inorganic silts, silty or clayey fine sands, with slight plasticity	ML	0.26	1.28		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Uniform inorganic silt	(ML)	0.40	1.10		Hough, B., Basic soil engineering. Ronald Press Company, New York, 1969.
Inorganic clays, silty clays, sandy clays of low plasticity	CL	0.41	0.69		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Organic silts and organic silty clays of low plasticity	OL	0.74	2.26		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers; Hough, B., Basic soil engineering.

					Ronald Press Company, New York, 1969.
Silty or sandy clay	(CL-OL)	0.25	1.80		Hough, B., Basic soil engineering. Ronald Press Company, New York, 1969.
Inorganic silts of high plasticity	MH	1.14	2.10		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Inorganic clays of high plasticity	CH	0.63	1.45		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers
Soft glacial clay	-	-	-	1.20	Terzaghi, K., Peck, R., and Mesri, G., Soil Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. &

					Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012
Stiff glacial clay	-	-	-	0.60	Terzaghi, K., Peck, R., and Mesri, G., Soil Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. & Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012
Organic clays of high plasticity	OH	1.06	3.34		Swiss Standard SN 670 010b, Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers; Hough, B., Basic soil engineering. Ronald Press Company, New York, 1969.

Soft slightly organic clay	(OH-OL)	-	-	1.90	Terzaghi, K., Peck, R., and Mesri, G., Soil Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. & Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012
Peat and other highly organic soils	Pt	-	-		Terzaghi, K., Peck, R., and Mesri, G., Soil Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. & Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012
soft very organic clay	(Pt)	-	-	3.00	Terzaghi, K., Peck, R., and Mesri, G., Soil

					Mechanics in Engineering Practice. Wiley, New York, 1996; Obrzud R. & Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012

- Stress Increment

The "average method" referred to as the "2:1 method" is a specific approach used in geotechnical engineering to estimate stress increments within a soil layer. It assumes that the vertical stress increment is twice the horizontal stress increment for a given depth. This simplification allows for a quick approximation of stress distribution in certain scenarios, particularly when dealing with relatively uniform soil conditions and shallow depths.

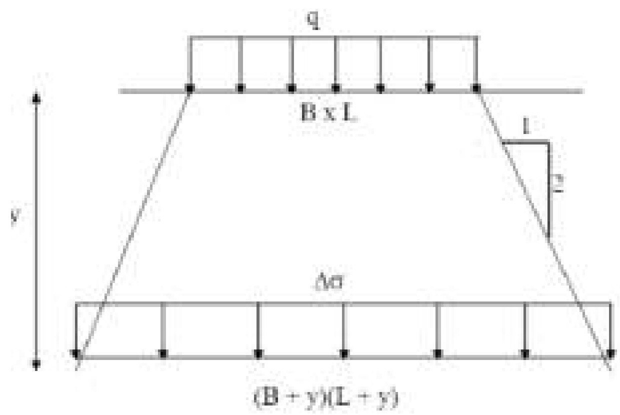


Figure 5.13 Average or 2:1 Method

It is expressed as:

$$\Delta_{\sigma} = \frac{qBL}{(B + y)(L + y)}$$

where,

q = pressure exerted by the footing, kN/m2

B = width of loaded area, m

L = length of loaded area, m

y = depth at which the stress increase

Example Calculation for Consolidation Settlement

At BH 3,

GWT = 5.5 m,

B x L = 7.4 m x 7.4 m

Depth of footing = 2.5 m

Clay Layer 1:

Depth of Clay Layer 1, H_0 = 3.5 m

y = (6-2.5) /2 = 1.75 m

C_c = 0.35; e_0 = 0.80

$$\Delta_{\sigma} = \frac{qBL}{(B + y)(L + y)} = \frac{1859.8}{(7.4 + 1.75)(7.4 + 1.75)} = 22.30\ kN/m^2$$

$$S_C = \frac{C_c H_0}{1 + e_0} log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right) = \frac{0.35(3.5)}{1 + 0.80} log\left(\frac{59.5 + 22.30}{59.5}\right)$$

$= 0.12286m \ = 122.86mm$

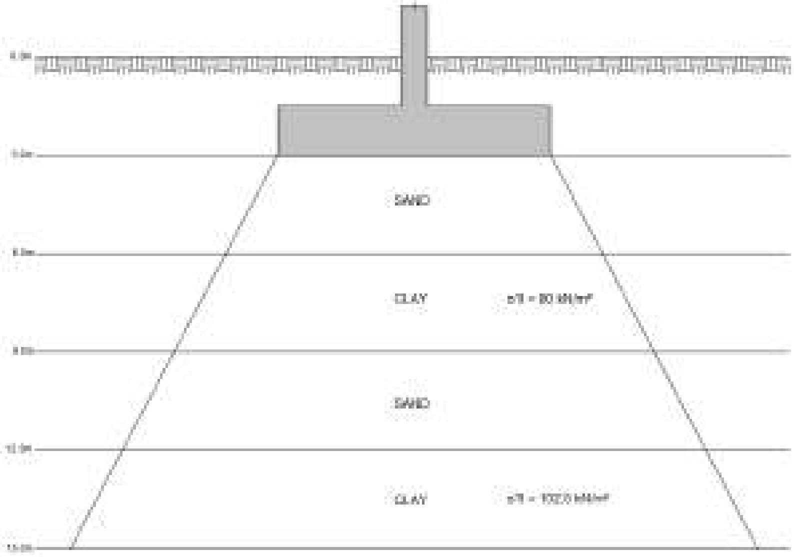


Figure 5.14 Consolidation settlement in borehole 5

At BH 5,

$Q_{superstructure}$ = 1629.8 kN

Foundation Selfweight = (8.3 x 8.3 x 0.15) x 25 = 258.34 kN

Total Load = 1888.14 kN

GWT = 3.8 m,

B x L = 8.3 m x 8.3 m

Depth of footing = 3 m

Clay Layer 1:

Depth of Clay Layer 1, H_0 = 3 m

y = (6-3) /2 = 1.5 m

C_c = 0.35; e_0 = 0.80

$$\Delta_{\sigma} = \frac{qBL}{(B+y)(L+y)} = \frac{1888.14}{(8.3+1.5)(8.3+1.5)} = 19.66\ kN/m^2$$

$$S_C = \frac{C_c H_0}{1+e_0} log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right) = \frac{0.35(3)}{1+0.80} log\left(\frac{23.66+19.66}{23.66}\right)$$

$$= 0.153235m\ = 153.24mm$$

Clay Layer 2:

Depth of Clay Layer 1, H_0 = 3 m

y = (3/2) + (12-3) = 10.5 m

C_c = 0.3; e_0 = 0.80

$$\Delta_{\sigma} = \frac{qBL}{(B+y)(L+y)} = \frac{1888.14}{(8.3+10.5)(8.3+10.5)} = 5.34\ kN/m^2$$

$$S_C = \frac{C_c H_0}{1+e_0} log\left(\frac{\sigma_0' + \Delta\sigma}{\sigma_0'}\right) = \frac{0.3(3)}{1+0.80} log\left(\frac{23.66+5.34}{23.66}\right)$$

$$= 0.044211m\ = 44.21mm$$

∴ Total Consolidation Settlement for BH 5 = 153.24 + 44.21 = 197.45 mm

Total Settlement of Shallow Foundation

As per the Indian Standard Code of Practice for Foundation (IS-1904, 1966), the maximum allowable settlement for isolated shallow foundations is stipulated at 40mm for sandy soils and 65mm for clayey soils. These values represent the permissible amount of settlement deemed safe for the structure and are accompanied by a factor of safety to ensure stability and optimal performance. It is crucial to recognize that these values are specific to the 1966 version of the code. For the most current and precise guidelines on allowable settlement criteria for shallow foundations in various soil types, it is advisable to refer to the latest version of the code and seek the guidance of geotechnical experts.

Table 5.16 Summary of Shallow Foundation Settlement

Borehole	Intermediate Settlement (mm)	Consolidation Settlement (mm)	Total Settlement (mm)	Allowable Settlement	
				Sand 40 mm	Clay 65 mm
BH 3	4.27	122.87	127.94	OK	NOT OK
BH 5	8.85	197.45	206.30	OK	NOT OK

5.5.1.4 Summary of Shallow Foundation

In conclusion, upon careful evaluation of the results, it has been noted that the anticipated settlement surpasses the acceptable limit. Consequently, it can be inferred that a shallow foundation is not a feasible solution for this project. Taking these considerations into account, the recommendation is to propose a deep foundation as a more appropriate and viable alternative. Deep foundations can offer the required support and mitigate settlement issues, thereby ensuring the stability and sustained performance of the structure over the long term.

5.5.2 Deep Foundation

A deep foundation can be straightforwardly contrasted with a shallow foundation based on its depth of embedment in the soil. Deep foundations extend deeper into various soil layers, enabling them to withstand greater loads from the structure above and efficiently transmit these loads to the ground. Deep foundations become a preferred choice when shallow foundations are deemed geotechnically inadequate to support the vertical load requirements. Piles are often employed in deep foundations to resist both vertical loads and uplift resistance from the soil.

In this project, two sizes of piles have been proposed, determined based on the allowable load-bearing capacity of the structure. The square reinforced concrete (RC) piles are designed at sizes of 150mm x 150mm and 200mm x 200mm. These piles are precast concrete and are selected based on their availability in the Malaysian market.

Additionally, group piles are considered to enhance the efficiency of the foundation at the selected borehole. Therefore, it is imperative to take into account the settlement of the piles for the overall safety of the structure and to prevent potential failures.

5.5.2.1 Bearing Capacity of Deep Foundation

In deep foundations, the ultimate loading capacity is determined by two main components: shaft resistance (Q_s) and base resistance (Q_p). Shaft resistance (Q_s) arises from the skin friction between the soil and the pile when it is driven into the ground. It acts as a force opposing the direction of the pile surface, impeding any rotation or motion of the pile. On the other hand, base resistance (Q_p) is generated by the interaction of the pile's tip with the surrounding soil or hard rock. This component is influenced by both the base area of the pile and the effective stress of the soil at the depth of the pile's base.

Therefore, the ultimate loading capacity (Q_u) of a deep foundation can be determined by summing both the shaft resistance (Q_s) and the base resistance (Q_p):

$$Q_u = Q_p + \Sigma Q_s$$

Nevertheless, equation of ultimate loading capacity will differ in different types of soil due to its cohesion properties. Where,

- In clay,

$$Q_u = A_p \times c_u \times N_c + \sum \alpha \times c_u \times p \times (\Delta L)$$

A_p = cross-sectional area of pile base

c_u = undrained shear strength (refer Table 4.6)

N_c = bearing capacity factor = $9c_u$

α = adhesion factor = 1 for $c_u \leq 25$ kPa

= 0.5 - 1 for c_u = 25 - 75 kPa

= 0.3 - 5 for c_u > 75 kPa

p = perimeter of pile

ΔL = length of pile segment of interest

- In sand,

$$Q_u = q' \times N_q \times A_p + \sum K \times \sigma v' \times \tan \delta \times p \times (\Delta L)$$

q' = effective vertical stress at pile base

N_q = bearing capacity factor

A_p = cross-sectional area of pile base

p = perimeter of pile

ΔL = length of pile segment of interest

K = coefficient of lateral stress on displacement of soil during pile installation

= K_o for bored pile

= K_o to 1.4 K_o for low displacement pile

= K_o to 1.8 K_o for high displacement pile

K_o = coefficient of lateral earth pressure at rest

= 1 - sin φ

δ = interface friction angle between pile and soil

σv' = effective vertical stress at depth of interest (value of σv' becomes constant when L'=15D)

5.5.2.2 Allowable Load Capacity

To ensure the safety and stability of the pile foundations in withstanding the vertical load imposed by the structure above, it is essential to consider the allowable load capacity (Q_{all}). This represents the maximum load that a pile can bear without experiencing severe settlement or failure. Calculating and designing the allowable load capacity of the piles should adhere to a specified factor of safety (FOS). The factor of safety value (FOS) is determined based on the category of the structure the piles are intended to support. This factor of safety introduces a margin in the allowable load capacity, setting a limit for engineers to design within a specified range. Hence,

- Partial

$$Q_{all} = \frac{Q_p}{FOS_p} + \Sigma \frac{Q_S}{FOS_S}$$

in which,

FOSp = Partial FOS point = 3.0

FOSs = Partial FOS shaft = 1.5

- Global

$$Q_{all} = \frac{Q_u}{FOS}$$

in which,

FOS = Factor of Safety = 2 to 4 = 2.0

5.5.2.3 Summary of Allowable Load Capacity for BH3 and BH5 of Single Pile

Table 5.17 and 5.18 below shows the allowable load capacity for both boreholes of both sizes of 150mmx150mm and 200mmx200mm for the location in borehole 3 and 5 while Table 5.19 until 5.21 shows the detailed calculations of each dimension and also the location of the borehole.

Table 5.17 Allowable Load Bearing Capacity of Single Pile

BH 3		
Level Depth	**Allowable Load Bearing Capacity (Q_{all})**	
m	**150mm x 150mm**	**200mm x 200mm**
1.5	0	0
3	5.4	8.7
4.5	16.65	25.7
6	27.9	41.2
7.5	65.7	103.6
9	67.95	104.6
10.5	84.15	130.2
12	92.25	141.0
13.5	95.4	143.2
15	107.55	161.4
16.5	120.6	180.8
18	129.6	192.8
19.5	133.65	196.2
21	146.7	215.6
22.5	150.75	219.0
24	168.75	247.0
25.5	173.7	251.6
27	187.65	272.2
28.5	207.45	302.6
30	234	344.0

31.5	273.15	406.2
33	277.2	405.6
34.5	283.5	410.0
36	307.8	446.4
37.5	348.75	511.0
39	354.6	512.8
40.5	382.5	554.0
42	397.35	571.8
43.5	406.35	579.8
45	477.9	697.2
46.5	534.6	784.8
48	527.4	759.2
49.5	547.65	784.2
51	557.1	790.8
52.5	563.85	793.8
54	582.75	819.0
55.5	606.6	852.8
57	641.25	905.0
58.5	648.9	909.2
60	678.6	952.8
61.5	720	1016.0
63	745.2	1049.6
64.5	775.35	1091.8
66	781.65	1092.2
67.5	893.25	1277.0
69	907.2	1285.6
69.5	1000.8	1434.4

Table 5.18 Allowable Load Bearing Capacity of Single Pile

BH 5		
Level Depth	**Allowable Load Bearing Capacity (Q_{all})**	
m	**150mm x 150mm**	**200mm x 200mm**
1.5	0	0
3	34.65	60.2
4.5	36	60
6	36.45	58.6
7.5	22.5	32
9	29.7	42.1
10.5	58.5	90
12	58.95	88.6
13.5	48.15	67.2
15	58.05	80.9
16.5	168.75	269
18	193.5	304
19.5	214.2	331.6
21	234.9	359.2
22.5	280.35	429.8
24	295.65	446.2
25.5	289.35	425.8
27	302.4	441.2
28.5	334.35	489.8
30	344.25	499
31.5	367.2	531.6
33	361.35	513.8

34.5	405.45	584.6
36	425.25	611
37.5	425.25	603
39	441.45	624.6
40.5	452.7	637.6
42	482.85	683.8
43.5	481.05	673.4
45	515.25	727
46.5	533.25	751
48	561.15	792.2
49.5	571.05	801.4
51	603.9	851.2
52.5	629.55	887.4
54	651.15	916.2
55.5	687.6	970.8
57	706.95	994.6
58.5	720.45	1008.6
60	766.8	1080.4
60.5	797.85	1123.8

Table 5.19 Detailed Calculations of Allowable Load Bearing Capacity of Single Pile

150 x 150										
Upper Depth (m)	**Level Depth**	**N**	**N_{avg}**	**Soil Description (S=Sand, C=Clay)**	**Q_b**	**Q_s**	**$\sum Q_s$**	**Q_u**	**$Q_{all(s+b)}$**	**Q_{all}**
0	1.5	0		C	0			0	0	0
			1.5	C		4.1	4.1			
1.5	3	3		C	6.8			10.8	4.95	5.4
			5	C		14	18			
3	4.5	7		C	16			33.3	16.95	16.7
			7.5	C		20	38			
4.5	6	8		C	18			55.8	31.2	27.9
			8	C		22	59			
6	7.5	8		S	72			131	63.6	65.7
			7.5	S		14	73			
7.5	9	7		S	63			136	69.6	68
			8	S		14	87			
9	10.5	9		S	81			168	85.2	84.2
			9	S		16	104			
10.5	12	9		S	81			185	96	92.3
			8.5	S		15	119			
12	13.5	8		S	72			191	103.2	95.4
			8.5	S		15	134			
13.5	15	9		S	81			215	116.4	108
			9.5	S		17	151			
15	16.5	10		S	90			241	130.8	121
			10	S		18	169			
16.5	18	10		S	90			259	142.8	130
			9.5	S		17	186			

18	19.5	9		S	81			267	151.2	134
			9.5	S		17	203			
19.5	21	10		S	90			293	165.6	147
			9.5	S		17	221			
21	22.5	9		S	81			302	174	151
			10	S		18	239			
22.5	24	11		S	99			338	192	169
			10.5	S		19	257			
24	25.5	10		S	90			347	201.6	174
			10.5	S		19	276			
25.5	27	11		S	99			375	217.2	188
			12	S		22	298			
27	28.5	13		S	117			415	237.6	207
			14.5	S		26	324			
28.5	30	16		S	144			468	264	234
			18.5	S		33	357			
30	31.5	21		S	189			546	301.2	273
			19.5	S		35	392			
31.5	33	18		S	162			554	315.6	277
			17	S		31	423			
33	34.5	16		S	144			567	330	284
			17	S		31	454			
34.5	36	18		S	162			616	356.4	308
			20.5	S		37	491			
36	37.5	23		S	207			698	396	349
			21.5	S		39	529			
37.5	39	20		S	180			709	412.8	355
			21	S		38	567			
39	40.5	22		S	198			765	444	383
			21.5	S		39	606			
40.5	42	21		S	189			795	466.8	397

