KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR REPORT ON

"POTENTIAL STUDY OF MEDIUM HYDROPOWER PROJECT OF NEPAL: A CASE STUDY OF KABELI-A HEP"

A Final Year Project Report submitted in partial fulfilment of the requirements for the degree of Bachelor of Engineering in Civil Engineering (Specialization in Hydropower)

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JULY, 2025

DEDICATED TO OUR PARENTS

DECLARATION

We certify that the project "**Potential Study of Medium Hydropower Project of Nepal: A case Study of Kabeli-A HEP**" is an authentic record of our own work in fulfillment of the requirements for the Bachelor of Engineering in Civil Engineering (Specialization in Hydropower). No other bachelor's degree requirements have been met by this project, nor has it ever been published or submitted. Any information, writing, or data taken from outside sources has been appropriately acknowledged and referenced in the references. The data and findings in this report are not guaranteed to be used in real building projects; it was created purely for academic purposes to fulfill our bachelor's degree requirements.

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CERTIFICATION

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ON
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Thank You,

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EXECUTIVE SUMMARY

This project report documents the potential Study of Medium Hydropower of Nepal: A Case study of Kabeli-A HEP carried out by the fourth-year students of Department of Civil Engineering in Kathmandu University. This potential study incorporates alternatives study, hydrological analysis at proposed intake and powerhouse area, hydraulic design of civil components, water conveyance system along with their stability analysis, design of powerhouse, optimization study and financial analysis of the project.

Kabeli-A Hydroelectric Project is RoR development scheme located in Panchthar and Taplejung district being developed by Kabeli Energy Limited (KEL). The project can tap the potential of Kabeli river originates at an elevation of 2000m above the sea level. Due to its favorable topography and consistent river flow, which allows power generation with minimal environmental impact and without large reservoir storage, so a run-of river type development was selected for the power generation.

Intake site was proposed at the left bank of Kabeli River having straight reach and the narrowest section of the river. The alignment of Headrace tunnel is made such that there is minimum number of bends with at least minimum overburden pressure of 30m. The powerhouse area is located on the area where the gradient of the river has started to turn into gentle slope and the location with hard rock. The width of the river at headworks site is sufficient to accommodate river diversion facilities during construction. The project includes a sharp crested weir and under sluice, side intake, gravel trap, approach canal, settling basin, headrace tunnel, surge tank, penstock, and semi-surface powerhouse.

Department of Hydrology and Meteorology (DHM) has recorded the runoff data in the Tamor river through Station No. 684 over the past 23 years, so, using catchment area ratio method runoff data at proposed intake and powerhouse was calculated. Flood Frequency Studies are carried out using Gumbel's and Log Pearson Type III. Maximum instantaneous flow values are used for the flood flow analysis. Their calculated flood flow values are compared with WECS/DHM method. The best distribution frequency studies are obtained from Gumbel's method and the high flood discharge for a return period of 100 years is calculated to be 645.11 m^3/s from this method. On the similar note, stream flow analysis is done using average daily and monthly values of the flow in the river. Flow Duration

Curve and Mean Monthly Hydrograph are deduced at the proposed headworks. The project is designed for probability of exceedance of 40% that corresponds to the discharge of 48.83 m^3/s with the gross head of 124.46 m.

The hydraulic design of weir, under sluice, side intake, gravel trap, approach canal, settling basin, Headrace tunnel, penstock, surge shaft, etc. are done along with the design of powerhouse and tailrace channel. The diversion weir is sharp crested weir with its crest level at 582.81 amsl while the turbine axis level at the powerhouse is kept at 457.44 amsl. Side Intake is aligned at 105° to the direction of flow in order to minimize the amount of sediment flow towards the side intake. Side Intake consists of 4 openings in which invert level is kept at 579.61 amsl. It is followed by gravel trap which can settle particles up to 5mm of 15m length. The approach canal of trapezoidal shape is 162 long with 2.46m deep which conveys the water from gravel trap to the settling basin. Hooper type of settling basin is designed having the length of 154.48 m with each chamber having the width of 19.31m. Trash racks of bar spacing 50 mm are kept at the gravel trap and settling basin while side intake has trash rack of 100 mm bar spacing. Flushing arrangements are also designed for removing out the settled particles back to the river.

Water conveys towards the head pond and enters the Headrace tunnel of Inverted D-shaped type having 4.8m diameter and 5090m long. Then, it leads to the surge tank of 29.8m long with outer diameter of 10.9m followed by the penstock pipe of the 3.65m diameter and 301.38 m long. There is trifurcation penstock pipe where water can flow through three units of vertical shaft Francis turbine with rated speed of 500 rpm. The potential of Kabeli-A hydroelectric project is found to be 49.49 MW with the net head of 120.14 m.

Quantity estimation and the rate analysis are done for the total cost that can incurred for the development of this project which is NRs. 7,25,33,38,034(Seven Arab Twenty-Five crore thirty-three lakh thirty-eight thousand and thirty-four only) including VAT and other taxes. On the other hand, the annual revenue that the project can generate from the hydroelectric production is calculated as NRs. 1,19,82,10,018 (One Arab nineteen crore eighty-two lakh ten thousand and eighteen only). The economic analysis of the project is performed and the Benefit-Cost Ratio, Internal rate of Return (IRR) and Net Present Value (NPV) are found out to be 2.27, 15% and NRs. 14,94,23,64,997 respectively.

SYMBOLS AND ABBREVIATIONS

amsl	Above Mean Sea Level
BCR	Benefit Cost Ratio
cm	Centimetre
cm^2	Square Centimetre
cumecs	Cubic Meter Per Second
D/S	Downstream
DOED	Department of Electricity Development
DHM	Department of Hydrology and Meteorology
etc.	Et. Cetera
FDC	Flow Duration Curve
GIS	Geographic Information System
HEP	Hydroelectric Project
IEA	International Energy Agency
IRR	Internal rate of Return
IS	Indian Standard
HFL	High Flood Level
HRT	Headrace Tunnel
km	Kilometer
km^2	Square Kilometer
kN	Kilo Newton
m	Meter
masl	Meter Above Sea Level
MW	Megawatt
NEA	Nepal Electricity Authority
NPV	Net Present Value
NWL	Normal Water Level
PH	Powerhouse
RoR	Run of River

RPM	Revolution per minute
RMR	Rock Mass Rating
RQD	Rock Quality Designation
U/S	Upstream
USGS	United States Geological Survey
WECS	Water and Energy Commission Secretariat

SALIENT FEATURES

Project Features	Features Details
General	
Project Boundary	27°13'41" N to 27°17'32" N
	87°40'55" E to 87°45'50" E
Gross Head	124.45 m
Net Head	120.14 m
Power Production	49.49 MW
Weir Crest Level	582.81 masl
High Supply Level	585.65 masl
Normal Water Level	583.93 masl
Turbine Central Line	457.44 masl
Hydrology	
Catchment Area at Proposed Intake	861.87 km^2
Catchment Area at Proposed Powerhouse	3926 km^2
Design Discharge (Q_{40})	48.83 m^3/sec
Design flood at Intake(Q_{100})	645.11 m^3/sec
Design Flood at Powerhouse(Q_{200})	3185.41 m^3/sec
Diversion Structure	
Types of Diversion headwork	Sharp crested weir
Weir Crest Level	582.81 masl
Total Length of Weir	61m
Width of Weir	50 m
River Bed Level	578.81 masl
Under sluice	
Length of Under sluice base with Protection	81.5 m
Width of Under sluice	12 m
Under sluice Sill level	578.81 masl
Stilling Basin	
Stilling Basin for weir	26.65m × 50m
Stilling Basin for Under sluice	26.65m × 12m
Floor level of stilling basin	578.8 masl
End Sill Level of stilling basin	580.3 masl
Intake	
Side Intake orifice	4 Nos: 2.2m (H) x 8m (B)
Invert Level	578.61 masl
No. of openings	4
Intake Discharge	58.60 m^3/s (20% Extra)
Gravel Trap	
Size (B x H)	11 m x 9m
Length	15m
Gravel Trap: Flushing	

Size (B x H)	2m x 2m
Number of culverts	2
Approach Canal	
Type	Trapezoidal
Size (B x H)	4.5m x 2.46m
Length	162m
Settling Basin	
Location	**Surface**
Type	Hooper
Number of compartments	2
Effective length	154.48 m
Total width of basin	39.42 m
Width of one compartment	19.31 m
Height in rectangular section	9.17 m
Side slope of the compartment	0:01
Width of the flushing channel	3 m
Height of Flushing Culvert	3m
Water Conveyance System (Headrace Tunnel)	
Shape of Tunnel	Inverted D type
Length	5.090 km
Finish Diameter	4.8 m
Finish Height	5 m
Gradient of HRT	0.39
Tunnel Inlet Portal Level	575.77 masl
Surge shaft bottom	571 masl
No. of bends in HRT	0
Support	Shotcrete, Concrete lining, Steel Ribs
Penstock	
Diameter	3.65 m
Total Length (with bends)	301.38m
Thickness	26.38 mm
Surge Shaft	
Diameter	10 m
Type	Simple Cylindrical
Height	29.8 m
Powerhouse	
Type of Power house	**Surface**
Powerhouse dimension	62.76m (L) x 26.77m (W) x 28.55m (H)
Turbine Axis Level	EL. 457.44 masl
Tailrace	
Type	RCC Box Type
Length	123 m
Shape	Rectangular
Individual duct width	3.26m

Combined duct width	9.78m
Depth of canal	2.33
Tailrace Water Level	459.47
Turbine	
Type of turbine	Francis
Shaft configuration	Vertical Axis
No. of turbine	3
Turbine Output	16.49 MW per unit
Rated speed	500 rpm
Rated Efficiency	90%
Generator	
Frequency	50 Hz
No. of Units	3
Efficiency	97%
Transformer	
Efficiency	98.50%
Power and Energy Generation	
Wet Energy	213.74 GWh
Dry Energy	29.61 GWh
Total Energy	243.35 GWh
Financial	
Total Project cost	NRs. 7,25,33,38,034
Annual Revenue	NRs. 1,19,82,10,018
B/C Ratio	2.27
Net Present Value	NRs. 14,94,23,64,997
Internal Rate of Return	15%
Payback Period	6 years

TABLE OF CONTENTS

DECLARATION ..... **i**
CERTIFICATION ..... **ii**
ACKNOWLEDGEMENT ..... **iii**
EXECUTIVE SUMMARY ..... **iv**
SYMBOLS AND ABBREVIATIONS ..... **vi**
SALIENT FEATURES ..... **viii**
TABLE OF CONTENTS ..... **xi**
LIST OF TABLES ..... **xvi**
LIST OF FIGURES ..... **xvii**
CHAPTER 1: INTRODUCTION **1**
1.1. BACKGROUND 1
1.2. OBJECTIVES 2
1.2.1. PRIMARY OBJECTIVE 2
1.2.2. SECONDARY OBJECTIVES 2
1.3. SCOPE OF STUDY 2
1.4. LIMITATIONS 2
1.5. METHODOLOGY 3
1.5.1. DESK STUDY AND CONSULTATION 4
1.5.2. DATA COLLECTION 4
1.5.3. LAYOUT OF HYDROPOWER COMPONENT 4
1.5.4. HYDROLOGICAL ANALYSIS 4
1.5.5. HYDRAULIC DESIGN 4
1.5.6. STABILITY ANALYSIS 4
1.5.7. ESTIMATION AND COSTING 5
1.5.8. FINANCIAL ANALYSIS 5
CHAPTER 2: LITERATURE REVIEW **6**
2.1. THEORITICAL REVIEW TO DESIGN HYDROPOWER PROJECT 6
2.2. HYDROLOGY 6
2.2.1. CATCHMENT AREA 7

2.2.2. HYDROLOGICAL EQUATION 8
2.2.3. FLOW ANALYSIS 9
2.2.4. FLOW DURATION CURVE 9
2.2.5. RATING CURVE 10
2.3. FLOOD ANALYSIS 11
2.3.1. FLOOD PEAK ESTIMATION 12
2.3.2. WECS/DHM METHOD 12
2.3.3. RETURN PERIOD 13
2.3.4. GUMBEL METHOD 13
2.3.5. LOG PEARSON METHOD 14
2.4. HEADWORKS 15
2.4.1. WEIR 15
2.4.2. HYDRAULIC DESIGN OF WEIR AND UNDERSLUICE 16
2.4.3. INTAKE 16
2.4.4. TRASH RACK 17
2.4.5. GRAVEL TRAP 18
2.4.6. HYDRAULIC DESIGN OF GRAVEL TRAP 18
2.4.7. SETTLING BASIN 19
2.4.8. DESIGN CRITERIA of SETTLING BASIN 19
2.4.9. COMPONENTS OF SETTLING BASIN 20
2.4.10. DESIGN OF SETTLING BASIN: 21
2.5. UNDERGROUND STRUCTURE 23
2.5.1 GENERAL 23
2.5.2. ROCK MASS CLASSIFICATION 24
2.5.3. ROCK MASS RATING (RMR) 24
2.5.4. ROCK MASS QUALITY (Q-SYSTEM) 24
2.5.5. GEOLOGICAL STRENGTH INDEX (GSI) 25
2.5.6. ROCK SUPPORTS 26
2.5.7. NUMERICAL MODELLING BY PHASE 2 27
2.6. WATER CONVEYANCE SYSTEM 28
2.6.1. PENSTOCK 28
2.6.2. PENSTOCK HEAD LOSS 28

2.6.3. SURGE TANK 30
2.6.4. ANCHOR BLOCK AND SUPPORT PIERS 31
2.7. POWER HOUSE 33
2.7.1. ARCHITECTURAL LAYOUT OF POWERHOUSE 33
2.7.2. SELECTION OF TURBINE 35
2.7.3. SELECTION OF NUMBER OF UNITS: 37
2.7.4. FRANCIS TURBINE 38
2.8. ECONOMIC CONSIDERATION FOR HYDROPOWER PROJECT DESIGN 39
2.9. SOCIAL AND ENVIRONMENTAL CONSIDERATION FOR HYDROPOWER 39
CHAPTER 3: DESCRIPTION OF CASE STUDY 40
3.1. KABELI-A HEP DESCRIPTION 40
3.1.1. PROJECT LOCATION 41
3.1.2. PROJECT ACCESIBILITY 42
3.2. TOPOGRAPHY 43
3.3. CLIMATE 43
3.4. GEOLOGY 44
3.5. TOPOGRAPHICAL STUDY 45
3.6. LAYOUT OF HYDROPOWER COMPONENTS 45
3.6.1. ALTERNATIVE I 46
3.6.2. ALTERNATIVE II 47
3.6.3. ALTERNATIVE ANALYSIS 48
3.7. CATCHMENT AREA DELINEATION: 49
3.8. HYDROLOGICAL ANALYSIS 52
3.9. FLOOD FREQUENCY ANALYSIS 52
3.9.1. GUMBEL'S METHOD 53
3.9.2. LOG PEARSON TYPE III METHOD 55
3.9.3. WECS/DHM METHOD 57
3.9.4. SUMMARY OF FLOOD FREQUENCY ANALYSIS: 58
3.10. LONG TERM STREAM FLOW ANALYSIS 60
3.10.1. MEAN MONTHLY HYDROGRAPH 61
3.10.2. FLOW DURATION CURVE 62
CHAPTER 4: DESIGN OF CIVIL COMPONENTS 63

4.1. HYDRAULIC DESIGN OF HEADWORK 63
4.1.1. HYDRAULIC DESIGN OF WEIR AND UNDER SLUICE 63
4.1.2. HYDRAULIC DESIGN OF SIDE INTAKE 64
4.1.3. HYDRAULIC DESIGN OF GRAVEL TRAP 64
4.1.4. HYDRAULIC DESIGN OF APPROACH CANAL 64
4.1.5. HYDRAULIC DESIGN OF SETTLING BASIN 65
4.2. OPTIMISATION OF WATER CONVEYANCE SYSTEM 65
4.2.1. OPTIMISATION OF HEADRACE TUNNEL 65
4.2.2. OPTIMISATION OF PENSTOCK 66
4.3. HYDRAULIC DESIGN OF SURGE TANK 67
4.4. DESIGN OF ANCHOR BLOCKS: 68
4.5. HYDRAULIC DESIGN OF POWERHOUSE 68
4.5.1. HYDROMECHANICAL & ELECTROMECHANICAL WORKS 68
4.5.2. POWERHOUSE GENERAL LAYOUT: 69
4.5.3. STRUCTURAL MEMBERS: 69
4.6. HYDRAULIC DESIGN OF TAILRACE 69
CHAPTER 5: NUMERICAL MODELLING & STATIC ANALYSIS 71
5.1. FIELD STRESS 71
5.2. GEOMECHANICAL PROPERTIES 72
5.3. MATERIAL PROPERTIES 73
5.4. SUPPORT PARAMETERS 73
5.5. PHASE 2 SIMULATION OF TUNNEL BEHAVIOUR 74
5.6. SUMMARY OF RESULT 75
CHAPTER 6: FINANCIAL ANALYSIS 78
6.1. COST ESTIMATES: 78
6.2. POWER AND ENERGY 79
6.3. REVENUE GENERATION: 80
6.4. FINANCIAL ANALYSIS: 81
6.4.1. NET PRESENT VALUE (NPV): 81
6.4.2. INTERNAL RATE OF RETURN (IRR): 81
6.4.3. PAYBACK PERIOD: 82
6.4.4. BENEFIT-COST RATIO (BC RATIO): 82

6.4.5. SENSITIVITY ANALYSIS: 82
CHAPTER 7: CONCLUSION & RECOMMENDATIONS 86
7.1 CONCLUSIONS..... 86
7.2 RECOMMENDATIONS..... 86
REFERENCES..... 88
ANNEX I - HYDROLOGICAL ANALYSIS 91
ANNEX II - DESIGN OF CIVIL STRUCTURES & ANALYSIS 110
ANNEX III-OPTIMISATION OF CONVEYANCE SYSTEM 227
ANNEX IV - NUMERICAL MODELLING & STATIC ANALYSIS..... 255
ANNEX V - FINANCIAL ANALYSIS 275
ANNEX VI - DESIGN DRAWINGS..... 353

LIST OF TABLES

Table 1 : Licensed Geographical Coordinates of Kabeli -A Hydroelectric Plant..... 42
Table 2 : Comparison of Alternatives..... 49
Table 3 : Catchment Details at proposed intake and powerhouse 50
Table 4 : Estimated Flood(Xt) m3/s at intake..... 54
Table 5 : Estimated Flood(Xt) m3/s at powerhouse 54
Table 6 : Log Pearson Type III at Proposed Intake 56
Table 7 : Log Pearson Type III at Proposed Powerhouse..... 56
Table 8 : Discharge at Different Proposed Intake..... 58
Table 9 : Comparison of Flood Frequency at Intake 59
Table 10 : Comparison of Flood Frequency at Powerhouse..... 60
Table 11 : Mean Monthly Flow 61
Table 12 : Flow Duration curve at Proposed Intake 62
Table 13 : Value for stress for different rock class..... 72
Table 14 : GSI value based on class of rock..... 72
Table 15 : Material Properties..... 73
Table 16 : Dimensions of Tunnel Support System..... 75
Table 17 : Amount of closure prior to support 77
Table 18 : Project Cost Summary 78
Table 19 : Monthly Power Generation of Kabeli A..... 79
Table 20 : Yearly Revenue Generation of Kabeli A..... 80
Table 21 : Variation of NPV, IRR & B/C ratio 82
Table 22 : Data for Sensitivity Analysis..... 82
Table 23 : Variation of B/C Ratio with cost and revenue..... 83
Table 24 : Variation of IRR with cost and revenue 83
Table 25 : Variation of NPV with cost and revenue..... 84

LIST OF FIGURES

Figure 1 : Catchment area (Jarrett, R. D, 1990) 8
Figure 2 : Flow Duration Curve (Jarrett, R. D, 1990) 10
Figure 3 : Rating Curve (Jarrett, R. D, 1990) 11
Figure 4 : Flood Frequency curve (Siddharth Saksena, 2016) 12
Figure 5 : Common Types of Weirs (SK GARG, 1976) 15
Figure 6 : Typical arrangement for side Intake (Sanjeev Baral, 2019) 17
Figure 7 : Values of Trashrack coefficient 18
Figure 8 : Camp's diagram for sediment trapping efficiency 23
Figure 9 : Permanent support recommendations based on Q values and span/ESR 25
Figure 10 : General flow chart for design of tunnel support 26
Figure 11 : General Alignment of Penstock (Sanjeev Baral, 2019) 28
Figure 12 : Anchor Block (Rishiraj P Moni, 2018) 33
Figure 13 : Cross section of Power House (Bureau of Indian Standards., 1998) 35
Figure 14 : Specific Speed vs Head (Bureau of Indian Standards., 1998) 36
Figure 15 : Schematic Diagram of Francis Turbine (RK Rajput, 2016) 38
Figure 16 : Study Area map of the Project 41
Figure 17 : Project Boundary 42
Figure 18 : Physiographical Map of Nepal (Kshetri, R., 2023) 43
Figure 19 : Climatological Map of Nepal (Ojha, R. B., & Panday, D., 2021) 44
Figure 20 : Geologic map of the Nepal (Neupane, A., 2024) 45
Figure 21 : Layout of Components in Alignment I in Topographical Sheet 47
Figure 22 : Layout of Components in Alignment II in Topographical Sheet 48
Figure 23 : Catchment area at the DHM Station No. 684 50
Figure 24 : Catchment area at Proposed Intake 51
Figure 25 : Catchment Area at Proposed Powerhouse 51
Figure 26 : Flood Probability by Gumbel's Distribution at Intake 54
Figure 27 : Flood Probability by Gumbel's Distribution at Powerhouse 55
Figure 28 : Flood Analysis by Log Pearson Type III at Proposed Intake 56
Figure 29 : Flood analysis by Log Pearson Type III at Proposed Powerhouse 57
Figure 30 : Flood Probability Analysis by WECS Method at Proposed Intake 58
Figure 31 : Comparison of Flood Frequency at Proposed Intake 59
Figure 32 : Comparison of Flood Frequency at Proposed Powerhouse 60
Figure 33 : Mean monthly hydrograph at the proposed intake site 61
Figure 34 : Flow duration curve at the proposed intake site 62
Figure 35 : Head race Tunnel Optimization 66
Figure 36 : Optimization of Penstock 67
Figure 37 : Turbine Selection Based on Head vs Discharge and Head vs Specific Speed 68
Figure 38 : Turbine Selection Based on Speed Number 69
Figure 39 : Closure length graph for deformation in tunnel 75
Figure 40 : Tunnel after placement of support linings 76
Figure 41 : Support Capacity plot for concrete lining for class III 77
Figure 42 : Coverage of Different Components Cost in the Project 79

Figure 43 : Sensitivity Analysis of BC Ratio..... 83
Figure 44 : Sensitivity Analysis of IRR..... 84
Figure 45 : Sensitivity Analysis of NPV..... 85

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

Hydropower, or hydroelectric power, is one of the oldest and largest sources of renewable energy, which uses the natural flow of moving water to generate electricity. As the world's largest producer of renewable energy, hydropower also ensures global decarbonization goals remain within reach, while complementing variable renewables through its flexibility and storage.

Hydropower plays a predominant role in Nepal's electricity system. With over 90% of the country's total electricity generation capacity generated by hydropower plants, Nepal is heavily dependent on hydro resources to meet its energy demands. Hydropower plays a particularly important role in Nepal's economic future because of the scale of its potential. It is estimated that Nepal has the economically viable potential to put in place over 40,000 megawatts (MW) of hydro generation capacity. If such potential is realized, it could easily meet Nepal's suppressed demand and create a surplus that could be exported to neighboring countries in South Asia (Karki, S., 2024).

Currently, total installed capacity has reached 3,157 MW as per the annual report of NEA as of 2025 (Nepal Electricity Authority, 2025). Only 5% of Nepal's economic hydropower potential of about 40 gigawatts has been harnessed. Nepal has a current daily demand of around 32000MWh with a total peak demand of around 1700MW (Shrestha, P. M., 2023).

In order to meet the increasing power demand, necessary steps are taken to consolidate and strengthen existing generating facilities to increase efficiency in the production and distribution of energy. The Government of Nepal (GoN) has adopted an open and free market policy to attract domestic and foreign hydropower developers for expediting hydropower development. The GoN has promulgated Water Resources Act 1992, and Water Resources Regulation 1993. In addition to this, GoN has adopted the new Hydropower Policy in 2001. These acts, regulations, and policies are focusing on easing and simplifying procedures of licenses, royalties, income taxes, customs and excise duties, foreign currency, and the selling of electricity. Many hydropower projects are in different stages of study, licensing, and development. Nepal government have target to produce 35GW up to the year 2035BS which shows the important of potential study of Hydropower.

1.2. OBJECTIVES

1.2.1. PRIMARY OBJECTIVE

1) To conduct the potential study of Medium Hydropower of Nepal: A case study of Kabeli-A HEP.

1.2.2. SECONDARY OBJECTIVES

1) To identify suitable locations for hydropower components using topographic maps considering geological, hydrological, and accessibility factors.
2) To conduct hydrological analysis to determine design discharge and other parameters essential for hydraulic design.
3) To design key civil structures such as the intake, weir, approach canal, settling basin, headrace tunnel, surge shaft, penstock, and powerhouse.
4) To perform stability analysis of all major civil components to ensure structural integrity and safety.
5) To estimate quantities and costs for construction activities, materials, and labor involved in project development.
6) To carry out financial analysis using Benefit-Cost Ratio (BCR) and Internal Rate of Return (IRR) methods.

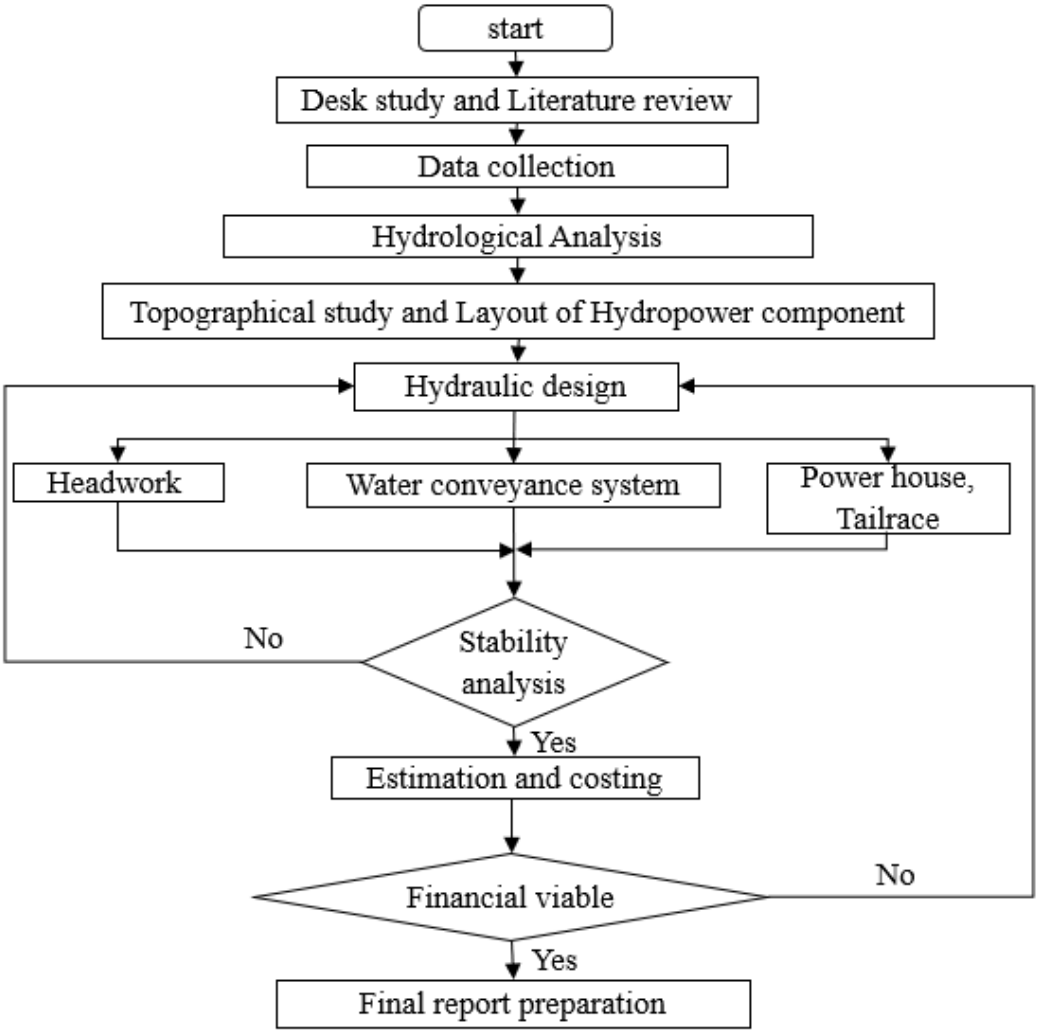
1.3. SCOPE OF STUDY

1) Topographical Study of the area and Layout of Components
2) Detailed hydrological analysis at the proposed intake and powerhouse
3) Hydraulic Design of Headworks, Headrace Tunnel & Surge Tank
4) Design of Anchor Blocks & Powerhouse
5) Stability Analysis of Weir and Anchor Blocks
6) Numerical Modelling of Headrace Tunnel using Phase 2 for different rock classes
7) Structural Analysis of Powerhouse using ETABS for different load combinations
8) Preparation of cost estimates of project and financial analysis using IRR, NPV & B/C Ratio.

1.4. LIMITATIONS

1) Detailed structural design of the civil structures has not been done in the project.
2) Geological assessment of the proposed alignment has not been considered in depth.
3) Precipitation Factor has not been considered in hydrological analysis.

1.5. METHODOLOGY



1.5.1. DESK STUDY AND CONSULTATION

The initial investigation for the project was carried out with the support of resources provided by the consulting firm. Relevant literature including books on hydropower development, design guidelines, textbooks, manuals, technical drawings, and previous reports was thoroughly reviewed. A comprehensive desk study was conducted to familiarize the team with all essential parameters required for the successful completion of the project.

Dr Shyam Sundar Khadka, Associate Professor of Civil Engineering, Kathmandu University supervised the team through the entire duration of the project. The study and consultation with the supervisor were done on regular basis.

1.5.2. DATA COLLECTION

The required data were collected from client' office (Kabeli Energy Ltd.), Department of Hydrology and Meteorology (DHM). The data collected were survey data, hydrological data and precipitation data.

1.5.3. LAYOUT OF HYDROPOWER COMPONENT

The layout of different components of the hydropower was prepared with the help of topographic map. The best possible location was chosen.

1.5.4. HYDROLOGICAL ANALYSIS

The discharge data acquired from DHM was used to undertake hydrological research includes flow duration curve (FDC) analysis, flood analysis (using Gumbel and Log Pearson Type III statistical methods), flood level (HEC-RAS), rating curve to develop highest flood discharge to determine the elevation up to which the water level rises in the river during the highest design return flood, power computation, and revenue generation.

1.5.5. HYDRAULIC DESIGN

Design of every component of the hydropower such as intake, weir, gravel trap, settling basin, headrace tunnel, penstock, surge tank, anchor block, powerhouse and tailrace was carried out using books, IS code and other relevant documents.

1.5.6. STABILITY ANALYSIS

Stability analysis of the weir and other components by checking FOS against sliding, overturning and bearing was done

1.5.7. ESTIMATION AND COSTING

The quantity estimation of the excavation, filling, concrete, and reinforcement etc of the hydraulic structures was calculated and cost estimation calculated using available district rate of materials. The operation and maintenance cost along with cost for staff is determined and profit earned per year is calculated.

1.5.8. FINANCIAL ANALYSIS

The financial analysis was done using benefit-cost ratio method, internal rate of return, net present value and sensitivity analysis and the project was concluded if it was economically viable or not.

CHAPTER 2: LITERATURE REVIEW

Pre-feasibility study of the Kabeli Khola Hydroelectric Project was done and had evaluated the viability of the project in technical, financial, socio-economic, institutional, and environmental along with other relevant aspects of project development based on desk study, preliminary investigations analysis, layout and design, and cost estimate at pre- feasibility level. This study is prepared based on the information obtained from the existing 1:50,000 and 1:25,000 scale topographical map from the Department of Survey. The possible alternatives of the project considering different locations of different alignments on both banks of the river valley have been considered to select the best layout and location.

2.1. THEORITICAL REVIEW TO DESIGN HYDROPOWER PROJECT

The Guidelines for Study of Hydropower Projects, 2018 is a document prepared by the Department of Electricity Development (DOED) in Nepal. The purpose of this document is to provide a comprehensive set of guidelines for conducting feasibility studies, preparing detailed project reports, and designing hydropower projects in Nepal.

The document provides detailed information on various aspects of hydropower projects, including site selection, hydrological and geological studies, environmental and social impact assessments, project design, cost estimation, financial analysis, and risk assessment.

The guidelines also include information on the legal and regulatory framework governing hydropower development in Nepal, as well as the procedures and requirements for obtaining various permits and approvals from government agencies.

The various studies that are done under this project are based on the recommendations from the Guidelines for Study of Hydropower Projects, 2018.

2.2. HYDROLOGY

Hydrology is the study or understanding of water, with hydro denoting water and logy denoting knowledge. It is a multidisciplinary subject that deals with the occurrences, circulation, storage, distribution and properties of surface and ground water on the earth. Hydrological observations can be defined as a scientific method of collecting flow data at a specific location along a river. Stream flow or discharge is the volume of water that moves through a specific point in a stream during a given period of time. To determine discharge, a cross-sectional area of the stream or river is measured and the velocity

of the stream is measured using a Flow Rate Sensor. The discharge can then be calculated by multiplying the cross-sectional area by the flow velocity.

$$\boldsymbol{Q} = \boldsymbol{A} \times \mathbf{V}$$

The primary purpose of a hydrology study in hydropower projects is to determine the available water resources and the characteristics of the water resources that may impact the project. The main objective of the hydrological study is:

1. To study rainfall pattern,
2. To pertain discharging capacity of the catchment,
3. To predict design discharge,
4. To predict high flow and low flow

The study typically includes the following components: water availability assessment, watershed analysis, hydrologic modeling, water quality assessment, and environmental impact assessment.

Water availability assessment: assesses the water resources available in the region, including surface water and groundwater sources.

Watershed analysis: examines the physical characteristics of the watershed, including topography, land use, soil type, and vegetation cover.

Hydrologic modeling: uses hydrologic modeling tools to estimate water availability, water quality assessment, and environmental impact assessment.

Environmental impact assessment: assesses the potential environmental impact of the hydropower project on the watershed, including the impact on aquatic and terrestrial ecosystems, water quality, and land use.

2.2.1. CATCHMENT AREA

The catchment region is the area from which surface runoff is derived. It is sometimes referred to as a watershed region, a drainage basin, or simply a basin or catchment. The catchment area is measured in kilometers squared. It refers to all of the land that drains into the river/stream under consideration. All precipitation that falls on a river's catchment zone will flow down the land and join the river, either by surface runoff or through base flow, to add to its volume (underground water flow). The ridge line marks the catchment's boundaries. The catchment region is the area from which surface runoff is derived. It is

sometimes referred to as a watershed region,

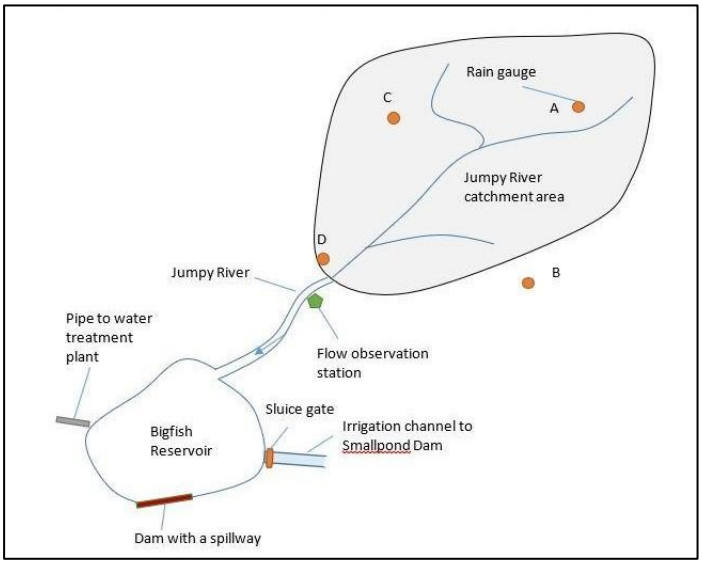


Figure 1 : Catchment area (Jarrett, R. D, 1990)

2.2.2. HYDROLOGICAL EQUATION

The hydrological equation is a mathematical representation of the water balance in a hydrological system. It is used to estimate the amount of water that enters and leaves a particular region, such as a catchment area or a river basin.

The general form of the hydrological equation is:

$$P = ET + Q \pm \Delta S$$

Where:

P = Precipitation

ET = Evapotranspiration (the combined processes of evaporation from the land surface and transpiration from plants)

Q = Surface and subsurface runoff

ΔS = Change in storage (change in the amount of water stored in the system)

In this equation, the total precipitation (P) is either used for evapotranspiration (ET) or runoff (Q), or is stored as a change in storage (ΔS). The change in storage can occur in the form of groundwater recharge, surface water storage, or soil moisture storage.

2.2.3. FLOW ANALYSIS

Flow analysis is an important part of hydropower generating. It entails researching the flow of water in the river or stream that will power the hydropower plant. Flow analysis aids in determining the quantity of water available for generating electricity as well as the design of the hydroelectric plant. Flow analysis helps to identify the types of the flow. Various types of flows in hydrology are as follows:

1) Steady & Unsteady Flows.

2) Uniform & Non-uniform Flows.

3) Laminar & Turbulent Flows.

4) Compressible & Incompressible Flows.

5) Rotational & Irrotational Flows.

The first stage in flow analysis is to determine how much water flows through the river or stream. This is often accomplished by putting a flow meter in an appropriate point along the river. The flow meter monitors the velocity of the water and estimates the flow rate. The flow rate is then utilized to calculate the quantity of water available for power generation.

Once the flow rate has been calculated, the following step is to analyze the flow characteristics of the river or stream. This includes studying the water level, flow velocity, and direction of flow. This information is important for designing the intake structure, penstock, and turbine.

2.2.4. FLOW DURATION CURVE

A flow duration curve (FDC) is a graphical representation of the frequency and duration of streamflow or river flow in a given watershed or catchment area. It is a plot of percentage of time during which a given discharge value is equaled or exceeded against the corresponding discharge value. In other words, it shows the cumulative distribution of streamflow over time, from highest to lowest discharge values. FDC are an important tool for understanding the hydrological regime of a watershed or catchment area, and for making informed decisions about the management and use of water resources.

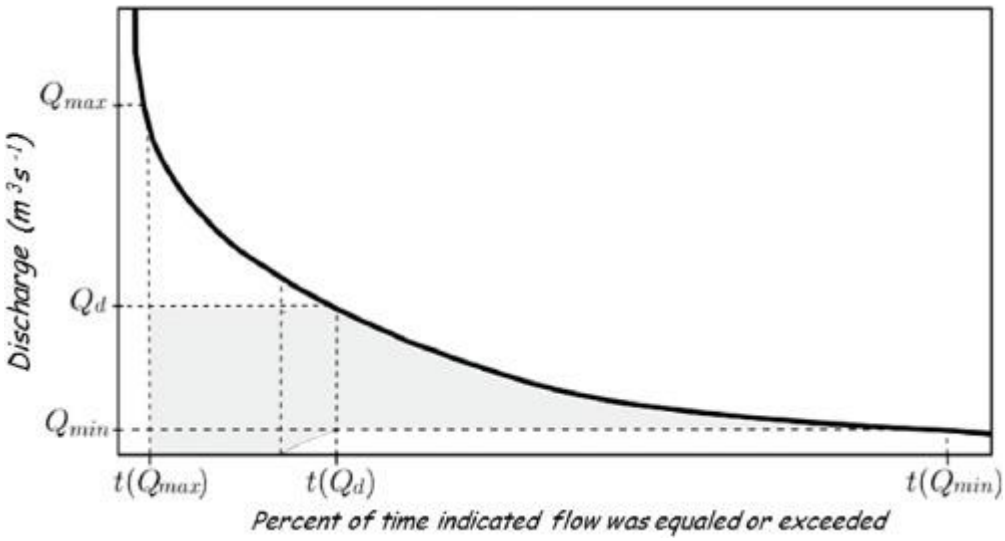


Figure 2 : Flow Duration Curve (Jarrett, R. D, 1990)

2.2.5. RATING CURVE

A rating curve is a graphical relationship between the water level (stage) and discharge (flow) of a river or stream. It is commonly used in hydrology to estimate the flow rate of a river based on its water level, and it is essential for flood forecasting, water resources management, and other applications.

A rating curve is typically developed by collecting water level and flow data over a range of different flow conditions. The data is then plotted on a graph, with the water level on the x-axis and the flow rate on the y-axis. A curve is fitted to the data points, which represents the relationship between water level and flow rate. The curve can then be used to estimate the flow rate for any given water level.

The shape of the rating curve depends on the characteristics of the river or stream. For example, rivers with steep channels and narrow floodplains tend to have steeper rating curves, while rivers with broad floodplains and shallow channels tend to have flatter rating curves.

Rating curves are commonly used in conjunction with river gauging stations, which measure water level and flow rate continuously. The rating curve is used to convert the water level measurements into flow rate measurements, which can then be used for various applications.

It is important to note that rating curves are specific to each river or stream and may change over time due to natural or human-induced changes in the river's characteristics. Therefore, regular updates to the rating curve may be necessary to ensure accurate estimates of flow rate.

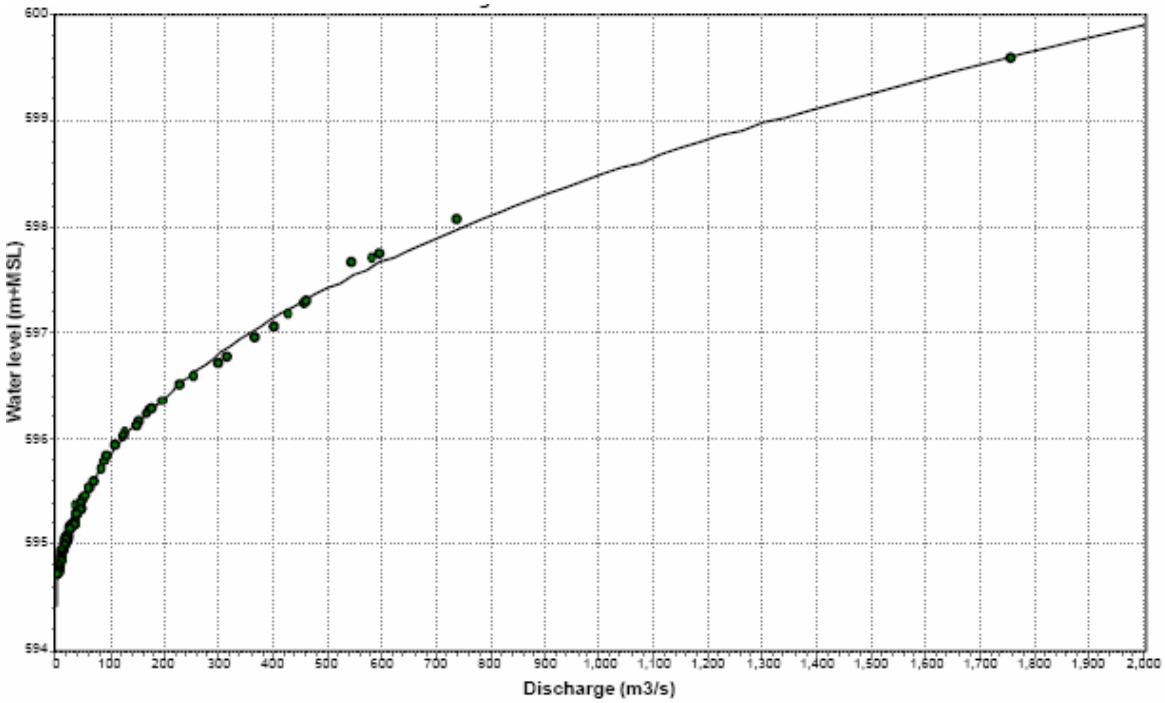


Figure 3 : Rating Curve (Jarrett, R. D, 1990)

2.3. FLOOD ANALYSIS

Flood analysis is a critical component of hydropower design and operation. Hydropower plants rely on the availability and dependability of water supplies, and flood risk management is crucial to ensuring the safety and operation of these plants. In hydropower, flood analysis is assessing the possible impact of floods on the plant and developing suitable mitigation measures to limit the risk of damage or failure.

Hydrologists utilize flood frequency analysis to anticipate flow values matching to specified return times or probabilities along a river. Gumbel pioneered the application of statistical frequency curves to floods. Gumbel, Normal, Log-normal, Exponential, Weibull, Pearson, and Log-Pearson distributions are considered as the best frequency distributions from among the available statistical distributions. Flood frequency curves are produced after selecting the probability distribution that best matches the yearly maxima data. These graphs are then used to estimate design flow values at specified return periods, which may subsequently be utilized for hydrologic planning.

Flood frequency is critical in generating estimates of flood recurrence, which is utilized in the construction of infrastructure such as dams, bridges, culverts, levees, roads, sewage disposal facilities, waterworks, and industrial buildings. These estimations are valuable in giving a measuring parameter for analyzing the damage caused by distinct flood flows.

The flood frequency curve is used to relate flood discharge values to return periods to provide an estimate of the intensity of a flood event. The discharges are plotted against return periods using either a linear or a logarithmic scale. In order to provide an estimate of return period for a given discharge or vice versa, the observed data is fitted with a theoretical distribution using a cumulative density function (CDF). This helps the users in analyzing the flood frequency curve.

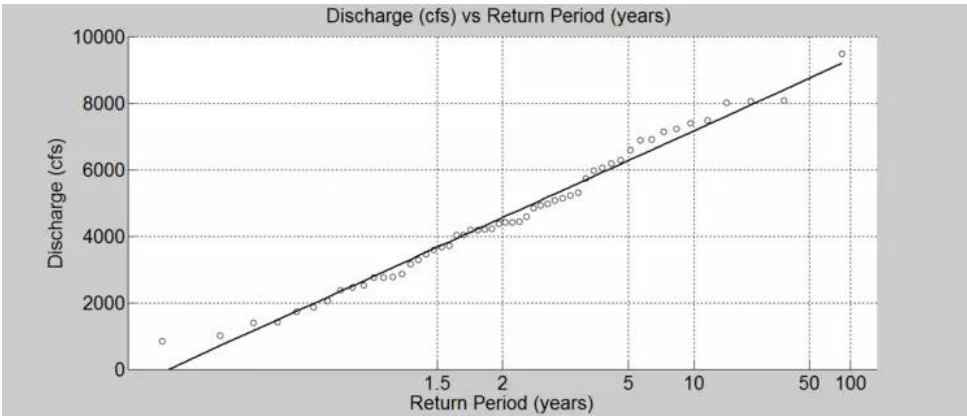


Figure 4 : Flood Frequency curve (Siddharth Saksena, 2016)

2.3.1. FLOOD PEAK ESTIMATION

For the flood peak estimation, the DoED guideline has suggested empirical formula such as WECS, MIP, CAR etc for ungauged river while statistical methods such as Gumbel's method, Log Pearson's Type III distribution method etc have been suggested for gauged river basins

2.3.2. WECS/DHM METHOD

The WECS/DHM method was developed by the Water and Energy Commission Secretariat, Department of Hydrology and Meteorology (WECS/DHM) of Nepal to determine the hydro- logical features of an ungauged basin for the pre-feasibility study of hydro-electric projects in Nepal.

In this method, the most significant independent variable is the area of the basin below 3000m elevation. This area represents the portion of the basin that is influenced by monsoon precipitation. The results of this method are not applicable to basins located entirely above 3000m elevation. Also, even if the proportion of a basin lying below 3000m is very small, the results of this method will not be particularly reliable.

As per the recommendation of the Water and Energy Commission Secretariat / Department of Hydrology and Meteorology (WECS/DHM) of Nepal, the flood flows of any river of catchment area A (km²) lying below 3000m elevation are given by:

Instantaneous Peak flood for a return period of 2 years, $Q_2 = 1.8767(A + 1)0.8783$.

Instantaneous Peak flood for a return period of 100 years, $Q_{100} = 14.63(A + 1)0.7342$

The flood flow for any other return period, T years, can be found as:

$$\boldsymbol{QT} = \boldsymbol{exp}^{(\boldsymbol{ln}\ \boldsymbol{Q2} + \boldsymbol{s\sigma})}$$

Where, A = area below 3000m elevation

σ = standard deviation of natural logarithms of annual floods = ln (Q100 / Q2) / 2.326

s = Standardized normal variate from a particular return period = 0, 0.842, 1.282, 1.645, 2.054, 2.326, and 2.576 for T = 2, 5, 10, 20, 50, 100, and 200 years, respectively.

2.3.3. RETURN PERIOD

Flood return period refers to the average length of time between floods of a certain magnitude occurring in a specific location. It is a statistical concept used in flood frequency analysis to estimate the likelihood of a flood event of a particular magnitude occurring in a given time period.

The return period is usually expressed in years, and it is calculated by dividing the total length of the data record by the rank of the flood event. For example, if a flood event of a certain magnitude has a rank of 10 in a 100-year data record, the return period would be (100+1)/10, which equals 10.1 years.

The return period provides an indication of the likelihood of a flood event of a certain magnitude occurring in a given time period. For example, a flood event with a return period of 100 years has a 1% chance of occurring in any given year. Similarly, a flood event with a return period of 50 years has a 2% chance of occurring in any given year, and a flood event with a return period of 10 years has a 10% chance of occurring in any given year.

2.3.4. GUMBEL METHOD

The Gumbel method is a statistical tool for analyzing flood frequency. It is widely used to assess the likelihood of a specific size of flood occurring in a certain time period. The Gumbel approach is based on the assumption that flood occurrences follow a certain distribution known as the Gumbel distribution.

The Gumbel technique of flood analysis generally includes the following steps:

The first step is to gather historical data on the size of floods that have occurred in the region of interest. The information should span at least 30 years.

Data arrangement: The flood data is then sorted descendingly from the greatest to the smallest flood

occurrence.

The return period is calculated as follows: The return period is the average length of time between flood events of a certain magnitude. It is calculated using the following formula:

$$T = \frac{N+1}{m}$$

where:

T = Return period (in years)

N = Number of years of flood data

m = Rank of the flood event (i.e., the number of years between the flood event and the largest flood event in the data set, plus 1)

Equation for discharge with return period T`

$X_T = \bar{X} + K\sigma_{n-1}$

Where, $\bar{x}$= mean

K= frequency factor

$$K = \frac{y_T - \bar{y}}{s_n}$$

$$y_T = -\ln(\ln(\frac{T}{T-1}))$$

$\bar{y}$ and s_n are determined from the Gumbel's distribution table

σ_{n-1}= Standard Deviation =√(((Σ(xi-$\bar{x}$))/(N-1))

Flood analysis is carried out through use of flood frequency plot.

2.3.5. LOG PEARSON METHOD

The Log Pearson Type III approach, like the Gumbel method, is a statistical methodology used for flood frequency analysis. This approach is used to calculate the likelihood of a specified size of flood occuring in a certain time period. The Log Pearson technique is based on the assumption that flood occurrences follow a certain distribution known as the Log Pearson Type III distribution.

This method is used widely in USA and is also recommended as one of the method of flood discharge analysis as per guideline of DoED. Equation for discharge with return period T

$Z_T = Z_{avg} + k_z\sigma_z$

Where, $Z_T = \log X_T$

Z_{avg}= Mean of the Z values

K_z= percentage chance

$\sigma_s = Standard\ deviation\ of\ the\ Z\ variate\ sample = \sqrt{\frac{\sum(Z-Z_{avg})^2}{N-1}}$

$C_s = G = cofficient\ of\ skew\ of\ variate = \frac{N(Z-Z_{avg})^3}{(N-1)*(N-2)*\sigma_Z{}^3}$

2.4. HEADWORKS

2.4.1. WEIR

A weir is a popular hydraulic structure used in hydroelectric projects to monitor water, regulate flow, and divert water. A weir is a concrete or masonry structure placed across a river or stream to force water to flow over it, generating a certain water level upstream of the weir (called the "crest" or "weir pool").

A weir's principal role in a hydroelectric plant is to control the flow of water to the turbine. The water pouring over the weir generates a head or height differential, which reflects the potential energy that the hydropower turbine can harvest. The flow of water to the turbine may be regulated by adjusting the height of the weir pool, which in turn affects the power production of the hydropower plant.

Commonly, the function of the weirs is to prevent flooding, measure water discharge, and help render rivers more navigable by boat. In some locations, the terms dam and weir are synonymous, but normally there is a clear distinction made between the structures. Usually, a dam is designed specifically to

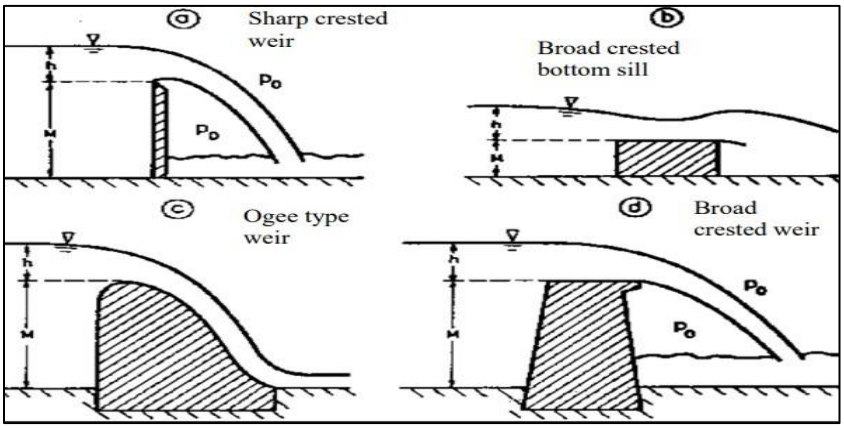


Figure 5 : Common Types of Weirs (SK GARG, 1976)

impound water behind a wall, whereas a weir is designed to alter the river flow characteristics. Some common types of weirs are shown below;

2.4.2. HYDRAULIC DESIGN OF WEIR AND UNDERSLUICE

Weir and under sluice are designed as per the Design Guidelines for Headworks or Hydropower Projects issued by Department of Electricity Development (DoED). Similarly, IS 6966-1 (1989): Hydraulic design of barrages and weir - Guidelines was also used as a reference. In this project sharp crested weir with sloping glacis has been designed. Weir and under sluice portion are separated by a divide wall. Flood walls are constructed at a higher elevation than the High Flood Level of 100 years return period i.e. 585.65 masl.

Design Procedure:

i. Suitable weir height shall be taken such that the pondage height will be enough for the design discharge of the project.
ii. The width of weir and under sluice shall be taken such that 15 % to 20 % of the flood discharge is discharged through under sluice and the overflow section (weir) is long enough to discharge the remaining flood as per the guidelines of DoED.
iii. The clear waterway is obtained from Lacey's' equation.
iv. The weir and under sluice shall safely discharge the flood discharge even in 20% concentration and 0.5m retrogression.
v. The u/s and d/s sheet piles to avoid seepage failure is designed as per IS 8414 (2014) Guidelines for design of under seepage control measures.
vi. The pre-jump and post-jump profiles of the weir is calculated using the Montague curves with the help of "Irrigation engineering and hydraulic structures" book by S.K. Garg as a reference.
vii. The thickness of weir and under sluice floor at different points of the headworks body is calculated using the following formula as we can obtain the unbalanced head from pre-jump and post-jump profile calculations.

$$\text{Thickness} = \frac{\frac{2}{3} * \textit{Unbalanced head at high flood}}{G-1}$$

viii. After the completion of design of weir and under sluice the stability of the structure is checked and factor of safety for different parameters are checked as per IS 11130- (1984) Criteria for structural design of barrages and weirs.

2.4.3. INTAKE

The intake is a crucial component of a hydropower plant as it is responsible for capturing and directing water from the source (river or stream) to the power plant. The design of an intake for a hydropower plant involves several considerations, including location, type of intake, size, screens, sedimentation

tanks, velocity, head losses, and potential risks. The intake should be located in a position that provides access to the required amount of water at the appropriate head, take into account the topography and geology of the area, take into account the topography and geology of the area, take into account the topography and geology of the area, take into account the topography and geology of the area, take into account the topography and geology of the area, take into account the topography and geology of the area, take into account the topography and geology of the area, and take into account the potential risks.

Side intake is used in this project is the side intake with bell mouth. Side intakes are simple, less expensive, easy to build and maintain and can be installed and used for all type of hydropower projects. A side intake with bell mouth is used to draw water from the river through an intake structure located on the riverside, its longitudinal axis shall be aligned perpendicular to the axis of the river. It shall be sited immediately upstream of the diversion structure (within the pocket of under-sluice portion separated by divide wall).

Design Procedure:

i. Fixing the Invert level: It is fixed based on the sediment in the river and can range from 0.5m to 2m from the river bed.

ii. Intake Opening: The area of bell mouth intake is given as,

$$Area\ of\ Intake = \frac{Area\ of\ pipe}{c_c * \cos\alpha}$$

Where, Cc = Coefficient of contraction (0.7 for low heads and 0.6 for high and medium heads)

α = Angle of inclination of central line of pipeline

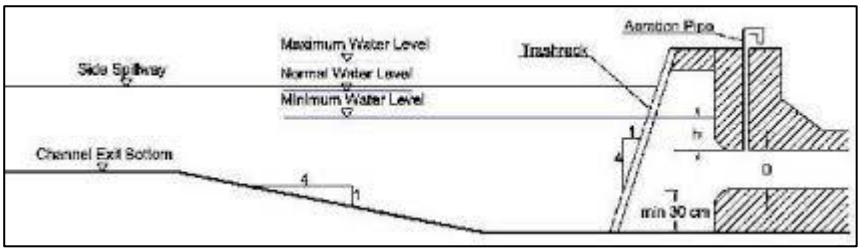


Figure 6 : Typical arrangement for side Intake (Sanjeev Baral, 2019)

2.4.4. TRASH RACK

Trashrack is a wooden or metal structure, frequently supported by masonry, that prevents water-borne debris (such as logs, boats, animals, masses of cut waterweed, etc.) from entering the intake of a water mill, pumping station or water conveyance.

Head loss in trashrack is given as:

$$h_r = k\frac{t^{\frac{4}{3}}}{a}\frac{v^2}{2g}\sin\alpha$$

Where, hf= head loss through trash rack

k= factor depending upon the shape of the bar

t= thickness of rack bars (mm)

a= clear spacing between rack bars (mm)

v= velocity of flow

α= angle of inclination of trashrack bar to the horizontal

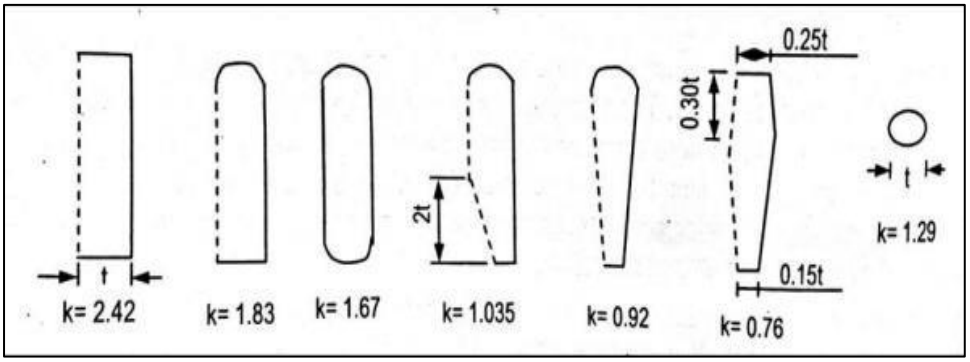


Figure 7 : Values of Trashrack coefficient

2.4.5. GRAVEL TRAP

A gravel trap is a structure used in hydropower plants to remove sediment and other debris from the water before it enters the plant. It is essentially a settling basin designed to slow down the velocity of water and allow sediment and other particles to settle to the bottom. The design of the gravel trap involves several considerations, including the size of the particles in the water, the velocity of the water, and the hydraulic capacity of the trap. The gravel trap typically consists of a basin or channel filled with coarse gravel or other materials, with a series of baffles or weirs to slow down the flow of water. The design should consider the site conditions, the size of the particles in the water, and the required flow rate, and should be validated through field measurements and other methods.

2.4.6. HYDRAULIC DESIGN OF GRAVEL TRAP

Critical Velocity:

$V_{CR}=a\sqrt{d}$

Where, a = 44 (for particle size greater than 1 mm);

d is the particle size to be transported by the flow in mm.

Length of gravel trap:

The length of settling trap shall is obtained as $L=t_{set}.V$

Where, t_{set}=h/w

L is the length of settling trap in m, t_{set} is the settling time of particle h is the depth of the flow in m and w is the settling velocity in m/s.

Flushing velocity:

$V_f = \Psi\sqrt{2gh}$

Where, Ψ is the velocity coefficient (0.60 to 0.80)

V_f is the flushing velocity in m/s

g is the acceleration due to gravity in m/s^2 and h is the differential head in m. Flushing time:

$T=V_o/Q_f$

Where, T is the flushing time in sec, V_0 is the volume of the gravel-water mixture in the gravel trap basin in m^3 and Q_f is the flushing discharge of the two-phase mixture at the gallery in $\frac{m^3}{s}$

2.4.7. SETTLING BASIN

A settling basin is a structure commonly used in hydropower plants to remove sediment and other suspended particles from the water before it enters the power plant. It works by slowing down the velocity of the water and allowing the heavier particles, such as sand, silt, and gravel, to settle to the bottom of the basin. The design of the settling basin involves several considerations, including the size and concentration of particles in the water, the hydraulic capacity of the basin, and the desired settling velocity. The settling basin typically consists of a large, rectangular tank or basin with a series of weirs or baffles to slow down the flow of water. Its design should consider the site conditions, the size and concentration of particles in the water, and the required flow rate, and should be validated through field measurements and other methods. The main principle of the design of settling basin is to reduce mean velocity of the flow, by increasing the cross- sectional area.

2.4.8. DESIGN CRITERIA of SETTLING BASIN

The basic principle of settling is that the greater the basin surface area and the lower the through velocity, the smaller the particles that can settle. A settling basin has a significantly larger cross- sectional area than the headrace canal and therefore the flow velocity is lower which allows the settling of the suspended materials. A settling basin must satisfy the following three criteria:

1. **Settling capacity:**

The length and width of the basin must be large enough to allow a large percentage of the fine sediment to fall out of suspension and be deposited on the bed. The sediment concentration, the geometry of the

inlet, the width of the basin and any curvature must be such as to cause minimum turbulence, which might impair the efficiency.

2. **Storage capacity:**

The basin should be able to store the settled particles for some time unless it is designed for continuous flushing. Continuous flushing mechanisms are however not incorporated in micro hydro schemes due to the complexity of the design and the flow of water during the low flow season. Hence, the storage capacity must be sufficiently large that the basin does not require frequent flushing.

3. **Flushing capacity:**

The basin should be able to be operated to remove the stored particles from it. This is done by opening gates or valves and flushing the sediment along with the incoming flow in the basin. The bed gradient must be steep enough to create velocities capable of removing all the sediment during flushing.

2.4.9. COMPONENTS OF SETTLING BASIN

- **Inlet Transition:**

The inlet transition for settling basins shall be designed to prevent turbulent flow at the entrance to the settling basin chamber. The approach canal to the settling basin shall have a straight alignment for a stretch equal to about 10 times the width of the canal upstream of its junction to maintain an even flow distribution at the start of the inlet transition. The hydraulic design of the canal shall eliminate secondary currents in its flow caused by rotational flow. It shall also ensure flow velocities in the range of 1.1 to 1.3 m/s. To maintain gradual expansion of inlet channel, set the horizontal expansion ratio at about 1:5(or $\alpha = 7°$ to $15°$). The vertical expansion ratio can be set at about 1:2 (or $\alpha = 20°$ to $30°$). If space constraints do not permit a straight section of approach canal, even flow in the settling basin, may be achieved using a tranquilizer or baffle blocks. (Sanjeev Baral, 2019)

- **Settling chamber**:

The hydraulic design of the settling chamber should be carried out to secure an even flow distribution between parallel settling basins for various flows and even flow distribution inside each basin. Efficient removal of deposits during flushing of the basin is most for settling basin. Design parameters includes:

  - Mean depth of flow in the basin
  - Mean longitudinal velocity
  - Fall velocity
  - Flushing discharge
  - Sediment concentration of flow

- **Outlet Zone**:

The operation water level of the settling basin is controlled at the outlet zone. The outlet zone is designed

for decanting the outflow from the settling basin over a small weir/ spillway or simple transition structure. The major parts included in the outlet zone are: transitions to headrace/ forebay inlet with or without control gate mechanism, sediment flushing gate/valves arrangements. The outlet transition can be more abrupt than the inlet expansion. The horizontal and vertical expansion ratio can be set at about 1:2 and 1:1 respectively.

2.4.10. DESIGN OF SETTLING BASIN:

Following factors should be considered in the design of the settling basin

Characteristics of suspended sediments, particles of hard or soft rock or soil origin

i. Concentration of sediments with the river flow

ii. Required removal percentage of suspended sediments

a) Calculate surface area

$$As = KQ/wt$$

Where, As = the required surface area of a settling basin wt= target sediment particle size with a fall velocity

Q= the design flow rate K= coefficient to account for turbulence (Range between 1.2 to 1.5)

b) Calculate L and B using the relation

$$\boldsymbol{L/B} = 4 \text{ to } 10$$

As=L.B

And check for necessary length and breadth using other approaches.

c) Calculate the limiting flow velocity (Vc) in the basin

$$\boldsymbol{Vc = a\sqrt{D}}$$

Where, d= size of gravel to be removed in mm

a= 0.36 for, d>1 mm =0.44 for 1 mm>d>0.1 mm =0.51 for 0.1 mm>d

Note: The maximum horizontal velocity of flow to allow the sand grain to fall out should not be greater than 0.3 m/s

d) Calculate depth (D) of basin

$$\boldsymbol{V = \frac{Q}{BD}}$$

$$\boldsymbol{D = \frac{Q}{VB}}$$

Where, Q= design flow rate (m3 /s)

B= width of the settling basin

v= horizontal flow velocity (m/s)

e) Check the calculated values of L, B, H

Check Width $B = 4.75\sqrt{\boldsymbol{Q}}$

M.A. Velikanov's Method

$$L = \frac{\left(\lambda^2 v^2 \left(\sqrt{h} - 0.2\right)^2\right)}{7.51w\text{^}2} m$$

Where, λ depends on the removal ratio, defined by the function λ=f (W) Where W denotes the ratio of settled sediment to the total load entering with the flow and given by

$$W = 100 - 100\frac{C_p}{C}\%$$

Trap efficiency computation methods

To determine the efficiency of the settling basin following methods are suggested by textbooks:

a) Vetter's method

b) Camp's Method

c) Hazen's Method

- **Vetter's method**

$$\eta = 1 - e^{-\left(\frac{wAs}{Q}\right)}$$

- **Camp's Method**

$$\eta = f\left\{\frac{wA_s}{Q}, \frac{w}{V}\right\}$$

Where;

As = basin surface area

V = shear velocity

Se = hydraulic gradient

M = Manning's number (1/n)

The trapping efficiency is read in the below figure (Fig 4.12) for the computed values of w/v and wA_S/Q.

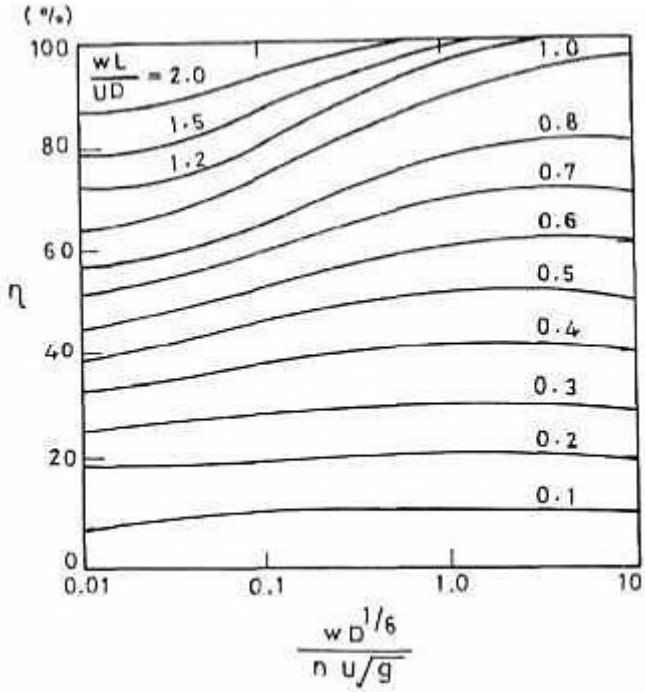


Figure 8 : Camp's diagram for sediment trapping efficiency

- **Hazen's Method:**

$$1-\eta = \left[1 + \frac{mwA_S}{Q}\right]^{-\frac{1}{m}}$$

Where, m = performance parameter (m=0 for best and m=1 for very poor)

2.5. UNDERGROUND STRUCTURE

2.5.1 GENERAL

In the context of hydropower development in Nepal, the country's rugged topography and steep river gradients provide excellent conditions for high-head power generation. To harness this potential efficiently, tunnels are preferred, particularly in mountainous terrain where surface conveyance is limited by land availability, slope instability, and environmental concerns.

However, the geological complexity of Nepal poses significant challenges to underground construction. The region is part of the young and tectonically active Himalayan belt, characterized by intensely folded, faulted, and sheared rock masses. This results in weak, anisotropic geological formations such as phyllite, schist, quartzite, and limestone, especially within the Lesser Himalayan Zone. As a result,

tunnel development requires detailed geological investigations, proper planning, and the use of appropriate excavation techniques. Factors such as rock mass behavior, groundwater conditions, and construction risks must be thoroughly assessed to ensure tunnel stability, safety, and cost-effectiveness.

2.5.2. ROCK MASS CLASSIFICATION

Rock mass classification plays a crucial role in the design of tunnels, as it helps to assess the strength and behavior of the rock to ensure stability and safety during construction. In the Himalayan region of Nepal, the most commonly used classification systems are the Rock Mass Rating (RMR) system developed by Bieniawski (1989), the Q-system or Rock Mass Quality Index introduced by Barton et al. (1974), and the Geological Strength Index (GSI) proposed by Hoek and colleagues between 1994 and 2005. These methods assess rock mass quality by combining geological and engineering parameters to provide a numerical rating.

RMR and the Q-system use similar inputs, such as joint spacing, condition, and groundwater, but differ in weighting and approach. RMR directly includes uniaxial compressive strength (UCS), while the Q-system considers strength through a stress reduction factor. GSI, on the other hand, is a more visual and descriptive method, often used with numerical models for estimating rock strength. These classification systems are critical in Nepal's weak and fractured rock formations for planning safe and cost-effective tunnel construction.

2.5.3. ROCK MASS RATING (RMR)

The Rock Mass Rating (RMR) system, also known as the Geomechanics Classification, was developed by Bieniawski and later refined based on extensive case studies. The widely used 1989 version classifies rock masses using six key parameters: uniaxial compressive strength of the rock material, Rock Quality Designation (RQD), spacing of discontinuities, condition of discontinuities, groundwater conditions, and orientation of joints. The site is typically divided into geological units, and each parameter is assigned a rating to calculate the overall RMR value. This system provides guidelines for excavation and support design in tunneling projects.

projects.

2.5.4. ROCK MASS QUALITY (Q-SYSTEM)

The Rock Mass Quality (Q) system was developed by Barton et al. (1974) at the Norwegian Geotechnical Institute based on over 200 tunnel and cavern case studies. It is a quantitative classification method widely used for the empirical design of tunnel support systems. The Q-value is calculated using six key parameters: Rock Quality Designation (RQD), joint set number (Jn), joint roughness (Jr), joint alteration

(Ja), joint water reduction factor (Jw), and stress reduction factor (SRF), as shown in the equation:

$$Q = \frac{RQD}{Jn} * \frac{Jr}{Ja} * \frac{Jw}{SRF}$$

The Q-values range logarithmically from 0.001 to 1000 and are used with support charts to select appropriate tunnel support systems based on excavation size and safety requirements. In poor quality rock (Q < 1), reinforced ribs with shotcrete (RRS) are often preferred. The Q-system is considered one of the most effective classification systems for support design and has been extended to broader rock mass characterization (Barton, 2002). In the support chart shown in Figure 19, the Q values are plotted along the horizontal axis and the Equivalent dimension along the vertical axis on the left-hand side. For the given combination of Q- value and Equivalent dimension, a given type of support has been used and the support chart has been divided into areas according to type of support.

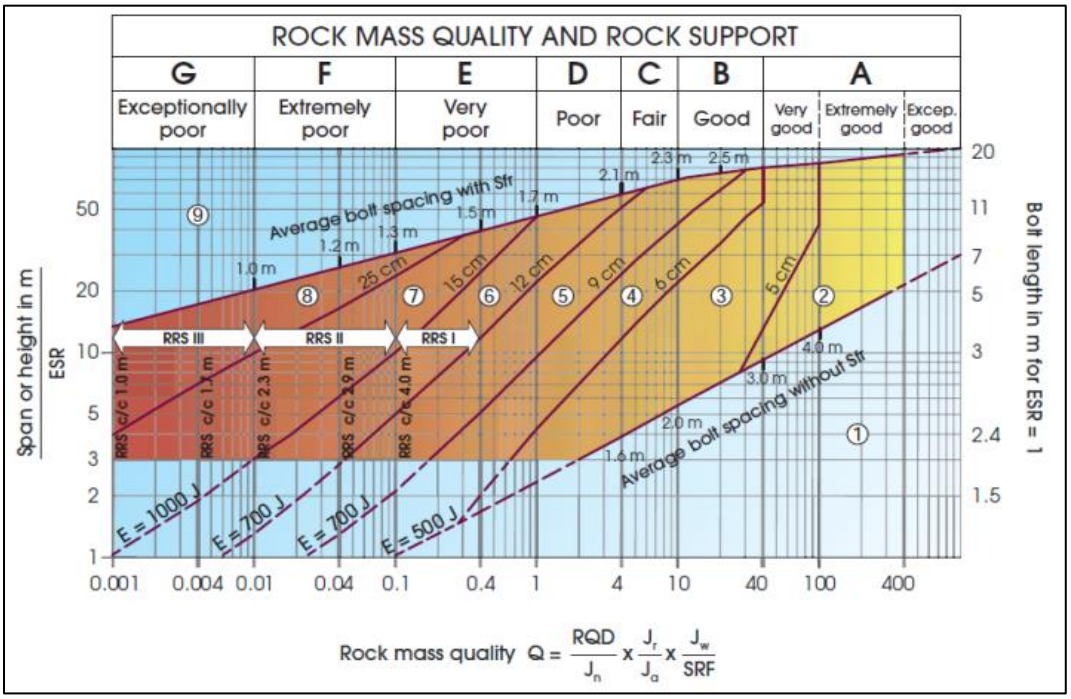


Figure 9 : Permanent support recommendations based on Q values and span/ESR

2.5.5. GEOLOGICAL STRENGTH INDEX (GSI)

The Geological Strength Index (GSI), proposed by Hoek (1995), is a rock mass characterization method developed to provide reliable input parameters for numerical analysis in the design of tunnels, slopes, and foundations. Unlike other systems, GSI relies on the visual assessment of the rock mass structure and the condition of the rock material, making it especially useful in weak or complex geological conditions. GSI, by avoiding dependence on RQD and focusing on geological observations, offers a more suitable alternative for estimating rock mass properties—especially in difficult tunneling environments.

The general approach adopted for design and estimation of tunnel support in the Himalayan region of Nepal is shown in the Figure 10

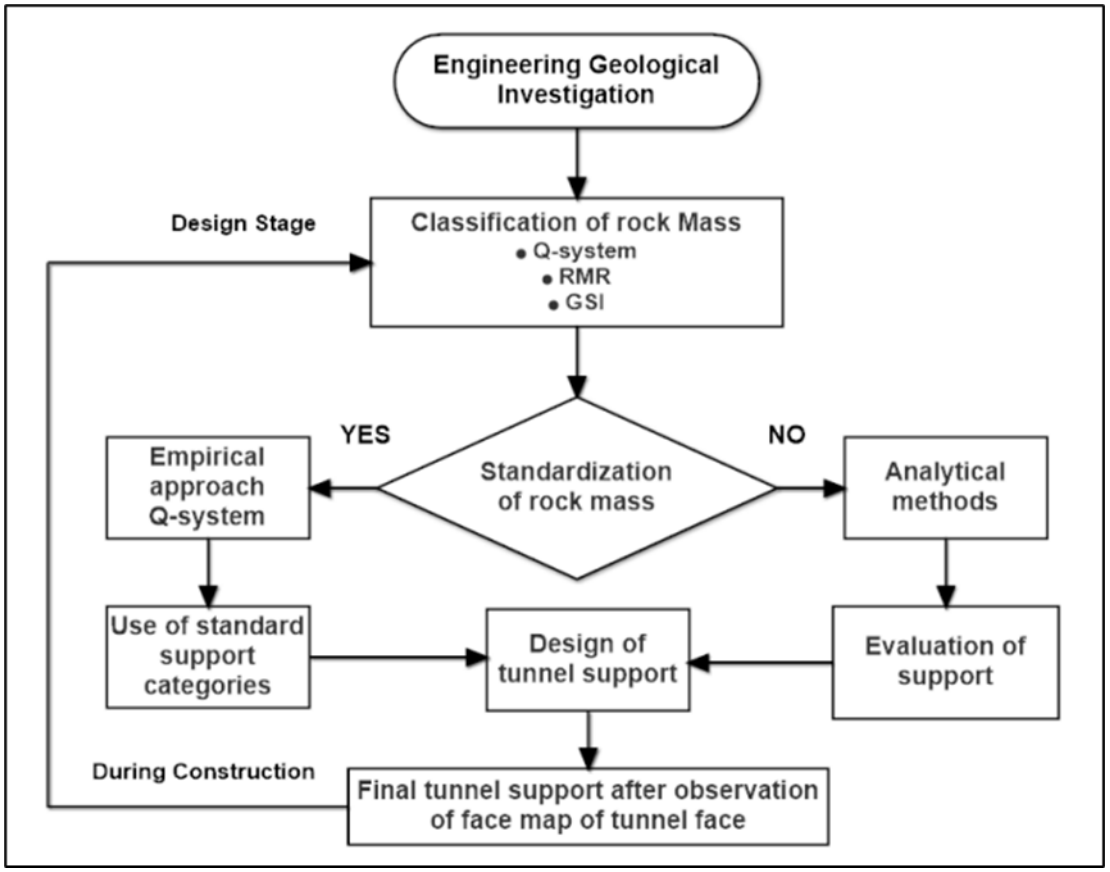


Figure 10 : General flow chart for design of tunnel support

2.5.6. ROCK SUPPORTS

Rock bolts are among the most commonly used support elements in tunnels. Their primary function is to stabilize rock by holding it together and preventing movement. Although the design of rock bolts is largely experience-based, it involves selecting the appropriate bolt type, as well as determining the suitable length and spacing based on rock conditions. Typically, rock bolts are plain steel rods anchored mechanically or chemically at one end, with a face plate and nut on the other. They are tensioned after installation to provide immediate support.

2.5.6.2 SHOTCRETE

Shotcrete is a type of concrete or mortar that is sprayed onto rock surfaces using high-pressure air. It is widely used in tunnel support systems to provide immediate surface stabilization. Shotcrete adheres well to uneven surfaces and helps bond loose rock fragments, reducing the risk of falls or collapses. Depending on the application, shotcrete can be applied as dry-mix or wet-mix. For added strength and

durability, it may include steel fibers or wire mesh reinforcement. It is especially effective in combination with other support elements like rock bolts and steel ribs, forming an integrated support system that adapts to varying ground conditions.

2.5.6.2. CONCRETE LINING

Concrete lining is a permanent support method used in tunnels to provide structural stability and durability. It involves placing cast-in-place or precast concrete along the tunnel after excavation and initial support. Concrete lining improves the tunnel's load-bearing capacity, controls water ingress, and offers a smooth, finished surface suitable for long-term use. It is commonly applied after temporary supports like shotcrete and rock bolts, ensuring safety during construction and enhancing long-term performance. In tunnels with high groundwater pressure or soft ground conditions, reinforced concrete lining is often used to prevent deformation and leakage.

2.5.6.3. STEEL RIBS

Steel ribs are widely used as primary support systems in tunnel construction, particularly in weak or unstable ground conditions. These structural elements are typically made of rolled steel sections (such as I-beams or H-beams) and are installed in a series along the tunnel perimeter to form a continuous frame. Steel ribs provide immediate support by resisting ground pressure and controlling deformation during and after excavation. They are often used in combination with other support systems such as rock bolts, shotcrete, and lagging to enhance stability. The spacing and shape of the ribs depend on the ground conditions, tunnel size, and design requirements.