			20	S		36	642			
42	43.5	19		S	171			813	484.8	406
			24.5	S		44	686			
43.5	45	30		S	270			956	547.2	478
			33	S		59	745			
45	46.5	36		S	324			1069	604.8	535
			32	S		58	803			
46.5	48	28		S	252			1055	619.2	527
			27.5	S		50	852			
48	49.5	27		S	243			1095	649.2	548
			25.5	S		46	898			
49.5	51	24		S	216			1114	670.8	557
			22.5	S		41	939			
51	52.5	21		S	189			1128	688.8	564
			21	S		38	977			
52.5	54	21		S	189			1166	714	583
			21.5	S		39	1015			
54	55.5	22		S	198			1213	742.8	607
			23.5	S		42	1058			
55.5	57	25		S	225			1283	780	641
			23.5	S		42	1100			
57	58.5	22		S	198			1298	799.2	649
			23	S		41	1141			
58.5	60	24		S	216			1357	832.8	679
			26	S		47	1188			
60	61.5	28		S	252			1440	876	720
			28	S		50	1238			
61.5	63	28		S	252			1490	909.6	745
			28.5	S		51	1290			
63	64.5	29		S	261			1551	946.8	775
			27	S		49	1338			

64.5	66	25		S	225			1563	967.2	782
			34	S		61	1400			
66	67.5	43		S	387			1787	1062	893
			40.5	S		73	1472			
67.5	69	38		S	342			1814	1096	907
			44	S		79	1552			
69		50		S	450			2002	1184	1001

Table 5.20 Detailed Calculations of Allowable Load Bearing Capacity of Single Pile

200 x 200										
Upper Depth	**Level Depth**	**N**	**N_{avg}**	**Soil Description (S=Sand, C=Clay)**	**Q_b**	**Q_s**	**$\sum Q_s$**	**Qu**	**$Q_{all(s+b)}$**	**Q_{all}**
0	1.5	0		C	0			0	0	0
			1.5	C		5.4	5.4			
1.5	3	3		C	12			17.4	7.6	8.7
			5	C		18	23.4			
3	4.5	7		C	28			51.4	24.9	25.7
			7.5	C		27	50.4			
4.5	6	8		C	32			82.4	44.3	41.2
			8	C		28.8	79.2			
6	7.5	8		S	128			207.2	95.5	103.6
			7.5	S		18	97.2			
7.5	9	7		S	112			209.2	102.1	104.6
			8	S		19.2	116.4			
9	10.5	9		S	144			260.4	125.6	130.2
			9	S		21.6	138			
10.5	12	9		S	144			282	140.0	141.0
			8.5	S		20.4	158.4			
12	13.5	8		S	128			286.4	148.3	143.2
			8.5	S		20.4	178.8			
13.5	15	9		S	144			322.8	167.2	161.4
			9.5	S		22.8	201.6			
15	16.5	10		S	160			361.6	187.7	180.8

			10	S		24	225.6			
16.5	18	10		S	160			385.6	203.7	192.8
			9.5	S		22.8	248.4			
18	19.5	9		S	144			392.4	213.6	196.2
			9.5	S		22.8	271.2			
19.5	21	10		S	160			431.2	234.1	215.6
			9.5	S		22.8	294			
21	22.5	9		S	144			438	244.0	219.0
			10	S		24	318			
22.5	24	11		S	176			494	270.7	247.0
			10.5	S		25.2	343.2			
24	25.5	10		S	160			503.2	282.1	251.6
			10.5	S		25.2	368.4			
25.5	27	11		S	176			544.4	304.3	272.2
			12	S		28.8	397.2			
27	28.5	13		S	208			605.2	334.1	302.6
			14.5	S		34.8	432			
28.5	30	16		S	256			688	373.3	344.0
			18.5	S		44.4	476.4			
30	31.5	21		S	336			812.4	429.6	406.2
			19.5	S		46.8	523.2			
31.5	33	18		S	288			811.2	444.8	405.6
			17	S		40.8	564			
33	34.5	16		S	256			820	461.3	410.0
			17	S		40.8	604.8			
34.5	36	18		S	288			892.8	499.2	446.4
			20.5	S		49.2	654			
36	37.5	23		S	368			1022	558.7	511.0
			21.5	S		51.6	705.6			
37.5	39	20		S	320			1025.6	577.1	512.8
			21	S		50.4	756			

39	40.5	22		S	352			1108	621.3	554.0
			21.5	S		51.6	807.6			
40.5	42	21		S	336			1143.6	650.4	571.8
			20	S		48	855.6			
42	43.5	19		S	304			1159.6	671.7	579.8
			24.5	S		58.8	914.4			
43.5	45	30		S	480			1394.4	769.6	697.2
			33	S		79.2	993.6			
45	46.5	36		S	576			1569.6	854.4	784.8
			32	S		76.8	1070			
46.5	48	28		S	448			1518.4	862.9	759.2
			27.5	S		66	1136			
48	49.5	27		S	432			1568.4	901.6	784.2
			25.5	S		61.2	1198			
49.5	51	24		S	384			1581.6	926.4	790.8
			22.5	S		54	1252			
51	52.5	21		S	336			1587.6	946.4	793.8
			21	S		50.4	1302			
52.5	54	21		S	336			1638	980.0	819.0
			21.5	S		51.6	1354			
54	55.5	22		S	352			1705.6	1019.7	852.8
			23.5	S		56.4	1410			
55.5	57	25		S	400			1810	1073.3	905.0
			23.5	S		56.4	1466			
57	58.5	22		S	352			1818.4	1094.9	909.2
			23	S		55.2	1522			
58.5	60	24		S	384			1905.6	1142.4	952.8
			26	S		62.4	1584			
60	61.5	28		S	448			2032	1205.3	1016.0
			28	S		67.2	1651			
61.5	63	28		S	448			2099.2	1250.1	1049.6

			28.5	S		68.4	1720			
63	64.5	29		S	464			2183.6	1301.1	1091.8
			27	S		64.8	1784			
64.5	66	25		S	400			2184.4	1322.9	1092.2
			34	S		81.6	1866			
66	67.5	43		S	688			2554	1473.3	1277.0
			40.5	S		97.2	1963			
67.5	69	38		S	608			2571.2	1511.5	1285.6
			44	S		105.6	2069			
69		50		S	800			2868.8	1645.9	1434.4

Table 5.20 Detailed Calculations of Allowable Load Bearing Capacity of Single Pile

BH 5 (150mm x 150mm)										
Upper Depth m	**Level Depth m**	**N**	**N_{avg}**	**Soil Description (S=Sand, C=Clay)**	**Q_b kN**	**Q_s kN**	**$\sum Q_s$ kN**	**Q_u kN**	**$Q_{all(s+b)}$ kN**	**Q_{all} kN**
0	1.5	0		S	0					
			3.5			6.3	6.3			
1.5	3	7		S	63			69.3	25.2	34.65
			6.5			11.7	18			
3	4.5	6		S	54			72	30	36
			5.5			9.9	27.9			
4.5	6	5		S	45			72.9	33.6	36.45
			4.5			8.1	36			
6	7.5	4		C	9			45	27	22.5
			4.5			12.15	48.15			
7.5	9	5		C	11.25			59.4	35.85	29.7
			5.5			14.85	63			
9	10.5	6		S	54			117	60	58.5
			5.5			9.9	72.9			
10.5	12	5		S	45			117.9	63.6	58.95
			5.5			9.9	82.8			
12	13.5	6		C	13.5			96.3	59.7	48.15
			6.5			17.55	100.35			
13.5	15	7		C	15.75			116.1	72.15	58.05
			14.5			39.15	139.5			
15	16.5	22		S	198			337.5	159	168.75
			22.5			40.5	180			
16.5	18	23		S	207			387	189	193.5

			23			41.4	221.4			
18	19.5	23		S	207			428.4	216.6	214.2
			23			41.4	262.8			
19.5	21	23		S	207			469.8	244.2	234.9
			25.5			45.9	308.7			
21	22.5	28		S	252			560.7	289.8	280.35
			27			48.6	357.3			
22.5	24	26		S	234			591.3	316.2	295.65
			23			41.4	398.7			
24	25.5	20		S	180			578.7	325.8	289.35
			19.5			35.1	433.8			
25.5	27	19		S	171			604.8	346.2	302.4
			20.5			36.9	470.7			
27	28.5	22		S	198			668.7	379.8	334.35
			21			37.8	508.5			
28.5	30	20		S	180			688.5	399	344.25
			20.5			36.9	545.4			
30	31.5	21		S	189			734.4	426.6	367.2
			18.5			33.3	578.7			
31.5	33	16		S	144			722.7	433.8	361.35
			19			34.2	612.9			
33	34.5	22		S	198			810.9	474.6	405.45
			22			39.6	652.5			
34.5	36	22		S	198			850.5	501	425.25
			20			36	688.5			
36	37.5	18		S	162			850.5	513	425.25
			18			32.4	720.9			
37.5	39	18		S	162			882.9	534.6	441.45
			17.5			31.5	752.4			
39	40.5	17		S	153			905.4	552.6	452.7
			18.5			33.3	785.7			

40.5	42	20		S	180			965.7	583.8	482.85
			18			32.4	818.1			
42	43.5	16		S	144			962.1	593.4	481.05
			18			32.4	850.5			
43.5	45	20		S	180			1030.5	627	515.25
			20			36	886.5			
45	46.5	20		S	180			1066.5	651	533.25
			21			37.8	924.3			
46.5	48	22		S	198			1122.3	682.2	561.15
			21			37.8	962.1			
48	49.5	20		S	180			1142.1	701.4	571.05
			21.5			38.7	1000.8			
49.5	51	23		S	207			1207.8	736.2	603.9
			23.5			42.3	1043.1			
51	52.5	24		S	216			1259.1	767.4	629.55
			24			43.2	1086.3			
52.5	54	24		S	216			1302.3	796.2	651.15
			25.5			45.9	1132.2			
54	55.5	27		S	243			1375.2	835.8	687.6
			26.5			47.7	1179.9			
55.5	57	26		S	234			1413.9	864.6	706.95
			25			45	1224.9			
57	58.5	24		S	216			1440.9	888.6	720.45
			26.5			47.7	1272.6			
58.5	60	29		S	261			1533.6	935.4	766.8
			29.5			53.1	1325.7			
60	60.45	30		S	270			1595.7	973.8	797.85

Table 5.21 Detailed Calculations of Allowable Load Bearing Capacity of Single Pile

BH 5 (200mm x 200mm)										
Upper Depth m	**Level Depth** m	**N**	N_{avg}	**Soil Description (S=Sand, C=Clay)**	Q_b kN	Q_s kN	$\sum Q_s$ kN	Q_u kN	$Q_{all(s+b)}$ kN	Q_{all} kN
0	1.5	0		S	0					
			3.5			8.4	8.4			
1.5	3	7		S	112			120.4	42.9	60.2
			6.5			15.6	24.0			
3	4.5	6		S	96			120.0	48.0	60.0
			5.5			13.2	37.2			
4.5	6	5		S	80			117.2	51.5	58.6
			4.5			10.8	48.0			
6	7.5	4		C	16			64.0	37.3	32.0
			4.5			16.2	64.2			
7.5	9	5		C	20			84.2	49.5	42.1
			5.5			19.8	84.0			
9	10.5	6		S	96			180.0	88.0	90.0
			5.5			13.2	97.2			
10.5	12	5		S	80			177.2	91.5	88.6
			5.5			13.2	110.4			
12	13.5	6		C	24			134.4	81.6	67.2
			6.5			23.4	133.8			
13.5	15	7		C	28			161.8	98.5	80.9
			14.5			52.2	186.0			
15	16.5	22		S	352			538.0	241.3	269.0
			22.5			54	240.0			
16.5	18	23		S	368			608.0	282.7	304.0

			23			55.2	295.2			
18	19.5	23		S	368			663.2	319.5	331.6
			23			55.2	350.4			
19.5	21	23		S	368			718.4	356.3	359.2
			25.5			61.2	411.6			
21	22.5	28		S	448			859.6	423.7	429.8
			27			64.8	476.4			
22.5	24	26		S	416			892.4	456.3	446.2
			23			55.2	531.6			
24	25.5	20		S	320			851.6	461.1	425.8
			19.5			46.8	578.4			
25.5	27	19		S	304			882.4	486.9	441.2
			20.5			49.2	627.6			
27	28.5	22		S	352			979.6	535.7	489.8
			21			50.4	678.0			
28.5	30	20		S	320			998.0	558.7	499.0
			20.5			49.2	727.2			
30	31.5	21		S	336			1063.2	596.8	531.6
			18.5			44.4	771.6			
31.5	33	16		S	256			1027.6	599.7	513.8
			19			45.6	817.2			
33	34.5	22		S	352			1169.2	662.1	584.6
			22			52.8	870.0			
34.5	36	22		S	352			1222.0	697.3	611.0
			20			48	918.0			
36	37.5	18		S	288			1206.0	708.0	603.0
			18			43.2	961.2			
37.5	39	18		S	288			1249.2	736.8	624.6
			17.5			42	1003.2			
39	40.5	17		S	272			1275.2	759.5	637.6
			18.5			44.4	1047.6			

40.5	42	20		S	320			1367.6	805.1	683.8
			18			43.2	1090.8			
42	43.5	16		S	256			1346.8	812.5	673.4
			18			43.2	1134.0			
43.5	45	20		S	320			1454.0	862.7	727.0
			20			48	1182.0			
45	46.5	20		S	320			1502.0	894.7	751.0
			21			50.4	1232.4			
46.5	48	22		S	352			1584.4	938.9	792.2
			21			50.4	1282.8			
48	49.5	20		S	320			1602.8	961.9	801.4
			21.5			51.6	1334.4			
49.5	51	23		S	368			1702.4	1012.3	851.2
			23.5			56.4	1390.8			
51	52.5	24		S	384			1774.8	1055.2	887.4
			24			57.6	1448.4			
52.5	54	24		S	384			1832.4	1093.6	916.2
			25.5			61.2	1509.6			
54	55.5	27		S	432			1941.6	1150.4	970.8
			26.5			63.6	1573.2			
55.5	57	26		S	416			1989.2	1187.5	994.6
			25			60	1633.2			
57	58.5	24		S	384			2017.2	1216.8	1008.6
			26.5			63.6	1696.8			
58.5	60	29		S	464			2160.8	1285.9	1080.4
			29.5			70.8	1767.6			
60	60.45	30		S	480			2247.6	1338.4	1123.8

5.5.2.4 Group Pile

In situations where individual piles may not suffice to support the imposed load from a structure, the utilization of group piles becomes a viable option. This approach not only increases the allowable load-bearing capacity of the piles but also enhances their stability within the soil. The principle behind group piles involves distributing the load among each pile in the group rather than relying on a single pile alone. Consequently, each pile in the group is subjected to a smaller load compared to when it stands alone. This strategy enables the collective group of piles to withstand a larger load capacity and results in reduced settlement. A group pile, covering a larger area than individual piles, proves advantageous in enhancing lateral stability and addressing uneven loads from the structure or soil.

When contemplating the use of group piles, several factors must be determined, including the required number of piles, the spacing between piles, and the arrangement of piles. Subsequently, the group of piles can undergo further analysis concerning the combined load-bearing capacity and the overall efficiency of the group.

Determination Number of Piles Required

A single pile can be considered to fail when load imposed is more than the allowable load carrying capacity. Hence, the number of piles in a group can be determined, the equation is as follows:

$$N = \frac{Axial\ Load\ (from\ structure)}{Qall}$$

Efficiency of Group Pile

According to eurocode equation, the efficiency of group pile in sand can be determined as follows:

$$\eta = \frac{Qg(u)}{\Sigma Qu}$$

Where,

$Qg(u) = PgLfave$, (Group pile Capacity of Block)

$\Sigma Qu = No. of\ pile\ x\ Qu$, (Individual pile Capacity for no. of pile)

$Qu = pLfave$ (Individual pile Capacity)

Allowable Load Capacity of Group Pile

The new allowable bearing capacity of group pile of sand can be obtained after calculate the efficiency. Then, if the value of efficiency is more than 1, so it can assume as below:

$$Qg(u) = \Sigma Qu$$

Table 5.22 shown the catalogue of pile dimension and working load from manufacturer that used to determine the length of the pile that suitable with load imposed requirement.

Table 5.22 Pile dimensions and working load from manufacturer (OKA Corporation Bhd., n.d.