2.5.7. NUMERICAL MODELLING BY PHASE 2

In numerical analysis for tunnel design, it is essential to incorporate accurate engineering geological parameters of the surrounding rock mass. These parameters significantly influence the simulation results, particularly in estimating rock mass behavior, deformation, and required support systems. Due to the complex and variable nature of geological conditions, direct laboratory modeling is often impractical.

The RS2 (Phase2) finite element software is used to analyze stress distribution and plastic zones around the tunnel. The Generalized Hoek-Brown failure criterion is applied to estimate rock mass strength and yield zones, assuming elastic rock behavior. RS2, a 2D finite element tool, enables detailed analysis of deformation, stress fields, and support performance for underground excavations and other geotechnical

applications. For the simulation, in-situ stress conditions are considered with σ_1 (major principal stress) and σ_3 (minor principal stress) assumed as horizontal and vertical stresses, respectively.

2.6. WATER CONVEYANCE SYSTEM

2.6.1. PENSTOCK

Penstocks are like large pipes laid with some slope which carries water from intake structure or reservoir to the turbines. They run with some pressure so, sudden closing or opening of penstock gates can cause water hammer effect to the penstocks. So, these are designed to resist the water hammer effect apart from this penstock is similar to normal pipe. To overcome this pressure, heavy wall is provided for short length penstock and surge tank is provided in case of long length penstocks.

Steel or Reinforced concrete is used for making penstocks. If the length is small, separate penstock is used for each turbine similarly if the length is big single large penstock is used and at the end it is separated into branches. A general alignment for penstock is shown in figure 11 below,

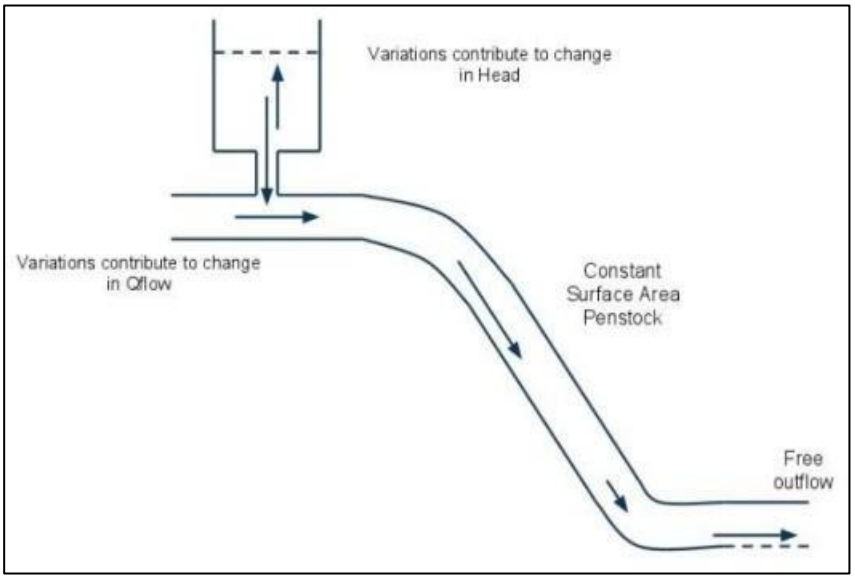


Figure 11 : General Alignment of Penstock (Sanjeev Baral, 2019)

2.6.2. PENSTOCK HEAD LOSS

Velocity of flow $V = \frac{4Q}{\pi D^2}$

Where: V is velocity in m/s. Q is design flow in m3 /s.

d is the pipe internal diameter in m.

Total head loss = wall loss + turbulence losses wall losses are calculated as follows:

First, we determine the roughness value, 'k' in mm and then use the Moody Chart to find the corresponding friction factor f for the selected pipe material, diameter and the design flow.

The wall loss can now be calculated from either of the following equations:

$$h_{loss}=\frac{fLv^2}{2gD}$$

Turbulence losses are calculated as follows:

$$h_{turboloss} = \frac{v^2}{2g}(K_{Entrance} + K_{Bend} + K_{Contraction})$$

Where K is head loss coefficients.

Economic diameter of penstock

There are two ways for determining the economic diameter of the penstock:

Analytical method of penstock optimization

Graphical method of penstock optimization

Out of these two alternatives, graphical method of penstock optimization is used. Graphical method of penstock optimization Monthly revenue and energy can be calculated from the monthly discharge data, head, and design discharge. The steel rate, discount rate, and project life are used to calculate expenditure. So, the economic diameter is a function of head loss, cost and the value of energy.

The thickness of pipe is determined by following formula:

$$t = \frac{PR}{\sigma\eta} + 0.15$$

Where,

t = thickness of pipe

P = internal pressure, kg/cm^3 R = internal radius of pipe

η = joint efficiency factor

σ = Allowable tensile stress

0.15 cm is for the corrosion allowance

Knowing thickness, calculate of approximate volume per meter as = $(\pi * d * t) * 1$

Then, by knowing the density of the steel, calculate the weight of steel and thus the cost of penstock pipe per meter = C_t

From monthly discharge data and design discharge, annual energy is calculated and multiplying it by rate, total revenue loss can be calculated. Total cost of energy loss is continued up to the life of the penstock. If n is the life of penstock and A is the annual revenue loss,

Present value of energy loss= $C_e = \frac{A\{(1+i)^n - 1\}}{i(1+i)^n}$

The procedure is repeated for different diameters. For different diameters, the present value of energy loss is calculated and plotted to get optimum diameter.

2.6.3. SURGE TANK

A surge tank is a water storage tank or reservoir that is commonly used in hydropower plants as a means of regulating water pressure and flow rate within the system. The function of a surge tank is to absorb and regulate pressure and flow rate fluctuations in the hydropower system, particularly during start, shutdown, or sudden changes in load.

In a hydropower system, the water flows from the penstock into the turbine, which converts the energy of the water into mechanical energy. The surge tank is typically located at the downstream end of the penstock, just before the turbine. Its primary's function is to absorb the pressure and flow rate fluctuations that occur during sudden changes in the hydropower system.

During normal operation, the surge tank is filled with water up to a predetermined level. When there is a sudden increase in the demand for power, such as during startup or an increase in load, the water is drawn out of the surge tank to meet the demand. Conversely, when there is a

sudden decrease in the demand for power, such as during shutdown or a decrease in load, the excess water is directed back into the surge tank.

The surge tank is an important component of a hydropower system, as it helps to maintain a stable and constant flow rate and pressure within the system. This is particularly important during sudden changes in load, as it helps to prevent damage to the turbine and other equipment, and ensures that the hydropower plant operates efficiently and reliably.

The design of the surge tank should take into account the site conditions, the size and capacity of the hydropower system, and the expected load and flow rate fluctuations. Proper sizing and design of the surge tank can help to ensure that the hydropower system operates reliably and efficiently, with minimal wear and tear on the equipment.

2.6.3.1. HYDRAUIC DESIGN OF SURGE TANK

The starting time is given as:

$$T_w = \frac{\mathbf{L \times v}}{\mathbf{g \times H}} > 3.0s$$

Where; Tw = starting time (if grid stabilization is required 2.5 s)

v = flow velocity (m/s)

g = gravity acceleration constant

For stability of governing a minimum cross section area (THOMA Criterion) of the surge tank is required

$$A_{st},n = \frac{\mathbf{LH \times AH}}{\mathbf{HL,min \times (H - HL,min)}} \times \left(\frac{\mathbf{vH\ 2}}{\mathbf{2g}}\right)$$

Where; L_H = length of headrace tunnel, (m) A_H = area of headrace tunnel, (m²) $H_{L,min}$ = minimum head loss in tunnel, (m) H = minimum gross head, (m) v_H = velocity in headrace tunnel, (m/s) .In order to sufficiently dampen possible oscillations a safety factor n is applied to the minimum surge tank area varying in the range n = 1.3 … 1.6:

2.6.3.2. LOAD CASES

The load cases producing maximum up and down-surges are described in the following for three turbine units for a surge tank at the end of a headrace tunnel. In the event of a different number of turbines they must be modified accordingly.

- **Load Case I: Maximum Down surge**

Full load acceptance of one turbine is followed by the other turbines after a time interval to be defined. For this load case the minimum reservoir level and the maximum head losses have to be considered. The minimum down surge occurs approximately at a time interval equal to T/2

$$T = 2\pi \times \sqrt{\frac{L \times A_{st}}{g \times A_H}}$$

where T is the period of the surge oscillation.

- **Load Case II: Maximum Down surge**

The maximum down surge may alternatively occur for a load reduction by 50 per cent and subsequent complete load acceptance. For this load case the minimum reservoir level and the maximum head losses have to be considered, too.

- **Load Case III: Maximum Upsurge**

The most unfavorable load case with regard to the upsurge is a total load rejection subsequent to Load Case 1 or Load Case 2. The load case producing the higher discharge in the pipe prior to rejection is the relevant one. For load case 3 the maximum water level in the reservoir and the minimum head losses must be considered.

2.6.4. ANCHOR BLOCK AND SUPPORT PIERS

Anchor blocks rigidly hold the penstock pipe. It is normally provided at every bend and at every 30m span of straight sections of penstock line. It should be provided immediately upstream of powerhouse to minimize the penstock load on turbine.

Support piers support the penstock vertically and prevent the penstock from sagging. It allows the axial movement of penstock. It is generally provided at the span of 3m interval in MHP.

2.6.4.1. DESIGN OF ANCHOR BLOCKS AND SUPPORT PIERS

The design of anchor blocks and support piers requires calculation of forces acting on it. First the structures are tentatively sized and the various forces that act on them are resolved. Various forces that can act on anchor blocks and support piers are:

i. Component of the weight of pipe and enclosed water perpendicular to the pipe alignment,

ii. Frictional force of pipe on support piers,

iii. Force due to hydrostatic pressure within a bend,

iv. Force due to the component of the weight of pipe parallel to the pipe alignment,

v. Force that is transmitted to the anchor block due to thermally induced stresses in the absence of an expansion joint,

vi. Force due to friction within the expansion joint,

vii. Hydrostatic force on exposed ends of pipe expansion joints,

viii. Dynamic forces at the pipe bend,

ix. Force exerted due to the reduction of pipe diameter,

x. Force on the anchor blocks or support piers due to the soil pressure acting on the upstream face.

2.6.4.2. SAFETY CHECK OF ANCHOR BLOCK

1. Safety against overturning

Finally, e should be greater than $e_{allowable}$.

2. Safety against bearing

$$P_{base} = \frac{\sum V}{A_{base}}(1 + \frac{6e}{L_{base}})$$

Where:

P_{base}= maximum pressure transmitted to the foundation

V= the sum of the vertical forces acting on the anchor block

L_{base}=Length of base

A_{base}= the base area of the block

e=eccentricity calculated

The calculated P_{base} must be less then the allowable bearing pressure($P_{allowable}$)

3. Safety against sliding

$$\frac{\sum V}{\sum H} \geq 1.5$$

Where:

$\sum V$= sum of vertical force

$\sum H$=sum of horizontal force

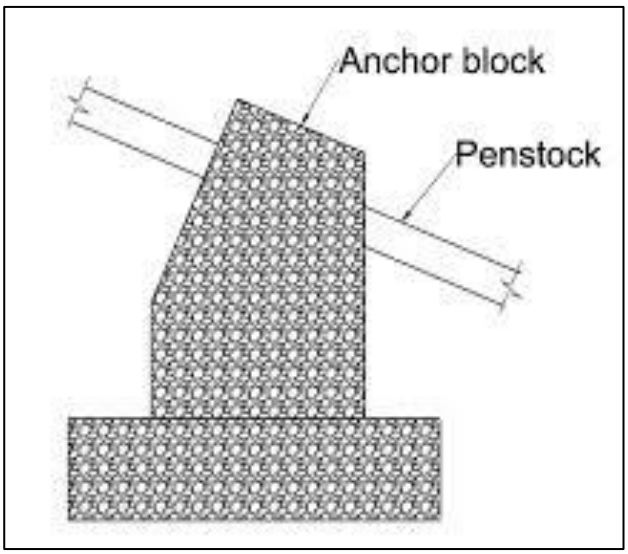


Figure 12 : Anchor Block (Rishiraj P Moni, 2018)

2.7. POWER HOUSE

Power house is a building provided to protect the hydraulic and electrical equipment. Generally, the whole equipment is supported by the foundation or substructure laid for the power house. In case of reaction turbines some machines like draft tubes, scroll casing etc. are fixed with in the foundation while laying it. So, the foundation is laid in big dimensions. When it comes to super structure, generators are provided on the ground floor under which vertical turbines are provided. Besides generator horizontal turbines are provided. Control room is provided at first floor or mezzanine floor.

2.7.1. ARCHITECTURAL LAYOUT OF POWERHOUSE

Three essential constitutes (bay) of superstructure of powerhouse are:

Unit Bay

Erection or Loading Bay

Control Bay

Length:

For determination of unit bay length, 1.5m to 2m clearance is added on either side of the hydro- mechanical equipment and the unit spacing is determined. Length of erection bay is taken as 1 to 1.5 times the unit bay. The total length of power house for placement of Hydromechanical equipment can be determined by the formula:

$L = N_o \times (Unit\ Spacing) + L_e + K$

Where, L = Total length of powerhouse required for placement of hydro-mechanical equipment N_o = Number of units

L_e = Length of erection bay

K = Length required for the E.O.T crane to handle the last unit. (3 to 5m)

Width:

Width of superstructure column should be 2 to 2.5m from the extremities of hydro-mechanical equipment on the downstream and 3 to 4m on the upstream.

Height:

Total height of the power can be calculated as

$H = H_1 + H_2 + H_3$

Where, H= total height of power house

H_1 = Vertical Length of draft tube from center of turbine

$H_2 = L_t + h_j + K$ = c/c distance between generator and turbine H3 = Height above generator

L_t = Length of stator frame

h_j = Height of load bearing bracket

K= 5.5 to 7m depending upon size of machine

Loading Bay

Loading bay, also known as erection bay or service bay, is a space where the heavy vehicles can be loaded and unloaded, the dismantled parts of the machines can be placed and where small assembling of the equipment ‘s can be done. The loading bay should be sufficient to receive the large parts like rotor and runner. The loading bay floor will be having a width at

least equal to the center-to-center distance between the machines.

Control Bay

Control bay is the main room and control other equipment ‘s like runner, gate valves, generator etc. it may be adjacent to the unit bay i.e., machine halls as it sends instructions to the operation bay from where the operation control is received.

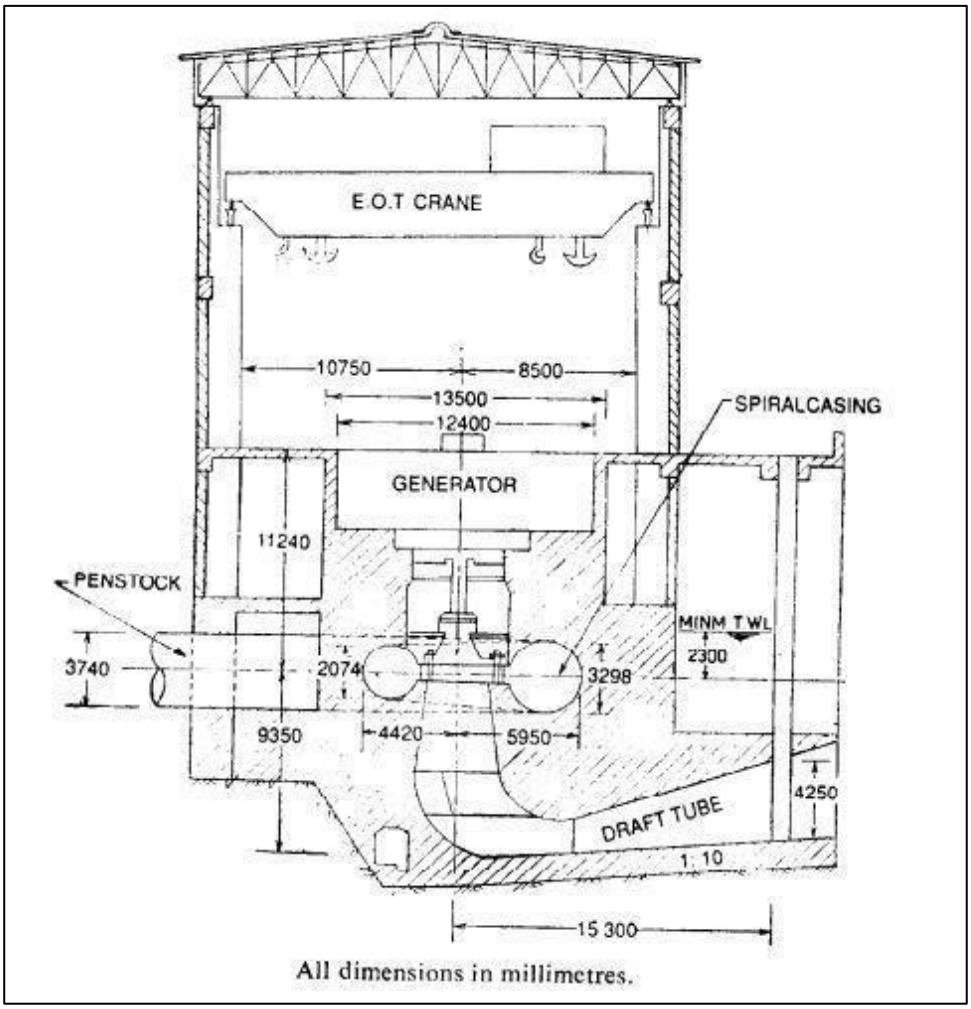


Figure 13 : Cross section of Power House (Bureau of Indian Standards., 1998)

2.7.2. SELECTION OF TURBINE

Turbine selection and plant capacity determination require detailed information on head and possible plant discharge.

It has been seen that various parameters can be changed to achieve the best installation. The usual practice is to base the selection on the annual energy output of the plant and the least cost of the energy of scale of hydropower installation. The turbine that we have selected is a vertical axis Pelton turbine based on several criteria. Factors to be considered while selecting a turbine:

Available head and its functions

Very high head (> 350 m) – Pelton turbine (no other)

High head (150 – 300 m) – Pelton or Francis turbine (For higher specific speed, Francis turbine is more compact and economical than Pelton turbine)

Medium head (60 – 150 m) – Francis turbine

Low head (Below 60 m) – Between 30-60 m both Kaplan and Francis turbines can be used. The former is more expensive but yields higher efficiency at part load and overload. Kaplan turbine is generally used under 30 m. Propeller turbines are commonly used for heads up to 15 m. They are adopted only when there is practically no-load variation.

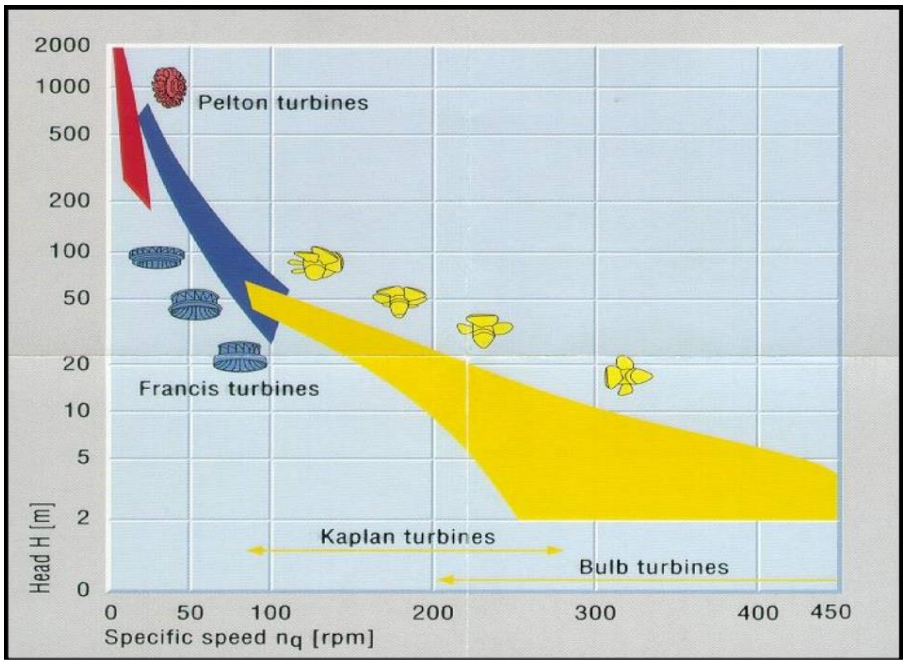


Figure 14 : Specific Speed vs Head (Bureau of Indian Standards., 1998)

Specific speed

High specific speed is essential where the head is low, and the output is large because otherwise, the rotational speed will be low which means the cost of the turbo generator and powerhouse will be high. On the other hand, there is practically no need of choosing a high- value specific speed for high installation because even with a low specific speed high rotational speed can be attained with the medium capacity plant.

Rotational speed

Rotational speed depends upon a specific speed. Also, the rotational speed of an electrical generator with which the turbine is to be directly coupled depends on the frequency and number of pair poles. The

value of the specific speed adopted should be such that will give the synchronous speed of the generator.

Efficiency

The turbine selected should be such that it gives highest overall efficiency for various operating condition.

Deposition of the turbine shaft

Experience has shown that the vertical shaft arrangement is better for large sized turbine; therefore, it is almost universally adopted. In case of large sized turbine, horizontal shaft arrangement is almost employed.

Conveyance or Maintenance

Maintenance of the reaction turbine is costlier than the impulse turbine.

Water Quality

The quality of water is more crucial for reactive turbine than reaction turbine.

2.7.3. SELECTION OF NUMBER OF UNITS:

It is most effective to have a minimum number of units at a given installation. An increase in turbine size increases the efficiency of the plant. However, multiple units may be necessary to make the most efficient use of water where flow variation is great. Factors such as space limitation by geological characteristics of the existing structure may dictate large or small units. The difficulty in transportation or large runners sometimes makes it necessary to limit their size. An isolation system may require a greater number of units. The percentage of load covered by the plant is another important factor if the contribution of the plant to the system is more; the number of units should be more. For the power plant, it is better to make the units identical also somehow dictates the number of plants. If the power generation from the plant is fluctuating, the number of units will be increased and vice versa.

2.7.4. FRANCIS TURBINE

The modern Francis turbine is an inward mixed flow reaction turbine (the Francis turbine had a purely radial flow runner in earlier stages of development), which means that water under pressure enters the runner from the guide vanes towards the center in a radial direction and discharges out of the runner axially. The Francis turbine uses a medium amount of water and operates at medium heads. It is used in medium-head power plants. This type of turbine can handle a broad variety of heads. Water is routed to a number of stationary orifices positioned all around the perimeter of the runner through a penstock brought down to the turbine. These fixed orifices are also known as guide vanes or wicket gates.

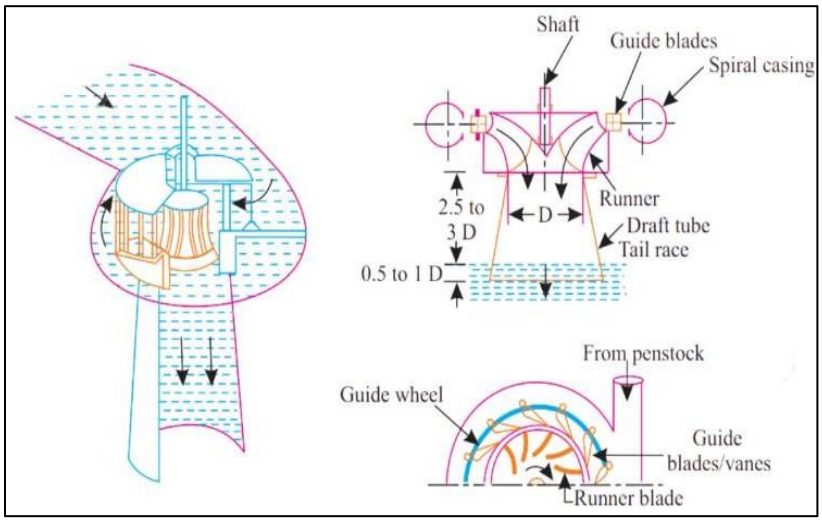


Figure 15 : Schematic Diagram of Francis Turbine (RK Rajput, 2016)

The figure shows a schematic diagram of a Francis turbine. The main parts of a Francis turbine are:

Penstock: It is a large size conduit that conveys water from the upstream of the dam/reservoir to the turbine runner.

Spiral/scroll casing: It constitutes a closed passage whose cross-sectional area gradually decreases along the flow direction, the area is maximum inlet and nearly zero at the exit.

Guide vanes/wicket gates: These vanes direct the water onto the runner at an angle appropriate to the design. The motion to them is given by means of a hand wheel or automatically by a governor.

Governing mechanism: It changes the position of the guide blades/vanes to affect a variation in water flow rate when the load conditions on the turbine change.

Runner and runner blades: The driving force on the runner is both due to impulse and reaction effects; The number of runner blades usually varies between 16 to 24.

Draft Tube: It is a gradually expanding tube that discharges water, passing through the runner to the

tail race.

The head operating on the turbine is partially converted into kinetic energy, with the remainder remaining as pressure head. The response pressure is the differential in pressure between the guide vanes and the runner, and it is responsible for the runner's motion. As a result, a Francis turbine is often referred to as a response turbine.

The pressure at the inlet of a Francis turbine is greater than the pressure at the outlet. This means that the water in the turbine must flow through a closed tube. Unlike the Pelton turbine, where water only strikes a few of the runner buckets at a time, the Francis turbine's runner is always full of water. The runner's moment is impacted by changes in both the potential and kinetic energy of water. After finishing the work, the water is discharged to the tail race via a closed tube with a gradually expanding portion. This is known as a draft tube. It does not enable water to descend freely to the tail race level as the Pelton turbine does. The free end of the draft tube is immersed deep in tailwater, completely enclosing the whole water flow from the head race to the tail race.

2.8. ECONOMIC CONSIDERATION FOR HYDROPOWER PROJECT DESIGN

The economic considerations for hydropower project design include the project's financial viability, cost estimation, and economic evaluation. The financial viability of the project depends on various factors such as the capital cost, operating cost, revenue, and financing options. The cost estimation should consider the various components of the project such as civil works, electro-mechanical equipment, and transmission lines. The economic evaluation should consider various factors such as the net present value, internal rate of return, and payback period to assess the project's economic feasibility.

2.9. SOCIAL AND ENVIRONMENTAL CONSIDERATION FOR HYDROPOWER

Hydropower project design in Nepal should also consider the social and environmental impacts of the project on the local communities and the environment. The social impact assessment should consider the project's potential impacts on the local communities, including displacement, loss of livelihood, and cultural heritage. The environmental impact assessment should consider the project's potential impacts on the ecology, water quality, and biodiversity.

CHAPTER 3: DESCRIPTION OF CASE STUDY

3.1. KABELI-A HEP DESCRIPTION

The Kabeli-A Hydroelectric Project (KAHEP) is situated in Province No. 1 of Nepal, spanning the districts of Panchthar and Taplejung. The project was first proposed during the Koshi River Basin Master Plan Study conducted between 1983 and 1985. In 2010, Kabeli Energy Limited secured the development rights by signing a Project Development Agreement (PDA) with the Department of Electricity Development (DoED), Government of Nepal.

The project utilizes a 15 km natural loop of the Kabeli River formed with the Tamor River. Water from the Kabeli River is diverted through an approximately 4.67 km-long tunnel and discharged into the Tamor River to generate electricity. The project has a gross head of 120.5 meters and is designed for a flow of 37.23 m^3/s, based on the 40th percentile flow of the river.

KAHEP was initially intended to be a Peaking Run-of-River (PROR) project with a peaking reservoir made possible by damming the Kabeli River at the headworks. The plant was scheduled to run during two peak hours each day: two hours in the morning and four hours in the afternoon. The annual average energy generation was initially estimated at 213 GWh before accounting for outages, and 201 GWh after considering a 6% outage. On October 12, 2015, Zhejiang Hydropower Construction and Installation Company Limited was given the Engineering, Procurement, and Construction (EPC) contract, and construction got underway. However, due to various challenges, construction was halted. After a three-year pause, the project is now set to resume with updated feasibility studies. The design has been revised to a Run-of-River (RoR) type project.

The project's installed capacity is 37.6 MW, according the updated Power Purchase Agreement (PPA) and the revised feasibility study. The annual contracted energy is 218.354 GWh, comprising 67.206 GWh (30.78%) of dry season energy and 151.148 GWh (69.22%) of wet season energy. The primary objective of the project is to generate electricity and sell it to the national grid under a PPA signed with the Nepal Electricity Authority (NEA), the sole government agency authorized to purchase electricity.

Through the Kabeli-A switchyard, which is connected to the 132 kV Kabeli Corridor transmission line constructed by NEA, power from KAHEP will be evacuated to the national grid. It is anticipated that the project will greatly improve Eastern Nepal's (Province No. 1) electrical supply.

3.1.1. PROJECT LOCATION

The project can tap the potential of Kabeli river originates at an elevation of 2000m above the sea level. The Kabeli-A River is a tributary of the Tamor River, which is a significant branch of Nepal's Saptakoshi river system. It is located in Panchthar and Taplejung district of Province no. 1 in Eastern Nepal. The study area map of the project is shown in the figure 16 below:

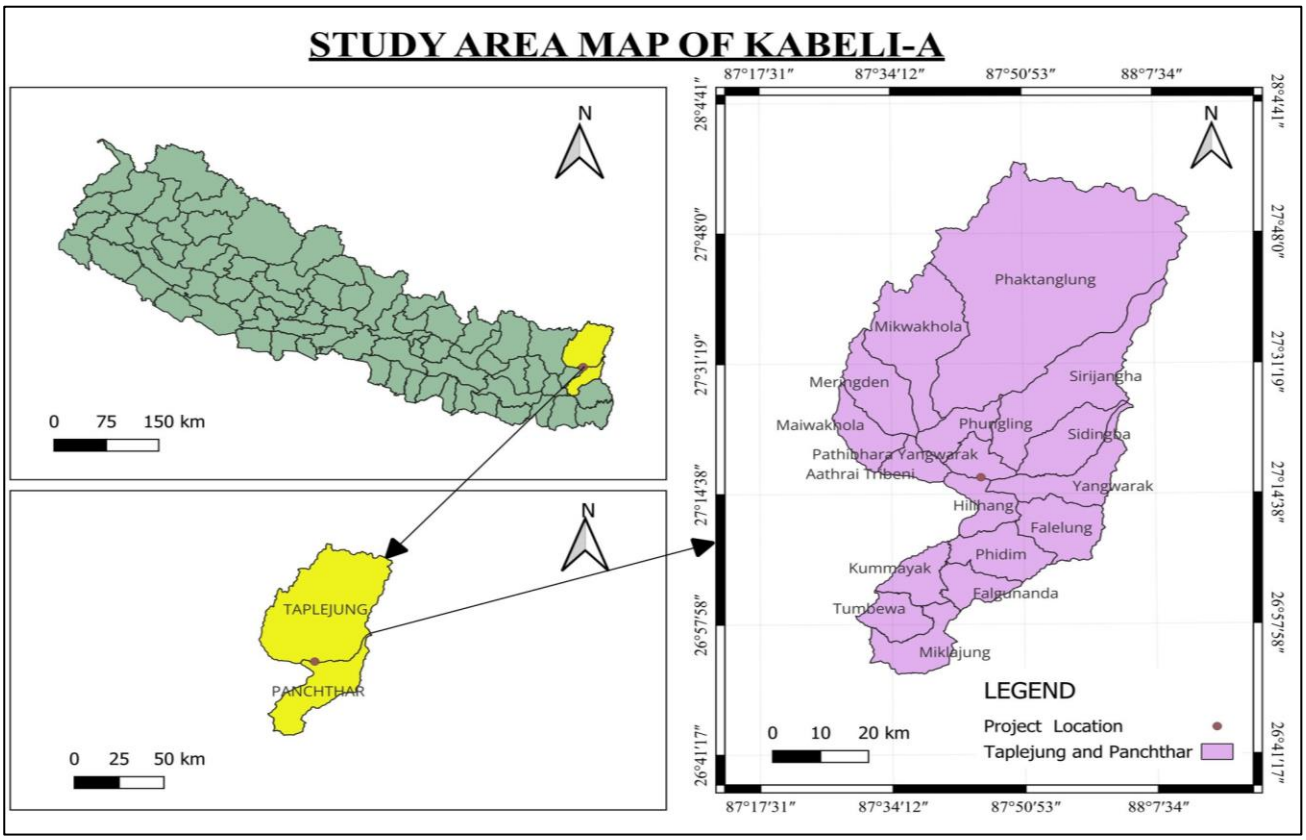


Figure 16 : Study Area map of the Project

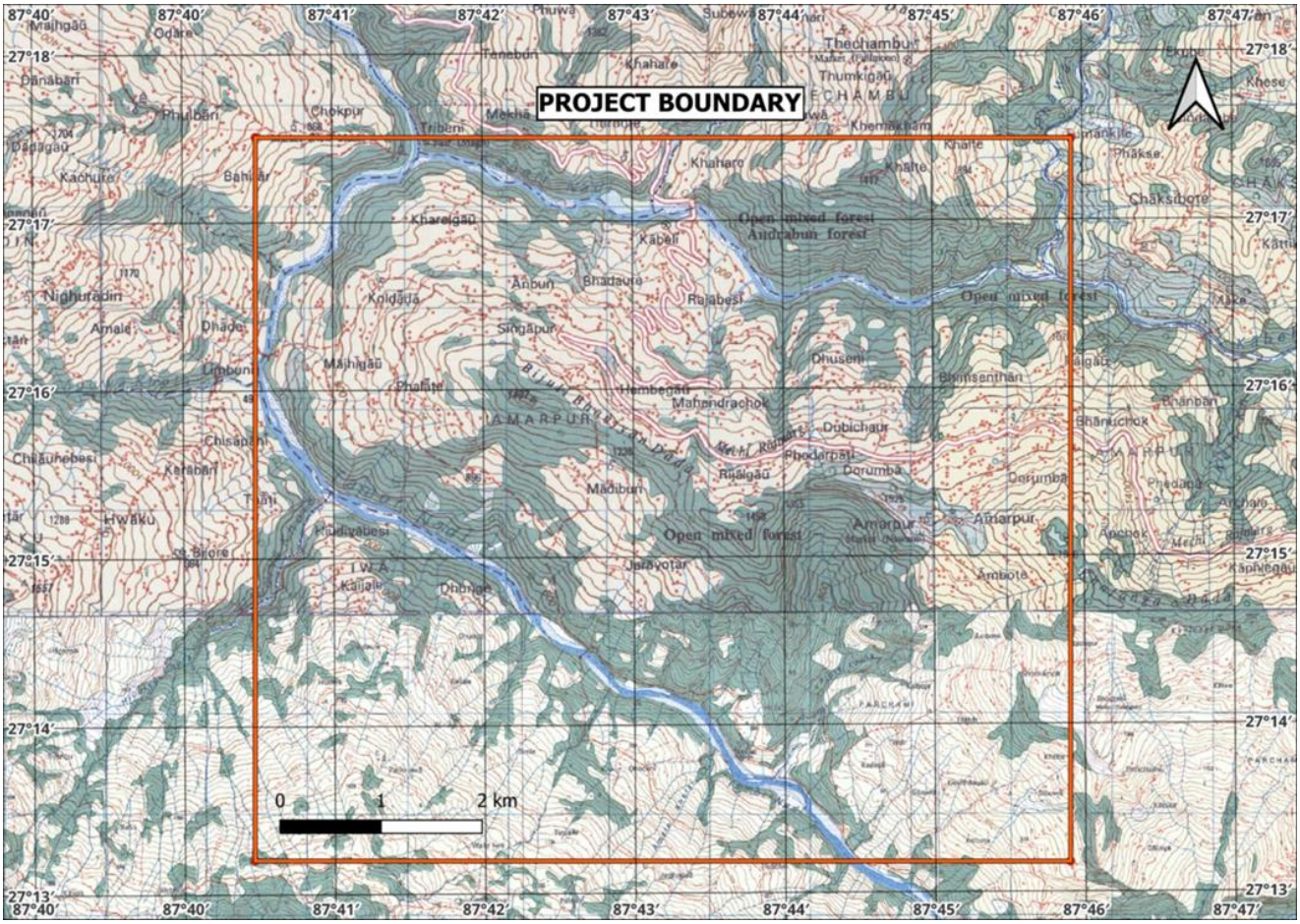


Figure 17 : Project Boundary

Table 1 : Licensed Geographical Coordinates of Kabeli -A Hydroelectric Plant

Coordinates	From	To
Latitude	27° 13' 41"	27° 17' 32"
Longitude	87° 40' 55"	87° 45' 50"

3.1.2. PROJECT ACCESIBILITY

In terms of proximity to major urban centers, the project site boasts connectivity to Kathmandu via an asphalt road, predominantly in good condition. Various access routes to the site from Kathmandu have been identified, among which the most preferred ones are via the following:

- Kathmandu-Koteshwor-Banepa-Badribas- Chaaraali-Ganeshchowk-Powerhouse
- Suketar Airport of the Taplejung is the nearest airport from the project.

3.2. TOPOGRAPHY

Project area lies in the Lesser Himalayan region and the catchment area above the proposed intake site of the project is 861.868 km2 and the elevation ranging from 550 masl to 5500 masl and flows towards south. The topography of the area is characterized by gentle and steep slope. Abundance of vegetation can be observed in the project area. There are not major landslides within the project area.

3.3. CLIMATE

The project area which is entirely in Kabeli basin for the water source is under the influence of south-west monsoon. The climate of the basin is also influenced by the physiography of the region ranging from tropical to alpine. The difference between the warm humid summer and the cold dry winter becomes more marked with the change in altitude.

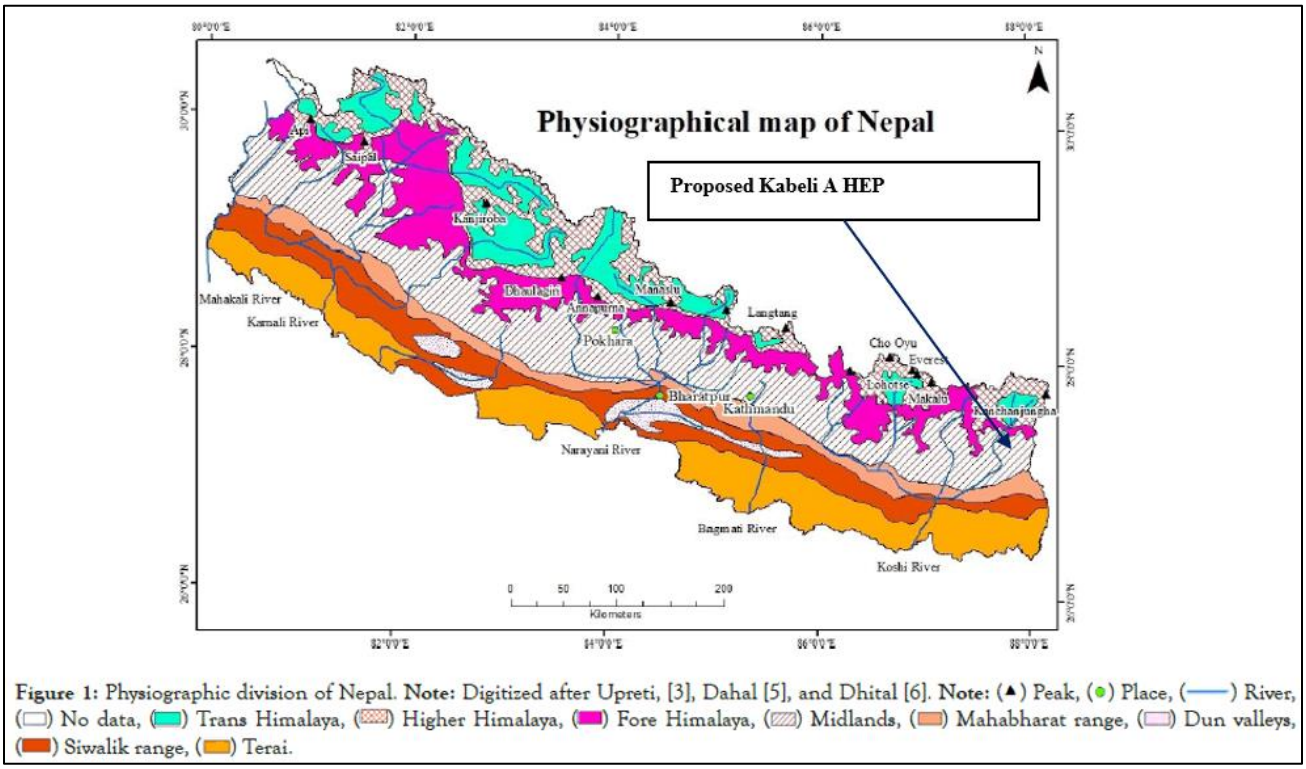


Figure 18 : Physiographical Map of Nepal (Kshetri, R., 2023)

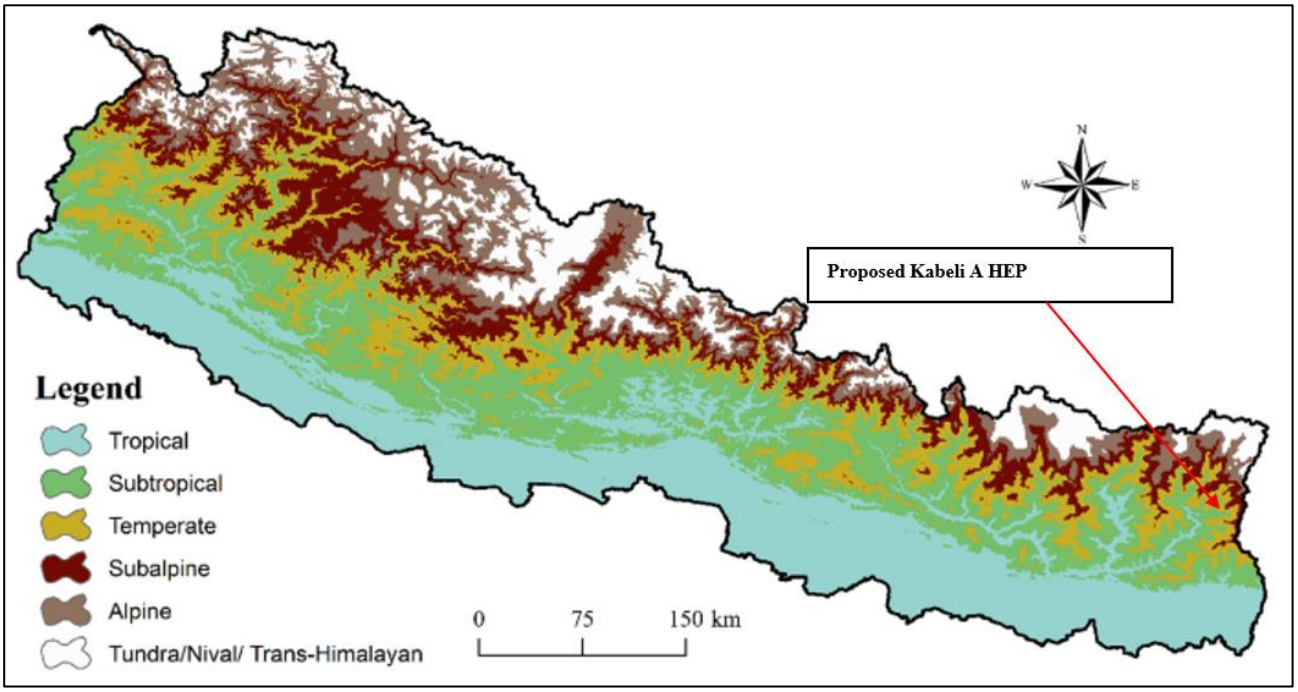


Figure 19 : Climatological Map of Nepal (Ojha, R. B., & Panday, D., 2021)

3.4. GEOLOGY

The Project Area of KAHEP lies in the Lesser Himalaya of Central Nepal, consisting of granite, schist, and phyllite schist. Structurally, Main Central Thrust (MCT) is located towards North of the project area. Rocks in this area are deformed due to presence of thrusts and folds. Geologically, the project lies in metasedimentary rocks of Taplejung Window of the Eastern Nepal, Lesser Himalaya. In the project area, phyllite and quartzites of the Lesser Himalayan rocks are found intruded with granites. Headworks and two third stretch of headrace tunnel passes through granites whereas remaining stretch of tunnel and powerhouse site comprises phyllite, quartzite, gneiss and schist. Physio graphically, the project area belongs to the Middle Mountains while the upper catchment of the Kabeli River extends also to the High Mountain region covering the elevations higher than 5000m which indicates that seasonal snow will occur in winter in the upper part of the catchment.'

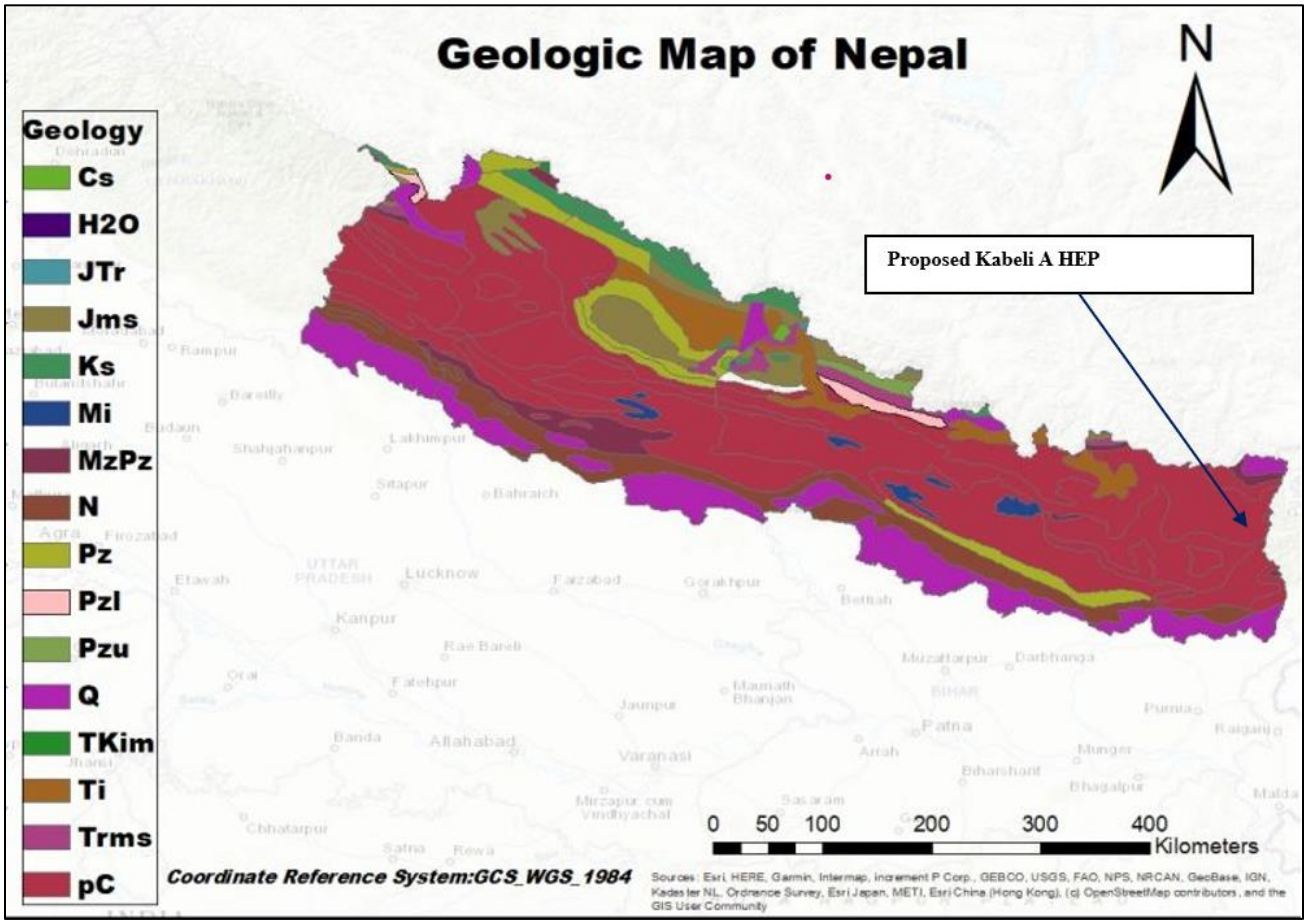


Figure 20 : Geologic map of the Nepal (Neupane, A., 2024)

3.5. TOPOGRAPHICAL STUDY

The terrain of the project area was analysed using the Topographical map of the site (Sheet No.2787 11 Taplejung, Sheet No.2787 12 Chyanthapu, Sheet No.2787 15B Sankranti Bajar, Sheet No.2787 16A Phidim). Due to its favorable topography and consistent river flow, which allows power generation with minimal environmental impact and without large reservoir storage, so a run-of river type development was selected for the power generation. Topographically, there were no any sections where the river is narrow nor its immediate upper course is a wide valley to facilitate the large storage capacity with relatively small dam. So, the possibility of reservoir type and pondage type find less space to be chosen for the further study and the layout of components for RoR was planned accordingly.

3.6. LAYOUT OF HYDROPOWER COMPONENTS

The layout of the headworks of run-of-river hydropower projects were planned to ensure safe and

regular power generation under normal conditions. The diversion structure was located in a straight reach and the narrow section of the Kabeli-A River, which is downstream of Kabeli-A, so that the uniform velocities and a fairly constant river cross section will be available at the structure. All the other components of headworks such as gravel trap, approach canal, settling basin were planned in the topographical map considering that they do not exhibit higher excavation cost and crosses lesser number of small streams. The powerhouse area was located on the area where the gradient of the river has started to turn into gentle slope and the location with hard rock. Following the headpond after settling basin, the headrace tunnel was planned as waterway route since the gradient of Kabeli-A River is high. The alignment of the non-pressure tunnel was made in such a way that there were lesser number of bends that can connect headworks and powerhouse in the shortest route with due consideration of at least overburden pressure of 30m through the alignment for the safety of the tunnelling work.

These hydropower components were planned in two different alignments of the Kabeli River. Apart from the technical aspects, socio-economic aspects have also been considered to some extent while planning the alignment in the topographical map. The coverage of those hydropower components through the agricultural land are avoided.

While planning the layout of components, geological consideration has also been taken into account and the components are located on the sound geology in both of the banks. Both of the alignment follows the possible shortest route with minimum number of stream crossings in order to minimize the construction cost of cross drainage structures.

While planning the layout of penstock alignment, it was made sure that the alignment follows through the ridge of the downslope hill while the valley part of such hill was completely avoided. This will ease the alignment of penstock pipe and avoids the intervention of lower Kholsi otherwise can create significant issues in the stability of the penstock pipe.

With the planning of two alternatives of Kabeli River, comparison was made in terms of various technical and geological aspects and the best alternative was chosen for the detailed design and analysis of the project.

3.6.1. ALTERNATIVE I

In this alternative, intake weir site is located on the straight and narrow section of Kabeli River and the entire headworks are located on the left bank of the river. The water conveyed from headworks flows through the headrace tunnel and meets the underground surge tank. In downstream of the surge

tank, there is vertical shaft followed by the inclined embedded penstock and finally meets the powerhouse area.

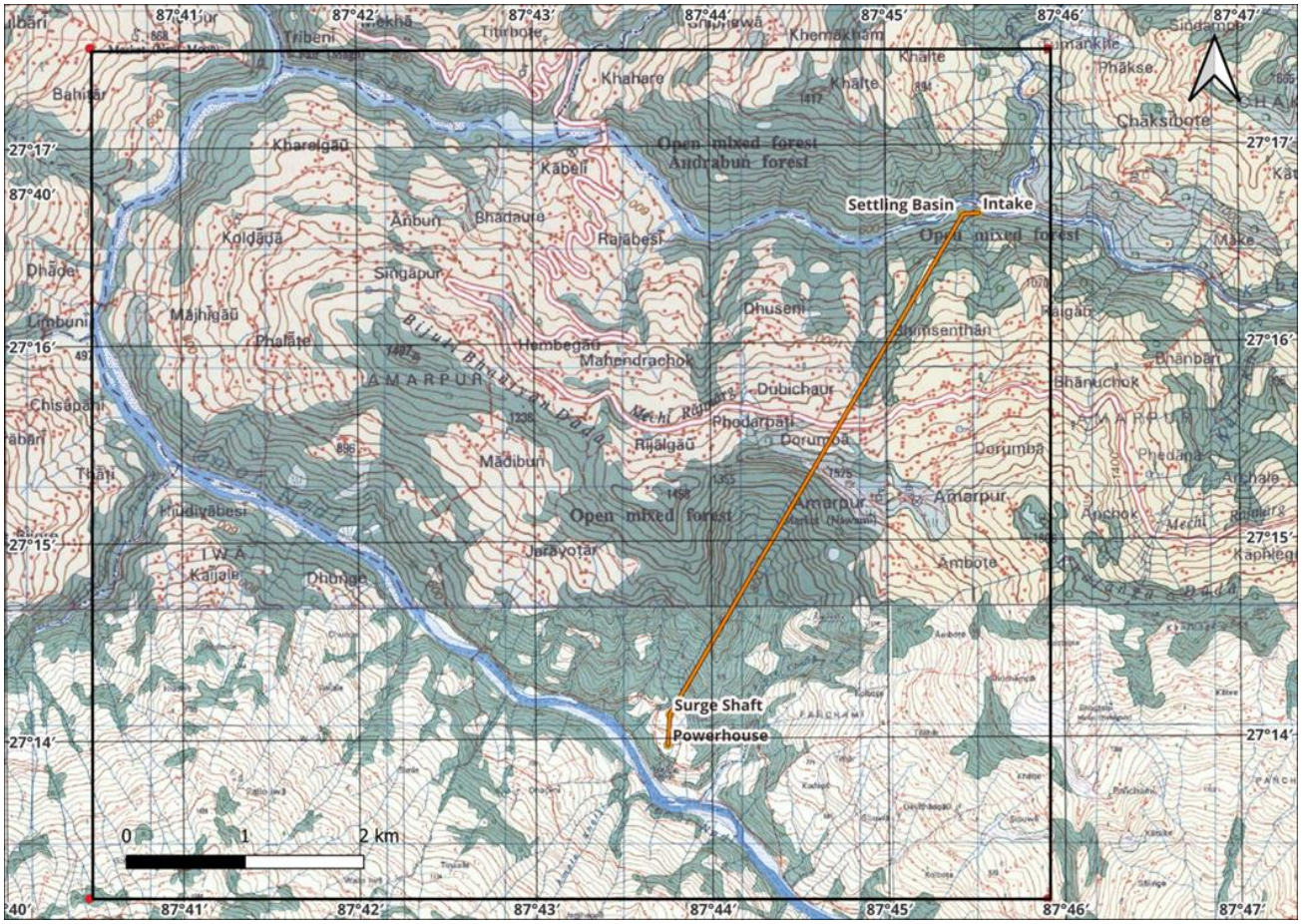


Figure 21 : Layout of Components in Alignment I in Topographical Sheet

3.6.2. ALTERNATIVE II

In this alternative, intake weir site is located after certain distance from the Alignment I in the narrow section and the entire headworks are located on the left bank of the river. The water conveyed from headworks flows through the headrace tunnel and meets the underground surge tank. In downstream of the surge tank, there is vertical shaft followed by the inclined embedded penstock and finally meets the powerhouse area.

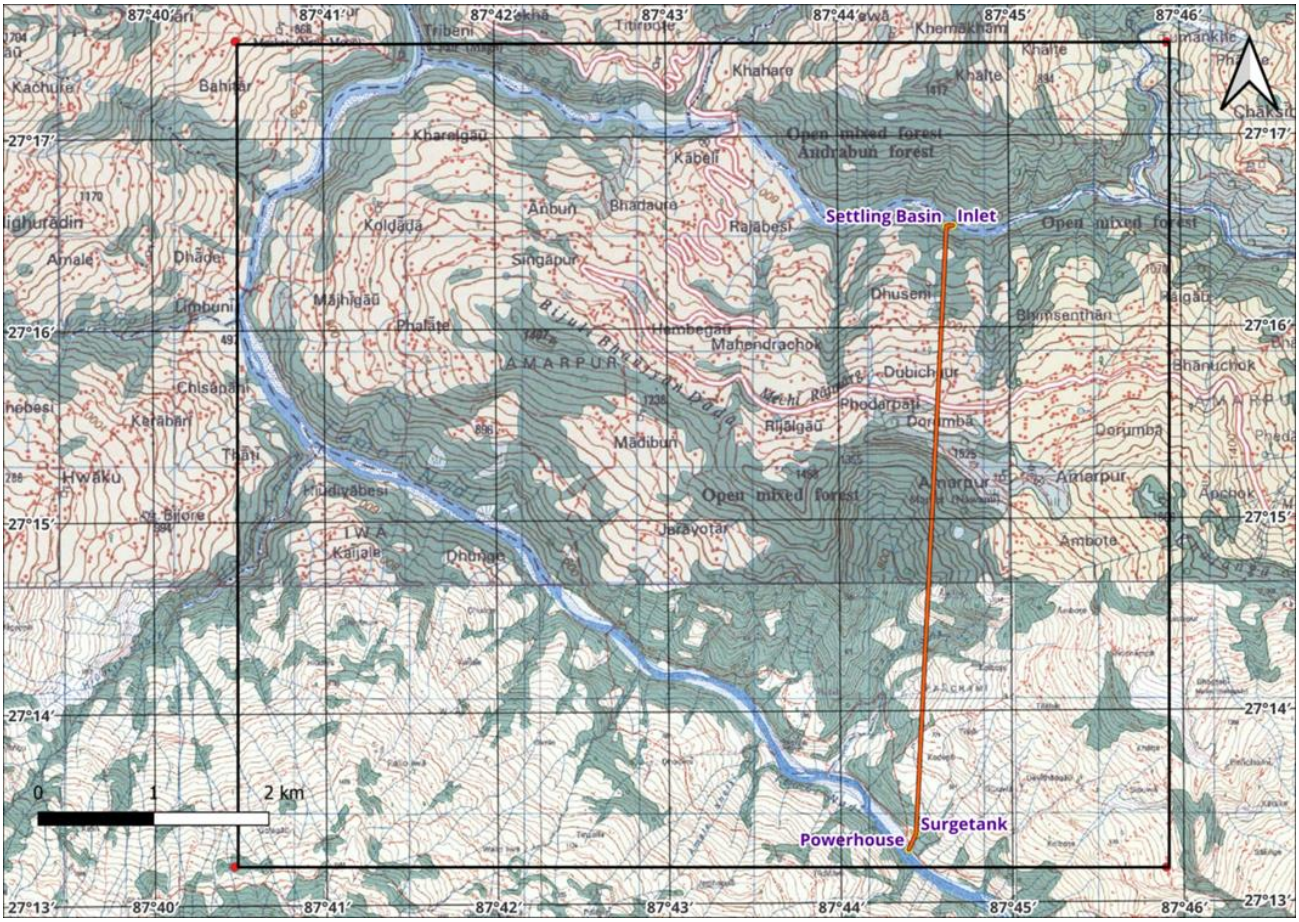


Figure 22 : Layout of Components in Alignment II in Topographical Sheet

3.6.3. ALTERNATIVE ANALYSIS

Based on the comparison of the two proposed alternatives for the Kabeli Hydropower Project layout, Alternative 1 is recommended for implementation due to its clear technical, environmental, and economic advantages. The intake location in Alternative 1 is situated upstream near Kabeli village, which provides better control of water flow and sediment exclusion due to its proximity to tributaries and more stable geological conditions. The headrace tunnel alignment in this option passes through relatively gentle terrain, resulting in a shorter tunnel length that significantly reduces excavation costs, construction time, and associated risks. In contrast, Alternative 2 proposes a tunnel through steeper and more rugged topography, increasing both the complexity and cost of construction.

The location of the surge tank and powerhouse in Alternative 1 is also more favorable, lying close to existing access roads and settlements like Kattare, which simplifies transportation of materials and future operation and maintenance activities. Additionally, the surrounding area has fewer environmental and social sensitivities, minimizing impacts on forest cover, agricultural land, and local communities. Alternative 2, on the other hand, would involve more extensive land clearing and a

higher likelihood of resettlement, increasing both social impact and mitigation costs.

Overall, Alternative 1 is technically more feasible, economically more viable, and environmentally more sustainable. Its layout ensures easier construction, reliable operation, and reduced long-term costs. Therefore, it is the preferred option for the project and should be adopted for further development and inclusion in the project's progress report.

Table 2 : Comparison of Alternatives

Particulars		Alignment-I	Alignment-II
Gross Head		120.5m	80m
Headworks		Common headworks	Common headworks
River crossing		No	No
HRT	Length	5090m	5278m
	No. of Bend	No	No
Penstock		301.38m	150m
Power Production		49.49MW	34.10MW
Human settlement		No effect in human settlement	No effect in human settlement
Road access		Yes	Yes
Risk of Landslide		Low	High

From the above table, it can be clearly observed that the Alternative I have higher gross head resulting in the greater power production. In the similar regards, the length of headrace Tunnel and Penstock is higher in the Alignment II then alignment I so, the cost of the construction is more in alignment II then I. Not only this, there is more risk of landslide in the Alignment II then Alignment I.

Overall, Alternative 1 is technically more feasible, economically more viable, and environmentally more sustainable. Its layout ensures easier construction, reliable operation, and reduced long-term costs. Therefore, it is the preferred option for the project and should be adopted.

3.7. CATCHMENT AREA DELINEATION:

Understanding the basin characteristics at the proposed intake and powerhouse locations is crucial, as it provides insight into the volume of flow that can be expected from upstream sources. To support this, the catchment areas for both the proposed intake and powerhouse sites were delineated using QGIS. Additionally, to enable the transfer of discharge data from the gauging station to the project site using the basin area ratio method, the catchment area of DHM Station No. 684 (located on the Tamor River) was also delineated. For use with the WECS/DHM method, the catchment area was further classified based on elevation zones—below 3000 m, between 3000–5000 m, and above 5000

m—and these values are presented in the table below. The delineated catchment areas are as follows: Proposed Intake – 861.868 km², DHM Station No. 684 – 4012.66 km², and Proposed Powerhouse – 852.813 km².

Table 3 : Catchment Details at proposed intake and powerhouse

Catchment Details	Proposed Intake	Proposed Powerhouse
Basin area, km^2	861.868	3919.043
Area below 3000m, km^2	633.215	1573.250
Area 3000m- 5000m, km^2	226.973	1492.980
Area above 5000m, km^2	0.603	852.813

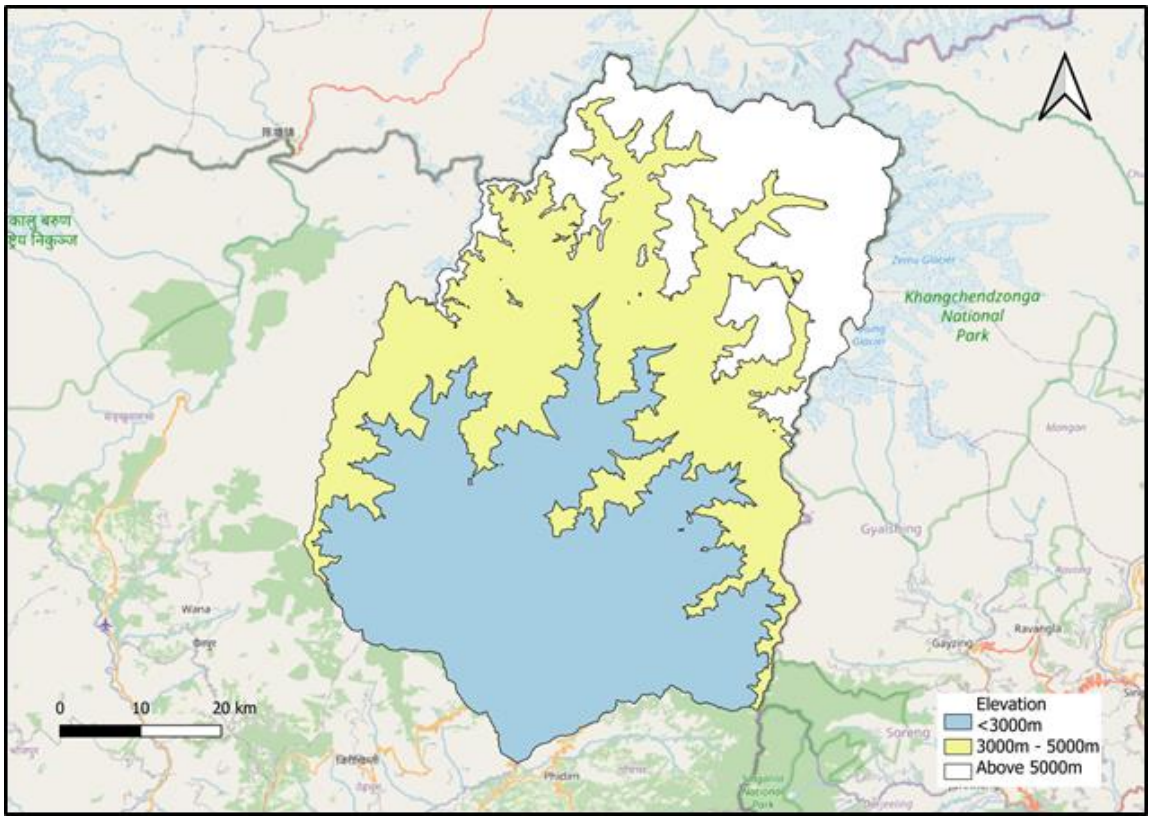


Figure 23 : Catchment area at the DHM Station No. 684

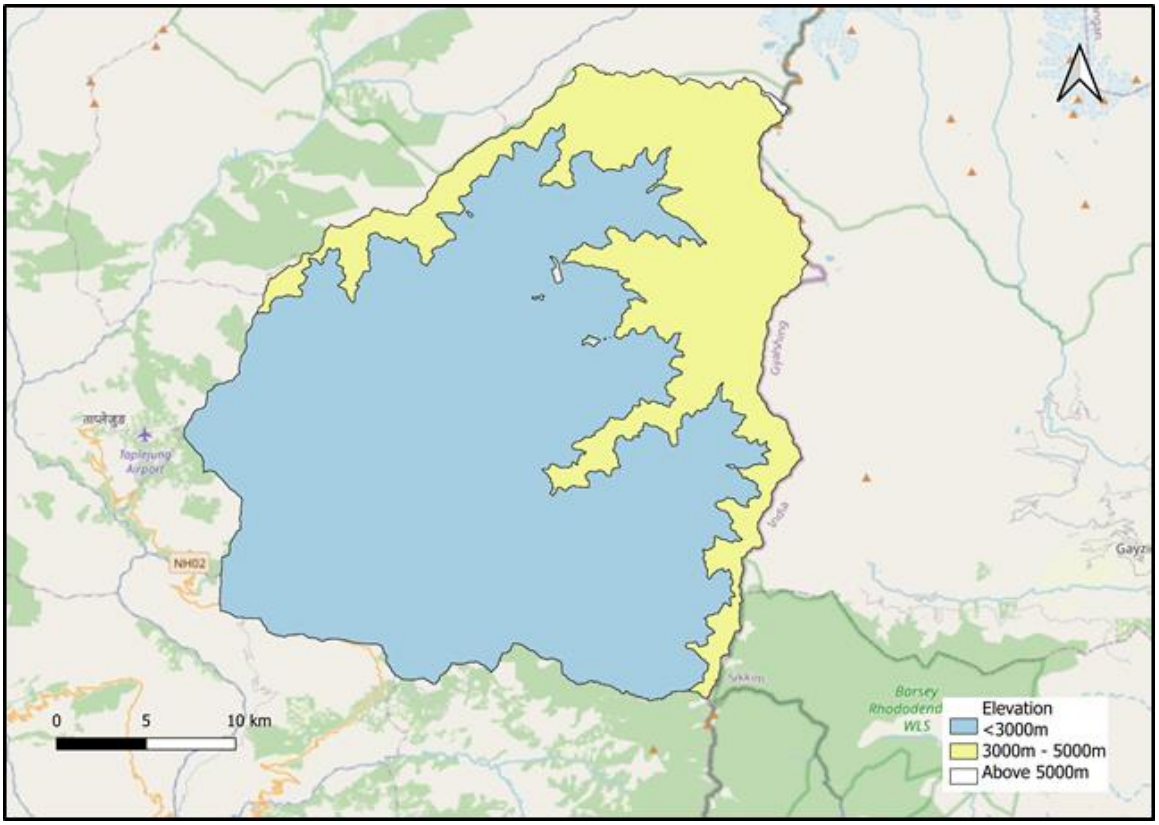


Figure 24 : Catchment area at Proposed Intake

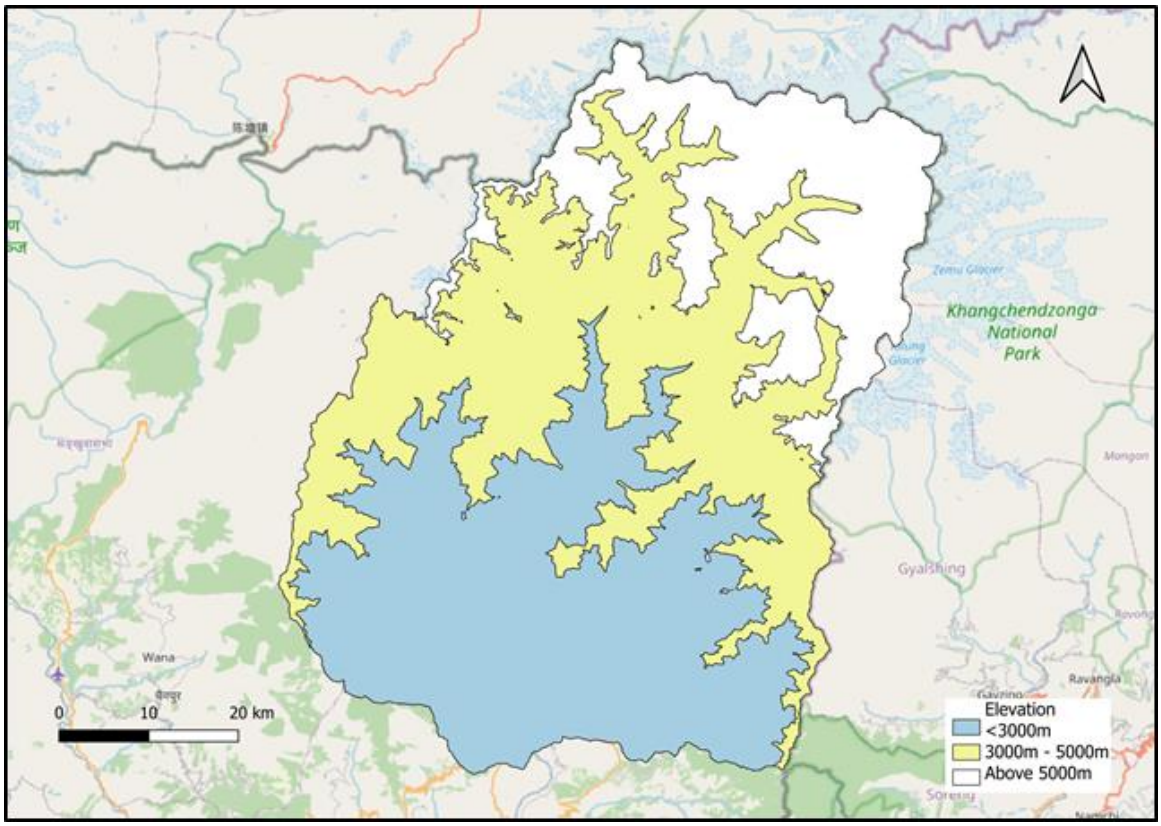


Figure 25 : Catchment Area at Proposed Powerhouse

3.8. HYDROLOGICAL ANALYSIS

For effective hydropower planning, it is essential to utilize hydrological data spanning the longest possible time period. This process relies on the available data and information regarding the characteristics of the drainage area, as well as the river basin's runoff records. In the case of the Kabeli-A River basin, drainage characteristics were assessed using QGIS, while runoff data was obtained from the Department of Hydrology and Meteorology (DHM). Hydrological assessments were conducted at the locations of the proposed intake and powerhouse. Since runoff data is typically collected at designated gauging stations, it must be adjusted to suit the intended sites. This is commonly achieved using the catchment area ratio method.

$$Q_{proposed\ site} = \left(\frac{A_{proposed\ site}}{A_{gauge\ station}}\right) \times Q_{gauge\ station}$$

3.9. FLOOD FREQUENCY ANALYSIS

Flood hydrology studies are essential for estimating flood events of various return periods, which in turn support the determination of the inflow design flood for the overflow section of the diversion structure (DOED, 2018). Flood frequency analysis plays a key role in estimating peak discharges associated with specific return periods, helping designers determine the appropriate height of flood protection structures to safeguard hydropower components against extreme flood events.

As the river under study is ungauged and lacks direct discharge measurements, the Catchment Area Ratio Method was used to estimate streamflow. This method assumes that the hydrological characteristics between the reference and target catchments are sufficiently similar, enabling the estimation of discharge at the project site based on the proportional catchment area.

The following steps were followed for flood estimation in the Kabeli basin:

1. A time series of annual maximum instantaneous flows was collected. These flows were adjusted to represent conditions at the proposed intake and powerhouse sites using the catchment area ratio method.

2. The adjusted discharge values were ranked in descending order, and the probability of exceedance, p for each was calculated using the formula:

$$p = \frac{m}{n+1}$$

where *m* is the rank (order number) and *n* is the total number of flow records.

3. Three statistical methods—Gumbel, Log Pearson Type III, and Log Normal—were applied to perform flood frequency analysis.

4. The estimated flood values were then compared with results obtained using the WECS/DHM method.

3.9.1. GUMBEL'S METHOD

Gumbel's method is one of the most widely used probability distribution functions for extreme values in hydrological studies for the prediction of flood peaks, maximum rainfalls, maximum wind speed, etc. (K Subramanya, 2008). Extreme values from this method are widely adopted in context of Nepal as well. Following key formulas were used in this method:

$$X_T = X + K \times \boldsymbol{\sigma}_{n-1}$$

$$N = \Sigma(X - \bar{X})^2 / (N - 1)$$

$$K = (Y_T - Y_N) / S_N$$

$$Y_T = -ln. \ln\left(\frac{T}{T-1}\right)$$

Where,

X_T= Value of variate X at return period T

$\bar{X}$=Mean of variate X

K=Frequency Factor

$\boldsymbol{\sigma}_{n-1}$= Standard deviation of sample size N

Y_T= Reduced Variate
Y_N= Reduced Mean S_N= Reduced Standard Deviation

3.9.1.1 At Proposed Intake

Table 4 : Estimated Flood(Xt) m3/s at intake

Return period (T)	Reduced variate(Yt)	Frequency factor (K)	Mean variate (X)	Estimated Flood (Xt) m3/s
10.00	2.25	1.58	328.11	462.12
25.00	3.20	2.46	328.11	535.96
50.00	3.90	3.10	328.11	590.74
75.00	4.31	3.48	328.11	622.58
100.00	4.60	3.75	328.11	645.11
200.00	5.30	4.39	328.11	699.29
1000.00	6.91	5.87	328.11	824.78

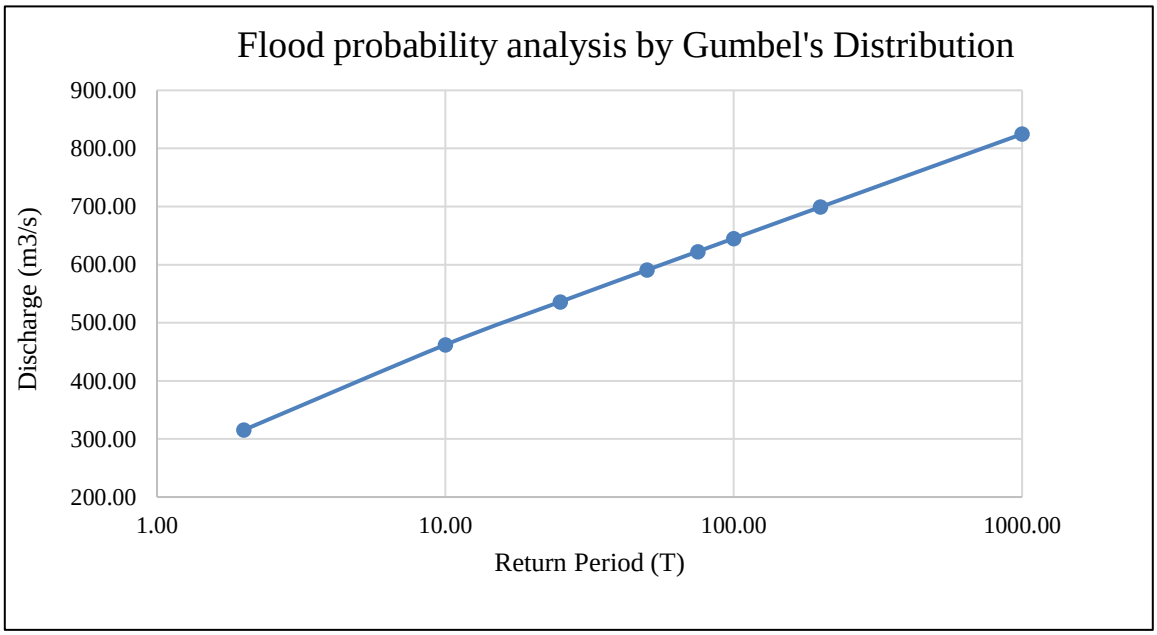


Figure 26 : Flood Probability by Gumbel's Distribution at Intake

3.9.1.2. At Proposed Powerhouse

Table 5 : Estimated Flood(Xt) m3/s at powerhouse

Return Period(T)	**Reduced Variate(Y_T)**	**Frequency Factor(F)**	**Estimated Flood (m^3/s)**
2	0.37	-0.150	1436.78
10	2.25	1.58	2105.06

25	3.2	2.46	2441.42
50	3.90	3.10	2690.94
75	4.31	3.48	2835.98
100	4.60	3.75	2938.63
200	5.29	4.39	3185.41
1000	6.91	5.87	3757.06

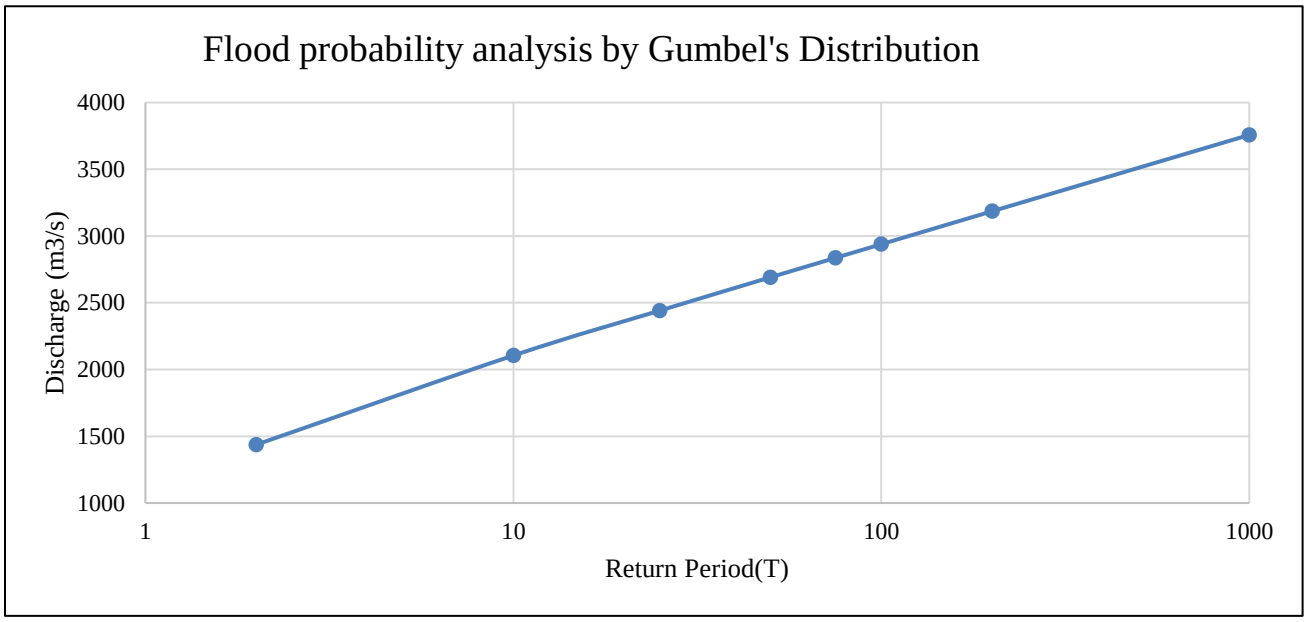


Figure 27 : Flood Probability by Gumbel's Distribution at Powerhouse

3.9.2. LOG PEARSON TYPE III METHOD

Log Pearson Type III Method is also widely used extreme value prediction method. In this, the variate is first transformed into logarithmic form (base 10) and the transformed data is then analysed. Following key formulas were used in this method:

$$z = \log x$$

$$z_T = \bar{z} + K_z \sigma_z$$

$$\sigma_z = \sqrt{\frac{\sum (z - \bar{z})^2}{N - 1}}$$

$$C_s = N \frac{\sum (z - \bar{z})^3}{(N-1)(N-2)({\sigma_z}^3)}$$

$$\bar{z} = mean\ of\ the\ z\ values$$

$$N = sample\ size = number\ of\ years\ of\ record$$

3.9.2.1: At Proposed Intake

Table 6 : Log Pearson Type III at Proposed Intake

T	K_z	$K_z * \sigma_z$	$z_T = \bar{z} + K_z * \sigma_z$	$antilog(Z_T)$
2	0.0315	0.0035	2.5060	320.6502
10	1.2592	0.1400	2.6425	439.0858
25	1.6835	0.1872	2.6897	489.4776
50	1.9503	0.2169	2.7194	524.0883
100	2.1852	0.2430	2.7455	556.5674
200	2.3971	0.2666	2.7691	587.6034

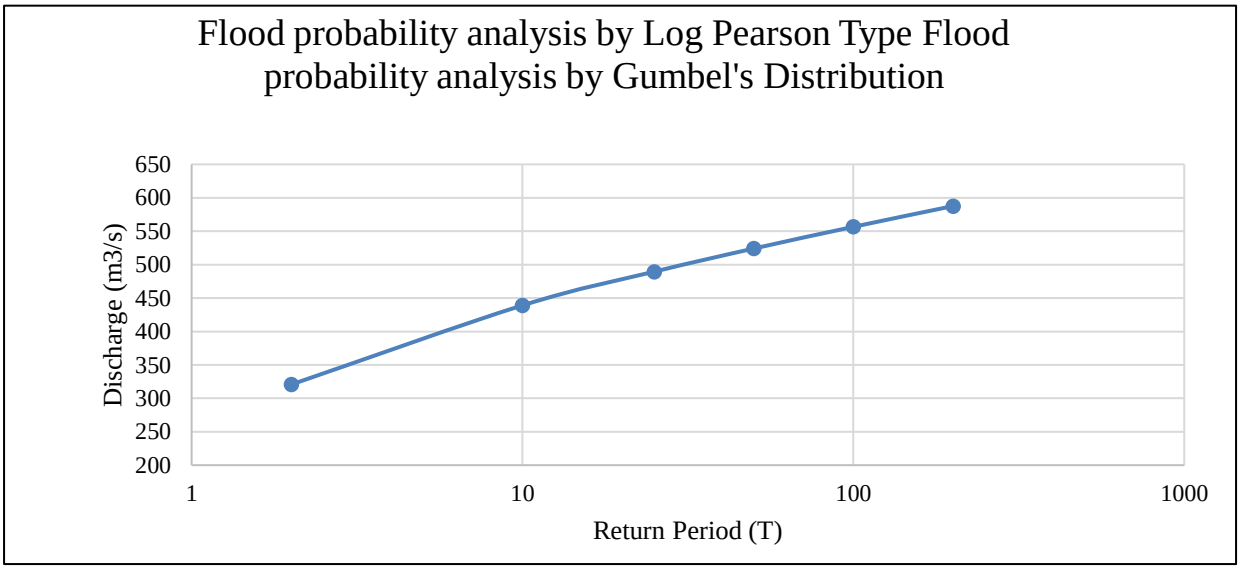


Figure 28 : Flood Analysis by Log Pearson Type III at Proposed Intake

3.9.2.2. At Proposed Powerhouse

Table 7 : Log Pearson Type III at Proposed Powerhouse

T	K_z	$K_z * \sigma_z$	$z_T = \bar{z} + K_z * \sigma_z$	$antilog(Z_T)$
2	0.031	0.003	3.165	1460.633
10	1.259	0.140	3.301	2000.133
25	1.683	0.187	3.348	2229.679
50	1.950	0.217	3.378	2387.338
100	2.185	0.243	3.404	2535.288
200	2.397	0.267	3.428	2676.664

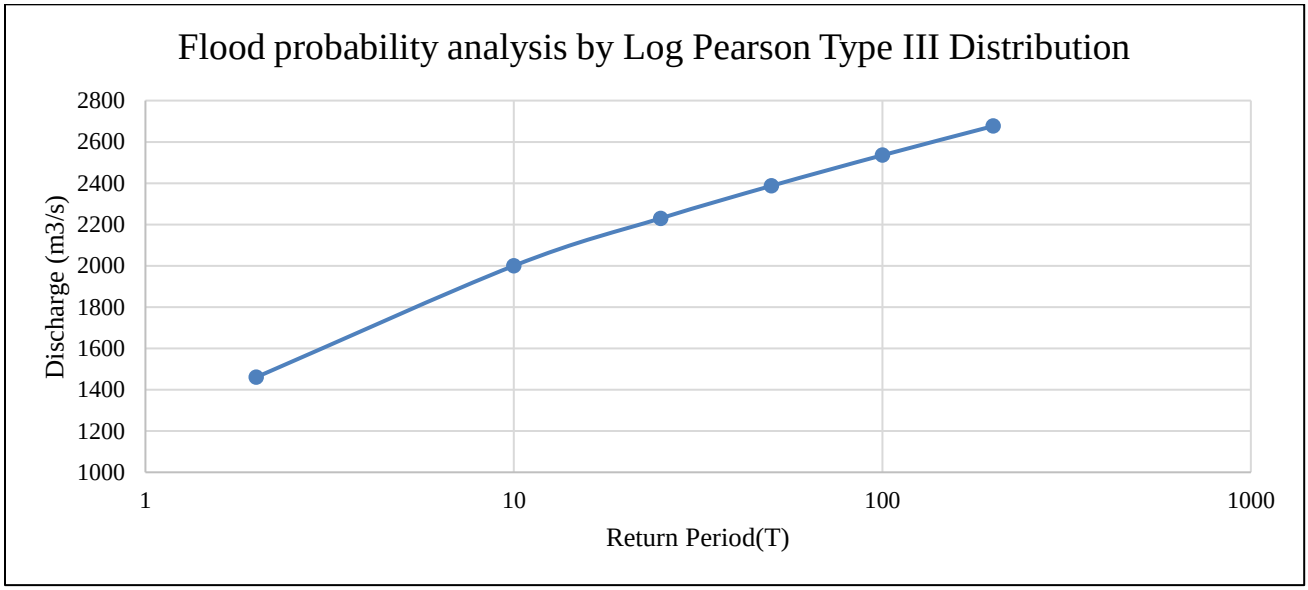


Figure 29 : Flood analysis by Log Pearson Type III at Proposed Powerhouse

3.9.3. WECS/DHM METHOD

The WECS/DHM method was developed by the Water and Energy Commission Secretariat, Department of Hydrology and Meteorology (WECS/DHM) of Nepal. This method is generally used to determine the hydrological features of an ungauged basin for the pre-feasibility study of hydro-electric projects in Nepal. Following key formulas were used in this method:

$$Q_2 = 1.8767 \times (A_{below3000m} + 1)^{0.8783} \quad (2)$$

$$Q_{100} = 14.630 \times (A_{below3000m} + 1)^{0.7342} \quad (3)$$

$$Q_T = e^{(\ln Q_2 + S\sigma)} \quad (4)$$

$$\sigma = \ln(Q_{100}/Q_2)/2.326 \quad (5)$$

Q_2 - two-year instantaneous flood in m^3/s;

Q_{100} – 100-year instantaneous flood in m^3/s;

Q_T – T-year instantaneous flood in m^3/s;

$A_{below\ 3000m}$ – basin area below 3000 m elevation in km^2;

σ is a parameter; S is a standard normal variate whose value depends on return periods

3.6.3.1: AT PROPOSED INTAKE

Table 8 : Discharge at Different Proposed Intake

Return period(f)	s	Qf(m3/s)
2	0	526.8766
5	0.842	799.9184
p	1.282	994.9608
25	1.645	1191.196
50	2.054	1459.04
100	2.326	1669.73
1000	3.09	2438.848

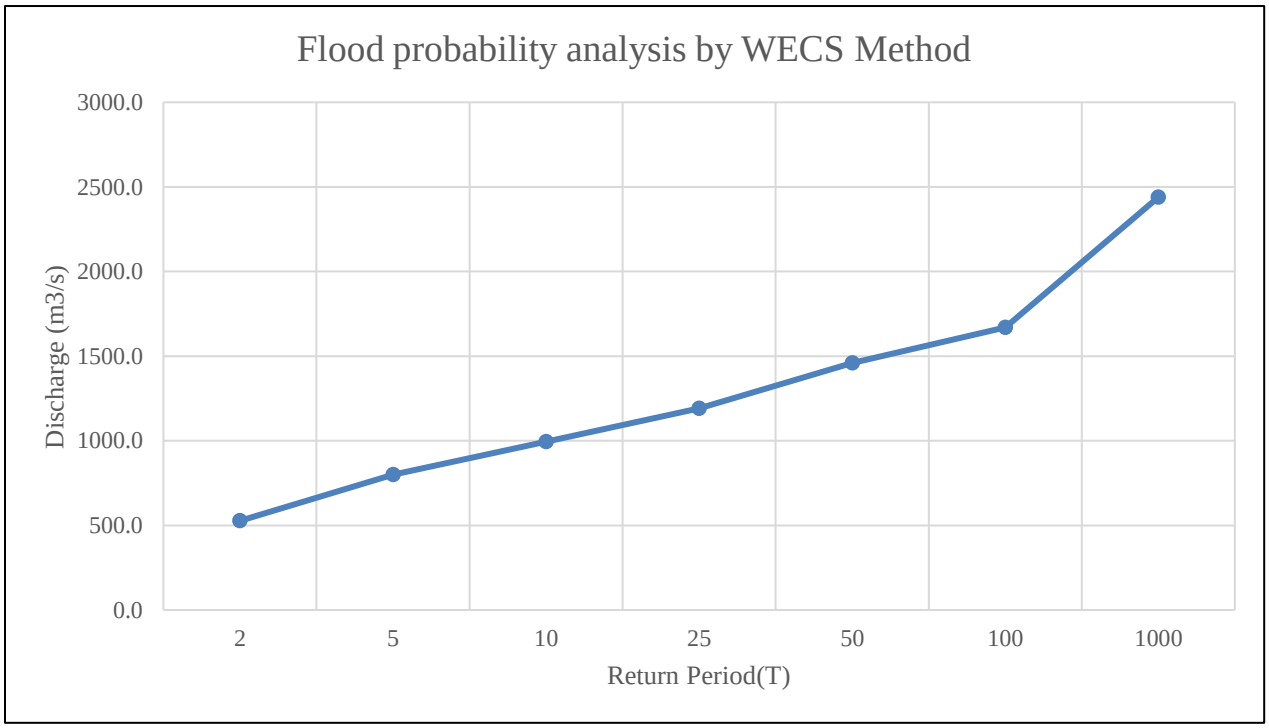


Figure 30 : Flood Probability Analysis by WECS Method at Proposed Intake

3.9.4. SUMMARY OF FLOOD FREQUENCY ANALYSIS:

The flood frequency analysis was carried out using Gumbel's method, Log Pearson Type III method

and WECS Method. With all these values, the best adopted method for flood frequency analysis was Gumbel's method. This method fitted the best distribution curve amongst all other methods while Log Pearson Type III and WECS have overestimated the flood values.

3.6.4.1. AT PROPOSED INTAKE:

Table 9 : Comparison of Flood Frequency at Intake

SN	Return Period(T)	Discharge(m3/s)			
		Gumbel's	Log Pearson Type III	WECS/DHM	Adopted
	2	315.41	320.65	526.88	315.41
	10	462.12	439.09	994.96	462.12
	25	535.96	489.48	1191.20	535.96
	50	590.74	524.09	1459.04	590.74
	100	645.11	556.57	1669.73	645.11

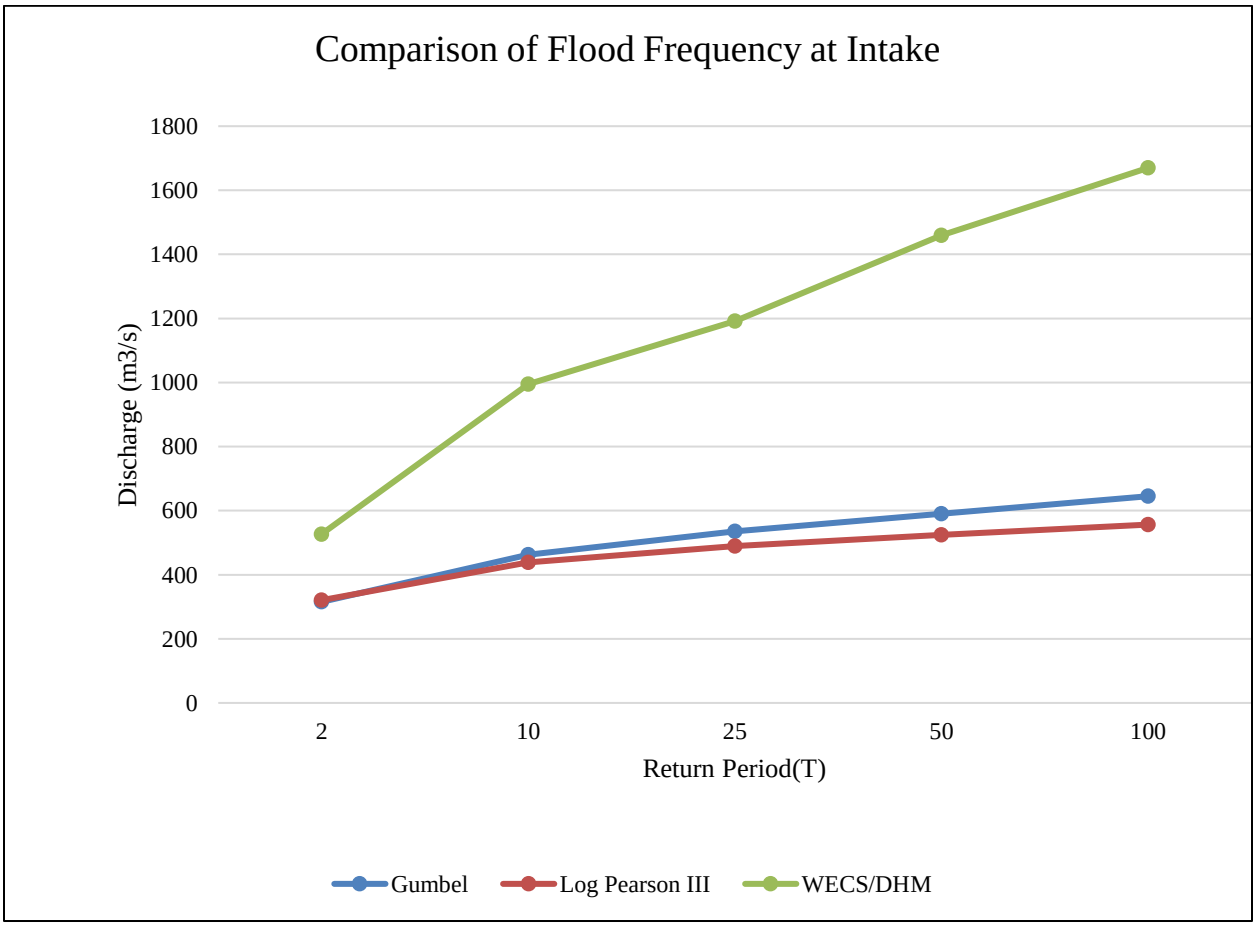


Figure 31 : Comparison of Flood Frequency at Proposed Intake

Table 10 : Comparison of Flood Frequency at Powerhouse

SN	Return Period(T)	Discharge(m3/s)			
		Gumbel's	Log Pearson Type III	WECS/DHM	Adopted
1	2	1436.78	1460.63	1165.78	1436.78
2	10	2105.07	2000.13	2052.88	2105.07
3	25	2441.42	2229.68	2409.60	2441.42
4	50	2690.95	2387.34	2886.33	2690.95
5	100	2938.63	2535.29	3254.51	2938.63

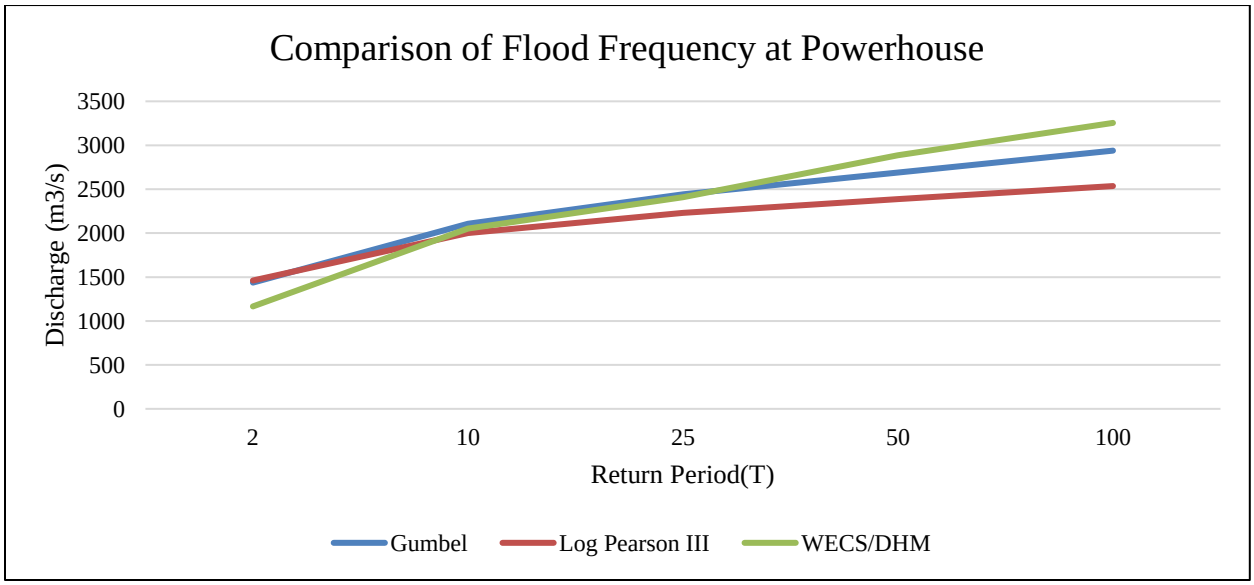


Figure 32 : Comparison of Flood Frequency at Proposed Powerhouse

3.10. LONG TERM STREAM FLOW ANALYSIS

The mean monthly hydrograph and flow duration curve for the Kabeli basin were developed using the average monthly flows. The following steps were undertaken to analyze the mean monthly flow in this ungauged section of the Kabeli River:

1. Discharge data from the gauging station were transferred to the proposed site using the catchment area ratio method.
2. A yearly series of mean monthly flows was generated by averaging the daily flow values for each calendar month.
3. The long-term mean monthly flow for each of the 12 months was then computed by averaging the corresponding monthly values across all years.

4. These calculated mean monthly flows were subsequently used to construct the mean monthly hydrograph and the flow duration curve at the proposed location.

3.10.1. MEAN MONTHLY HYDROGRAPH

Hydrograph is the response of a given catchment to a rainfall input (K Subramanya, 2008). Mean monthly hydrograph was prepared for the calendar months on the abscissa and the long term average flow on the ordinate.

Table 11 : Mean Monthly Flow

Month	Q (m^3/sec) at ungauzed station
January	10.98
February	9.45
March	9.72
April	15.01
May	27.19
June	68.00
July	139.40
August	155.98
September	105.09
October	45.22
November	21.77
December	14.48

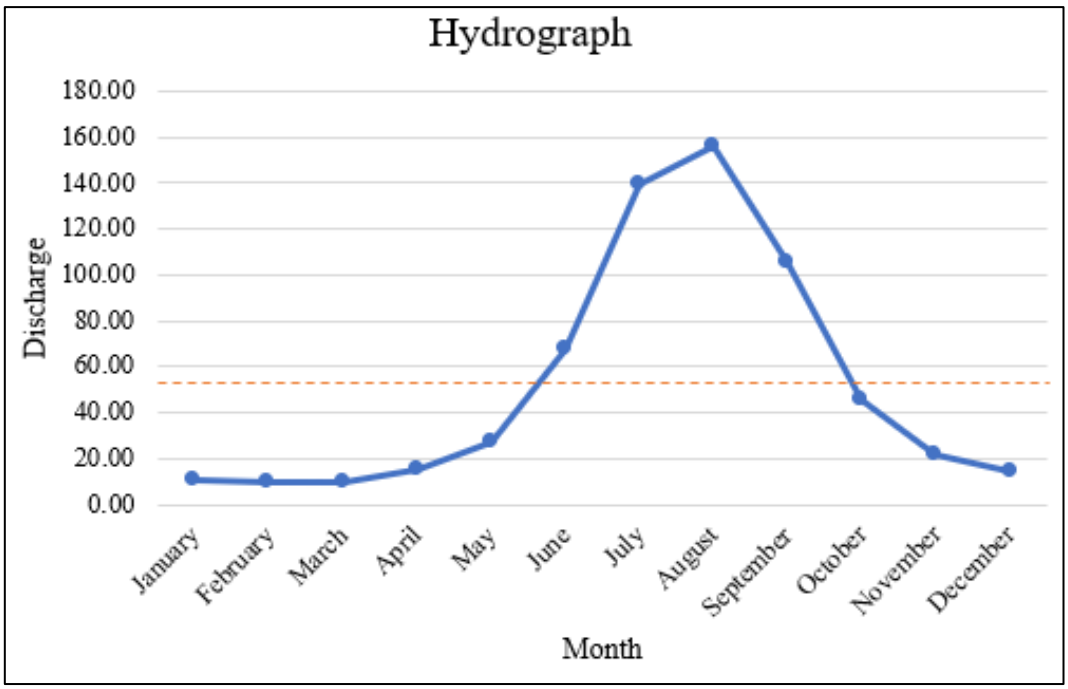


Figure 33 : Mean monthly hydrograph at the proposed intake site

3.10.2. FLOW DURATION CURVE

The flow duration curve is highly useful in the planning and design of hydropower as it helps to determine the potential for hydropower generation for different percentage of time due to the monthly variations of discharge in the river. FDC was prepared by plotting the flow values in order of magnitude as ordinates and percent of time as abscissas.

Table 12 : Flow Duration curve at Proposed Intake

Month	Q (m^3/sec) at ungauged station	Q in Desec. Order (ungauged station)	Rank	Frequency	Probability of Exceedance
January	10.98	155.98	1.00	12.00	8.33
February	9.45	139.40	2.00	6.00	16.67
March	9.72	105.09	3.00	4.00	25.00
April	15.01	68.00	4.00	3.00	33.33
May	27.19	45.22	5.00	2.40	41.67
June	68.00	27.19	6.00	2.00	50.00
July	139.40	21.77	7.00	1.71	58.33
August	155.98	15.01	8.00	1.50	66.67
September	105.09	14.48	9.00	1.33	75.00
October	45.22	10.98	10.00	1.20	83.33
November	21.77	9.72	11.00	1.09	91.67
December	14.48	9.45	12.00	1.00	100.00

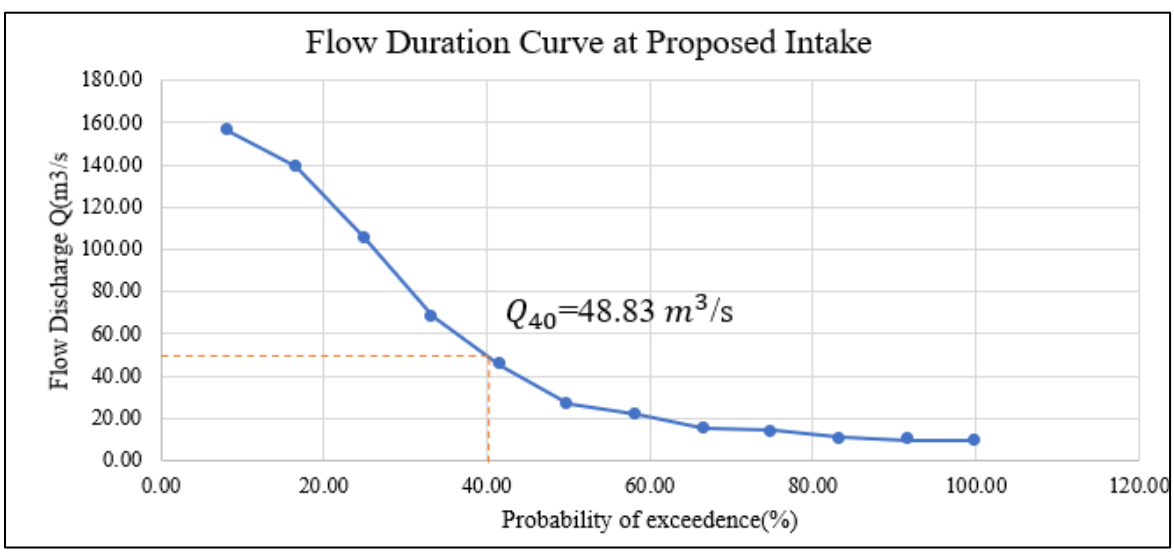


Figure 34 : Flow duration curve at the proposed intake site

CHAPTER 4: DESIGN OF CIVIL COMPONENTS

4.1. HYDRAULIC DESIGN OF HEADWORK

4.1.1. HYDRAULIC DESIGN OF WEIR AND UNDER SLUICE

The diversion structure is planned on a curvature and aligned perpendicular to the river course of Kabeli River. This minimized its length and ensured normal and uniform flow through its bays. The sharp crested weir with sloping glacis is designed as the diversion structure of the Kabeli-A HEP. The intake is designed at the outer bend so as to minimize the sediment flow and maximize water intake. Normal water level at the headworks is calculated from HEC-RAS and rating curve and its value is 581.93 masl for design discharge of 48.83 m^3/s. The crest level of weir is maintained at 582.81 masl while the full supply level is 582.93 masl. The entire headworks area is designed for flood of 100-year return period whose value is 645.113 m^3/s that corresponds to the elevation of 585.65 masl. The total length of weir portion is 61 m and its width is 50 m. Cutoff walls has been designed using the Khosla's Theory and they have been provided at the both the upstream and downstream of the diversion structure with the depth of 7.8m and 8.4m at u/s and d/s respectively.

The under sluice has been designed for the passage of bed load downstream of the diversion structure and to prevent the bed load entering the intake. It doesn't only flush the bed material deposited in the upstream of diversion structure but also creates pocket which helps to maintain the uniform flow towards the intake. The Sill level of under Sluice is kept at 573.81 masl and the dimensions of under sluice are 81.5 m long and 12 m wide with 2 bays of 10 m each and a pier of 2 m.

Stilling basin has also been designed to dissipate the energy of discharge passing the overflow section before the discharge is returned to the downstream river channel. The floor level of stilling basin has been set to 578.8 masl and the end sill level of stilling basin is 580.3 masl. The stilling basin has been designed for both the weir and under sluice with the length of 26.65 m. Flood walls are designed for design flood of RL. 585.65 masl and its height is maintained at 587.00 masl which will be enough to withstand the flow of extreme flood.

Refer to Annex II & VI for detailed calculation and drawings.

4.1.2. HYDRAULIC DESIGN OF SIDE INTAKE

Side Intake is designed to draw required amount of flow for the power production and flushing of deposits from settling basin. The additional discharge of 20% is taken at the intake in order to consider for the flushing arrangements (i.e., 20% of 48.83 m^3/s=58.596 m^3/s). The side intake is aligned at 105° to the direction of flow in order to minimize the entrance of sediments through the intake. Side intake consists of 4 openings of size 2.2 m high and 8 m wide and its invert level is kept at 579.81 masl which is slightly higher than that of under sluice sill level to prevent the entry of sediments and bed particles through it. The coarse trash rack bars of 20 mm thick with 100 mm bars spacing are designed at the side intake with the inclination of 70° with the horizontal. 60 mm thick slab is used to support the trash rack with steel lining of 16 mm. The velocity through the intake has been taken as 0.9 m/s.

Refer to Annex II & VI for detailed calculation and drawings.

4.1.3. HYDRAULIC DESIGN OF GRAVEL TRAP

Gravel Trap is also designed with the same purpose that during floods, bed load of smaller sizes and gravels may be transported in suspension mode and can enter though intake. Two bays of gravel trap are designed in this study with the dimensions of 18 m long, 9 m wide and 11 m high. Gravel Trap is provisioned for settling the particles up to 5 mm which will then be flushed via flushing culvert. Before water flow through approach canal, trash rack bars of 20 mm thick with the clear spacing of 50 mm is inclined at the end of gravel trap. Stone Pitching of 20 cm is provisioned in the gravel trap to reduce the scouring effect in the bottom level of the structure. The velocity in the gravel trap has been taken as 1.011 m/s. Manhole has also been facilitated in the gravel trap for the inspection and maintenance purposes.

Refer to Annex II & VI for detailed calculation and drawings.

4.1.4. HYDRAULIC DESIGN OF APPROACH CANAL

The approach canal connects gravel trap to the settling basin in this study. It has been designed as trapezoidal with freeboard of 0.75 m. Two canals start from the Gravel trap each having 2.04 m wide and 2.46 m high. The velocity in the approach canal is taken as 2.42 m/s. Stone Pitching of 20 cm is provisioned in the approach canal to reduce the scouring effect in the bottom level of the structure. Manhole in every 50-75m has been kept in the approach canal for the maintenance purposes.

Refer to Annex II & VI for detailed calculation and drawings.

4.1.5. HYDRAULIC DESIGN OF SETTLING BASIN

Surface settling basin with hooper type is designed in this study. Due to the high level of turbulence in the river, considerable part of the suspended sediments can enter into the intake which can cause severe erosion to hydro-mechanical equipment. So, settling basins are designed to trap the suspended sediment and flush them back to the river. It is designed with 2 compartments of effective length 154.48 m having 19.31 m wide and 8.17 m high of each compartment. Gated Flushing Culvert has been provisioned in the settling basin which can intermittently flush the trapped particles back to the river of 3m x 3m Dimensions.

Refer to Annex II & VI for detailed calculation and drawings.

4.2. OPTIMISATION OF WATER CONVEYANCE SYSTEM

The hydroelectric project's water conveyance system must be optimized because doing so would not only help ensure that the project produces technically sound results but also help make it financially feasible. In this work, the headrace tunnel and pressure shaft have been optimized.

4.2.1. OPTIMISATION OF HEADRACE TUNNEL

For the optimization of diameter of the headrace tunnel, velocity requirement, head loss in tunnel, interest of capital cost of tunnel, annual operation and maintenance charge were the factors which have been considered. The optimization study is based on the increment of tunnel cost with respect to the tunnel diameter and the value of energy lost which is a function of the tunnel sectional area. It is based on the fact that the higher diameter of tunnel will have lesser head losses but eventually can increase the tunnel cost excessively or vice-versa. The optimization study is done in order to find out the optimum diameter of tunnel which will have optimum effect in power production and capital investment.

The proposed headrace tunnel of Inverted D-shaped in the project is 5090.77m long that stretch from head pond to the surge shaft. The friction factor has been taken as 0.009 for Darcy Weisbach Equation and Manning’s Coefficient of Rugosity as 0.01 for the head loss calculation. The optimized diameter of the headrace tunnel is calculated to be 4.8 m.

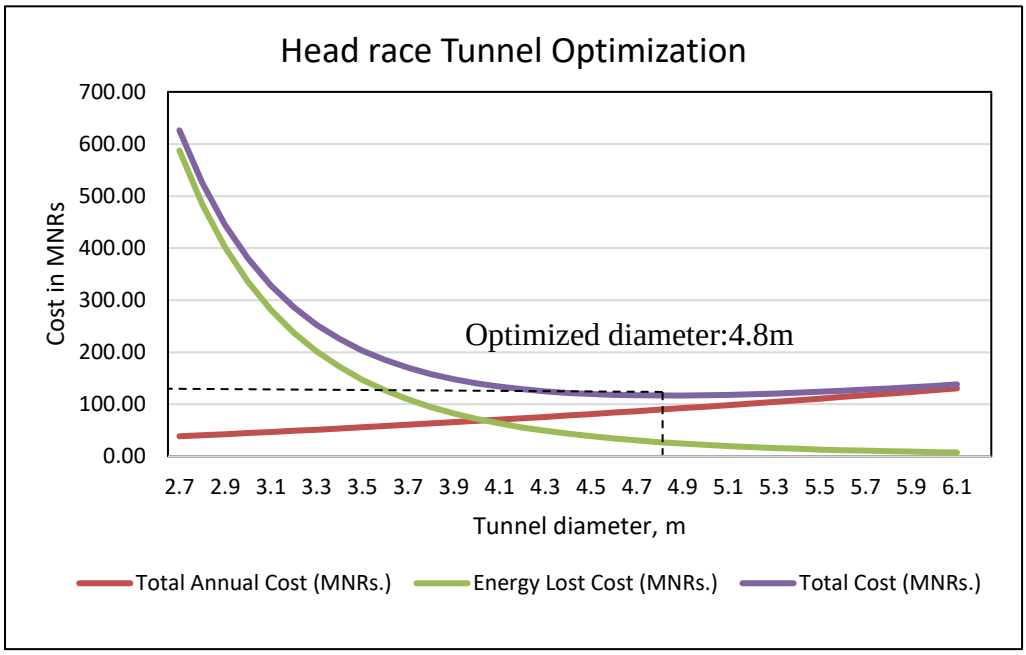


Figure 35 : Head race Tunnel Optimization

4.2.2. OPTIMISATION OF PENSTOCK

Penstock will be located in the downstream of headrace tunnel and surge tunnel. Before the hydraulic design of pressure shaft, its optimization study is carried out. The optimization of pressure shaft can be done by both the analytical and graphical method. In this study, the optimization study has been done using graphical method. For its optimization, monthly energy and revenue were calculated from the monthly discharge data, head and design discharge. The optimized diameter of pressure shaft is calculated to be 2.5 m. The summary of the optimization of pressure shaft is given below:

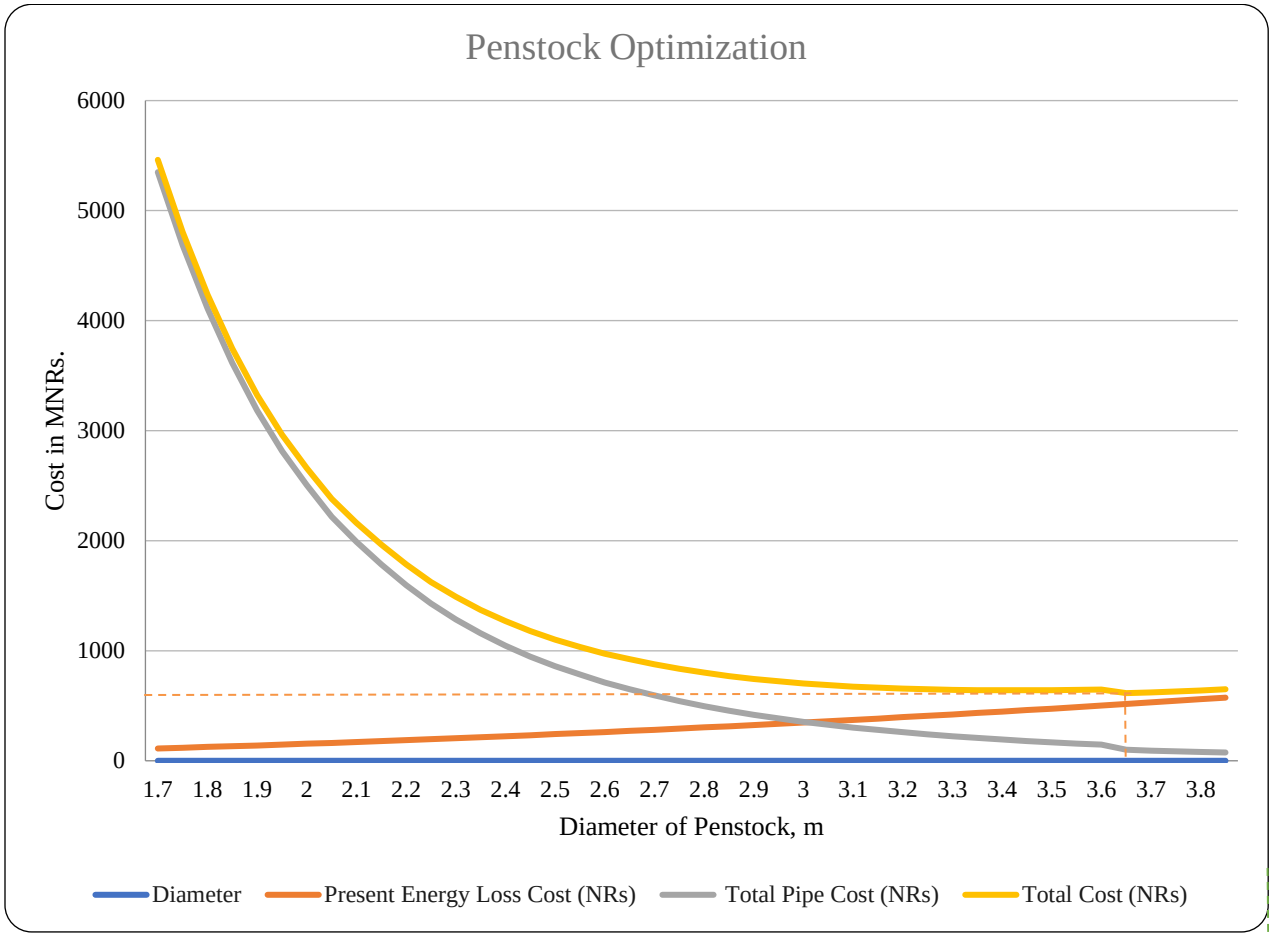


Figure 36 : Optimization of Penstock

4.3. HYDRAULIC DESIGN OF SURGE TANK

Before commencing the design of surge tank, the headrace tunnel and pressure shaft is optimized followed by its hydraulic design which is explained in Chapter 6 of this report. Simple cylindrical surge tank is provided which can control the hydraulic transient in the project during the load rejection or acceptance or during the sudden closure of main inlet valves.

The distance between the surge tank and the powerhouse is kept at nearly 190 m. The simple surge tank will be connected to the junction of headrace tunnel and pressure shaft. The bottom level of surge tank is kept at 566.2 masl while the maximum upsurge and down surge at surge tank will be 597.82 masl and 578.14 masl respectively with the optimized diameter of 10 m and the total length of 29.8 m.

Refer to Annex II & VI for detailed calculation and drawings.

4.4. DESIGN OF ANCHOR BLOCKS:

Anchor blocks are designed and proposed throughout the penstock in this study. The design of anchor blocks require calculation of forces acting on it. Ten different forces that act on the anchor block are considered during the design of anchor blocks. There are two horizontal bends in the wye branch of penstock before the pipe enters powerhouse. Anchor block has been designed with due consideration of such horizontal bends as well.

Refer to Annex II & VI for detailed calculation and drawings.

4.5. HYDRAULIC DESIGN OF POWERHOUSE

4.5.1. HYDROMECHANICAL & ELECTROMECHANICAL WORKS

The vertical Francis turbine was selected on the basis of three different charts shown below. There are three units of turbine with its runner diameter of 4.03 m. The length, depth and Height of draft-tube at exit end is found to be 5.06m, 3.18m and 1.18m respectively

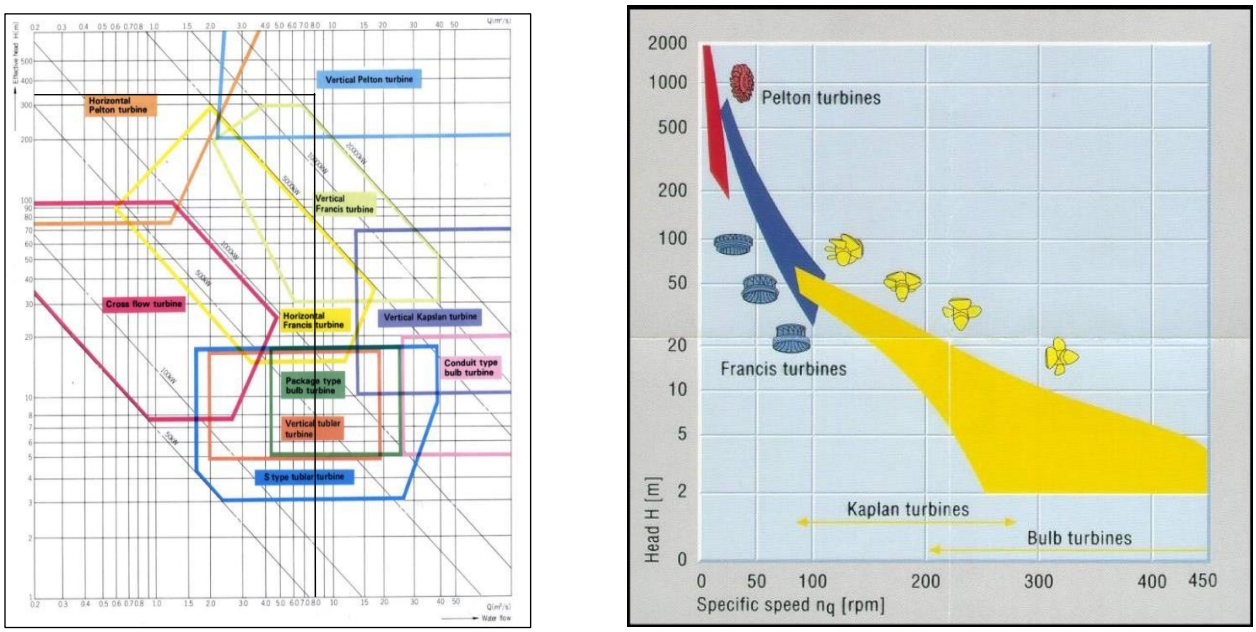


Figure 37 : Turbine Selection Based on Head vs Discharge and Head vs Specific Speed

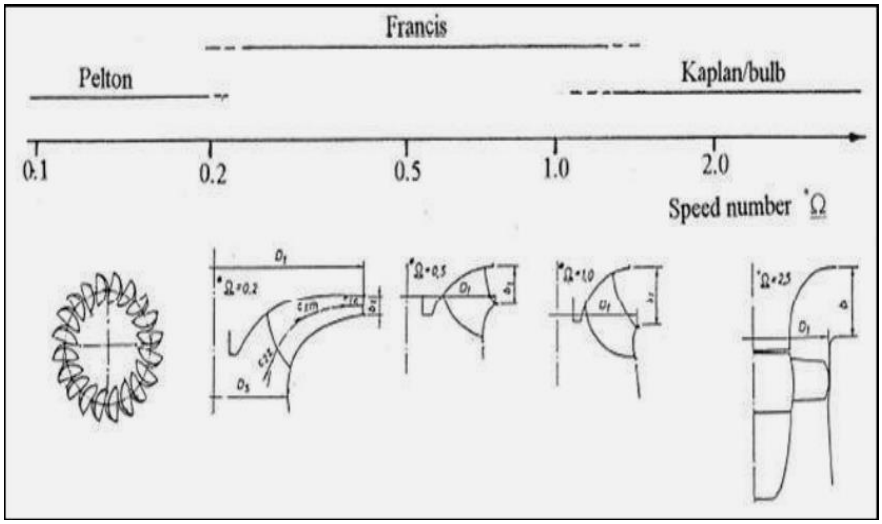


Figure 38 : Turbine Selection Based on Speed Number

4.5.2. POWERHOUSE GENERAL LAYOUT:

The unit spacing of the turbine in the powerhouse is 12.45 m. The control room is designed outside the main powerhouse with dimension of 4 m high and 6m width. The length of erection bay is kept 12.45 m. The efficiencies of the turbine, generator and transformer is taken as 90 %, 97 % and 98.5 % respectively. The overall length, breadth and height of the powerhouse are 55.07m, 25.29m and 31.34m respectively.

4.5.3. STRUCTURAL MEMBERS:

The column size of 850 mm by 850 mm with spacing at x-direction and y-direction is taken as 5.42 m and 6.15 m respectively. The width and depth of beam are 280mm and 400mm depth respectively. The depth of Generator Floor Slab taken is 220mm. The width and depth of Machine Hall Column taken is 850mm x850mm respectively. The depth of Control Room Roof Slab taken is 210mm. The size of control room column taken is 100mmx100mm.The external wall of 250 mm thick is used to surround the powerhouse while the partition wall of 140 mm is used to divide the control room and battery room in the control bay.

4.6. HYDRAULIC DESIGN OF TAILRACE

The tailrace is a channel that carries water away from the turbine after it has passed through the powerhouse in a hydropower plant. It is designed as a rectangular canal, typically sized to handle the design discharge efficiently and safely. For this project, the tailrace consists of either three individual ducts or two combined ducts, each designed for a normal discharge of 16.28 m^3/s per duct (total 48.83

m^3/s), with a permissible velocity of 1.5 m/s to prevent erosion and ensure smooth flow. The typical canal section has a water depth of about 2.33 m and a width of 4.66 m for individual ducts, with a gentle slope of 1 in 3225, ensuring subcritical flow conditions for stability and efficient water conveyance. During overloading (10% higher discharge), the section and slope are adjusted accordingly to maintain safe velocities and flow conditions

Refer to Annex II & VI for detailed calculation and drawings.

CHAPTER 5: NUMERICAL MODELLING & STATIC ANALYSIS

Numerical modeling of the underground structure was conducted using **Phase2**, a 2D elastic-plastic finite element software developed for the analysis and design of underground excavations and their support systems. The analysis focused on evaluating the performance of two different support systems based on parameters such as induced stresses, total displacement, and thickness of the plastic zone. The tunnel alignment passes through varying rock mass classes (Class II to Class VI), and simulations were carried out for each class to assess support requirements. The geological and mechanical input parameters used in the analysis are described in the following section.

5.1. FIELD STRESS

Field stresses were estimated based on the overburden depth at the tunnel alignment. The locations with the highest and lowest overburden were identified and used in the analysis to represent the range of stress conditions. Vertical stress (σ_v) was calculated using the unit weight of Augen Gneiss, assumed to be 26.5 kN/m³. This value was used to compute the in-situ stresses required for the numerical simulation.

$$\sigma_v = \gamma Z$$

The values of maximum horizontal stress (σH) in each section of the tunnel and cavern is obtained from the equation

$$\sigma_H = 1.5 + 1.2\sigma_v$$

Where,

σ_H = horizontal stress, principal stress or σ_1

σ_v = vertical stress or σ_3

γ = unit weight of overburden rock

Z = overburden depth

Since σH is highest of all the stress tensors it will be taken as σ_1 and σ_V as σ3.

Table 13 : Value for stress for different rock class

Rock class	Q-Value	Maximum Overburden	Sigma 1 (Mpa)	Sigma 3 (Mpa)	sigma Z (Mpa)
Class I	>10	1035	34.413	27.4275	27.4275
Class II	1-10	1035	34.413	27.4275	27.4275
Class III	0.5-1	1035	34.413	27.4275	27.4275
Class IV	0.1-0.5	1035	34.413	27.4275	27.4275
Class V	0.01-0.1	1035	34.413	27.4275	27.4275
Class VI	<0.01	1035	34.413	27.4275	27.4275

5.2. GEOMECHANICAL PROPERTIES

For analyzing different rock mass conditions, geomechanical properties were estimated by combining basic intact rock data with GSI values, modulus, and material index. When lab test results weren't available, data from previous studies on similar rock types were used. GSI was determined by evaluating the overall condition of the rock mass and its relationship to RMR.

These GSI values were then applied to derive the parameters for the Generalized Hoek-Brown failure criterion, which is used to model the strength and behavior of fractured rock. Tools like RocLab or the built-in calculator in Phase2 were used for these calculations.

In some cases, GSI was also estimated from Q-values using a logarithmic correlation proposed by Salminen, Lindfors, and Haapalehto (2018), which is:

$GSI = 9 \times \ln(Q) + 44$

This approach helped in assigning suitable input parameters for numerical modeling across different rock classes. Using the correlation mentioned above, appropriate GSI values were assigned to different rock classes, as summarized in the following table.

Table 14 : GSI value based on class of rock

Rock class	Q-Value	Adopted Q value	GSI
Class I	>10	11	65.58
Class II	1-10	10	64.72
Class III	0.5-1	1	44
Class IV	0.1-0.5	0.5	37.76
Class V	0.01-0.1	0.1	23.28
Class VI	<0.01	0.01	2.55

5.3. MATERIAL PROPERTIES

Table 15 : Material Properties

Rock Type	: Augen Gniess
Initial Element Loading	: Field Stress Only
Elastic Type	: Isotropic
Poisson's Ratio	: 0.3
Failure Criterion	: Generalized Hoek-Brown
Material Type	: Plastic
Disturbance factor	: 0.8 for drill and blast
Density	: 2701 kg/m^3
Uniaxial Compressive Strength	: 250 MPa

5.4. SUPPORT PARAMETERS

1. Rock Bolt

- Bolt Type: End Anchored
- Grade: Fe500
- Bolt Diameter: 25 mm
- Bolt Length: 2.5m for Class III support system
- Bolt Spacing: 1.5m for Class III
- Young's Modulus: 200000 MPa

The bolt pattern varies due to blot spacing so it differs from one class to another

2. Fiber Shotcrete

- Grade: M40 (Plain shotcrete mix reinforced with steel Fibre)
- Compressive Strength: 40MPa
- Tensile Strength: 8MPa
- Young's Modulus: 38000MPa

- Poisson Ratio: 0.2
- Thickness: 0.1 m

The thickness of shotcrete layer varies from one class to another.

3. Steel Rib

- Section depth: 150 mm
- Area: 0.191 m2
- Moment of Inertia: $246*10^6$ mm^4
- Young's Modulus: 2 × 105 Mpa
- Poisson's ratio: 0.25
- Spacing: 1.5m
- Compressive strength: 400 Mpa
- Tensile strength: 400 Mpa

5.5. PHASE 2 SIMULATION OF TUNNEL BEHAVIOUR

The excavation was modeled as a D-shaped tunnel with a diameter of 4.8 meters using AutoCAD. After defining the external boundary, the model geometry was discretized, and a mesh surface was generated to support numerical analysis. Initial field stresses were assigned to the model, and a series of uniform loads were applied across 10 construction stages. Each stage corresponds to a different load factor: 1, 0.8, 0.4, 0.2, 0.1, 0.08, 0.04, 0.02, 0.01, and 0. A factor of 1 indicates that the applied load fully balances the in-situ stress, while a factor of 0 means no external load is present. Intermediate values allow the load to be incrementally reduced or increased.

At the first stage (factor = 1), the pressure applied exactly counteracts the in-situ stress, resulting in a stress-balanced condition where no tunnel deformation should occur. In subsequent stages, as the load factor decreases, the support pressure is gradually reduced. This reduction leads to increased tunnel deformation due to the imbalance between the internal tunnel pressure and the surrounding rock stresses.

To estimate the tunnel deformation at the point where support is installed, the empirical method developed by Vlachopoulos and Diederichs is used. This approach requires two outputs from the finite-element simulation: (a) the maximum tunnel wall displacement at a location far behind the tunnel face, and (b) the radius of the plastic (yielded) zone in the same region. The extent of this plastic zone defines the area of failed rock around the tunnel and is critical for understanding deformation

behavior during excavation.

5.6. SUMMARY OF RESULT

The dimension of the support system for different classes of rock is shown in the table below:

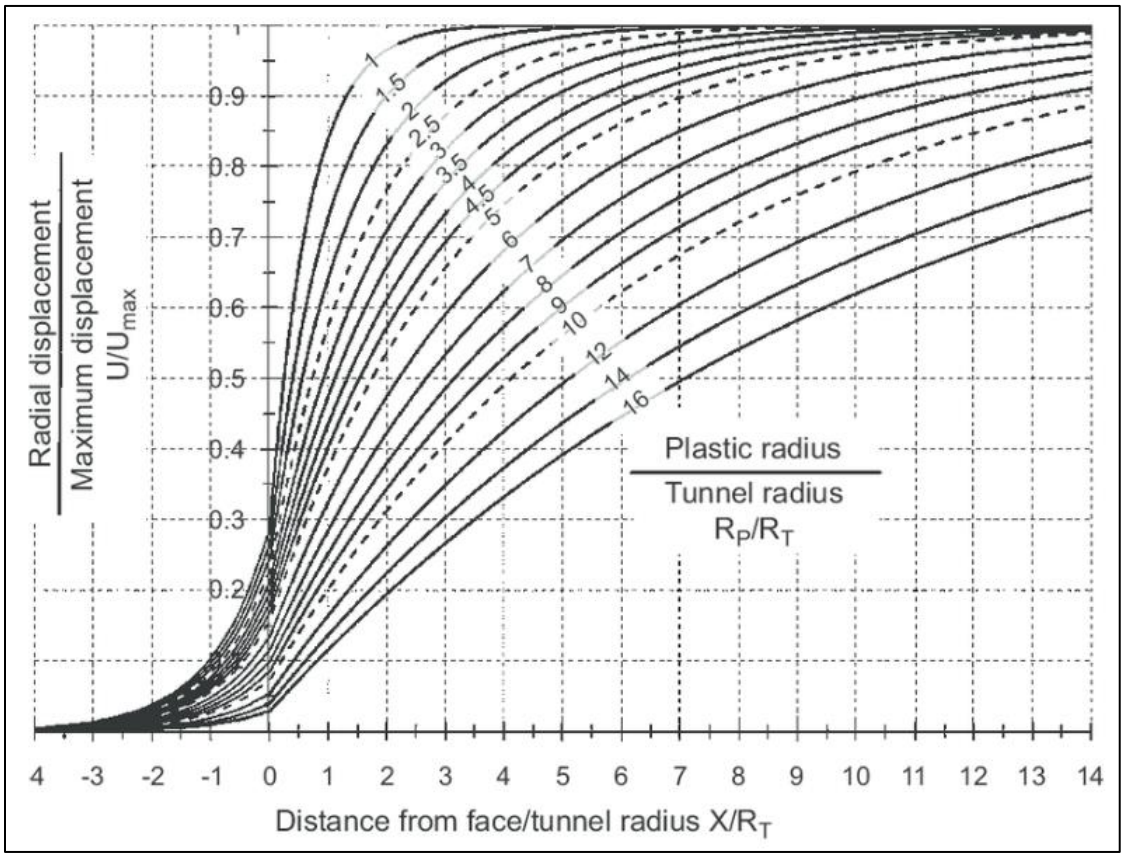


Figure 39 : Closure length graph for deformation in tunnel

Table 16 : Dimensions of Tunnel Support System

Rock Class	Support System
Class II	Rock bolt at 2 m spacing of 2.5 m length Fiber shotcrete of 5 cm Concrete Lining 20 cm at invert
Class III	Rock bolt at 1.5 m spacing of 2.5 m length Fiber shotcrete of 10 cm Concrete Lining 20 cm at invert

Class IV	Rock bolt at 1.5 m spacing of 2.5 m length Fiber shotcrete of 15 cm Concrete Lining 20 cm at invert
Class V	Rock bolt at 1 m spacing of 2.5 m length Fiber shotcrete of 15 cm Concrete Lining 20 cm at invert, wall and crown Steel Ribs of ISMB 150*75 @ 1.5m c/c
Class VI	Rock bolt at 1 m spacing of 2.5 m length Fiber shotcrete of 15 cm Concrete Lining 30 cm at invert, 25 cm at crown and wall Steel Ribs of ISMB 150*75 @ 1.5m c/c

The support analysis for different support system of Rock Class III are shown in the figure below:

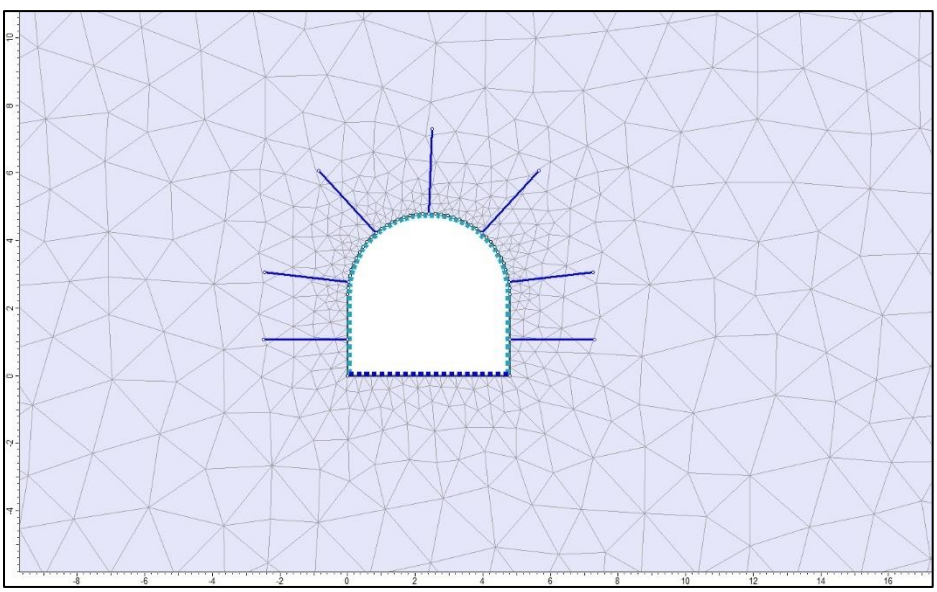


Figure 40 : Tunnel after placement of support linings

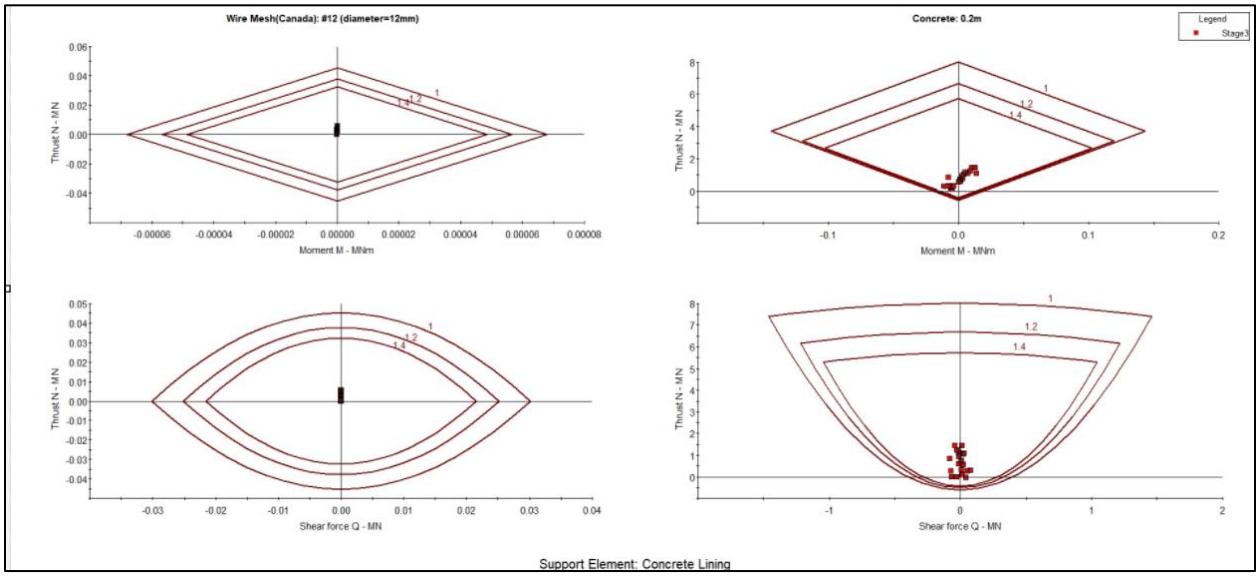


Figure 41 : Support Capacity plot for concrete lining for class III

Table 17 : Amount of closure prior to support

Plastic zone radius	3.913 m
Distance from tunnel face	2.5 m
Tunnel radius	2.4 m
Total displacement (from stage 10)	0.0165
Distance from tunnel face/ tunnel radius	0.833
Plastic zone radius/ tunnel radius	1.63
From graph Closure / Maximum closure =	0.68
So, closure	0.0112

CHAPTER 6: FINANCIAL ANALYSIS

6.1. COST ESTIMATES:

This sub-chapter deals with total cost of the project including major cost components. The details of the cost required for constructing the project based on the design and drawings has been found out. Rates used in the cost estimates were in accordance with the districts rates of Taplejung where the project is situated. The cost estimate was prepared on the basis of the sequential execution of the following steps:

1. Sub-division of the total project into several components such as headworks, headrace tunnel, pressure shaft, powerhouse, tailrace, etc.
2. Breaking down of structures into several distinct construction tasks such as site clearance, earthwork excavation, formwork, concrete work, stone pitching and reinforcement.
3. Calculation of the quantities of each item from the design drawings and topographical map of the project.
4. Unit rate analysis for every major item of the components.

Beside civil works, hydro-mechanical works, electro-mechanical work, preliminary expenses, land acquisition cost, etc. were also determined. The total cost for the development of the Kabeli-A HEP is estimated to be NRs. 7,25,33,38,034 (Seven Arab Twenty-Five crore thirty-three lakh thirty eight thousand and thirty four only) inclusive of contingencies and VAT. The cost of the project per megawatts is NRs.14,65,61,689 (Fourteen Crore sixty-five lakh sixty-one thousand six hundred and eighty-nine only). The project cost summary of the project is shown in the table below:

Table 18 : Project Cost Summary

Project Cost Summary			
S.N.	**Description of work**	**Amount (NRs)**	**Coverage %**
1	Civil Works	3,518,720,019	48.51
2	Hydro mechanical works	202,721,897	2.79
3	Electro-mechanical	1,292,818,695	17.82
4	Preliminary Expenses	400,000,000	5.51
5	Environment mitigation and social contribution	183,907,500	2.54
6	Project Management and Supervision	256,284,000	3.53
7	Transmission line cost	116,390,000	1.60
8	Land Acquisition cost	47,460,000	0.65

9	Vehicles	47,460,000	0.65
10	Infrastructure Development Cost	47,460,000	0.65
Total Cost		6,113,222,110	
Contingency		305,661,106	5%
Total Project Cost excluding VAT		6,418,883,216	
Total Project Cost including VAT		7,253,338,034	13%

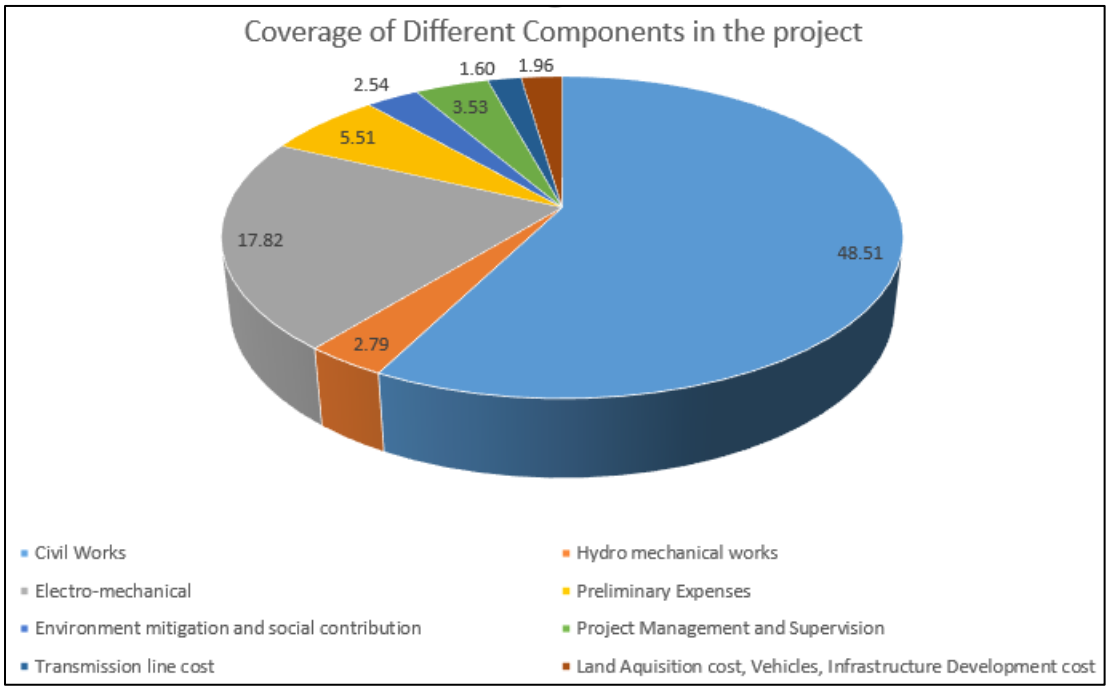


Figure 42 : Coverage of Different Components Cost in the Project

6.2. POWER AND ENERGY

The total power production that can be generated from Kabeli A hydropower Project is 49.49 MW with the design discharge of 48.83m^3/s and net head of 120.35 m.

Table 19 : Monthly Power Generation of Kabeli A

Month	No of days	Monthly flow (m3/s)	Env. Release (m3/s)	Available Flow (m3/s)	Design Flow (m3/s)	Gross Head	Head Loss	Net Head (m)	Power Generation (kW)
Jan	31	10.98	0.945	10.03	10.03	124.46	0.33	124.13	10505.58
Feb	28	9.45	0.945	8.50	8.50	124.46	0.28	124.18	8908.61
Mar	31	9.72	0.945	8.77	8.77	124.46	0.28	124.18	9190.35
Apr	30	15.01	0.945	14.07	14.07	124.46	0.50	123.96	14711.29
May	31	27.19	0.945	26.25	26.25	124.46	1.36	123.10	27254.99

Jun	30	68.00	0.945	67.05	48.83	124.46	4.32	120.14	49487.31
Jul	31	139.40	0.945	138.45	48.83	124.46	4.32	120.14	49487.31
Aug	31	155.98	0.945	155.04	48.83	124.46	4.32	120.14	49487.31
Sep	30	105.09	0.945	104.14	48.83	124.46	4.32	120.14	49487.31
Oct	31	45.22	0.945	44.28	44.28	124.46	3.58	120.88	45151.16
Nov	30	21.77	0.945	20.83	20.83	124.46	0.91	123.55	21708.80
Dec	31	14.48	0.945	13.53	13.53	124.46	0.47	123.99	14151.69

6.3. REVENUE GENERATION:

The source of the revenue generation of the project is the selling of the hydroelectric energy as per the tariff rate for RoR hydropower schemes in Power Purchase Agreement (PPA) with NEA which amounts at the rate of NRs. 4.8 per kWh during the wet months and NRs. Per kWh during the dry months.

The total annual energy that can be generated from this project is 243.35 GWh where the dry energy generation is 29.61 GWh and the wet energy generation is 213.74 GWh. With this energy generation, the total annual revenue of the project is expected to be NRs. 1,19,82,10,018 (One Arab nineteen crore eighty-two lakh ten thousand and eighteen only).

Table 20 : Yearly Revenue Generation of Kabeli A

Month	Operating (hrs.)	Dry Energy (kWh)	Wet Energy (kWh)	Total Energy (kWh)	Outage/Transmission loss (kWh)	Salable Energy (kWh)	PPA Rate (NRs.)	Monthly Revenue (NRs.)
Jan	706.8	7425345.316		7425345.316	445520.719	6979824.597	8.4	58,630,526.62
Feb	638.4	5687257.382		5687257.382	341235.4429	5346021.939	8.4	44,906,584.29
Mar	706.8	6495738.527		6495738.527	389744.3116	6105994.215	8.4	51,290,351.41
Apr	684		10062521.64	10062521.64	603751.2981	9458770.337	4.8	45,402,097.62
May	706.8		19263830.35	19263830.35	1155829.821	18108000.52	4.8	86,918,402.52
Jun	684		33849318.96	33849318.96	2030959.138	31818359.82	4.8	152,728,127.14
Jul	706.8		34977629.59	34977629.59	2098657.775	32878971.82	4.8	157,819,064.71

Aug	706.8		34977629.59	34977629.59	2098657.775	32878971.82	4.8	157,819,064.71
Sep	684		33849318.96	33849318.96	2030959.138	31818359.82	4.8	152,728,127.14
Oct	706.8		31912838.01	31912838.01	1914770.281	29998067.73	4.8	143,990,725.12
Nov	684		14848819.01	14848819.01	890929.1409	13957889.87	4.8	66,997,871.39
Dec	706.8	10002415.85		10002415.85	600144.9511	9402270.9	8.4	78,979,075.56
	SUM	29610757.08	213741906.1	243352663.2	14601159.79	228751503.4		**1,198,210,018.24**

6.4. FINANCIAL ANALYSIS:

Various financial indicators have been analyzed in this study in order to determine the financial viability of the project. The economic life of the project is considered to be of 30 years where thereafter, the project shall be handover to the Government of Nepal. The construction period of the project has been taken as 3 years. The discount rate of 12% has been considered in the project. Benefit-Cost Ratio, Net Present Value, Internal Rate of Return, Payback Period and Sensitivity Analysis have been calculated and their results are presented below:

6.4.1. NET PRESENT VALUE (NPV):

Net Present Value (NPV) is the value obtained by discounting all cash outflows and inflows of a capital investment project by a chosen target rate of return or cost of capital. It is calculated as the difference of present value of cash inflows and the present values of cash outflows over the economic life of the project. The NPV of the project is calculated as NRs. 14,94,23,64,997.

6.4.2. INTERNAL RATE OF RETURN (IRR):

Internal rate of return (IRR) is a discounted cash flow investment appraisal method which calculates the discount rate causing the net present value of an investment to become zero. A project is acceptable if it has an IRR greater than the cost of capital in the financial market. With the attainment of annual cash inflows of the project over its life, IRR of the project is calculated out to be 15% which is greater than the prevalent discount rate. So, the project can be considered as financially viable for an investment.

Table 21 : Variation of NPV, IRR & B/C ratio

Year	IRR	B/C ratio	NPV
10	3%	0.86	-1995264200
20	13.49%	1.67	5727838009
30	15%	2.27	14942364997

6.4.3. PAYBACK PERIOD:

The amount of time that it can take to recover the cost of an investment for this project is 6 years. This means that it will take not more than 6 years for cash inflows from project to accumulate equal to or exceed project outflows after the project is in operation phase.

6.4.4. BENEFIT-COST RATIO (BC RATIO):

Benefit-Cost ratio is the ratio of present value of the project's future cash flows divided by the initial capital outlay. The BC ratio of the project is found to be 2.27 which further signifies that the project is financially feasible.

6.4.5. SENSITIVITY ANALYSIS:

Sensitivity analysis is performed in this study to analyze the risk in the financial viability of the project due to unforeseen changes in various factors like total costs, discount rates, delay in construction, etc. This helped us to know if the project is attractive even during the variation in the above-mentioned parameters. The variation range for the total capital cost and revenue decrease has been analyzed from -20% to 20%. The sensitivity analysis of BC Ratio, IRR and NPV has also been deduced which are shown in the figure below:

Table 22 : Data for Sensitivity Analysis

Sensitivity Analysis	
Capital Investment	7,253,338,034
Annual Revenue	1,198,210,018
Annual Operation and maintenance	108,800,070.51
Useful Life	30
MARR	10%

Table 23 : Variation of B/C Ratio with cost and revenue

B/C Ratio		
Variation	**Cost Variation**	**Revenue Variation**
-20%	2.92	1.76
-15%	2.73	1.89
-10%	2.56	2.02
-5%	2.41	2.15
0%	2.27	2.27
5%	2.15	2.40
10%	2.04	2.53
15%	1.94	2.66
20%	1.84	2.79

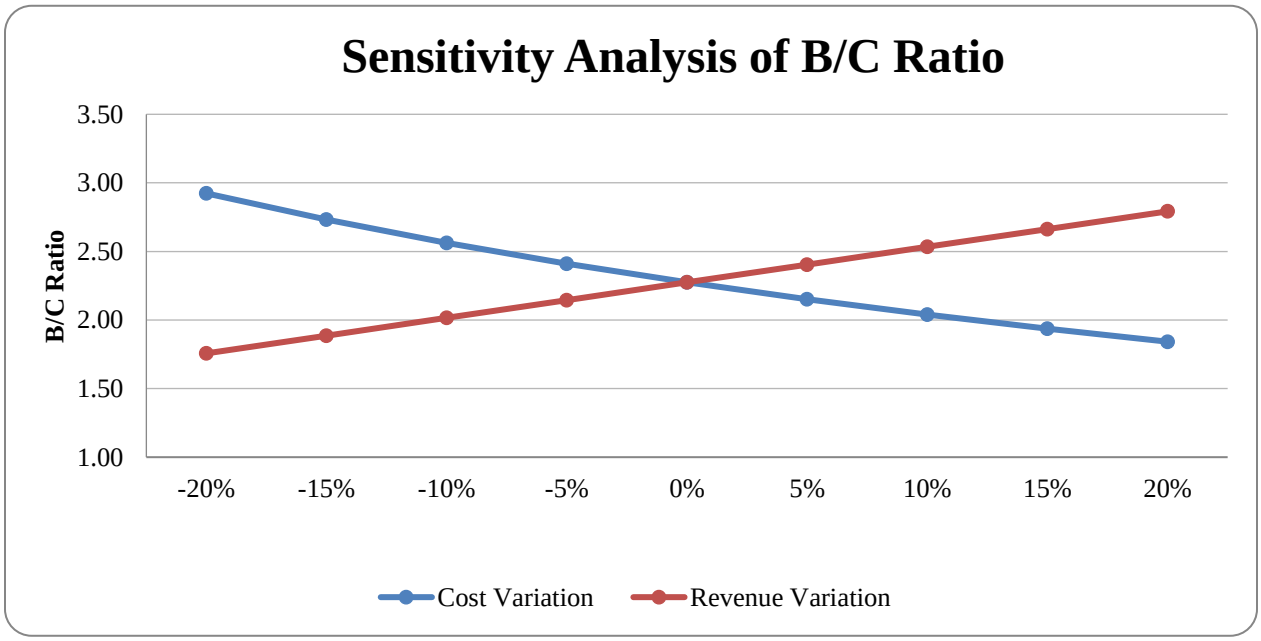


Figure 43 : Sensitivity Analysis of BC Ratio

Table 24 : Variation of IRR with cost and revenue

IRR		
Variation	**Cost Variation**	**Revenue Variation**
-20%	18.45%	12.07%
-15%	17.49%	12.85%
-10%	16.62%	13.61%
-5%	15.82%	14.35%

0%	15.08%	15.08%
5%	14.39%	15.78%
10%	13.75%	16.47%
15%	13.15%	17.14%
20%	12.59%	17.80%

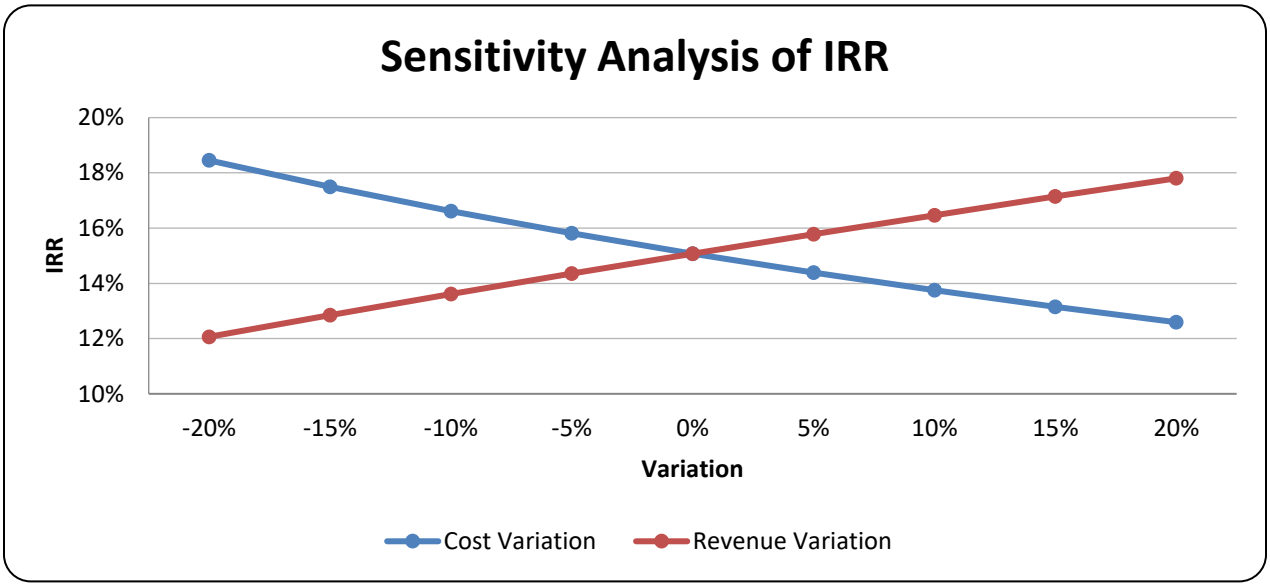


Figure 44 : Sensitivity Analysis of IRR

Table 25 : Variation of NPV with cost and revenue

NPV		
Variation	**Cost Variation**	**Revenue Variation**
-20%	18055760566	8840496429
-15%	17277411674	10365963571
-10%	16499062782	11891430713
-5%	15720713889	13416897855
0%	14942364997	14942364997
5%	14164016105	16467832139
10%	13385667213	17993299281
15%	12607318321	19518766423
20%	11828969428	21044233565

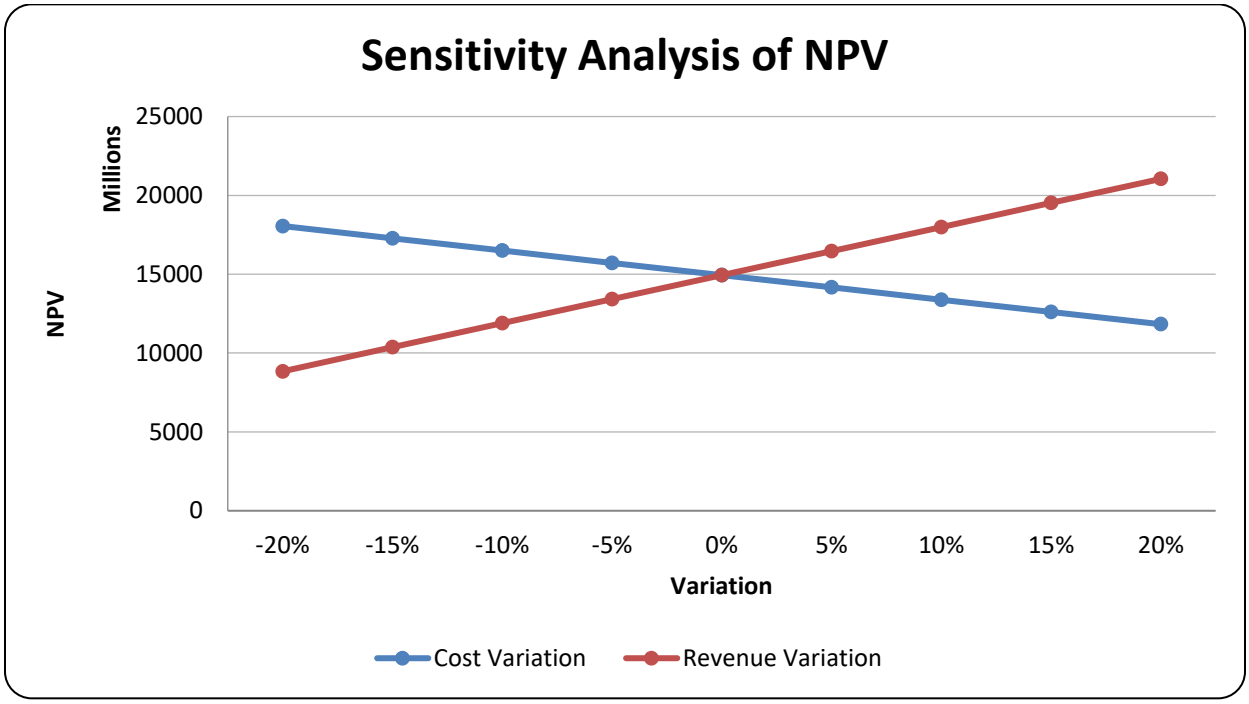


Figure 45 : Sensitivity Analysis of NPV

Refer to Annex V for detailed financial evaluation.

CHAPTER 7: CONCLUSION & RECOMMENDATIONS

Based on the above studies on followings points can be concluded for the design of hydropower project components: The report entitled "Potential Study of Medium Hydropower Project of Nepal: A Case study of Kabeli-A HEP" is an outcome of the study after data analysis, design activities, structural analysis, report reviews and consultations. The report also contains financial evaluations of the project. Major conclusions and recommendations drawn from the project are briefed below.