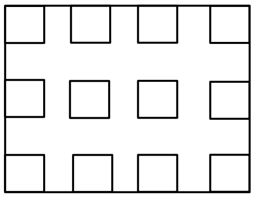
Pile Dimensions and Details														
Pile Nominal Size A x C (mm x mm)	Pile Length L (M)	Maximum Structural Load (ton)	Recommended Axial Working Load (ton)	Pile Dimensions A (mm)	B (mm)	C (mm)	Main Reinforcement (No/Dia)	Links Wire Size (mm)	P1 (mm)	X (mm)	P2 (mm)	Y (mm)	P3 (mm)
OKA Class "MS" Piles (Conform To MS1314 : 2004)													
150 X 150	6.3	32	25	153	147	150	4 T 9	4.5	45	450	45 - 75	450	75
175 X 175	6.3	44	35	178	172	175	4 T 10	4.5	40	525	40 - 87	525	87
200 X 200	9,6.3	58	45	203	197	200	4 T 12	5.0	45	600	45 - 100	600	100
225 X 225	9,6.3	71	57	228	222	225	4 T 12	5.0	42	675	42 - 112	675	112
250 X 250	9,6.3	89	75	253	247	250	8 T 10	5.5	40	750	40 - 125	750	125
250 X 250	12	92	75	253	247	250	4 T 16	5.5	40	750	40 - 125	750	125
275 X 275	9,6.3	105	85	278	272	275	8 T 10	5.5	41	825	41 - 117	825	117
275 X 275	12	108	85	278	272	275	4 T 16	5.5	41	825	41 - 117	825	117
300 X 300	12,9,6.3	126	105	303	297	300	4 T 16	6.0	43	900	43 - 135	900	135
325 X 325	12,9,6.3	148	120	328	322	325	8 T 12	6.0	42	975	42 - 131	975	131
350 X 350	12,9,6.3	172	140	353	347	350	4 T 16 + 4 T 10	6.0	40	1050	40 - 120	1050	120
375 X 375	12,9,6.3	198	160	378	372	375	4 T 20	6.5	45	1125	45 - 136	1125	136
400 X 400	12,9,6.3	227	190	403	397	400	4 T 20 + 4 T 10	6.5	44	1200	44 - 133	1200	133
450 X 450	12,9,6.3	282	230	453	447	450	4 T 20 + 4 T 12	6.5	41	1350	41 - 120	1350	120
OKA Class "C" Piles													
150 X 150	6.3	32	25	153	147	150	4 T 9	4.5	45	450	45 - 75	450	75
175 X 175	6.3	43	35	178	172	175	4 T 9	4.5	40	525	40 - 87	525	87
200 X 200	6.3	55	45	203	197	200	4 T 10	5.0	45	600	45 - 100	600	100

Elastic Settlement of Group Pile

As similar to individual piles, group piles also undergo elastic settlement but in group. In group settlement, the maximum limit is less than 75mm (in clay/silt). Hence, if group settlement is lesser than 75mm, and for sand it has to be pass 40mm. the group pile design passes the safety requirement.

Sample Calculation of Group Pile

Group Pile 150 x 150



Load of structure = 1629.8 kN

Location = BH3

Termination depth = 18 m

Size = 0.15 x 0.15

Ultimate Bearing Capacity, Qu = 259.2 kN

Base Resistance, Qp = 90 kN

Shaft Resistance, Qs = 169.2 kN

Allowable Load Capacity, Qall = 129.6 kN

Area of Pile = 0.0225 m^2

Spacing = 3.5D

No. of Pile = 1629.8/129.6 = 12

$Qu = pLfave$ = ((4 x 0.15) (18) $fave$ = *1218.24*

For 12 Pile

$\Sigma Qu = No. of\ pile\ x\ Qu$ = 12 x 1218.24 = 14618.88

Bg = 3(3.5 (0.15)) + 0.15 = 1.725

Lg = 2(3.5(0.15) + 0.15 = 1.2

Lg/Bg = 0.9/1.275 = 1.44

$Qg(u) = PgLfave$ = 2(1.725 + 1.2) x 18$fave$ = 11877.84

$\eta = \frac{Qg(u)}{\Sigma Qu}$ = 11877.84/14618.88 $= 1 > 1$

Thus,

$Qg(u) = \ \Sigma Qu$ = 14618.88

The allowable capacity = 14618.88kN > 1629.8 kN , Ok!

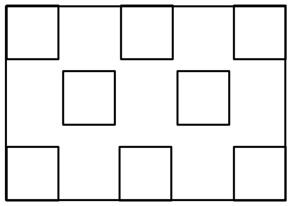
Eccentricity:

$\sum x^2 = 4.13\ m^2$

$\sum y^2 = 0.55\ m^2$

Q8 = 275.569 kN < Qu/2 = 609.12 kN , Pass!

Group Pile 200 x 200



Load of structure = 1629.8 kN

Location = BH3

Termination depth = 18 m

Size = 0.2 x 0.2

Ultimate Bearing Capacity, Qu = 385.6 kN

Base Resistance, Qp = 160 kN

Shaft Resistance, Qs = 225.6 kN

Allowable Load Capacity, Qall = 192.8 kN

Area of Pile = 0.0225 m^2

No. of Pile = 1629.8/192.8 = 8

$Qu = pLfave$ = ((4 x 0.2) (8) $fave$ = 1624.32

<u>For 8 Pile</u>

$\Sigma Qu = No. of\ pile\ x\ Qu$ = 8 x 1624.32= 12994.56

S = 3D

Bg = 2(3 x 0.2) + 0.2 = 2

Lg = 2(3 x 0.2) + 0.2 = 1.4

Lg/Bg = 1.2/1.2 = 1.43

$Qg(u) = PgLfave$ = 2(2 + 1.4) x 18$fave$ = 18408.96

$\eta = \frac{Qg(u)}{\Sigma Qu}$ = 18408.96/12994.56 = 1.42 > 1

Thus,

$Qg(u) = \Sigma Qu$ = 12994.56

The allowable capacity = 12994.56 > 1629.8 kN , Ok!

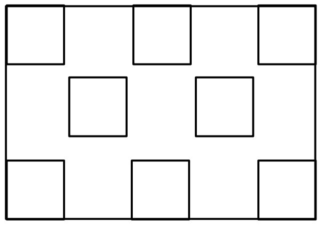
Eccentricity:

$\sum x^2 = 5.6\ m^2$

$\sum y^2 = 4.2\ m^2$

Q8 = 260.3 kN < Qu/2 = 812.16 kN , Pass!

Group Pile 150 x 150



Load of structure = 1629.8 kN

Location = BH5

Termination depth = 18 m

Size = 0.15 x 0.15

Ultimate Bearing Capacity, Qu = 387 kN

Base Resistance, Qp = 207 kN

Shaft Resistance, Qs = 180 kN

Allowable Load Capacity, Qall = 193.5 kN

Area of Pile = 0.0225 m^2

No. of Pile = 1629.8/193.5 = 8

$Qu = pLfave$ = ((4 x 0.15) (18) $fave$ = 1296

For 8 Pile

$\Sigma Qu = No.of\ pile\ x\ Qu$ = 8 x 1296 = 10368

S = 3D = 3(0.15) = 0.45

Bg = 1.05

Lg = 1.05

Lg/Bg = 0.9/0.9 =1

$Qg(u) = PgLfave$ = 2(0.9+0.9) x 18$fave$ = 9072

$\eta = \frac{Qg(u)}{\Sigma Qu}$ = 9072/10368 = 1 > 1

Thus,

$Qg(u) = \Sigma Qu$ = 10368

The allowable capacity = 10368 > 1629.8 kN , Ok!

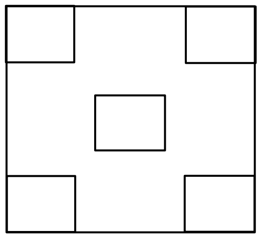
Eccentricity:

$\sum x^2 = 0.911\ m^2$

$\sum y^2 = 1.215\ m^2$

Q8 = 320.28 kN < Qu/2.5 = 648 kN , Pass!

Group Pile 200 x 200



Load of structure = 1629.8 kN

Location = BH5

Termination depth = 18 m

Size = 0.2 x 0.2

Ultimate Bearing Capacity, Qu = 608 kN

Base Resistance, Qp = 368 kN

Shaft Resistance, Qs = 240 kN

Allowable Load Capacity, Qall = 304 kN

Area of Pile = 0.04 m^2

No. of Pile = 1629.8/304 = 5

$Qu = pLfave$ = ((4 x 0.2) (18) $fave$ = 1728

For 8 Pile

$\Sigma Qu = No. of\ pile\ x\ Qu$ = 5 x 1728 = 8640

S = 3D = 3(0.2) = 0.6

Bg = 0.8

Lg = 1.4

Lg/Bg = 1.4/0.8 =1.8

$Qg(u) = PgLfave$ = 2(00.8+1.4) x 18$fave$ = 12672

$\eta = \frac{Qg(u)}{\Sigma Qu}$ = 12672/11520 = 1.5 > 1

Thus,

$Qg(u) = \Sigma Qu$ = 8640

The allowable capacity = 8640 > 1629.8 kN , Ok!

Eccentricity:

$\sum x^2 = 5.76\ m^2$

$\sum y^2 = 0.54\ m^2$

Q8 = 471.5 kN < Qu/2 = 864 kN , Pass!

5.6. Retaining Wall

A retaining wall is a structure designed to restrain soil and other materials from moving downhill due to erosion or other factors. It is commonly used in landscaping, construction, and civil engineering to create level surfaces on sloping terrain or to prevent soil erosion. Retaining walls can be found in various settings, including residential yards, highways, commercial developments, and agricultural areas.

The primary purpose of a retaining wall is to support and retain soil or other materials, preventing them from sliding or eroding. These walls are especially useful in areas where the natural slope of the land needs to be modified for practical or aesthetic reasons. Retaining walls can be made from various materials, such as concrete, wood, steel, or reinforced masonry, depending on the specific requirements of the site and the engineer's design.

The are various types of retaining walls. Including gravity wall, cantilever wall, anchored wall, pile wall and reinforced soil wall. Each with its own design principles and advantages based on factors such as soil conditions and available space. Some examples of the various types of retaining wall are illustrated in Figure 4.15.

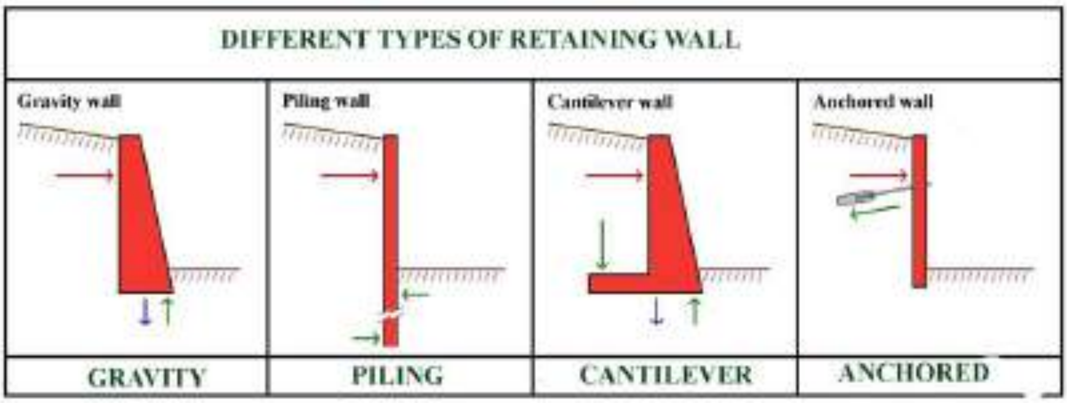


Figure 4.15 Example of typical retaining wall

5.6.1 Cantilever Retaining Wall

During our Integrated Design Project phase 1, Earthwork Department has pointed out the steepest slope of the project area as illustrated in Figure 4.16.

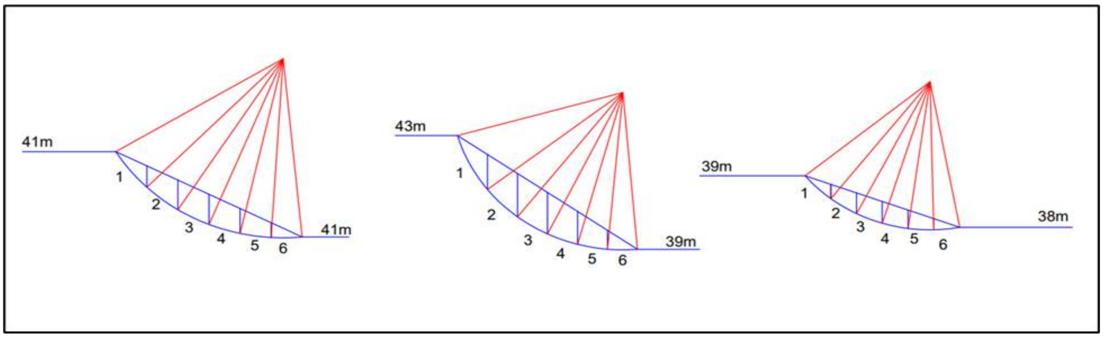


Figure 4.16 Highest slope proposed within project site

From the proposed slope, we have chosen to design the retaining wall for the most slope which is 4 m height. Since it is considerably a high slope, therefore, we have chosen the cantilever retaining wall as the countermeasure to stabilising the soil slope.

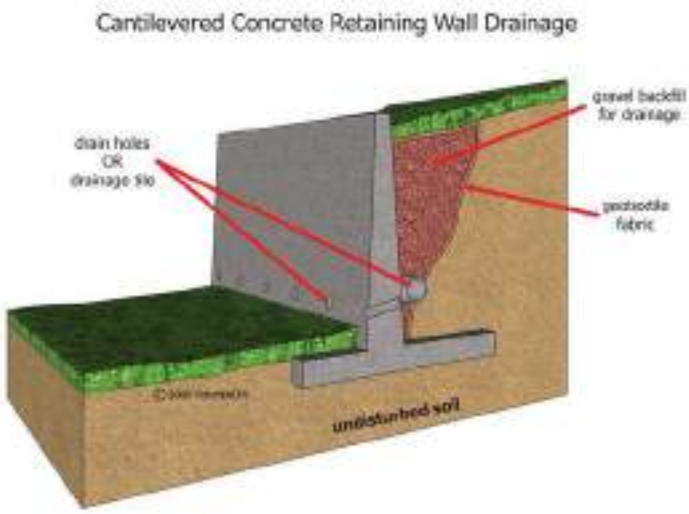


Figure 4.17 Cantilever Retaining Wall

A cantilever retaining wall is a type of retaining wall structure that utilizes the principle of a cantilever to support and retain soil on one side. The term "cantilever" refers to a structural element that is supported at one end and extends horizontally into space. In the context of retaining walls, the cantilever design helps resist the lateral pressure of the retained soil.

A cantilever retaining wall is often chosen for its advantages in terms of structural efficiency, design flexibility, and cost-effectiveness. One key reason for selecting a cantilever retaining wall is its ability to efficiently withstand and distribute lateral earth pressure without the need for additional support or bracing. The cantilever design incorporates a base slab or footing that extends horizontally into the retained soil, providing stability against overturning and sliding. This design allows for a relatively thin and lightweight wall structure, reducing the material and construction costs compared to other types of retaining walls. Additionally, the cantilever retaining wall offers versatility in accommodating various site conditions, such as variable soil properties, height requirements, and surcharge loads. Its wide range of applications and benefits make the cantilever retaining wall a popular choice in civil engineering projects.

5.6.2 Active Soil Pressure

Active soil pressure is a term used in geotechnical engineering to describe the lateral pressure exerted by soil against a retaining structure, such as a retaining wall. This pressure is considered to be the maximum horizontal force that the soil exerts on the wall when the soil is in its most stable and least compressed state.

Active soil pressure is a key consideration in the design of retaining walls, other types of soil pressures, such as passive soil pressure and at-rest soil pressure, also play roles in different soil and wall conditions. The proper analysis of these pressures is crucial for the safe and effective design of retaining structures. Engineers often use sophisticated software and detailed geotechnical investigations to determine the appropriate parameters for accurate calculations.

The active soil pressure acting on the retaining wall is estimated using Rankine Theory with the assumption that:

(a) No adhesion or friction between wall and soil. (wall is smooth)

(b) Failure is assumed to occur in the form of a sliding wedge along a failure plane.

(c) The direction of resultant pressure is parallel to the backfill and act to 13 from the wall base.

(d) Could be used for cohesionless and cohesion material.

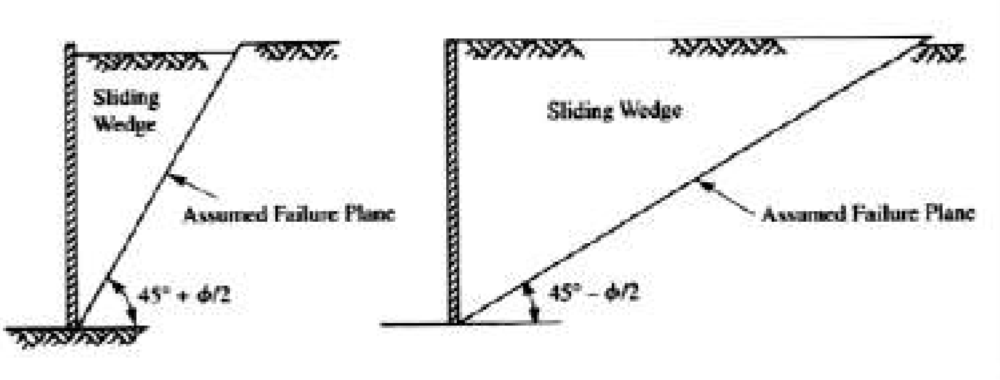


Figure 4.18 Failure mode according to Rankine Theory

Below ground, the soil we are dealing with in our project site is sand. Since our backfill, surface is level, therefore, the active earth pressure coefficient, is given by the formula:

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

The active earth pressure is then computed using the formula:

$$P_a = \frac{1}{2}\gamma H^2 K_a$$

5.6.3 Stability of Retaining Wall

Checking for retaining wall stability is crucial to ensure the safety of people and property, maintain the structural integrity of the wall, and prevent potential failure. The lateral force due to earth pressure constitutes the main force acting on the retaining wall, which might cause it to overturn, slide and settle. So, the safety of the wall depends on its stability against these three modes of failure under the ultimate limit state (EQU, STR, and GEO) as defined in EN1990:2002- Eurocode as shown in Table 4.23.