7.1 CONCLUSIONS

1. The hydropower potential of Kabeli-A Hydroelectric project is found to be 49.49 MW with design discharge Q40 of 48.83 m3 /s and net head of 120.14 m.
2. Alternative 1 is technically more feasible, economically more viable, and environmentally more sustainable.
3. Hydraulic design of components of hydropower have been done following DOED standards/guidelines and IS where needed.
4. The design of civil structures of the project was carried out followed by the stability analysis of weir and anchor blocks.
5. The optimized diameter of headrace tunnel and pressure shaft was calculated to be 4.8 m and 3.65 m respectively. Followed by their optimization, support system for the tunnel was designed for different rock classes.
6. The powerhouse was designed and analyzed on the basis of architectural drawings drafted. The preliminary design was structurally analyzed, followed by the design of the components. The dimensions, loads and cost estimation were also taken into account.
7. The total cost of the project is estimated at 7253.338 million NRs.
8. Benefit cost (B/C) ratio of this project is found to be 2.27 which is more than 1 so the project is found to be economically feasible.

7.2 RECOMMENDATIONS

1. Actual field survey which includes hydrological, geological survey of the project site should be thoroughly conducted for the detail design of project components.
2. Hydraulic models of the components should be made and tested for further optimization of

hydropower project.

3. The financial analysis has been carried out based on prevailing financial assumptions and methodology. The financial analysis would change with change in assumptions made.

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ANNEX I - HYDROLOGICAL ANALYSIS

1. **Monthly Discharge of gauging station at Tamor (684)**

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1996	68.57	57.02	63.00	72.49	169.35	341.93	871.03	776.90	594.67	254.68	124.92	79.95
1997	59.27	51.39	52.32	71.38	117.81	345.33	616.00	739.58	518.53	218.87	106.72	74.73
1998	51.38	42.57	47.36	85.88	180.61	525.37	845.26	1155.48	547.10	229.03	107.49	63.55
1999	43.47	31.94	28.93	55.07	165.94	416.03	806.32	833.81	603.43	335.45	117.17	67.69
2000	44.48	37.12	35.78	68.87	160.25	365.23	725.10	1207.58	584.03	158.42	88.44	48.28
2001	50.88	46.85	40.78	65.58	128.42	336.27	445.52	765.97	451.77	298.00	118.81	79.59
2002	59.21	48.57	50.55	75.04	123.58	236.43	766.58	768.00	289.27	134.94	82.95	60.75
2003	48.95	46.35	48.55	86.46	99.75	347.67	817.00	731.00	543.37	201.77	108.63	77.77
2004	60.33	50.11	52.64	80.88	140.84	278.07	578.55	539.77	370.60	232.32	102.98	72.90
2005	54.11	46.29	48.47	58.63	104.75	199.46	488.90	623.84	321.33	173.81	93.90	62.45
2006	46.27	40.20	38.85	49.01	111.83	366.97	496.13	471.10	426.87	183.13	95.79	66.78
2007	48.55	48.30	55.76	80.09	114.42	235.80	608.00	555.16	568.20	193.71	100.91	66.46
2008	47.08	37.49	42.98	75.99	98.65	297.13	605.71	872.94	391.00	153.06	83.93	56.25
2009	40.31	32.24	29.17	59.35	106.29	171.16	436.61	695.61	331.60	163.26	93.34	66.28
2010	49.44	42.30	51.98	80.94	116.03	259.17	645.32	877.23	627.50	171.13	91.78	59.90
2011	71.89	74.20	62.60	89.46	123.43	225.03	637.84	633.19	380.63	174.94	100.03	71.66
2012	55.85	59.79	68.68	113.73	130.59	386.47	664.97	616.29	496.37	192.32	91.00	62.77
2013	46.52	38.71	40.11	53.03	141.27	266.93	703.81	489.55	340.77	192.19	98.43	64.76
2014	44.31	33.63	31.63	47.14	84.73	248.57	659.84	713.32	437.73	160.45	83.76	56.95
2015	38.52	29.71	30.63	37.46	148.05	391.33	502.03	586.52	459.60	177.71	90.70	66.52
2016	52.35	46.47	45.64	63.88	99.82	379.25	646.81	437.65	687.30	334.68	150.23	85.48
2017	56.10	42.86	45.19	73.00	122.92	320.13	595.71	821.32	518.27	276.90	100.72	65.34
2018	47.03	39.83	38.08	54.54	133.64	352.90	740.48	875.10	623.00	177.61	85.04	59.50
2019	41.77	31.93	36.21	79.70	115.35	305.07	672.52	642.48	629.17	264.84	115.34	81.12
Average	51.11	43.99	45.25	69.90	126.60	316.57	649.00	726.22	489.25	210.55	101.38	67.39

2. Mean Monthly Discharge of ungauged station at proposed intake

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1996	14.73	12.25	13.53	15.57	36.38	73.44	187.09	166.87	127.73	54.70	26.83	17.17
1997	12.73	11.04	11.24	15.33	25.30	74.17	132.31	158.85	111.37	47.01	22.92	16.05
1998	11.04	9.14	10.17	18.45	38.79	112.84	181.55	248.18	117.51	49.19	23.09	13.65
1999	9.34	6.86	6.21	11.83	35.64	89.36	173.19	179.09	129.61	72.05	25.17	14.54
2000	9.55	7.97	7.68	14.79	34.42	78.45	155.74	259.37	125.44	34.03	19.00	10.37
2001	10.93	10.06	8.76	14.09	27.58	72.23	95.69	164.52	97.03	64.01	25.52	17.09
2002	12.72	10.43	10.86	16.12	26.54	50.78	164.65	164.96	62.13	28.98	17.82	13.05
2003	10.51	9.95	10.43	18.57	21.42	74.67	175.48	157.01	116.71	43.34	23.33	16.70
2004	12.96	10.76	11.31	17.37	30.25	59.73	124.26	115.94	79.60	49.90	22.12	15.66
2005	11.62	9.94	10.41	12.59	22.50	42.84	105.01	133.99	69.02	37.33	20.17	13.41
2006	9.94	8.64	8.35	10.53	24.02	78.82	106.56	101.19	91.69	39.33	20.57	14.34
2007	10.43	10.37	11.98	17.20	24.58	50.65	130.59	119.24	122.04	41.61	21.67	14.28
2008	10.11	8.05	9.23	16.32	21.19	63.82	130.10	187.50	83.98	32.88	18.03	12.08
2009	8.66	6.93	6.27	12.75	22.83	36.76	93.78	149.41	71.22	35.07	20.05	14.24
2010	10.62	9.09	11.17	17.39	24.92	55.67	138.61	188.42	134.78	36.76	19.71	12.87
2011	15.44	15.94	13.45	19.21	26.51	48.33	137.00	136.00	81.76	37.57	21.49	15.39
2012	12.00	12.84	14.75	24.43	28.05	83.01	142.83	132.37	106.61	41.31	19.55	13.48
2013	9.99	8.31	8.62	11.39	30.34	57.33	151.17	105.15	73.19	41.28	21.14	13.91
2014	9.52	7.22	6.79	10.12	18.20	53.39	141.73	153.21	94.02	34.46	17.99	12.23
2015	8.27	6.38	6.58	8.05	31.80	84.05	107.83	125.98	98.72	38.17	19.48	14.29

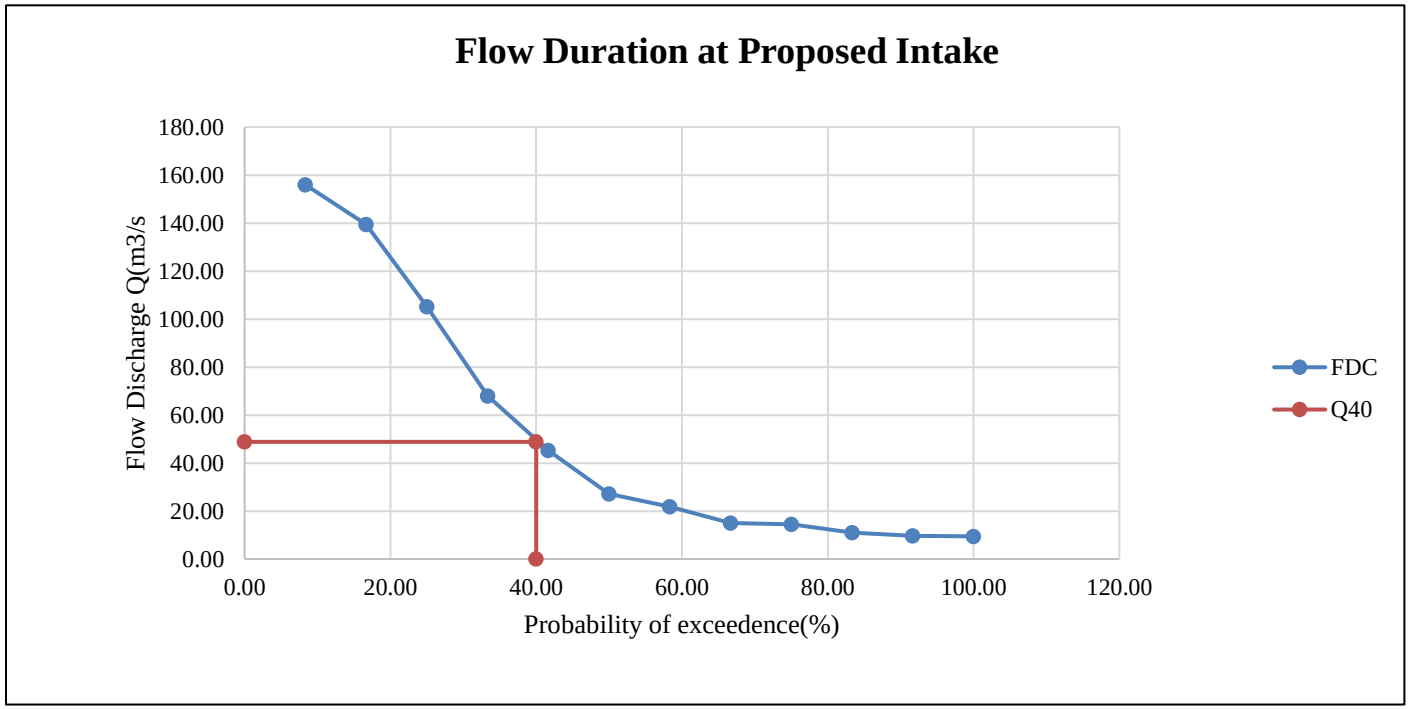
2016	11.24	9.98	9.80	13.72	21.44	81.46	138.93	94.00	147.62	71.88	32.27	18.36
2017	12.05	9.21	9.71	15.68	26.40	68.76	127.95	176.41	111.32	59.48	21.63	14.03
2018	10.10	8.56	8.18	11.72	28.70	75.80	159.05	187.96	133.81	38.15	18.26	12.78
2019	8.97	6.86	7.78	17.12	24.78	65.52	144.45	138.00	135.14	56.88	24.77	17.42
Average	10.98	9.45	9.72	15.01	27.19	68.00	139.40	155.98	105.09	45.22	21.77	14.48

Ungauged station	Catchment area	861.868	Km2
Station no. 684	Catchment Area	4012.657	Km2
Catchment area ratio		0.214787	

3. Flow Duration Curve at Proposed Intake

Month	Q (m^3/sec) at ungauzed station	Q in Desec. Order (ungauzed station)	Q (m^3/sec) at Gauzing Sataion	Q in Desec. Order (Gauzing Sation)	Rank	Frequency	Probability of Exceedence
January	10.98	155.98	51.11	726.22	1.00	12.00	8.33
February	9.45	139.40	43.99	649.00	2.00	6.00	16.67
March	9.72	105.09	45.25	489.25	3.00	4.00	25.00
April	15.01	68.00	69.90	316.57	4.00	3.00	33.33
May	27.19	45.22	126.60	210.55	5.00	2.40	41.67
June	68.00	27.19	316.57	126.60	6.00	2.00	50.00
July	139.40	21.77	649.00	101.38	7.00	1.71	58.33
August	155.98	15.01	726.22	69.90	8.00	1.50	66.67
September	105.09	14.48	489.25	67.39	9.00	1.33	75.00
October	45.22	10.98	210.55	51.11	10.00	1.20	83.33
November	21.77	9.72	101.38	45.25	11.00	1.09	91.67

December	14.48	9.45	67.39	43.99	12.00	1.00	100.00



Flood Frequency Analysis at Proposed Intake Site:

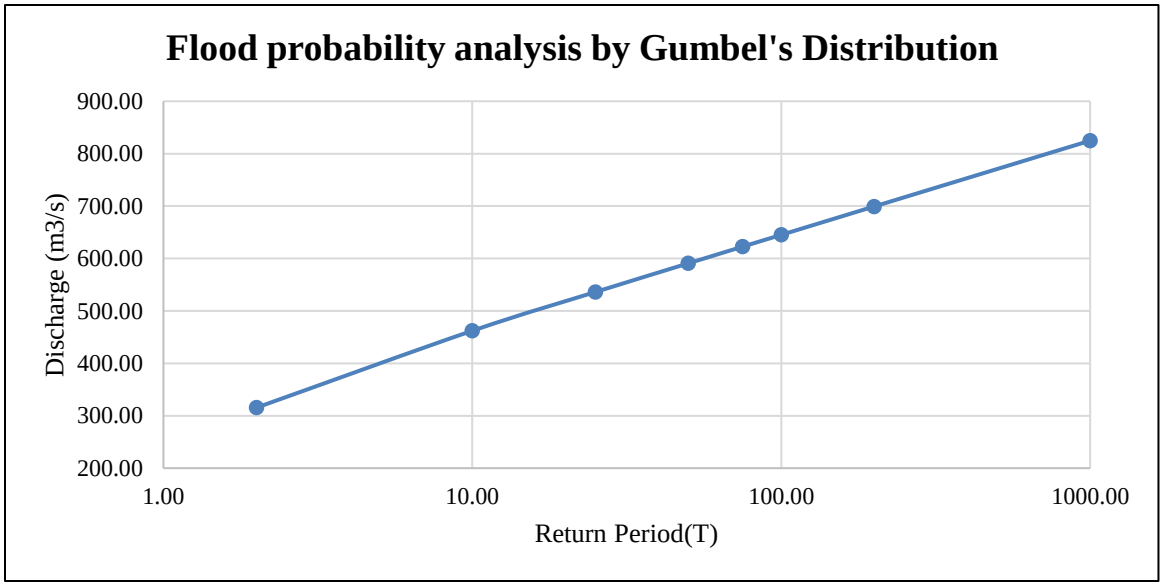
1. **Gumbel's Extreme Method:**

Year	Q m3/s	Q m3/s2	Ranked(Q)	Rank (m)	p=m/(n+1)	Return period (T)	Yt	Kt	Qt
1996	1923.00	413.04	588.30	1.00	0.04	25.00	3.20	2.46	535.96
1997	1702.00	365.57	415.83	2.00	0.08	12.50	2.48	1.80	480.34
1998	1850.00	397.36	413.04	3.00	0.12	8.33	2.06	1.41	447.06
1999	1858.00	399.07	399.07	4.00	0.16	6.25	1.75	1.12	422.90
2000	2739.00	588.30	397.36	5.00	0.20	5.00	1.50	0.89	403.68
2001	1287.00	276.43	375.88	6.00	0.24	4.17	1.29	0.70	387.57
2002	1480.00	317.89	365.57	7.00	0.28	3.57	1.11	0.54	373.56
2003	1936.00	415.83	358.05	8.00	0.32	3.13	0.95	0.39	361.07
2004	898.00	192.88	357.41	9.00	0.36	2.78	0.81	0.26	349.70
2005	1562.00	335.50	335.50	10.00	0.40	2.50	0.67	0.13	339.18
2006	828.00	177.84	329.91	11.00	0.44	2.27	0.55	0.01	329.32
2007	1214.00	260.75	325.83	12.00	0.48	2.08	0.42	-0.10	319.95
2008	1667.00	358.05	317.89	13.00	0.52	1.92	0.31	-0.20	310.96
2009	1536.00	329.91	317.03	14.00	0.56	1.79	0.20	-0.31	302.23
2010	1750.00	375.88	305.64	15.00	0.60	1.67	0.09	-0.41	293.68
2011	1106.00	237.55	300.70	16.00	0.64	1.56	-0.02	-0.51	285.20
2012	1423.00	305.64	289.10	17.00	0.68	1.47	-0.13	-0.61	276.71
2013	1476.00	317.03	281.37	18.00	0.72	1.39	-0.24	-0.71	268.08
2014	1346.00	289.10	276.43	19.00	0.76	1.32	-0.36	-0.81	259.17
2015	1517.00	325.83	260.75	20.00	0.80	1.25	-0.48	-0.93	249.81
2016	1310.00	281.37	255.81	21.00	0.84	1.19	-0.61	-1.05	239.70
2017	1664.00	357.41	237.55	22.00	0.88	1.14	-0.75	-1.18	228.34
2018	1400.00	300.70	192.88	23.00	0.92	1.09	-0.93	-1.34	214.72
2019	1191.00	255.81	177.84	24.00	0.96	1.04	-1.17	-1.56	195.83

N	24.00					2.00	0.37	-0.15	315.41
Max	588.30					10.00	2.25	1.58	462.12
mean	328.11					25.00	3.20	2.46	535.96
stdev(σ)	84.60					50.00	3.90	3.10	590.74
Yn	0.53					75.00	4.31	3.48	622.58
Sn	1.09					100.00	4.60	3.75	645.11
						200.00	5.30	4.39	699.29
						1000.00	6.91	5.87	824.78

Return period (T)	Reduced variate(Yt)	Frequency factor (K)	Mean variate (X)	Estimated Flood (Xt) m3/s
10.00	2.25	1.58	328.11	462.12
25.00	3.20	2.46	328.11	535.96
50.00	3.90	3.10	328.11	590.74
75.00	4.31	3.48	328.11	622.58
100.00	4.60	3.75	328.11	645.11
200.00	5.30	4.39	328.11	699.29
1000.00	6.91	5.87	328.11	824.78

Return period (T)	Flood discharge
2.00	315.41
10.00	462.12
25.00	535.96
50.00	590.74
75.00	622.58
100.00	645.11
200.00	699.29
1000.00	824.78



2. Log Pearson Type III Method:

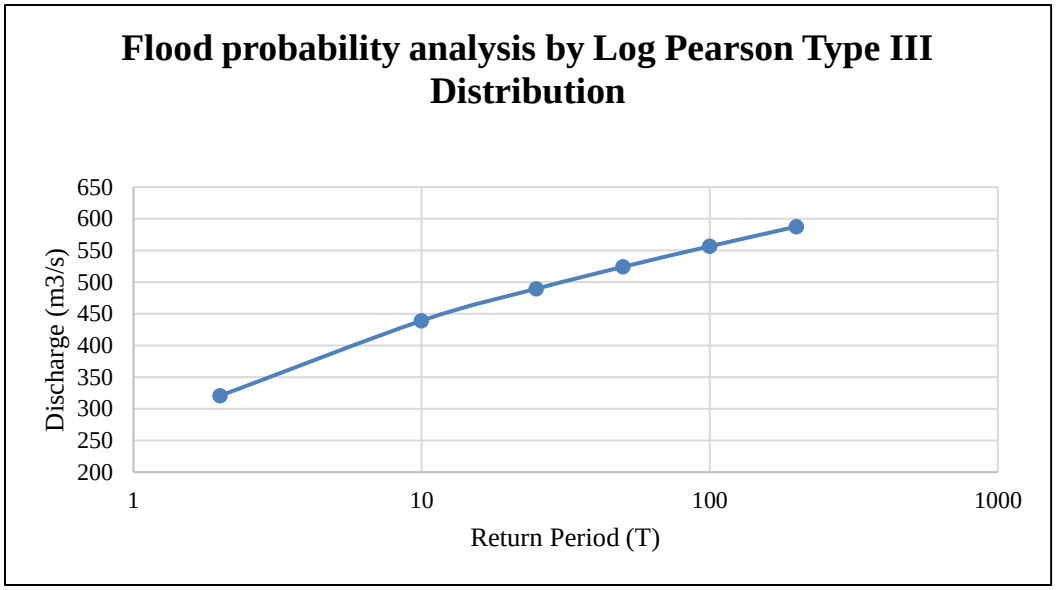
Rank	Max discharge	z=log(x)	$(z-\bar{z})^3$	$(z-\bar{z})^2$
1	588.3026	2.7696	0.0190	0.0713
2	415.8283	2.6189	0.0016	0.0135
3	413.0361	2.6160	0.0015	0.0129
4	399.0749	2.6011	0.0010	0.0097
5	397.3566	2.5992	0.0009	0.0093
6	375.8779	2.5750	0.0004	0.0053
7	365.5681	2.5630	0.0002	0.0037
8	358.0505	2.5539	0.0001	0.0026
9	357.4062	2.5532	0.0001	0.0026
10	335.4979	2.5257	0.0000	0.0005
11	329.9134	2.5184	0.0000	0.0003
12	325.8324	2.5130	0.0000	0.0001
13	317.8853	2.5023	0.0000	0.0000
14	317.0261	2.5011	0.0000	0.0000
15	305.6424	2.4852	0.0000	0.0003
16	300.7023	2.4781	0.0000	0.0006
17	289.1038	2.4611	-0.0001	0.0017
18	281.3714	2.4493	-0.0002	0.0028
19	276.4313	2.4416	-0.0002	0.0037
20	260.7519	2.4162	-0.0006	0.0074
21	255.8117	2.4079	-0.0008	0.0090
22	237.5548	2.3758	-0.0020	0.0161

23	192.8790	2.2853	-0.0103	0.0472
24	177.8439	2.2500	-0.0161	0.0638
	sum		-0.0055	0.2844
N	24.00			
Avg		2.50		
med		2.51		

skewness coefficient (cs)	-0.190
SD	0.111
avg	2.503
N	24.00000

T	K_z	$K_z * \sigma_z$	$z_T = \bar{z} + K_z * \sigma_z$	$antilog(Z_T)$
2	0.0315	0.0035	2.5060	320.6502
10	1.2592	0.1400	2.6425	439.0858
25	1.6835	0.1872	2.6897	489.4776
50	1.9503	0.2169	2.7194	524.0883
100	2.1852	0.2430	2.7455	556.5674
200	2.3971	0.2666	2.7691	587.6034

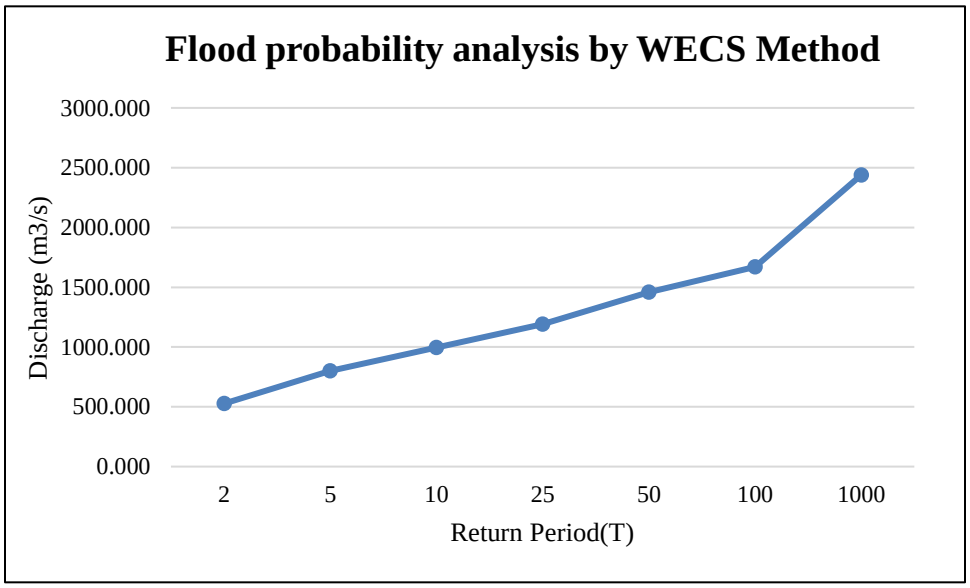
Return period	**Discharge in m3/s**
2	320.65
10	439.09
25	489.48
50	524.09
100	556.57
200	587.60



3. WECS/DHM Method:

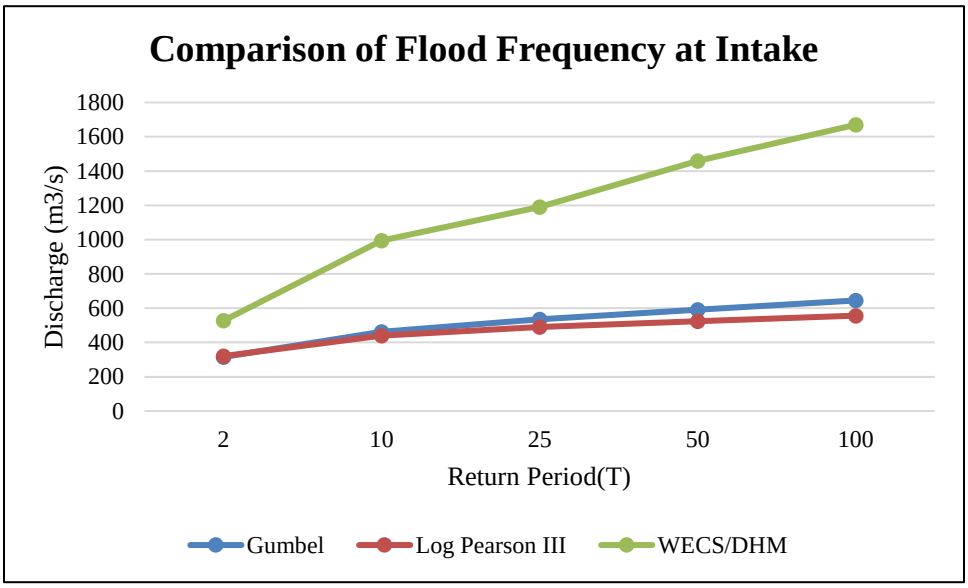
WECS Method			
Return Periods(Years)	Constant coefficient(α)	Power(β)	
2	1.8767	0.8737	
100	14.63	0.7342	
Table: Prediction coefficient for instantaneous flow			
Area of basin		860.791	km2
Area below 3000m		633.215	km2
Area between 5000 to 3000m		226.973	km2
Flood flow estimation			
Two years instantaneous flood (Q_2)= α*(Area below 3000m+1)$^{\beta}$			
		526.8765775	
100 years instantaneous flood (Q_{100})= α*(Area below 3000m+1)$^{\beta}$			
		1669.730466	
Flood peak discharge (Q_f) =$e^{(\ln Q2+s*\sigma)}$			
	σ =	ln(Q_{100}/Q_2)/2.326	
		0.495894743	
Where,			
s=standard normal variable			
σlnQ$_f$	ln(Q_f/Q_2)/2.326		
lnQ$_2$	6.266966323		
Standard normal variate for different return period			
Return period(f)	s	Q_f(m^3/s)	
2	0	526.877	
5	0.842	799.918	

10	1.282	994.961	
25	1.645	1191.196	
50	2.054	1459.040	
100	2.326	1669.730	
1000	3.09	2438.848	



4. Comparison of Flood Frequency Analysis:

SN	Return Period(T)	Discharge(m3/s)			
		Gumbel's	Log Pearson Type III	WECS/DHM	Adopted
	2	315.414	320.65	526.877	315.414
	10	462.121	439.086	994.961	462.121
	25	535.961	489.478	1191.196	535.961
	50	590.739	524.088	1459.04	590.739
	100	645.113	556.567	1669.73	645.113


Comparison of Flood Frequency at Intake
Discharge (m3/s)
1800
1600
1400
1200
1000
800
600
400
200
0
2
10
25
50
100
Return Period(T)
Gumbel
Log Pearson III
WECS/DHM

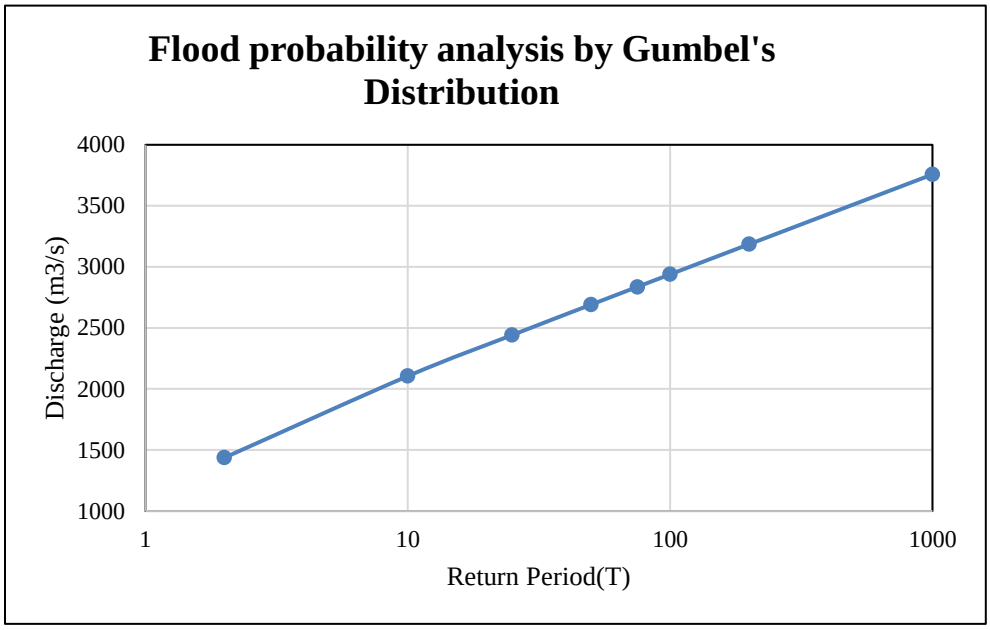
Flood Frequency Analysis at Proposed Powerhouse:

1. **Gumbel's' Extreme Method**

Year	Q m3/s	Ungauged Q m3/s	Ranked Q	Rank (m)	p=m/(n+1)	Return period (T)	Yt	Kt	Qt
1996	1923.00	1881.47	2679.85	1.00	0.04	25.00	3.20	2.46	2441.42
1997	1702.00	1665.24	1894.19	2.00	0.08	12.50	2.48	1.80	2188.06
1998	1850.00	1810.05	1881.47	3.00	0.12	8.33	2.06	1.41	2036.48
1999	1858.00	1817.87	1817.87	4.00	0.16	6.25	1.75	1.12	1926.38
2000	2739.00	2679.85	1810.05	5.00	0.20	5.00	1.50	0.89	1838.86
2001	1287.00	1259.21	1712.21	6.00	0.24	4.17	1.29	0.70	1765.46
2002	1480.00	1448.04	1665.24	7.00	0.28	3.57	1.11	0.54	1701.66
2003	1936.00	1894.19	1631.00	8.00	0.32	3.13	0.95	0.39	1644.76
2004	898.00	878.61	1628.06	9.00	0.36	2.78	0.81	0.26	1592.97
2005	1562.00	1528.27	1528.27	10.00	0.40	2.50	0.67	0.13	1545.05
2006	828.00	810.12	1502.83	11.00	0.44	2.27	0.55	0.01	1500.11
2007	1214.00	1187.78	1484.24	12.00	0.48	2.08	0.42	-0.10	1457.44
2008	1667.00	1631.00	1448.04	13.00	0.52	1.92	0.31	-0.20	1416.48
2009	1536.00	1502.83	1444.12	14.00	0.56	1.79	0.20	-0.31	1376.74
2010	1750.00	1712.21	1392.27	15.00	0.60	1.67	0.09	-0.41	1337.77
2011	1106.00	1082.11	1369.77	16.00	0.64	1.56	-0.02	-0.51	1299.16
2012	1423.00	1392.27	1316.93	17.00	0.68	1.47	-0.13	-0.61	1260.46
2013	1476.00	1444.12	1281.71	18.00	0.72	1.39	-0.24	-0.71	1221.15
2014	1346.00	1316.93	1259.21	19.00	0.76	1.32	-0.36	-0.81	1180.60
2015	1517.00	1484.24	1187.78	20.00	0.80	1.25	-0.48	-0.93	1137.95
2016	1310.00	1281.71	1165.28	21.00	0.84	1.19	-0.61	-1.05	1091.89

2017	1664.00	1628.06	1082.11	22.00	0.88	1.14	-0.75	-1.18	1040.16
2018	1400.00	1369.77	878.61	23.00	0.92	1.09	-0.93	-1.34	978.08
2019	1191.00	1165.28	810.12	24.00	0.96	1.04	-1.17	-1.56	892.06
N	24.00					2	0.37	-0.15	1436.78
Max	2679.85					10	2.25	1.58	2105.06
mean	1494.63					25	3.20	2.46	2441.42
stdev(σ)	385.39					50	3.90	3.10	2690.95
Yn	0.53					75	4.31	3.48	2835.98
Sn	1.09					100	4.60	3.75	2938.63
						200	5.30	4.39	3185.41
						1000	6.91	5.87	3757.06

Return period (T)	**Qt m3/s**
2	1436.78
10	2105.06
25	2441.42
50	2690.95
75	2835.98
100	2938.63
200	3185.41
1000	3757.06



2. Log Pearson Type III Method:

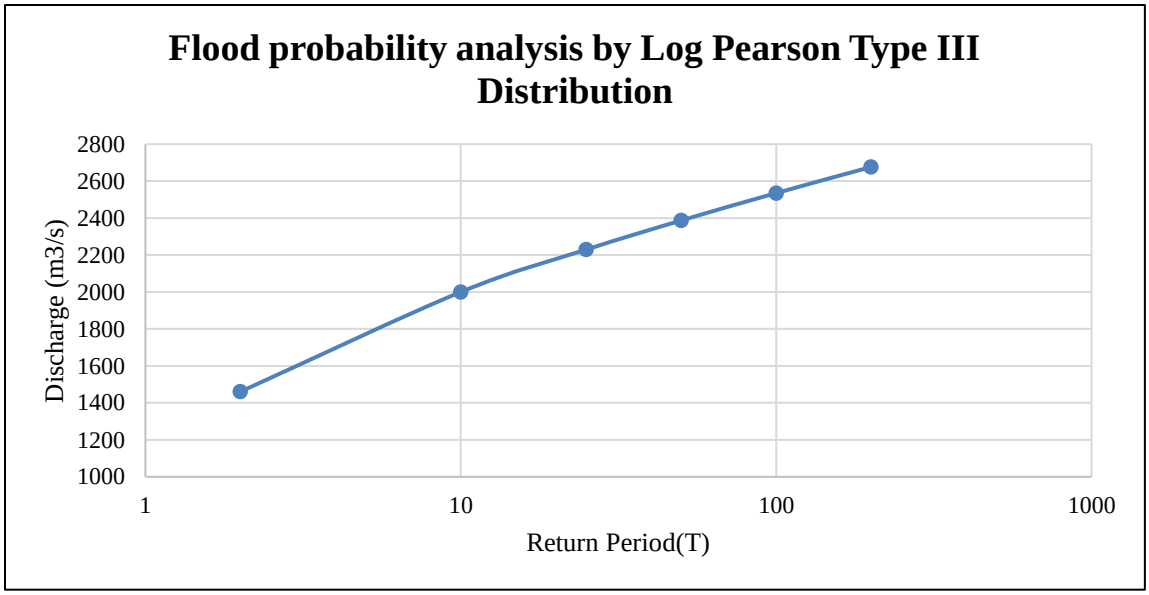
Rank	Max discharge	z=log(x)	$(z-\bar{z})^3$	$(z-\bar{z})^2$
1	2679.8488	3.4281	0.0190484436	0.0713246524
2	1894.1903	3.2774	0.0015762893	0.0135443224
3	1881.4711	3.2745	0.0014603587	0.0128718120
4	1817.8748	3.2596	0.0009562665	0.0097062759
5	1810.0476	3.2577	0.0009027297	0.0093405368
6	1712.2071	3.2336	0.0003812796	0.0052581022
7	1665.2438	3.2215	0.0002207243	0.0036523022
8	1630.9996	3.2125	0.0001358786	0.0026430214
9	1628.0644	3.2117	0.0001297698	0.0025631991
10	1528.2672	3.1842	0.0000124159	0.0005361889
11	1502.8287	3.1769	0.0000039939	0.0002517280
12	1484.2390	3.1715	0.0000011445	0.0001094180
13	1448.0380	3.1608	0.0000000000	0.0000000695
14	1444.1244	3.1596	-0.0000000030	0.0000020705
15	1392.2690	3.1437	-0.0000051960	0.0002999954
16	1369.7657	3.1366	-0.0000145219	0.0005952253
17	1316.9319	3.1196	-0.0000713712	0.0017206083
18	1281.7094	3.1078	-0.0001510276	0.0028359864
19	1259.2061	3.1001	-0.0002263869	0.0037145038
20	1187.7826	3.0747	-0.0006428829	0.0074488273
21	1165.2793	3.0664	-0.0008469534	0.0089517171

22	1082.1149	3.0343	-0.0020372813	0.0160706706
23	878.6069	2.9438	-0.0102535202	0.0471971016
24	810.1186	2.9085	-0.0160974851	0.0637536942
	sum		-0.0055173352	0.2843920293
N	24			
Avg		3.1610435		
med		3.1661419		

T	K_z	$K_z * \sigma_z$	$z_T = \bar{z} + K_z * \sigma_z$	$antilog(Z_T)$
2	0.031	0.003	3.165	1460.633
10	1.259	0.140	3.301	2000.133
25	1.683	0.187	3.348	2229.679
50	1.950	0.217	3.378	2387.338
100	2.185	0.243	3.404	2535.288
200	2.397	0.267	3.428	2676.664

skewness coefficient (cs)	-0.190329331
SD	0.111197441
avg	3.161043533
N	24

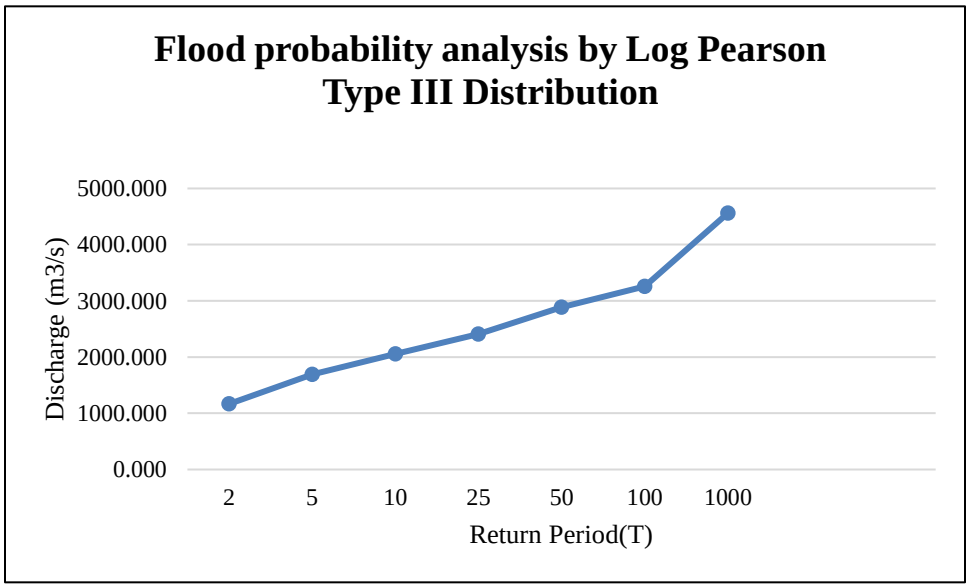
Return period	**Discharge in m3/s**
2	1460.63
10	2000.13
25	2229.68
50	2387.34
100	2535.29
200	2676.66



3. WECS/DHM method

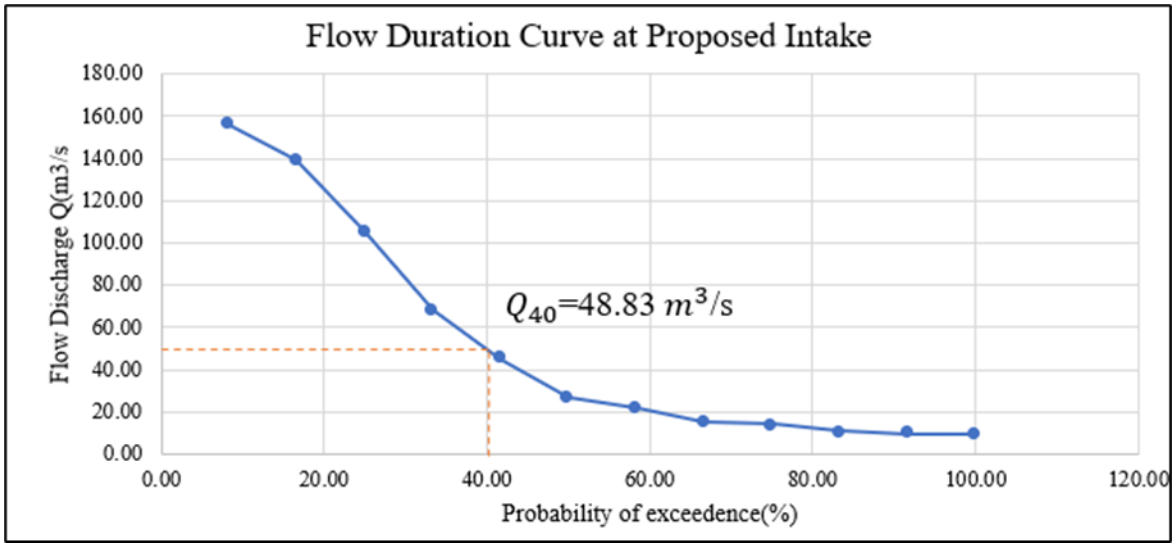
WECS Method			
Return Periods(Years)	**Constant coefficient(α)**	**Power(β)**	**Unit**
2	1.8767	0.8737	
100	14.63	0.7342	
Table: Prediction coefficient for instantaneous flow			
Area of basin		3919.043	km2
Area below 3000m		1573	km2
Area between 5000 to 3000m		1492	km2
Flood flow estimation			
Two years instantaneous flood (Q2)= α*(Area below 3000m+1)β			
		1165.783448	
100 years instantaneous flood (Q100)= α*(Area below 3000m+1)β			
		3254.506906	
Flood peak discharge (Qf) =e(lnQ2+s*σ)			
	σ =	ln(Q100/Q2)/2.326	
		0.441378946	
Where,			
s=standard normal variable			
σlnQf	ln(Qf/Q2)/2.326		

lnQ2	7.061148628		
Standard normal variate for different return period			
Return period(f)	s	Qf(m3/s)	
2	0	1165.783	
5	0.842	1690.517	
10	1.282	2052.875	
25	1.645	2409.602	
50	2.054	2886.330	
100	2.326	3254.507	
1000	3.09	4559.688	



4. Comparison of Flood Frequency Analysis at Proposed Powerhouse:

SN	Return Period(T)	Discharge(m3/s)			
		Gumbel's	Log Pearson Type III	WECS/DHM	Adopted
1	2	1436.781	1460.633	1165.783	1436.781
2	10	2105.065	2000.133	2052.875	2105.065
3	25	2441.42	2229.679	2409.602	2441.42
4	50	2690.948	2387.338	2886.33	2690.948
5	100	2938.633	2535.288	3254.507	2938.633


Flow Duration Curve at Proposed Intake
Flow Discharge Q(m3/s
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
Probability of exceedence(%)
Q_{40}=48.83 m^3/s

ANNEX II - DESIGN OF CIVIL STRUCTURES & ANALYSIS

Hydraulic Design of Headworks:

1. **Weir**

Design Parameter of Weir and Under sluice				
S.N	**Parameter**	**Symbol/Equation**	**Value**	**Remarks**
	Given			
A	High Flood Discharge 100 yrs. (m^3/s)	Q_{hf}	645.113	m^3/s
	Bed level of river (m)		578.81	
	Water Surface Elevation for Q_{45} (m)		581.93	
	High flood level before weir construction (m)		585.65	Taken E.G. Elev of 100yrs flood for safe
	Permissible afflux (m)		1	desirable limit of afflux is 1-1.2m. More commonly 1.0 m. However, in steep reaches with rocky bed, higher afflux is permitted.
	Pond level (m)		582.93	Generally obtained by adding 1 to 1.2 m to canal FSL(i.e. FSL Q_{45})
	Channel Depth (m)		4.12	
	Free board (m)		1	
	Height of weir (m)		4	Assume
	Safe exit Gradient	G_E	1/5	0.14 to 0.17 for fine sand 0.17 to 0.20 for coarse

				sand 0.020 to 0.25 for shingle
	Assumptions			
B	Average grain size (mm)	d_{mm}	26	
	Lacey's silt factor	f	1	
	Coefficient of discharge for weir	C_d	1.7	broad Crested weir
	Specific gravity of concrete (tons $cu.m^{-1}$)	G_c	2.4	
	Specific gravity of boulders (tons $cu.m^{-1}$)	G_b	2.65	
	Specific gravity of plum concrete (tons $cu.m^{-1}$)	G_p	2.525	
Fixing the Crest level and Waterways				
S.N	Parameter	Symbol/Equation	Value	Remarks
A	Weir crest level (m)	Average bed level height of weir	582.81	
	Under sluice crest level (m)	bed level of river	578.81	
	Waterways (P) in m	$4.75*\sqrt{Q}$	120.65	Lacey's Wetted Perimeter equation
	Number of gated bay		2	10 m of each bay for under sluice
	Length of total piers		2	1 pier of 2m each
	Total under sluice portion (m)	L_u	8	2 bays of 3.5m each
	Weir Portion (m)	L_w	50	Assumed waterways
	Divide wall portion (m)	L_d	2	Assumed waterways

	Total waterways (m)	$L_u + L_w + L_d$	60	
Check for the Maximum Flood Passage Over this Waterways with Afflux				
S.N	Parameter	Symbol/Equation	Value	Remarks
A	d/s HFL (m)	HFL before weir construction	585.65	
	u/s HFL (m)	weir crest level+Affux head	586.65	
	Average discharge intensity (cumecs/meter)	$q=\frac{Q_hf}{Total\ waterways}$	10.75	
	Scour depth (m)	$R=1.35(\frac{q^2}{f})^{1/3}$	6.58	
	Velocity of approach (m/s)	$V=\frac{q}{R}$	1.63	
	Velocity head (m)	$\frac{V^2}{2g}$	0.14	
	u/s TEL (m)	u/s HFL+Velocity head	586.79	
	Head over the under sluice crest (m)	H_u = u/s TEL - under sluice crest level	7.98	
	Head over the weir crest (m)	H_w = u/s TEL -weir crest level	3.98	
	Discharge through under sluice (m^3/s)	$Q_u = 1.7(L_u - KnH_u)H_u^{3/2}$	184.18	K=0.1, n=2*no. of gated bays
	Discharge through weir (m^3/s)	$Q_w = C_d L_w H_w^{3/2}$	673.95	Baral book, page 275, 3rd Edition
	Total discharge	$Q = Q_u + Q_w$	858.13	$Q > Q_{hf}$; Hence safe.
Design of Weir				
S.N	Parameter	Symbol/Equation	Value	Remarks

1A	**1. High Flood Condition**			
	a) Assuming no concentration and retrogression			
	d/s TEL (m)	d/s HFL+Velocity head	585.79	
	u/s TEL (m)	u/s HFL+ velocity head +Afflux	587.79	
	Head losss (m)	H_L = u/s TEL - d/s TEL	4.98	
	Discharge intensity (cumecs/meter)	$q_p = C_d H_u^{3/2}$	13.48	
	b) High flood with 20% concentration and 0.5 m retrogression			
1B	Increase in discharge intensity (m^3/s)	$q_n = 0.2 * q_p$	2.70	Total discharge intensity (1.2 q)
	Increase in velocity head (m)	$(\frac{New\ discharge\ intensity}{Cd})$^2/3	1.36	
	u/s TEL (m)	u/s TEL of case 1(a) + increase in velocity head	589.15	
	d/s TEL (m)	d/s TEL-retrogression depth	585.29	
	Head loss(m)		3.86	
	2. Pond Level Condition			
	2.a With no concentration and retrogression			
S.N	Parameter	Symbol/equation	Value	Remarks
A	Head over the crest of under sluices	H_{up} = pond level- bed level	4.12	
	Head over the crest of weir (m)	H_{wp} =pond level - weir crest level	0.12	
	Discharge passing through undersluice for this head	$Q_{up} = 1.7(L_u\text{-}KnH_{up})H_{up}^{3/2}$	102.02	

	Discharge passing through weir for this head	$Q_{wp} = C_d L_w H_{wp}^{3/2}$	3.53	
	Total Discharge (m^3/s)	$Q_p=Q_{up}+Q_{wp}$	105.55	
	Average discharge intensity (cumecs/meter)	$q=\frac{Q_p}{Total\ waterways}$	1.76	
	Normal scoured depth	$R=1.35(\frac{q^2}{f})^{1/3}$	1.97	
	Velocity Approach	$V=\frac{q}{R}$	0.89	
	Velocity head	$\frac{V^2}{2g}$	0.04	
	u/s TEL (m)	pond level + velocity head	582.97	
	d/s TEL (m)	stage discharge curve for Q_p + velocity head	581.97	stage discharge can be obtained from rating curve in hec-ras
	Head loss (m)		1.00	
	Discharge Intensity(cumecs/meter)	$q_{2a} = C_d H_u^{3/2}$	0.07	
2.b Pond Level with 20% concentration and 0.5m retrogression				
B	Increase in discharge intensity (cumecs)	$q_{2b} = 0.2 * q_{2a}$	0.01	Total discharge intensity (1.2 q)
	New head (m)	$(\frac{New\ discharge\ intensity}{Cd})^{2/3}$	0.04	
	u/s TEL (m)	u/s TEL of case 2(a) + increase in velocity head	583.01	
	d/s TEL (m)	d/s TFL(case 2a) -0.5	581.47	
	Head loss (m)		1.54	

Bays of weir					
Items	**High Flood Level**		**Pond Level Flow**		**Remarks**
	Without concentration and Retrogression	**With concentration and retrogression**	**Without Concentration and retrogression**	**With concentration and retrogression**	
Discharge Intensity, q (cumecs/meter)	13.48	16.17	0.07	0.08	
u/s TEL (in m)	587.79	589.15	582.97	583.01	
d/s TEL (in m)	585.79	585.29	581.97	581.47	
Head loss Hl (in m)	4.98	3.86	1.00	1.54	
E_f2(from plate no. 10.1) (in m)	5.9	6.4	2.4	2.5	Plate 10.1 (q vs Ef1)
Level at which jump will form (in m)	579.89	578.89	579.57	578.97	(d/s TEL - E_f2)
$Ef1 = Ef2 + Hl$ (in m)	10.88	10.26	3.40	4.04	
y_1 (Plate No. 10.2) (in m)	1.1	1.2	0.9	0.8	y_1 corresponding to E_{f1}
y_2(Plate No. 10.2) (in m)	5.6	6.2	1.8	2.4	y_2 corresponding to E_{f2}
Length of concrete floor (in m)	22.5	25	4.5	8	$5*(y_2-y_1)$
Froude No , $Fr1$ (in m)	3.73	3.93	0.03	0.04	
	Length of d/s floor, m	25	Take 25m		

	R.L of d/s floor, m	578.9			

Calculation of floor length for Khosla's safe exit gradient			
Parameters	Symbol/Equation	Value	Remarks
Depth of Sheet Pile Lines from Scour Consideration			
Total discharge passing through Weir		673.95	Calculated earlier
Overall waterways of under sluices (m)		50	
Average discharge intensity (q)	$R=1.35(\frac{q^2}{f})^{1/3}$	13.48	
Depth of Scour ®		7.65	
Bottom RL of d/s cutoff	d/s flood level - 1.5R	574.2	d/s cutoff at depth 1.5R
Depth of d/s cut-off (m)	d_{cutoff} = RL of d/s floor - RL of d/s cutoff	4.7	
RL of u/s cutoff	u/s flood level-1.25R	577.09	u/s cutoff at depth of 1.25R
RL of u/s floor	bed level	578.81	
Depth of u/s cutoff	u_{cutoff} = bed level - RL of u/s cutoff	1.72	adopt 2m
New RL of u/s cutoff		577.09	
Glacis gradient	1 in	3	V:H (Assume)
Horizontal length of glacis (m)	Gradient*depth of u/s floor	11.76	Adopt 12m
Maximum static head (m)	H = Pond level-d/s floor level	4.04	
Safe exit gradient (G_E)	$Ge=\frac{H}{3.41*d_cutoff*\sqrt{\lambda}}$	0.2	

λ	$\lambda = 1+\frac{\sqrt{1+\alpha^2}}{2}$	2.828553436	From Plate 11.2 Garg Book
α		9	From Plate 11.2 Garg Book
Total Floor length (m)	$\alpha * d_{cutoff}$	42.38	
		42.00	
u/s floor length (m)	Total floor length-horizontal glacis length-length of d/s floor	5.62	adopt 6m

Parameter	Symbol/Equation	Value	Remarks
Uplift pressure			
Given			
Total floor length(m)	b	42.00	Slightly greater than Floor area of weir
Depth of u/s pile(m)	d1	1.72	Slightly greater than u/s floor depth
Depth of d/s pile(m)	d2	4.7	Slightly greater than d/s floor depth
Distance between two piles		40.50	Piles are off settled 0.75m inside from floor ends
Assumption			
u/s floor thickness(m)		1	
d/s floor thickness(m)		1.5	
u/s pile line			
α	b/d1	24.453	

λ	λ=(1+SQRT(1+α^2)/2	12.737	
ϕ_E	ϕ_E=1/π*arccosine((λ-2)/λ)	0.181	
ϕ_E(%)		18.090	
ϕ_E1(%)		100.000	
ϕ_C1(%)	100-ϕ_E(%)	81.910	
ϕ_D	ϕ_D=1/π*arccosine((λ-1)/λ)	0.127	
ϕ_D(%)		12.704	
ϕ_D1(%)	100-ϕ_D(%)	87.296	
d/s pile line			
α	b/d2	8.919	
λ	λ=(1+SQRT(1+α^2)/2	4.987	
ϕ_C2(%)		0.000	
ϕ_E2(%)	ϕ_E2(%)=1/π*arccosine((λ-2)/λ)	29.572	
ϕ_D2(%)	ϕ_D2(%)=1/π*arccosine((λ-1)/λ)	20.521	
Correction to ϕ_C1(%)			
a) Mutual interference			
Depth of d/s pile bottom level below point C1(m)	D	3.629	
Total floor length(m)	b	42.000	

Distance between two piles(m)	b'	40.50	
Depth of pile on which effect is considered(m)	d1	1.718	
Correction(%)	Correction=19(d+D)/b*SQRT(D/b')	0.724	Positive correction
b) Floor thickness			
Correction(%)	Thickness*(ϕ_D1(%)-ϕ_C1(%))/(River bed level-bottom level of u/s cutoff)	3.135	Positive correction
ϕ_C1(%)		85.770	Corrected
Correction to ϕ_E2(%)			
a) Mutual interference			
Depth of u/s pile bottom level below point C2(m)	D	0.298	
Total floor length(m)	b	42.000	
Distance between two piles(m)	b'	40.500	
Depth of pile on which effect is considered(m)	d2	4.709	
Correction(%)	Correction=19(d+D)/b*SQRT(D/b')	0.194	Negative correction
b) Floor thickness			
Correction(%)	Thickness*(ϕ_E2(%)-ϕ_D2(%))/(d/s floor level-bottom level of d/s cutoff)	2.883	Negative correction
ϕ_E2(%)		26.49	Corrected

Condition of flow	**u/s water**	**d/s water**	**Head(m)**	**Elevation of subsoil HGL**	
				u/s pile	**d/s pile**

	level (m)	level (m)		ϕ_E1(%)	ϕ_D1(%)	ϕ_C1(%)	ϕ_E2(%)	ϕ_D2(%)	ϕ_C2(%)
				100	87.296	81.910	29.572	20.521	0
No flow, maximum static head	582.93	578.89	4.04	4.040	3.527	3.309	1.195	0.829	0.000
				582.930	582.417	582.199	580.085	579.719	578.890
High flood with concentration and retrogression	587.79	585.29	2.50	2.500	2.182	2.048	0.739	0.513	0.000
				587.786	587.469	587.334	586.026	585.799	585.286
Pond level with concentration and retrogression	582.93	581.4	1.5	1.500	1.309	1.229	0.444	0.308	0
				582.930	582.739	582.659	581.874	581.738	581.430

Parameter	Symbol/Equation	Value	Remarks
Design of Stilling Basin			
y2(m)		6.5	Highest from previous table
Froude No.	F_r=q/SQRT(gy1^3)	3.10	F_r <4.5, Stilling Basin I is provided as per IS 4997:1968
L_b/y2		4.1	From graph
Length of stilling basin(m)	L_b(m)	26.65	
Design of end sill (IS:4997:1968)			
Height(m)	0.2*y2	1.3	Take 1.5 m
Length(m)	2*height	2.6	
Width(m)	0.15*y2	0.975	Take 1 m
Spacing(m)	0.15*y2	0.975	Clear spacing
Top crest(m)	0.02*y2	0.062	

t					
Distance from the start of glacis	Glacis level in meter	High level flood (q=15.86 cumecs per m)		Pond level flood q= 0.08 cumecs per m	
		Ef1=u/s TEL-Glacis level	Y1 from plate 10.2	Ef1=u/s TEL-Glacis level	Y1 from plate 10.2
0	582.81	6.34	1.700	0.20	0.1

3	581.81	7.34	1.500	1.20	0.05
6	580.81	8.34	1.400	2.20	0.05
9	579.81	9.34	1.300	3.20	0.05
11.49	578.98	10.17	1.200	4.03	0.05
11.94	578.83	10.32	1.200	4.18	0.05
12	578.81	10.34	1.200	4.20	0.05

Post-Jump Profile Calculation			
X/Y_1 on plate 10.3(a)	High level flow		
	Fr= 3.85, F^2=14.8225, Y_1=1.2		
	Y/Y_1	Y	X=col. 1 * 1.2
5	2.6	3.12	6
10	3.9	4.68	12
15	4.3	5.16	18
20	4.8	5.76	24
25	5	6	30
30	5.2	6.24	36

Thickness of Glacis Floor				
Distance	Unbalanced Heads	Thickness	Actual Thickness	Remarks
Point of Jump	5.17	4.2	4.2	Thickness= $\frac{\frac{2}{3} * Unbalanced\ head\ at\ high\ flood}{G-1}$
5m beyond toe	5.14	4.1	4.1	Thickness= $\frac{Unblanced\ Static\ Head}{G-1}$
10m beyond toe	4.22	3.4	3.4	
15m beyond toe	3.74	3.0	3.0	
20m beyond toe	3.05	2.5	2.5	
25m beyond toe	2.90	2.3	2.3	
30m beyond toe	2.66	2.1	2.1	
d/s protection works				
Thickness of launching apron	t=2.25D/L	2		
Normal Scour Depth(m)	R	8		

D(m)	2R-y	9	y=d/s concentrated HFL-d/s floor level
Length of launching apron	L=1.5D	13	
Size of c.c. block			At 10cm clear gap filled with Bajri, for 1.5D m run
Length(m)		1.2	
Breadth(m)		1.2	
Thickness(m)		1	1m filter at base added
c.c. block floor length(m)	1.2D	10.68	
		5.00	
Number of rows		4	
u/s protection works			
Thickness of launching apron	t	2	
Anticipated Scour Depth(m)	1.5R	11	
D(m)	1.5R-y	7	y=d/s concentrated HFL-d/s floor level
Length of launching apron	L=1.25D/t	4	
Size of c.c. block			At 10cm clear gap filled with Bajri, for 1.5D m run
Length(m)		1.2	
Breadth(m)		1.2	
Thickness(m)		1	1m filter at base added
c.c. block floor length(m)	1.2D	8	
Number of rows		7	

2. Under sluice

Design Parameter of Weir and Under sluice				
S. N	Parameter	Symbol/Equation	Value	Remarks
	Given			
A	High Flood Discharge 100 yrs (m^3/s)	Q_{hf}	645.113	m^3/s
	Bed level of river (m)		578.81	

	Water Surface Elevation for Q_{40} (m)		581.93	
	High flood level before weir construction (m)		585.65	Taken E.G. Elev of 100yrs flood for safe
	Permissible afflux (m)		1	desirable limit of afflux is 1-1.2m. More commonly 1.0 m. However,in steep reaches with rocky bed, higher afflux is permitted.
	Pond level (m)		582.93	Generally obtained by adding 1 to 1.2 m to canal FSL(i.e. FSL Q_{45})
	Channel Depth (m)		4.12	
	Free board (m)		1	
	Height of weir (m)		4.00	Assume
	Safe exit Gradient	G_E	1/5	0.14 to 0.17 for fine sand 0.17 to 0.20 for coarse sand 0.020 to 0.25 for shingle
	Assumptions			
B	Average grain size (mm)	d_{mm}	26	
	Lacey's silt factor	f	1	
	Coefficient of discharge for weir	C_d	1.7	Sharp Crested weir
	Specific gravity of concrete (tons $cu.m^{-1}$)	G_c	2.4	
	Specific gravity of boulders (tons $cu.m^{-1}$)	G_b	2.65	

	Specific gravity of plum concrete (tons cu.m^{-1})	G_p	2.525	
Fixing the Crest level and Waterways (IS : 6966-1989)				
S.N	Parameter	Symbol/Equation	Value	Remarks
A	Weir crest level (m)	Average bed level+height of weir	582.81	
	Under sluice crest level (m)	bed level of river	578.81	
	Waterways (P) in m	4.75*√Q	120.65	Lacey's Wetted Perimeter equation
	Number of gated bay		2	10 m of each bay for under sluice
	Length of total piers		2	1 pier of 2m
	Total under sluice portion (m)	L_u	8	2 bays of 3m each
	Weir Portion (m)	L_w	50	Assumed waterways
	Divide wall portion (m)	L_d	2	Assumed waterways
	Total waterway including pier thichkness (m)	L_u+ L_w+L_d	60	
Check for the Maximum Flood Passage Over this Waterways with Afflux				
S.N	**Parameter**	**Symbol/Equation**	**Value**	**Remarks**
A	d/s HFL (m)	HFL before weir construction	585.65	
	u/s HFL (m)	d/s HFL+Affux head	586.65	

	Average discharge intensity (cumecs/meter)	$q=\frac{Q_hf}{Total\ waterways}$	10.75	
	Scour depth (m)	$V=\frac{q}{R}$	6.58	Lacey's formula
	Velocity of approach (m/s)	$R=1.35(\frac{q^2}{f})^{1/3}$	1.63	
	Velocity head (m)	$\frac{V^2}{2g}$	0.14	
	u/s TEL (m)	u/s HFL+Velocity head	586.79	
	Velocity Head over the under-sluice crest (m)	H_u = u/s TEL - under sluice crest level	7.98	
	Velocity Head over the weir crest (m)	H_w = u/s TEL -weir crest level	3.98	
	Discharge through under sluice (m^3/s)	$Q_u = 1.7(L_u\text{-}KnH_u)H_u^{3/2}$	184.18	K=0.1, n=3*no. of gated bays
	Discharge through weir (m^3/s)	$Q_w = C_dL_wH_w^{3/2}$	673.95	Baral book, page 275, 3rd Edition
	Total discharge	$Q = Q_u+Q_w$	858.13	$Q > Q_{hf}$; Hence safe.
Design of Weir				
S.N	Parameter	Symbol/Equation	Value	Remarks
1A	**1. High Flood Condition**			
	a) Assuming no concentration and retrogression			
	d/s TEL (m)	d/s HFL+Velocity head	585.79	
	u/s TEL (m)	u/s HFL+ velocity head +Afflux	587.79	
	Head losss (m)	H_L = u/s TEL - d/s TEL	4.98	

	Average discharge intensity (cumecs/meter)	q=Q/Total waterways	10.75	
	Discharge intensity between piers (cumecs/meter)	$q_p = C_d H_u^{3/2}$	38.30	
	b) High flood with 20% concentration and 0.5 m retrogression			
1 B	Discharge intensity between piers (cumecs/meter)	$q_n = 1.2 * q_p$	45.95	
	New velocity head (m)		9.14	
	u/s TEL (m)	River Bed Level + new velocity head	587.95	
	d/s TEL (m)	d/s TEL-retrogression depth	585.29	
	Head loss(m)		2.67	
	2. Pond Level Condition			
	2.a With no concentration and retrogression			
S. N	Parameter	Symbol/equation	Value	Remarks
A	Head over the crest of undersluices	H_{up} = pond level- bed level	4.12	
	Head over the crest of weir (m)	H_{wp} = pond level - weir crest level	0.12	
	Discharge passing through undersluice for this head	$Q_{up} = 1.7(L_u\text{-}KnH_{up})H_{up}^{3/2}$	102.16	
	Discharge passing through weir for this head	$Q_{wp} = C_d L_w H_{wp}^{3/2}$	3.71	
	Total Discharge (m^3/s)	$Q_p=Q_{up}+Q_{wp}$	105.87	

	Average discharge intensity (cumecs/meter)	$q=\frac{Q_p}{Total\ waterways}$	1.76	
	Normal scoured depth	$R=1.35(\frac{q^2}{f})^{1/3}$	1.97	
	Velocity Approach	$V=\frac{q}{R}$	0.90	
	Velocity head	$\frac{V^2}{2g}$	0.04	
	u/s TEL (m)	pond level + velocity head	582.97	
	d/s TEL (m)	stage discharge curve for Q_p + velocity head	581.97	stage discharge can be obtained from rating curve in hec-ras
	Head loss (m)		1.00	
	Discharge Intensity between piers(cumecs/meter)	$q_{2a} = C_d H_u^{3/2}$	14.24	
	2.b Pond Level with 20% concentration and 0.5m retrogression			
B	New discharge intensity between piers (cumecs)	$q_{2b} = 1.2 * q_{2a}$	17.08	
	New head (m)	$(\frac{New\ \ discharge\ intensity}{Cd})^{2/3}$	4.66	
	u/s TEL (m)	Bed level + new head	583.47	
	d/s TEL (m)	d/s TFL(case 2a) -0.5	581.47	

	Head loss (m)		2.00	

	Under sluice Portion of Weir					
S. N	**Items**	**High Flood Level**		**Pond Level Flow**		**Remarks**
		Without concentration and Retrogression	**With concentration and retrogression**	**Without Concentration and retrogression**	**With concentration and retrogression**	
1	Discharge Intensity, q (cumecs/meter)	38.30	45.95	14.24	17.08	
2	u/s TEL (in m)	587.79	587.95	582.97	583.47	
3	d/s TEL (in m)	585.79	585.29	581.97	581.47	
4	Head loss Hl (in m)	4.98	2.67	1.00	2.00	
5	E_f2(from plate no. 10.1) (in m)	10.86	11.25	4.9	6.8	Plate 10.1 (q vs Ef1)
6	Level at which jump will form (in m)	574.93	574.04	577.07	574.67	(d/s TEL - E_f2)
7	$Ef1 = Ef2 + Hl$ (in m)	15.84	13.92	5.90	8.80	
8	y_1 (Plate No. 10.2) (in m)	2.4	3.2	1.5	1.8	y_1 corresponding to E_{f1}
9	y_2(Plate No. 10.2) (in m)	10.3	5.8	2	4.2	y_2 corresponding to E_{f2}
10	Length of concrete floor (in m)	39.5	13	2.5	12	$5*(y_2-y_1)$

11	Froude No , $Fr1$ (in m)	3.29	2.56	2.47	2.26	F=q/(gy^3)^0.5
		Length of d/s floor, m	39.5	Take 40 m		
		R.L of d/s floor, m	574.0	0.2m below the lowest level where the jump will form		

	Calculation of floor length for Khosla's safe exit gradient			
S. N	**Parameters**	**Symbol/Equation**	**Value**	**Remarks**
	Depth of Sheet Pile Lines from Scour Consideration			
A	Total discharge passing through under sluices		184.18	Calculated earlier
	Overall waterways of under sluices (m)		10	
	Average discharge intensity (q)	$R=1.35(\frac{q^2}{f})^{1/3}$	18.42	
	Depth of Scour ®		9.42	
	Bottom RL of d/s cutoff	d/s flood level - 1.5R	571.5	d/s cutoff at depth 1.5R
	Depth of d/s cutoff (m)	d_{cutoff} = RL of d/s floor - RL of d/s cutoff	2.5	Adopt 3m
	RL of u/s cutoff	u/s flood level-1.25R	574.88	u/s cutoff at depth of 1.25R
	RL of u/s floor	bed level	578.81	
	Depth of u/s cutoff	u_{cutoff} = bed level - RL of u/s cutoff	3.93	Adopt 4m
	New RL of u/s cutoff		570.41	
	New Rl of d/s cutoff		571.5	

	Glacis and Sheet Pile			
			2m	
	Glacis gradient	1 in	3	V:H (Assume)
	Horizontal length of glacis (m)	Gradient*(depth of u/s floor - depth of d/s floor)	14.43	adopt 14.5
	Maximum static head (m)	H = Pond level-d/s floor level	8.93	
	Safe exit gradient (G_E)	$Ge=\frac{H}{3.41*d_cutoff*\sqrt{\lambda}}$	0.2	
	λ		10.3	From Plate 11.2 Garg Book
	1/(3.14*λ^0.5)		0.099437084	
	α	From Plate 11.2 Garg Book, pg 564-565	8	From Plate 11.2 Garg Book
	Total Floor length (m)	$\alpha*d_{cutoff}$	19.78	
			20.00	adopt
	u/s floor length (m)	Total floor length-horizontal glacis length-length of d/s floor	-34.15	adopt 6m (i.e minimum equal to weir)

Parameter	**Symbol/Equation**	**Value**	**Remarks**
Uplift pressure			
Given			

Total floor length(m)	b	20.00	
Depth of u/s pile(m)	d1	8.40	
Depth of d/s pile(m)	d2	2.5	
Distance between two piles		18.50	Piles are offsetted 0.75m inside from floor ends
Assumption			
u/s floor thickness(m)		1	
d/s floor thickness(m)		1.5	
u/s pile line			
α	b/d1	2.381	
λ	λ=(1+SQRT(1+α^2)/2	1.791	
ϕ_E	ϕ_E=1/π*arccosine((λ-2)/λ)	0.537	
ϕ_E(%)		53.746	
ϕ_E1(%)		100.000	
ϕ_C1(%)	100-ϕ_E(%)	46.254	
ϕ_D	ϕ_D=1/π*arccosine((λ-1)/λ)	0.355	
ϕ_D(%)		35.455	
ϕ_D1(%)	100-ϕ_D(%)	64.545	
d/s pile line			
α	b/d2	8.088	
λ	λ=(1+SQRT(1+α^2)/2	4.575	

ϕ_C2(%)		0.000	
ϕ_E2(%)	ϕ_E2=1/π*arccosine((λ-2)/λ)	30.988	
ϕ_D2(%)	ϕ_D2=1/π*arccosine((λ-1)/λ)	21.461	
Correction to ϕ_C1(%)			
a) Mutual interference			
Depth of d/s pile bottom level below point C1(m)	D	6.283	
Total floor length(m)	b	20.000	
Distance between two piles(m)	b'	18.50	
Depth of pile on which effect is considered(m)	d1	8.400	
Correction(%)	Correction=19(d+D)/b*SQRT(D/b')	8.129	Positive correction
b) Floor thickness			
Correction(%)	Thickness*(ϕ_D1(%)-ϕ_C1(%))/(River bed level-bottom level of u/s cutoff)	2.178	Positive correction
ϕ_C1(%)		56.560	Corrected
Correction to ϕ_E2(%)			
a) Mutual interference			
Depth of u/s pile bottom level below point C2(m)	D	2.090	
Total floor length(m)	b	20.000	
Distance between two piles(m)	b'	18.500	

Depth of pile on which effect is considered(m)	d2	2.473	
Correction (%)	Correction=19(d+D)/b*SQRT(D/b')	1.457	Negative correction
b) Floor thickness			
Correction (%)	Thickness*(ϕ_E2(%)-ϕ_D2(%))/(d/s floor level-bottom level of d/s cut-off)	5.779	Negative correction
ϕ_E2(%)		23.75	Corrected

Condition of flow	**u/s water level (m)**	**d/s water level (m)**	**Head(m)**	**Elevation of subsoil HGL**					
				u/s pile			**d/s pile**		
				ϕ_E1(%)	**ϕ_D1(%)**	**ϕ_C1(%)**	**ϕ_E2(%)**	**ϕ_D2(%)**	**ϕ_C2(%)**
				100	64.545	46.254	30.988	21.461	0
No flow, maximum static head	582.93	574.0	8.934	8.934	5.766	4.132	2.768	1.917	0.000
				582.934	579.766	578.132	576.768	575.917	574.000
High flood with concentration and retrogression	587.79	585.29	2.5	2.500	1.614	1.156	0.775	0.537	0.000
				587.786	586.900	586.443	586.061	585.823	585.286
Pond level with concentration and retrogression	582.93	581.6	1.4	1.354	0.874	0.626	0.420	0.291	0
				582.934	582.454	582.206	581.999	581.870	581.580

Pre-Jump Profile Calculation						
	Distance from the	**Glacis level in meter**	**High level flood q=37.92 cumecs per m**		**Pond level flood q= 17.08 cumecs per m**	
			Ef1=u/s TEL-Glacis level	**y1 from plate 10.2**	**Ef1=u/s TEL-Glacis level**	**Y1 from plate 10.2**

	start of glacis						
	0	578.81	9.14		3.8	4.66	2.50
	3	577.81	10.14		3.4	5.66	2.20
	6	576.81	11.14		3.1	6.66	1.90
	9	575.81	12.14		2.9	7.66	1.80
	12	574.81	13.14		2.8	8.66	1.70
	12.39	574.68	13.27		2.8	8.79	1.60
	14.28	574.05	13.90		2.7		
	14.3	574.04	13.91		2.7		

Post-Jump Profile Calculation

X/Y_1 on plate 10.3(a)	High level flow			Pond level flow		
	$F=3.26$, $F^2= 10.6$, $Y_1=2.4$			$F=2.47$, $F^2=6.1$, $Y_1=1.5$		
	Y/Y_1	Y	X=col. 1 * 2.4	Y/Y_1	Y	X=col. 1 * 1.5
0	1	2.4	0	1	1.5	0
5	2.8	6.72	12	2.5	3.75	7.5
10	3.2	7.68	24	2.9	4.35	15
15	3.9	9.36	36	3	4.5	22.5
20	4.1	9.84	48	3	4.5	30

Maximum unbalanced head in the jump				
			RL of HGL	Unbalanced Head
HFL	Start of u/s floor	0	586.90	5.18
	Point of Jump	12.39	574.68	11.203
	End of d/s Floor	14.30	586.061	11.043

Thickness of Glacis Floor				
Distance	**Unbalanced Heads**	**Thickness**	**Actual Thickness**	**Remarks**

Point of Jump	11.20334516	6.0	6.0	Thickness= $\frac{\frac{2}{3} * Unbalanced\ head\ at\ high\ flood}{G-1}$
5m beyond toe	5.225	4.21	4.2	Thickness= $\frac{Unblanced\ Static\ Head}{G-1}$
10m beyond toe	4.62	3.73	3.7	
15m beyond toe	4.4748	3.61	3.6	
20m beyond toe	1.94	1.56	1.6	
1.5m thickness beyond that point				
d/s protection works				
Normal Scour Depth(m)	R	6.6		
D(m)	2R-y	6.7	y=d/s concentrated HFL-d/s floor level	
Length of launching apron	L=1.2D	8.1		
Thickness of launching apron	t=2.25D/L	1.9		
Size of c.c. block			At 10cm clear gap filled with Bajri, for 1.5D m run	
Length(m)		1.2		
Breadth(m)		1.2		
Thickness(m)		1	1m filter at base added	
c.c. block floor length(m)	1.2D	8.07		
Number of rows		7		
u/s protection works				
Anticipated Scour Depth(m)	1.5R	10		
D(m)	1.5R-y	11	y=d/s concentrated HFL-d/s floor level	
Length of launching apron	L=1.25D/t	13	16	
Thickness of launching apron		1.0	Assumed	
Size of c.c. block			At 10cm clear gap filled with Bajri, for 1.5D m run	
Length(m)		1.2		
Breadth(m)		1.2		
Thickness(m)		1	1m filter at base added	
c.c. block floor length(m)	1.2D	13		
Number of rows		11		

3.Stability analysis of weir and Under sluice

STABILITY ANALYSIS OF WIER					
Assumptions made					
The soil are assumed in saturated condition (i.e. extreme condition)					
Earthquake force and silt pressure are not considered in this analysis					
Assumed Values					
Description	Symbol			Values	Unit
Unit weight of Boulder	γb			26.00	kN/m3
Unit weight of concrete	γ_c			24.00	kN/m3
Mean Unit weight of concrete	γ_{mean}			24.28	kN/m3
Average Unit weight of concrete	$\gamma_{average}$			24.85	kN/m3
Unit weight of Water	γ_w			9.81	kN/m3
Unit weight of submerged soil	γ_{sub}			12.00	kN/m3
angle of internal friction of silt	Φ			30.00	Degree
coefficient of friction`	μ			0.7	
angle made by u/s face with vertical (1H:1V)	i			45.00	Degree
tan(i)				1.00	
$\tan^2(i)$				1.00	
$\sec^2(i)$				2.00	
angle made by d/s face with vertical (3H:1V)	α			0.32	radian
	α			71.57	degree
$\tan\alpha$				3.00	

$\tan^2(\alpha)$				9.00	
$\sec^2(\alpha)$				10.00	
Length of weir	L		Adopt	100.00	m
Bearing capacity of soil				150.00	KN/m2
Horizontal seismic coefficient				0.2	
Vertical seismic coefficient				0.15	

Force calculations								
Name of the Force	**Designation**	**Area(sq. m)**	**γ**	**Force(A*G)**		**Lever arm(m)**	**Moment (KNm) per meter width**	
				Vertical	**Horizontal**		**Anticlockwise**	**clockwise**
Vertical Force calculation								
Self-weight force calculation(w)								
Weir body (u/s Triangle Portion 1:1)	W11	8.00	24.00	192.00		14.33	2752.00	
middle rectangle portion	W12	4.00	24.00	96.00		12.50	1200.00	
d/s triangle portion 1:3	W13	24.00	24.00	576.00		8.00	4608.00	
Weight of water during pool level	W2	10.13	9.81	99.33		15.67	1556.11	
Weight of water during high flood level	W3	23.12	9.81	226.81		14.73	3341.63	
Hydrostatic forces								
Pool level condition(H=4.5m)	H1	10.13	9.81		-99.33	1.50		148.99
High flow condition (H=7m)	H2	23.12	9.81		-226.81	2.27		514.10

Uplift pressure								
For pool level	U1	38.25	9.81	-375.23		11.33		4252.64
High flood level	U2	57.80	9.81	-567.02		11.33		6426.20
Earthquake forces								
Horizontal earthquake force	P1				-38.40	3.20		122.88
Vertical earthquake forces	P2			28.80		9.91	285.33	

No Water Condition

Designation	Symbol	Value	Unit	Remarks
Sum of vertical forces	ΣV	864.00	KN	
Sum of horizontal forces	ΣH	0.00	KN	
Sum of resisting moment	ΣM_R	8560.00	KNm	
Sum of overturning moment	ΣM_0	0.00	KNm	
Sum of moments	ΣM	8560.00	KNm	
length of weir adopted		17.00		
Centroid	x	9.91		
Eccentricity	e	1.41		Within middle third
Maximum vertical stress	P_{max}	76.07	KN/m	
Minimum vertical stress	P_{min}	25.58	KN/m	
Fos against Overturning		∞		

FoS against Sliding		∞		

No water condition with EQ

Designation	Symbol	Value	Unit	Remarks
Sum of vertical forces	ΣV	892.80	KN	
Sum of horizontal forces	ΣH	-38.40	KN	
Sum of resisting moment	ΣM_R	8845.33	KNm	
Sum of overturning moment	ΣM_0	122.88	KNm	
Sum of moments	ΣM	8722.45	KNm	
length of weir adopting		17.00		
Centroid	x	9.77		
Eccentricity	e	1.27		Within middle third
Maximum vertical stress	P_{max}	76.05	KN/m	
Minimum vertical stress	P_{min}	28.98	KN/m	
Fos against Overturning		71.98		>1.5, Safe
FoS against Sliding		16.28		>1.5, Safe

High flood level

Designation	Symbol	Value	Unit	Remarks
Sum of vertical forces	ΣV	523.79	KN	

Sum of horizontal forces	ΣH	-226.81	KN	
Sum of resisting moment	ΣM_R	11901.63	KNm	
Sum of overturning moment	ΣM_0	6940.30	KNm	
Sum of moments	ΣM	4961.33	KNm	
Length of weir adopted		17		
Centroid	x	9.471989419		
Eccentricity	e	0.971989419		Within middle third
Maximum vertical stress	P_{max}	41.38104415	KN/m	
Minimum vertical stress	P_{min}	20.24121467	KN/m	
Fos against Overturning		1.714857503		>1.5, Safe
FoS against Sliding		1.616582013		>1.5, Safe