Table 4.23 Partial safety factor at the ultimate limit state

Persistent or transient design situation	Permanent actions		Loading variable action	Accompanying variable action
	Unfavorable	Favourable	Unfavorable	Unfavourable
For consideration of structural or geotechnical failure: combination 1 (STR & GEO	1.35	1.00	1.50 (0 if favourable)	1.50 (0 if favourable)
For consideration of structural or geotechnical failure: combination 2(STR & GEO)	1.00	1.00	1.30 (0 if favourable)	1.30 (0 if favourable)
For checking static equilibrium (EQU)	1.00	0.90	1.50 (0 if favourable)	1.50 (0 if favourable)

The 3 modes of failure for retaining wall will be further discussed as follows:

1. Overturning Stability

   Retaining wall stability against overturning refers to the ability of the wall to resist the moments generated by the lateral forces acting on it and prevent rotational failure. To ensure stability, the retaining wall must have a sufficient resisting moment provided by the weight of the wall and the foundation. The overturning moment, calculated by multiplying the sum of the lateral forces by their respective lever arms, should be less than the resisting moment. A partial safety factor of 0.9 is applied to the permanent vertical load ΣVk (weight of wall + weight of soil) if its effect is ‘favourable’. The ‘unfavourable’ effects of the permanent earth pressure loading Hk at the rear face of the wall are multiplied by a partial safety factor of 1.1. The 'unfavourable' effects of the variable surcharge loading, if any, are multiplied by a partial safety factor of 1.5. The stability requirement against overturning then becomes:

$$0.9(\Sigma V_{kx}) \geq \gamma_f H_{ky}$$

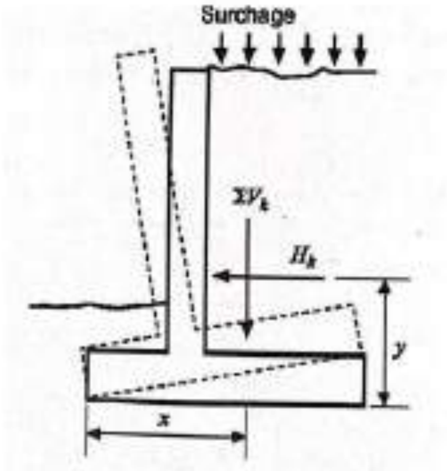


Figure 4.19 An Overturning Failure

2. Sliding Stability

Retaining wall stability against sliding refers to the ability of the wall to resist horizontal movement along its base and maintain its position. Sliding stability is achieved by ensuring that the shear forces acting on the base of the wall are less than the frictional resistance between the wall and the foundation or soil. Since the passive earth pressure came from material backfilled against the retaining wall face, its resistance cannot be guaranteed and is usually ignored. A partial safety factor of γ f = 0.9 is applied to the permanent vertical load ΣVk if its effect is 'favourable' (i.e. contribute to the sliding resistance) and the 'unfavourable' effects of the permanent earth and surcharge pressures at the rear face of the wall are multiplied by a partial safety factor of γ f = 1.35 and

1.5 respectively. Thus, if the coefficient of friction between the base and the soil is μ, the stability requirement against sliding then becomes:

$$\mu(\gamma_f \sum V_k) \geq \gamma_f H_k$$

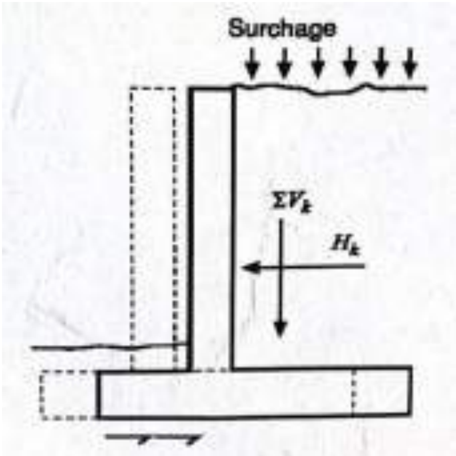


Figure 4.20 A Sliding Failure

3. Bearing capacity stability

Retaining wall stability with respect to bearing capacity and settlement refers to the ability of the wall and its foundation to safely support the vertical loads without excessive soil settlement or foundation failure. It involves ensuring that the foundation soil beneath the wall can withstand the applied loads without experiencing excessive settlement or reaching its bearing capacity. To determine the required size of the base, the bearing pressure underneath it is assessed on the basis of the ultimate limit state (GEO). Since the base slab of the wall is subjected to the combined effects of an eccentric vertical load coupled with an overturning moment, the analysis is similar to that for foundation design. The distribution of bearing pressure will be as shown in Figure 3.21 provided the effective eccentricity; e lies within the middle third of the base. The bearing pressure is then given by,

$$P = \Sigma\mathrm{N}/\mathrm{A} \pm \Sigma\mathrm{M}/\mathrm{Z}$$

Where:

$\Sigma M = \Sigma Ne + \Sigma Hk$

A = Area of base slab

e = eccentricity

Z = Section

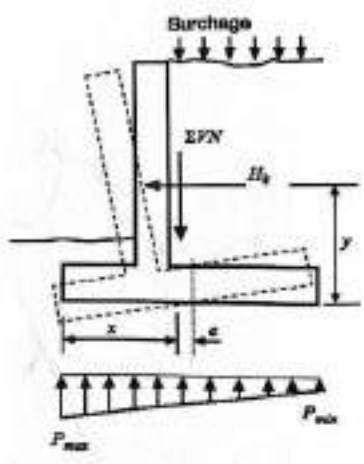


Figure 4.21 A Settlement Failure

5.6.4 Calculation of Stability

For retaining wall design, we use data in borehole 5.

Earth Pressure:

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \frac{1 - \sin 29}{1 + \sin 29} = 0.35$$

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi} = \frac{1 - \sin 29}{1 + \sin 29} = 2.88$$

Element	Force (kN/m)	Total	Level Arm (m)	Moment (kNm/m)
HORIZONTAL				
Active				
P1	0.35 x 10 x 1.5	5.25	4.75	24.94
P2	0.35 x 10 x 4	14	2	28
P3	0.33 x 17 x 0.5 x 1.5 x 1.5	6.69	4.5	30.12
P4	0.35 x 17 x 1.5 x 4	35.70	2	71.40
P5	0.5 x 0.35 x (15.5-9.81) x 4 x 4	15.93	1.33	21..24
P6	4 x 4 x 9.81 x 0.5	78.48	1.33	104.64
	SUM	**156.06**		**280.34**
Passive				

Pp	0.5 x 1.5 x 1.5 x 17 x 3	57.38	0.5	28.69
VERTICAL				
W1	0.5 x (0.4-0.24) x 4.9 x 25	9.8	1.61	15.78
W2	0.24 x 4.9 x 25	29.4	1.78	52.33
W3	0.6 x 4.4 x 25	66	2.2	145.20
W4	5.5 x 17 x 2.5	233.75	2.99	698.91
W5	0.9 x 1.5 x 15.5	20.93	0.75	15.69
	SUM	**359.88**		**927.92**

a) FOS Overturning

$$FOS = \frac{Resisting\ moment}{Disturbing\ moment} = \frac{927.92}{280.34} = 3.31$$

b) FOS Sliding

$$FOS = \frac{R_v \tan\delta + 0.5\ P_p}{R_H} = \frac{359.88 \tan 29 + (0.5\ x\ 57.38)}{156.06} = 1.50$$

c) Base Pressure

$$\bar{x} = \frac{\sum Moment}{R_v} = \frac{972.92 - 280.34}{359.88} = 1.80$$

$$e = \frac{B}{2} = \frac{4.4}{2} = 2.2$$

$$e = 2.2 - 1.8 = 0.4$$

$$q_b = \frac{359.88}{4.4}\left\{1 \pm \frac{6\ x\ 0.4}{4.4}\right\} = 126.40\ and\ 37.18$$

5.6.5 Reinforced Concrete Design of Retaining Wall

SPECIFICATION

(a) Height of slope, h_1 = 4.0 m

(b) Surcharge, w = 10 kN/m^2

(c) Soil Profile:

- Density, γ_s = 17 kN/m
- Internal friction angle, Ø = 29°
- Friction coefficient, μ = 0.5
- Cohesion, c = 10
- Ultimate bearing capacity, q_{rd} = 164.50 kN/m^2

(d) Characteristic strength of concrete, f_{ck} = 20 N/mm^2

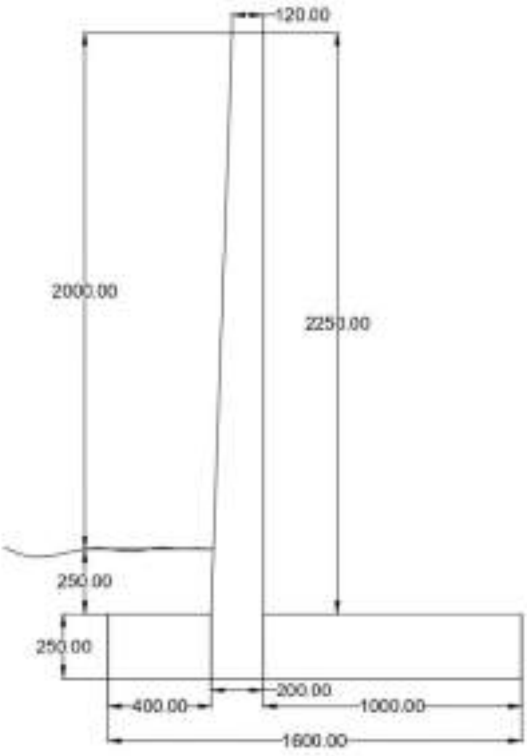
(e) Characteristic strength of steel, f_{yk} = 500 N/mm^2

(f) Unit weight of reinforced concrete, γ_c = 25 kN/m^3

(g) Concrete cover, c = 45 mm

(h) Bar diameter, $Ø_{bar}$ = 12 mm (assumed)

DIMENSION & SOIL PRESSURE



Data:

h_1	=	4000 mm
h_2	=	900 mm
h_3	=	4900 mm
h	=	600 mm
t	=	400 mm
t_c	=	240 mm
a_1	=	1500 mm
a_2	=	2500 mm
B	=	4400 mm

Active Soil Pressure

$P = (\gamma H + w)K_a$

Where, $K_a = \frac{(1-\sin\emptyset)}{(1+\sin\emptyset)}$

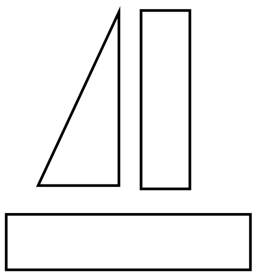
$$K_a = \frac{(1-\sin 29)}{(1+\sin 29)} = 0.35$$

$$P = (17H + 10)\ x\ \ 0.35$$

$$P = 5.95H + 3.5$$

H (m)	p kN/m^2
0	3.5
4.9	32.66
5.5	36.23

STABILITY ANALYSIS

Element	**Load (kN)**	**Level arm**	**Moment (kN/m)**	
			$\curvearrowright$	$\curvearrowleft$
Wall 	(i) $(t - t_c)\ x\ h_3\ x\ \gamma_c/2$ $(0.4 - 0.24)\ x\ 4.9\ x\ 25/2$ = 9.8 (ii) $t_c\ x\ h_3\ x\ a_2$ $0.24\ x\ 4.9\ x\ 25$ = 29.4 (iii) $h\ x\ B\ x\ a_2$ $0.6\ x\ 4.4\ x\ 25$ = 66	1.61 1.78 2.2	15.78 52.33 145.20	
Soil	$\gamma\ x\ h_3\ x\ a_2$ 17 x 4.9 x 2.5 = 208.25	3.15	602.44	
Surcharge	$w\ x\ a_2$ 10 x 2.5 = 25	3.15	78.75	
Active Pressure				

- Surcharge	$3.5\ x\ 5.5$ = 19.25	2.75		52.94
- Soil	$(36.23 - 3.5)\ x\ 5.5/2$ = 90.06	1.83		164.81
Total: Moment, M	Permanent	=	815.75	164.81
	Variable	=	78.75	52.94
Total: Vertical Load, V_k	Permanent	=	313.45	
	Variable	=	25	
Horizontal Load, H_k	Permanent	=	90.06	
	Variable	=	19.25	

a) Stability against overturning (@point A)

- Overturning moment = $(1.1\ x\ 164.81) + (1.5\ x\ 52.94)$
  = 260.70 kNm
- Restraining moment = $(0.9\ x\ 815.75) + (0\ x\ 78.75)$
  = 734.18 kNm

  Overturning moment < Restraining moment OK!

b) Stability against sliding

- Sliding force = $(1.35\ x\ 90.06) + (1.5\ x\ 19.25)$
  = 150.46 kN

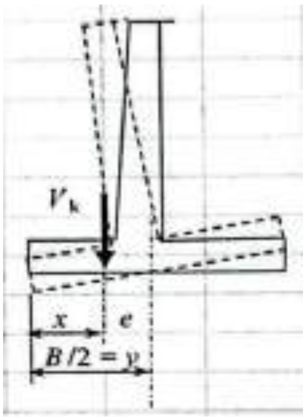
- Friction force = μV_k

$= 0.5\ [(1.0\ x\ 313.45) + ((0\ x\ 25)]$

= 156.73 kN

Sliding force < Friction force OK!

c) Stability against settlement



- $V_k = 313.45 + 25$

  $= 338.45$ kN
- $\Delta M = 815.75 + 78.75 - 764.81 - 52.94$

  $= 676.75$ kNm
- $x = \frac{\Delta M}{V_k} = \frac{676.75}{338.45} = 1.99 \approx 2.0$ m

- $Eccentricity, c = \frac{B}{2} - x$

  $= \frac{4.4}{2} - 2 = 0.2\ m \quad < \quad \frac{4.4}{6} = 0.73$ m
- $A = B\ x\ 1.0$

  $= 4.4\ x\ 1.0 = 4.4\ m^2$
- $y = 2.2\ m$
- $I = 1.0\ x\ \frac{4.4^2}{12} = 7.1\ mm^4$

Bearing Pressure,

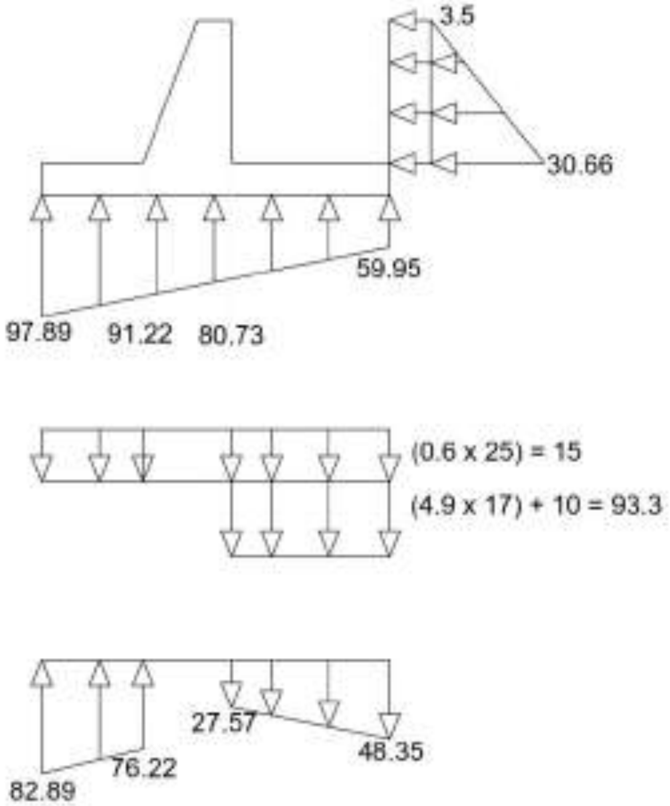
$$q_{ed} = \frac{N}{A} \pm \frac{My}{I}$$

$$= \frac{338.45}{4.4} \pm \left(338.45\ x\ 0.2\ x\ \frac{2.2}{7.1}\right)$$

$$= 97.89\ and\ 55.96\ kN/m^2$$

< 164.50 kN/m^2

ELEMENT DESIGN



Main reinforcement

h	=	600 mm	b	=	2500 mm
f_{ck}	=	30 N/mm^2	f_{yk}	=	500 N/mm^2
$\emptyset_{bar}$	=	12 mm	c	=	45 mm

$d = h - c - \emptyset_{bar}$

$= 600 - 45 - {}^{12}/_{2} = 549\ mm$

i. Wall

M_{ab} = $1.50(3.5\ x\ 4.9\ x\ 4.9/2) + 1.35((32.66 - 3.5)\ x\ (4.9/2)\ x\ (4.9/3))$

= 238.06 kNm/m

K = $M/bd^2 f_{ck}$

= $238.06\ x\ 10^6/2500\ x\ 549^2\ x\ 30$

= 0.011 < 0.167

z = $d\left[0.5+\sqrt{0.25-K/1.134}\right]$
= 0.99 d
A_s = $M/0.87f_{yk}z$
= $238.06\ x10^6\ /0.87\ x\ 500\ x\ 0.99\ x\ 549$ Use: H12-100
= 1007 mm²/m (1131 mm²/m)

ii. Toe

M_{ac} = $1.35(76.22\ x\ 1.5\ x\ 1.5/2)+1.35((82.89-76.22)\ x\ (1.5/2)\ x\ (1.5/3))$
= 119.14 kNm/m
K = M/bd^2f_{ck}
= $119.14\ x\ 10^6/2500\ x\ 549^2\ x\ 30$
= 0.005 < 0.167
z = $d\left[0.5+\sqrt{0.25-K/1.134}\right]$
= 0.99 d
A_s = $M/0.87f_{yk}z$
= $119.14\ x10^6\ /0.87\ x\ 500\ x\ 0.99\ x\ 549$ Use: H12-200
= 503.92 mm²/m (566 mm²/m)

iii. Heel

M_{bd} = $1.35(27.57\ x\ 2.5\ x\ 2.5/2)+1.35((48.35-27.75)\ x\ (2.5/2)\ x\ (2.5/3))$
= 145.53 kNm/m
K = M/bd^2f_{ck}
= $145.53\ x\ 10^6/2500\ x\ 549^2\ x\ 30$
= 0.006 < 0.167
z = $d\left[0.5+\sqrt{0.25-K/1.134}\right]$
= 0.99 d
A_s = $M/0.87f_{yk}z$
= $145.53\ x10^6\ /0.87\ x\ 500\ x\ 0.99\ x\ 549$ Use: H12-175
= 615.54 mm²/m (645 mm²/m)