High Flood Level with EQ

Designation	Symbol	Value	Unit	Remarks
Sum of vertical forces	ΣV	552.59	KN	
Sum of horizontal forces	ΣH	-265.21	KN	
Sum of resisting moment	ΣM_R	12186.96	KNm	
Sum of overturning moment	ΣM_0	7063.18	KNm	
Sum of moments	ΣM	5123.78	KNm	
Length of weir adopting		17.00		
Centroid	x	9.27		

Ecentricity	e	0.77		Within middle third
Maximum vertical stress	P_{max}	41.37	KN/m	
Minimum vertical stress	P_{min}	23.64	KN/m	
Fos against Overturning		1.73		>=1.5, Safe
FoS against Sliding		1.50		>=1.5, Safe

4. Intake

Parameter of Intake				
SN	**Description**	**values**	**unit**	**Remarks**
1	Design discharge(Q40)	48.83	m3/s	
2	Intake Discharge (Qd)	58.60	m3/s	20% for flusing and losses
3	Maximum discharge (Q100 years)	585.65	m3/s	
4	RL of NWL	581.93	m	masl
5	weir crest level (hr)	582.81	m	masl
6	Canal water level (hh)	582.71	m	masl
7	River bed level	578.81	m	masl
8	Invert level	579.61	m	As per sediment
9	Coefficient of Discharge	0.6		

Assumed values				
1	Velocity at intake entry	0.9	m/s	
2	Depth of intake	2.2	m	
3	Total numbers of Bays	4	no	
4	Intake loss due to sudden contraction (Ki)	0.04		Bell mouth
5	Gradual contraction losses(Kt)	0.04		450
6	Intake loss coefficient (K)	0.08		Ki+Kt
7	Thickness of bar (t)	20	mm	
8	Clear spacing between the bars (b)	100	mm	
9	Angle of inclination of trash rack(α)	70	Degree	
10	Factor depending on bar shape (kr)	1.67		Rounded bars
11	width of pier (end)	0.7	m	For one side groove only
12	width of pier (centre)	1	m	For both side grooves

Calculation of Intake				
Dimension of Intake				
S.N	**Description**	**Values**	**Formula**	**Remarks**

1	Area of Intake required	65.10666667	A=Qd/V	
2	Width of intake	29.59393939		
3	Total width adopted	32		
4	Total area adopted	70.4		
5	Discharge in intake	59.16616374	A*Cd √(2g(hr-hh)	Discharge in intake >Qd
6	Velocity at inlet	0.840428462	Q/A	<1m/s (ok)

Calculation of Intake					
Dimension of Intake					
S.N	**Description**	**Values**	**Unit**	**Formula**	**Remarks**
1	Area of Intake required	65.17	m2	A=Qd/V	
2	Width of intake	29.59	m		
3	Total width adopted	32	m		
4	Total area adopted	70.4	m2		
5	Discharge in intake	59.16	m3/s	A*Cd √(2g(hr-hh)	Discharge in intake >Qd
6	Velocity at inlet	0.84	m/s	Q/A	<1m/s (ok)
Loss in intake					
1	Intake losses	0.00288	m	k*v2/2g	

Calculation of trashrack			
SN	**Description**	**Values**	**unit**
1	Total submerged width of trash rack	36.4	m
2	Area of submerged trash rack	85.21	m2
3	Percentage of area opening	0.833	
4	Net area opening	71.01	m2
5	Approach velocity	0.825	m/s

5. Gravel Trap

Parameters of Gravel trap				
S.N.	**Description**	**Value**	**Unit**	**Remark**

1	Design discharge (Qd)	48.83	m3/s	
2	Flushing discharge in %	0.2		20%extra discharge for flushing
3	Total discharge (Qt)	58.596	m3/s	
4	No of bays	2		
5	Discharge in each bays	29.298	m3/s	
6	Dimeter of particle to settle	5	mm	
7	coefficient of turbulence(K)	1.5		
8	Specific gravity of particle(S)	2.65		
9	Width of one bay Gravel trap	11	m	21m both way
10	velocity in gravel trap	0.3		
11	Critical velocity	0.98387		$a\sqrt{d}$,a=0.36 ford>1mm

According to Newton's equation	0.519139	m/s
According to Zanke.	0.309095	m/s
Adopted particle fall velocity	0.309095	m/s

Calculation of Gravel trap				
S.N.	**Description**	**Value**	**Unit**	**Remark**
1	Area of gravel trap	142.18	m2	As= k×Q/wt
2	Depth of gravel trap	8.88	m	flowing velocity
3	Depth of gravel trap	2.71	m	critical velocity
4	Adopted depth	9.00	m	Adopted max of both
5	Length of gravel trap	12.93	m	On the basis of As=L*B
6	Length of gravel trap	9.12	m	On the basis of turbulence
7	Adopted length	15.00	m	max of both
8	Actual area of gravel trap	165.00	m2	L*B
9	Efficiency of gravel trap	0.82		η=1-e((-ω*As)/Q)

Exit transition length				
S.N.	**Description**	**Value**	**Unit**	**Remark**
1	Width of Gravel trap basin (B)	11	m	
2	Width of approach culvert (B')	4.5	m	
3	Opening angle of inlet transition	30	degree	
4	Length of horizontal transition	5.629165	m	
5	Vertical angle	45	°	

°

Calculation of trashrack				
1	Total submerged width of trash rack	44	m	Width of transited end
2	Total width trashrack excluding piers	42.6		
3	Depth of trashrack	2	m	
4	Angle of inclination of trashrack	70	Degree	
5	Bar thickness of trashrack	20	mm	
6	Clear spacing between bars	50	mm	
7	Net area of trashrack	90.66795	m2	
8	% of opening	0.714286		

9	Net area of trashrack	64.76282	m2	
10	velocity in trashrack	0.452389	m/s	
11	Factor depending on bar shape(kr)	1.67		Rounded bars

Check the length of spillway in Main gravel trap		
	Limiting head over crest	0.8m
	Adopt broad crested weir, C	3m
	Length of spillway, L = Q / (C *H3/2)	13.65m

Loss in Trash rack			
1	Head loss through trash rack	0.004824	Head loss (Hr) = k*(t/a)^(4/3)* (v^2/2g)* sinα

Gravel Trap Flushing Canal

Parameter	Value	Remarks
Design Discharge	48.83	
Flushing Discharge (m^3/s)	9.77	20% of Design Discharge
Width (b), m	2.00	Trial
Depth (y), m	2.00	Trial
Area (A), m^2	4.00	A=by
Slope, S	0.05	
Wetted Perimeter, m	6.00	
Hydraulic Depth, R, m	0.67	
Manning's Coefficient	0.02	concrete-lined channels
Velocity (v), m/s	11.38	
Discharge Capacity (m^3/s)	45.51	1.33
Adopt Width (w), m	2.00	
Adopt Depth (d), m	2.00	

6. Approach Canal

Parameters of approach canal				
S.N.	**Description**	**Value**	**Unit**	**Remark**
1	Type of approach Canal	Trapezoidal		
2	Design discharge (Q_d)	48.83	m^3	
3	Flushing discharge(%)	10%		>=10%
4	Total discharge (Q_t)	53.71	m^3	
5	Critical velocity	2.70	m/s	
6	Limiting velocity	1.00	m/s	

7	Freeboard	0.75	m	
8	Manning's coefficient(n)	0.02		Trowel float finish
9	Bed slope	0.0010		
10	Side slope	1.00		H:V
11	No. of canals	2.00		

Calculation of Approach canal				
S.N.	**Description**	**Value**	**Unit**	**Remark**
1	Discharge in one canal	26.86	m^3	Q_t/no of canal
2	Depth of canal	2.46	m	Q=A*V
3	Width of canal	2.04	m	0.828Y
4	Top width of canal	6.96	m	b+2ny
5	Area of flow	11.09	m^2	$1.828y^2$
6	Adopted depth (including free board)	3.21	m	y+FB
7	Area of canal	16.87	m^2	(b+ny)y
8	Velocity in canal	2.42	m/s	$V_{lim}<V_{canal}<V_{critical}$
9	Length of Approach Canal	162	m	

7. Settling Basin

Design of Settling Basin for kabeli A					
S N	**Descriptions**	**Formula**	**Unit**	**Value**	**Remarks**
	Assumptions				
	Temperature of water		°c	20°c	From temperature table
	Length / Breadth ratio	L/B		8	Recommended ratio 4 to 10
	Acceleration due to gravity		m/s^2	9.81	
	Specific gravity of particle			2.6	
	Specific gravity of water			1	
	Kinematic viscosity		m^2/s	$1*10^{-6}$	
	Limiting diameter of the particle(d)		mm	0.15	
	Longitudinal slope of settling basin(S)			0.02	
	Manning's coefficient(n)			0.015	
	λ for 90% efficiency			0.9	From Velikanov's relationship
	Width of Side wall		m	1	
	Width of Dividing wall		m	1.5	
	Given				
	Design Discharge (Q_d)		m^3/s	48.83	Output from hydrological calculations
	Discharge in Settling Basin (Q_D)	$Q_D=1.10 *Q_d$	m^3/s	53.71	Flusing requires 10-20% additional discharge

	No. of Chamber			2	
	Q_D through each chamber(Q)	Q_D/ No. of basin		26.85	
	Calculations				
	Fall velocity (ω)		mls	0.0135	From the graph at 20°c for d
	Function of diameter (a)	a= 0.44 for 0.1mm<d<1mm		0.44	since d=0.15
	Flow velocity (v)	$v= a (d)^{1/2}$	m/s	0.17	
	Coefficient to account the turbulence(k)			1.5	Range: 1.2 to 1.5
	Surface Area (A_s)	$A_s=kQ/\omega$	m^2	2983.33	
	Calculations for Length, Breadth and Depth				
	Surface Area(A_s)	A_s=Length * Breadth	m^2	2984	Adopted
	Width of Basin (B)	$B=(A_s/8)^{1/2}$	m	19.31	
	Length of basin (L)	L=8*B	m	154.48	Adopted
	Check for basin width(B_c)	$B=4.75(Q)^{1/2}$	m	24.61	Taking B=8.85 ,which is lesser for flushing
	Depth of Basin(H)	H=Q/v.B	m	8.17	Equation of horizontal velocity
	Checking for Length	$L=\{\lambda^2v^2(H^{1/2}-0.2)^2\}/(7.51\omega^2)$	m	120.86	Velikanov's relation
	Check for Efficiency				
i.	Vetter's Method	$\eta=1-e^{(-\omega*As/Q)}$		0.78	
ii.	Hazen's Method	$\eta=1-\{1+(m.\omega/v)\}^{-1/m}$		0.83	m is the performance coefficient= 0.17 for very good
iii.	Camp's Equation				

	Cross-section area(A_x)	A_x=B*H	m^2	157.76	
	Wetted perimeter(P)	P=2H+B	m	35.65	
	Hydraulic radius(R)	R=A/P	m	4.42	
	Shear velocity(v*)		m/s	0.006	
	Ratio	ω/v*		2.25	
	Ratio	$\omega A_s/Q$		1.5	
	Efficiency(η)			100%	From chart
	Calculation of Inlet and Outlet transition				
	Given				
	Total Width of Settling Basin(TB)		m	39.42	
	Width of Settling Basin (B)		m	19.31	Single Bay
	Width of Apporach Canal(B')		m	4.5	From calculation table of Approach Canal
	Inlet horizontal angle(β)		°	12°	
	Inlet vertical expansion angle(α)		°	8°	
	Outlet vertical transition angle (β")		°	40°	
	Outlet transition angle (β')		°	15°	
	Calculation				
	Length of horizontal inlet transition (L_{ih})	L_{ih}=(B-B')/2tan(β)	m	34.83	Single Bay
	Length of vertical inlet transition (L_{iv})	L_{iv}=L_{ih}*tan(α)	m	4.89	

	Length of horizontal outlet transition (L_{oh})	L_{oh}=(B-B')/2tan(β')	m	14.85	
	Length of vertical outlet transition (L_{ov})	L_{ov}=L_{oh}*tan(β'')	m	12.46	
	Length of settling basin (L)	L_T=L+L_{ih}+L_{oh}	m	204.16	
	Design of Sediment Storage Volume				
	Assumption				
	Freeboard (FB)		m	1	
	Retention Time (T)		sec	21600	6hr=21600 sec
	Packing factor of sediment in submergence (Pf)			0.5	Usually taken as 50%
	Given				
	Sediment concentration©		kg/m^3	5	5 kg/m^3=5000ppm
	Density of sediment(ρ)		kg/m^3	2600	
	Calculation				
	Sediment load (S_L)	S_L=Q*T*C	kg	2899800	
	Sediment volume (S_V)	S_V=S_L/(ρ* P_F)	m^3	2230.615385	
	Depth of the sediment (S_D)	S_D=S_V/(L*B)	m	0.74	
	Angle for settlement of sediment at bottom of settling tank	tan^{-1}(S_D/L)	°	0.27°	Hence slope =1:28.75

	Design of Flushing Canal				
	Discharge through flushing canal (Q_F)	Q_F=10% of Q_d	m^3/s	4.883	
	Depth of basin (H)		m	8.17	
	(V_f)	V_f=$C_A\sqrt{(2gH)}$	m/s	7.59	CA= 0.6
	Area of flushing canal(A_f)	A_f=Q_f/V_f	m^2	0.64	
	width of flushing (B_f)		m	3	Adopted
	Depth of flushing (H_f)		m	3	Adopted
	Wetted perimeter(P_f)	P_f=2*H_f + B_f	m	9	
	Hydraulic radius(R_f)	R_f=A_f / P_f	m	0.07	
	Slope of flushing canal (S_f)		°	0.02	slope should be within 1:50
	Critical Depth (H_c)	H_c=$\sqrt{(Q_f^2/g)}$	m	1.55	
	Critical Velocity (V_c)	V_c=Q_f/(H_c * B_f)	m/s	1.05	
	Velocity through the opening(V_o)	V_o=1/n *($R^{2/3}$ *$S^{1/2}$)	m/s	1.6	n = 0.015 for concrete
	Scouring velocity(V_s)	V_s=$(8bgd(\rho -1)/f)^{1/2}$	m/s	3.5	Greater than velocity at using the formula
	Design of Hooper Flushing System				
	Inclination of Hooper (Lateral Slope)(β')		°	40	Inclination is used to calculate the hopper dimension in relation to basin dimension which was assumed to be rectangular for solving

					purposes. General inclination used in design is 40°
	Width of settling basin (B)		m	19.31	
	Depth of settling zone except hopper(H)	H+FB	m	9.17	
	Width of flushing canal below hopper (B_f)		m	3	
	Depth of Hopper(H_h)	H_h=(B - B_f)/2 *tan(β')	m	6.84	
	Total Depth of settling basin(H_T)	H_T=H + H_h+FB	m	16.01	
	Calculation of trashrack				
	S.N.	**Description**	**Value**	**Unit**	**Remark**
	1	Total submerged width of trash rack	19.31	m	Width of transited end
	2	Total width trashrack excluding piers	17.91		
	3	Depth of trashrack	1.5	m	
	4	Angle of inclination of trashrack	70	Degree	
	5	Bar thickness of trashrack	20	mm	
	6	Clear spacing between bars	50	mm	

	7	Net area of trashrack	28.589	m2	
	8	% of opening	0.714		
	9	Net area of trashrack	20.421	m^2	
	10	velocity in trashrack	1.315	m/s	

8. Head pond

Design of Head pond				
S. N	**Description**	**Values**	**Units**	**Remarks**
1	**Available Data**			
	Design Discharge (Q_d)	48.83		
	Detention time (t)	2.00	minutes	
	Adopted discharge (Q_t) = 2 * Q_d	97.66		
	Diameter of the pipe (D)	3.80	m	
2	**Assumptions**			
	Depth of settling zone	0.50	m	Baral, S. (2013) Fundamentals of Hydropower Engineering
	Freeboard	1.00	m	
	Velocity (v)	0.48	m/s	

3	**Calculations**			
	Volume stored in head pond (V) = Qt*t*60	11719.20		$v_P = Q_t \vert A$
		4.31	m/s	
	$submergence\ head(h_s) = \frac{1.5 * v_p^2}{2g}$ and $0.5 * v_p * \sqrt{D_p}$	1.42	m	
		4.20	m	
	Adopted submergence head, h_s	7.90	m	
	Effective depth of head pond(h_e) = Pipe diameter + Submergence head	11.70	m	Baral, S. (2013) Fundamentals of Hydropower Engineering
	Total depth (h) = effective depth + depth of settling zone + freeboard	13.20	m	
	Width of head pond (b) = $Q_t/(v * h_e)$	15.41	m	
	Adopted width of head pond = Width of desanding basin	21.31	m	
	Length = Volume / (Width * total height)	41.66	m	
	Adopted length of head pond (L)	46.50	m	
4	**Checking the limiting velocity in the Head pond**			
	v = Q/(BH)	0.35		> (0.2 m/s), OK
5	**Check the length of spillway in head pond**			
	Limiting head over crest(H)	3.00	m	
	Adopt broad crested weir(C)		m	
	Length of spillway, L = Q / (C *$H^{3/2}$)	8.54		
6	**Final Dimensions**			

	Submergence head (h_s)	7.90	m	
	Effective depth of head pond(h_e)	11.70	m	
	Total depth (h)	13.20	m	
	Width of head pond (b)	21.31	m	
	Length of head pond (L)	46.50	m	
	Velocity in head pond (v)	0.35	m/s	

Hydraulic Design of Surge Tank:

Design of Surge Tank		
Particulars	**Value**	**Unit**
Design Discharge	48.83	m^3/s
Length of Headrace Tunnel	5032.21	m
Velocity in Headrace Tunnel	2.69	m/s
Diameter of Tunnel	4.80	m
Diameter of Penstock	3.65	m
Net Head	121.92	m
Head loss in the headrace tunnel	2.54	m
Area of Headrace Tunnel	18.16	m^2
Area of Surge Tank,Ast	68.86	m^2
Preliminary Diameter of Surge Tank	9.36	m
Using factor of Safety for Ast as 2,Then		
Area of surge Tank,Ast	137.71	
Diameter of Surge Tank,Dst	13.23	m
Maximum Amplitiude,Zmax	22.12	m
Po	0.11	
Upsurge Head, Zup	20.46	m
Downsurge, Zdown	-17.04	m

Diameter(m)	Ast(m^2)	Z,max(m)	Po	Zup(m)	Zdown(m)
8	50.24	32.54	0.38	24.81	-7.76
9	63.59	28.93	0.43	21.26	-4.15
10	78.50	26.04	0.48	18.43	-1.26
11	94.99	23.67	0.52	16.13	1.11
12	113.04	21.70	0.57	14.22	3.08
13	132.67	20.03	0.62	12.62	4.75
14	153.86	18.60	0.67	11.25	6.18
15	176.63	17.36	0.71	10.08	7.42
16	200.96	16.27	0.76	9.06	8.51
17	226.87	15.31	0.81	8.17	9.47
18	254.34	14.46	0.86	7.38	10.32
19	283.39	13.70	0.90	6.69	11.08
20	314.00	13.02	0.95	6.07	11.76
21	346.19	12.40	1.00	5.51	12.38
22	379.94	11.83	1.05	5.02	12.95
23	415.27	11.32	1.09	4.57	13.46
24	452.16	10.85	1.14	4.16	13.93

Let's take diameter of surge tank as 10 m		
Upsurge head from Static Level	18.43	m
Downsurge head from Static Level	-1.26	m
Normal level of intake	581.93	m
Static level at surge tank	579.39	m
Crown level of tunnel	570.00	m
Diameter of Penstock	3.65	m
Area of Penstock	10.47	m2
velocity flow at penstock	4.66	m/s
hsub, 1st	1.66	m
hsub, 2nd	5.48	m
The maximum downsurge level at surge shaft	575.48	m
Downsurge level considering maximum downsurge at surge shaft	578.14	m
Submergance Available	8.14	m

Design of Surge Tank		
Particulars	**Value**	**Unit**
Design Discharge	48.83	m^3/s
Length of Headrace Tunnel	5090.76	m
Velocity in Headrace Tunnel	2.69	m/s
Diameter of Tunnel	4.80	m
Diameter of Penstock	3.65	m
Net Head	116.23	m
Head loss in the headrace tunnel	5.86	m
Area of Headrace Tunnel	18.16	m^2
Area of Surge Tank,Ast	72.23	m^2
Preliminary Diameter of Surge Tank	9.58	m
Using factor of Safety for Ast as 2,Then		
Area of surge Tank,Ast	144.45	m^2
Diameter of Surge Tank,Dst	13.55	m
Maximum Amplitude,Zmax	21.72	m
Po	0.27	
Upsurge Head, Zup	17.99	m
Down surge, Zdown	-10.00	m

Hence , this is higher than 5.48 m so we take the diameter 10m as the surge tank diameter

Design of Anchor Blocks:

Anchor Block 1:

Definitions and Symbol			
Symbols	**Definitions**	**Value**	**Unit**
α	Upstream penstock angle with respect to the horizontal.	25.00	degrees
β	Downstream penstock angle with respect to the horizontal.	25.00	degrees
γ_{water}	Unit weight of water	9.81	kN/cu.m
$\gamma_{concrete}$	Unit weight of concrete	24.00	kN/cu.m
$\gamma_{masonary}$	Unit weight of masonry	24.00	kN/cu.m
$\gamma_{pipe\ material}$	Unit weight of pipe material	77.00	kN/cu.m
γ_{soil}	Unit weight of soil	20.00	kN/cu.m
Φ	Soil angle of friction	32.00	degrees
a	Coefficient of linear expansion of pipe	0.00	
d	Pipe internal diameter	3.65	m
d_{big}	Internal diameter of larger pipe in case of reduction in pipe diameter	0.00	m
d_{small}	Internal diameter of smaller pipe in case of reduction in pipe diameter	0.00	m
E	Young's modulus of elasticity	200000.00	N/mm^2
f	Coefficient of friction between pipe and support piers.	0.25	
g	acceleration due to gravity	9.80	m/s^2

h_1	Buried depth of block at the upstream face	8.03	m
h_2	Buried depth of block at the downstream face	6.03	m
h_{total}	Total head including surge. (*1.3)	121.92	m
i	Uphill ground slope.(Note that i may not always be equal toα)	0.00	degrees
K_a	Active soil pressure coefficient	0.65	
L_{1d}	Half the distance from anchor block centreline to the centreline of the first downstream support pier	4.00	m
L_{1u}	Half the distance from anchor block centreline to the centreline of the first upstream support pier	4.00	m
L_{2d}	Distance between two consecutive support piers downstream of the anchor block.	8.00	m
L_{2u}	Distance between two consecutive support piers upstream of the anchor block.	8.00	m
L_{4d}	Distance from the anchor block centreline to the downstream expansion joint	0.00	m
L_{4u}	Distance from the anchor block centreline to the upstream expansion joint	0.00	m
Q	Flow in the penstock pipe	48.83	cu.m/s
t	Wall thickness of penstock	0.025	m
W	Width of the anchor block	5.25	m
W_p	Weight of pipe	889.03	kN/m
Ww	Weight of water in pipe	102.64	kN/m
A	Area of pipe	10.46	sq.m
T	Maximum temperature change (°C) that the pipe will experience after being fixed at anchor blocks.	4.00	Celsius

Forces on Anchor Block				
SN	**Description of Force**	**Magnitude**		**Remarks**
1	F1= combination of F1u and F1d F1u= (Wp+Ww)* L1u cos α F1d= (Wp+Ww)* L1d cos β If pipe is straight, F1=(Wp+Ww)*(L1u+L1d)* cos α	F1u	3595.05	F1 is the component of weight of pipe and water perpendicular to the pipe. Applies to both support piers and anchor blocks
		F1d	3595.05	
2	F2u= f(Wp+Ww)*L2u*cosα F2d= f(Wp+Ww)*L2d*cosα	F2u	7190.10	F2 is the frictional force due to the pipe sliding on the support piers. Applies to support piers and anchor blocks. The force acting at an anchor block is the sum of forces acting on the support blocks between the anchor block and expansion joints, but opposite in direction
		F2d	7190.10	
3		F3	0.00	F3 is the hydrostatic force on bends

	F3= 2ϒw*htotal*(πd2/4)* sin(β-α)/2 = 15.4 htotal *d2* sin(β-α)/2			that acts along the bisector of the bend. Only applies to anchor blocks that have horizontal and/or vertical bends
4	F4= combination of F4u and F4d F4u=Wp*L4u*sinα F4d=Wp*L4d*sinβ	F4u	0.00	F4 is the component of pipe weight acting parallel to pipe. Applies to anchor blocks only. Calculate only if the angles (α or β) are larger than 20°
		F4d	0.00	
5	F5 = 1000Ea T (d+t)t	F5	0.00	F5 is the thermally induced force restrained by the anchor block in the absence of an expansion joint. Applies to anchor blocks only. Calculate only if expansion joints are not installed between anchor blocks
6	F6 = 100d	F6	365.00	F6 is the factional force in the expansion joint. The F6 force is felt because the joint will resist sliding. Applies to anchor blocks only
7	F7 = water total Π(d+t) t =31h_total(d+t)t Usually insignificant	F7u	351.02	F7 is the hydrostatic force on bends that acts along the bisector of the bend. Applies to anchor blocks only.
		F7d		
8	F8 = [2Q^2 /(1/4) Π d^2] sin (β - α)/2 = 2.5 (Q^2 / d^2) sin (β - α)/2 Usually insignificant	F8	0.00	F8 is the dynamic force at a bend due to change in direction of moving water. Velocities are usually low in penstocks so this force is small. Applies to anchor blocks only

9	F9 = water* h_totalx Π/4(d_big^ 2 – d_small^ 2) =7.7htotal(dbig 2 - dsmall 2	F9	0.00	F9 is the force due to reduction in pipe diameter from dbig to d small Applies to anchor blocks only.
10	F10 =((ϒ_soil*)h_1)^2)/2)cos i x Ka x w	F10	2212.70	F10 is the force due to soil pressure upstream of the block. Applies to both anchor blocks and support piers Calculate F10 if (h1 - h2) is more than 1 m. The force acts at 1/3 of the height (h1) from the base of the block
11	Wb = Vol. black X γblock	Wb		Wb is the weight of block. Applies to anchor blocks and support piers.

Resolution of Forces

Forces		X-Component(-ve)	Y-Component (+ve)	Remarks
F1u=	3595.05	-1519.33	3258.22	
F1d=	3595.05	-1519.33	3258.22	
F2u=	7190.10	6516.44	3038.67	
F2d=	7190.10			
F3=	0.00	0.00	0.00	
F4u=	0.00			
F4d=	0.00			
F5=	0.00	0.00	0.00	
F6=	365.00	0.00	0.00	
F7u=	351.02	318.13	148.35	
F7d=	0.00			
F8	0.00	0.00	0.00	
F9=	0.00			
F10=	0.00			
Wb=			7144.89	
Sum		3795.91	16848.35	

Anchor Block 2:

Definitions and Symbol			
Symbols	**Definitions**	**Value**	**Unit**
α	Upstream penstock angle with respect to the horizontal.	1.00	degrees
β	Downstream penstock angle with respect to the horizontal.	1.00	degrees
γ_{water}	Unit weight of water	9.81	kN/cu.m
$\gamma_{concrete}$	Unit weight of concrete	24.00	kN/cu.m
$\gamma_{masonary}$	Unit weight of masonry	24.00	kN/cu.m
$\gamma_{pipe\ material}$	Unit weight of pipe material	77.00	kN/cu.m
γ_{soil}	Unit weight of soil	20.00	kN/cu.m
Φ	Soil angle of friction	32.00	degrees
a	Coefficient of linear expansion of pipe	0.00	
d	Pipe internal diameter	3.65	m
d_{big}	Internal diameter of larger pipe in case of reduction in pipe diameter	0.00	m
d_{small}	Internal diameter of smaller pipe in case of reduction in pipe diameter	0.00	m
E	Young's modulus of elasticity	200000.00	N/mm^2
f	Coefficient of friction between pipe and support piers.	0.25	
g	acceleration due to gravity	9.80	m/s^2
h_1	Buried depth of block at the upstream face	6.83	m
h_2	Buried depth of block at the downstream face	6.83	m

h_{total}	Total head including surge.(*1.3)	121.92	m
i	Uphill ground slope .(Note that i may not always be equal toα)	0.00	degrees
K_a	Active soil pressure coefficient	0.65	
L_{1d}	Half the distance from anchor block centreline to the centreline of the first downstream support pier	4.00	m
L_{1u}	Half the distance from anchor block centreline to the centreline of the first upstream support pier	4.00	m
L_{2d}	Distance between two consecutive support piers downstream of the anchor block.	8.00	m
L_{2u}	Distance between two consecutive support piers upstream of the anchor block.	8.00	m
L_{4d}	Distance from the anchor block centreline to the downstream expansion joint	30.00	m
L_{4u}	Distance from the anchor block centreline to the upstream expansion joint	0.00	m
Q	Flow in the penstock pipe	48.83	cu.m/s
t	Wall thickness of penstock	0.03	m
W	Width of the anchor block	5.25	m
W_p	Weight of pipe	888.97	kN/m
Ww	Weight of water in pipe	102.64	kN/m
A	Area of pipe	10.46	sq.m
T	Maximum temperature change (°C) that the pipe will experience after being fixed at anchor blocks.	4.00	Celsius

Forces on Anchor Block				
SN	**Description of Force**	**Magnitude**		**Remarks**
1	F1= combination of F1u and F1d F1u= (Wp+Ww)* L1u cos α F1d= (Wp+Ww)* L1d cos β If pipe is straight, F1=(Wp+Ww)*(L1u+L1d)* cos α	F1u	3965.83	F1 is the component of weight of pipe and water perpendicular to the pipe. Applies to both support piers and anchor blocks
		F1d	3965.83	
2	F2u= f(Wp+Ww)*L2u*cosα F2d= f(Wp+Ww)*L2d*cosα	F2u	7931.67	F2 is the frictional force due to the pipe sliding on the support piers. Applies to support piers and anchor blocks. The force acting at an anchor block is the sum of forces acting on the support blocks between the anchor block and expansion joints, but opposite in direction
		F2d	7931.67	
3	F3= 2ϒw*htotal*(πd2/4)* sin(β-α)/2 = 15.4 htotal *d2* sin(β-α)/2	F3	0.00	F3 is the hydrostatic force on bends that acts along the bisector of the bend. Only applies to anchor blocks that have horizontal and/or vertical bends

4	F4= combination of F4u and F4d F4u=Wp*L4u*sinα F4d=Wp*L4d*sinβ	F4u	0.00	F4 is the component of pipe weight acting parallel to pipe. Applies to anchor blocks only. Calculate only if the angles (α or β) are larger than 20°
		F4d	465.44	
5	F5 = 1000Ea T (d+t)t	F5	0.00	F5 is the thermally induced force restrained by the anchor block in the absence of an expansion joint. Applies to anchor blocks only. Calculate only if expansion joints are not installed between anchor blocks
6	F6 = 100d	F6	365.00	F6 is the factional force in the expansion joint. The F6 force is felt because the joint will resist sliding. Applies to anchor blocks only
7	F7 = γ_water h_total Π(d+t) t =31h_total(d+t)t <u>Usually insignificant</u>	F7u	347.24	F7 is the hydrostatic force on bends that acts along the bisector of the bend. Applies to anchor blocks only.
		F7d		
8	F8 = [2Q^2 /(1/4) Π d^2] sin (β - α)/2 = 2.5 (Q^2 / d^2) sin (β - α)/2 <u>Usually insignificant</u>	F8	0.00	F8 is the dynamic force at a bend due to change in direction of moving water. Velocities are usually low in penstocks so this force is small. Applies to anchor blocks only

9	F9 = γ_water* h_totalx Π/4(d_big^ 2 – d_small^ 2) =7.7htotal(dbig 2 - dsmall 2	F9	0.00	F9 is the force due to reduction in pipe diameter from dig to d small Applies to anchor blocks only.
10	F10 =((ϒ_soil*)h_1)^2)/2)cos i x Ka x w	F10	0.00	F10 is the force due to soil pressure upstream of the block. Applies to both anchor blocks and support piers Calculate F10 if (h1 - h2) is more than 1 m. The force acts at 1/3 of the height (h1) from the base of the block
11	Wb = Vol. black X γblock	Wb		Wb is the weight of block. Applies to anchor blocks and support piers.

Resolution of Forces

Forces		X-Component(-ve)	Y-Component (+ve)	Remarks
F1u=	3965.83	-69.21	3965.23	
F1d=	3965.83	-69.21	3965.23	
F2u=	7931.67	7930.46	138.43	
F2d=	7931.67			
F3=	0.00	0.00	0.00	
F4u=	0.00			
F4d=	0.00			
F5=	0.00	0.00	0.00	
F6=	365.00	0.00	0.00	
F7u=	347.24	347.19	6.06	
F7d=	0.00			
F8	0.00	0.00	0.00	
F9=	0.00			
F10=	0.00			
Wb=	0.00		7144.89	
Sum		8139.22	15219.84	

Anchor Block 3:

Definitions and Symbol			
Symbols	**Definitions**	**Value**	**Unit**
α	Upstream penstock angle with respect to the horizontal.	25.00	degrees
β	Downstream penstock angle with respect to the horizontal.	0.00	degrees
γ_{water}	Unit weight of water	9.81	kN/cu.m
$\gamma_{concrete}$	Unit weight of concrete	24.00	kN/cu.m
$\gamma_{masonary}$	Unit weight of masonry	24.00	kN/cu.m
$\gamma_{pipe\ material}$	Unit weight of pipe material	77.00	kN/cu.m
γ_{soil}	Unit weight of soil	20.00	kN/cu.m
Φ	Soil angle of friction	32.00	degrees
a	Coefficient of linear expansion of pipe	0.00	
d	Pipe internal diameter	3.65	m
d_{big}	Internal diameter of larger pipe in case of reduction in pipe diameter	0.00	m

d_{small}	Internal diameter of smaller pipe in case of reduction in pipe diameter	0.00	m
E	Young's modulus of elasticity	200000.00	N/mm^2
f	Coefficient of friction between pipe and support piers.	0.25	
g	acceleration due to gravity	9.80	m/s^2
h_1	Buried depth of block at the upstream face	8.21	m
h_2	Buried depth of block at the downstream face	5.60	m
h_{total}	Total head including surge. (*1.3)	121.92	m
i	Uphill ground slope.(Note that i may not always be equal toα)	0.00	derees
K_a	Active soil pressure coefficient	0.65	
L_{1d}	Half the distance from anchor block centreline to the centreline of the first downstream support pier	4.00	m
L_{1u}	Half the distance from anchor block centreline to the centreline of the first upstream support pier	4.00	m

L_{2d}	Distance between two consecutive support piers downstream of the anchor block.	8.00	m
L_{2u}	Distance between two consecutive support piers upstream of the anchor block.	8.00	m
L_{4d}	Distance from the anchor block centreline to the downstream expansion joint	0.00	m
L_{4u}	Distance from the anchor block centreline to the upstream expansion joint	30.00	m
Q	Flow in the penstock pipe	48.83	cu.m/s
t	Wall thickness of penstock	0.025	m
W	Width of the anchor block	5.25	m
W_p	Weight of pipe	888.97	kN/m
Ww	Weight of water in pipe	102.64	kN/m
A	Area of pipe	10.46	sq.m
T	Maximum temperature change (°C) that the pipe will experience after being fixed at anchor blocks.	4.00	Celsius

Forces on Anchor Block				
SN	**Description of Force**	**Magnitude**		**Remarks**
1	F1= combination of F1u and F1d F1u= (Wp+Ww)* L1u cos α F1d= (Wp+Ww)* L1d cos β If pipe is straight, F1=(Wp+Ww)*(L1u+L1d)* cos α	F1u	3594.81	F1 is the component of weight of pipe and water perpendicular to the pipe. Applies to both support piers and anchor blocks
		F1d	3594.81	
2	F2u= f(Wp+Ww)*L2u*cosα F2d= f(Wp+Ww)*L2d*cosα	F2u	7189.63	F2 is the frictional force due to the pipe sliding on the support piers. Applies to support piers and anchor blocks. The force acting at an anchor block is the sum of forces acting on the support blocks between the anchor block and expansion joints, but opposite in direction
		F2d	7189.63	
3	F3= 2ϒw*htotal*(πd2/4)* sin(β-α)/2 = 15.4 htotal *d2* sin(β-α)/2	F3	-5414.00	F3 is the hydrostatic force on bends that acts along the bisector of the bend. Only applies to anchor blocks that have horizontal and/or vertical bends

4	F4= combination of F4u and F4d F4u=Wp*L4u*sinα F4d=Wp*L4d*sinβ	F4u	11270.80	F4 is the component of pipe weight acting parallel to pipe. Applies to anchor blocks only. Calculate only if the angles (α or β) are larger than 20°
		F4d	0.00	
5	F5 = 1000Ea T (d+t)t	F5	0.00	F5 is the thermally induced force restrained by the anchor block in the absence of an expansion joint. Applies to anchor blocks only. Calculate only if expansion joints are not installed between anchor blocks
6	F6 = 100d	F6	365.00	F6 is the factional force in the expansion joint. The F6 force is felt because the joint will resist sliding. Applies to anchor blocks only
7	F7 = γ_water h_total Π(d+t) t =31h_total(d+t)t <u>Usually insignificant</u>	F7u	347.24	F7 is the hydrostatic force on bends that acts along the bisector of the bend. Applies to anchor blocks only.
		F7d		
8	F8 = [2Q^2 /(1/4) Π d^2] sin (β - α)/2 = 2.5 (Q^2 / d^2) sin (β - α)/2 <u>Usually insignificant</u>	F8	-96.84	F8 is the dynamic force at a bend due to change in direction of moving water. Velocities are usually low in penstocks so this force is small. Applies to anchor blocks only
9	F9 = γ_water* h_totalx Π/4(d_big^ 2 – d_small^ 2) =7.7htotal(dbig 2 - dsmall 2	F9	0.00	F9 is the force due to reduction in pipe diameter from dbig to d small Applies to anchor blocks only.

10	F10 =((ϒ_soil*)h_1)^2)/2)cos i x Ka x w	F10	2313.01	F10 is the force due to soil pressure upstream of the block. Applies to both anchor blocks and support piers Calculate F10 if (h1 - h2) is more than 1 m. The force acts at 1/3 of the height (h1) from the base of the block
11	Wb = Vol. black X γblock	Wb		Wb is the weight of block. Applies to anchor blocks and support piers.

Resolution of Forces				
Forces		**X-Component(-ve)**	**Y-Component (+ve)**	**Remarks**
F1u=	3594.81	-1519.23	3258.01	
F1d=	3594.81	-1519.23	3594.81	
F2u=	7189.63	6516.02	3038.47	
F2d=	7189.63			
F3=	-5414.00	-1171.80	5285.67	
F4u=	0.00			
F4d=	11270.80			
F5=	0.00	0.00	0.00	
F6=	365.00	-34.20	-154.26	

F7u=	347.24	314.71	146.75	
F7d=	0.00			
F8	-96.84	-20.96	-94.55	
F9=	0.00			
F10=	0.00			
Wb=	0.00		7144.89	
Sum		2565.30	22219.79	

Anchor Block 4:

Definitions and Symbol			
Symbols	**Definitions**	**Value**	**Unit**
α	Upstream penstock angle with respect to the horizontal.	1.00	degrees
β	Downstream penstock angle with respect to the horizontal.	25.00	degrees
γ_{water}	Unit weight of water	9.81	kN/cu.m
$\gamma_{concrete}$	Unit weight of concrete	24.00	kN/cu.m

$\gamma_{masonary}$	Unit weight of masonry	24.00	kN/cu.m
$\gamma_{pipe\ material}$	Unit weight of pipe material	77.00	kN/cu.m
γ_{soil}	Unit weight of soil	20.00	kN/cu.m
Φ	Soil angle of friction	32.00	degrees
a	Coefficient of linear expansion of pipe	0.00	
d	Pipe internal diameter	3.65	m
d_{big}	Internal diameter of larger pipe in case of reduction in pipe diameter	0.00	m
d_{small}	Internal diameter of smaller pipe in case of reduction in pipe diameter	0.00	m
E	Young's modulus of elasticity	200000.00	N/mm^2
f	Coefficient of friction between pipe and support piers.	0.25	
g	acceleration due to gravity	9.80	m/s^2
h_1	Buried depth of block at the upstream face	6.11	m
h_2	Buried depth of block at the downstream face	6.98	m
h_{total}	Total head including surge.(*1.3)	121.92	m
i	Uphill ground slope .(Note that i may not always be equal toα)	0.00	degrees

K_a	Active soil pressure coefficient	0.65	
L_{1d}	Half the distance from anchor block centreline to the centreline of the first downstream support pier	4.00	m
L_{1u}	Half the distance from anchor block centreline to the centreline of the first upstream support pier	4.00	m
L_{2d}	Distance between two consecutive support piers downstream of the anchor block.	8.00	m
L_{2u}	Distance between two consecutive support piers upstream of the anchor block.	8.00	m
L_{4d}	Distance from the anchor block centreline to the downstream expansion joint	0.00	m
L_{4u}	Distance from the anchor block centreline to the upstream expansion joint	0.00	m
Q	Flow in the penstock pipe	48.83	cu.m/s
t	Wall thickness of penstock	0.025	m
W	Width of the anchor block	5.25	m
W_p	Weight of pipe	889.03	kN/m
Ww	Weight of water in pipe	102.64	kN/m
A	Area of pipe	10.46	sq.m
T	Maximum temperature change (°C) that the pipe will experience after being fixed at anchor blocks.	4.00	Celsius

Forces on Anchor Block				
SN	**Description of Force**	**Magnitude**		**Remarks**
1	F1= combination of F1u and F1d F1u= (Wp+Ww)* L1u cos α F1d= (Wp+Ww)* L1d cos β If pipe is straight, F1=(Wp+Ww)*(L1u+L1d)* cos α	F1u	3966.10	F1 is the component of weight of pipe and water perpendicular to the pipe. Applies to both support piers and anchor blocks
		F1d	3966.10	
2	F2u= f(Wp+Ww)*L2u*cosα F2d= f(Wp+Ww)*L2d*cosα	F2u	7932.19	F2 is the frictional force due to the pipe sliding on the support piers. Applies to support piers and anchor blocks. The force acting at an anchor block is the sum of forces acting on the support blocks between the anchor block and expansion joints, but opposite in direction
		F2d	7932.19	

3	F3= 2ϒw*htotal*(πd2/4)* sin(β-α)/2 = 15.4 htotal *d2* sin(β-α)/2	F3	5200.68	F3 is the hydrostatic force on bends that acts along the bisector of the bend. Only applies to anchor blocks that have horizontal and/or vertical bends
4	F4= combination of F4u and F4d F4u=Wp*L4u*sinα F4d=Wp*L4d*sinβ	F4u F4d	0.00 0.00	F4 is the component of pipe weight acting parallel to pipe. Applies to anchor blocks only. Calculate only if the angles (α or β) are larger than 20°
5	F5 = 1000Ea T (d+t)t	F5	0.00	F5 is the thermally induced force restrained by the anchor block in the absence of an expansion joint. Applies to anchor blocks only. Calculate only if expansion joints are not installed between anchor blocks
6	F6 = 100d	F6	365.00	F6 is the factional force in the expansion joint. The F6 force is felt because the joint will resist sliding. Applies to anchor blocks only
7	F7 = γ_water h_total Π(d+t) t =31h_total(d+t)t <u>Usually insignificant</u>	F7u	351.02	F7 is the hydrostatic force on bends that acts along the bisector of the bend. Applies to anchor blocks only.

		F7d		
8	F8 = [2Q^2 /(1/4) Π d^2] sin (β - α)/2 = 2.5 (Q^2 / d^2) sin (β - α)/2 <u>Usually insignificant</u>	F8	93.03	F8 is the dynamic force at a bend due to change in direction of moving water. Velocities are usually low in penstocks so this force is small. Applies to anchor blocks only
9	F9 = γ_water* h_totalx Π/4(d_big^ 2 – d_small^ 2) =7.7htotal(dbig 2 - dsmall 2	F9	0.00	F9 is the force due to reduction in pipe diameter from dbig to d small Applies to anchor blocks only.
10	F10 =((ϒ_soil*)h_1)^2)/2)cos i x Ka x w	F10	0.00	F10 is the force due to soil pressure upstream of the block. Applies to both anchor blocks and support piers Calculate F10 if (h1 - h2) is more than 1 m. The force acts at 1/3 of the height (h1) from the base of the block
11	Wb = Vol. black X γblock	Wb		Wb is the weight of block. Applies to anchor blocks and support piers.

Resolution of Forces				
Forces		**X-Component(-ve)**	**Y-Component (+ve)**	**Remarks**
F1u=	3966.10	-69.22	3965.49	
F1d=	3966.10	-69.22	3594.50	
F2u=	7932.19	7930.98	138.44	
F2d=	7932.19			
F3=	5200.68	1169.90	-5067.39	
F4u=	0.00			
F4d=	0.00			

F5=	0.00	0.00	0.00	
F6=	365.00	34.14	147.89	
F7u=	351.02	350.97	6.13	
F7d=	0.00			
F8	93.03	20.93	90.64	
F9=	0.00			
F10=	0.00			
Wb=	0.00		7144.89	
Sum		9368.48	10020.58	

Stability Analysis of Anchor Blocks:

Anchor Block 1:

Constants	Value	Unit	Remarks
Unit Weight of Plum Concrete	23	kN/cu.m	
Unit Weight of Water	9.81	kN/cu.m	

Dimensions	Value	Unit
Area of AB (from CAD)	72.25	sq.m
Length	10.04	m
Width	5.25	m
Height	8.03	m

SN	Name of Forces	Designation(if any)	Magnitude (kN)		Lever Arm(m)		Moment,anticlockwise +ve	
			Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	Wt.of Anchor Block	W1	10673.86		4.77		50914.32	
2	Forces due to Pipe on AB	Fx		-3795.91		5.10		-19359.14
		Fy	16848.35		4.77		80366.63	
		SUM	27522.21	-3795.91		SUM	131280.95	-19359.14
						Net Moment	111921.81	

Stresses	Value	Unit	Remarks
$\bar{X}$	4.07	m	Net Moment/Vertical Force
e	0.95	m	
B/6	1.67	m	Max. force at toe, e>(B/6)
Resultant acting on toe			
P max on toe	4303.12		
P min on heel	1179.39		
Safety Calculation	Value	Unit	Remarks
Against Overturning	6.78		>1.5

Against Sliding	5.44		>1
Against Bearing	819.64	kN/m^2	>350

Anchor Block 2:

Constants	Value	Unit	Remarks
Unit Weight of Plum Concrete	23	kN/cu.m	
Unit Weight of Water	9.81	kN/cu.m	

Dimensions	Value	Unit
Area of AB (from CAD)	68.3	sq.m
Length	10	m
Width	5.25	m
Height	6.83	m

SN	Name of Forces	Designation (if any)	Magnitude (kN)		Lever Arm(m)		Moment,anticlockwise +ve	
			Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	Wt.of Anchor Block	W1	5839.66		5.00		29198.29	
2	Forces due to Pipe on AB	Fx		-8139.22		3.42		-27795.44
		Fy	15219.84		5.00		76099.20	
		SUM	21059.50	-8139.22		SUM	105297.49	-27795.44
						Net Moment	77502.06	

Stresses	Value	Unit	Remarks
$\overline{X}$	3.68	m	Net Moment/Vertical Force
e	1.32	m	
B/6	1.67	m	Max. force at toe, e>(B/6)
Resultant acting on toe			
P max on toe	3773.68		
P min on heel	438.22		

Safety Calculation	Value	Unit	Remarks
Against Overturning	3.79		>1.5
Against Sliding	1.94		>1
Against Bearing	718.80	kN/m^2	>350

Anchor Block 3:

Constants	Value	Unit	Remarks
Unit Weight of Plum Concrete	23	kN/cu.m	
Unit Weight of Water	9.81	kN/cu.m	

Dimensions	Value	Unit
Area of AB (from CAD)	69.05	sq.m
Length	10	m
Width	5.25	m
Height	8.21	m

SN	Name of Forces	Designation(if any)	Magnitude (kN)		Lever Arm(m)		Moment,anticlockwise +ve	
			Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	Wt.of Anchor Block	W1	7075.85		3.5		24694.70	
2	Forces due to Pipe on AB	Fx		-2565.30		5.18		-13288.25
		Fy	22219.79		3.5		77547.07	
		SUM	29295.64	-2565.30		SUM	102241.77	-13288.25
						Net Moment	88953.51	

Stresses	Value	Unit	Remarks
$\bar{X}$	3.04	m	Net Moment/Vertical Force
e	1.96	m	
B/6	1.67	m	Max. force at toe, e>(B/6)
Resultant acting on toe			
P max on toe	6381.04		
P min on heel	-521.92		

Safety Calculation	Value	Unit	Remarks
Against Overturning	7.69		>1.5
Against Sliding	8.56		>1
Against Bearing	1215.44	kN/m^2	>350

Anchor Block 4:

Constants	Value	Unit	Remarks
Unit Weight of Plum Concrete	23	kN/cu.m	
Unit Weight of Water	9.81	kN/cu.m	

Dimensions	Value	Unit
Area of AB (from CAD)	66.81	sq.m
Length	10	m
Width	5.25	m
Height	6.29	m

SN	Name of Forces	Designation(if any)	Magnitude (kN)		Lever Arm(m)		Moment,anticlockwise +ve	
			Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	Wt.of Anchor Block	W1	7214.50		4.42		31888.09	
2	Forces due to Pipe on AB	Fx		-9368.48		4.72		-44219.23
		Fy	10020.58		4.42		44290.96	
		SUM	17235.08	-9368.48		SUM	76179.06	-44219.23
						Net Moment	31959.83	

Stresses	Value	Unit	Remarks
$\bar{X}$	1.85	m	Net Moment/Vertical Force
e	3.15	m	
B/6	1.67	m	Max. force at toe, e>(B/6)
Resultant acting on toe			
P max on toe	4976.44		
P min on heel	-1529.43		

Safety Calculation	Value	Unit	Remarks
Against Overturning	1.72		>1.5
Against Sliding	1.38		>1
Against Bearing	947.89	kN/m^2	>350

Head loss Calculation:

HEAD LOSS CALCULATION IN HEADWORK					
SN	**Description**		**Unit**	**Quantity**	**Remarks**
1	**Basic Design Data**				
	Design Discharge		cumec	48.83	
2	**HEAD LOSS FROM INTAKE TO TUNNEL**				
A	**Trash rack losses (H_t)**				
	Trash rack opening	b	mm	100.00	
	Thickness of bar	t	mm	20.00	
	Shape factor for Rounded bar	K_r		1.67	
	Angle of inclination with horizontal	Φ	degree	70.00	
	Approach Velocity	v	m/s	0.83	<1m/s , okay
	Head loss through trash rack	H_t	m	0.01	
B	**Trash rack in gravel trap**				
	Head loss through trash rack $H_t = K_r \left(\frac{t}{b}\right)^{4/3} \left(\frac{V^2}{2g}\right) \sin\Phi$	H_t	m	0.00	
C	**Entrance Losses**				
	Velocity at inlet		m/s	0.84	
	Intake loss due to sudden contraction	ki		0.04	Bell mouth
	Gradual contraction losses	kt		0.04	450
	Intake loss coefficient	k		0.08	Ki+Kt
	Intake losses			0.00	k*v2/2g
D	**Gate groove losses**				
	Gate groove loss coefficient (Ref: sec 4.6 of IS 4880 part III)	K_g		0.10	
	No. of gate grooves	n_g		2.00	

	Gate groove losses $h_{L\ g} = K_g * n_g * V_{inl}^2/2g$	$h_{L\ g}$		0.01	
E	**Loss in Approach canal**				
	Canal Length	L	m	162.00	
	Manning's roughness coefficient	n		0.02	
	Flow velocity	v	m/s	2.42	
	Depth of canal	y	m	2.46	
	Hydraulic radius	R	m	1.23	R=y/2
	Major Head loss $h_f = \frac{L \cdot n^2 \cdot V^2}{R^{4/3}}$	h_f		0.29	
		h_f			
	Total loss in headwork			**0.31**	

HEAD LOSS CALCULATION					**Monthly Head Loss Calculation**											
Project:Kabeli-A Hydropower Project					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design discharge		Q_d	m^3/s	48.83	10.03	8.50	8.77	14.07	26.25	48.83	48.83	48.83	48.83	44.28	20.83	13.53
A	**Headrace tunnel Loss**															
1	***Entrance loss***															
	Diameter of Headrace at Entrance	D_{hr}	m	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80
	Area of Inlet channel	A_{hr}	m^2	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57
	Velocity of flow	V_{hr}	m/s	2.37	0.49	0.41	0.43	0.68	1.28	2.37	2.37	2.37	2.37	2.15	1.01	0.66
	Coefficient	k_e		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Head loss	h_e	m	0.144	0.006	0.004	0.005	0.012	0.042	0.144	0.144	0.144	0.144	0.118	0.026	0.011
2	***Friction loss***															

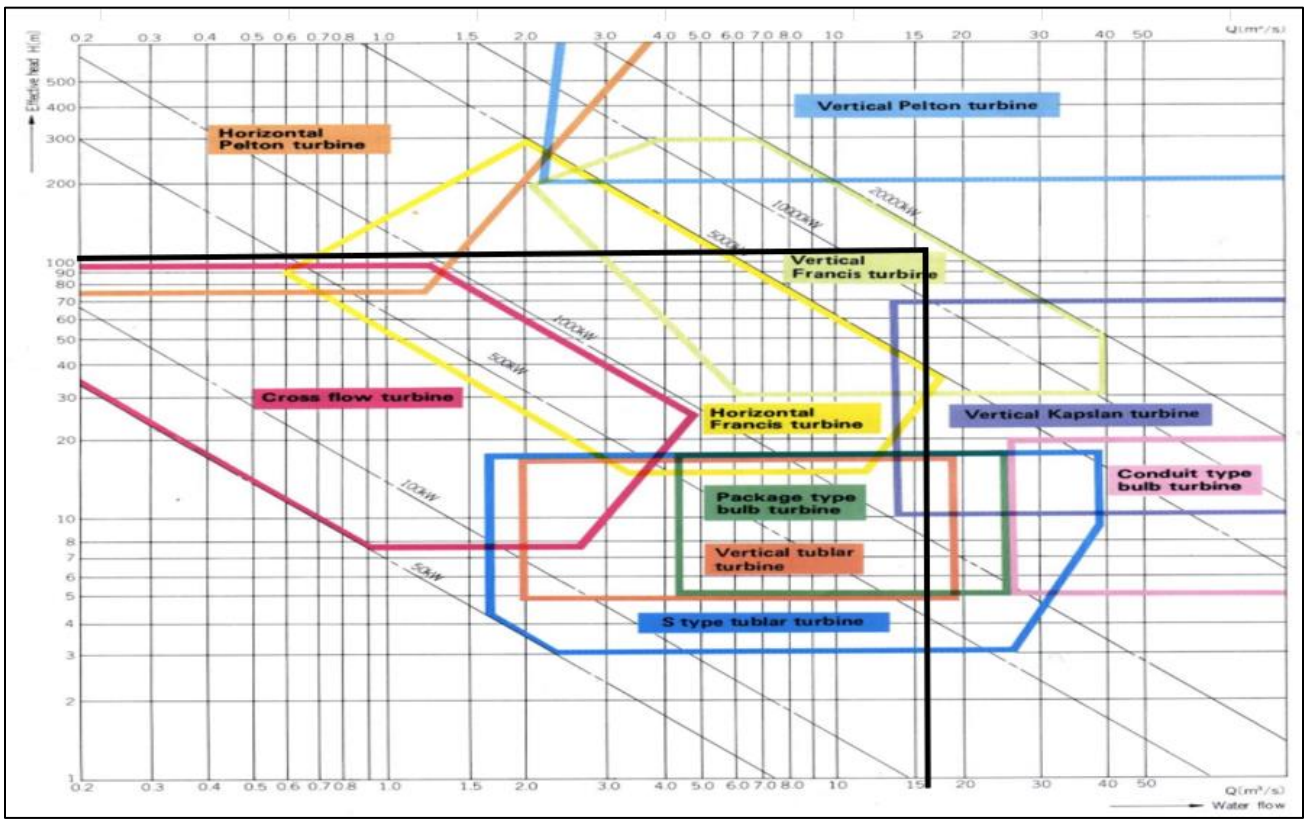
	Equivalent diameter of tunnel	D		4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80	4.80
	Area of Tunnel	A	m	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57
	Length of the tunnel	L		5091	5091	5091	5091	5091	5091	5091	5091	5091	5091	5091	5091	5091
	Manning's friction coefficient	n		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Hydraulic Radius	R		1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
	Friction coefficient	f	m/s	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Velocity of flow	V_{hr}	m	2.37	0.49	0.41	0.43	0.68	1.28	2.37	2.37	2.37	2.37	2.15	1.01	0.66
	Head loss	h_f		2.250	0.095	0.068	0.073	0.187	0.650	2.250	2.250	2.250	2.250	1.850	0.409	0.173
B	**Penstock Pipe Loss**															
1	***Contraction Loss***															
	Diameter of Penstock	d_p	m	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65
	Area of Inlet channel	A_p	m^2	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46
	Velocity of flow	V_p	m/s	4.67	0.96	0.81	0.84	1.35	2.51	4.67	4.67	4.67	4.67	4.23	1.99	1.29
	Coefficient	k		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Head loss	h_e	m	0.555	0.023	0.017	0.018	0.046	0.160	0.555	0.555	0.555	0.555	0.457	0.101	0.043
2	***Friction loss***															
	Length of the penstock	hf_p	m	301	301	301	301	301	301	301	301	301	301	301	301	301
	Friction coefficient	f		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Velocity of flow	v_p	m/s	4.67	0.96	0.81	0.84	1.35	2.51	4.67	4.67	4.67	4.67	4.23	1.99	1.29
	Head loss	h_{f_p}	m	1.101	0.046	0.033	0.036	0.091	0.318	1.101	1.101	1.101	1.101	0.905	0.200	0.084

3	**Bend Loss**															
	Loss coefficient	k		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Head loss	$h_{b,p}$	m	0.013	0.001	0.000	0.000	0.001	0.004	0.013	0.013	0.013	0.013	0.011	0.002	0.001
4	***Entrance loss***															
	Coefficient			0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Head loss	h_e	m	0.056	0.002	0.002	0.002	0.005	0.016	0.056	0.056	0.056	0.056	0.046	0.010	0.004
5	***Valve Loss***															
	Coefficient	k	m	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Head loss	h_{val}	m	0.056	0.002	0.002	0.002	0.005	0.016	0.056	0.056	0.056	0.056	0.046	0.010	0.004
Headwork losses			m	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Headrace Tunnel losses			m	2.39	0.10	0.07	0.08	0.20	0.69	2.39	2.39	2.39	2.39	1.97	0.44	0.18
Penstock Pipe Loss			m	1.78	0.08	0.05	0.06	0.15	0.51	1.78	1.78	1.78	1.78	1.46	0.32	0.14
Total Head Loss Des/PH			m	4.32	0.33	0.28	0.28	0.50	1.36	4.32	4.32	4.32	4.32	3.58	0.91	0.47
Gross Head			m	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46
Net Head			m	120.14	124.13	124.18	124.18	123.96	123.10	120.14	120.14	120.14	120.14	120.88	123.55	123.99
Turbine Efficiency			%	90.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Generator Efficiency			%	97.00	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Transformer Efficiency			%	98.50	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Overall Efficiency			%	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Power Produced By Project			MW	49.49	10.50	8.90	9.19	14.71	27.26	49.49	49.49	49.49	49.49	45.15	21.71	14.15

Design of Powerhouse:

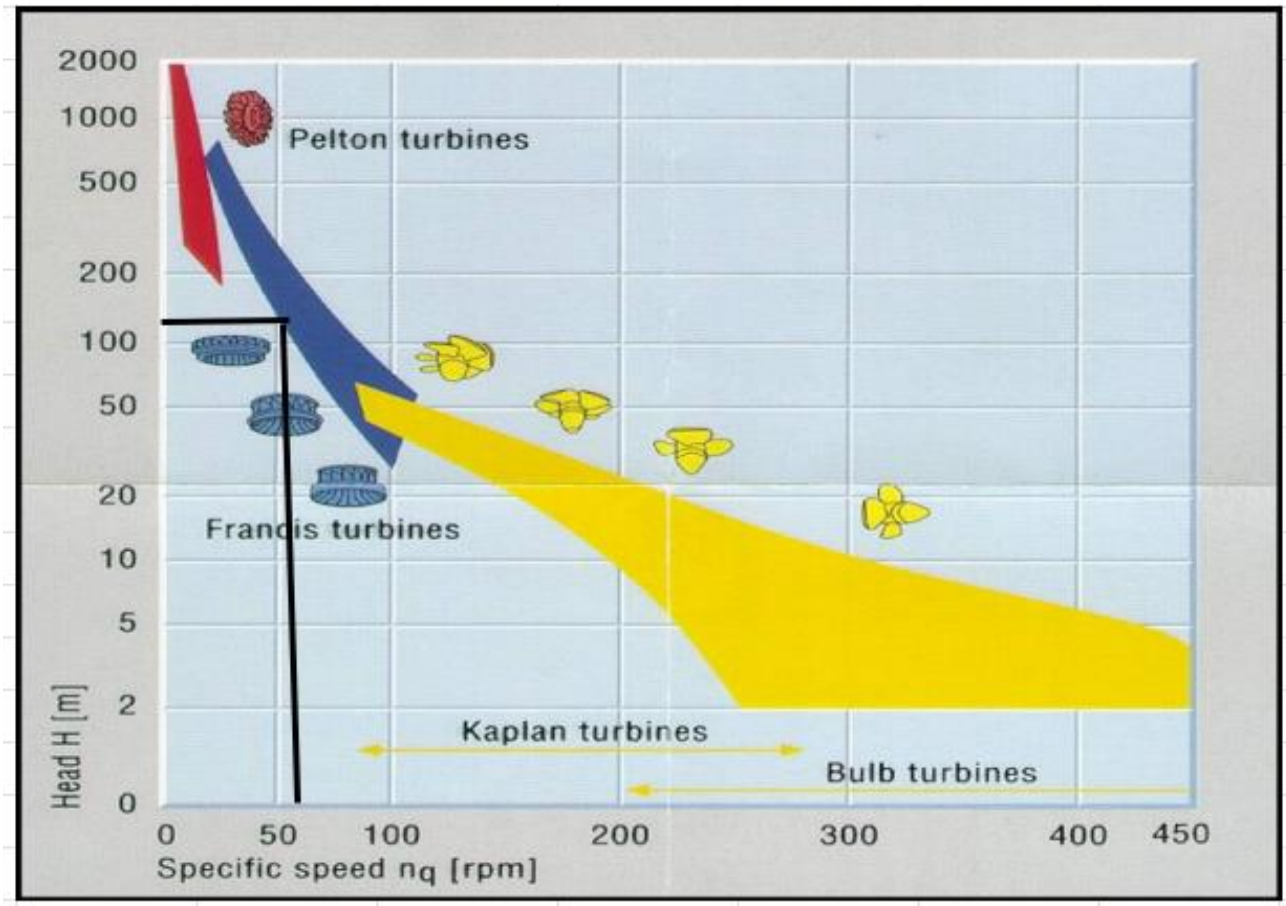
SELECTION OF TURBINE

According to Head & Discharge				
	Value	Unit	Remarks	Reference
Gross Head (H_g)	124.46	[m]		Fundamentals of Hydropower Engineering
Net Head (H)	120.14	[m]		
Discharge (Q)	48.83	[m^3/s]		
Choice of turbine based on Head vs Discharge Graph	Francis			



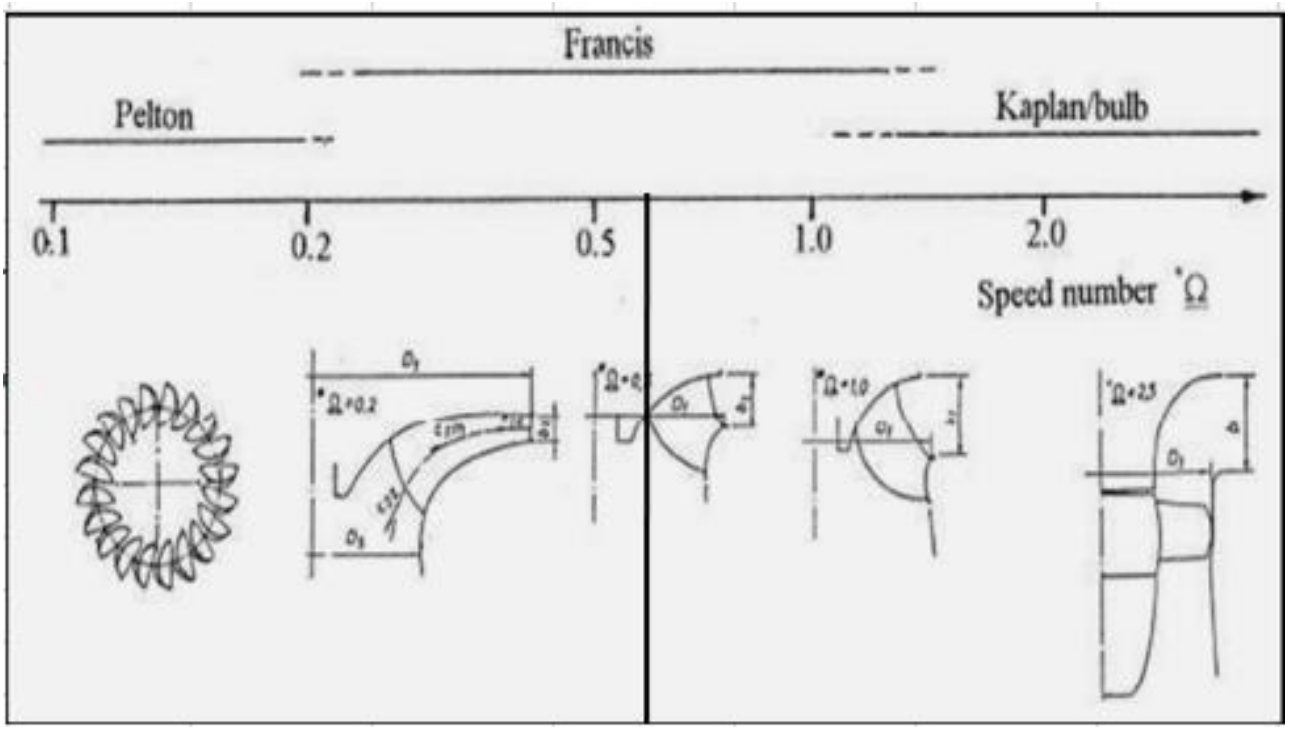
According to Head & Specific Speed				
	Value	Unit	Remarks	Reference
Overall Efficiency	0.86		Assumption	Powerhouse Design Guidelines, DOED
No of Units (n)	3.00			
Discharge per unit (q)	16.28		Q/n	
Power generated by each unit(P)	16.42	[MW]		
Frequency (f)	50.00	[Hz]		
No of poles (p)	6.00		Assumption	
Speed in RPM (N)	500.00	[RPM]		

Specific Speed (Ns)	55.59	[RPM]		$(N * \sqrt{q})/H^{0.75}$
Choice of turbine based on Head vs Specific Speed Graph	Francis			



According to Speed Number				Reference
ω	Value	Unit	Remarks	Powerhouse Design Guidelines, DOED
	52.360		$\omega = 2\pi N/60$	
$\bar{\omega}$.	1.078		$\bar{\omega} = \frac{\omega}{\sqrt{2gh}}$	
$\bar{Q}$	0.335		$\bar{Q} = \frac{Q}{\sqrt{2gh}}$	
Speed Number Ω	0.624		$\Omega = \bar{\omega}.\sqrt{\bar{Q}}$	
Choice of turbine based on Speed number	Francis			

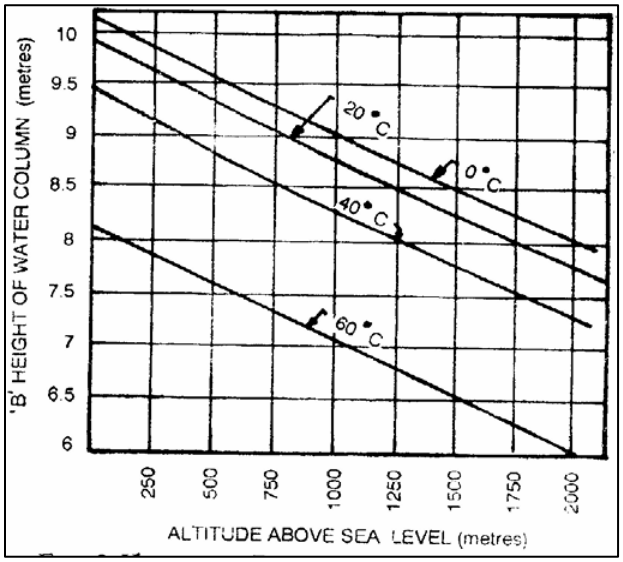
Turbine Selected				**Francis**	

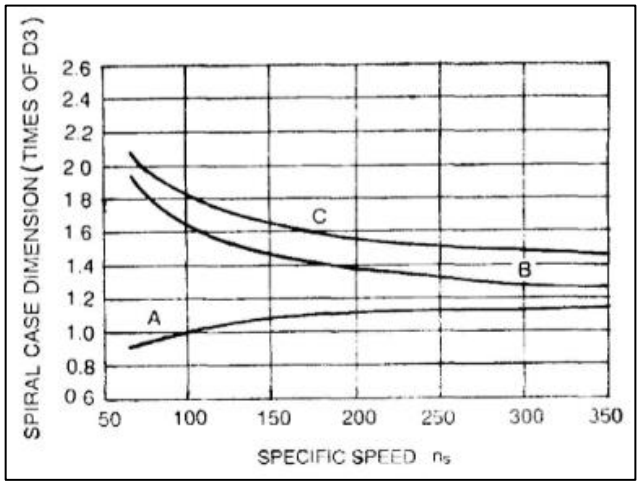


DIMENSIONING OF TURBINE					
SN	**Description**	**Symbols**	**Value**	**Unit**	**Remarks**
1	**PROVIDED**				
	a) Design discharge	Q_{design}	48.83	m^3/s	
	b) Net Head	H_n	120.35	m	
	c) Power P= η γ Q H	P	49579.29	KW	
2	**SELECTION OF TURBINE DEPENDING UPON HEAD**				
	Selected turbine	Francis Turbine			
	Number of units	N	3	no.s	
	Turbine output	P	16526.43	KW	
3	**ASSUMPTIONS**				
	Frequency	f	50	Hz	
	Number of pair of poles	p	6	no.s	
	Rated speed	n	500	rpm	

	Height of Barometric water column	H_b	9.4	m	
	Peripheral velocity coefficient for Francis Turbine	K_u	0.65		IS 12800 (Part 1) : 1993 Figure-6
	Efficiency of machine	η	0.9		
	Thomas coefficient	σ	0.1		
CALCULATION					
SYNCRONOUS SPEED					
A	Specific Speed	n_s	187.91	rpm	IS 12800 (Part 1) : 1993 Figure 1
	Rated speed $p=\frac{60*f}{n}$	n	500	rpm	IS 12800 (Part 1) : 1993 clause 4.2.2.3
B	**TURBINE SETTING**				
	Suction head $H_s \leq H_b - \sigma H - H_v$				
	$H_s \leq$	-2.07			
With the further margin of 0.5 meter, the centre of line of distributor should be set =2.07 + 0.5 = 2.75 meter below minimum tailrace level.					
				2.57	
C	**SIZE OF RUNNER**				
	Discharge diameter		1.21	m	
	$D_3 = \frac{60*\sqrt{2gH}*Ku}{\pi*n}$				
D	**RUNNER DIAMETER**				
	Coefficient of velocity	Φ	0.80		IS 12800
	Wheel Velocity $u = \emptyset\sqrt{2gH}$	u	38.87	m/s	
	Runner diameter $D = \frac{60u}{\pi N_s}$	D	3.95		
E	**DIMENSIONS OF SPIRAL CASE**				
	The main dimensions of spiral casing can be determined in accordance to figure 6-22 to 6-26 and 6-27 IS 12800 (Part 1) : 1993				
	A	1.15	1.39	m	
	B	1.4	1.69	m	
	C	1.58	1.91	m	
	D	1.78	2.15	m	
	E	1.3	1.57	m	
	F	1.69	2.04	m	
	G	1.4	1.69	m	
	H	1.2	1.45	m	
	I	0.23	0.28	m	
	M	0.6	0.72	m	

	L	0.98	1.18	m	





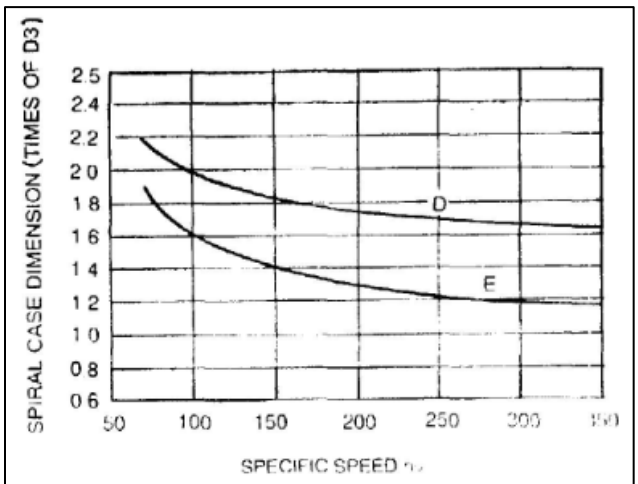
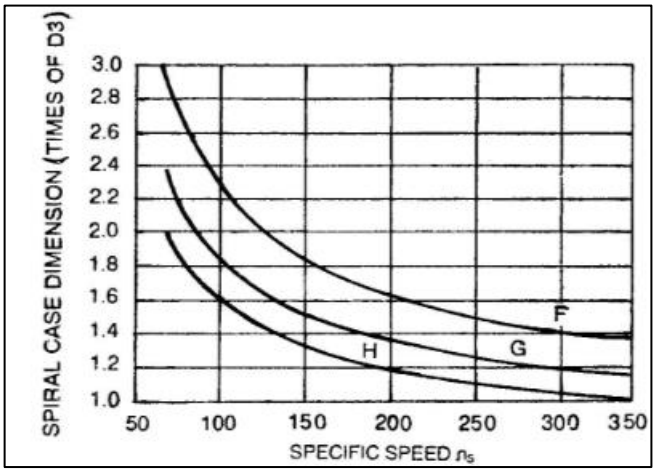
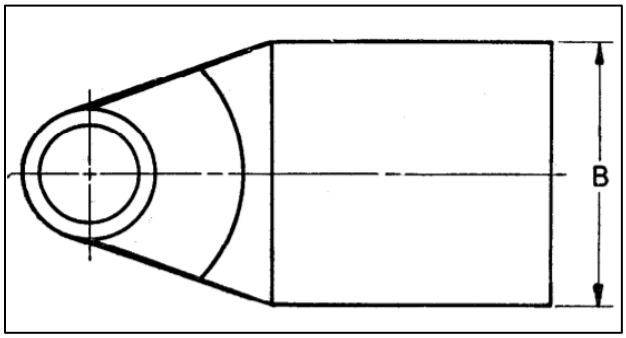


FIG. 9 SPIRAL CASING DIMENSIONS WITH RESPECT TO RUNNER DIAMETER D_3 OR D_R AND SPECIFIC SPEED n_s





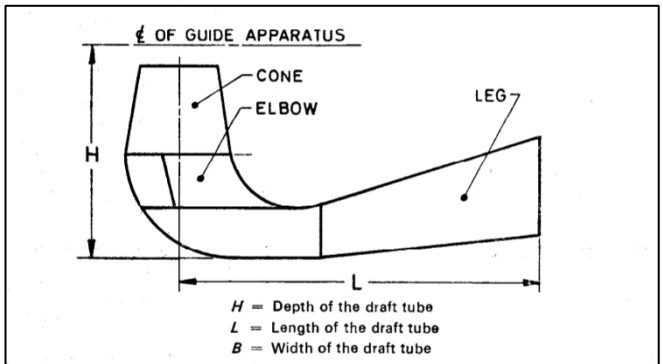
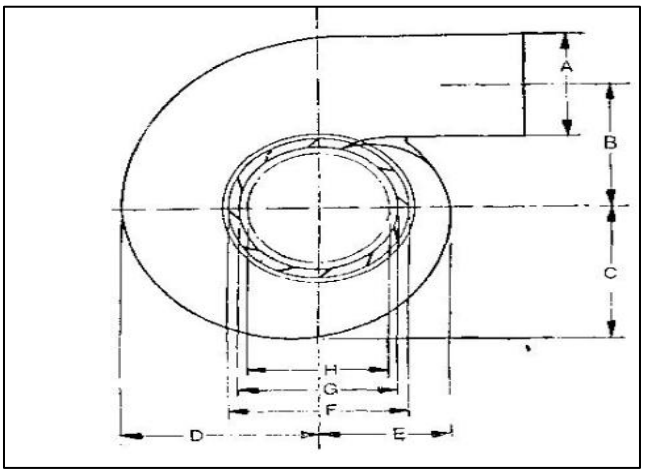


FIG. 1 DRAFT TUBE DESIGN TYPE 1 (FOR HEADS UP TO 200-250 m)

F	SIZE OF DRAFT-TUBE				
	Clear width of the draft-tube at exit end	B	2.80	**3.38**	B= 2.6 D3 to 3.3 D3
	Depth of draft tube	H	2.90	**3.50**	H= 2.5 D3 to 3.0 D3
	Length of draft-tube	L	4.50	**5.43**	L = 4 D3 to 5 D3
	Height of draft-tube at exit end	h	1.00	**1.21**	h = 0.94 D3 to 1.32 D3
	Power of single unit	P	16526.43	KW	
	Discharge in cumecs Q= P / (η γ H)	Q	15.55	m^3/s	
	Area at exit end of draft-tube	A	4.08	m^2	
	velocity at exit end of draft-tube	V_e	3.82	m/s	
	Minimum submergence at outlet end of draft-tube $V_e^2/2g$		0.74	m	IS 5496: 1969
	Provide submergance as it should be greater than 0.3 meters		0.30	m	IS 5496: 1969
	Slope along L		1 in 10		1 vertical to 10 horizontals
	Height of opening above bottom of draft tube		0.54	m	
	Top of exit of draft tube above bottom of draft tube		1.75	m	
	Top of exit of draft tube below tail water level		4.32	m	



GENERATOR PARAMETERS				
Rated kVA of generator	W	18362.70	KVA	
Maximum peripheral velocity	V_r	92.00	m/s	IS 12800 (Part 1) : 1993 fig 15
Air Gap Diameter $D_g = \frac{60}{\pi} * \frac{Vr}{n}$	D_g	3.51	m	
Outer Core Diameter $D_o = D_g\,(1+\frac{\pi}{2p})$	D_o	4.43	m	
Stator frame diameter $D_f = D_o + 1.2$ meters	D_f	5.63	m	
Inner diameter of generator barrel $D_b = D_f + 2.8$ meters	D_b	8.43	m	IS 12800 (Part 1) : 1993 fig 16
Output Coefficient	K_o	5.90		
Core Length of Stator $L_c = \frac{W}{K_o\,Dg^2\,n}$	L_c	0.50	m	
Length of Stator Frame $L_f = L_c + 1.5$ meters	L_f	2.00	m	
Weight of generator per m of Lc		85.00	tonnes	IS 12800 (Part 1) : 1993 Fig 18
Total weight		42.84	tonnes	IS 12800 (Part 1) : 1993 fig 19a
Weight of runner of francis turbine		30.00	tonnes	
Number of Arms of Brackets		4.00		Generally 4 to 8
K	K	0.65		0.65 for < 50 tonnes per arm of bracket Page 9
Axial hydraulic thrust cofficient	k	0.18		

inner diameter of runner	D 1	0.90	m	from figure 7
Height of load bearing bracket $h_j = K * \sqrt{D_f}$	h_j	1.54		For suspended type construction
Axial hydraulic thrust		17.55	tonnes	
total weight		90.39	tonnes	

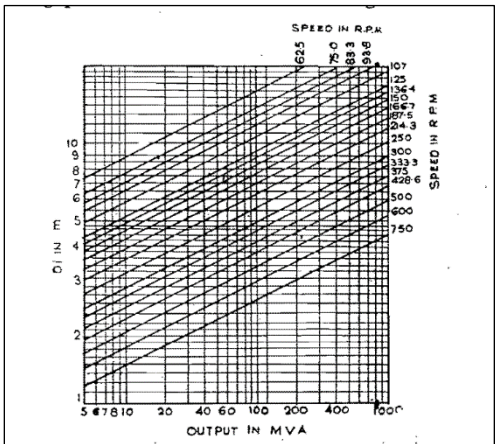
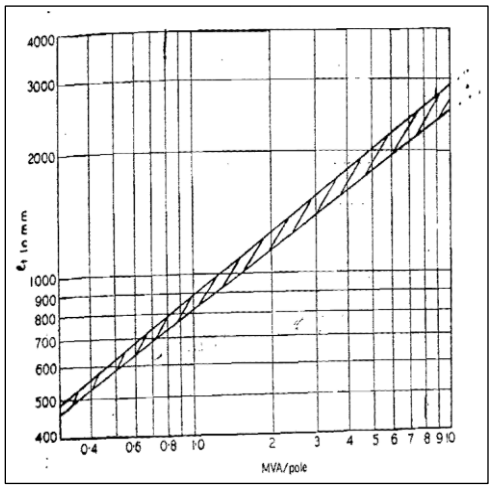