Minimum and maximum reinforcement area,

$A_{s,min}$ = $0.26(f_{ctm}/f_{yk})bd$

= $0.26(2.9/500)\ x\ 2500\ x\ 549$

= 2069 mm^2/m

$A_{s,max}$ = $0.04\ A_C$

= $0.04\ x\ 2500\ x\ 600$

= 60000 mm^2/m

Secondary bar:
H12-50
(2262 mm^2/m)

<u>Shear</u>

i. Wall

V_{ab} = $1.50(3.5\ x\ 4.9) + 1.35((32.66 - 3.5)\ x\ (4.9/2))$

= 122.17 kN/m

V_{ac} = $1.35(82.89 + 76.22)\ x\ (1.5/2))$

= $238.06\ x\ 10^6/2500\ x\ 549^2\ x\ 30$

= 161.10 kN/m

V_{bd} = $1.35(27.57 + 48.35)\ x\ (2.5/2))$

= 128.12 kN/m

Max. design shear force, V_{Ed} = 161.10 kN/m

Design shear resistance,

$V_{Rd,c}$ = $(0.12k(100\rho_1 f_{ck})^{1/3})bd$

k = $1 + (200/d)^{1/2} \leq 2.0$

= $1 + (200/549)^{1/2}$

= $1.6 \leq 2.0$

ρ_1 = $A_{s1}/bd \leq 0.02$

= $2262/2500\ x\ 549$

= $0.002 \leq 0.02$

$V_{Rd,c}$ = $\left(0.12\ x\ 1.6x(100\ x\ 0.002\ x\ 30)^{1/3}\right)x\ 2500\ x\ 549$

= 478.85 kN

V_{min} = $\left(0.035k^{3/2}{f_{ck}}^{1/2}\right)bd$

$= \left(0.035\ x\ 1.6^{3/2} x\ 30^{1/2}\right) x\ 2500\ x\ 549$

$= 532.5$ kN

So, $V_{Rd,c} > V_{Ed} = 161.10$ kN OK!

Cracking

Steel stress under the action of quasi-permanent loading

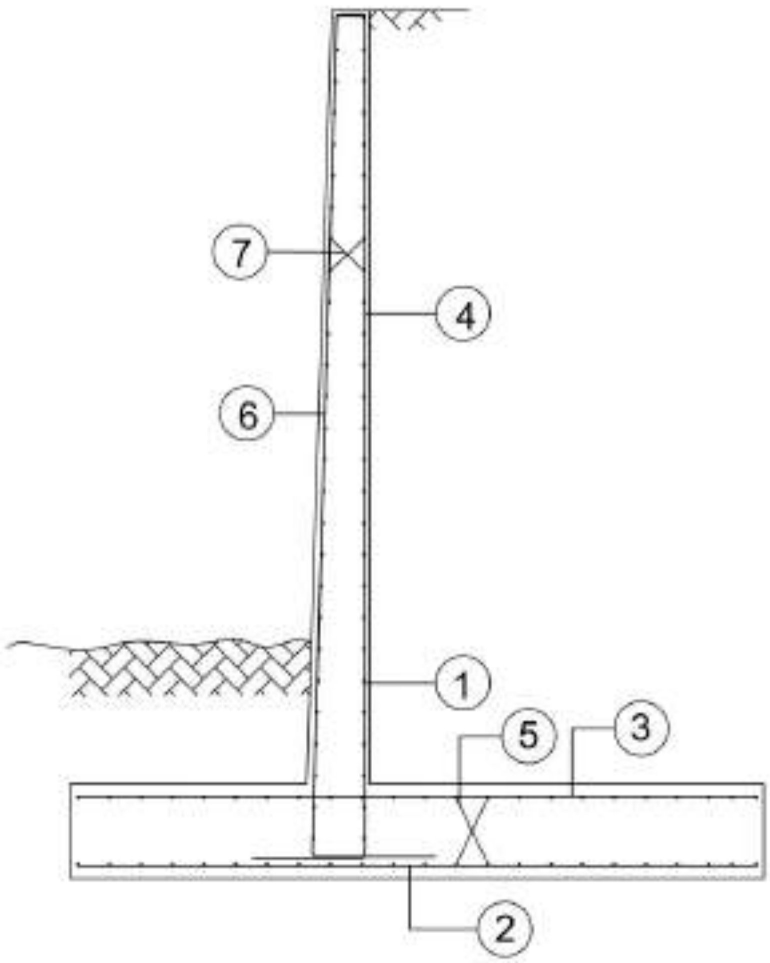
$$f_s = \left(\frac{f_{yk}}{1.15}\right)\left(\frac{N_{quasi-permanent}}{N_{ultimate}}\right)\left(\frac{A_{s,req}}{A_{s,prov}}\right)$$

$$= \left(\frac{500}{1.15}\right)\left(\frac{320.95}{460.66}\right)\left(\frac{1007}{1131}\right) = 269.71\ N/mm^2$$

For design crack width		=	0.3 mm	
Ma. Allowable bar spacing		=	250 mm	
Bar Spacing				
Wall:	100 mm	<	250 mm	OK!
Toe:	200 mm	<	250 mm	OK!
Heel:	175 mm	<	250 mm	OK!

DETAILING

Bar No.	
1.	H12 – 100
2.	H12 – 200
3.	H12 – 175
4.	H12 – 100
5.	H12 – 50
6.	H12 – 50
7.	H12 - 50
Cover	= 45 mm



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UNIVERSITI TEKNOLOGI MALAYSIA

SEAA4032 | INTEGRATED DESIGN PROJECT 2
SEMESTER SESSION 2023/2024-1

SEWERAGE DEPARTMENT

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CHAPTER 6

DRAINAGE DEPARTMENT

6.1 Introduction

Sewage systems are considered critical infrastructures during the construction of residential, industrial, or commercial projects due to their immediate influence on the quality of life in a community. Sludge processing plants, pumping stations, sewage treatment facilities, and underground sewer pipelines comprise it. It consists of an intricate network of pipelines, each with a unique diameter and length. The transportation of wastewater treatment services for residential, commercial, industrial, and domestic use requires these conduits. The effluent will be transported to an outlet or sewage treatment facility via pumps or gravity. Environmental and public health protection are reliant on the sewage system. Integrated sewer systems and separate sewer systems are the two varieties of sewer systems.

A separate sewer system consists of two sets of sewers: one is designated for the conveyance of stormwater or precipitation, while the other is used to transport domestic or industrial sanitary sewage. Sewage is transported to the treatment facility via the first set of sewers, whereas stormwater or precipitation is delivered untreated to a natural stream or river via the second set of sewers. A combined sewer system, on the other hand, transports stormwater or precipitation, industrial sewage, and domestic or sanitary sewage through a single network of sewers. As a result, stormwater or precipitation is conveyed alongside effluent to a sewage treatment facility for ultimate disposal.

The efficacy of the sewage system is influenced by the passage of wastewater. During the design phase, the pipe type and size utilized in a sewage system must be sufficient to accommodate the system's peak discharge. The population equivalent, which is a direct estimation of the population in a given area, is used to compute peak flow. Sewer planning in Malaysia is governed by a set of standards and eligibility requirements. Based on the British Standard BS 8005:1987, the Malaysian Standard Code of Practice for Sewage Design (MS 1228:1991) was established.

The potential lack of applicability of the British Standard in Malaysia can be attributed to climate and seasonal factors that directly influence peak flow. This study's primary objective is to determine whether the standard is suitable for implementation in Malaysia.

6.2 Overview

The population equivalent (PE) of each zone must first be calculated using an estimate of the number of staff members per building in order to satisfy the objectives. The kind of sewage treatment plant (STP) and land requirement can be determined using the PE obtained. In order to ensure accuracy and guard against data loss, extensive computations on the manhole and sewerage system design were then carried out using Microsoft Excel. Lastly, to confirm precise measurements, a detailed drawing of the planned sewerage system was manually made using Autodesk AutoCAD. The given manuals and references serve as the foundation for all computations and considerations.

6.3 Objective

- To understand and implement the foundational principles necessary for the design of a sewerage system in the designated area, including the determination of the sewer conduit size and placement.

- To ascertain the sewerage system's optimal and most cost-effective diameter for sewerage purposes.

- To determine the population equivalent (PE) in order to determine the appropriate sizing of the sewage system and its constituent parts, including pipelines and pumps, in order to guarantee that the system possesses sufficient capacity to manage the projected wastewater flow and avert complications such as overflow.

- To ascertain the manhole locations and sewer pipe alignments.

6.4 Methodology

To meet the goals, the population equivalent (PE) of each zone must first be computed based on an estimate of the number of staff per building. The PE acquired can be used to calculate the type of sewage treatment plant (STP) and the amount of land required. Following that, thorough calculations on the manhole and sewerage system design were performed on Microsoft Excel to assure precision and protect against data loss. Finally, a detailed drawing of the intended sewerage system was created manually using Autodesk AutoCAD to verify accurate measurements. All calculations and considerations are based on the manuals and references that have been provided.

6.5 Manual and References

Design of sewerage system must comply with:

1. Malaysia Sewerage Industry Guidelines (MSIG) (Volume 4 – Sewage Treatment Plants)
2. Malaysia Sewerage Industry Guidelines (MSIG) (Volume 3 – Sewer Networks & Pump Stations)
3. MS 1228: 1991 Code of Practice for Design and Installation of Sewerage System
4. Sewerage Policy for New Developments (Volume 1)

6.6 Design Consideration

Sewage system design is a multifaceted undertaking that necessitates the incorporation of numerous factors to guarantee the system's effectiveness, security, and sustainability. The design procedure commences with a site investigation and assessment, during which the design team performs an exhaustive analysis of the system's intended service area. Population density, projected growth, commercial and industrial activities, topography, soil conditions, weather patterns, and extant infrastructure are all factors that the team takes into account.

The scope of work that was involved in designing this sewerage system was determined. earlier before starting this project. The basic scope of work for developing the sewerage.

1. Find the optimal location of the Sewage Treatment Plant (STP)
2. Classify the STP(s) in accordance with the classes and justify the appropriate treatment system to be utilized based on the computed population equivalent (PE).
3. Design the sewer network to transport sewage from every site to the STP(s) on the plan layout. Place all manhole locations on the layout.
4. Calculate and produce a table with all the design's specifics in it.
5. Outline the sewer system's longitudinal section. (Select the sewer line that is the longest from the line's starting to the STP).
6. Display detailed drawings of various manhole types, together with bedding, manhole coverings, connections, and other pertinent information.

6.7 Location of STP

For location of STP, there are a few considerations to locate the STP which are:

1. It must be about 30m from residential areas.
2. It must have access to plants and land availability.
3. The topography, which is the lowest level to permit gravity flow from the sewer.
4. Soil characteristics.
5. Must have a power supply.
6. Buffer zone considering

Fig 6.1 STP Location

6.8 Population Equivalent (PE)

Sewage treatment facilities are occasionally classified according to the population equivalents (PE) that represent their design capacities. The appropriate classification and PE recommended for each premise are as follows:

Type of Premise	Population Equivalent
Residential	5 per house
Commercial	3 per 100 m2 gross area
School: - Day School - Fully residential	0.2 per non-residential student 1 per residential student
Hospitals	4 per bed
Hotel with dining and laundry facilities	4 per room
Factories, excluding process water	0.3 per staff
Market (Wet Type)	3 per stall
Market (Dry Type)	1 per stall
Petrol Station	15 per toilet
Bus Terminal	4 per bus bay
Taxi Terminal	4 per taxi bay
Church/Temple	0.2 per person
Mosque	0.5 per person
Stadium	0.2 per person

Swimming Pool	0.5 per person
Public Toilet	1.5 per toilet
Airport	0.2 per passenger/day 0.3 per employee
Laundry	10 per machine
Prison	1 per person
Golf Course	20 per hole

6.8.1 Calculation of PE

Qty of promise x Population Equivalent (based on table) = Actual PE

SAMPLE

Semi-Detached House

Qty of promise x Population Equivalent (based on table) = Actual PE

From Manhole 22 to 23, quantity of houses is 5, so PE from MH22 to MH23:
5 unit x 5 PE/unit = 25 PE

6.8.2 Total PE Calculation

Type of premises	Quantity	PE	Unit/per	Population Equivalent
Semi-Detached House	654	5	staff	3270
Electrical Power Supply Provider	10	0.3	staff	3
Musholla	50	0.5	person	25
Community Hall	23	3	100m2	69
Pre-School	100	0.2	student	20
TOTAL Q	**837**		**TOTAL PE**	3387

This project will include one sewage treatment plant (STP) in the layout. The total population equivalent (PE) for this project is calculated in the table and comes out to be 3361 (Zone A) The STP is classified as Class 2 under the Environmental Equipment Act of 3076 m2, as the PE ranges from 1001 to 5001.

Classification	**PE**
Class 1	<1000
Class 2	1001-5000
Class 3	5001-20000
Class 4	>20000

Table 6.1 PE Classification

Population Equivalent	Area Requirement	
	(m^2)	(acre)
5001	3076	0.76
6000	4006	0.99
7000	4897	1.21
8000	5908	1.46
9000	6920	1.71
10 000	7810	1.93
15 000	9996	2.47
20 000	11 938	2.95

Table 6.2 Area Requirement to sustain Population Equivalent

The table presents the recommended amount of land needed for Class 2 with a population equivalent of 3387. This is equivalent to 3076 square meters or 0.76 acres. The area does not include the 30m buffer zone around the facility but does include necessary setbacks and paths within the plant. These requirements ensure that the facility produces effluent that meets discharge regulations. It is important to include appropriate buffers in the planning process to prevent potential complaints about the plant's location. The effluent from the STP will be discharged into a nearby water body, such as a river.

6.9 Sewer Network Layout

Fig 6.2 Sewer Layout Network

6.10 Design Calculation

6.10.1 Hydraulic Design

To calculate the flow rate (Qavg), peak flow factor (PFF) and peak flow (Qpeak), the equations below will be used to estimate the sewage quantity flow to each STP:

Q_{avg} = Design Flow Rate x PE

PFF = 4.7 x $p^{-0.11}$

Q_{peak} = PFF x Average Daily Flow

6.10.2 Manning's Formula

The flow velocity through the sewer pipes can be determined using the Manning's formula as displayed below. The table below can be used to select the Manning's coefficient,n, based on the type of material being used.

$$V = \frac{R^{\frac{2}{3}}\sqrt{S}}{n}$$

Where,

V = Velocity of flow in the sewer, m/s

A = Cross section area of flow, m2

R = Hydraulic Radius, m = A/P

P = Wetted perimeter

n = roughness coefficient, depends on the type of materials

6.10.3 Detailed Calculation

For demonstration purposes, we will perform a sample calculation from Manhole 57 to Manhole 58.

Sample Calculation of Peak Flow

Pipe Information:

Type of Pipe Material = VCP

Manning Coefficient, n = 0.014 (assuming good condition)

Pipe Diameter, D = 225mm

Gradient, S = 100m/m

Total PE = No. of unit x No. of Staff per unit

= 7*5 = 35

Cumulative PE = 2275.00

Peak Flow Factor, PFF = $-4.7(PE/1000)^{-0.11}$

= 4.3

Flow Average, Q_{avg} = PE x 0.225

= 2275*0.225 = 511.8750m^3/day = 0.0059m^3/s

Peak Flow, $Q_{peak} = Q_{avg}$ x PFF

= 0.0059 * 4.3 = 0.0254

6.10.4.1 Sample Calculation of Pipe Size Determination

Pipe Surface Area = $\pi D^2/4$

= $\pi(0.225m)^2/4 = 0.0398m^2$

Wetted Perimeter = $\pi D = \pi(0.225m) = 0.7070m$

Hydraulic Radius, $R = A/P = 0.0398m^2/0.7070m = 0.05625m$

Pipe Velocity, $V = (R^{2/3}S^{1/2})/n$

$= ((0.05625^{2/3}*(0.007^{1/2})/0.014$

= 0.8562m/s

Pipe Capacity, Q = A*V

= 0.8562m/s*0.0398m^2

= 0.0340m^3/s

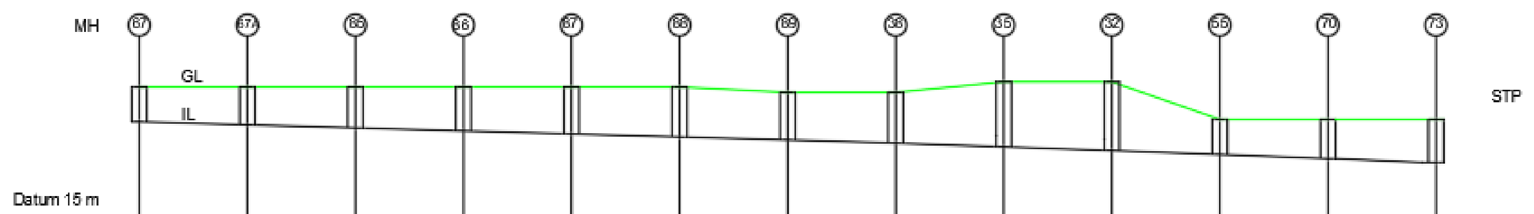
6.10.4.2 Sample Calculation of Manhole Depth Determination

For initial pipe, we will start from MH56
Length of pipe MH1-MH2, L = 100m
Gradient, S = 1/150 = 0.007
Ground Level, GL of 1st MH = 39.0m
Depth of 1st MH = 2.092
Fall = L x S = 100m*0.007 = 0.667
Invert Level, IL 1st MH = GL - Depth of 1st Manhole - Pipe Size
= 39 - 1.2 - 0.225
= 37.58m

Ground Level, GL 2nd MH = 39m
Invert Level, IL2nd MH = IL 1st MH - Fall = 37.58m - 0.667m
= 36.91m
Depth of 2nd Manhole = GL 2nd MH - IL 2nd MH
= 39.0m - 36.91m
= 2.092m > 1.2m (OK!)