Fig. 6.5 Output V_s speed and D_1'



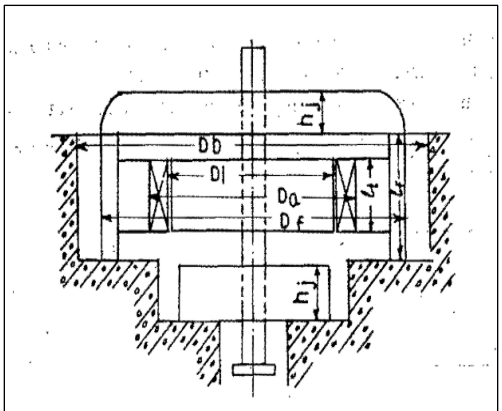


Fig. 6.8 Suspended type construction

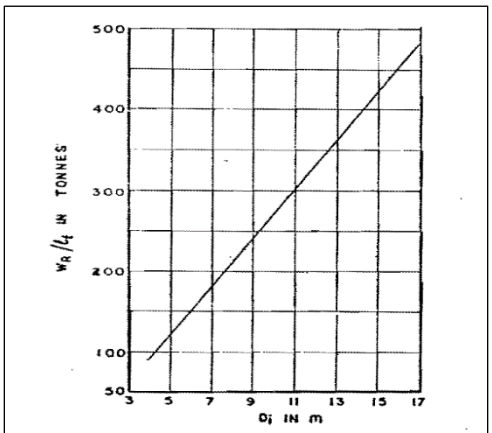


Fig. 6.9 Generator rotor weight

H	DIMENSION OF POWERHOUSE				
	Width of a unit		8.43	m	
	concrete thickness		1.64	m	
	Clearance on either side		1.50	m	

	Space required for a unit		14.71	m	
	Length of erection/service bay	L_e	14.71	m	1 to 1.5 times the unit bay size
	Space required for the E.O.T crane		3.90	m	3 to 5 meters
	Overall length of Powerhouse	**L**	**62.76**	**m**	
	Clearance width		1.50	m	
	Gallery for draft tube		1.50	m	
	Clearance for pressure relief valve		2.00	m	
	Staircase		4.50	m	
	Inlet valve clearance		2.00	m	
	Width of a unit		8.43	m	
	Partition walls		0.84		0.42 m each
	width of control bay		6.00		
	height of control bay		4.00		
	Overall width of Powerhouse	**B**	**26.77**	**m**	
	Height from center line of spiral casing upto top of generator	H_4	9.05	m	
	Height from bottom of draft tube chamber		3.50	m	
	Height of generator room		12.00	m	
	Clearance for E.O.T crane hook level		3.00	m	
	Roof clearance		4.00	m	
	Overall height of Powerhouse	**H**	**28.55**	**m**	

Preliminary Design of Beam (Machine & Erection Bay)			
Beam Along X-axis			
Particulars	Value	Unit	Reference
Longest Span of Beam, L	6.19	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25.00	[Mpa]	
Yield Stress,fy	500.00	[Mpa]	
$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290.00		Assume Area of steel provided is same as that of required
Minimum requirement of 2% steel for tension requirement, Pst			
Modification Factor, α	0.70		Clause 23.2.1c,fig no (4) IS 456:2000

Effective Depth of Beam, Deff =(L/26)×α	340.05	[mm]	
Adopting Effective depth of beam	350.00	[mm]	
Effective Cover	40.00	[mm]	
Overall Depth of beam, D	390.00	[mm]	
$Width\ of\ the\ beam = \frac{1}{2} \times D\ to \frac{2}{3} \times D$	260.13	[mm]	
Adopted Depth of Beam	420.00	[mm]	
Adopted Width of Beam	280.00	[mm]	

Preliminary Design of Beam (Machine & Erection Bay)			
Beam Along Y-axis			
Particulars	Value	Unit	Reference
Longest Span of Beam, L	6.64	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25.00	[Mpa]	
Yield Stress,fy	500.00	[Mpa]	
$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290.00		Assume Area of steel provided is same as that of required
Minimum requirement of 2% steel for tension requirement, Pst			
Modification Factor, α	0.70		Clause 23.2.1c,fig no (4) IS 456:2000
Effective Depth of Beam, Deff =(L/26)×α	364.84	[mm]	
Adopting Effective depth of beam	370.00	[mm]	
Effective Cover	40.00	[mm]	
Overall Depth of beam, D	410.00	[mm]	
$Width\ of\ the\ beam = \frac{1}{2} \times D\ to \frac{2}{3} \times D$	273.47	[mm]	
Adopted Depth of Beam	420.00	[mm]	
Adopted Width of Beam	280.00	[mm]	

Preliminary Design of Beam (Control room, Office room, Battery Room)			
Beam Along X-axis			
Particulars	Value	Unit	Reference
Longest Span of Beam, L	6.19	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25.00	[Mpa]	
Yield Stress,fy	500.00	[Mpa]	
$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290.00		Assume Area of steel provided is same as that of required
Minimum requirement of 2% steel for tension requirement, Pst			
Modification Factor, α	0.70		Clause 23.2.1c,fig no (4) IS 456:2000
Effective Depth of Beam, Deff =(L/26)×α	340.05	[mm]	
Adopting Effective depth of beam	350.00	[mm]	
Effective Cover	40.00	[mm]	
Overall Depth of beam, D	390.00	[mm]	
$Width\ of\ the\ beam = \frac{1}{2} \times D\ to \frac{2}{3} \times D$	260.13	[mm]	
Adopted Depth of Beam	420.00	[mm]	
Adopted Width of Beam	280.00	[mm]	

Preliminary Design of Generator Floor Slab			
Particulars	Value	Unit	Reference
Size of Slab	6.19× 6.64	m2	
Span of Slab, L	6.186	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25	[Mpa]	
Yield Stress,fy	500	[Mpa]	

$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290		Assume Area of steel provided is same as that of required
Minimum requirement of 0.3% steel for tension requirement, Pst			
Modification Factor, α	1.3		Clause 23.2.1c,fig no (4) IS 456:2000
Effective Depth of Slab, Deff =(L/26)×α	183.02	[mm]	
Adopting Effective depth of slab	200.00	[mm]	
Effective Cover	30.00	[mm]	
Overall Depth of Slab, D	230.00	[mm]	
Check:			
Self Weight	5.75	[kN/m2]	
Imposed Load	9.00	[kN/m2]	
Floor Finish	1.10	[kN/m2]	
Total Load	15.85	[kN/m2]	
Factored Load, Wu	23.78	[kN/m2]	
Factored Bending Moment, Mu	113.72		
Effective Depth, d	181.56		
Effective Cover	30.00		
Overall Depth, D	211.56		
Adopted Depth of Slab	250.00	[mm]	

Preliminary Design of Control Room Roof Slab			
Particulars	Value	Unit	Reference
Size of Slab	6.19×5.7	m2	
Span of Slab, L	5.70	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25.00	[Mpa]	
Yield Stress,fy	500.00	[Mpa]	

$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290.00		Assume Area of steel provided is same as that of required
Minimum requirement of 0.3% steel for tension requirement, Pst			
Modification Factor, α	1.30		Clause 23.2.1c,fig no (4) IS 456:2000
Effective Depth of Slab, Deff =(L/26)×α	168.64	[mm]	
Adopting Effective depth of slab	180.00	[mm]	
Effective Cover	30.00	[mm]	
Overall Depth of Slab, D	210.00	[mm]	
Check:			
Self Weight	5.25	[kN/m2]	
Imposed Load	5.00	[kN/m2]	
Floor Finish	1.10	[kN/m2]	
Total Load	11.35	[kN/m2]	
Factored Load, Wu	17.03	[kN/m2]	
Factored Bending Moment, Mu	69.14		
Effective Depth, d	141.57		
Effective Cover	30.00		
Overall Depth, D	171.57		
Adopted Depth of Slab	210.00	[mm]	

Preliminary Design of Powerhouse Bottom Floor Slab			
Particulars	Value	Unit	Reference
Size of Slab	6.19×6.64	m2	
Span of Slab, L	6.19	[m]	
L/Deff =26 *Modification factor			
For Modification Factor,			
Compressive Strength, fck	25.00	[Mpa]	
Yield Stress,fy	500.00	[Mpa]	
$f_s = 0.58 \times f_y \times \frac{Area\ of\ steel\ requied}{Area\ of\ steel\ provided}$	290.00		Assume Area of steel provided is same as that of required

Minimum requirement of 0.3% steel for tension requirement, Pst			
Modification Factor, α	1.30		Clause 23.2.1c,fig no (4) IS 456:2000
Effective Depth of Slab, Deff =(L/26)×α	183.14	[mm]	
Adopting Effective depth of slab	200.00	[mm]	
Effective Cover	30.00	[mm]	
Overall Depth of Slab, D	250.00	[mm]	
Check:			
Self Weight	6.25	[kN/m2]	
Imposed Load	18.00	[kN/m2]	
Floor Finish	1.10	[kN/m2]	
Total Load	25.35	[kN/m2]	
Factored Load, Wu	38.03	[kN/m2]	
Factored Bending Moment, Mu	182.12		
Effective Depth, d	229.76		
Effective Cover	30.00		
Overall Depth, D	259.76		
Adopted Depth of Slab	260.00	[mm]	

Preliminary Design of Machine Hall Column			
Particulars	Value	Unit	Remarks/ Reference
Wt. from crane	500.00	[kN]	Powerhouse Design Guideline
Load from gantry	5.00	[kN]	
Total Load on rail runway	3000.00	[kN]	
Load from gantry on each column	15.00	[kN]	
Truss Load	100.00	[kN]	
Load from beam on column		[kN]	IS 4247:1997 (Part I)
Self Wt of beam (B×D×Unit wt of concrete)	2.80	[kN/m]	
Weight of beam on column	9.30	[kN]	
Load Transferred to Column	3632.10	[kN]	Adding 20% for earthquake and FOS 3
Factored Load, Pu	13075.55	[kN]	
Assuming 3% Steel			Cl. No. 39.3, IS 456:2000
Gross Area, Ag (Pu=0.4×fck×(Ag-ASt)+0.67×fy×Ast)	662052.94	[mm2]	
Dims. Of Column	813.67	[mm]	

Adopted Size of Column	850×850	[mm2]	
Unsupported Length of Column, L	4.77	[m]	
Effective Length of Column, Le	3.10	[m]	0.65L
Dmin	850.00	[mm]	
Check for Short Column			
Ratio (Le/D)	3.65		<12 (Short Column)

Preliminary Design of Control Room Column			
Particulars	Value	Unit	Remarks/ Reference
Load from beam on column			IS 4247:1997 (Part I)
Self Wt of beam (B×D×unit wt of concrete)	2.80	[kN/m]	
Weight of beam on column	7.98	[kN]	
Load from slab on column			
Self Wt of slab (B×D×unit wt of concrete)	5.25	[kN/m]	
Weight of slab on column	15.75	[kN]	
Load Transferred to Column	31.78	[kN]	Adding 20% for earthquake and FOS 3
Factored Load, Pu	114.41	[kN]	
Assuming 3% Steel			Cl. No. 39.3, IS 456:2000
Gross Area, Ag (Pu=0.4×fck×(Ag-ASt)+0.67×fy×Ast)	5792.81	[mm2]	
Dims. Of Column	76.11	[mm]	
Adopted Size of Column	300×300	[mm2]	

Design Loads in Roof Truss			
Particulars	Value	Remarks	Reference
Total Length of building	63.56	[m]	
Total Width of building (w/o control bay)	21.43	[m]	
Height of building (Superstructure)	16.00	[m]	
		[m]	
Configuration of Truss		[m]	Sec 14.24, Fundamentals of Structural Design (ML Gambhir)
Span of Truss	21.43	[m]	
Spacing of Truss	4.29	Span/5 [m]	

Inclination of roof (α)	30.00		
Pitch of roof	0.29	$(tan\alpha)/2$	
Length of Rafter (L_r)	12.37	$\frac{Span}{2} \times sec\alpha$ [m]	
Length of Panels	6.19	$L_r/2$ [m]	
Length of Struts, U_1L_1	3.57	$5.5sin\alpha$ [m]	
Length of Tie, L_oL_1	7.14		
Length of Main Sling, L_1U_2	7.14		
Loading on the Roof			
Weight of CGI Sheets	0.13	[kN/m^2]	Table 14.1, Fundamentals of Structural Design (ML Gambhir)
Weight of bracings	0.02	[kN/m^2]	
Weight of purlins	0.12	[kN/m^2]	
Weight of truss	0.12	[kN/m^2]	
Total Dead Load	**0.38**	[kN/m^2]	Sec 14.25, Fundamentals of Structural Design (ML Gambhir)
Concentrated load at intermediate nodes	**8.76**	[kN]	
Concentrated load at support node	**2.17**	[kN]	
Live Load	**0.35**	0.75-0.02(α-10) [kN/m^2]	
Concentrated load at intermediate nodes	**8.04**	[kN]	
Concentrated load at support node	**2.00**	[kN]	
Basic Wind Speed (V_b)	47.00	[m/s]	NBC 104-1994
Risk Coefficient (K_1)	1.00	For Design Life 50yrs	Table 1, IS:875 (Part 3)-1987
Factor (K_2)	0.88	Class C, Category 3	Table 2, IS:875 (Part 3)-1987
Topography Factor (K_3)	1.00	Slope less than 3°	Sec. 5.3.3.1, IS:875 (Part 3)-1987
Design Wind Speed (V_z)	41.36	$K_1K_2K_3V_b$ [m/s]	Sec. 5.3, IS:875 (Part 3)-1987
Design Wind Pressure (p_z)	1.03	$0.6V_z^2$ [kN/m^2]	Sec. 5.4, IS:875 (Part 3)-1987
Height/Width Ratio (h/w)	0.75		

External Pressure Coefficient is given as:			Table 5, IS:875 (Part 3)-1987

Wind Angle	External Pressure Coefficient (C_{pe})	
	Windward (WW)	Leeward (LW)
0	-0.2	-0.5
90	-0.8	-0.8

Wind Angle	**External Pressure Coefficient (C_{pe})**		**Internal Pressure Coefficient (C_{pi})**	**C_{pe}-C_{pi}**		**Wind Load (F), kN**	
	Windward (WW)	**Leeward (LW)**		**WW**	**LW**	**WW**	**LW**
0	-0.20	-0.50	0.20	-0.40	-0.70	-10.89	-19.05
	-0.20	-0.50	-0.20	0.00	-0.30	0.00	-8.16
90	-0.80	-0.80	0.20	-1.00	-1.00	-27.21	-27.21
	-0.80	-0.80	-0.20	-0.60	-0.60	-16.33	-16.33

Internal Pressure Coefficient (C_{pi})	-0.20		Sec. 6.2.3, IS:875 (Part 3)-1987
Internal Pressure Coefficient (C_{pi})	0.20		
Concentrated Wind Load on intermediate node (W_w)	**-27.21**	[kN]	
Concentrated Wind Load on support node (W_w)	**-15.64**	[kN]	

Analysis of Truss			
Particulars	**Value**	**Remarks**	**Reference**
Dead Loads:			
Reactions, R_{Lo}	15.31	[kN]	Methods of Joints
Joint Lo:			
F_{LoU1}	-26.27	[kN]	
F_{LoL1}	22.75	[kN]	
Joint U1:			
F_{U1L1}	-7.59	[kN]	
F_{U1U2}	-21.89	[kN]	
Joint L1:			
F_{L1U2}	7.59	[kN]	
F_{L1L2}	15.17	[kN]	
Wind Loads:			

Resultants force, $W_{w,R=W_{w,L}}$	56.46	[kN]	
Vertical Component, V_w	48.90	[kN]	
Horizontal Components, H_w	28.23	[kN]	
Joint Lo:			
F_{LoU1}	70.70	[kN]	
F_{LoL1}	-53.41	[kN]	
Joint U1:			
F_{U1L1}	27.21	[kN]	
F_{U1U2}	70.70	[kN]	
Joint L1:			
F_{L1U2}	-27.21	[kN]	
F_{L1L2}	-26.20	[kN]	

Design of Truss members			
Particulars	**Value**	**Remarks**	**Reference**
Design of Rafter			
Grade of Tube	Y_{st} 250		
f_y	250.00	[N/mm$^{2]}$	
f_u	330.00	[N/mm$^{2]}$	
Design Compressive Force, P_u	75.57	[kN]	
Design Tensile Force, T_u	73.22	[kN]	
Trial Design Compressive Stress	80.00	[N/mm$^{2]}$	
Trial Section Area, A	944.59	[mm^2]	
Nominal Bore Medium tube	80.00	[mm]	Table 1, IS 1161 (1998)
External Diameter	**88.90**	[mm]	
Thickness	**4.00**	[mm]	
Area Taken, A_e	1070.00	[mm^2]	
Radius of gyration, r	30.00	[mm]	
Effective Length of Rafter Panel, KL	4330.42	[mm]	
Slenderness ratio, λ	144.35		
Design Compressive Stress, $f_{d,c}$	73.63	[N/mm$^{2]}$	Table 9 a), IS 800:2007
Design Compressive Strength, P_d	78.78	Greater than P_u, (OK) [kN]	
Check for design tensile strength			
Design Strength due to yielding of gross section, T_{dg}	243.18	[kN]	
Design Strength due to rupture of net section, T_{dn}	225.98	[kN]	

Design Tensile Strength of member, T_d	225.98	Greater than T_u, (OK) [kN]	

Design of Main Tie
Member size will be same as that of Rafter since the rafter members are able to withstand compressive load of 45.99 kN and tensile load of 65.44 kN

Design of Main Slings			
Particulars	**Value**	**Remarks**	**Reference**
Grade of Tube	Yst 250		
f_y	250.00	[N/mm$^{2]}$	
f_u	330.00	[N/mm$^{2]}$	
Design Compressive Force, P_u	29.44	[kN]	
Design Tensile Force, T_u	21.82	[kN]	
Trial Design Compressive Stress	35.00	[N/mm$^{2]}$	
Trial Section Area, A	841.25	[mm^2]	
Nominal Bore Light tube	80.00	[mm]	Table 1, IS 1161 (1998)
External Diameter	**88.90**	[mm]	
Thickness	**3.20**	[mm]	
Area Taken, A_e	861.00	[mm^2]	
Radius of gyration, r	30.30	[mm]	
Effective Length of Rafter Panel, KL	5000.33	[mm]	
Slenderness ratio, λ	165.03		
Design Compressive Stress, $f_{d,c}$	58.18	[N/mm$^{2]}$	Table 9 a), IS 800:2007
Design Compressive Strength, P_d	50.09	Greater than P_u, (OK) [kN]	
Check for design tensile strength			
Design Strength due to yielding of gross section, T_{dg}	195.68	[kN]	
Design Strength due to rupture of net section, T_{dn}	181.84	[kN]	
Design Tensile Strength of member, T_d	181.84	Greater than T_u, (OK) [kN]	

Design of Struts

Member size will be same as that of Slings since the slings members are able to withstand compressive load of 21.82 kN and tensile load of 29.44kN

Dimensioning of Purlin			
Grade of Steel Tube	Yst 250		
Purlin Length, L	4286.00	[mm]	
Diameter of Purlin, D	61.23	L/70, [mm]	Sec 6.5.4.1, IS 806 (1968)

Adopt 65mm diameter purlin of grade Y_{st} 25

Design of Crane Beam:

DESIGN OF CRANE BEAM

Particulars	**Value**	**Unit/Remarks**	**References**
Total No. of Wheels	4.00		Pg. 269, Powerhouse Guidelines, DOED
Wt. of Crane Bridge Girder	250.00	[kN]	
Hoist Capacity	903.90	Wt. of Generator [kN]	
Wt. of Trolley	50.00	[kN]	
Min Distance of hoisted load from wheel	1.20	[m]	
Case I: When crane is in rest and near to one of the supports			
Ra	171.99	[kN]	
Rb	128.00	[kN]	
Maximum load per wheel	86.00	[kN]	
Minimum load per wheel	64.00	[kN]	
Case II: When crane is carrying maximum load and near to one of the supports			
Ra	1012.12	[kN]	
Rb	181.77	[kN]	
Maximum load per wheel	506.06	[kN]	
Maximum impact load per wheel	126.52	(25% of Max. Load per wheel) [kN]	
Lateral Surge per wheel	95.39	10% of (Trolley+Hoisting Load) [kN]	
Tractive Force (along the crane)	25.30	5% of (Max Load per wheel) [kN]	
Max Vertical Load on wheel with max carrying load and impact load	632.58	[kN]	

Max Vertical Load	727.97	[kN]	
Clear Span, L	6.19	[m]	
Bending Moment, M	1126.53	[kNm]	
Factored Bending Moment, Mu	1689.79	[kNm]	
Width of Crane Beam, b	600.00	Assumption based on column size [mm]	
Effective Depth,d	920.33	Mu=0.133fckbd2 [mm]	
Effective Cover	50.00	[mm]	
Overall Depth of Crane Beam	970.33	[mm]	
Adopted Depth of Crane Beam, D	1000.00	[mm]	

DESIGN OF CORBEL			
Particulars	**Value**	**Unit/Remarks**	**References**
			Pg. 281, Powerhouse Design Guidelines-2018, DOED
Unit Wt. of RCC Concrete	25.00	[kN/m3]	
Unit Wt. of Brick Masonry	19.50	[kN/m3]	
Unit Wt. of Crane Rail	0.65	[kN/m]	
Grade of Steel Bar, fy	500.00	[N/mm2]	
Grade of Concrete, fck	35.00	[N/mm2]	
Max. C/C Span of Column	6.19	[m]	
Width of Crane Beam, B	0.60	[m]	
Depth of Crane Beam, D	1.00	[m]	
Span of EOT Crane	19.95	[m]	
Wheel Distance of Crane	4.00	[m]	
Total Load per wheel including impact	632.58	[kN]	
Beam Weight transferred to corbel	65.00	70% of beam wt. is considered [kN]	
Rail Weight	4.02	[kN]	
Total Load due to Crane and Rail	636.60	[kN]	
Total Vertical Load on Corbel	701.59	[kN]	
FOS for Crane & Rail	1.05		
FOS for RCC Beam	1.50		

Factored Vertical Load due to EOT Crane & Rail	668.43	[kN]	
Factored Vertical Load of RCC Beam	97.49	[kN]	
Total Factored Vertical Load, Pu	765.92	[kN]	
Check for Bearing Stress			
Bearing Strength of concrete	28.00	0.8*fck [N/mm2]	Pg. 414. Reinforced Concrete Design, AK Jain
Bearing area required	27354.32	[mm2]	
Length of Base Plate	550.00	[mm]	
Width of Base Plate	49.74	[mm]	
Adopted Length of Plate	550.00	[mm]	
Adopted Width of Plate	100.00	[mm]	
Depth of Corbel at support			
Width of Corbel, b	720.00	Width of Crane Beam+120 [mm]	Pg. 282, Powerhouse Design Guidelines-2018, DOED
Max Shear Stress of M25 Concrete	3.10	[N/mm2]	
Design Shear Strength of Concrete	2.50	80% of Max Shear stress [N/mm2]	
Calculated Depth of Corbel, d	425.51	[mm]	
Effective Cover, d'	50.00	[mm]	
Overall Depth, D	475.51	[mm]	
Adopted Overall Depth, D	600.00	[mm]	
Adopted Effective Depth, d	550.00	[mm]	
Dist. of load from face of corbel, a	40.00	[mm]	
Span Depth Ratio (a/d)	0.07	a/d< 0.6 , OK [mm]	
Depth of Corbel at the face	360.00	0.6 of total depth of corbel [mm]	
Adopted Depth of corbel at face	400.00	[mm]	
Vertical Depth of Inclined Face	200.00	[mm]	
Calculation of Lever Arm			

α

α	0.09		Powerhouse Design Guidelines-2018, DOED
β=a/d	0.07		
$\frac{z}{d}=\frac{1}{2}(\frac{\beta}{\alpha+\beta})\pm\sqrt{\frac{1}{4}*\frac{\beta^2}{(\alpha+\beta)^2}-\frac{\alpha*\beta^2}{\alpha+\beta}}$	0.44		
$\frac{z}{d}=\frac{1}{2}(\frac{\beta}{\alpha+\beta})\pm\sqrt{\frac{1}{4}*\frac{\beta^2}{(\alpha+\beta)^2}-\frac{\alpha*\beta^2}{\alpha+\beta}}$	0.01		
z	242.22	[mm]	
Depth of neutral axis, xm	363.18	[mm]	
xm/d	0.66	>0.46 so compression bar is required	
Calculation of area of Tension Steel			
Ft	126.48	must be >0.5 Pu [kN]	
0.5Pu	382.96	[kN]	
Let Horizontal resistance force, Ft	510.00	[kN]	
Max Strain in tension steel, εs	0.0018		
Strain in reinforcement at yield point	0.0021		
Stress in Tension Reinforcement	370.65	[N/mm2]	
Required area of tension bars	1375.96	[mm2]	
Calculation for Tension Reinforcement			
Diameter of main bars, Φ	25.00	[mm]	
No. of bars, n	5.00		
Area of bars provided, At	2454.37	[mm2]	
Percentage Tension Steel, Pt	0.62	Within 0.4%-1.3%, OK	Cl. 7.7.2 SP 34,1987
Calculation of Shear Reinforcement			
Min Area of Shear Bars, Asv	1227.18	[mm2]	
Provide 12mm-4legged in 3 rows in 2/3d			
Dia. Of Shear Bar	12.00	[mm]	

Type of rebar	4.00	legged	
No. of rows in Upper 2/3 d	3.00		
Area of shear bars	1356.00	OK [mm2]	
Spacing of shear bars	145.00	[mm]	

Design of Tailrace:

SIZING AND SLOPE CALCULATION OF TAIL RACE DUCT				
S. N	**Description**	**Quantity**	**Units**	**Remarks**
A	**Normal Flow Condition (Without Consideration of Overloading)**			
i	**For Individual Ducts**			
1	**Provided**			
	Design Discharge (Q)	16.28	m^3/s	Q40/2
	Number of canal	3	no.s	
	Roughness coefficient (n)	0.013	`	
	Free board (FB)	1	m	
2	**Assumptions**			
	Canal Type	Rectangular		
	Permissible velocity v	1.5	m/s	(<2.7 m/s for concrete)
3	**Calculation**			
	Area of flow in single channel (A)	10.85	m2	For Normal Water Level
	For economical section, b=2y	where, b= width of the canal & y = water depth at the canal		
	A= b*y =2y^2			
	or, 2.23 = 2* y^2			
	or, y =	2.33		
	And, Height of water in canal	2.33	m	
	Width of canal	4.66	m	
	Hydraulic Radius	1.16	m	
	Now,			
	Velocity, v= 1/n * R^2/3 * S^1/2			
	or, S=	0.000310		
		3222	i.e. 1 in 3225	
	Depth of single canal , H	**3.33**	**m**	
	Breadth of single canal, B	**3.26**	**m**	
	Slope, S	**1 in 3225**		
	Check of Flow Type			
	Critical depth of flow	**1.36**		$y = \frac{\left(\frac{Q}{b}\right)^{2/3}}{g^{1/3}}$
	Froude Number	**0.41**		$Fr = \frac{V}{(gy)^{1/2}}$
	As Critical Depth of flow is less than the actual depth of flow, also Froude Number is less than 1 hence flow in the duct is Subcritical Flow.			
ii	**For Combined Duct**			

1	**Provided**			
	Design Discharge (Q)	48.83	m^3/s	
	Number of canal	2	no.s	
	Roughness coefficient (n)	0.013	`	
	Free board (FB)	1	m	
2	**Assumptions**			
	Canal Type	Rectangular		
	Permissible velocity v	1.5	m/s	(<2.7 m/s for concrete)
3	**Calculation**			
	Area of flow in single channel (A)	32.55	m2	For Normal Water Level
	And, Height of water in canal	2.33	m	
	Width of canal	9.78	m	
	hydraulic Radius	1.16	m	
	Now,			
	Velocity, v= 1/n * R^2/3 * S^1/2			
	or, S=	0.000310		
		3222	i.e. 1 in 3225	
	Depth of combined canal , H	**3.33**	**m**	
	Breadth of combined canal, B	**9.78**	**m**	
	Slope, S	**1 in 3225**		
	Check of Flow Type			
	Critical depth of flow	**1.36**		$y = \frac{\left(\frac{Q}{b}\right)^{2/3}}{g^{1/3}}$
	Froude Number	**0.41**		$Fr = \frac{V}{(gy)^{1/2}}$
	As Critical Depth of flow is less than the actual depth of flow, also Froude Number is less than 1 hence flow in the duct is Subcritical Flow.			
B	**Overloading Flow Condition**			
i	**For Individual Ducts**			
1	**Provided**			
	Overloading factor	1.1		(Discharge 10% higher than the normal condition)
	Design Discharge (Q)	17.90	m^3/s	
	Number of canal	3	no.s	
	Roughness coefficient (n)	0.013	`	
	Free board (FB)	1	m	
2	**Assumptions**			

	Canal Type	Rectangular		
	Permissible velocity v	1.5	m/s	(<2.7 m/s for concrete)
3	**Calculation**			
	Area of flow in single channel (A)	11.94	m2	For Normal Water Level
	For economical section, b=2y	where, b= width of the canal & y = water depth at the canal		
	A= b*y =2y^2			
	or, 2.453 = 2* y^2			
	or, y =	2.443		
	And, Height of water in canal	2.44	m	
	Width of canal	4.89	m	
	hydraulic Radius	1.22	m	
	Now,			
	Velocity, v= 1/n * R^2/3 * S^1/2			
	or, S=	0.00029		
		3433.86	i.e. 1 in 800	
	Depth of single canal , H	**3.44**	**m**	
	Internal Breadth of single canal, B	**4.89**	**m**	
	Slope, S	**1 in 800**		
	Outer Breadth of single canal, B	**6.09**		
	Check of Flow Type			
	Critical depth of flow	**1.11**		$y = \frac{\left(\frac{Q}{b}\right)^{2/3}}{g^{1/3}}$
	Froude Number	**0.45**		$Fr = \frac{V}{(gy)^{1/2}}$
	As Critical Depth of flow is less than the actual depth of flow, also Froude Number is less than 1 hence flow in the duct is Subcritical Flow.			
ii	**For Combined Duct**			
1	**Provided**			
	Overloading factor	1.10		(Discharge 10% higher than the normal condition)
	Design Discharge (Q)	53.71	m^3/s	
	Number of canal	3.00	no.s	
	Roughness coefficient (n)	0.01	`	
	Free board (FB)	1.00	m	
2	**Assumptions**			
	Canal Type	Rectangular		

	Permissible velocity v	1.5	m/s	(<2.7 m/s for concrete)
3	**Calculation**			
	Area of flow in single channel (A)	35.81	m2	For Normal Water Level
	And, Height of water in canal	2.44	m	
	Width of canal	14.66	m	
	hydraulic Radius	1.22	m	
	Now,			
	Velocity, v= 1/n * R^2/3 * S^1/2			
	or, S=	0.00		
		3433.86	i.e. 1 in 800	
	Depth of combined canal , H	**3.44**	**m**	
	Internal Breadth of combined canal, B	**14.66**	**m**	
	Slope, S	**1 in 800**		
	Outer breadth of combined canal	**15.86**		
	Check of Flow Type			
	Critical depth of flow	**1.11**		$y = \frac{\left(\frac{Q}{b}\right)^{2/3}}{g^{1/3}}$
	Froude Number	**0.45**		$Fr = \frac{V}{(gy)^{1/2}}$
	As Critical Depth of flow is less than the actual depth of flow, also Froude Number is less than 1 hence flow in the duct is Subcritical Flow.			

Structure Analysis from ETABS:

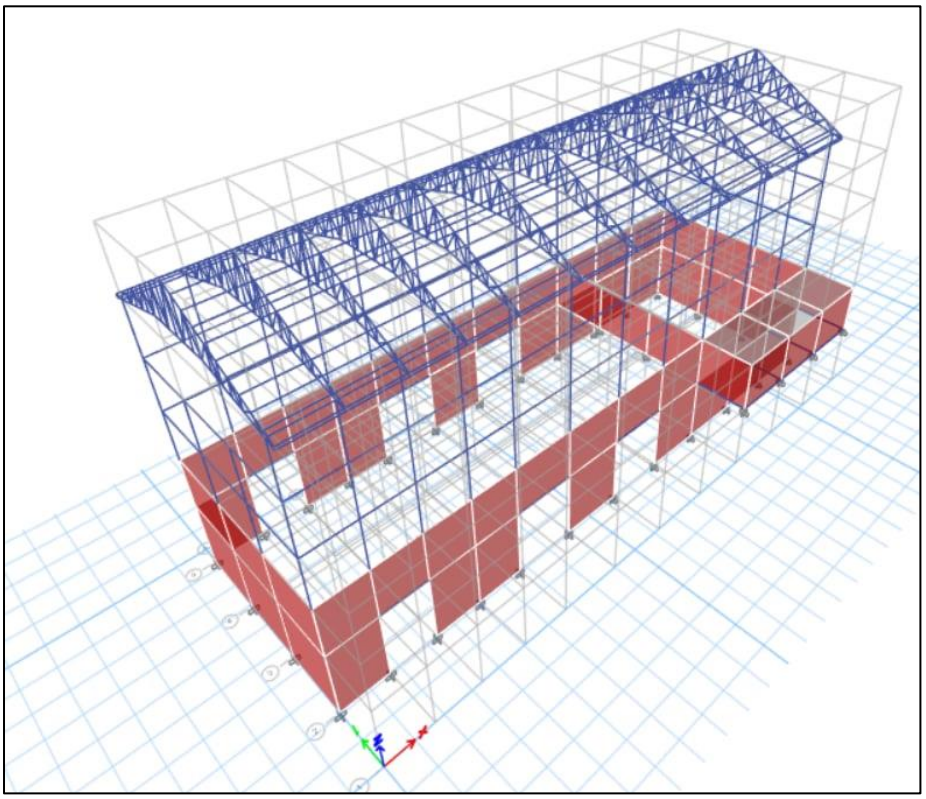


Fig: Powerhouse Superstructure Model View in extrude and standard form

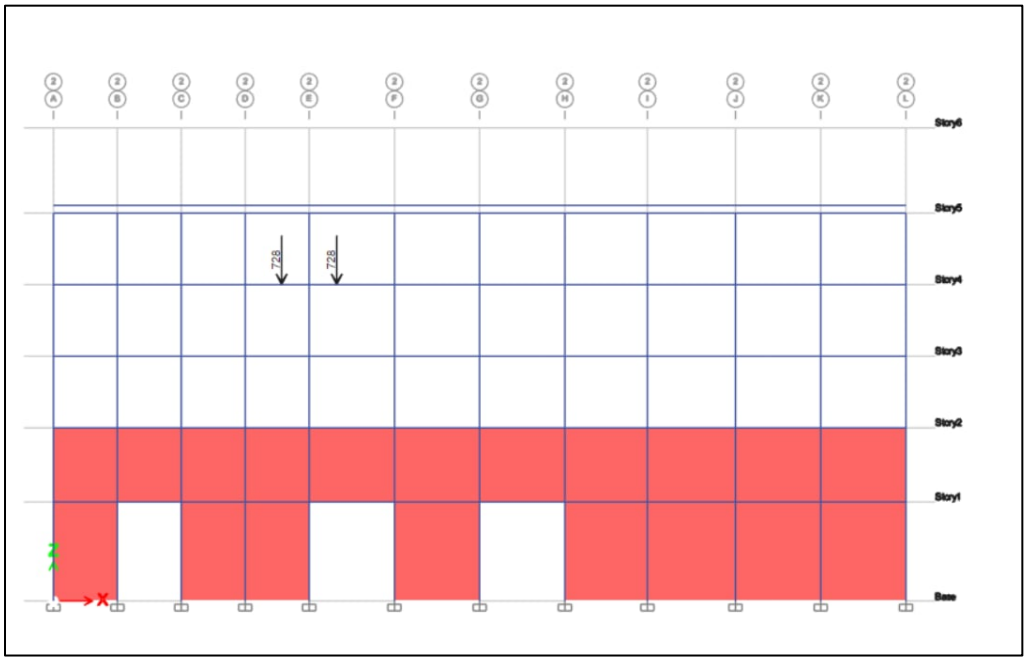


Fig: Application of crane load in the crane beam of powerhouse

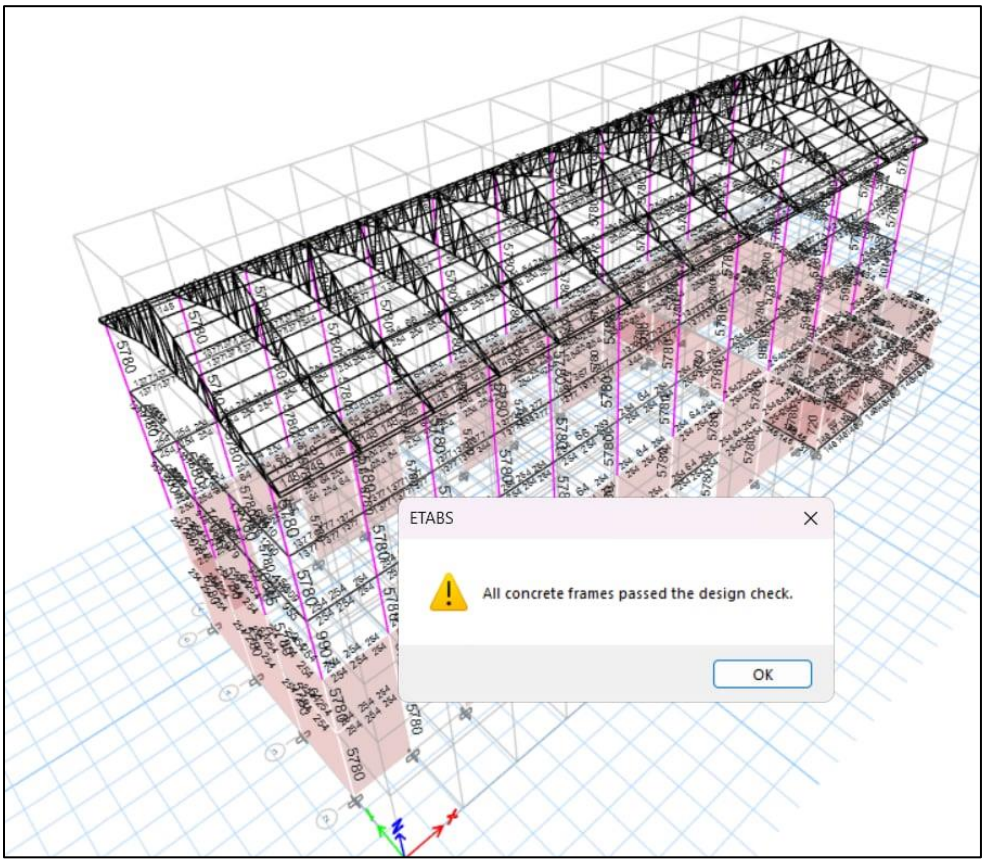


Fig: Passing of frame elements after analysis

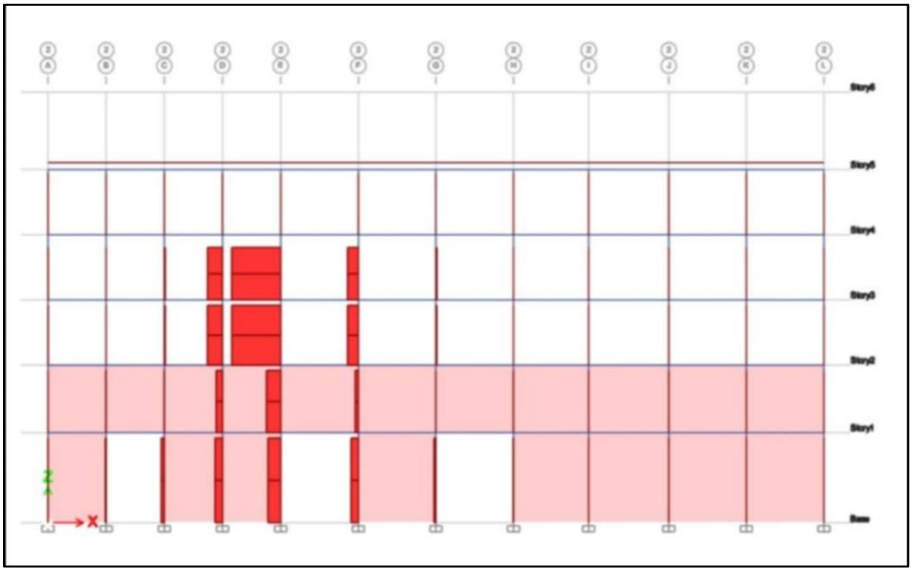


Fig: Axial Force Diagram in the crane beam after point crane load from two wheel

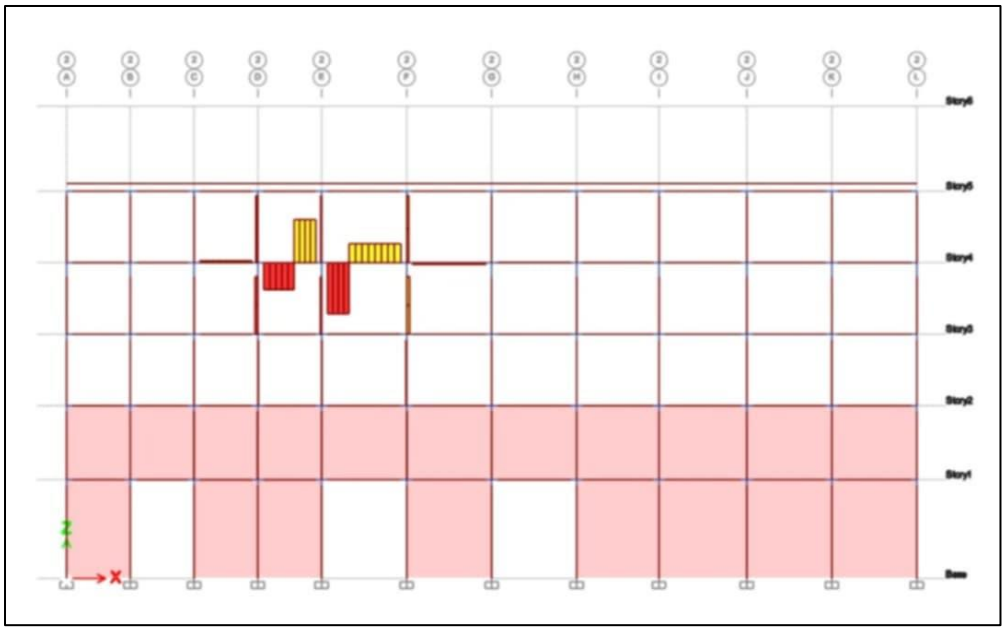


Fig: Shear Force Diagram in the crane beam after point crane load from two wheel

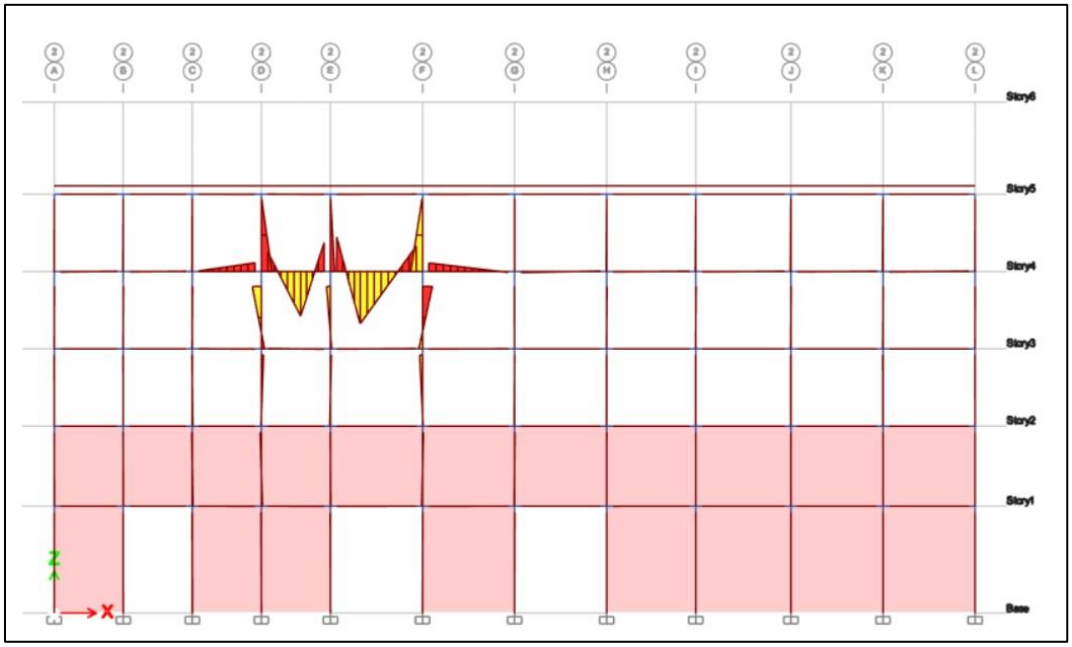


Fig: Bending Moment Diagram in the crane beam after point crane load from two wheel

ANNEX III-OPTIMISATION OF CONVEYANCE SYSTEM

Optimization of Headrace Tunnel:

1. Mean Monthly Flow Data for the River

MEAN MONTHLY FLOW DATA CALCULATION				Env. Release (m^3/s)	Available Design Flow (m^3/s)	Design Flow (m^3/s)	Q'/Q
MONTH	Day	HOURS	DISCHARGE (m^3/s)				
Jan	31	744	10.98	0.944930579	10.03	10.03	0.205
Feb	28	672	9.45	0.944930579	8.50	8.50	0.174
Mar	31	744	9.72	0.944930579	8.77	8.77	0.180
Apr	30	720	15.01	0.944930579	14.07	14.07	0.288
May	31	744	27.19	0.944930579	26.25	26.25	0.538
Jun	30	720	68.00	0.944930579	67.05	48.83	1.000
Jul	31	744	139.3972847	0.944930579	138.45	48.83	1.000
Aug	31	744	155.98	0.944930579	155.04	48.83	1.000
Sep	30	720	105.0856104	0.944930579	104.14	48.83	1.000
Oct	31	744	45.22	0.944930579	44.28	44.28	0.907
Nov	30	720	21.77	0.944930579	20.83	20.83	0.427
Dec	31	744	14.48	0.944930579	13.53	13.53	0.277

2. Assumption Data	
Gross head (m)	124.46
Head loss (m)	0.15
Efficiency (%)	0.86
Net head (m)	124.31
Wet Outage (%) = 5%	0.05
Dry Outage (%) = 5%	0.05
Design Flow (m^3/s)	48.83
10% D/S release (m^3/s) =	0.944930579
Tunnel Excavation rate including mucking and explosives (NRs)	5810
Shotcrete rate (NRs) per m2	6154.14
PCC rate (NRs) per m3	13000

Length of tunnel (m)	5090.77
Interest rate(i) = 10	0.1
Life of project = 30 years	30
Wet season Energy rate(NRs) = 4.8 per unit	4.8
Dry season Energy rate(NRs) = 8.4 per unit	8.4
Manning's coefficient (n) = 0.013	0.013
Absolute roughness for concrete (e) = 0.3	0.3
Capital recovery factor (CRF)	0.106079248

Item	**Rate (NRs.)**	**Unit**
Excavation	4370	NRs. /m3
R. Shotcrete (20 cm thick)	2198	NRs. /m2
Invert RCC (50 mm thick)	2198	NRs. /m3
Level PCC (10 cm thick)	2831	NRs. /m3

For concrete lined tunnel		
$D = 0.62*Q^{0.48}$	4.01	m

3. Incremental cost with tunnel diameter									
Tunnel Diameter, D (m)	**Inside area, A (m^2)**	**Wetted Perimeter (m)**	**Hydraulic Radius, R (m)**	**Total Excavation Area (m^2)**	**Excavation Cost (MNRs.)**	**Rock bolt + Shotcrete Cost (MNRs).**	**RCC Cost (MNRs.)**	**PCC Cost (MNRs.)**	**Total Annual Cost (MNRs.)**
1.7	2.58	6.07	0.43	3.83	85.24	67.92	19.02	24.50	20.86
1.8	2.89	6.43	0.45	4.21	93.67	71.92	20.14	25.94	22.45
1.9	3.22	6.78	0.48	4.61	102.50	75.92	21.26	27.38	24.09
2	3.57	7.14	0.50	5.02	111.72	79.91	22.38	28.82	25.76
2.1	3.94	7.50	0.53	5.45	121.34	83.91	23.50	30.27	27.48
2.2	4.32	7.86	0.55	5.90	131.36	87.90	24.62	31.71	29.23
2.3	4.72	8.21	0.58	6.37	141.77	91.90	25.74	33.15	31.03
2.4	5.14	8.57	0.60	6.86	152.58	95.89	26.85	34.59	32.88
2.5	5.58	8.93	0.63	7.36	163.79	99.89	27.97	36.03	34.76
2.6	6.03	9.28	0.65	7.88	175.40	103.88	29.09	37.47	36.69
2.7	6.51	9.64	0.68	8.42	187.40	107.88	30.21	38.91	38.66
2.8	7.00	10.00	0.70	8.98	199.80	111.88	31.33	40.35	40.67
2.9	7.51	10.36	0.73	9.56	212.60	115.87	32.45	41.79	42.72
3	8.03	10.71	0.75	10.15	225.79	119.87	33.57	43.24	44.81
3.1	8.58	11.07	0.78	10.76	239.39	123.86	34.69	44.68	46.95
3.2	9.14	11.43	0.80	11.39	253.38	127.86	35.81	46.12	49.13
3.3	9.72	11.78	0.83	12.04	267.76	131.85	36.93	47.56	51.35
3.4	10.32	12.14	0.85	12.70	282.55	135.85	38.04	49.00	53.62
3.5	10.94	12.50	0.88	13.38	297.73	139.84	39.16	50.44	55.92
3.6	11.57	12.85	0.90	14.08	313.30	143.84	40.28	51.88	58.27
3.7	12.22	13.21	0.93	14.80	329.28	147.84	41.40	53.32	60.66
3.8	12.89	13.57	0.95	15.54	345.65	151.83	42.52	54.77	63.09
3.9	13.58	13.93	0.98	16.29	362.42	155.83	43.64	56.21	65.57
4	14.28	14.28	1.00	17.06	379.59	159.82	44.76	57.65	68.08

4.1	15.01	14.64	1.03	17.85	397.15	163.82	45.88	59.09	70.64
4.2	15.75	15.00	1.05	18.66	415.11	167.81	47.00	60.53	73.24
4.3	16.51	15.35	1.08	19.48	433.47	171.81	48.11	61.97	75.89
4.4	17.28	15.71	1.10	20.33	452.23	175.80	49.23	63.41	78.57
4.5	18.08	16.07	1.13	21.19	471.38	179.80	50.35	64.85	81.30
4.6	18.89	16.43	1.15	22.07	490.93	183.80	51.47	66.30	84.07
4.7	19.72	16.78	1.18	22.96	510.87	187.79	52.59	67.74	86.88
4.8	20.57	17.14	1.20	23.88	531.22	191.79	53.71	69.18	89.73
4.9	21.43	17.50	1.23	24.81	551.96	195.78	54.83	70.62	92.63
5	22.32	17.85	1.25	25.76	573.10	199.78	55.95	72.06	95.56
5.1	23.22	18.21	1.28	26.73	594.63	203.77	57.07	73.50	98.54
5.2	24.14	18.57	1.30	27.72	616.57	207.77	58.19	74.94	101.57
5.3	25.08	18.93	1.33	28.72	638.90	211.76	59.30	76.38	104.63
5.4	26.03	19.28	1.35	29.74	661.62	215.76	60.42	77.82	107.74
5.5	27.00	19.64	1.38	30.78	684.75	219.75	61.54	79.27	110.89
5.6	28.00	20.00	1.40	31.84	708.27	223.75	62.66	80.71	114.08
5.7	29.00	20.35	1.43	32.91	732.19	227.75	63.78	82.15	117.31
5.8	30.03	20.71	1.45	34.01	756.51	231.74	64.90	83.59	120.58
5.9	31.07	21.07	1.48	35.12	781.22	235.74	66.02	85.03	123.90
6	32.14	21.42	1.50	36.24	806.33	239.73	67.14	86.47	127.26
6.1	33.22	21.78	1.53	37.39	831.84	243.73	68.26	87.91	130.66

4. Energy Lost Cost									
Tunnel Diameter, D (m)		1.7	1.8	1.9	2	2.1	2.2	2.3	2.4
X-sectional area, A (m^2)		2.58	2.89	3.22	3.57	3.94	4.32	4.72	5.14
Wetted Perimeter, P (m)		6.07	6.43	6.78	7.14	7.50	7.86	8.21	8.57
Hydraulic Radius, R (m)		0.43	0.45	0.48	0.50	0.53	0.55	0.58	0.60
Flow velocity (m/s)		18.93	16.88	15.15	13.67	12.40	11.30	10.34	9.50
Constant		3.413	2.516	1.886	1.434	1.106	0.863	0.681	0.542
Max. Power Lost (P_{max})		397354.47	292944.71	219559.96	167011.24	128746.70	100458.04	79254.49	63160.52
Month	Design Flow (m^3/s)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
Jan	10.03	2436021.72	1795927.12	1346034.52	1023879.29	789294.66	615868.19	485877.68	387211.98
Feb	8.50	1340087.32	987962.94	740471.15	563249.36	434201.29	338797.12	267287.65	213010.36
Mar	8.77	1628929.93	1200908.61	900072.40	684652.20	527789.09	411821.50	324898.86	258922.64
Apr	14.07	6500167.41	4792168.67	3591696.11	2732072.04	2106117.28	1643354.12	1296493.46	1033218.48
May	26.25	43613272.80	32153350.25	24098705.82	18331005.25	14131123.33	11026185.49	8698902.57	6932442.93
Jun	48.83	271790458.47	200374180.74	150179013.95	114235690.21	88062744.25	68713302.57	54210073.34	43201798.91
Jul	48.83	280850140.41	207053320.10	155184981.08	118043546.55	90998169.06	71003745.98	56017075.78	44641858.88
Aug	48.83	280850140.41	207053320.10	155184981.08	118043546.55	90998169.06	71003745.98	56017075.78	44641858.88
Sep	48.83	271790458.47	200374180.74	150179013.95	114235690.21	88062744.25	68713302.57	54210073.34	43201798.91
Oct	44.28	209409523.35	154384601.72	115710153.72	88016487.30	67850716.33	52942329.25	41767859.27	33286187.34
Nov	20.83	21095711.09	15552554.17	11656528.00	8866695.07	6835214.97	5333358.60	4207653.40	3353218.04
Dec	13.53	5974793.23	4404843.00	3301398.29	2511253.09	1935890.95	1510530.49	1191704.75	949708.89

Wet Season Energy Lost	1335786432.20	984792157.58	738094671.79	561441655.89	432807757.91	337709784.95	266429810.90	212326720.96
Dry Season Energy Lost	61493272.42	45335160.59	33978378.30	25846111.22	19924416.60	15546556.92	12265164.96	9774515.28
Total Energy Lost (TEL)	1397279704.62	1030127318.17	772073050.09	587287767.11	452732174.50	353256341.87	278694975.86	222101236.24
Total Energy Lost Cost	6928318363	5107817705	3828272802	2912027283	2244842337	1751598046	1381890478	1101274189
TEL Cost (MNRs.)	6928.32	5107.82	3828.27	2912.03	2244.84	1751.60	1381.89	1101.27

2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
5.58	6.03	6.51	7.00	7.51	8.03	8.58	9.14
8.93	9.28	9.64	10.00	10.36	10.71	11.07	11.43
0.63	0.65	0.68	0.70	0.73	0.75	0.78	0.80
8.75	8.09	7.50	6.98	6.50	6.08	5.69	5.34
0.436	0.354	0.289	0.238	0.198	0.165	0.139	0.117
50803.34	41214.29	33700.18	27758.51	23020.59	19212.87	16130.33	13617.76
Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
311455.04	252668.37	206602.38	170176.36	141130.02	117786.46	98888.63	83485.08
171335.48	138996.17	113654.67	93616.24	77637.47	64795.87	54399.93	45926.23
208265.15	168955.42	138151.81	113794.29	94371.46	78761.98	66125.29	55825.18
831072.18	674208.57	551288.22	454090.72	376584.81	314295.94	263869.84	222767.71
5576129.86	4523643.82	3698902.21	3046749.57	2526718.94	2108787.90	1770450.92	1494673.64
34749487.78	28190574.80	23050926.08	18986822.33	15746080.41	13141605.58	11033147.39	9314550.52
35907804.04	29130260.62	23819290.28	19619716.40	16270949.75	13579659.10	11400918.97	9625035.54
35907804.04	29130260.62	23819290.28	19619716.40	16270949.75	13579659.10	11400918.97	9625035.54
34749487.78	28190574.80	23050926.08	18986822.33	15746080.41	13141605.58	11033147.39	9314550.52
26773837.88	21720316.69	17760312.38	14628995.57	12132063.84	10125364.13	8500836.08	7176688.97
2697170.31	2188083.51	1789156.54	1473710.74	1222172.28	1020019.30	856365.93	722972.65

763901.01	619715.85	506730.51	417388.96	346147.45	288893.06	242542.64	204762.57
170785591.83	138550071.04	113289901.65	93315783.78	77388296.43	64587912.78	54225334.72	45778833.72
7862158.70	6378188.20	5215329.80	4295816.14	3562590.16	2973321.20	2496277.25	2107440.40
178647750.54	144928259.24	118505231.45	97611599.92	80950886.58	67561233.98	56721611.97	47886274.13
885812973.9	718617121.9	587600298.2	484000617.7	401389580.2	334997879.4	281250335.6	237440901.2
885.81	718.62	587.60	484.00	401.39	335.00	281.25	237.44

3.3	3.4	3.5	3.6	3.7	3.8	3.9	4
9.72	10.32	10.94	11.57	12.22	12.89	13.58	14.28
11.78	12.14	12.50	12.85	13.21	13.57	13.93	14.28
0.83	0.85	0.88	0.90	0.93	0.95	0.98	1.00
5.02	4.73	4.47	4.22	4.00	3.79	3.60	3.42
0.099	0.085	0.073	0.062	0.054	0.047	0.041	0.036
11556.63	9855.64	8443.89	7265.95	6278.12	5445.78	4741.27	4142.40
Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
70849.11	60420.99	51766.15	44544.63	38488.67	33385.88	29066.82	25395.42
38975.02	33238.38	28477.23	24504.58	21173.12	18366.01	15990.04	13970.35
47375.70	40402.58	34615.22	29786.31	25736.77	22324.62	19436.53	16981.53
189050.48	161224.57	138130.38	118860.84	102701.38	89085.35	77560.55	67763.97
1268445.79	1081746.17	926794.30	797504.09	689081.19	597723.61	520397.28	454666.52
7904737.29	6741257.18	5775623.62	4969909.15	4294236.17	3724911.32	3243026.89	2833403.98
8168228.53	6965965.76	5968144.41	5135572.78	4437377.37	3849075.03	3351127.78	2927850.78
8168228.53	6965965.76	5968144.41	5135572.78	4437377.37	3849075.03	3351127.78	2927850.78
7904737.29	6741257.18	5775623.62	4969909.15	4294236.17	3724911.32	3243026.89	2833403.98
6090453.94	5194014.03	4450011.22	3829223.11	3308629.57	2869975.31	2498692.26	2183085.38
613546.39	523239.91	448289.79	385752.20	333308.12	289118.51	251715.82	219921.89
173770.53	148193.64	126966.04	109253.94	94400.57	81885.05	71291.74	62286.97

38849931.97	33131699.81	28385837.06	24425939.17	21105164.76	18307066.54	15938717.43	13925516.80
1788466.62	1525226.33	1306749.32	1124454.40	971581.70	842770.52	733742.96	641064.75
40638398.59	34656926.14	29692586.37	25550393.57	22076746.46	19149837.06	16672460.39	14566581.55
201502793.1	171844060.3	147228712.1	126689925	109466077.1	94953191.78	82669284.52	72227424.56
201.50	171.84	147.23	126.69	109.47	94.95	82.67	72.23

4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
15.01	15.75	16.51	17.28	18.08	18.89	19.72	20.57
14.64	15.00	15.35	15.71	16.07	16.43	16.78	17.14
1.03	1.05	1.08	1.10	1.13	1.15	1.18	1.20
3.25	3.10	2.96	2.83	2.70	2.59	2.48	2.37
0.031	0.027	0.024	0.021	0.019	0.017	0.015	0.013
3631.27	3193.32	2816.70	2491.68	2210.24	1965.76	1752.74	1566.58
Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
22261.86	19576.99	17268.06	15275.47	13550.08	12051.29	10745.34	9604.07
12246.54	10769.56	9499.39	8403.23	7454.08	6629.57	5911.15	5283.33
14886.16	13090.83	11546.89	10214.47	9060.73	8058.51	7185.24	6422.09
59402.52	52238.32	46077.30	40760.34	36156.42	32157.11	28672.37	25627.06
398564.88	350496.25	309158.48	273484.04	242593.70	215760.11	192379.01	171946.36
2483788.15	2184232.70	1926622.78	1704305.76	1511802.46	1344580.12	1198873.09	1071540.33
2566581.09	2257040.46	1990843.54	1761115.95	1562195.87	1389399.45	1238835.52	1107258.34
2566581.09	2257040.46	1990843.54	1761115.95	1562195.87	1389399.45	1238835.52	1107258.34
2483788.15	2184232.70	1926622.78	1704305.76	1511802.46	1344580.12	1198873.09	1071540.33
1913712.85	1682910.91	1484427.23	1313136.08	1164815.84	1035974.12	923709.55	825602.01
192785.57	169534.80	149539.75	132284.05	117342.41	104363.02	93053.60	83170.34
54601.33	48016.18	42353.12	37465.90	33234.08	29558.02	26354.93	23555.76
12207236.90	10734992.03	9468899.61	8376263.56	7430154.91	6608296.28	5892180.37	5266369.69
561963.29	494188.12	435903.23	385603.45	342049.09	304214.62	271248.04	242438.68

12769200.19	11229180.16	9904802.84	8761867.01	7772204.01	6912510.90	6163428.41	5508808.38
63315228.79	55679142	49112305.28	43445134.07	38537955.97	34275224.98	30560949.32	27315059.47
63.32	55.68	49.11	43.45	38.54	34.28	30.56	27.32

4.9	5	5.1	5.2	5.3	5.4	5.5	5.6
21.43	22.32	23.22	24.14	25.08	26.03	27.00	28.00
17.50	17.85	18.21	18.57	18.93	19.28	19.64	20.00
1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.40
2.28	2.19	2.10	2.02	1.95	1.88	1.81	1.74
0.012	0.011	0.010	0.009	0.008	0.007	0.007	0.006
1403.44	1260.08	1133.79	1022.24	923.49	835.87	757.95	688.50
Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
8603.92	7725.06	6950.79	6266.97	5661.58	5124.39	4646.66	4220.91
4733.13	4249.66	3823.72	3447.54	3114.51	2818.99	2556.19	2321.98
5753.31	5165.63	4647.89	4190.63	3785.81	3426.60	3107.15	2822.46
22958.30	20613.20	18547.18	16722.49	15107.09	13673.68	12398.94	11262.88
154040.11	138305.54	124443.43	112200.58	101361.95	91744.39	83191.43	75568.96
959951.65	861896.46	775510.20	699214.81	631670.34	571735.38	518434.76	470932.84
991950.04	890626.34	801360.54	722521.97	652726.01	590793.23	535715.92	486630.60
991950.04	890626.34	801360.54	722521.97	652726.01	590793.23	535715.92	486630.60
959951.65	861896.46	775510.20	699214.81	631670.34	571735.38	518434.76	470932.84
739625.00	664075.29	597516.27	538732.09	486690.32	440511.54	399444.40	362845.05
74509.10	66898.30	60193.21	54271.34	49028.71	44376.70	40239.64	36552.66
21102.70	18947.14	17048.11	15370.90	13886.06	12568.51	11396.80	10352.56
4717937.48	4236019.19	3811450.96	3436477.01	3104511.72	2809945.45	2547985.38	2314524.58
217191.47	195006.23	175461.13	158199.10	142917.00	129356.56	117297.16	106549.74
4935128.95	4431025.42	3986912.08	3594676.11	3247428.72	2939302.02	2665282.54	2421074.32

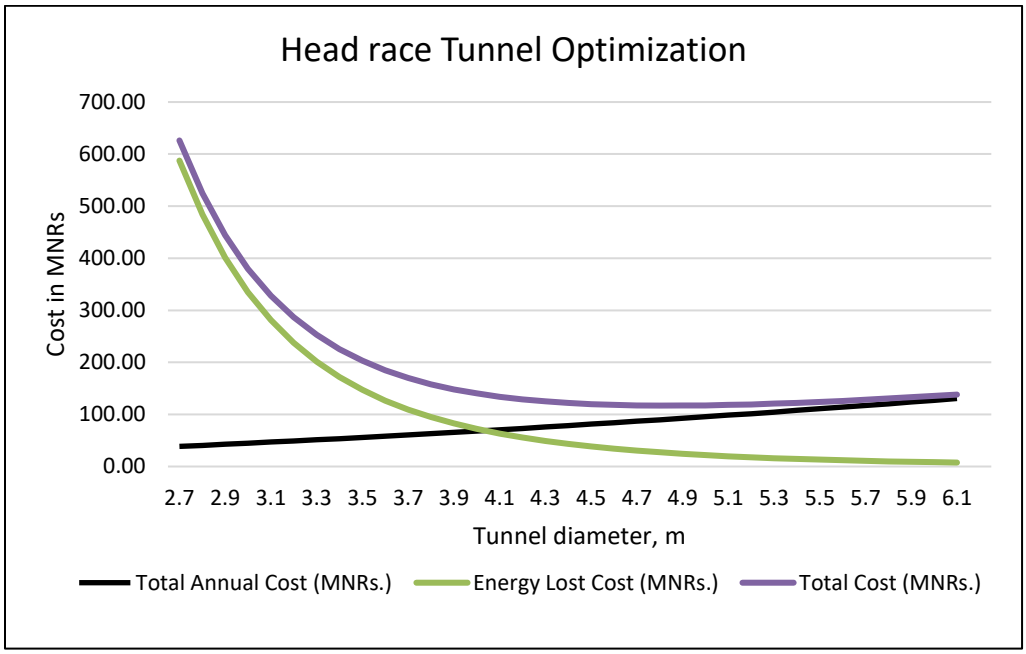
24470508.24	21970944.48	19768838.06	17823962.11	16102159.04	14574333.31	13215625.98	12004735.78
24.47	21.97	19.77	17.82	16.10	14.57	13.22	12.00

5.7	5.8	5.9	6	6.1
29.00	30.03	31.07	32.14	33.22
20.35	20.71	21.07	21.42	21.78
1.43	1.45	1.48	1.50	1.53
1.68	1.63	1.57	1.52	1.47
0.005	0.005	0.004	0.004	0.004
626.48	570.98	521.23	476.54	436.33
Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)	Energy Lost (kWh)
3840.69	3500.47	3195.44	2921.47	2674.95
2112.81	1925.65	1757.86	1607.14	1471.53
2568.21	2340.71	2136.74	1953.54	1788.70
10248.33	9340.49	8526.58	7795.53	7137.72
68761.77	62670.57	57209.59	52304.56	47890.99
428511.57	390552.26	356520.41	325953.10	298448.45
442795.29	403570.67	368404.42	336818.21	308396.74
442795.29	403570.67	368404.42	336818.21	308396.74
428511.57	390552.26	356520.41	325953.10	298448.45
330160.25	300913.30	274692.38	251140.84	229949.02
33260.02	30313.71	27672.24	25299.68	23164.84
9420.01	8585.54	7837.42	7165.46	6560.82
2106034.00	1919472.86	1752214.27	1601983.14	1466804.24
96951.82	88363.43	80663.64	73747.71	67524.71
2202985.82	2007836.29	1832877.91	1675730.84	1534328.95
10923358.47	9955722.528	9088203.038	8308999.784	7607867.899
10.92	9.96	9.09	8.31	7.61

5. Table for Optimization

Diameter, D (m)	Total Annual Cost (MNRs.)	Energy Lost Cost (MNRs.)	Total Cost (MNRs.)
1.7	20.86	6928.32	6949.18
1.8	22.45	5107.82	5130.27
1.9	24.09	3828.27	3852.36
2	25.76	2912.03	2937.79

2.1	27.48	2244.84	2272.32
2.2	29.23	1751.60	1780.83
2.3	31.03	1381.89	1412.92
2.4	32.88	1101.27	1134.15
2.5	34.76	885.81	920.57
2.6	36.69	718.62	755.30
2.7	38.66	587.60	626.26
2.8	40.67	484.00	524.67
2.9	42.72	401.39	444.11
3	44.81	335.00	379.81
3.1	46.95	281.25	328.20
3.2	49.13	237.44	286.57
3.3	51.35	201.50	252.86
3.4	53.62	171.84	225.46
3.5	55.92	147.23	203.15
3.6	58.27	126.69	184.96
3.7	60.66	109.47	170.13
3.8	63.09	94.95	158.05
3.9	65.57	82.67	148.24
4	68.08	72.23	140.31
4.1	70.64	63.32	133.96
4.2	73.24	55.68	128.92
4.3	75.89	49.11	125.00
4.4	78.57	43.45	122.02
4.5	81.30	38.54	119.84
4.6	84.07	34.28	118.34
4.7	86.88	30.56	117.44
4.8	89.73	27.32	117.05
4.9	92.63	24.47	117.10
5	95.56	21.97	117.54
5.1	98.54	19.77	118.31
5.2	101.57	17.82	119.39
5.3	104.63	16.10	120.73
5.4	107.74	14.57	122.31
5.5	110.89	13.22	124.10
5.6	114.08	12.00	126.08
5.7	117.31	10.92	128.23
5.8	120.58	9.96	130.54
5.9	123.90	9.09	132.99
6	127.26	8.31	135.57
6.1	130.66	7.61	138.27



6. Optimized Diameter (Dtunnel)	4.8	m

Check:

7. Velocity through tunnel (Vtunnel)	2.38	m/s
Check: For concrete-lined tunnel,		
Critical velocity = 1 m/s	OK	
Average Permissible velocity = 2.7 m/s	OK	
(IS 10430: 2000)		

8. Manning headloss	2.54	m
Darcy-Weisbach's head loss	2.45	m
Other Minor losses		
$(V^2/2g)$*(Kentrance + Kbend + Ktransition)	0.19	m
Kent = 0.05; Kbend = 4*0.1; Ktran= 0.2)		
Total headlosses in tunnel	2.73	

9. Slope of tunnel	0.000536
(Assuming energy grade line is equal to longitudinal slope)	1 in
	500

Friction factor	0.01266

Optimization of Penstock:

Month	No of days	Monthly flow (m3/s)	Available Flow (m3/s)	Design Flow (m3/s)	Operating (hrs.)
Jan	31	10.98	10.03	10.03	707
Feb	28	9.45	8.50	8.50	638
Mar	31	9.72	8.77	8.77	707
Apr	30	15.01	14.07	14.07	684
May	31	27.19	26.25	26.25	707
Jun	30	68.00	67.05	48.83	684
Jul	31	139.40	138.45	48.83	707
Aug	31	155.98	155.04	48.83	707
Sep	30	105.09	104.14	48.83	684
Oct	31	45.22	44.28	44.28	707
Nov	30	21.77	20.83	20.83	684
Dec	31	14.48	13.53	13.53	707

Assumption Data		
Data	**Value**	**Unit**
Design Discharge	48.83	m^3/s
Length of Pipe	242.83	m
Overall Efficiency of system	86%	%
Project Life Period	50	years
Interest Rate	10%	%
Capital Recovery Factor	0.110	
Dry season energy rate	8.4	Rs per kWhr
Wet season energy rate	4.8	Rs per kWhr
Dry season outage	5%	%
Wet season outage	5%	%
Environmental flow	10%	%
Pipe material	Galvanized Commercial Steel	
Roughness coefficient of commerical steel	0.15	mm

Diameter (m)	1.7	1.75	1.8	1.85	1.9	1.95	2	2.05	2.1	2.15	2.2
Cross Sectional Area (A), m^2	2.27	2.41	2.54	2.69	2.84	2.99	3.14	3.30	3.46	3.63	3.80
Wetted Perimeter (P), m	5.34	5.50	5.65	5.81	5.97	6.13	6.28	6.44	6.60	6.75	6.91
Velocity (v), m/s	21.51	20.30	19.19	18.17	17.22	16.35	15.54	14.79	14.10	13.45	12.85
Reynolds Number, Re	36426228.6	35385479.2	34402549.2	33472750.6	32591888.7	31756199.3	30962294.3	30207116.4	29487899.3	28802134.2	28147540.3
e/D	8.82353E-05	8.57143E-05	8.33333E-05	8.10811E-05	7.89474E-05	7.69231E-05	7.50000E-05	7.31707E-05	7.14286E-05	6.97674E-05	6.81818E-05
f(moody's Diagram)	0.0123	0.01246	0.01258	0.01269	0.01276	0.01285	0.01298	0.01301	0.01317	0.01328	0.01332
Head loss (hf), m	51.44	45.08	39.53	34.77	30.60	27.06	24.08	21.34	19.15	17.16	15.35
Gross Head, m	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46
hf%	41.33	36.22	31.76	27.94	24.58	21.74	19.35	17.14	15.38	13.79	12.33

2.25	2.3	2.35	2.4	2.45	2.5	2.55	2.6	2.65	2.7	2.75	2.8
3.98	4.15	4.34	4.52	4.71	4.91	5.11	5.31	5.52	5.73	5.94	6.16
7.07	7.23	7.38	7.54	7.70	7.85	8.01	8.17	8.33	8.48	8.64	8.80
12.28	11.75	11.26	10.79	10.36	9.95	9.56	9.20	8.85	8.53	8.22	7.93
27522039.4	26923734.2	26350888.8	25801911.9	25275342.3	24769835.4	24284152.4	23817149.5	23367769.3	22935032.8	22518032.2	22115924.5
6.66667E-05	6.52174E-05	6.38298E-05	6.25000E-05	6.12245E-05	6.00000E-05	5.88235E-05	5.76923E-05	5.66038E-05	5.55556E-05	5.45455E-05	5.35714E-05
0.01335	0.0134	0.01345	0.0135	0.01355	0.0136	0.013665	0.0137	0.01378	0.01381	0.01383	0.01386
13.75	12.36	11.14	10.07	9.11	8.27	7.53	6.85	6.26	5.71	5.22	4.78
124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46
11.04	9.93	8.95	8.09	7.32	6.64	6.05	5.50	5.03	4.59	4.20	3.84

2.85	2.9	2.95	3	3.05	3.1	3.15	3.2	3.25	3.3	3.35	3.4
6.38	6.61	6.83	7.07	7.31	7.55	7.79	8.04	8.30	8.55	8.81	9.08

8.95	9.11	9.27	9.42	9.58	9.74	9.90	10.05	10.21	10.37	10.52	10.68
7.65	7.39	7.14	6.91	6.68	6.47	6.27	6.07	5.89	5.71	5.54	5.38
21727925.8	21353306.4	20991386.0	20641529.5	20303143.8	19975673.7	19658599.6	19351433.9	19053719.6	18765026.9	18484951.8	18213114.3
5.26316E-05	5.17241E-05	5.08475E-05	5.00000E-05	4.91803E-05	4.83871E-05	4.76190E-05	4.68750E-05	4.61538E-05	4.54545E-05	4.47761E-05	4.41176E-05
0.01389	0.01392	0.01395	0.01397	0.01399	0.01401	0.01407	0.01409	0.01413	0.01416	0.01419	0.01422
4.39	4.03	3.71	3.41	3.15	2.91	2.69	2.49	2.31	2.15	2.00	1.86
124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46
3.52	3.24	2.98	2.74	2.53	2.33	2.16	2.00	1.86	1.73	1.60	1.49

3.45	3.5	3.55	3.6	3.65	3.7	3.75	3.8	3.85
9.35	9.62	9.90	10.18	10.46	10.75	11.04	11.34	11.64
10.84	11.00	11.15	11.31	11.47	11.62	11.78	11.94	12.10
5.22	5.08	4.93	4.80	4.67	4.54	4.42	4.31	4.19
17949156.1	17692739.6	17443546.1	17201274.6	16965640.72	16736375.3	16513223.63	16295944.37	16084308.73
4.34783E-05	4.28571E-05	4.22535E-05	4.16667E-05	4.10959E-05	4.05405E-05	0.00004	3.94737E-05	3.8961E-05
0.01425	0.01428	0.014301	0.01437	0.01041	0.01039	0.01037	0.01035	0.01033
1.73	1.61	1.51	1.41	0.95	0.89	0.83	0.78	0.73
124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46	124.46
1.39	1.30	1.21	1.13	0.77	0.71	0.67	0.62	0.58

Diameter (m)		1.7	1.75	1.8	1.85	1.9	1.95	2	2.05	2.1	2.15	2.2
Month	Design Flow (m^3/s)	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr
Jan	10.03	3076341.53	2695887.982	2364243.259	2079586.665	1830023.697	1618467.991	1440451.89	1276092.144	1145152.552	1026549.319	917835.528
Feb	8.5	2354772.084	2063555.59	1809699.597	1591810.46	1400783.584	1238849.2	1102587.56	976779.1153	876551.9804	785767.6581	702553.1652
Mar	8.77	2689881.876	2357222.094	2067239.619	1818342.478	1600130.391	1415150.975	1259497.81	1115785.454	1001294.903	897590.9799	802534.1556

Apr	14.07	4176257.549	3659776.533	3209555.461	2823122.668	2484330.886	2197135.494	1955471.47	1732346.49	1554590.718	1393582.053	1245998.702
May	26.25	8051242.787	7055539.335	6187575.827	5442587.233	4789443.873	4235771.163	3769876.58	3339722.71	2997034.345	2686632.066	2402111.925
Jun	48.83	14493721.12	12701271.36	11138777.06	9797660.262	8621881.818	7625168.881	6786472.76	6012116.496	5395214.27	4836432.951	4324244.251
Jul	48.83	14976845.15	13124647.08	11510069.62	10124248.94	8909277.878	7879341.177	7012688.52	6212520.379	5575054.745	4997647.383	4468385.726
Aug	48.83	14976845.15	13124647.08	11510069.62	10124248.94	8909277.878	7879341.177	7012688.52	6212520.379	5575054.745	4997647.383	4468385.726
Sep	48.83	14493721.12	12701271.36	11138777.06	9797660.262	8621881.818	7625168.881	6786472.76	6012116.496	5395214.27	4836432.951	4324244.251
Oct	44.28	13581296.4	11901686.92	10437556.48	9180867.15	8079107.607	7145140.842	6359243.24	5633635.109	5055568.792	4531964.492	4052019.659
Nov	20.83	6182760.82	5418133.985	4751602.008	4179505.699	3677939.756	3252759.938	2894987.25	2564660.795	2301501.397	2063135.334	1844644.844
Dec	13.53	4149840.568	3636626.56	3189253.369	2805264.963	2468616.213	2183237.48	1943102.1	1721388.506	1544757.131	1384766.928	1238117.118
Dry Season Energy Loss		12270836.06	10753292.23	9430435.844	8295004.565	7299553.886	6455705.646	5745639.37	5090045.219	4567756.566	4094674.885	3661039.967
Wet Season Energy Loss		90932690.1	79686973.66	69883983.14	61469901.15	54093141.51	47839827.55	42577901.1	37719638.85	33849233.28	30343474.61	27130035.08
Dry season energy loss cost (Rs)		10307502.9	90327654.71	79215661.09	69678038.34	61316252.64	54227927.43	48263370.7	42756379.84	38369155.15	34395269.03	30752735.72
Wet season energy loss cost (Rs)		43647691.2.5	38249747.3.5	33544311.9.1	29505552.5.5	25964707.9.3	22963117.2.3	20437392.5	18105426.6.5	16247631.9.8	14564867.8.1	13022416.8.4

Total energy loss cost (NRs)	53955193.4	47282512.8.3	41465878.0.1	36473356.3.9	32096333.1.9	28385909.9.7	25263729.6	22381064.6.3	20084547.4.9	18004394.7.2	16097690.4.1
Present value of energy loss (NRs)	53495573.45	46879734.32	41112648.81	36162656.23	31822918.93	28144103.14	25048519.22	22190410.39	19913456.24	17851023.36	15960561.41

2.25	2.3	2.35	2.4	2.45	2.5	2.55	2.6	2.65	2.7	2.75	2.8	2.85	2.9	2.95	3	3.05
Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr
822134.208	739332.269	666433.802	602076.3994	545108.4536	494553.078	450072.8108	409475.4521	374450.049	341781.776	312271.7915	285987.5435	262332.4344	241003.4666	221737.0021	204156.9535	188231.612
629299.011	565918.632	510118.821	460856.73	417250.8667	378553.477	344506.2521	313431.1826	286621.1419	261615.356	239027.0684	218907.9065	200801.2073	184475.0428	169727.6123	156271.0415	144081.059
718855.135	646455.035	582714.302	526441.6772	476630.2232	432425.772	393533.2553	358035.8639	327410.4615	298846.079	273043.2314	250060.893	229377.4128	210727.8567	193881.7057	178510.1178	164585.3676
11160803	1003673.34	904710.732	817342.9652	740006.6841	671375.725	610991.9706	555879.4209	508331.0252	463982.528	423921.536	388239.6106	356126.8471	327171.9142	301016.9124	277151.2883	255531.9957
2151647.35	1934942.38	1744156.26	1575723.378	1426629.801	1294318.87	11779907.406	10716658.088	9799991.4043	8944493.68	8172661.6676	7484871.886	6865662.9515	6307041.8743	5803018.6745	5343409.0756	4926630.0913
387336	348325	313980	283659	256819	233001	212045	192918	176416	161025	147122	134738	123593	11354	104468	96185.4	88682.4

1.85	2.96	2.77	2.537	6.616	2.55	0.457	2.098	5.171	3.51	1.649	7.362	9.868	51.64	0.585	8263	9717
4002473.92	3599361.39	3244462.87	29311 45.621	2653803.17	2407679.64	21911 32.139	1993488.168	1822970.677	1663928.62	1520262.371	1392300.274	1277137.864	11733 00.028	1079503.271	9939 16.6538	9163 85.8041
4002473.92	3599361.39	3244462.87	29311 45.621	2653803.17	2407679.64	21911 32.139	1993488.168	1822970.677	1663928.62	1520262.371	1392300.274	1277137.864	11733 00.028	1079503.271	9939 16.6538	9163 85.8041
3873361.85	3483252.96	3139802.77	2836 2.537	2568 6.616	2330012.55	2120 450.457	1929 2.098	1764 5.171	1610 253.51	1471 221.649	1347 7.362	1235 9.868	11354 51.64	1044 680.585	9618 54.8263	8868 24.9717
3629521.71	3263971.37	2942142.45	2658 0.236	2406 520.671	2183 331.03	1986 961.521	1807 734.1	1653 105.5	1508 883.05	1378 603.682	1262 565.147	11581 33.619	1063 971.436	9789 14.7012	9013 03.0807	8309 96.5883
1652306.52	1485893.08	1339383.41	1210 9.372	1095 546.498	9939 41.46	9045 46.0375	8229 54.395	7525 61.1411	6869 05.193	6275 96.7018	5747 71.2216	5272 29.7246	4843 63.2532	4456 41.9535	4103 09.974	3783 03.5872
11090 20.52	9973 24.587	8989 87.97	8121 72.8498	7353 25.7605	6671 28.927	6071 27.1316	5523 63.1971	50511 5.569 5	4610 47.6	4212 40.0138	3857 83.795	3538 74.1613	3251 02.3832	29911 2.8254	2753 98.1636	2539 15.6242
3279308.88	2949030.52	2658254.89	2401547.656	2174315.304	1972661.25	1795239.45	1633305.696	1493597.222	1363290.81	1245582.105	11407 40.138	1046385.216	9613 08.7493	8844 59.1455	8143 36.2763	7508 13.6628
2430 1227.4	2185 3708.9	1969 8924.1	1779 6602.27	16112 703.23	1461 8351.5	1330 3572.13	1210 3566.54	110 0.767	1010 2628.7	9230 351.626	8453 4203.138	7754 208.606	7123 751.812	6554 259.955	6034 61 6.379	5563 883.814
2754 6194.6	2477 1856.4	2232 3241.1	2017 3000.31	1826 4248.55	1657 0354.5	1508 0011.38	1371 9767.84	1254 6216.66	11451 642.8	1046 2889.68	9582 2107.158	8789 635.813	8074 993.494	7429 456.822	6840 424.721	6306 834.768

116 64 58 92	10 48 97 80 3	94 55 48 35. 8	85 42 36 90. 88	77 34 09 75. 48	70 16 80 87. 1	63 85 71 46. 2	58 09 711 9.3 7	53 12 76 51. 68	48 49 26 17. 8	44 30 56 87. 81	40 57 64 31. 06	37 22 02 01. 31	34 19 40 08. 7	31 46 04 47. 78	28 96 61 58. 62	26 70 66 42. 31
14 41 92 08 6	12 96 69 65 9	116 88 41 77	10 55 96 69 1.2	95 60 52 24. 03	86 73 84 41. 6	78 93 71 57. 58	71 81 68 87. 22	65 67 38 68. 35	59 94 42 60. 6	54 76 85 77. 49	50 15 86 48. 22	46 00 98 37. 12	42 26 90 02. 19	38 88 99 04. 61	35 80 65 83. 34	33 01 34 77. 08
14 29 63 77 85	12 85 65 06 13	115 88 84 93 1	10 46 97 16 04	94 79 08 06 0	85 99 95 55 8	78 26 47 27 4	71 20 511 14	65 114 42 21	59 43 36 22 4	54 30 20 28 6	49 73 13 69 2	45 61 79 00 0	41 90 89 31 5	38 55 86 19 0	35 50 15 63 1	32 73 22 50 1

3.1	3.15	3.2	3.25	3.3	3.35	3.4	3.45	3.5	3.55	3.6	3.65	3.7	3.75	3.8	3.85
Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr	Energy loss, kWhr
173 781 .56 74	161 107 .35 67	149 119 .74 26	138 388 .30 84	128 489 .48 78	119 435 .21 7	111 142 .21 7	103 536 .48 88	965 52. 167 9	900 73. 841 52	843 95. 309 1	570 50. 745 5	532 01. 423	496 59. 164 4	463 95. 798 98	433 86. 078 2
133 020 .33 59	123 318 .91 71	114 143 .05 06	105 928 .72 16	983 51. 712 89	914 21. 161 4	850 73. 320 7	792 51. 549 65	739 05. 431 96	689 46. 625 55	646 00. 017 9	436 69. 242	407 22. 795	380 11. 388 83	355 13. 460 12	332 09. 682 6
151 950 .58 28	140 868 .54 62	130 386 .85 37	121 003 .53 59	112 348 .23 61	104 431 .39 1	971 80. 183 6	905 29. 910 94	844 22. 982 3	787 58. 483 56	737 93. 306 16	498 83. 852 2	465 18. 094	434 20. 824 71	405 67. 413 46	379 35. 783 23
235 915 .47 81	218 709 .72 66	202 436 .05 75	187 867 .70 33	174 429 .65 55	162 138 .11 9	150 880 .03 6	140 554 .95 42	131 073 .45 73	122 278 .86 83	114 570 .03 17	774 48. 685 1	722 23. 075	674 14. 316 07	629 84. 166 04	588 98. 348 85
454 812 .17 79	421 641 .88 58	390 268 .51 87	362 182 .76 13	336 276 .07 72	312 579 .70 6	290 875 .69 2	270 970 .37 2	252 691 .36 66	235 736 .62 41	220 875 .06 12	149 310 .27 6	139 236 .03	129 965 .41 03	121 424 .69 82	113 547 .81 18

818745.7565	759033.1164	702555.2726	651995.7321	605358.9253	562701.09	523629.864	487796.618	454891.039	424369.3772	397615.8244	268786.019	250650.51	233961.6954	218586.8392	204406.9918
846037.2817	784334.2203	725973.7817	673728.9232	625537.5561	581457.793	541084.192	504056.5053	470054.0736	438515.0231	410869.6853	277745.553	259005.53	241760.4185	225873.0672	211220.5582
846037.2817	784334.2203	725973.7817	673728.9232	625537.5561	581457.793	541084.192	504056.5053	470054.0736	438515.0231	410869.6853	277745.553	259005.53	241760.4185	225873.0672	211220.5582
818745.7565	759033.1164	702555.2726	651995.7321	605358.9253	562701.09	523629.864	487796.618	454891.039	424369.3772	397615.8244	268786.019	250650.51	233961.6954	218586.8392	204406.9918
767203.1709	711249.6267	658327.2385	610950.5779	567249.7027	527277.31	490665.739	457088.3075	426254.2368	397654.0082	372584.6747	251865.106	234871.29	219233.0807	204826.1195	191538.9375
349262.2181	323789.8795	299697.4468	278129.656	258235.2327	240038.167	223371.085	208085.2663	194048.338	181028.3458	169615.7613	114659.283	106923	99803.85243	93245.21526	87196.3473
234423.1911	217326.2748	201155.5451	186679.3433	173326.2981	161112.511	149925.642	139665.8717	130244.3501	121505.3914	113845.3173	76958.7823	71766.226	66987.88578	62585.75874	58525.78644
693175.6772	642621.0949	594805.192	551999.9091	512515.7348	476400.282	443321.364	412983.8211	385124.9323	359284.342	336633.9504	227562.622	212208.54	198079.2637	185062.4313	173057.3305
5136759.121	4762125.792	4407787.37	4090580.009	3797983.631	3530351.07	3285220.66	3060405.147	2853957.624	2664646.547	2496465.548	1686346.5	1572565.5	1467860.887	1371400.012	1282436.545
5826675.689	5398017.197	4996363.613	4639792.37	4305132.172	4001762.37	3723899.45	3469064.097	3235049.431	3017988.473	2817725.183	1911526.02	1782551.7	1663865.815	1554524.423	1453681.576
24656443.78	22858203.8	21157379.38	19634784.04	18230321.43	16945685.1	15769059.2	14689944.7	13698996.59	12779839.91	11974159.43	8094463.18	7548314.3	7045732.259	6582720.057	6155695.418
304791	28256221	261537	242715	225354	209474	194929	181590	169340	157978	148018	100059	9330866	870959	813724	760937

19.47		42.99	83.28	53.6	47.5	58.6	08.8	46.03	28.38	84.62	89.2		8.074	4.48	6.994
302194815	280155189	259309510	240648246	223434842	207690056	193269069	180043204	167897925	156632538	146757940	99207527	92513806	86354049	80679269	75445561

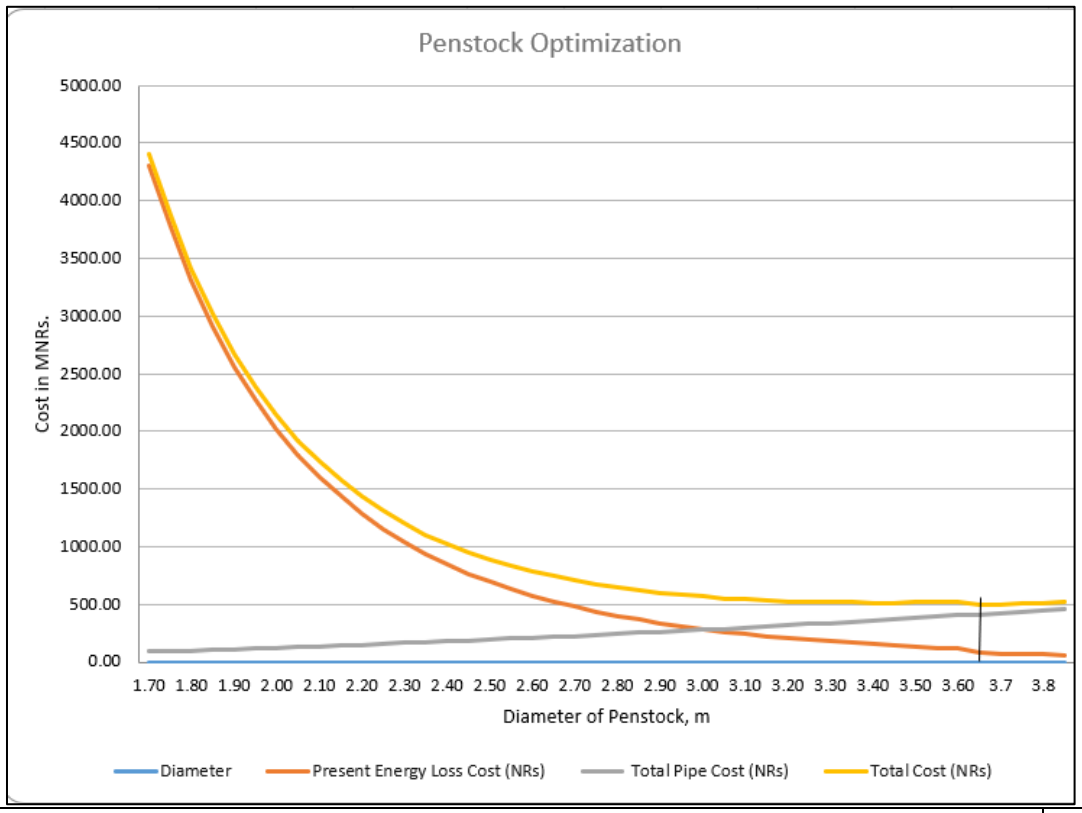
Cost of Penstock Pipe									
Diameter (m)	Thickness (m)	Volume per meter	Mass (kg)	Cost per meter (NRs.)	Total Cost of pipe (NRs.)	Uniform Annual Cost of Pipe (NRs)	Increment of Pipe Cost (NRs)	Present value of energy loss (NRs)	Total Cost (NRs)
1.70	0.030	0.16	1237.16	371148	111856462	12304211		5349557345	5349557345
1.75	0.030	0.17	1311.00	393301	118533016	13038632	734421	4687973432	4688707852
1.80	0.031	0.18	1386.99	416096	125403093	13794340	1490129	4111264881	4112755010
1.85	0.032	0.19	1465.11	439534	132466693	14571336	2267125	3616265623	3618532748
1.90	0.033	0.20	1545.38	463613	139723816	15369620	3065409	3182291893	3185357302
1.95	0.034	0.21	1627.78	488335	147174463	16189191	3884980	2814410314	2818295294
2.00	0.035	0.22	1712.33	513699	154818633	17030050	4725839	2504851922	2509577760
2.05	0.036	0.23	1799.02	539705	162656326	17892196	5587985	2219041039	2224629024
2.10	0.036	0.24	1887.84	566353	170687543	18775630	6471419	1991345624	1997817043
2.15	0.037	0.25	1978.81	593644	178912283	19680351	7376140	1785102336	1792478476
2.20	0.038	0.26	2071.92	621576	187330546	20606360	8302149	1596056141	1604358290
2.25	0.039	0.28	2167.17	650150	195942332	21553657	9249446	1429637785	1438887231
2.30	0.040	0.29	2264.56	679367	204747642	22522241	10218030	1285650613	1295868642

2.35	0.041	0.30	2364.09	709226	213746475	23512112	11207901	1158884931	1170092832
2.40	0.042	0.31	2465.76	739727	222938831	24523271	12219060	1046971604	1059190664
2.45	0.043	0.33	2569.57	770870	232324711	25555718	13251507	947908060.3	961159568
2.50	0.043	0.34	2675.52	802655	241904114	26609453	14305242	859995557.5	874300799
2.55	0.044	0.35	2783.61	835082	251677040	27684474	15380263	782647273.6	798027537
2.60	0.045	0.37	2893.84	868151	261643489	28780784	16476573	712051113.8	728527687
2.65	0.046	0.38	3006.21	901863	271803462	29898381	17594170	651144221.3	668738391
2.70	0.047	0.40	3120.72	936217	282156958	31037265	18733054	594336223.8	613069278
2.75	0.048	0.41	3237.37	971212	292703978	32197438	19893227	543020285.5	562913512
2.80	0.049	0.43	3356.17	1006850	303444520	33378897	21074686	497313692	518388378
2.85	0.049	0.44	3477.10	1043130	314378586	34581644	22277433	456178999.6	478456433
2.90	0.050	0.46	3600.17	1080052	325506175	35805679	23501468	419089315.3	442590784
2.95	0.051	0.47	3725.39	1117617	336827288	37051002	24746791	385586189.6	410332980
3.00	0.052	0.49	3852.74	1155823	348341924	38317612	26013401	355015631.2	381029032
3.05	0.053	0.51	3982.24	1194671	360050083	39605509	27301298	327322500.8	354623799
3.10	0.054	0.52	4113.87	1234162	371951765	40914694	28610483	302194815.3	330805298
3.15	0.055	0.54	4247.65	1274295	384046971	42245167	29940956	280155189.3	310096145
3.20	0.056	0.56	4383.57	1315070	396335700	43596927	31292716	259309509.9	290602226
3.25	0.056	0.58	4521.62	1356487	408817952	44969975	32665764	240648245.5	273314009
3.30	0.057	0.59	4661.82	1398546	421493728	46364310	34060099	223434841.8	257494941
3.35	0.058	0.61	4804.16	1441247	434363027	47779933	35475722	207690055.8	243165778
3.40	0.059	0.63	4948.63	1484590	447425849	49216843	36912632	193269068.7	230181701
3.45	0.060	0.65	5095.25	1528576	460682194	50675041	38370830	180043203.5	218414034

3.50	0.061	0.67	5244.01	1573203	474132063	52154527	39850316	167897924.9	207748241
3.55	0.062	0.69	5394.91	1618473	487775455	53655300	41351089	156632537.7	197983627
3.60	0.062	0.71	5547.95	1664385	501612370	55177361	42873150	146757940	189631090
3.65	0.063	0.73	5703.13	1710939	515642809	56720709	44416498	99207526.72	143624024.7
3.7	0.064	0.75	5860.45	1758135	529866771	58285345	45981134	92513805.72	138494939.5
3.75	0.065	0.77	6019.91	1805973	544284256	59871268	47567057	86354049.17	133921106.3
3.8	0.066	0.79	6181.51	1854454	558895264	61478479	49174268	80679269.46	129853537.5
3.85	0.067	0.81	6345.25	1903576	573699796	63106978	50802767	75445561.26	126248327.8

Table for Optimisation			
Diameter	**Present Energy Loss Cost (NRs)**	**Total Pipe Cost (NRs)**	**Total Cost (NRs)**
1.70	5349557345	111856462.2	5461413808
1.75	4687973432	118533015.7	4806506447
1.80	4111264881	125403092.6	4236667973
1.85	3616265623	132466692.7	3748732316
1.90	3182291893	139723816.1	3322015709
1.95	2814410314	147174462.8	2961584777
2.00	2504851922	154818632.8	2659670555
2.05	2219041039	162656326.1	2381697365
2.10	1991345624	170687542.7	2162033167
2.15	1785102336	178912282.5	1964014618
2.20	1596056141	187330545.7	1783386687
2.25	1429637785	195942332.2	1625580117
2.30	1285650613	204747641.9	1490398254
2.35	1158884931	213746474.9	1372631406
2.40	1046971604	222938831.3	1269910435
2.45	947908060.3	232324710.9	1180232771
2.50	859995557.5	241904113.8	1101899671
2.55	782647273.6	251677040	1034324314
2.60	712051113.8	261643489.5	973694603
2.65	651144221.3	271803462.2	922947684
2.70	594336223.8	282156958.3	876493182
2.75	543020285.5	292703977.7	835724263
2.80	497313692	303444520.3	800758212
2.85	456178999.6	314378586.3	770557586

2.90	419089315.3	325506175.5	744595491
2.95	385586189.6	336827288	722413478
3.00	355015631.2	348341923.8	703357555
3.05	327322500.8	360050082.9	687372584
3.10	302194815.3	371951765.3	674146581
3.15	280155189.3	384046971	664202160
3.20	259309509.9	396335700	655645210
3.25	240648245.5	408817952.3	649466198
3.30	223434841.8	421493727.8	644928570
3.35	207690055.8	434363026.7	642053083
3.40	193269068.7	447425848.8	640694918
3.45	180043203.5	460682194.3	640725398
3.50	167897924.9	474132063	642029988
3.55	156632537.7	487775455	644407993
3.60	146757940	501612370.3	648370310
3.65	99207526.72	**515642808.9**	**614850335.6**
3.7	92513805.72	529866770.8	622380576.5
3.75	86354049.17	544284256	630638305.2
3.8	80679269.46	558895264.5	639574533.9
3.85	75445561.26	573699796.2	649145357.5



Optimized Diameter of Pressure Shaft	**3.65 m**

Design of Penstock				
S. N	**Description**	**Values**	**Units**	**Remarks**
1	**Assumption Data**			
	Allowable stress	1200.00	kg/cm^2	
	Density of steel	7850.00	kg/m^3	
	Bulk Modulus of water	1.96×10^9	N/m^2	
	Ultimate tensile strength	410×10^6	N/m^2	
	Young's Modulus	2×10^{11}	N/m^2	
	Density of water	1000	kg/m^3	
	Welding joint efficiency	0.9		
	Modulus of Elasticity	2×10^5	N/m^2	
2	**Calculated Data**			
	Design discharge	48.83	m^3/s	

	Length of Penstock	301.38	m	
	Gross Head (H_g)	124.46	m	
	Net Head (H) (Calculated by subtracting head loss up to penstock)	120.14	m	
	Rated Head (h)	120.14	m	
	Static head (h_s)	120.14	m	
	Dynamic head (h_d) (20 % of h_s)	24.03	m	h_d = 20% of hs
3	**Calculations**			
	Design Pressure (p) = 9.81 kN/m^2	14.43	kg/cm^2	
	Economic diameter (D_e) $D_e = \sqrt[7]{5.2\frac{Q_d^3}{h_d}}$			
	From Design guideline by JNN:	4.25	m	
	From USBR method:			
	V_{eco} = 0.125 x $\sqrt{2gH}$	6.07	m/s	
		3.20	m	
	From Sarkaria Formula, $D_e = 0.62 * \frac{P^{0.32}}{H^{0.65}}$	0.97	m	
	P = Power in HP	51219.27	kW	68686.17
	From these first estimates, general idea for economic diameter of penstock is obtained and we shall use diameter of 1.70 m as starting diameter for the optimization study of the penstock.			
	Optimum Diameter of Penstock	3.65	m	
	Thickness of the shell (t) =	2.64	cm	
	Velocity of flow in penstock (v_p)	4.67	m/s	
4	**Head loss**			
	Total Head loss in Penstock	1.78	m	
5	**Final Dimensions**			
	Length of Penstock	301.38	m	
	Velocity of flow in penstock (v_p)	4.67	m/s	
	Optimum Diameter of Penstock	3.65	m	
	Thickness of the shell (t)	26.38	mm	

ANNEX IV - NUMERICAL MODELLING & STATIC ANALYSIS

Rock Class	Q-value	Maximum Overburden Pressure	Minimum Overburden Pressure	σ_1 (Mpa)	σ_3 (Mpa)
Class I	>10	1035	34.413	27.43	27.43
Class II	1-10	1035	34.413	27.43	27.43
Class III	0.5-1	1035	34.413	27.43	27.43
Class IV	0.1-0.5	1035	34.413	27.43	27.43
Class V	0.01-0.1	1035	34.413	27.43	27.43
Class VI	<0.01	1035	34.413	27.43	27.43

	Q-value (classification)	Adopted Q-value	GSI
Class I	>10	11	65.58
Class II	1-10	10	64.72
Class III	0.5-1	1	44
Class IV	0.1-0.5	0.5	37.76
Class V	0.01-0.1	0.1	23.28
Class VI	<0.01	0.01	2.55

Analysis procedure:

1. From the Analysis menu, the Project Settings dialog was accessed. Under the General tab, the unit system was set to Metric and ensured that stress is measured in MPa.

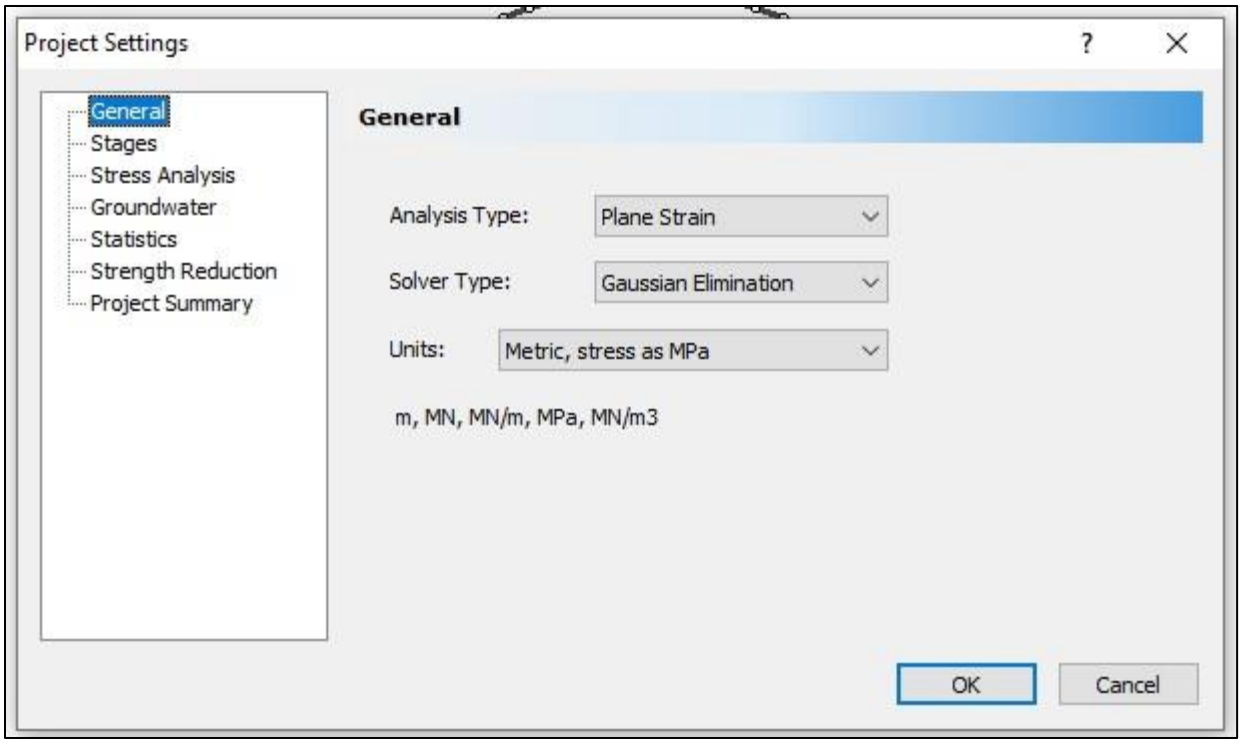


Fig: Project Setting in Phase 2 Software

2. The Stages tab was selected. The number of stages was changed to 10

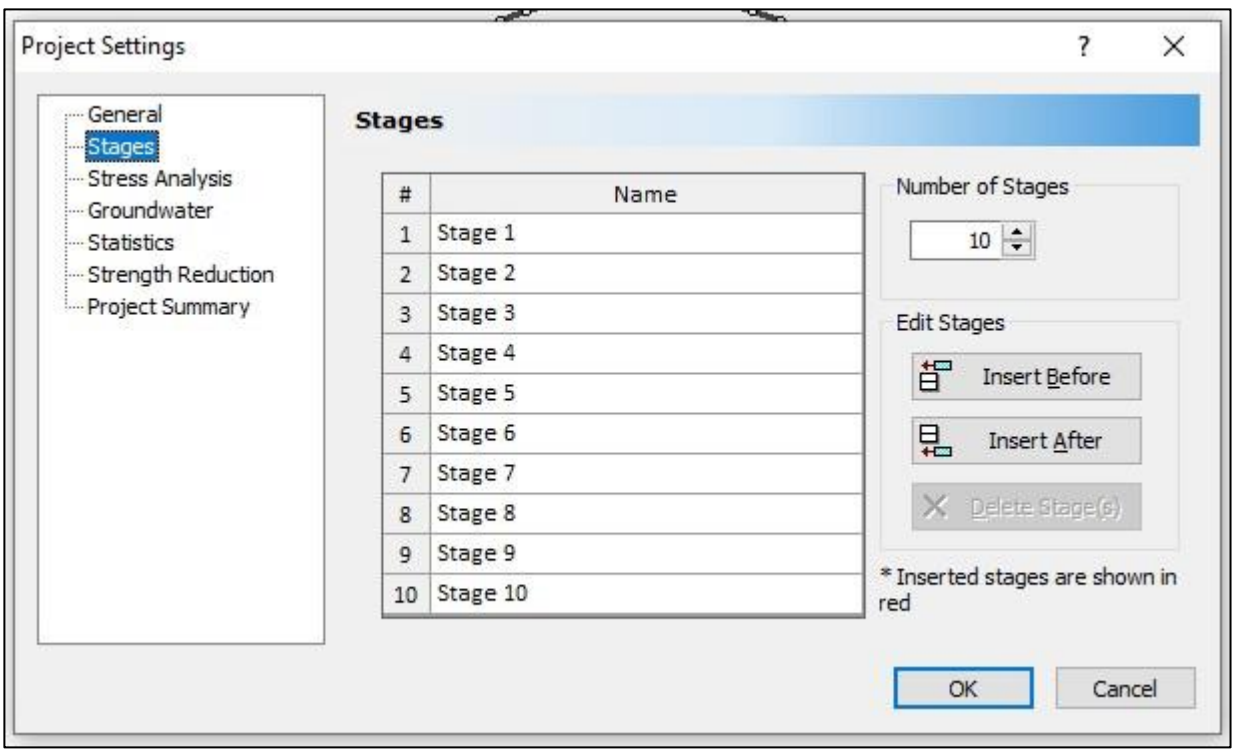


Fig: Stage Selection in Phase^2 Software

3. Boundary was selected and excavation was added. Then an inverted D tunnel of dimeter 4.8m was drawn.

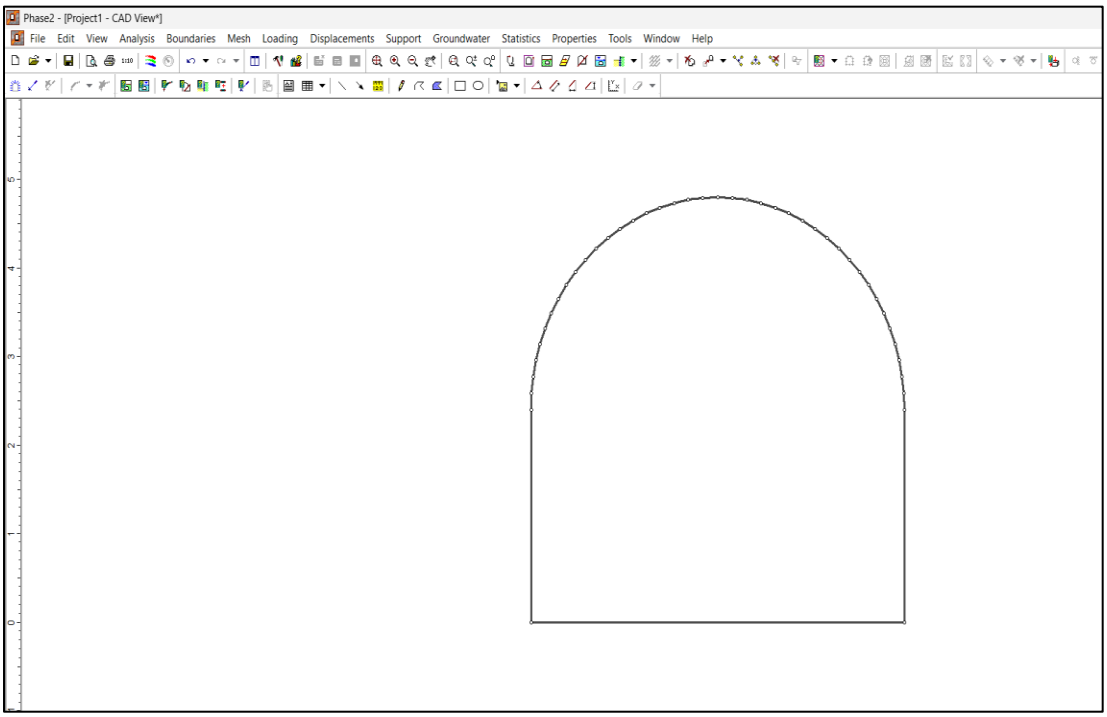


Fig: Inverted D-shaped Tunnel in Phase^2 software

4. Boundaries was selected then external was added. Then boundary type box and expansion factor as 5 was selected.

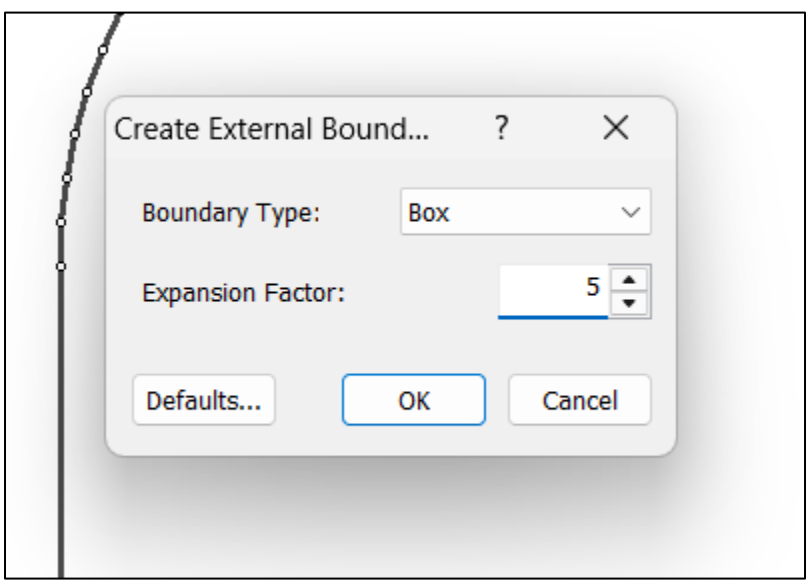


Fig: Expansion Factor

5. Once the boundary was defined, the finite element mesh was generated using the Mesh Setup option under the Mesh menu. This opened a dialog box offering various mesh configuration options, including mesh types (such as graded, uniform, radial, and no internal nodes) and element types (including 3- or 6-node triangles and 4- or 8-node quadrilaterals). For this model, a graded mesh was selected to provide finer control near the excavation boundary, and 6-node triangular elements were chosen to ensure higher accuracy in capturing stress variations.

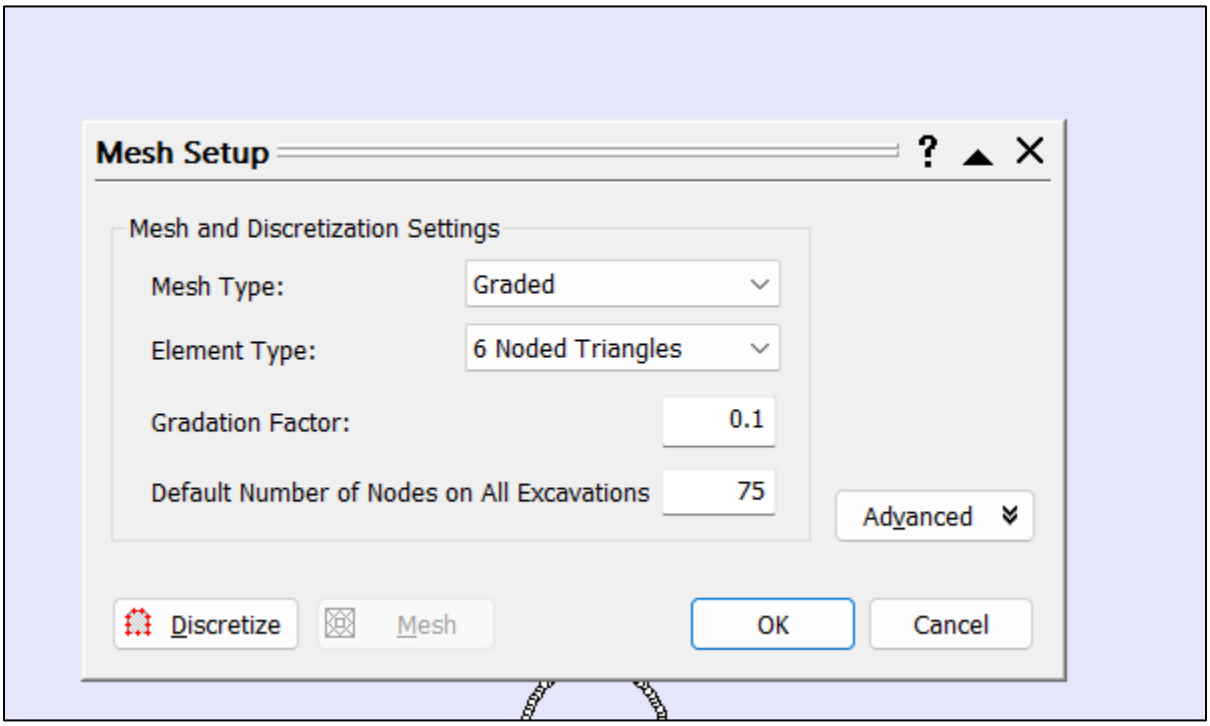
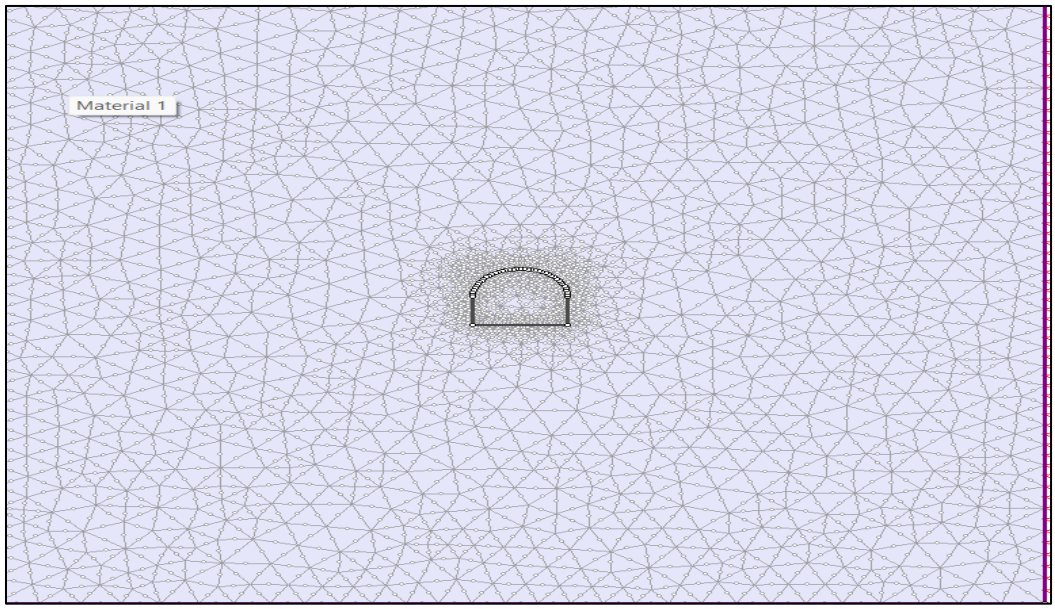


Fig: Mesh Setup

6. After selecting the mesh type and element type, discretize button was clicked followed by mesh button.



7. The stress parameters (σ_1, σ_3 and σ_z) were added by clicking the loading button and the field stress option.

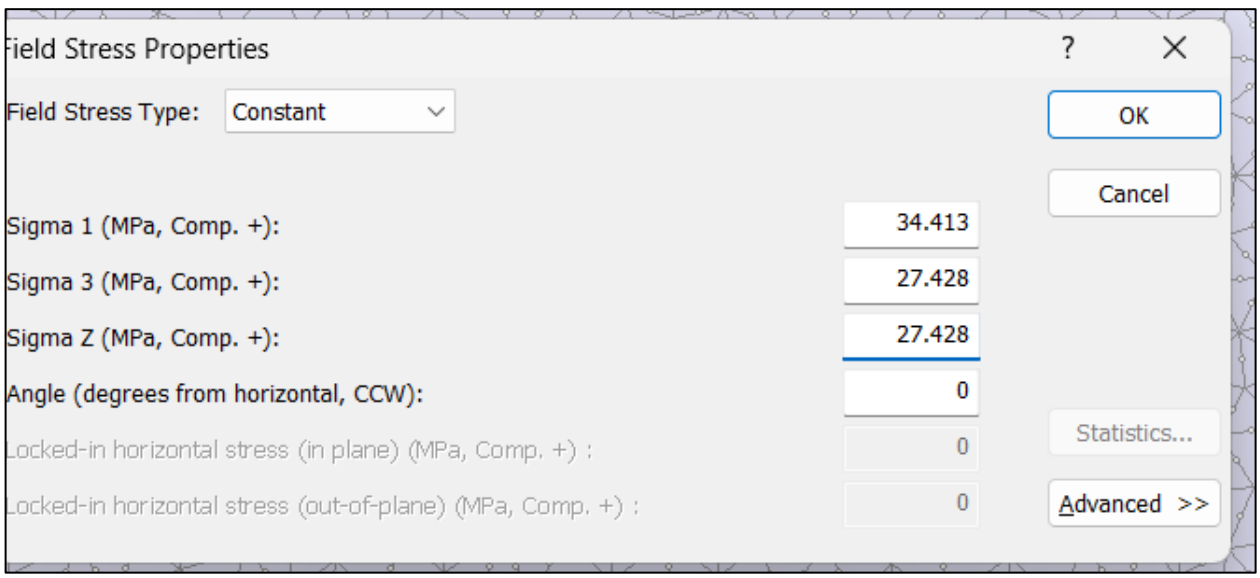


Fig: Field Stress

8. Excavation of the tunnel takes place in the first stage, so Stage 1 is selected from the timeline at the bottom of the screen. To simulate the excavation, the tunnel area is right-clicked, and the option Assign Material > Excavate is chosen. This action removes the material from the tunnel zone, visually representing it as a hollow space within the model.

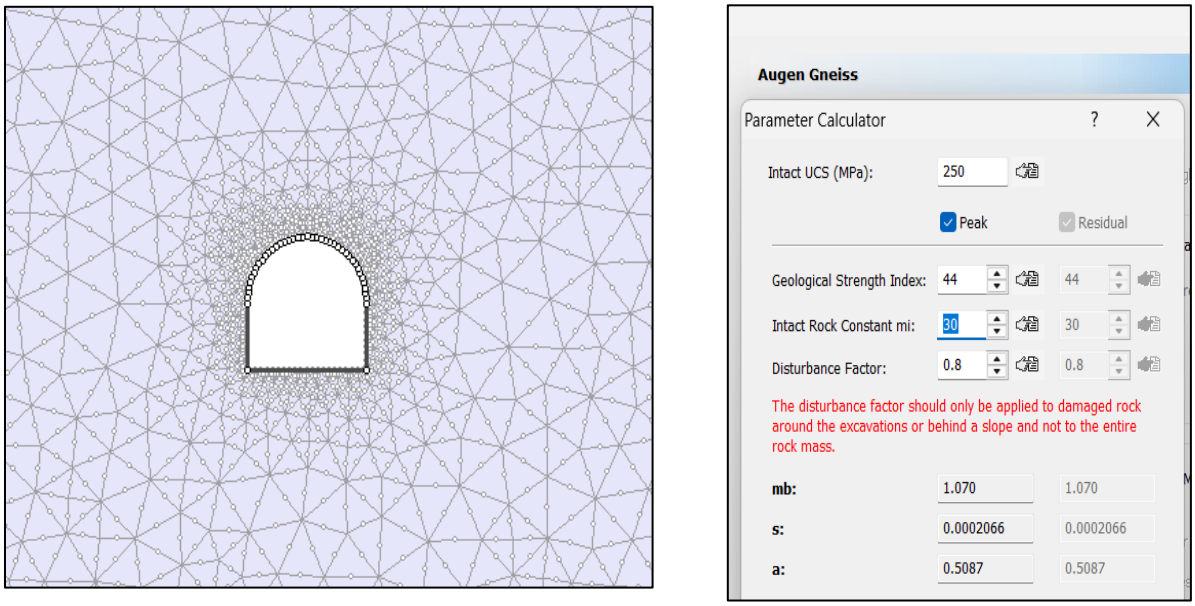


Fig: Assigning Material

9. Next, the Loading tab was opened, and the Distributed Load option was chosen, followed by selecting Add Uniform Load. From there, the Field Stress option was applied to simulate the in-situ conditions. The Stage Load setting was then enabled, and the Stage Factors tab was accessed to define how the load would vary across the different excavation stages.

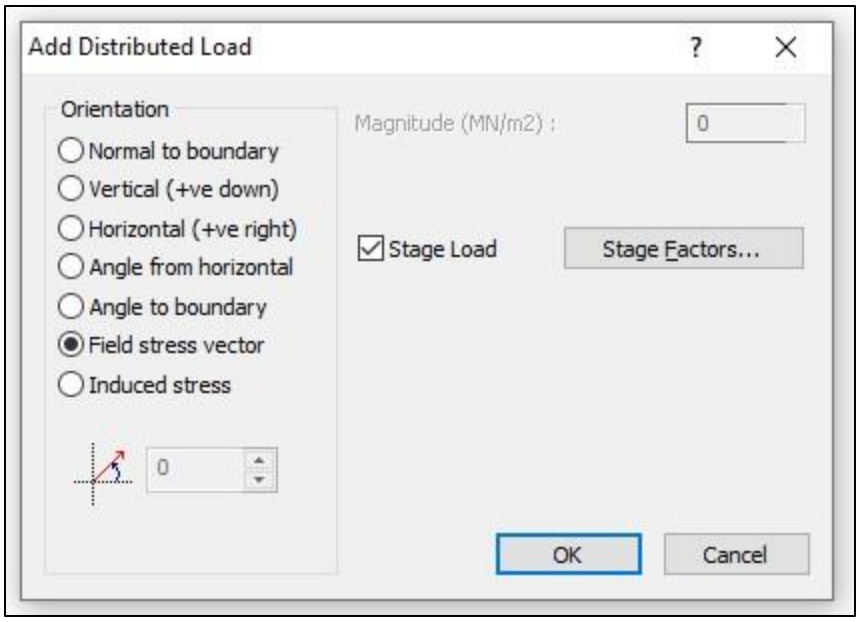
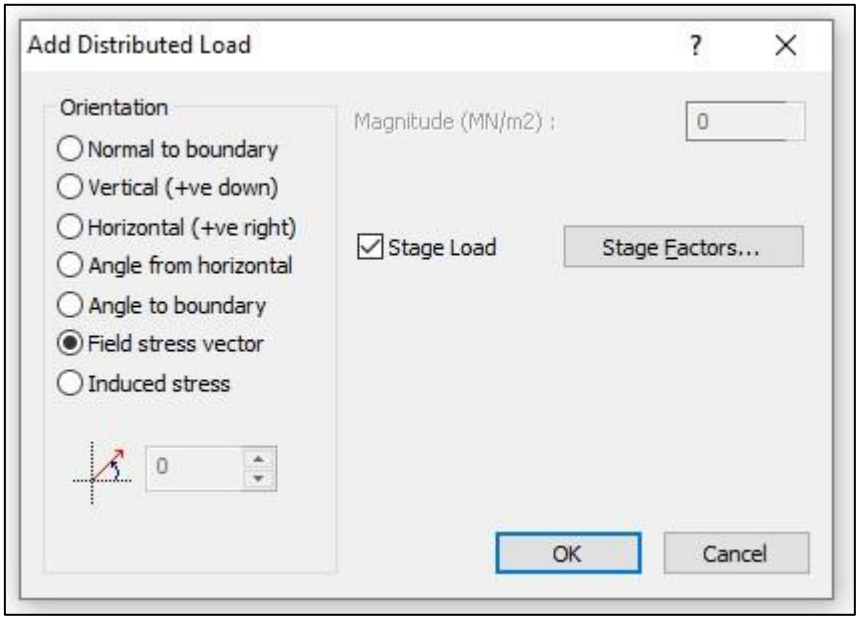


Fig: Addition of distributed load

10. Then the stage factors are added in the dialog box for all the stages. The stage factor for stage 1 is kept 1 and that for stage 10 is kept 0. Factor = 1 means the magnitude will be the same as the field stress while a Factor = 0 means no load will be applied at that stage. Other values of Factor can be used to increase or decrease the magnitude of a load at any stage of a model.



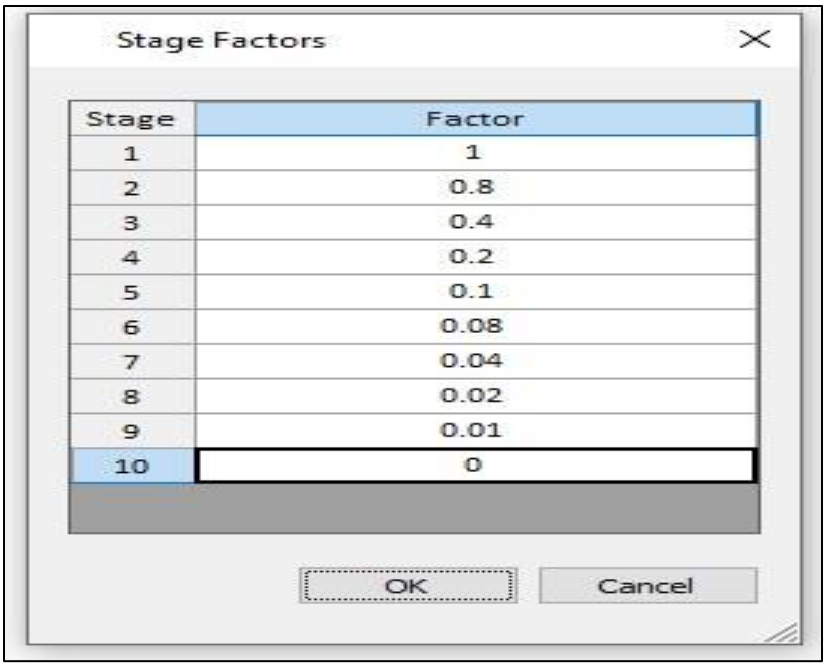


Fig: Stage Factor

11. After clicking OK, the excavated tunnel was selected and enter button was clicked.

12. The file was saved and then analysis tab was clicked. The Compute option was selected and then Interpret option.
13. The total displacement was selected from the dropdown toolbar. The displacement is null in stage 1 while it is maximum in stage 10.

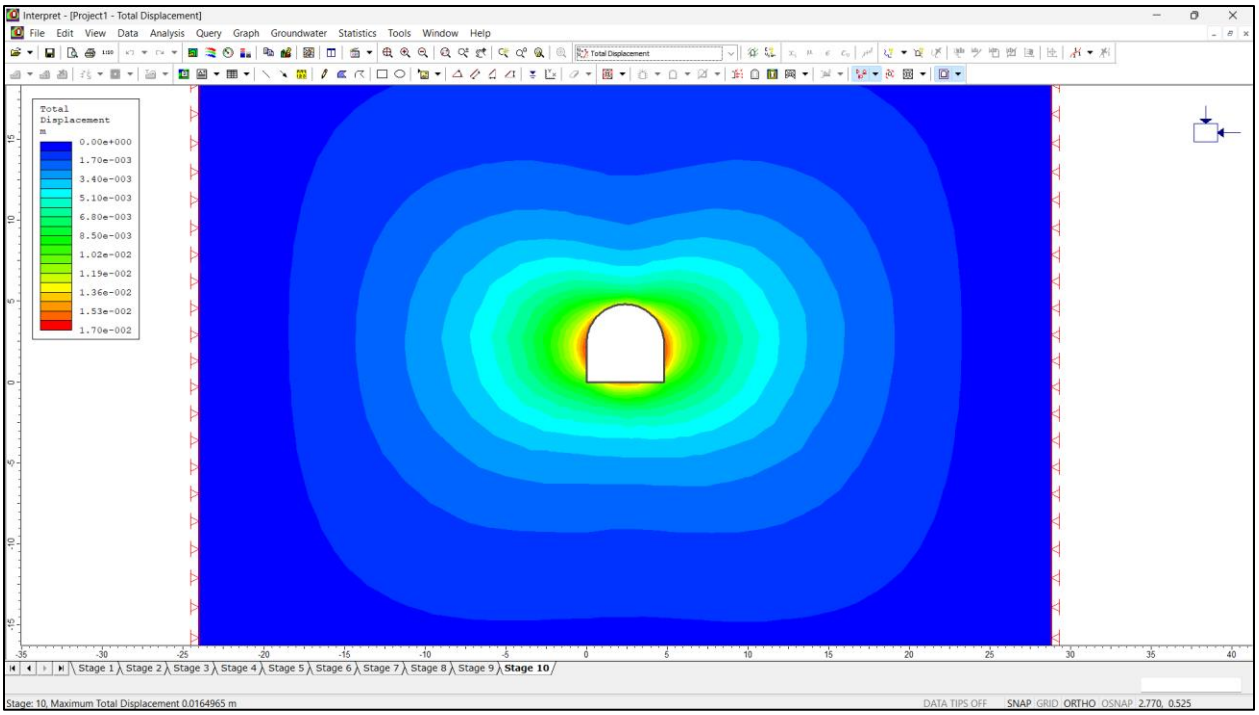


Fig: Total Displacement

14. In order to determine the radius of the plastic zone, the measuring tool was used to measure the distance from the center of the tunnel to the perimeter of the yielded/plastic zone. To measure the distance, the tools button is clicked and then the measure option is selected.

15. From the plot given by Vlachopoulos and Diederichs, we can estimate the amount of closure prior to support installation if we know the plastic radius and displacement far from the tunnel face.

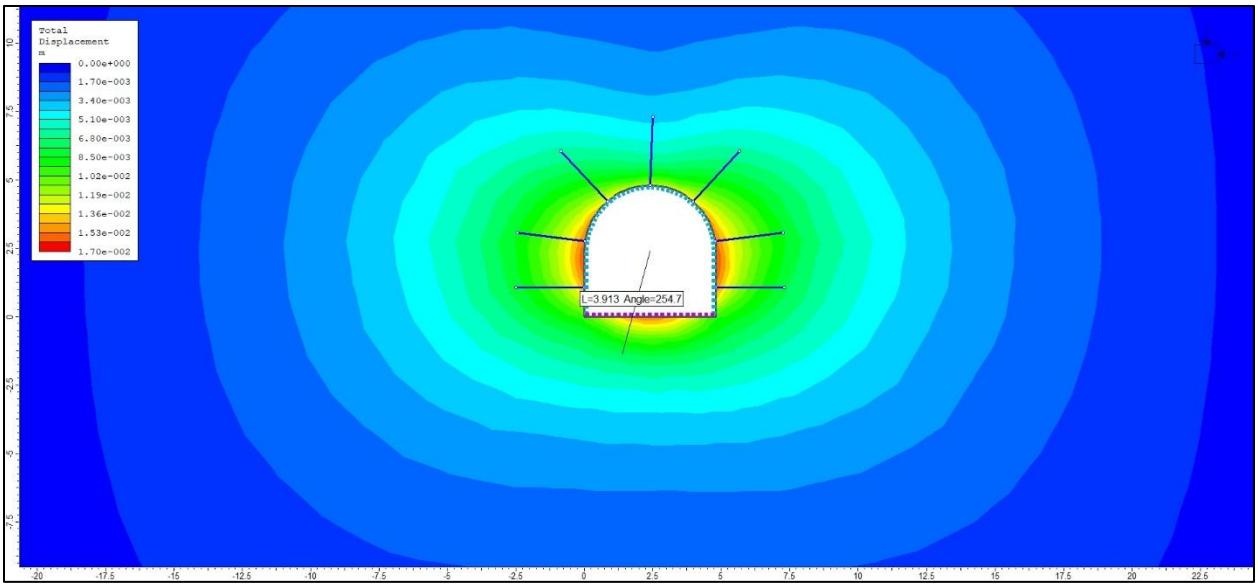


Fig: Radius of the plastic zone for support class

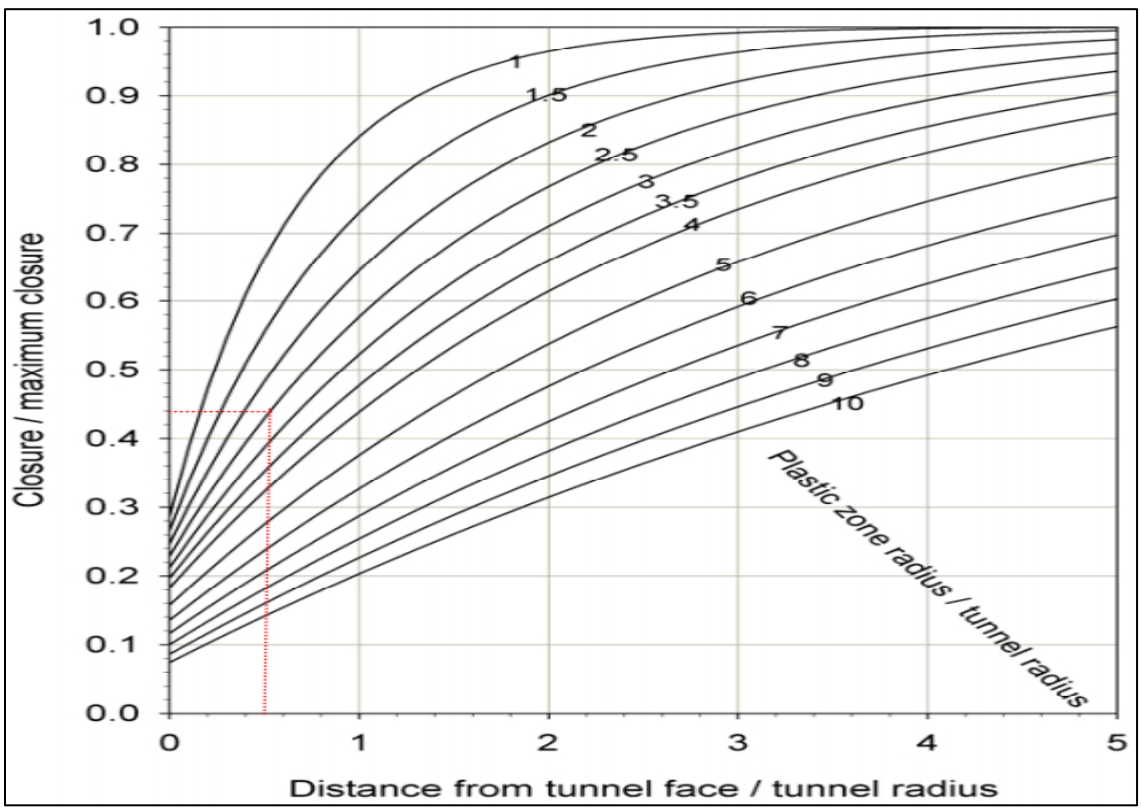


Fig: Vlachopoulos and Diederichs Plot

Plastic zone radius	3.913 m
Distance from tunnel face	2.5 m
Tunnel radius	2.4 m
Total displacement (from stage 10)	0.0165

Distance from tunnel face/ tunnel radius	0.833
Plastic zone radius/ tunnel radius	1.63
From graph Closure / Maximum closure =	0.68
So, closure	0.0112

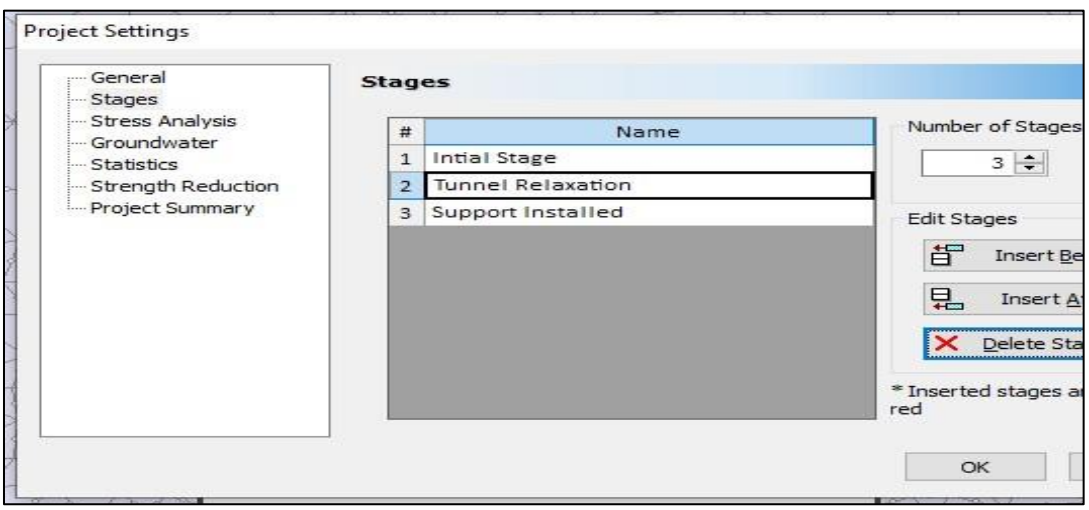
The tunnel roof displaces 0.0112 m before the support is installed.

16. Then the displacement vs stage was plotted. To create the graph, graph toolbar was clicked and then Graph Single Point vs Stage was selected. To enter the point, query toolbar was clicked and then query boundary was selected. Then the point on the boundary with highest value was selected.

17 Then click on the Plot button which creates the graph between total displacement on y-axis and Stage number in x-axis.

18 The sampler option was chosen by right clicking the plot and the sampler is moved until the displacement value is 0.0112

19 Then the screen was switched to the Phase2 Model Program by clicking on the Analysis and then Modeller. The Project Settings dialog was opened. The name of Stage 1 was changed to "Initial Stage", Stage 9 was changed to "Tunnel Relaxation" and that of Stage 10 was changed to "Support Installed".



20. To add the support bolts, the Properties toolbar was accessed, and the Define Bolts option was selected. The relevant bolt properties were then entered to specify their mechanical characteristics for the simulation.

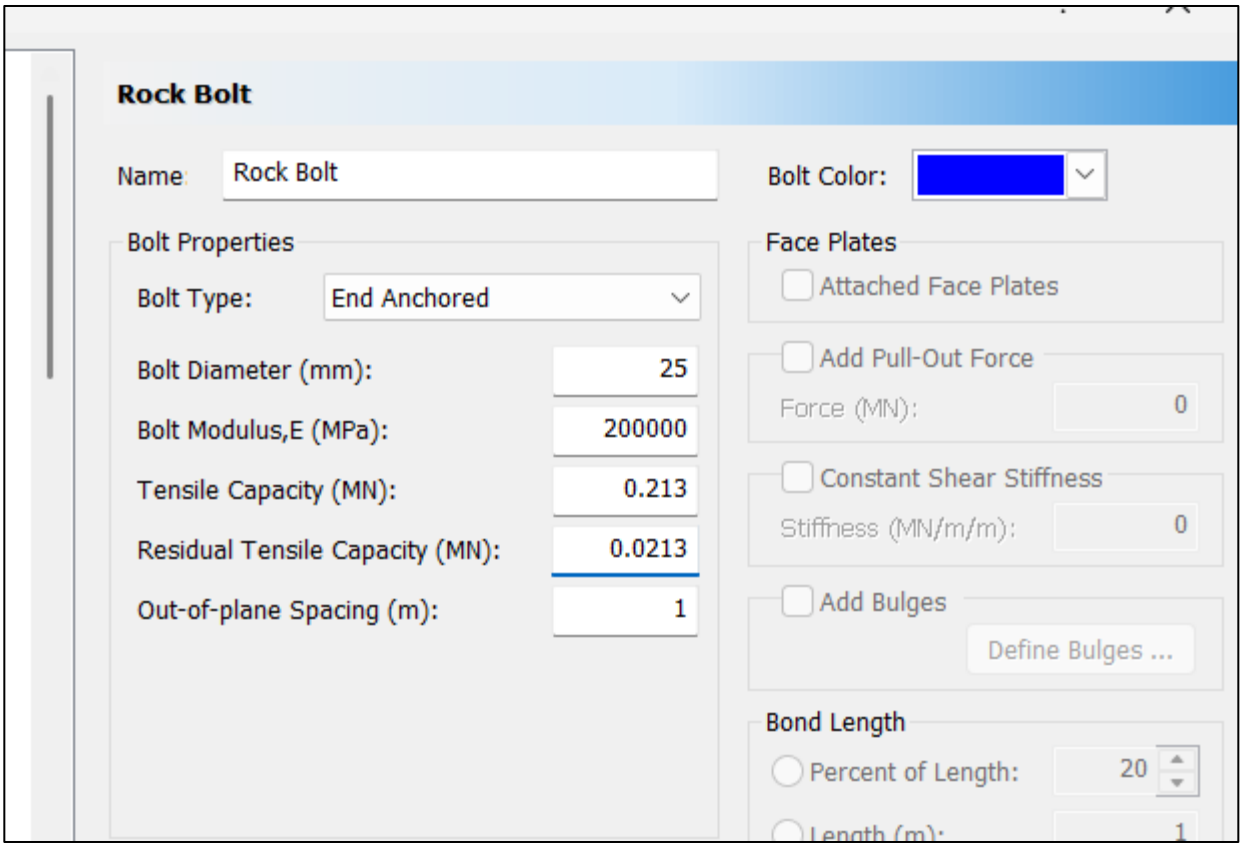


Fig: Rock bolt properties

21. Then click on add bolt pattern and specified bolt length and bolt spacing

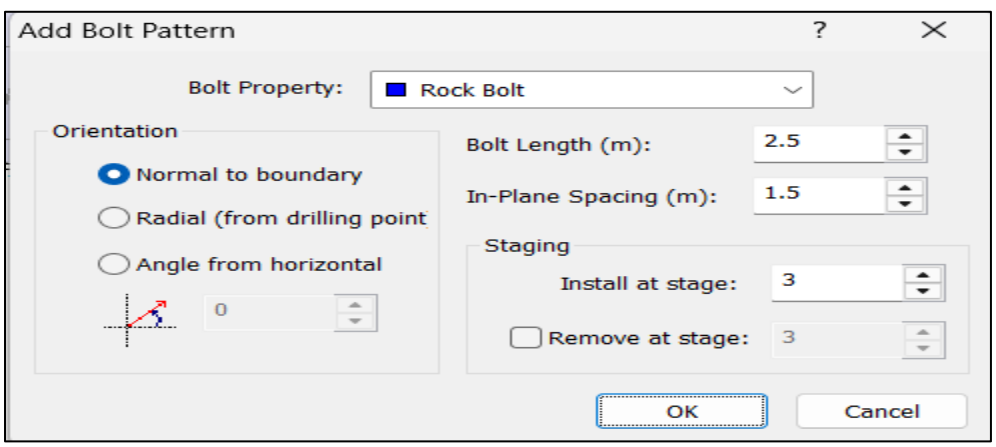


Fig: Bolt pattern

22. Then the Support button was clicked and add bolt option was selected. The bolts were added according to the number and spacing as per the design of support.

23. Then the lining was added. For the addition of lining, the properties toolbar was clicked and then “Define Liners” option was chosen. The properties of liners were inserted.

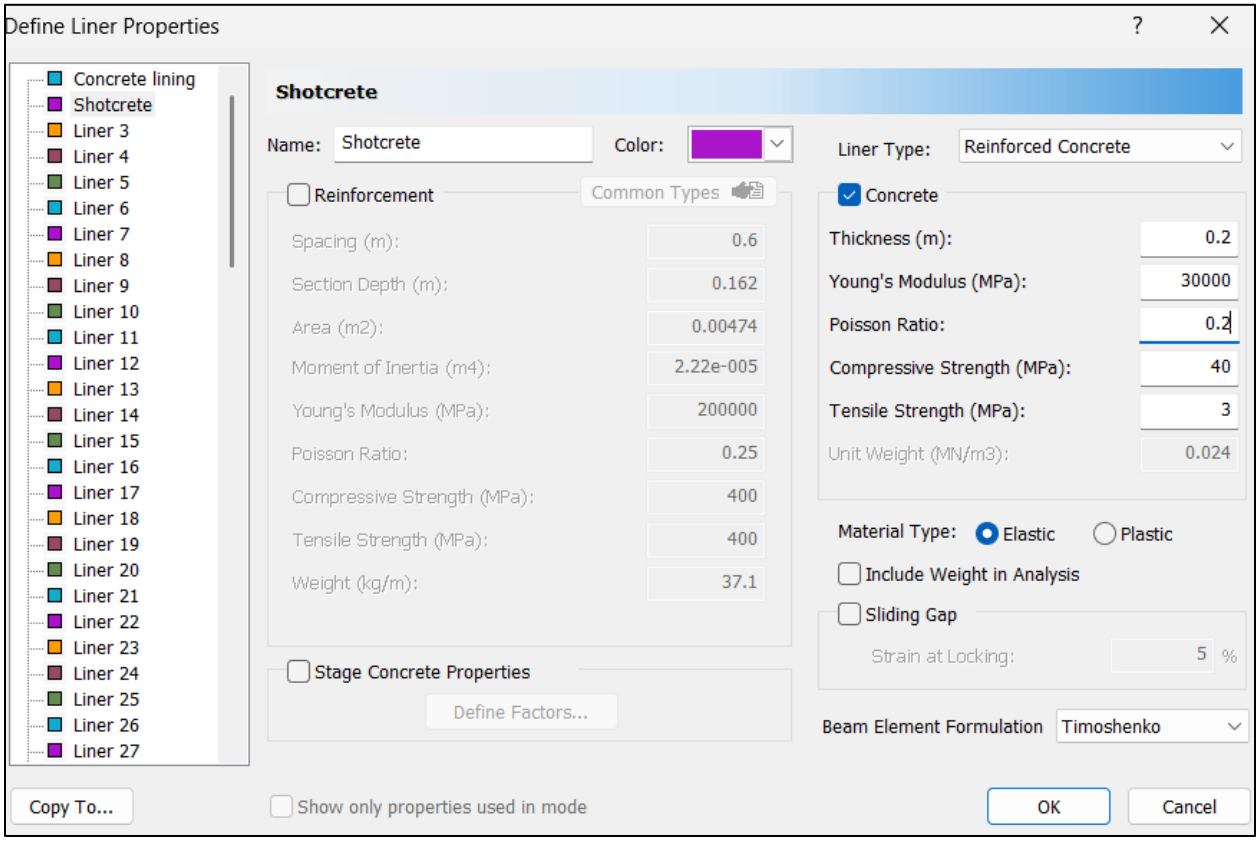


Fig: Fiber Shotcrete Properties

24. Then the Support button was clicked and “Add Liners” option was selected. The liners was added. The “Compute” button was selected and then “Interpret” button under “Analysis” Toolbar.

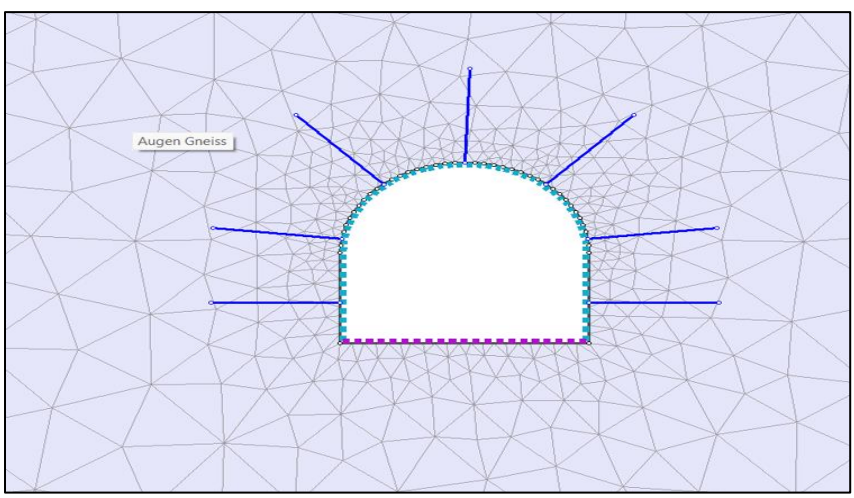


Fig: Tunnel after placement of preliminary support

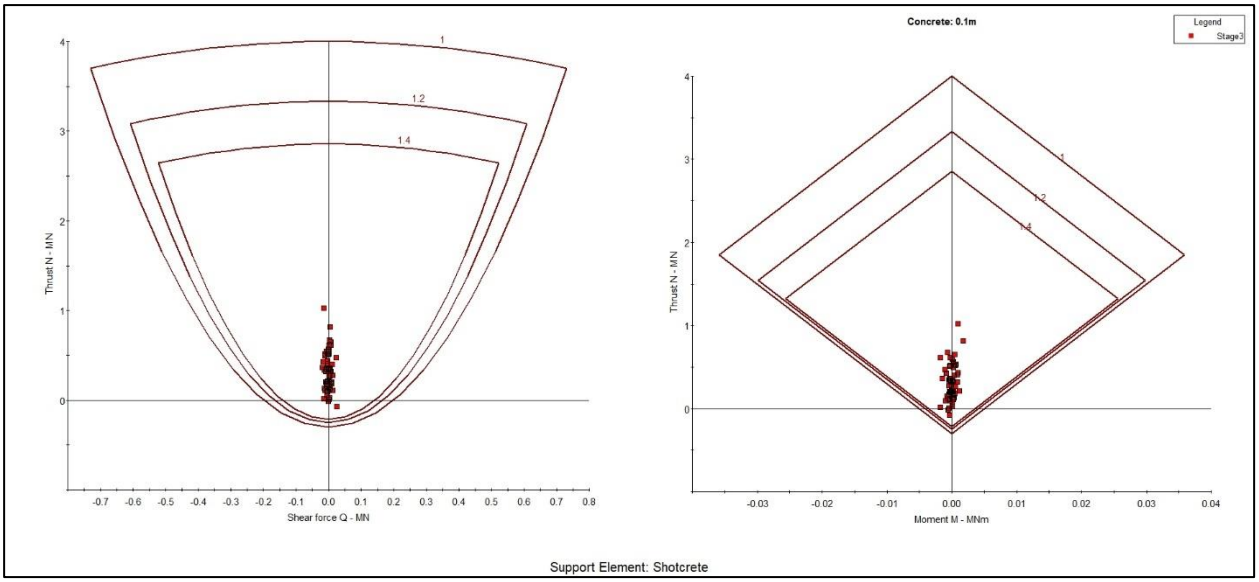
25. Go to Graph and select Support Capacity Plot. In the dialog box, choose the support element (e.g., liner type), number of envelopes, and relevant stages. A design factor of safety of 1.4 is used. The

dark red lines indicate capacity envelopes for safety factors of 1.0, 1.2, and 1.4. Liner points outside the envelope are at risk of cracking or crushing under load.

26. If the given preliminary support is not sufficient, we change the support type used. New support system is selected by the use of hit and trial and each support is checked by examining the support capacity plot. For this case, the support type found was:

    Fibre shotcrete of 10 cm

    Rock bolt at 1.5m spacing



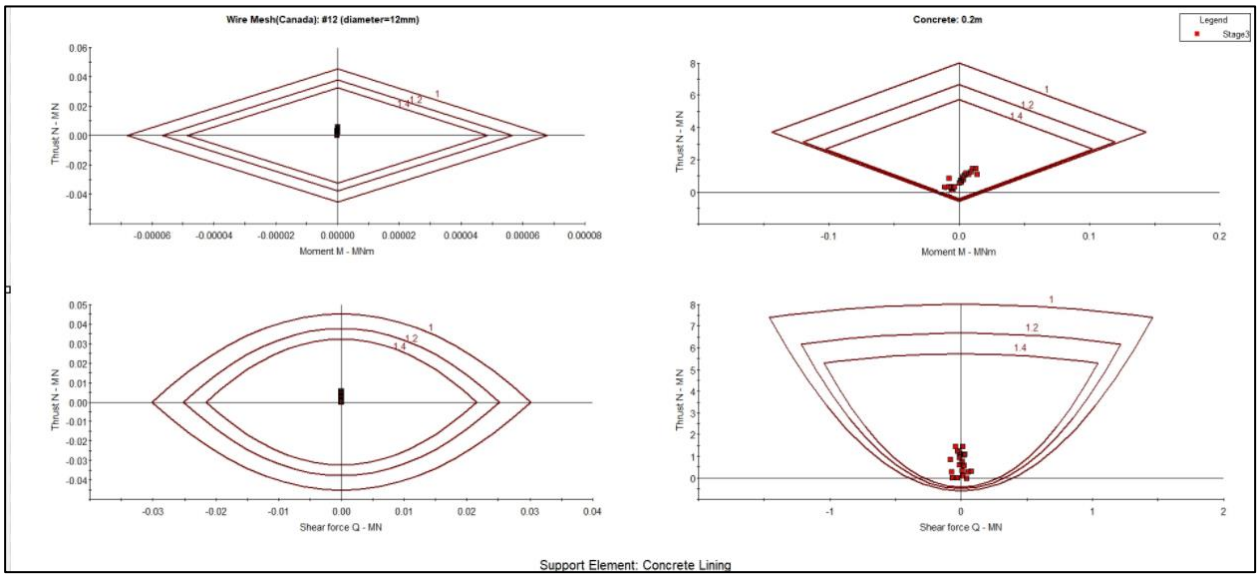


Fig: Support Capacity plots for the linings (Class III)

Hence, Support for a given tunnel for Rock Class III is designed.

Similarly, the analysis was repeated for other rock classes, and corresponding support capacity plots were generated for each case.