6.11 Longitudinal Section

Longitudinal Section D 225



Ground level (m)	36.00	36.00	36.00	36.00	36.00	36.00	36.00	41.00	41.00	39.00	36.00	36.00	36.00
Pipe Diameter (mm)	250	250	250	250	250	250	250	250	250	250	250	250	250
Change (m)	60.00	60.00	55.00	45.00	40.00	60.00	60.00	55.00	60.00	60.00	40.00	50.00	0.00
Depth (m)	2.59	2.94	3.26	3.62	3.76	4.11	4.46	7.76	6.10	6.70	6.10	6.60	6.60
Invert level (m)	35.4	35.0	34.7	34.5	34.2	33.9	33.5	33.2	32.9	32.3	31.9	31.4	31.4

Fig 6.3 Longitudinal Section for Manhole with Diameter of 225mm

6.12 Manhole

A manhole, also known as a maintenance hole, is a vertical access point in a sewerage system that allows maintenance personnel to enter and inspect the system. Manholes are typically located at regular intervals along the length of the sewer pipes, and they provide access to the pipes, pumps, and other infrastructure within the system.

Manholes typically consist of a circular or rectangular-shaped concrete structure, with a removable cover that can be locked or unlocked to provide access to the system. They are typically located at the bottom of a shaft, which allows maintenance personnel to safely enter and exit the system. Overall, the design of manholes is an important aspect of a sewerage system, and it plays a crucial role in ensuring the efficient and safe operation of the system. There are several to be considered regarding manholes, such as:

a) Location
b) Accessibility
c) Size and capacity
d) Safety
e) Durability

Manholes permit inspection and cleaning of sewers and removal of obstruction. Total of manholes constructed in this sewer network are 75 manholes. The location of manholes should propose to: -

- Every change in direction
- Every change in gradient (top and bottom location)
- Every change in diameter of the pipe
- At intersection and junctions

- Difference distance between manhole should less or equal to 100 m for maintenance purpose.

For our design project, the manhole is located according above propose. The minimum diameter of manhole chambers constructed from pre-cast concrete rings shall be as given in Table below:

Depth to Soffit from Cover Level (m)	DN Largest Pipe in Manhole (mm)	Min. Internal Dimensions* (mm)
< 1.5	< 150	1000
	225 to 300	1200
	375 to 450	1350
	525 to 710	1500
	820 to 900	1800
	> 900	Subject to designer's requirements based on site condition
≥ 1.5	≤ 300	1200
	375 to 450	1350
	525 to 710	1500
	820 to 900	1800
	> 900	Subject to designer's requirements based on site condition

Table 6.4 Minimum diameter of manhole chambers constructed from pre-cast concrete rings

6.12.1 Types of Manhole

- Shallow Manhole

Shallow Manhole is a manhole that has a constant diameter or same crosssection throughout. As stated in MS 1228: 1991 Clause 4.5.6, where the topography results in a shallow manhole that is in the depth of invert of sewer being from 0.75 m to 0.9m, a manhole of at least 1.0 mm in internal horizontal dimension and a clear opening of at least 900 mm shall be used.

- Normal Manhole

Normal Manhole is a manhole that has a constant diameter or same cross section throughout. The topography results in a normal manhole that is in the depth of invert level of sewer being from 0.9 m to 2 m.

- Deep Manhole

Deep manhole is a manhole with an access shaft of a smaller diameter or plan size than the main shaft. As stated in MS 1228: 1991 Clause 4.5.5, where the deep manhole is required, its internal dimension must be more than 2 meter and the manhole may be tapered upwards to a section with a minimum internal dimension of 0.75 meters.

- Drop Manhole

Drop manhole is a shaft in which sewage is dropped from a higher to a lower level. Based on MS 1228: 1991 Clause 4.5.7, if an incoming sewer is higher than the outgoing sewer by 600 mm or more, a drop manhole shall be used. But, if the difference in elevation between the incoming sewer and manhole invert is less than 600 mm, the invert shall fillet at the corners to prevent solids deposition. In the other terms, drop manhole also known as tumbling basin. It is used when a sewer enters a manhole at an elevation considerably higher than the outgoing pipe, generally it is not satisfactory to let the stream merely pour into the manhole because the structure does not provide an acceptable working space.

6.12.2 Material Specification

Bedding

Bedding is needed to maintain the pipe in proper alignment and sustain the weight of soil above the sewer and any superimposed load, especially when the sewer is buried under the roads with heavy vehicles moving through. Based on MS 1228: 1991, Clause 4.3.4.5, bedding can be divided into two class types which are:

Class A bedding:

Class A bedding made out of a pipe covered by layer of aggregates or crushed stone at the bottom and concrete layer at the top of the pipe. The strength of Class A bedding is high, and it is able to sustain high load from roadway. Concrete is casted above the pipe with thickness of 100mm. Beside that, it has high strength and able to resist high loads and normally, used for sewers under main roads.

Class B Bedding:

Class B bedding made out of a pipe covered by layer of aggregates or crushed stone at the bottom and layer of soil with the thickness more than 300 mm. The soil layer needs to be compacted. It is used in the road that do not need to carry high load and pressure, which is at the roadside, back lane, etc.

In this project, two different types of bedding will be employed. Class A bedding will be utilized for pipes situated in the front area of the industrial area, while Class B bedding will be employed for pipes located in the rear area of the industrial area. Moreover the place of bedding is also determined using the traffic calculation from our road department in the project.

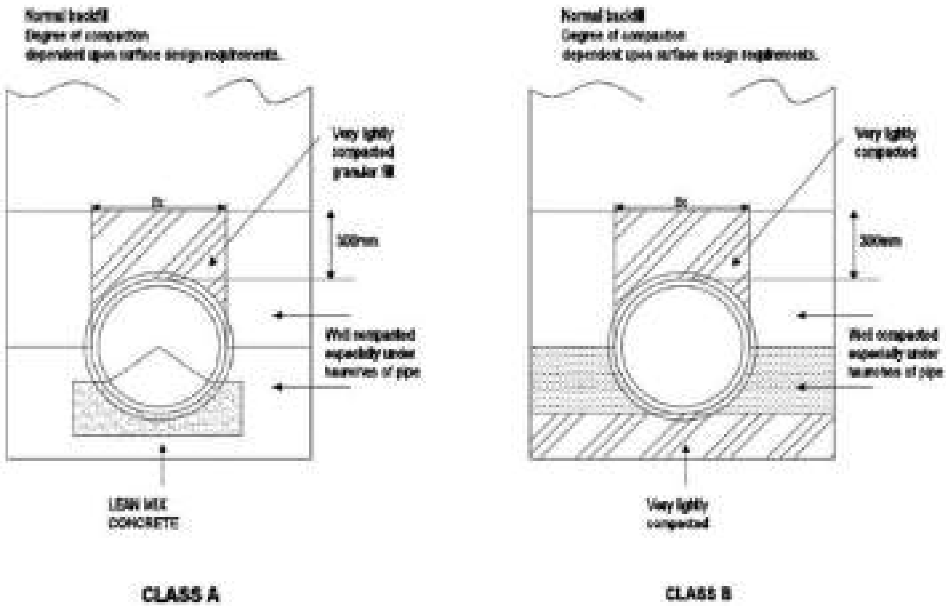


Fig 6.4 Types of manhole bedding

6.13 Pipe

Choice of material, based on:

- Life expectancy
- Previous local experience
- resistance to internal and external corrosion and abrasion
- Roughness coefficient
- Structural strength
- Cost of supply, transport, and ease of installation
- Local availability

Types of Pipe Material

- Vitrified Clay Pipe (VCP)
- Reinforced Concrete Pipe
- Cast Iron
- Asbestos Cement
- Fabricated Steel with Sulphate Resistance Cement Lining
- Plastic: UPVC, HDPE, PE, PP

The VCP pipe will be used in designing our system due to:

- Most gravity sewers use this type of pipe.
- Clay pipes have safe crushing test strengths.
- Have a flexible joint.
- Chemical resistance

VCP products use clay as a major component in its production, making its raw materials environmentally friendly. VCP's resistance to a wide variety of acids besides hydrofluoric acid make it a long-lasting choice for use in underground sewers.

The design of our project ensures that the sewage will naturally flow through the pipes by gravity, as the levels have been carefully planned to go from the highest point to the lowest point where the sewage treatment plant is located. The slope of the pipes is based on the overall elevation of the project. Additionally, to keep costs low, the use of sewage pumps should be avoided, as they can greatly increase expenses related to purchasing, upkeep, and labor. Using gravity as the method of flow is also the most eco-friendly option

Fig 6.5 Vitrified Clay Pipe (VCP)

6.14 Conclusion

In conclusion, A complex process is involved in designing and building a sewerage system, and many factors must be considered to make sure it is effective, secure, and long lasting. The design process is divided into several phases, beginning with conceptual design, site investigation and assessment, feasibility study, design development, cost estimation, permitting and approvals, awarding of the contract through bidding, construction oversight, commissioning, start-up, operation, and maintenance.

Manholes are a crucial part of a sewerage system because they allow access for maintenance and inspections and are crucial to the system's effective and secure operation. Location, accessibility, size and capacity, safety, durability, compliance with regulations, cost-effectiveness, future expansion, and environmental impact are just a few of the elements that need to be considered when designing manholes.

According to the Environmental Equipment Act of 1974, the STP used in this project falls into Class 2 as the PE ranges from 1001 to 5000. With an equivalent population of 3387, Class 2 will require the recommended amount of land. Thus, this is equivalent to the minimum requirement of 0.76 acres or 3076 square meters. Moreover, the STP size that has been taken is 3800 square meters with a buffer zone around 40 meters from the nearest unit. This project includes two pipe design trials. The first trial began with a pipe of 225mm diameter, and the second trial began with a pipe of 250mm diameter. The pipe design criteria will examine four major areas. The design check looks at pipe velocity, flow discharge, fall, and pipe depth. The gradient used in the first design stage is 1:150. Both trials met the requirement with the use of this gradient, so the manhole with the smaller diameter was used. In this case, as both trials passed, the diameter used is 225mm for the manhole.

Finally, the objectives of this project were achieved by determining the size of sewer pipes and identifying their proper locations. We also calculated the total PE 3387, to size the sewerage system including the pipes, to ensure the pipe has enough capacity to carry the flow of wastewater. Lastly, the number of manholes identified are 93 with distance in between is less than 100m.

6.15 Excel Data Sewerage Group 28

Semi-Detached House	654	5	staff	3270
Electrical Power Supply Provider	10	0.3	staff	3
Musholla	50	0.5	person	25
Community Hall	23	3	100m2	69
Pre-School	100	0.2	student	20
TOTAL Q	**837**		**TOTAL PE**	3387

Table 6.4. PE Calculation

	Manhole		Quantity	PE Factor	PE	∑Quantity	∑PE	DWF(m3/D)	PFF	Qpeak
	From	to								
ZONE A		1	4.0	5.0	20.0	4.0	20.0000	0.0001	7.2	0.0004
	1	**2**	4.0	5.0	20.0	8.0	40.0000	0.0001	6.7	0.0007
	3	4	10.0	5.0	50.0	18.0	90.0000	0.0002	6.1	0.0014
	4	**5**	10.0	5.0	50.0	28.0	140.0000	0.0004	5.8	0.0021
	6	7	6.0	5.0	30.0	34.0	170.0000	0.0004	5.7	0.0025
	7	8	12.0	5.0	60.0	46.0	230.0000	0.0006	5.5	0.0033
	8	**9**	9.0	5.0	45.0	55.0	275.0000	0.0007	5.4	0.0039
	10	11	12.0	5.0	60.0	67.0	335.0000	0.0009	5.3	0.0046

	11	12	11.0	5.0	55.0	78.0	390.0000	0.0010	5.2	0.0053
	12	**13**	11.0	5.0	55.0	89.0	445.0000	0.0012	5.1	0.0060
ZONE B	**14**	15	10.0	5.0	50.0	99.0	495.0000	0.0013	5.1	0.0065
	15	16	10.0	5.0	50.0	109.0	545.0000	0.0014	5.0	0.0071
	16	**17**	12.0	5.0	60.0	121.0	605.0000	0.0016	5.0	0.0078
	18	19	10.0	5.0	50.0	131.0	655.0000	0.0017	4.9	0.0084
	19	20	10.0	5.0	50.0	141.0	705.0000	0.0018	4.9	0.0090
	20	**21**	12.0	5.0	60.0	153.0	765.0000	0.0020	4.8	0.0096
	22	23	5.0	5.0	25.0	158.0	790.0000	0.0021	4.8	0.0099
	23	24	5.0	5.0	25.0	163.0	815.0000	0.0021	4.8	0.0102
	24	**25**	6.0	5.0	30.0	169.0	845.0000	0.0022	4.8	0.0105
ZONE C	**2**	2A	3.0	5.0	15.0	172.0	860.0000	0.0022	4.8	0.0107
	2A	**26**	4.0	5.0	20.0	176.0	880.0000	0.0023	4.8	0.0109
	5	5A	7.0	5.0	35.0	183.0	915.0000	0.0024	4.7	0.0113
	5A	**27**	6.0	5.0	30.0	189.0	945.0000	0.0025	4.7	0.0116
	9	28	11.0	5.0	55.0	200.0	1000.0000	0.0026	4.7	0.0122
	13	29	9.0	5.0	45.0	209.0	1045.0000	0.0027	4.7	0.0127

	26	27	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127
	27	28	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127
	28	**29**	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127
ZONE D	**17**	30	13.0	5.0	65.0	222.0	1110.0000	0.0029	4.6	0.0134
	30	31	13.0	5.0	65.0	235.0	1175.0000	0.0031	4.6	0.0141
	31	**32**	14.0	5.0	70.0	249.0	1245.0000	0.0032	4.6	0.0149
	21	33	12.0	5.0	60.0	261.0	1305.0000	0.0034	4.6	0.0155
	33	34	12.0	5.0	60.0	273.0	1365.0000	0.0036	4.5	0.0161
	34	**35**	12.0	5.0	60.0	285.0	1425.0000	0.0037	4.5	0.0168
	25	36	6.0	5.0	30.0	291.0	1455.0000	0.0038	4.5	0.0171
	36	37	6.0	5.0	30.0	297.0	1485.0000	0.0039	4.5	0.0174
	37	**38**	5.0	5.0	25.0	302.0	1510.0000	0.0039	4.5	0.0177

	38	35	0.0	5.0	0.0	302.0	4867.0000	0.0127	3.9	0.0501
	35	**32**	0.0	5.0	0.0	302.0	6112.0000	0.0159	3.9	0.0613
ZONE E	**39**	40	5.0	5.0	25.0	307.0	1535.0000	0.0040	4.5	0.0179
	40	41	5.0	5.0	25.0	312.0	1560.0000	0.0041	4.5	0.0182
	41	42	5.0	5.0	25.0	317.0	1585.0000	0.0041	4.5	0.0184
	42	**43**	3.0	5.0	15.0	320.0	1600.0000	0.0042	4.5	0.0186
	44	45	15.0	5.0	75.0	335.0	1675.0000	0.0044	4.4	0.0194
	45	46	15.0	5.0	75.0	350.0	1750.0000	0.0046	4.4	0.0201
	46	**47**	14.0	5.0	70.0	364.0	1820.0000	0.0047	4.4	0.0209
	48	49	13.0	5.0	65.0	377.0	1885.0000	0.0049	4.4	0.0215
	49	50	13.0	5.0	65.0	390.0	1950.0000	0.0051	4.4	0.0222
	50	**51**	14.0	5.0	70.0	404.0	2020.0000	0.0053	4.4	0.0229

	52	53	6.0	5.0	30.0	410.0	2050.0000	0.0053	4.3	0.0232
	53	54	6.0	5.0	30.0	416.0	2080.0000	0.0054	4.3	0.0235
	54	**55**	7.0	5.0	35.0	423.0	2115.0000	0.0055	4.3	0.0238
	29	43	5.0	5.0	25.0	428.0	2140.0000	0.0056	4.3	0.0241
	43	47	5.0	5.0	25.0	433.0	2165.0000	0.0056	4.3	0.0243
	47	51	5.0	5.0	25.0	438.0	2190.0000	0.0057	4.3	0.0246
	51	**55**	3.0	5.0	15.0	441.0	2205.0000	0.0057	4.3	0.0247
	32	**55**	0.0	5.0	0.0	441.0	10457.0000	0.0272	3.6	0.0989
ZONE F	**56**	57	7.0	5.0	35.0	448.0	2240.0000	0.0058	4.3	0.0251
	57	58	7.0	5.0	35.0	455.0	2275.0000	0.0059	4.3	0.0254
	58	**59**	8.0	5.0	40.0	463.0	2315.0000	0.0060	4.3	0.0258
	60	61	14.0	5.0	70.0	477.0	2385.0000	0.0062	4.3	0.0265

	61	62	14.0	5.0	70.0	491.0	2455.0000	0.0064	4.3	0.0272
	62	**63**	16.0	5.0	80.0	507.0	2535.0000	0.0066	4.2	0.0280
	64	65	7.0	5.0	35.0	514.0	2570.0000	0.0067	4.2	0.0284
	65	65A	7.0	5.0	35.0	521.0	2605.0000	0.0068	4.2	0.0287
	65A	66	7.0	5.0	35.0	528.0	2640.0000	0.0069	4.2	0.0290
	66	**67**	1.0	5.0	5.0	529.0	2645.0000	0.0069	4.2	0.0291
	59	63	0.0	5.0	0.0	529.0	2645.0000	0.0069	4.2	0.0291
	63	**67**	0.0	5.0	0.0	529.0	2645.0000	0.0069	4.2	0.0291
ZONE G	**68**	69	8.0	5.0	40.0	537.0	2685.0000	0.0070	4.2	0.0295
	69	70	2.0	5.0	10.0	539.0	2695.0000	0.0070	4.2	0.0296
	55	**70**	0.0	5.0	0.0	539.0	13152.0000	0.0343	3.5	0.1212
	71	72	10.0	5.0	50.0	549.0	2745.0000	0.0071	4.2	0.0301

	72	**73**	10.0	5.0	50.0	559.0	2795.0000	0.0073	4.2	0.0306
	70	73	0.0	5.0	0.0	559.0	2795.0000	0.0073	4.2	0.0306
	74	75	9.0	5.0	45.0	568.0	2840.0000	0.0074	4.2	0.0310
	75	**76**	15.0	5.0	75.0	583.0	2915.0000	0.0076	4.2	0.0317
	77	78	13.0	5.0	65.0	596.0	2980.0000	0.0078	4.2	0.0323
	78	**79**	13.0	5.0	65.0	609.0	3045.0000	0.0079	4.2	0.0330
	80	81	11.0	5.0	55.0	620.0	3100.0000	0.0081	4.1	0.0335
	81	**82**	11.0	5.0	55.0	631.0	3155.0000	0.0082	4.1	0.0340
	82	79	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340
	79	76	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340
	76	**73**	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340

	73	**STP**	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340
ZONE H	**83**	84	11.0	5.0	55.0	642.0	3210.0000	0.0084	4.1	0.0346
	84	**85**	0.0	5.0	0.0	642.0	3210.0000	0.0084	4.1	0.0346
	67	67A	6.0	5.0	30.0	648.0	3240.0000	0.0084	4.1	0.0348
	67A	85	6.0	5.0	30.0	654.0	3270.0000	0.0085	4.1	0.0351
	85	86	10.0	0.3	3.0	664.0	3243.0000	0.0084	4.1	0.0349
	86	87	50.0	0.5	25.0	714.0	3268.0000	0.0085	4.1	0.0351
	87	88	23.0	3.0	69.0	737.0	3337.0000	0.0087	4.1	0.0358
	88	89	0.0	0.0	0.0	737.0	3337.0000	0.0087	4.1	0.0358
	89	**38**	100.0	0.2	20.0	837.0	3357.0000	0.0087	4.1	0.0360
	93.0		837.0		3387.0			0.521	426.0	2.190
	Manholes		Units		m3/D					

Table 6.5. Flow Rate Calculations

Table 6.6 Detail Calculations for pipe diameter 225mm

Zone	Manhole From	Manhole to	Quantity	PE Factor	PE	∑Quantity	∑PE	DWF(m3/D)	PFF	Qpeak	Diameter (mm)	Area	Perimeter	R=A/P	n	Grad, m	1/Grad	Velocity of pipe	Check Vpipe	Qpipe	Check Q	Length	Fall	R level	Inv Level	Depth	Check Depth	type bedding
ZONE A		1	4.0	5.0	20.0	4.0	20.0000	0.0001	0	0	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	0	0.000	45.0	43.55	1.450	OK	Normal Manhole
	1	2	4.0	5.0	20.0	8.0	40.0000	0.0001	6.7	0.0007	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	45.0	42.55	2.450	OK	Deep Manhole
	3	4	10.0	5.0	50.0	18.0	90.0000	0.0002	6.1	0.0014	250.0	0.0491	0.7855	0.0625	0.014	70	0.014	1.3445	OK	0.0660	OK	80	1.143	45.0	43.55	1.450	OK	Normal Manhole
	4	5	10.0	5.0	50.0	28.0	140.0000	0.0004	5.8	0.0021	250.0	0.0491	0.7855	0.0625	0.014	70	0.014	1.3445	OK	0.0660	OK	80	1.143	45.0	42.41	2.593	OK	Deep Manhole
	6	7	6.0	5.0	30.0	34.0	170.0000	0.0004	5.7	0.0025	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	45.0	43.55	1.450	OK	Normal Manhole
	7	8	12.0	5.0	60.0	46.0	230.0000	0.0006	5.5	0.0033	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	45.0	42.75	2.250	OK	Deep Manhole
	8	9	9.0	5.0	45.0	55.0	275.0000	0.0007	5.4	0.0039	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	70	0.700	45.0	42.05	2.950	OK	Deep Manhole
	10	11	12.0	5.0	60.0	67.0	335.0000	0.0009	5.3	0.0046	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	80	0.889	45.0	43.55	1.450	OK	Normal Manhole
	11	12	11.0	5.0	55.0	78.0	390.0000	0.0010	5.2	0.0053	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	80	0.889	45.0	42.66	2.339	OK	Deep Manhole
	12	13	11.0	5.0	55.0	89.0	445.0000	0.0012	5.1	0.0060	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	70	0.778	45.0	41.88	3.117	OK	Deep Manhole
ZONE B	14	15	10.0	5.0	50.0	99.0	495.0000	0.0013	5.1	0.0065	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	43.0	41.55	1.450	OK	Normal Manhole
	15	16	10.0	5.0	50.0	109.0	545.0000	0.0014	5.0	0.0071	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	43.0	40.75	2.250	OK	Deep Manhole
	16	17	12.0	5.0	60.0	121.0	605.0000	0.0016	5.0	0.0078	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	60	0.600	43.0	40.15	2.850	OK	Deep Manhole
	18	19	10.0	5.0	50.0	131.0	655.0000	0.0017	4.9	0.0084	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	80	0.889	43.0	41.55	1.450	OK	Normal Manhole
	19	20	10.0	5.0	50.0	141.0	705.0000	0.0018	4.9	0.0090	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	80	0.889	43.0	40.99	2.006	OK	Deep Manhole
	20	21	12.0	5.0	60.0	153.0	765.0000	0.0020	4.8	0.0096	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	45	0.500	43.0	40.49	2.506	OK	Deep Manhole
	22	23	5.0	5.0	25.0	158.0	790.0000	0.0021	4.8	0.0099	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	43.0	41.55	1.450	OK	Normal Manhole
	23	24	5.0	5.0	25.0	163.0	815.0000	0.0021	4.8	0.0102	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	43.0	40.75	2.250	OK	Deep Manhole
	24	25	6.0	5.0	30.0	169.0	845.0000	0.0022	4.8	0.0105	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	50	0.500	43.0	40.25	2.750	OK	Deep Manhole
ZONE C	2	2A	3.0	5.0	15.0	172.0	860.0000	0.0022	4.8	0.0107	250.0	0.0491	0.7855	0.0625	0.014	70	0.014	1.3445	OK	0.0660	OK	62	0.886	43.0	39.36	3.636	OK	Deep Manhole
	2A	26	4.0	5.0	20.0	176.0	880.0000	0.0023	4.8	0.0109	250.0	0.0491	0.7855	0.0625	0.014	60	0.017	1.4523	OK	0.0713	OK	62	1.033	43.0	41.52	1.483	OK	Normal Manhole
	5	5A	7.0	5.0	35.0	183.0	915.0000	0.0024	4.7	0.0113	250.0	0.0491	0.7855	0.0625	0.014	60	0.017	1.4523	OK	0.0713	OK	55	0.917	43.0	41.49	1.510	OK	Normal Manhole
	5A	27	6.0	5.0	30.0	189.0	945.0000	0.0025	4.7	0.0116	250.0	0.0491	0.7855	0.0625	0.014	70	0.014	1.3445	OK	0.0660	OK	55	0.786	43.0	40.70	2.295	OK	Deep Manhole
	9	28	11.0	5.0	55.0	200.0	1000.0000	0.0026	4.7	0.0122	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	43.0	41.05	1.950	OK	Normal Manhole
	13	29	9.0	5.0	45.0	209.0	1045.0000	0.0027	4.7	0.0127	250.0	0.0491	0.7855	0.0625	0.014	80	0.013	1.2577	OK	0.0617	OK	50	0.625	43.0	41.26	1.742	OK	Normal Manhole
	26	27	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127	250.0	0.0491	0.7855	0.0625	0.014	80	0.013	1.2577	OK	0.0617	OK	55	0.688	43.0	39.81	3.193	OK	Deep Manhole
	27	28	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127	250.0	0.0491	0.7855	0.0625	0.014	80	0.013	1.2577	OK	0.0617	OK	55	0.688	43.0	39.12	3.881	OK	Deep Manhole
	28	29	0.0	5.0	0.0	209.0	1045.0000	0.0027	4.7	0.0127	250.0	0.0491	0.7855	0.0625	0.014	80	0.013	1.2577	OK	0.0617	OK	55	0.688	43.0	38.43	4.568	OK	Deep Manhole
ZONE D	17	30	13.0	5.0	65.0	222.0	1110.0000	0.0029	4.6	0.0134	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	41.0	39.15	1.850	OK	Normal Manhole
	30	31	13.0	5.0	65.0	235.0	1175.0000	0.0031	4.6	0.0141	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	41.0	38.15	2.850	OK	Deep Manhole
	31	32	14.0	5.0	70.0	249.0	1245.0000	0.0032	4.6	0.0149	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	41.0	37.35	3.650	OK	Deep Manhole
	21	33	12.0	5.0	60.0	261.0	1305.0000	0.0034	4.6	0.0155	250.0	0.0491	0.7855	0.0625	0.014	90	0.011	1.1858	OK	0.0582	OK	100	1.111	41.0	39.38	1.617	OK	Normal Manhole
	33	34	12.0	5.0	60.0	273.0	1365.0000	0.0036	4.5	0.0161	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	85	0.850	41.0	38.53	2.467	OK	Deep Manhole
	34	35	12.0	5.0	60.0	285.0	1425.0000	0.0037	4.5	0.0168	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	70	0.700	41.0	39.55	1.450	OK	Normal Manhole
	25	36	6.0	5.0	30.0	291.0	1455.0000	0.0038	4.5	0.0171	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	41.0	38.55	2.450	OK	Deep Manhole
	36	37	6.0	5.0	30.0	297.0	1485.0000	0.0039	4.5	0.0174	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	41.0	37.55	3.450	OK	Deep Manhole
	37	38	5.0	5.0	25.0	302.0	1510.0000	0.0039	4.5	0.0177	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	40	0.400	41.0	37.15	3.850	OK	Deep Manhole
	38	35	0.0	5.0	0.0	302.0	1510.0000	0.0039	4.5	0.0177	250.0	0.0491	0.7855	0.0625	0.014	120	0.008	1.0269	OK	0.0504	OK	55	0.458	41.0	32.20	8.804	OK	Deep Manhole
	35	32	0.0	5.0	0.0	302.0	1510.0000	0.0039	4.5	0.0177	250.0	0.0491	0.7855	0.0625	0.014	115	0.009	1.0490	OK	0.0515	OK	55	0.478	41.0	31.72	9.283	OK	Deep Manhole

ZONE E	39	40	5.0	5.0	25.0	307.0	1535.0000	0.0040	4.5	0.0179	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	39.0	37.55	1.450	OK	Normal Manhole
	40	41	5.0	5.0	25.0	312.0	1560.0000	0.0041	4.5	0.0182	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	39.0	36.75	2.250	OK	Deep Manhole
	41	42	5.0	5.0	25.0	317.0	1585.0000	0.0041	4.5	0.0184	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	39.0	35.95	3.050	OK	Deep Manhole
	42	43	3.0	5.0	15.0	320.0	1600.0000	0.0042	4.5	0.0186	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	84	0.840	39.0	35.11	3.890	OK	Deep Manhole
	44	45	15.0	5.0	75.0	335.0	1675.0000	0.0044	4.4	0.0194	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	37.55	1.450	OK	Normal Manhole
	45	46	15.0	5.0	75.0	350.0	1750.0000	0.0046	4.4	0.0201	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	36.55	2.450	OK	Deep Manhole
	46	47	14.0	5.0	70.0	364.0	1820.0000	0.0047	4.4	0.0209	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	95	0.950	39.0	35.60	3.400	OK	Deep Manhole
	48	49	13.0	5.0	65.0	377.0	1885.0000	0.0049	4.4	0.0215	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	37.55	1.450	OK	Normal Manhole
	49	50	13.0	5.0	65.0	390.0	1950.0000	0.0051	4.4	0.0222	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	36.55	2.450	OK	Deep Manhole
	50	51	14.0	5.0	70.0	404.0	2020.0000	0.0053	4.4	0.0229	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	71	0.710	39.0	35.84	3.160	OK	Deep Manhole
	52	53	6.0	5.0	30.0	410.0	2050.0000	0.0053	4.3	0.0232	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	37.55	1.450	OK	Normal Manhole
	53	54	6.0	5.0	30.0	416.0	2080.0000	0.0054	4.3	0.0235	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	36.55	2.450	OK	Deep Manhole
	54	55	7.0	5.0	35.0	423.0	2115.0000	0.0055	4.3	0.0238	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	45	0.450	39.0	36.10	2.900	OK	Deep Manhole
	29	43	5.0	5.0	25.0	428.0	2140.0000	0.0056	4.3	0.0241	250.0	0.0491	0.7855	0.0625	0.014	80	0.013	1.2577	OK	0.0617	OK	76	0.950	39.0	37.48	1.518	OK	Normal Manhole
	43	47	5.0	5.0	25.0	433.0	2165.0000	0.0056	4.3	0.0243	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	54	0.540	39.0	36.53	2.468	OK	Deep Manhole
	47	51	5.0	5.0	25.0	438.0	2190.0000	0.0057	4.3	0.0246	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	56	0.560	39.0	35.99	3.008	OK	Deep Manhole
	51	55	3.0	5.0	15.0	441.0	2205.0000	0.0057	4.3	0.0247	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	55	0.550	39.0	35.43	3.568	OK	Deep Manhole
	32	55	0.0	5.0	0.0	441.0	2205.0000	0.0057	4.3	0.0247	250.0	0.0491	0.7855	0.0625	0.014	110	0.009	1.0726	OK	0.0527	OK	60	0.545	39.0	31.17	7.828	OK	Deep Manhole
ZONE F	56	57	7.0	5.0	35.0	448.0	2240.0000	0.0058	4.3	0.0251	250.0	0.0491	0.7855	0.0625	0.014	150	0.007	0.9185	OK	0.0451	OK	100	0.667	39.0	37.55	1.450	OK	Normal Manhole
	57	58	7.0	5.0	35.0	455.0	2275.0000	0.0059	4.3	0.0254	250.0	0.0491	0.7855	0.0625	0.014	150	0.007	0.9185	OK	0.0451	OK	100	0.667	39.0	36.88	2.117	OK	Deep Manhole
	58	59	8.0	5.0	40.0	463.0	2315.0000	0.0060	4.3	0.0258	250.0	0.0491	0.7855	0.0625	0.014	150	0.007	0.9185	OK	0.0451	OK	95	0.633	39.0	36.22	2.783	OK	Deep Manhole
	60	61	14.0	5.0	70.0	477.0	2385.0000	0.0062	4.3	0.0265	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	37.55	1.450	OK	Normal Manhole
	61	62	14.0	5.0	70.0	491.0	2455.0000	0.0064	4.3	0.0272	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	39.0	36.55	2.450	OK	Deep Manhole
	62	63	16.0	5.0	80.0	507.0	2535.0000	0.0066	4.2	0.0280	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	90	0.900	39.0	35.65	3.350	OK	Deep Manhole
	64	65	7.0	5.0	35.0	514.0	2570.0000	0.0067	4.2	0.0284	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	85	0.850	39.0	37.55	1.450	OK	Normal Manhole
	65	65A	7.0	5.0	35.0	521.0	2605.0000	0.0068	4.2	0.0287	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	39.0	37.55	1.450	OK	Normal Manhole
	65A	66	7.0	5.0	35.0	528.0	2640.0000	0.0069	4.2	0.0290	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	80	0.800	39.0	36.70	2.300	OK	Deep Manhole
	66	67	1.0	5.0	5.0	529.0	2645.0000	0.0069	4.2	0.0291	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	35	0.350	39.0	35.90	3.100	OK	Deep Manhole
	59	63	0.0	5.0	0.0	529.0	2645.0000	0.0069	4.2	0.0291	250.0	0.0491	0.7855	0.0625	0.014	150	0.007	0.9185	OK	0.0451	OK	55	0.367	39.0	35.85	3.150	OK	Deep Manhole
	63	67	0.0	5.0	0.0	529.0	2645.0000	0.0069	4.2	0.0291	250.0	0.0491	0.7855	0.0625	0.014	145	0.007	0.9342	OK	0.0459	OK	55	0.379	39.0	35.47	3.529	OK	Deep Manhole
ZONE G	68	69	8.0	5.0	40.0	537.0	2685.0000	0.0070	4.2	0.0295	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	38.0	36.55	1.450	OK	Normal Manhole
	69	70	2.0	5.0	10.0	539.0	2695.0000	0.0070	4.2	0.0296	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	35	0.350	38.0	36.20	1.800	OK	Normal Manhole
	55	70	0.0	5.0	0.0	539.0	2695.0000	0.0070	4.2	0.0296	250.0	0.0491	0.7855	0.0625	0.014	105	0.010	1.0978	OK	0.0539	OK	40	0.381	38.0	30.79	7.209	OK	Deep Manhole
	71	72	10.0	5.0	50.0	549.0	2745.0000	0.0071	4.2	0.0301	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	75	0.750	38.0	36.55	1.450	OK	Normal Manhole
	72	73	10.0	5.0	50.0	559.0	2795.0000	0.0073	4.2	0.0306	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	60	0.600	38.0	35.95	2.050	OK	Deep Manhole
	70	73	0.0	5.0	0.0	559.0	2795.0000	0.0073	4.2	0.0306	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	50	0.500	38.0	30.29	7.709	OK	Deep Manhole
	74	75	9.0	5.0	45.0	568.0	2840.0000	0.0074	4.2	0.0310	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	38.0	36.55	1.450	OK	Normal Manhole
	75	76	15.0	5.0	75.0	583.0	2915.0000	0.0076	4.2	0.0317	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	38.0	35.55	2.450	OK	Deep Manhole
	77	78	13.0	5.0	65.0	596.0	2980.0000	0.0078	4.2	0.0323	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	38.0	36.55	1.450	OK	Normal Manhole
	78	79	13.0	5.0	65.0	609.0	3045.0000	0.0079	4.2	0.0330	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	85	0.850	38.0	35.70	2.300	OK	Deep Manhole
	80	81	11.0	5.0	55.0	620.0	3100.0000	0.0081	4.1	0.0335	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	100	1.000	38.0	36.55	1.450	OK	Normal Manhole
	81	82	11.0	5.0	55.0	631.0	3155.0000	0.0082	4.1	0.0340	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	70	0.700	38.0	35.85	2.150	OK	Deep Manhole
	82	79	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	55	0.550	38.0	35.30	2.700	OK	Deep Manhole
	79	76	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	55	0.550	38.0	34.75	3.250	OK	Deep Manhole
	76	73	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	55	0.550	38.0	34.20	3.800	OK	Deep Manhole
	73	STP	0.0	5.0	0.0	631.0	3155.0000	0.0082	4.1	0.0340	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	0	0.000	38.0	30.29	7.709	OK	Deep Manhole
ZONE H	83	84	11.0	5.0	55.0	642.0	3210.0000	0.0084	4.1	0.0346	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	95	0.950	38.0	36.55	1.450	OK	Normal Manhole
	84	86	0.0	5.0	0.0	642.0	3210.0000	0.0084	4.1	0.0346	250.0	0.0491	0.7855	0.0625	0.014	100	0.010	1.1249	OK	0.0552	OK	33	0.330	38.0	36.22	1.780	OK	Normal Manhole
	67	67A	6.0	5.0	30.0	648.0	3240.0000	0.0084	4.1	0.0348	250.0	0.0491	0.7855	0.0625	0.014	140	0.007	0.9507	OK	0.0467	OK	60	0.429	38.0	35.04	2.958	OK	Deep Manhole
	67A	85	6.0	5.0	30.0	654.0	3270.0000	0.0085	4.1	0.0351	250.0	0.0491	0.7855	0.0625	0.014	140	0.007	0.9507	OK	0.0467	OK	60	0.429	38.0	34.61	3.386	OK	Deep Manhole
	85	86	10.0	0.3	3.0	664.0	3273.0000	0.0085	4.1	0.0352	250.0	0.0491	0.7855	0.0625	0.014	140	0.007	0.9507	OK	0.0467	OK	55	0.393	38.0	34.22	3.779	OK	Deep Manhole
	86	87	50.0	0.5	25.0	714.0	3298.0000	0.0086	4.1	0.0354	250.0	0.0491	0.7855	0.0625	0.014	135	0.007	0.9682	OK	0.0475	OK	45	0.333	38.0	33.89	4.113	OK	Deep Manhole
	87	88	23.0	3.0	69.0	737.0	3367.0000	0.0088	4.1	0.0361	250.0	0.0491	0.7855	0.0625	0.014	132	0.008	0.9791	OK	0.0481	OK	40	0.303	38.0	33.58	4.416	OK	Deep Manhole
	88	89	0.0	0.0	0.0	737.0	3367.0000	0.0088	4.1	0.0361	250.0	0.0491	0.7855	0.0625	0.014	130	0.008	0.9866	OK	0.0484	OK	60	0.462	38.0	33.12	4.877	OK	Deep Manhole
	89	38	100.0	0.2	20.0	837.0	3387.0000	0.0088	4.1	0.0362	250.0	0.0491	0.7855	0.0625	0.014	128	0.008	0.9943	OK	0.0488	OK	60	0.469	38.0	32.65	5.346	OK	Deep Manhole

Table 6.7. Detail calculations for 250mm cover

Pipes	Entry	Exit	Change	CumC	GL	IL	Depth
		56	0.00	0.00	39.00	37.58	1.42
1	56	57	100.00	100.00	39.00	37.58	1.43
2	57	58	100.00	200.00	39.00	36.91	2.09
3	58	59	95.00	295.00	39.00	36.24	2.76
4	59	63	55.00	350.00	39.00	35.88	3.13
5	63	67	55.00	405.00	39.00	35.50	3.50
6	67	67A	60.0	465.00	38.0	35.1	2.93
7	67A	85	60.0	525.00	38.0	34.6	3.36
8	85	86	55.0	580.00	38.0	34.2	3.75
9	86	87	45.0	625.00	38.0	33.9	4.09
10	87	88	40.0	665.00	38.0	33.6	4.39
11	88	89	60.0	725.00	38.0	33.1	4.85
12	89	38	60.0	785.00	38.0	32.7	5.32
13	38	35	55.0	840.00	41.0	32.2	8.78
14	35	32	55.0	895.00	41.0	31.7	9.26
15	32	55	60.0	955.00	39.0	31.2	7.80
16	55	70	40.0	995.00	38.0	30.8	7.18
17	70	73	50.0	1045.00	38.0	30.3	7.68
18	73	STP	0.0	1045.00	38.0	30.3	7.68

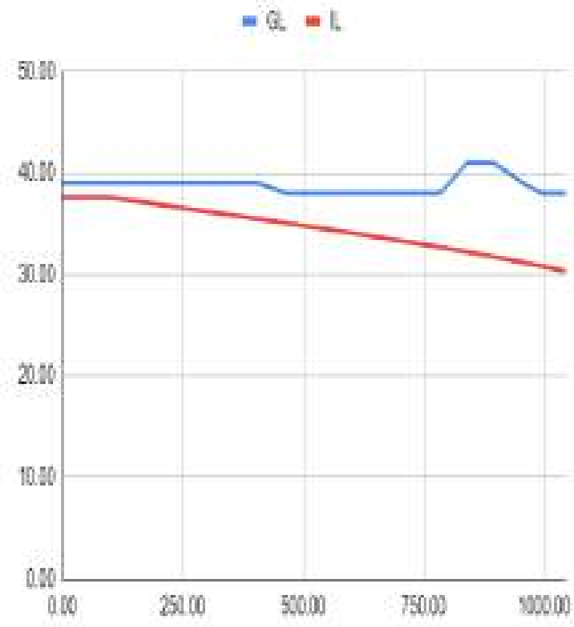


Table 6.8. Longitudinal Section Reduced Levels, Invert Levels and Depth for 225mm cover

6.16 Detailed Drawings

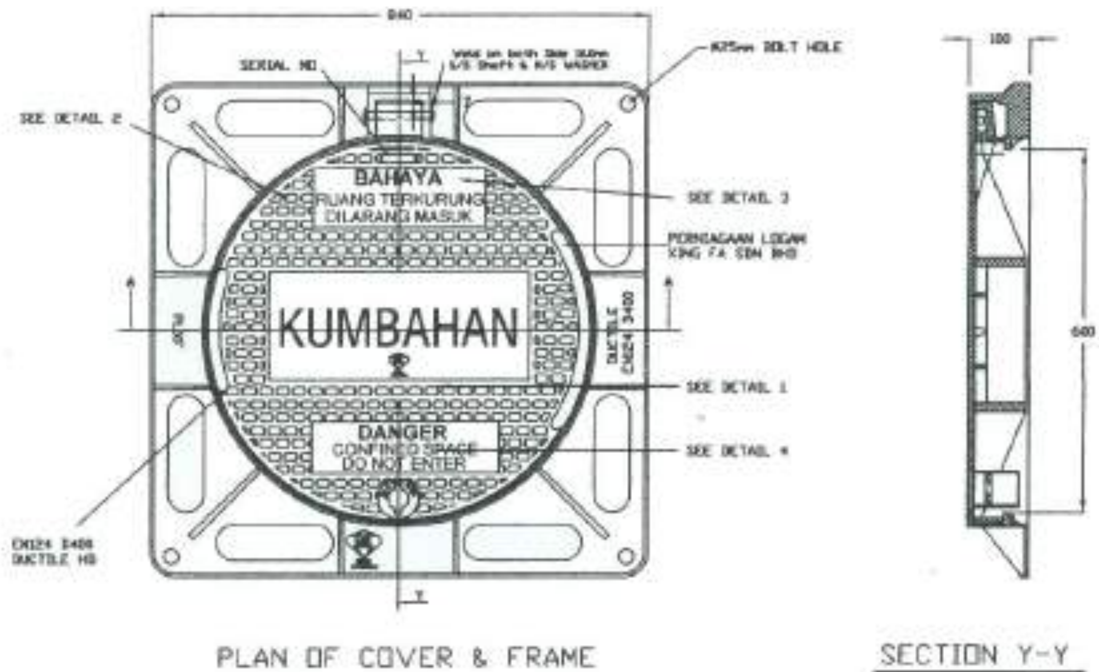


Fig 6.6 Manhole Cover Detail Drawing

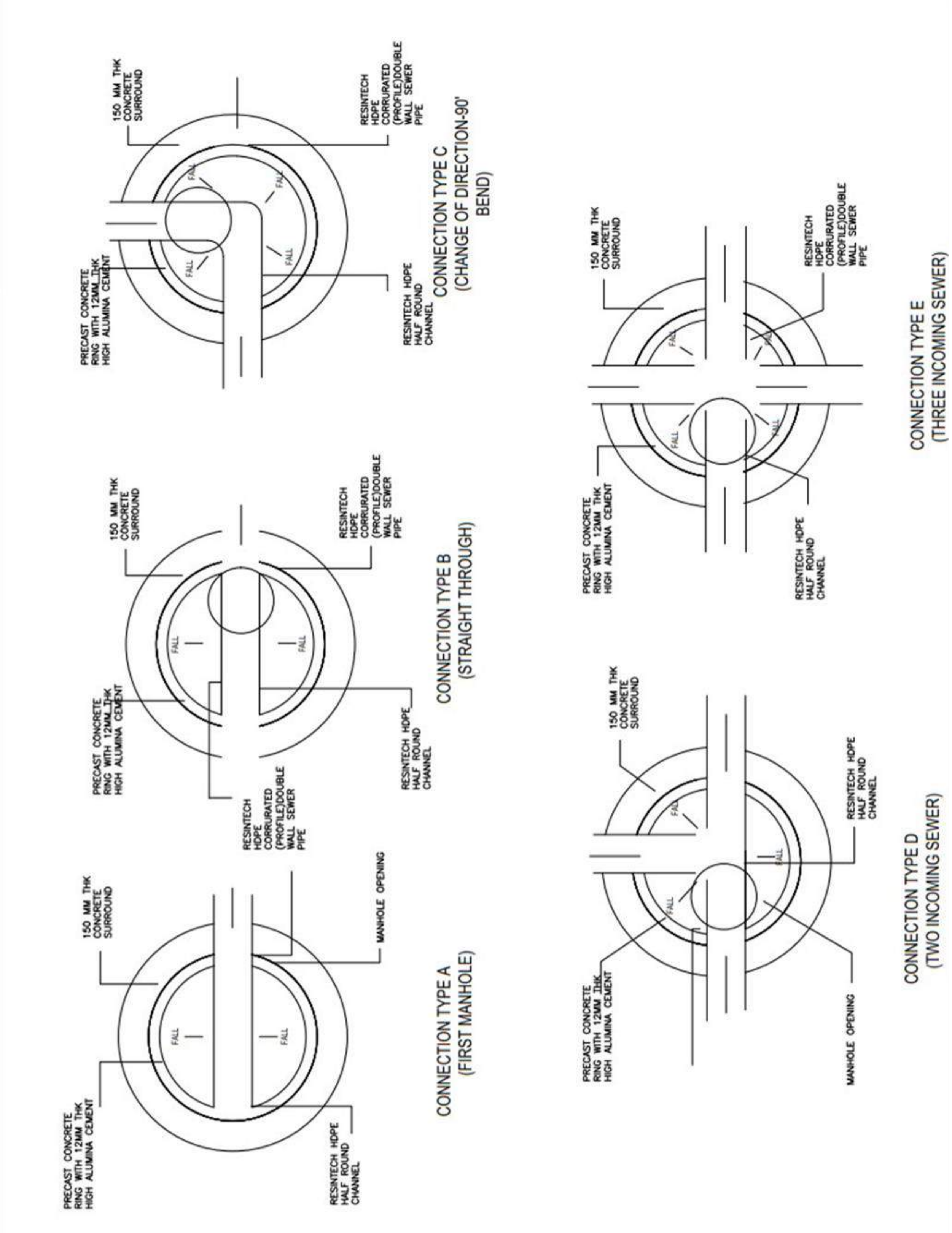


Fig 6.7 Manhole Connection Detail Drawing

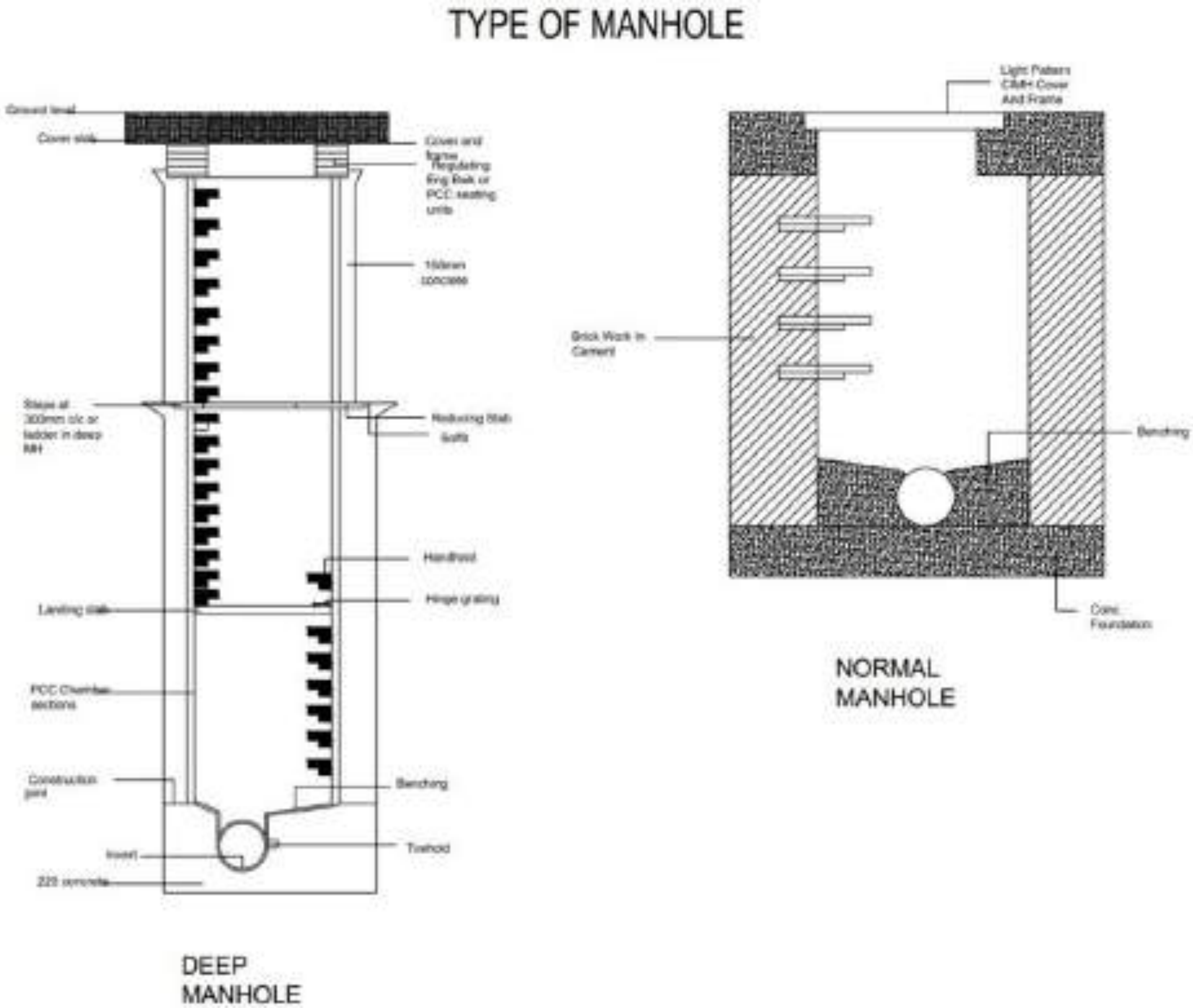


Fig 6.8 Type of Manhole Detail Drawing