For Class II:

Support used: Bolts at spacing of 2m and length 2.5 m

Fiber Shotcrete of 5 cm

Concrete lining of 20cm at invert

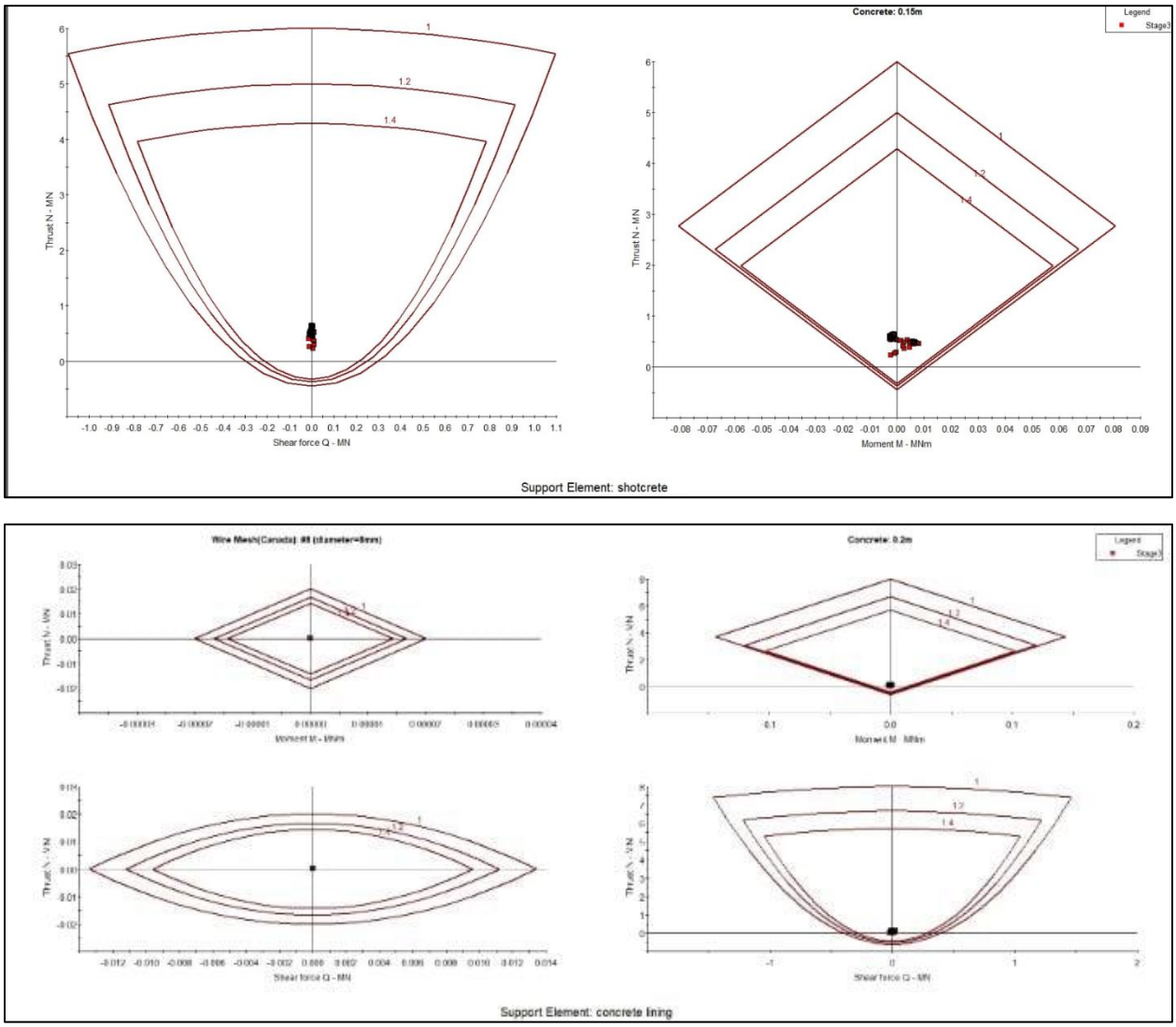


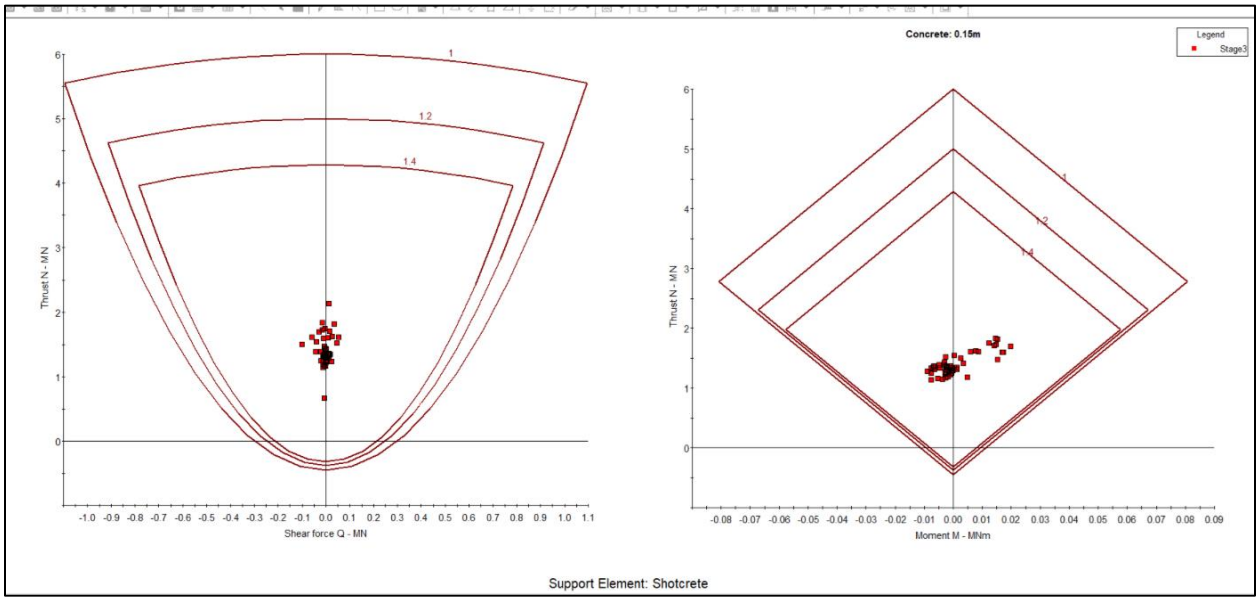
Fig: Support Capacity plots for the linings (Class II)

For Class IV:

Support used: Bolt at spacing of 1.5m and length 2.5m

Fiber Shotcrete of 15cm

Concrete lining of 20cm at invert



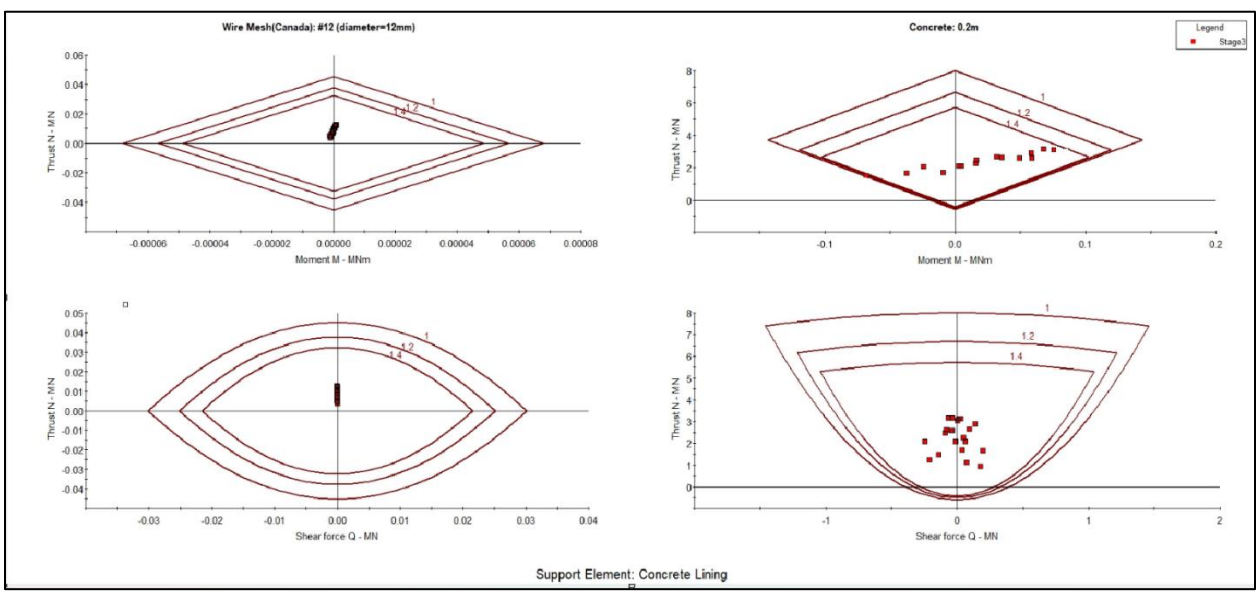


Fig: Support Capacity plots for the linings (Class IV)

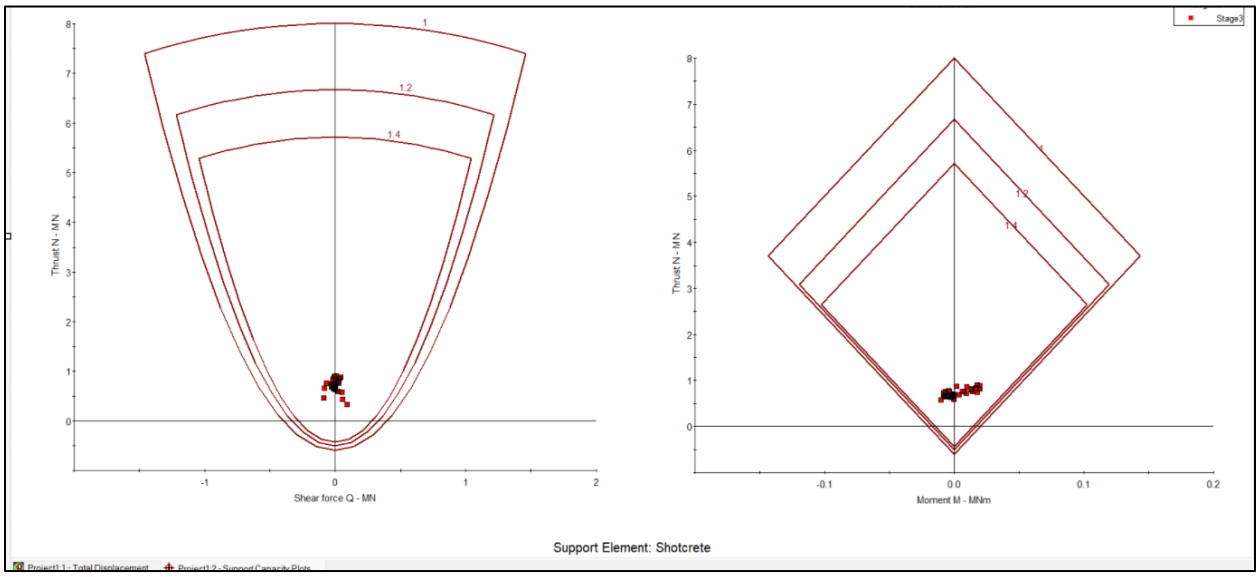
For Class V:

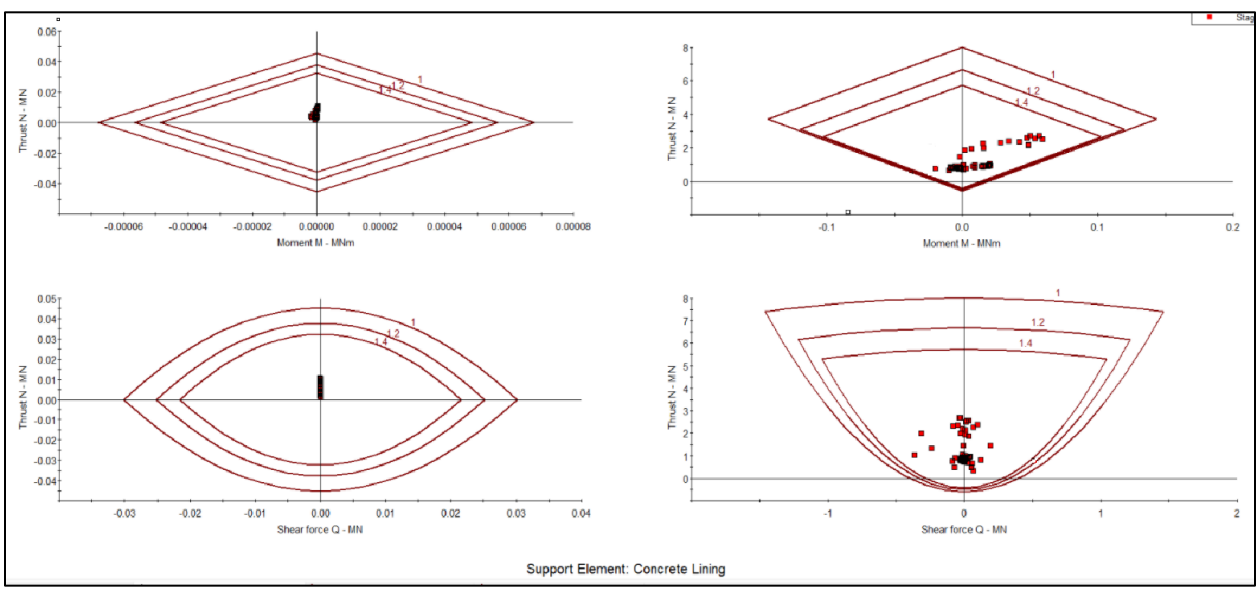
Support used: Bolt at spacing of 1m an length 2.5 m

Fiber Shotcrete of 15 cm

Concrete lining of 20 cm in wall and crown

Steel Ribs of ISMB 150*75 at 1.5m c/c





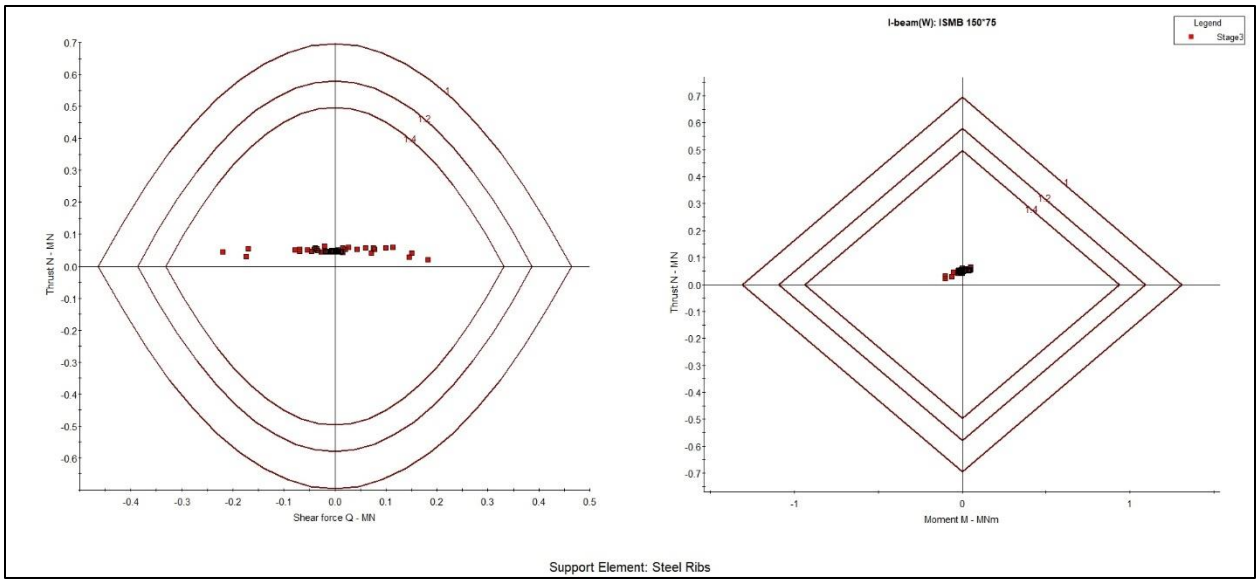


Fig: Support Capacity plots for the linings (Class V)

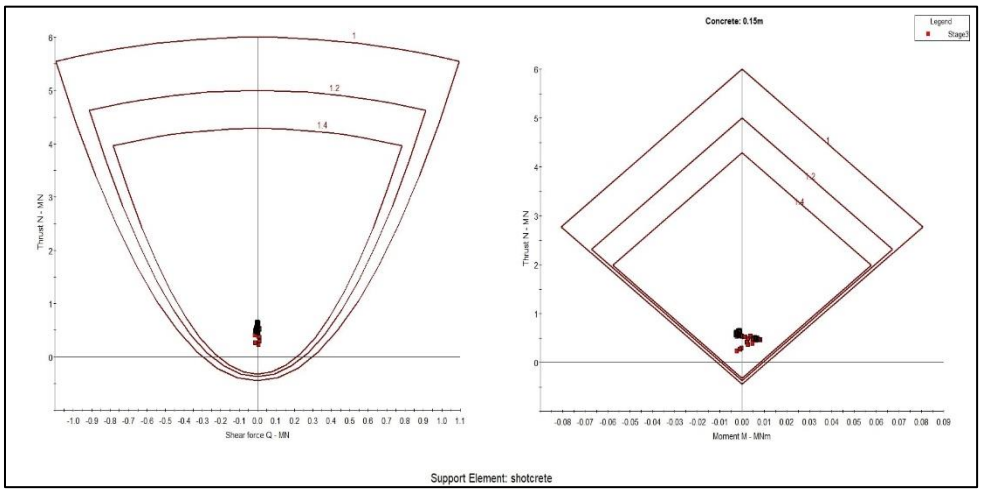
For Class VI:

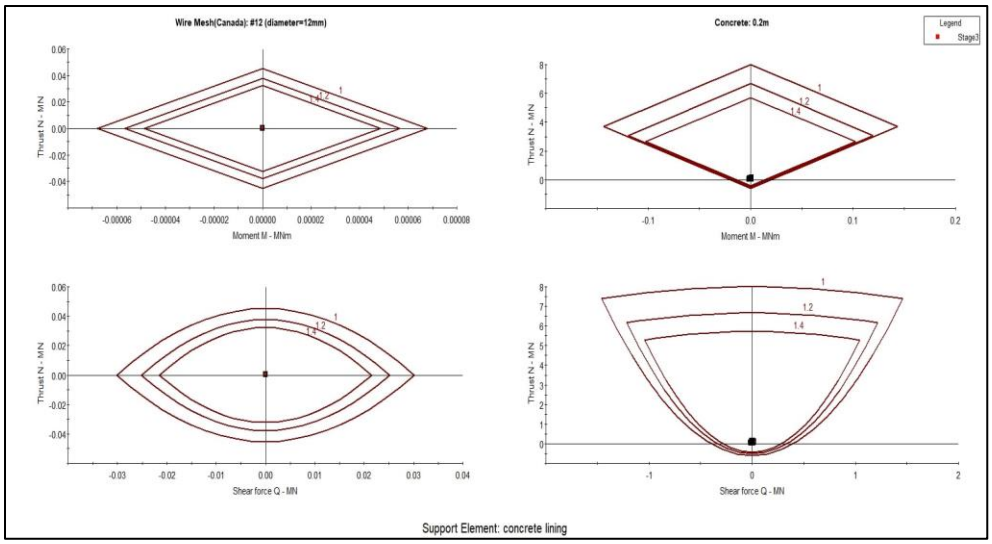
Support used: Bolt at spacing of 1m and length 2.5m

Fiber Shotcrete of 15 cm

Concrete lining of 30cm at invert and 25cm at wall and crown

Steel Ribs of ISMB 150*75 at 1.5m c/c





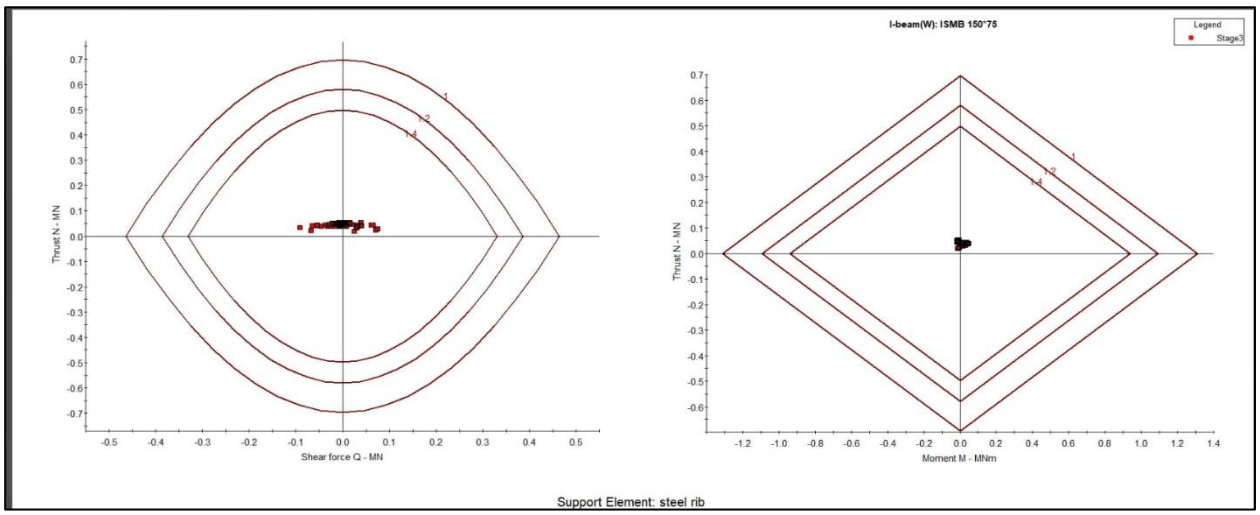


Fig: Support Capacity plots for the linings (Class VI)

ANNEX V - FINANCIAL ANALYSIS

Cost Estimates:

D-1 DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF CIVIL WORKS											
DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF WEIR, UNDERSLUICE, STILLING BASIN											
S.No.	**Description of Work**	**No.**	**Dimensions**				**Quantities (Q)**	**Total Quantities**	**Unit**	**Rate**	**Total cost**
			Length (m)	**Breadth (m)**	**Depth (m)**	**Area (m^2)**					
1	**Site clearance**										
	Weir,undersluice and divide wall	1				8255.630	8255.630	8255.630	m^2	25.000	206390.750
2	**Earthwork in Excavation**	1									
	Flood Wall										
	Cut	2	70	3	1.9		399.000	798.000	m^2		
	Weir										
	Cut	1	100	62.5	0.9		5625.000	5625.000			
	Undersluice										
	Cut	1	70	24	0.9		1512.000	1512.000			
							Total	**7935.000**		267.340	2121342.900
3	**C25 Concrete**										
	C25 Concrete at Weir	1	50			14.580	729.000	729.000	m^3		
	C25 Concrete at Undersluice	1	12			20.850	250.200	250.200	m^3		
	Total Binding Concrete(C15)							**979.200**	m^3	1397.350	1368285.120
4	**300mm boulder packing**										
	Weir	1	50			13.940	697.000	697.000	m^3		
	Undersluice	1	12			20.850	250.200	250.200	m^3		
	Total							**947.200**	m^3	5739.130	5436103.936

5	**C15 Concrete (Binding Concrete)**										
	C15 Concrete at Weir	1	50			14.580	50.000	50.000	m^3		
	C15 Concrete at Undersluice	1	12			20.580	246.960	246.960	m^3		
	Total C25 Concrete							**296.960**	m^3	16600.000	4929536.00
6	**Plum Concrete(40%)**										
	Weir portion	1	50			163.250	8162.500	8162.500	m^3		
	Undersluice portion	1	6			193.690	1162.140	1162.140	m^3		
	Divide wall and pier	2	81.5			14.350	1169.525	2339.050	m^3		
	Total Plum Concrete							**11663.690**	m^3	9845.120	114830427.693
7	**Launching Apron**								m^3		
	U/S Weir Portion	1			2	200.000	400.000	400.000	m^3		
	U/S Undersluice Portion	1			1	364.920	364.920	364.920	m^3		
	D/S Weir Portion	1			2	650.000	1300.000	1300.000	m^3		
	D/S Undersluice Portion	2			2	24.080	2.000	4.000			
	Total Apron							**2068.920**	m^3	5739.130	11873800.840
13	**Formworks**										
	U/S cutoff weir	1	50		2	200.000		200.000	m^2		
	U/S cutoff undersluice	1	12		4.9	117.600		117.600	m^2		
	D/S cutoff weir	1	50		4.5	450.000		450.000	m^2		

	D/S cutoff under sluice	1	12		3.9	93.600		93.600	m^2		
	Plum Concrete	1				371.290		371.290	m^2		
	Glacis	1				1092.000		1092.000	m^2		
	Formworks total					**2324.490**		**2440.715**	m^2	870.000	2123421.615
14	**Reinforcement**						3.564	27.974	ton	120000.000	3356835.84
15	**Guide Bund**										
	U/S River Training										
	Plum Concrete straight portion	2	41.6			41.84	1740.544	3481.088	m^3	9845.120	34271729.09
	Plum Concrete curve portion	2	49			37.26	1825.740	3651.480	m^3	9845.120	35949258.78
	Stone Pitching straight portion	2	41.6			8.51	354.016	708.032	m^3	5739.130	4063487.69
	Stone Pitching curve portion	2	49			20.52	1005.480	2010.960	m^3	5739.130	11541160.86
	D/S River Training	2	9.2			50.54	464.968	929.936	m^3	9845.120	9155331.51
	Total cost										**241227112.63**

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF INTAKE AND GRAVEL TRAP												
S. N	**Description of Work**	**No.**	**Dimensions**					**Quantities (Q)**	**Total Quantities**	**Unit**	**Rate**	**Cost**
			Length (m)	**Breadth (m)**	**Depth (m)**	**Plan Area(m^2)**	**Sectional Area (m^2)**					
1	**Site clearance**											

	Intake	**1**				200.200		200.200	200.200	m^2		
	Gravel trap	**1**				1498.450		1498.450	1498.450	m^2		
	Total site clearance								**1698.650**	m^2	25.000	42466.250
2	**Earthwork in Excavation**											
	Intake	1	5.5				333.460	1834.030	1834.030	m^3		
	Gravel trap	1	30				301.300	9039.000	9039.000	m^3		
	Total Exacavation								**10873.030**	m^3	272.240	2960073.687
3	**300mm boulder packing**											
	Intake	1	5.5				11.200	61.600	61.600			
	Gravel trap	1	30				33.560	1006.800	1006.800			
	Total boulder packing								**1068.400**	m^3	5739.130	6131686.492
4	**Concrete(C25)**											
	Intake main portion	1	5.5				66.100	364.150	364.150	m^3		
	Pier	1	7.7				13.380	103.026	103.026			
	Gravel Trap	1	30				64.730	1941.900	1941.900	m^3		
	Total Concrete								**2409.076**	m^3	16600.000	39990661.600
5	**Formworks**											
	Intake											
	Outside Face	2	5.5		9			49.500	99.000	m^2		
	Inside Face	2	5.5		9			49.500	99.000	m^2		
	Gravel Trap											
	Outside Face	2	62		10.8			669.600	1339.200	m^2		
	Inside Face	2	26		10.8			280.800	561.600	m^2		
	Formworks Total								**2518.560**	m^2	870.000	2191147.200

6	**Trashrack**	64	2.26				314.159	0.001	356.704	kg	130.000	46371.516
7	**Reinforcement(Total)**								226.935	Tons	133885.450	30383289.133
	Total Cost											**81745695.878**

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF APPROACH CANAL												
S. N	**Description of Work**	**No.**	**Dimensions**					**Quantities (Q)**	**Total Quantities**	**Unit**	**Rate**	**Cost**
			Length (m)	**Breadth (m)**	**Height (m)**	**Plan Area**	**Sectional Area (m^2)**					
1	**Site clearance**											
	Canal	2				2904.84			5809.680	m^2	25.000	145242.000
2	**Earthwork in Excavation**											
	Canal	2	645.520	4.5	3.3			9585.972	########	m^3	1530.120	29335374.953
3	**Binding concrete(C15)**											
	Canal	2	645.52				3.51	2265.775	4531.550	m^3	1397.350	6332161.951
4	**300 mm boulder packing**											
	Canal	2	645.52				3.83	2472.342	4944.683	m^3	5739.130	28378179.694
5	**Concrete (C25)**											
	Canal	2	645.52				3.28	2117.306	4234.611	m3	16600.000	70294545.920
6	**Formworks**	2	645.520		4.12			2659.542	5319.085	m^2	870.000	4627603.776

7	**Reinforcement (Total)**								825.772	ton	133885.450	110558912.413
	Total Cost											**249672020.7**

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF SETTLING BASIN AND HEADPOND												
S. N	**Description of Work**	**No.**	**Dimensions**					**Quantities (Q)**	**Total Quantities**	**Unit**	**Rate**	**Cost**
			Length (m)	**Breadth (m)**	**Height (m)**	**Plan Area(m^2)**	**Sectional Area (m^2)**					
1	**Earthwork in Excavation**	2	19.50				2459.08	47952.06	95904.12	m^3	1530.12	146744812.09
2	**Binding Concrete(C15)**											
	Settling Basin	2	154.48				12.31	1901.65	3803.30	m^3		
	Inlet Transition	2	11.91				17.51	208.46	416.91	m3		
	Outlet Transition	1	21.61				13.74	296.92	296.92			
	Total C15 concrete								4517.13	m^3	1397.35	6312014.54
3	**Concrete(C25)**											
	Settling Zone	1	154.20				151.39	23344.34	23344.34	m^3		
	Deduction of Plum Concrete	1	154.20				128.68	19842.69	19842.69			
	Inlet Transition	2										
	Area at Start						28.71					
	Area at End						34.64					
	Inlet Transition	2	34.83				6.34	220.65	441.30	m^3		
	Outlet Transition	1	46.50				6.44	299.41	299.41	m^3		
	Total C25 Concrete								4242.36	m^3	16600.000	70423180.98
4	**Formworks**											

	For Settling Zone											
	Outside face	4	154.20		19.00			2929.80	11719.20	m^2		
	Inside face	4	154.20		19.00			2929.80	11719.20	m^2		
	For Inlet Transition											
	Outside face	4	34.83		16.00			557.28	2229.12	m2		
	Inside face	4	34.83		16.00			557.28	2229.12	m^2		
	For Outlet Transition											
	Outside face	2	46.50		19.00			883.50	1767.00			
	Inside face	2	46.50		19.00			883.50	1767.00			
	Total Form Work								31430.64	m^2	870.00	27344656.80
5	**Reinforcements**								399.63	Ton	120000.00	47955640.83
6	**Gates**											
	Flushing Gates	2										
	Retaining Gates	2										
7	**300mm stone pitching**											
	Settling basin	1	154.48				135.95	21001.56	21001.56			
	Inlet transition	2	11.91				18.70	222.62	445.25			
	Outlet Transition	1	46.50				32.20	1497.07	1497.07			
	300mm total quantity								22943.87	m^3	5739.13	131677855.50
	Total Cost											**430458160.75**

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF HEADRACE TUNNEL									
S. N	**Description of Work**	**No.**	**Dimensions**			**Unit**	**Rate**	**Cost**	**Remarks**

			Length (m)	Perimeter (m)	Height (m)	Sectional Area (m^2)	Quantities (Q)	Total Quantities				
1	**Earthwork in Excavation for all types of rocks combined**	1	5724	19.6	5.45	26.67	152659.08	167924.99	m^3	15300	2569272467	Increment by 10%
2	**Fiber Shotcrete**											
	For class II-50 mm thick	1	715.5	24.82	0.05	17758.71	887.94		m^2			
	For class III-100 mm thick	1	1431	24.97	0.1	35732.07	3573.21		m^2			
	For class IV-150 mm thick	1	1431	25.23	0.15	36104.13	5415.62		m^2			
	For class V-150 mm thick	1	1431	27.40	0.15	39209.40	5881.41		m^2			
	For class VI-150 mm thick	1	715.5	27.90	0.15	19962.45	2994.37		m^2			
								18752.54	m^3			
	Total		5724					20627.79	m^3	13500	278475212	Increment by 10%
3	**Formworks**											
	Side wall	2	5724		2.6		14882.40	29764.80	m^2			

	Semicircular roof	1	5724	4.800			27475.20	27475.20	m^2			
	Total formworks							62964.00	m^2	870	54778680	Increament by 10%
5	**Rock Bolts**											
	For class II	2504	2.5			0.0004909	0.01	24.20	ton			2.5 m length bolts @ 2 m C/C spacing
	For class III	8586	2.5			0.0004909	0.01	82.97	ton			2.5 m length bolts @ 1.5 m C/C spacing
	For class IV	8586	2.5			0.0004909	0.01	82.97				2.5 m length bolts @ 1.3 m C/C spacing
	For class V	18603	2.5			0.0004909	0.01	179.76				2.5 m length bolts @ 1 m C/C spacing
	For class VI	7870.5	2.5			0.0004909	0.01	76.05	ton			2.5 m length bolts @ 1 m C/C spacing
	Total							445.94	ton	588006	262213069	
6	**Concrete Lining**											
	Side wall in Rock class V	1	1431			2.46	3520.26	3520.26				
	Side wall in Rock class VI	1	715.5			3.16	2260.98	2260.98				
							Total	6359.36	m^3	16677	106055686	Increment by 10%
7	**Steel reinforcement**											
	Bar	1					600.88	600.88	ton			1.2% of total concrete
								600.88	ton	220932	132754442	

8	**Invert lining**											
	Combined	1	6358	10.2	0.2		64851.60	12970.32	m^3			
							total	14267.35		15174	216493513	Incremental by 10%
9	**Steel ribs**	1431						21.47	ton	120000	2575800	
	ISMB 150*75(1kg/m)											
	Total cost										1053346402	
	Final cost										**1264015682**	20% extra for miscellaneous

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF SURGE TANK									
S.N.	**Particular of Items**	**No.**	**Height (m)**	**Sectional Area, m^2**	**Quantity (m^3)**	**Unit**	**Rate**	**Cost**	**Remarks**
1	**Earthwork in Excavation**	1	25.6	111.220	2847.23	m^3	5596.16	15933566	Diameter of Excavation = Outside Dia. Of Surge Tank + 1m (Considering 0.5m clearance radially)
2	**Concrete Lininig**								
	Straight Portion	1	29.8	10.360	308.728	m^3			
	Total				308.728	m^3	18530.2	5720792	

3	**Reinforcement**				29.08	ton	108454.2	3154085	Assuming 1.2% of total volume of concrete
4	**Formwork**	1			1122.49	m^2	1159.33	1301336	
	Total							**26109779**	

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF PENSTOCK											
S.N.	**Particular of Items**	**No.**	**Length (m)**	**Breadth (m)**	**Height (m)**	**Sectional Area, m^2**	**Quantity (m^3)**	**Unit**	**Rate**	**Cost**	**Remarks**
1	**Earthwork in Excavation**	1	45.92	3.65		10.46	480.3232	m^3	4735	2274330.352	
2	**Cost of pipe**		301.38	0.025			682.026	ton	100000	68202600	
	Total cost									**70476930.35**	

DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF ANCHOR BLOCK											
S. N.	**Particular of Items**	**No.**	**Length (m)**	**Breadth (m)**	**Height (m)**	**Sectional Area, m^2**	**Quantity (m^3)**	**Unit**	**Rate**	**Cost**	**Remarks**
1	**Earthwork in Excavation**										Depth Taken as the Highest Depth from the Surface
	Anchor Block 1	1	10.04	5.25	4.22	42.37	222.44	m^3			
	Anchor Block 2	1	10	5.25	2.53	25.30	132.83	m^3			
	Anchor Block 3	1	10	5.25	2.73	27.30	143.33	m^3			
	Anchor Block 4	1	10	5.25	3.69	36.90	193.73	m^3			

	Total						761.54	m^3	4735	3606055	Increment of 10%
2	**Plain Concrete in Base(1:3:6)**										Thickness of Plain Concrete = 0.1m
	Anchor Block 1	1	10.24	5.45	0.1	1.02	5.58	m^3			0.6m for stone and PCC offset
	Anchor Block 2	1	10.2	5.45	0.1	1.02	5.56	m^3			
	Anchor Block 3	1	10.2	5.45	0.1	1.02	5.56	m^3			
	Anchor Block 4	1	10.2	5.45	0.1	1.02	5.56	m^3			
	Total						22.26	m^3	9161	203895	
3	**Stone Soling**										Thickness of stone soling = 0.2m
	Anchor Block 1	1	10.24	5.45	0.15	1.54	8.37	m^3			0.6m for stone and PCC offset
	Anchor Block 2	1	10.2	5.45	0.15	1.53	8.34	m^3			
	Anchor Block 3	1	10.2	5.45	0.15	1.53	8.34	m^3			
	Anchor Block 4	1	10.2	5.45	0.15	1.53	8.34	m^3			
	Total						33.39	m^3	3047	101720	
4	**Reinforced Concrete for Blocks**										
	Anchor Block 1	1		5.25		37.84	198.66	m^3			
	Anchor Block 2	1		5.25		68.52	359.73	m^3			
	Anchor Block 3	1		5.25		69.07	362.62	m^3			
	Anchor Block 4	1		5.25		67.60	354.90	m^3			
	Total						1275.91	m^3			
	Less Penstock Volume										

	Anchor Block 1	1	10.24			10.46	107.11	m^3			
	Anchor Block 2	1	10.2			10.46	106.69	m^3			
	Anchor Block 3	1	10.2			10.46	106.69	m^3			
	Anchor Block 4	1	10.2			10.46	106.69	m^3			
	Total						427.19	m^3			
	Total volume of concrete						848.72	m^3	8782	7453868	
5	**Formwork**						1018.47	m^2	1159	1180737	
6	**Reinforcement**						79.95	ton	94063	7520288	1.2% of total concrete Volume
	Total Cost									**20066563**	

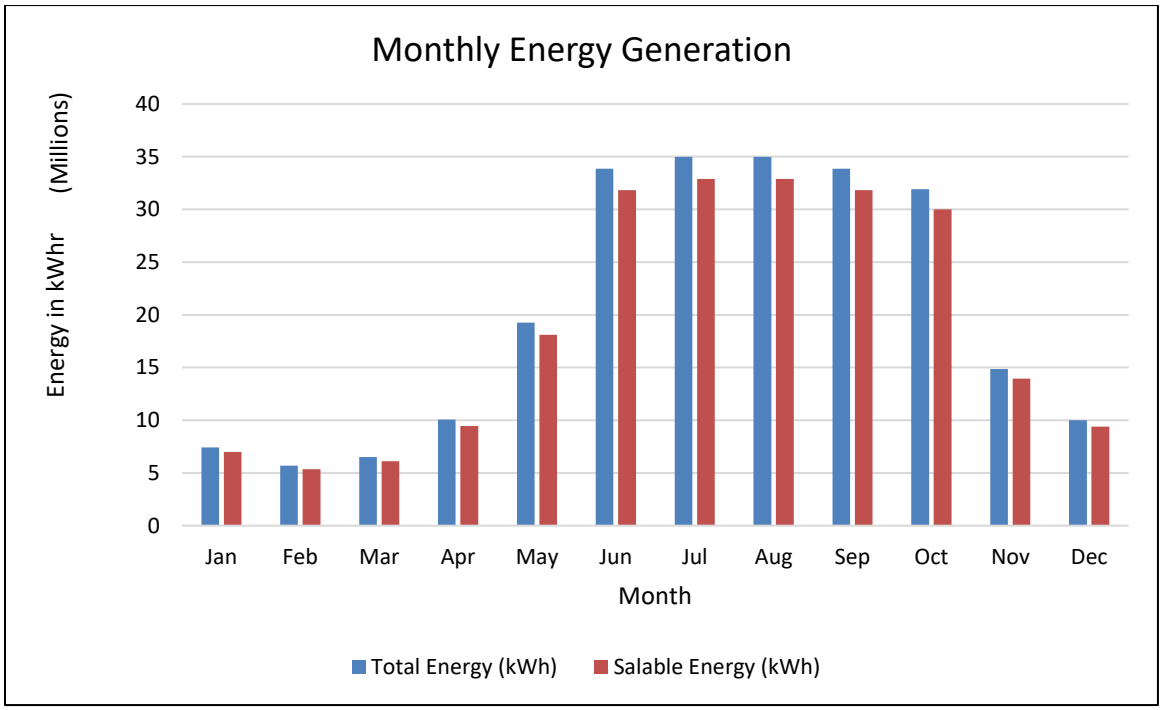
DETAILS OF MEASUREMENT AND CALCULATION OF QUANTITIES OF POWERHOUSE										
S.N.	**Particular of Items**	**No.**	**Length (m)**	**Breadth (m)**	**Height/Depth (m)**	**Area (m2)**	**Quantity (m^3)**	**Unit**	**Rate (NRs.)**	**Cost (NRs.)**
A.	**Civil Works**									
1	Earthwork in Excavation		62.76	26.77	12.55		21085.07	m^3	4305	90765530
2	Structural Concrete									
	Column (M25)	56	5.19	0.85	0.85		209.99	m^3	15123	3175587
	Tie Beam									
	Tie Beam 3.79m (M35)	16	3.79	0.42	0.28		7.13	m^3	15123	107844
	Tie Beam 5.34m (M35)	28	5.34	0.42	0.28		17.58	m^3	15123	265912
	Tie Beam 5.79m (M35)	12	5.79	0.42	0.28		8.17	m^3	15123	123566

	Crane Beam (M35)	2	62.76	0.97	1.00		121.80	m^3	15123	1841888
	Corbel (M35)	2	62.76	0.40	0.20		10.04	m^3	15123	151857
	Generator Floor (M35)	1	62.75	20.77	0.25		325.83	m^3	15123	4927436
	Erection Floor (M35)	1	62.75	20.77	0.25		325.83	m^3	15123	4927436
	Control Room (M35)	1	18.57	5.40	0.21		21.06	m^3	15123	318461
	MIV Pedestal (M35)	3	3.38	3.38	0.30		10.28	m^3	15123	155492
	Staircase (M25)	2	2.11			1.25	5.28	m^3	15123	79773
3	Formwork						3495.64	m^2	1159	4052600
4	Reinforcement						100.13	ton	94063	9418819
5	Brickwork									
	3.79m	16	3.79		4.77		289.25	m^2	2500	723132
	5.34m	28	5.34		4.77		713.21	m^2	2500	1783026
	5.79m	12	5.79		4.77		331.42	m^2	2500	828549
6	Plastering	78	5.18	0.10	4.73		191.11	m^2	382	73033
	m									**123719940**
B.	**Mechanical & Electrical Equipments**									
1	Turbine	3							161956670	485870010
2	Governor Equipment	3							26525187	79575561
3	Main Inlet Valve	3							39889801	119669402
4	Machine Hall Crane	1							17343392	17343392
5	Hydro-Generator	3							144163237	432489711
	Grand Total									**1134948075**

Revenue Generation:

Revenue Calculation

Data	Value	Unit
Design Discharge	48.83	m^3/s
Turbine Efficiency	0.90	
Generator Efficiency	0.97	
Transformer Efficiency	0.985	
Overall Efficiency	0.86	
Gross Head	124.46	m
Net Head	120.14	m
Dry season energy rate	8.4	Rs per kWhr
Wet season energy rate	4.8	Rs per kWhr
Dry season outage	5%	%
Wet season outage	5%	%
Environmental flow	10%	%
Installed Capacity	49.49	MW



POWER GENERATION BY THE KABELI-A HYDROELECTRIC PROJECT:

Month	No of days	Monthly flow (m^3/s)	Env. Release (m^3/s)	Available Flow (m^3/s)	Design Flow (m^3/s)	Gross Head	Head Loss	Net Head (m)	Power Generation (kW)
Jan	31	10.98	0.945	10.03	10.03	124.46	0.33	124.13	10505.58
Feb	28	9.45	0.945	8.50	8.50	124.46	0.28	124.18	8908.61
Mar	31	9.72	0.945	8.77	8.77	124.46	0.28	124.18	9190.35
Apr	30	15.01	0.945	14.07	14.07	124.46	0.50	123.96	14711.29
May	31	27.19	0.945	26.25	26.25	124.46	1.36	123.10	27254.99
Jun	30	68.00	0.945	67.05	48.83	124.46	4.32	120.14	49487.31
Jul	31	139.40	0.945	138.45	48.83	124.46	4.32	120.14	49487.31
Aug	31	155.98	0.945	155.04	48.83	124.46	4.32	120.14	49487.31
Sep	30	105.09	0.945	104.14	48.83	124.46	4.32	120.14	49487.31
Oct	31	45.22	0.945	44.28	44.28	124.46	3.58	120.88	45151.16
Nov	30	21.77	0.945	20.83	20.83	124.46	0.91	123.55	21708.80
Dec	31	14.48	0.945	13.53	13.53	124.46	0.47	123.99	14151.69

REVENUE GENERATION BY KHIMTI II PROJECT:

Month	Operating (hrs.)	Dry Energy (kWh)	Wet Energy (kWh)	Total Energy (kWh)	Outage/Transmission loss (kWh)	Salable Energy (kWh)	PPA Rate (NRs.)	Monthly Revenue (NRs.)
Jan	706.8	7425345.316		7425345.316	445520.719	6979824.597	8.4	58630526.62
Feb	638.4	5687257.382		5687257.382	341235.4429	5346021.939	8.4	44906584.29
Mar	706.8	6495738.527		6495738.527	389744.3116	6105994.215	8.4	51,290,351.41
Apr	684		10062521.64	10062521.64	603751.2981	9458770.337	4.8	45,402,097.62

May	706.8		19263830.35	19263830.35	1155829.821	18108000.52	4.8	86,918,402.52
Jun	684		33849318.96	33849318.96	2030959.138	31818359.82	4.8	152,728,127.14
Jul	706.8		34977629.59	34977629.59	2098657.775	32878971.82	4.8	157,819,064.71
Aug	706.8		34977629.59	34977629.59	2098657.775	32878971.82	4.8	157,819,064.71
Sep	684		33849318.96	33849318.96	2030959.138	31818359.82	4.8	152,728,127.14
Oct	706.8		31912838.01	31912838.01	1914770.281	29998067.73	4.8	143,990,725.12
Nov	684		14848819.01	14848819.01	890929.1409	13957889.87	4.8	66,997,871.39
Dec	706.8	10002415.85		10002415.85	600144.9511	9402270.9	8.4	78,979,075.56
SUM		29610757.08	213741906.1	243352663.2	14601159.79	228751503.4		1,198,210,018.24

FINANCIAL EVALUATION:

Total Construction Period	3	
Economic Life of Project	30	Years
Economic Life of Electromechanical equipment	25	Years
Economic Life of Transmission Line	25	Years
Discount Rate	12	%
Annual Cost of operation and Maintenance	2.5	%
Design Discharge	48.83	m3/s
Installed Capacity	49.49	MW
Gross Head	124.46	m
Net Head	120.14	m
Head Loss	4.32	m
Wet Months	16th of Jestha to 15th of Mangsir	
Dry Months	16th of Mangsir to 15th of Jestha	
Dry energy rate	8.4	Rs/KWhr
Wet energy rate	4.8	Rs/KWhr
Turbine Efficiency	90	%
Generator Efficiency	97	%
Hydraulic Efficiency	98	%
Transformer Efficiency	98.5	%
Overall efficiency	86	%
Transmission Efficiency	98	%
Riparian Release	10% of mimimum flow	
Outage	5	%

DEPRECIATION OF THE PROJECT COMPONENTS:

DEPRECIATION ON HM EQUIPMENTS:

Depreciation of Hydro mechanical components = 20%				
End of Year	**Opening Balance**	**Depreciation**	**Cumulative Depreciation**	**Closing Balance**
1	202,721,896.50	40,544,379.30	40,544,379.30	162,177,517
2	162,177,517.20	32,435,503.44	72,979,882.74	129,742,014
3	129,742,013.76	25,948,402.75	98,928,285.49	103,793,611
4	103,793,611.01	20,758,722.20	119,687,007.69	83,034,889
5	83,034,888.81	16,606,977.76	136,293,985.45	66,427,911
6	66,427,911.05	13,285,582.21	149,579,567.66	53,142,329
7	53,142,328.84	10,628,465.77	160,208,033.43	42,513,863
8	42,513,863.07	8,502,772.61	168,710,806.04	34,011,090
9	34,011,090.46	6,802,218.09	175,513,024.14	27,208,872

10	27,208,872.36	5,441,774.47	180,954,798.61	21,767,098
11	21,767,097.89	4,353,419.58	185,308,218.19	17,413,678
12	17,413,678.31	3,482,735.66	188,790,953.85	13,930,943
13	13,930,942.65	2,786,188.53	191,577,142.38	11,144,754
14	11,144,754.12	2,228,950.82	193,806,093.20	8,915,803
15	8,915,803.30	1,783,160.66	195,589,253.86	7,132,643
16	7,132,642.64	1,426,528.53	197,015,782.39	5,706,114
17	5,706,114.11	1,141,222.82	198,157,005.21	4,564,891
18	4,564,891.29	912,978.26	199,069,983.47	3,651,913
19	3,651,913.03	730,382.61	199,800,366.08	2,921,530
20	2,921,530.42	584,306.08	200,384,672.16	2,337,224
21	2,337,224.34	467,444.87	200,852,117.03	1,869,779
22	1,869,779.47	373,955.89	201,226,072.92	1,495,824
23	1,495,823.58	299,164.72	201,525,237.64	1,196,659
24	1,196,658.86	239,331.77	201,764,569.41	957,327
25	957,327.09	191,465.42	201,956,034.83	765,862

DEPRECIATION ON PRELIMINARY EXPENSES:

Preliminary Expenses

Year	**Opening Balance**	**Depreciation**	**Accumulated Depreciation**	**Closing Balance**
1	400,000,000	40,000,000	40,000,000	360,000,000
2	360,000,000	36,000,000	76,000,000	324,000,000
3	324,000,000	32,400,000	108,400,000	291,600,000
4	291,600,000	29,160,000	137,560,000	262,440,000
5	262,440,000	26,244,000	163,804,000	236,196,000
6	236,196,000	23,619,600	187,423,600	212,576,400
7	212,576,400	21,257,640	208,681,240	191,318,760
8	191,318,760	19,131,876	227,813,116	172,186,884
9	172,186,884	17,218,688	245,031,804	154,968,196
10	154,968,196	15,496,820	260,528,624	139,471,376

DEPRECIATION ON EM EQUIPMENT:

Depreciation of Electro mechanical components = 20%				
End of Year	**Opening Balance**	**Depreciation**	**Cumulative Depreciation**	**Closing Balance**
1	1,292,818,695.00	258,563,739.00	258,563,739.00	1,034,254,956
2	1,034,254,956.00	206,850,991.20	465,414,730.20	827,403,965
3	827,403,964.80	165,480,792.96	630,895,523.16	661,923,172
4	661,923,171.84	132,384,634.37	763,280,157.53	529,538,537
5	529,538,537.47	105,907,707.49	869,187,865.02	423,630,830
6	423,630,829.98	84,726,166.00	953,914,031.02	338,904,664
7	338,904,663.98	67,780,932.80	1,021,694,963.81	271,123,731
8	271,123,731.19	54,224,746.24	1,075,919,710.05	216,898,985
9	216,898,984.95	43,379,796.99	1,119,299,507.04	173,519,188
10	173,519,187.96	34,703,837.59	1,154,003,344.63	138,815,350
11	138,815,350.37	27,763,070.07	1,181,766,414.71	111,052,280
12	111,052,280.29	22,210,456.06	1,203,976,870.77	88,841,824
13	88,841,824.23	17,768,364.85	1,221,745,235.61	71,073,459
14	71,073,459.39	14,214,691.88	1,235,959,927.49	56,858,768
15	56,858,767.51	11,371,753.50	1,247,331,680.99	45,487,014
16	45,487,014.01	9,097,402.80	1,256,429,083.79	36,389,611
17	36,389,611.21	7,277,922.24	1,263,707,006.03	29,111,689
18	29,111,688.97	5,822,337.79	1,269,529,343.83	23,289,351
19	23,289,351.17	4,657,870.23	1,274,187,214.06	18,631,481
20	18,631,480.94	3,726,296.19	1,277,913,510.25	14,905,185
21	14,905,184.75	2,981,036.95	1,280,894,547.20	11,924,148
22	11,924,147.80	2,384,829.56	1,283,279,376.76	9,539,318
23	9,539,318.24	1,907,863.65	1,285,187,240.41	7,631,455
24	7,631,454.59	1,526,290.92	1,286,713,531.33	6,105,164
25	6,105,163.67	1,221,032.73	1,287,934,564.06	4,884,131

DEPRECIATION ON TRANSMISSION LINES:

Depreciation of Transmission Line = 5%				
End of Year	**Opening Balance**	**Depreciation**	**Cumulative Depreciation**	**Closing Balance**
1	116,390,000.00	5,819,500.00	5,819,500.00	110,570,500
2	110,570,500.00	5,528,525.00	11,348,025.00	105,041,975
3	105,041,975.00	5,252,098.75	16,600,123.75	99,789,876
4	99,789,876.25	4,989,493.81	21,589,617.56	94,800,382
5	94,800,382.44	4,740,019.12	26,329,636.68	90,060,363
6	90,060,363.32	4,503,018.17	30,832,654.85	85,557,345
7	85,557,345.15	4,277,867.26	35,110,522.11	81,279,478
8	81,279,477.89	4,063,973.89	39,174,496.00	77,215,504
9	77,215,504.00	3,860,775.20	43,035,271.20	73,354,729
10	73,354,728.80	3,667,736.44	46,703,007.64	69,686,992
11	69,686,992.36	3,484,349.62	50,187,357.26	66,202,643
12	66,202,642.74	3,310,132.14	53,497,489.40	62,892,511
13	62,892,510.60	3,144,625.53	56,642,114.93	59,747,885
14	59,747,885.07	2,987,394.25	59,629,509.18	56,760,491
15	56,760,490.82	2,838,024.54	62,467,533.72	53,922,466
16	53,922,466.28	2,696,123.31	65,163,657.04	51,226,343
17	51,226,342.96	2,561,317.15	67,724,974.18	48,665,026
18	48,665,025.82	2,433,251.29	70,158,225.47	46,231,775
19	46,231,774.53	2,311,588.73	72,469,814.20	43,920,186
20	43,920,185.80	2,196,009.29	74,665,823.49	41,724,177
21	41,724,176.51	2,086,208.83	76,752,032.32	39,637,968
22	39,637,967.68	1,981,898.38	78,733,930.70	37,656,069
23	37,656,069.30	1,882,803.46	80,616,734.17	35,773,266
24	35,773,265.83	1,788,663.29	82,405,397.46	33,984,603
25	33,984,602.54	1,699,230.13	84,104,627.58	32,285,372

DEPRECIATION ON CIVIL COMPONENTS:

Depreciation of civil components = 3%				
End of Year	**Opening Balance**	**Depreciation**	**Cumulative Depreciation**	**Closing Balance**
1	3,518,720,019	105,561,600.57	105,561,600.57	3,413,158,418.30
2	3,413,158,418.30	102,394,752.55	207,956,353.11	3,310,763,665.75
3	3,310,763,665.75	99,322,909.97	307,279,263.09	3,211,440,755.78
4	3,211,440,755.78	96,343,222.67	403,622,485.76	3,115,097,533.10
5	3,115,097,533.10	93,452,925.99	497,075,411.75	3,021,644,607.11
6	3,021,644,607.11	90,649,338.21	587,724,749.97	2,930,995,268.90
7	2,930,995,268.90	87,929,858.07	675,654,608.03	2,843,065,410.83
8	2,843,065,410.83	85,291,962.32	760,946,570.36	2,757,773,448.50
9	2,757,773,448.50	82,733,203.46	843,679,773.81	2,675,040,245.05
10	2,675,040,245.05	80,251,207.35	923,930,981.17	2,594,789,037.70
11	2,594,789,037.70	77,843,671.13	1,001,774,652.30	2,516,945,366.57
12	2,516,945,366.57	75,508,361.00	1,077,283,013.29	2,441,437,005.57
13	2,441,437,005.57	73,243,110.17	1,150,526,123.46	2,368,193,895.40
14	2,368,193,895.40	71,045,816.86	1,221,571,940.32	2,297,148,078.54
15	2,297,148,078.54	68,914,442.36	1,290,486,382.68	2,228,233,636.18
16	2,228,233,636.18	66,847,009.09	1,357,333,391.76	2,161,386,627.10
17	2,161,386,627.10	64,841,598.81	1,422,174,990.58	2,096,545,028.29
18	2,096,545,028.29	62,896,350.85	1,485,071,341.43	2,033,648,677.44

19	2,033,648,677.44	61,009,460.32	1,546,080,801.75	1,972,639,217.11
20	1,972,639,217.11	59,179,176.51	1,605,259,978.26	1,913,460,040.60
21	1,913,460,040.60	57,403,801.22	1,662,663,779.48	1,856,056,239.38
22	1,856,056,239.38	55,681,687.18	1,718,345,466.66	1,800,374,552.20
23	1,800,374,552.20	54,011,236.57	1,772,356,703.23	1,746,363,315.64
24	1,746,363,315.64	52,390,899.47	1,824,747,602.70	1,693,972,416.17
25	1,693,972,416.17	50,819,172.48	1,875,566,775.18	1,643,153,243.68
26	1,643,153,243.68	49,294,597.31	1,924,861,372.49	1,593,858,646.37
27	1,593,858,646.37	47,815,759.39	1,972,677,131.88	1,546,042,886.98
28	1,546,042,886.98	46,381,286.61	2,019,058,418.49	1,499,661,600.37
29	1,499,661,600.37	44,989,848.01	2,064,048,266.50	1,454,671,752.36
30	1,454,671,752.36	43,640,152.57	2,107,688,419.07	1,411,031,599.79

PAYBACK PERIOD:

Payback Period Calculation				
Years	**Operation and Maintenance Cost (NRs.)**	**Revenue Generated from energy (NRs.)**	**Net Cash Flow (NRs.)**	**Cumulative Cash Flow (NRs.)**
0			-7,253,338,034	-7,253,338,034
1	-108,800,071	1,198,210,018.24	1,307,010,089	-5,946,327,945
2	-114240074	1,198,210,018.24	1,312,450,092	-4,633,877,853
3	-119952077.7	1,198,210,018.24	1,318,162,096	-3,315,715,757
4	-125949681.6	1,198,210,018.24	1,324,159,700	-1,991,556,057
5	-132247165.7	1,198,210,018.24	1,330,457,184	-661,098,873
6	**-138859524**	**1,198,210,018.24**	**1,337,069,542**	**675,970,669**
7	-145802500.2	1,198,210,018.24	1,344,012,518	2,019,983,188
8	-153092625.2	1,198,210,018.24	1,351,302,643	3,371,285,831

9	-160747256.5	1,198,210,018.24	1,358,957,275	4,730,243,106
10	-168784619.3	1,198,210,018.24	1,366,994,638	6,097,237,743
11	-177223850.2	1,198,210,018.24	1,375,433,868	7,472,671,612
12	-186085042.8	1,198,210,018.24	1,384,295,061	8,856,966,673
13	-195389294.9	1,198,210,018.24	1,393,599,313	10,250,565,986
14	-205158759.6	1,198,210,018.24	1,403,368,778	11,653,934,764
15	-215416697.6	1,198,210,018.24	1,413,626,716	13,067,561,480
16	-226187532.5	1,198,210,018.24	1,424,397,551	14,491,959,030
17	-237496909.1	1,198,210,018.24	1,435,706,927	15,927,665,958
18	-249371754.6	1,198,210,018.24	1,447,581,773	17,375,247,731
19	-261840342.3	1,198,210,018.24	1,460,050,361	18,835,298,091
20	-274932359.4	1,198,210,018.24	1,473,142,378	20,308,440,469
21	-288678977.4	1,198,210,018.24	1,486,888,996	21,795,329,464
22	-303112926.3	1,198,210,018.24	1,501,322,945	23,296,652,409
23	-318268572.6	1,198,210,018.24	1,516,478,591	24,813,131,000
24	-334182001.2	1,198,210,018.24	1,532,392,019	26,345,523,019
25	-350891101.3	1,198,210,018.24	1,549,101,120	27,894,624,139
26	-368435656.3	1,198,210,018.24	1,566,645,675	29,461,269,813
27	-386857439.2	1,198,210,018.24	1,585,067,457	31,046,337,271
28	-406200311.1	1,198,210,018.24	1,604,410,329	32,650,747,600
29	-426510326.7	1,198,210,018.24	1,624,720,345	34,275,467,945
30	-447835843	1,198,210,018.24	1,646,045,861	35,921,513,806

PROJECT IRR:

Year	**Cost**			**Benefit**	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1198210018	1089409948
5		114240074	114240074	1234156319	1119916245
6		119952077.7	119952077.7	1271181008	1151228931
7		125949681.6	125949681.6	1309316439	1183366757
8		132247165.7	132247165.7	1348595932	1216348766
9		138859524	138859524	1389053810	1250194286

10		145802500.2	145802500.2	1430725424	1284922924
11		153092625.2	153092625.2	1473647187	1320554562
12		160747256.5	160747256.5	1517856602	1357109346
13		168784619.3	168784619.3	1563392300	1394607681
14		177223850.2	177223850.2	1610294069	1433070219
15		186085042.8	186085042.8	1658602891	1472517849
16		195389294.9	195389294.9	1708360978	1512971683
17		205158759.6	205158759.6	1759611808	1554453048
18		215416697.6	215416697.6	1812400162	1596983464
19		226187532.5	226187532.5	1812400162	1586212629
20		237496909.1	237496909.1	1866772167	1629275258
21		249371754.6	249371754.6	1922775332	1673403577
22		261840342.3	261840342.3	1980458592	1718618249
23		274932359.4	274932359.4	2039872349	1764939990
24		288678977.4	288678977.4	2101068520	1812389542
25		303112926.3	303112926.3	2164100575	1860987649
26		318268572.6	318268572.6	2229023593	1910755020
27		334182001.2	334182001.2	2295894300	1961712299
28		350891101.3	350891101.3	2364771130	2013880028
29		368435656.3	368435656.3	2435714263	2067278607
30		386857439.2	386857439.2	2508785691	2121928252
Total		**5948004812**	**13201342846**	**48007041621**	**42059036809**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1089409948	97142920.1	692339716.6	595196796.5	-5880997877

5	1119916245	102000066.1	711727019.8	609726953.7	-5271270923
6	1151228931	107100069.4	731626797.8	624526728.4	-4646744195
7	1183366757	112455072.9	752050967.4	639595894.6	-4007148300
8	1216348766	118077826.5	773011630.5	654933804	-3352214496
9	1250194286	123981717.8	794521070.1	670539352.3	-2681675144
10	1284922924	130180803.7	816591747.4	686410943.7	-1995264200
11	1320554562	136689843.9	839236297.4	702546453.4	-1292717747
12	1357109346	143524336.1	862467523.7	718943187.6	-573774559.1
13	1394607681	150700552.9	886298393.6	735597840.7	161823281.6
14	1433070219	158235580.6	910742031.9	752506451.3	914329732.9
15	1472517849	166147359.6	935811713.6	769664354	1683994087
16	1512971683	174454727.6	961520856.9	787066129.3	2471060216
17	1554453048	183177464	987883014	804705550	3275765766
18	1596983464	192336337.2	1014911862	822575525.2	4098341292
19	1586212629	201953154	1008066802	806113648.1	4904454940
20	1629275258	212050811.7	1035433881	823383069.1	5727838009
21	1673403577	222653352.3	1063478226	840824873.4	6568662882
22	1718618249	233786019.9	1092212967	858426947.4	7427089830
23	1764939990	245475320.9	1121651271	876175950	8303265780
24	1812389542	257749087	1151806319	894057232.4	9197323012
25	1860987649	270636541.3	1182691295	912054753.4	10109377765
26	1910755020	284168368.4	1214319359	930150990.3	11039528756
27	1961712299	298376786.8	1246703631	948326844	11987855600

28	2013880028	313295626.1	1279857166	966561539.5	12954417139
29	2067278607	328960407.4	1313792928	984832520.4	13939249660
30	2121928252	345408427.8	1348523765	1003115337	14942364997
Total		11786913255	26729278253	14942364997	

Year	IRR	B/C ratio	NPV
10	3%	0.86	-1995264200
20	13.49%	1.67	5727838009
30	15%	2.27	14942364997

SENSITIVITY ANALYSIS:

COST INCREASE BY 5%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2284801481		2284801481	0	0
2	3046401974		3046401974	0	0
3	2284801481		2284801481	0	0
4		114240074	114240074	1198210018	1083969944
5		119952077.7	119952077.7	1234156319	1114204241
6		125949681.6	125949681.6	1271181008	1145231327
7		132247165.7	132247165.7	1309316439	1177069273
8		138859524	138859524	1348595932	1209736408
9		145802500.2	145802500.2	1389053810	1243251310
10		153092625.2	153092625.2	1430725424	1277632799
11		160747256.5	160747256.5	1473647187	1312899930
12		168784619.3	168784619.3	1517856602	1349071983
13		177223850.2	177223850.2	1563392300	1386168450
14		186085042.8	186085042.8	1610294069	1424209027
15		195389294.9	195389294.9	1658602891	1463213597
16		205158759.6	205158759.6	1708360978	1503202219
17		215416697.6	215416697.6	1759611808	1544195110
18		226187532.5	226187532.5	1812400162	1586212629
19		237496909.1	237496909.1	1812400162	1574903253
20		249371754.6	249371754.6	1866772167	1617400412

21		261840342.3	261840342.3	1922775332	1660934989
22		274932359.4	274932359.4	1980458592	1705526232
23		288678977.4	288678977.4	2039872349	1751193372
24		303112926.3	303112926.3	2101068520	1797955594
25		318268572.6	318268572.6	2164100575	1845832003
26		334182001.2	334182001.2	2229023593	1894841591
27		350891101.3	350891101.3	2295894300	1945003199
28		368435656.3	368435656.3	2364771130	1996335473
29		386857439.2	386857439.2	2435714263	2048856824
30		406200311.1	406200311.1	2508785691	2102585380
Total		**6245405053**	**13861409988**	**48007041621**	**41761636569**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2284801481	2040001322		-2040001322	-2040001322
2	-3046401974	2720001763		-2720001763	-4760003085
3	-2284801481	2040001322		-2040001322	-6800004407
4	1083969944	102000066.1	688882496	586882429.9	-6213121977
5	1114204241	107100069.4	708096938.2	600996868.8	-5612125108
6	1145231327	112455072.9	727815212.1	615360139.2	-4996764969
7	1177069273	118077826.5	748048802.5	629970975.9	-4366793993
8	1209736408	123981717.8	768809357.2	644827639.4	-3721966354
9	1243251310	130180803.7	790108683.2	659927879.5	-3062038474
10	1277632799	136689843.9	811958741.2	675268897.3	-2386769577
11	1312899930	143524336.1	834371640.8	690847304.7	-1695922272
12	1349071983	150700552.9	857359634.3	706659081.4	-989263190.7

13	1386168450	158235580.6	880935109.8	722699529.2	-266563661.5
14	1424209027	166147359.6	905110583.9	738963224.3	472399562.7
15	1463213597	174454727.6	929898693.2	755443965.6	1227843528
16	1503202219	183177464	955312185.4	772134721.5	1999978250
17	1544195110	192336337.2	981363909	789027571.8	2789005822
18	1586212629	201953154	1008066802	806113648.1	3595119470
19	1574903253	212050811.7	1000879489	788828677.1	4383948147
20	1617400412	222653352.3	1027887202	805233849.6	5189181996
21	1660934989	233786019.9	1055554213	821768192.9	6010950189
22	1705526232	245475320.9	1083892754	838417432.8	6849367622
23	1751193372	257749087	1112915047	855165959.7	7704533582
24	1797955594	270636541.3	1142633284	871996742.6	8576530324
25	1845832003	284168368.4	1173059608	888891239.1	9465421563
26	1894841591	298376786.8	1204206087	905829300.3	10371250864
27	1945003199	313295626.1	1236084696	922789069.5	11294039933
28	1996335473	328960407.4	1268707284	939746876.3	12233786810
29	2048856824	345408427.8	1302085552	956677124	13190463934
30	2102585380	362678849.2	1336231020	973552171.3	14164016105
Total		**12376258918**	**26540275023**	**14164016105**	

Year	IRR	B/C ratio	NPV
10	2%	0.82	-2386769577
20	12.71%	1.58	5189181996
30	14%	2.15	14164016105

COST INCREASE BY 10%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2393601551		2393601551	0	0
2	3191468735		3191468735	0	0
3	2393601551		2393601551	0	0
4		119680077.6	119680077.6	1198210018	1078529941
5		125664081.4	125664081.4	1234156319	1108492237
6		131947285.5	131947285.5	1271181008	1139233723
7		138544649.8	138544649.8	1309316439	1170771789
8		145471882.3	145471882.3	1348595932	1203124049
9		152745476.4	152745476.4	1389053810	1236308333
10		160382750.2	160382750.2	1430725424	1270342674
11		168401887.7	168401887.7	1473647187	1305245299
12		176821982.1	176821982.1	1517856602	1341034620
13		185663081.2	185663081.2	1563392300	1377729219
14		194946235.3	194946235.3	1610294069	1415347834
15		204693547	204693547	1658602891	1453909344
16		214928224.4	214928224.4	1708360978	1493432754
17		225674635.6	225674635.6	1759611808	1533937172
18		236958367.4	236958367.4	1812400162	1575441794
19		248806285.8	248806285.8	1812400162	1563593876
20		261246600	261246600	1866772167	1605525567
21		274308930	274308930	1922775332	1648466402
22		288024376.5	288024376.5	1980458592	1692434215
23		302425595.4	302425595.4	2039872349	1737446754
24		317546875.1	317546875.1	2101068520	1783521645
25		333424218.9	333424218.9	2164100575	1830676357
26		350095429.8	350095429.8	2229023593	1878928163
27		367600201.3	367600201.3	2295894300	1928294099
28		385980211.4	385980211.4	2364771130	1978790918
29		405279222	405279222	2435714263	2030435041
30		425543183.1	425543183.1	2508785691	2083242508
Total		**6542805293**	**14521477131**	**48007041621**	**41464236328**

Year	Cash flow	Present Value			Cumulative Discounted Cash Flow
		PV cost	**PV Benefit**	**NPV**	
0					

1	-2393601551	2137144242		-2137144242	-2137144242
2	-3191468735	2849525656		-2849525656	-4986669898
3	-2393601551	2137144242		-2137144242	-7123814140
4	1078529941	106857212.1	685425275.4	578568063.3	-6545246077
5	1108492237	112200072.7	704466856.6	592266783.9	-5952979293
6	1139233723	117810076.3	724003626.4	606193550	-5346785743
7	1170771789	123700580.2	744046637.5	620346057.3	-4726439686
8	1203124049	129885609.2	764607084	634721474.8	-4091718211
9	1236308333	136379889.6	785696296.3	649316406.7	-3442401804
10	1270342674	143198884.1	807325735	664126850.9	-2778274954
11	1305245299	150358828.3	829506984.3	679148156	-2099126798
12	1341034620	157876769.7	852251744.9	694374975.2	-1404751822
13	1377729219	165770608.2	875571825.9	709801217.7	-694950604.7
14	1415347834	174059138.6	899479135.8	725419997.2	30469392.51
15	1453909344	182762095.6	923985672.8	741223577.2	771692969.7
16	1493432754	191900200.3	949103514	757203313.6	1528896283
17	1533937172	201495210.4	974844803.9	773349593.6	2302245877
18	1575441794	211569970.9	1001221742	789651771	3091897648
19	1563593876	222148469.4	993692175.5	771543706.1	3863441354
20	1605525567	233255892.9	1020340523	787084630	4650525984
21	1648466402	244918687.5	1047630200	802711512.3	5453237496

22	1692434215	257164621.9	1075572540	818407918.3	6271645415
23	1737446754	270022853	1104178822	834155969.4	7105801384
24	1783521645	283523995.7	1133460248	849936252.8	7955737637
25	1830676357	297700195.4	1163427920	865727724.8	8821465362
26	1878928163	312585205.2	1194092816	881507610.3	9702972972
27	1928294099	328214465.5	1225465760	897251295	10600224267
28	1978790918	344625188.8	1257557402	912932213.1	11513156480
29	2030435041	361856448.2	1290378176	928521727.7	12441678208
30	2083242508	379949270.6	1323938276	943989005.1	13385667213
Total		12965604581	26351271794	13385667213	

Year	IRR	B/C ratio	NPV
10	1%	0.78	-2778274954
20	11.97%	1.50	4650525984
30	14%	2.04	13385667213

COST INCREASE BY 15%:

Year	**Cost**			**Benefit**	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2502401622		2502401622	0	0
	3336535496		3336535496	0	0
3	2502401622		2502401622	0	0
4		125120081.1	125120081.1	1198210018	1073089937
5		131376085.1	131376085.1	1234156319	1102780234
6		137944889.4	137944889.4	1271181008	1133236119
7		144842133.9	144842133.9	1309316439	1164474305
8		152084240.6	152084240.6	1348595932	1196511691

9		159688452.6	159688452.6	1389053810	1229365357
10		167672875.2	167672875.2	1430725424	1263052549
11		176056519	176056519	1473647187	1297590668
12		184859344.9	184859344.9	1517856602	1332997257
13		194102312.2	194102312.2	1563392300	1369289988
14		203807427.8	203807427.8	1610294069	1406486642
15		213997799.2	213997799.2	1658602891	1444605092
16		224697689.1	224697689.1	1708360978	1483663289
17		235932573.6	235932573.6	1759611808	1523679234
18		247729202.3	247729202.3	1812400162	1564670960
19		260115662.4	260115662.4	1812400162	1552284499
20		273121445.5	273121445.5	1866772167	1593650721
21		286777517.8	286777517.8	1922775332	1635997814
22		301116393.7	301116393.7	1980458592	1679342198
23		316172213.3	316172213.3	2039872349	1723700136
24		331980824	331980824	2101068520	1769087696
25		348579865.2	348579865.2	2164100575	1815520710
26		366008858.5	366008858.5	2229023593	1863014734
27		384309301.4	384309301.4	2295894300	1911584999
28		403524766.5	403524766.5	2364771130	1961246363
29		423701004.8	423701004.8	2435714263	2012013259
30		444886055	444886055	2508785691	2063899636
Total		**6840205534**	**15181544273**	**48007041621**	**41166836087**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2502401622	2234287162		-2234287162	-2234287162
2	-3336535496	2979049550		-2979049550	-5213336712
3	-2502401622	2234287162		-2234287162	-7447623874
4	1073089937	111714358.1	681968054.8	570253696.7	-6877370177
5	1102780234	117300076	700836775	583536699	-6293833478

6	1133236119	123165079.8	720192040.7	597026960.9	-5696806518
7	1164474305	129323333.8	740044472.5	610721138.7	-5086085379
8	1196511691	135789500.5	760404810.8	624615310.3	-4461470069
9	1229365357	142578975.5	781283909.4	638704933.9	-3822765135
10	1263052549	149707924.3	802692728.7	652984804.4	-3169780330
11	1297590668	157193320.5	824642327.7	667449007.2	-2502331323
12	1332997257	165052986.5	847143855.5	682090869	-1820240454
13	1369289988	173305635.9	870208542.1	696902906.2	-1123337548
14	1406486642	181970917.7	893847687.8	711876770.1	-411460777.7
15	1444605092	191069463.5	918072652.3	727003188.8	315542411.1
16	1483663289	200622936.7	942894842.5	742271905.8	1057814317
17	1523679234	210654083.6	968325698.9	757671615.3	1815485932
18	1564670960	221186787.7	994376681.5	773189893.8	2588675826
19	1552284499	232246127.1	986504862.2	754258735.1	3342934561
20	1593650721	243858433.5	1012793844	768935410.5	4111869972
21	1635997814	256051355.2	1039706187	783654831.8	4895524803
22	1679342198	268853922.9	1067252327	798398403.7	5693923207
23	1723700136	282296619.1	1095442598	813145979.1	6507069186
24	1769087696	296411450	1124287213	827875763	7334944949
25	1815520710	311232022.5	1153796233	842564210.6	8177509160
26	1863014734	326793623.6	1183979544	857185920.3	9034695080
27	1911584999	343133304.8	1214846825	871713520.5	9906408601
28	1961246363	360289970.1	1246407520	886117549.9	10792526150

29	2012013259	378304468.6	1278670800	900366331.3	11692892482
30	2063899636	397219692	1311645531	914425838.9	12607318321
Total		**13554950244**	**26162268564**	**12607318321**	

Year	IRR	B/C ratio	NPV
10	0%	0.74	-3169780330
20	11.28%	1.43	4111869972
30	13%	1.94	12607318321

COST INCREASE BY 20%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2611201692		2611201692	0	0
2	3481602256		3481602256	0	0
3	2611201692		2611201692	0	0
4		130560084.6	130560084.6	1198210018	1067649934
5		137088088.8	137088088.8	1234156319	1097068230
6		143942493.3	143942493.3	1271181008	1127238515
7		151139617.9	151139617.9	1309316439	1158176821
8		158696598.8	158696598.8	1348595932	1189899333
9		166631428.8	166631428.8	1389053810	1222422381
10		174963000.2	174963000.2	1430725424	1255762424
11		183711150.2	183711150.2	1473647187	1289936036
12		192896707.8	192896707.8	1517856602	1324959895
13		202541543.1	202541543.1	1563392300	1360850757
14		212668620.3	212668620.3	1610294069	1397625449
15		223302051.3	223302051.3	1658602891	1435300840
16		234467153.9	234467153.9	1708360978	1473893824
17		246190511.6	246190511.6	1759611808	1513421296
18		258500037.1	258500037.1	1812400162	1553900125
19		271425039	271425039	1812400162	1540975123
20		284996291	284996291	1866772167	1581775876
21		299246105.5	299246105.5	1922775332	1623529226
22		314208410.8	314208410.8	1980458592	1666250181
23		329918831.3	329918831.3	2039872349	1709953518

24		346414772.9	346414772.9	2101068520	1754653747
25		363735511.5	363735511.5	2164100575	1800365064
26		381922287.1	381922287.1	2229023593	1847101306
27		401018401.5	401018401.5	2295894300	1894875899
28		421069321.5	421069321.5	2364771130	1943701808
29		442122787.6	442122787.6	2435714263	1993591476
30		464228927	464228927	2508785691	2044556764
Total		**7137605775**	**15841611415**	**48007041621**	**40869435847**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2611201692	2331430082		-2331430082	-2331430082
2	-3481602256	3108573443		-3108573443	-5440003525
3	-2611201692	2331430082		-2331430082	-7771433608
4	1067649934	116571504.1	678510834.2	561939330.1	-7209494278
5	1097068230	122400079.3	697206693.4	574806614.1	-6634687664
6	1127238515	128520083.3	716380455	587860371.7	-6046827292
7	1158176821	134946087.5	736042307.5	601096220.1	-5445731072
8	1189899333	141693391.8	756202537.6	614509145.7	-4831221926
9	1222422381	148778061.4	776871522.5	628093461.1	-4203128465
10	1255762424	156216964.5	798059722.5	641842758	-3561285707
11	1289936036	164027812.7	819777671.2	655749858.5	-2905535849
12	1324959895	172229203.3	842035966.2	669806762.8	-2235729086
13	1360850757	180840663.5	864845258.3	684004594.7	-1551724491
14	1397625449	189882696.7	888216239.8	698333543.1	-853390947.9

15	1435300840	199376831.5	912159631.9	712782800.4	-140608147.6
16	1473893824	209345673.1	936686171	727340497.9	586732350.4
17	1513421296	219812956.8	961806593.9	741993637.1	1328725987
18	1553900125	230803604.6	987531621.3	756728016.7	2085454004
19	1540975123	242343784.8	979317548.9	736973764.1	2822427768
20	1581775876	254460974.1	1005247165	750786190.9	3573213959
21	1623529226	267184022.8	1031782174	764598151.3	4337812110
22	1666250181	280543223.9	1058932113	778388889.2	5116201000
23	1709953518	294570385.1	1086706374	792135988.9	5908336988
24	1754653747	309298904.4	1115114178	805815273.2	6714152262
25	1800365064	324763849.6	1144164546	819400696.3	7533552958
26	1847101306	341002042.1	1173866272	832864230.3	8366417188
27	1894875899	358052144.2	1204227890	846175746	9212592934
28	1943701808	375954751.4	1235257638	859302886.6	10071895821
29	1993591476	394752488.9	1266963424	872210934.9	10944106756
30	2044556764	414490113.4	1299352786	884862672.7	11828969428
Total		**14144295906**	**25973265335**	**11828969428**	

Year	IRR	B/C ratio	NPV
10	-1%	0.71	-3561285707
20	10.63%	1.36	3573213959
30	13%	1.84	11828969428

COST DECREASE BY 5%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**

0					
1	2067201340		2067201340	0	0
2	2756268453		2756268453	0	0
3	2067201340		2067201340	0	0
4		103360067	103360067	1198210018	1094849951
5		108528070.3	108528070.3	1234156319	1125628248
6		113954473.8	113954473.8	1271181008	1157226535
7		119652197.5	119652197.5	1309316439	1189664241
8		125634807.4	125634807.4	1348595932	1222961124
9		131916547.8	131916547.8	1389053810	1257137262
10		138512375.2	138512375.2	1430725424	1292213049
11		145437993.9	145437993.9	1473647187	1328209193
12		152709893.6	152709893.6	1517856602	1365146709
13		160345388.3	160345388.3	1563392300	1403046912
14		168362657.7	168362657.7	1610294069	1441931412
15		176780790.6	176780790.6	1658602891	1481822101
16		185619830.2	185619830.2	1708360978	1522741148
17		194900821.7	194900821.7	1759611808	1564710986
18		204645862.7	204645862.7	1812400162	1607754299
19		214878155.9	214878155.9	1812400162	1597522006
20		225622063.7	225622063.7	1866772167	1641150103
21		236903166.9	236903166.9	1922775332	1685872165
22		248748325.2	248748325.2	1980458592	1731710266
23		261185741.5	261185741.5	2039872349	1778686608
24		274245028.5	274245028.5	2101068520	1826823491
25		287957280	287957280	2164100575	1876143295
26		302355144	302355144	2229023593	1926668449
27		317472901.2	317472901.2	2295894300	1978421399
28		333346546.2	333346546.2	2364771130	2031424583
29		350013873.5	350013873.5	2435714263	2085700390
30		367514567.2	367514567.2	2508785691	2141271124
Total		**5650604571**	**12541275704**	**48007041621**	**42356437050**

Year	Cash flow	Present Value			Cumulative Discounted Cash Flow
		PV cost	PV Benefit	NPV	
0					
1	-2067201340	1845715482		-1845715482	-1845715482

2	-2756268453	2460953976		-2460953976	-4306669458
3	-2067201340	1845715482		-1845715482	-6152384940
4	1094849951	92285774.09	695796937.2	603511163.1	-5548873776
5	1125628248	96900062.8	715357101.5	618457038.7	-4930416738
6	1157226535	101745065.9	735438383.5	633693317.6	-4296723420
7	1189664241	106832319.2	756053132.4	649220813.2	-3647502607
8	1222961124	112173935.2	777213903.7	665039968.5	-2982462639
9	1257137262	117782632	798933457	681150825	-2301311813
10	1292213049	123671763.6	821224753.7	697552990.1	-1603758823
11	1328209193	129855351.7	844100953.9	714245602.2	-889513221.2
12	1365146709	136348119.3	867575413.1	731227293.7	-158285927.4
13	1403046912	143165525.3	891661677.5	748496152.2	590210224.8
14	1441931412	150323801.5	916373479.9	766049678.4	1356259903
15	1481822101	157839991.6	941724734.1	783884742.5	2140144646
16	1522741148	165731991.2	967729528.3	801997537.1	2942142183
17	1564710986	174018590.8	994402119	820383528.3	3762525711
18	1607754299	182719520.3	1021756923	839037402.4	4601563113
19	1597522006	191855496.3	1015254115	823398619.1	5424961733
20	1641150103	201448271.1	1042980560	841532288.7	6266494021
21	1685872165	211520684.7	1071402239	859881553.9	7126375575
22	1731710266	222096718.9	1100533181	878436461.9	8004812037
23	1778686608	233201554.9	1130387495	897185940.3	8901997977

24	1826823491	244861632.6	1160979355	916117722.2	9818115700
25	1876143295	257104714.2	1192322982	935218267.7	10753333967
26	1926668449	269959950	1224432630	954472680.3	11707806648
27	1978421399	283457947.5	1257322566	973864618.5	12681671266
28	2031424583	297630844.8	1291007048	993376202.8	13675047469
29	2085700390	312512387.1	1325500304	1012987917	14688035386
30	2141271124	328138006.4	1360816510	1032678504	15720713889
Total		**11197567593**	**26918281482**	**15720713889**	

Year	IRR	B/C ratio	NPV
10	4%	0.91	-1603758823
20	14.33%	1.77	6266494021
30	16%	2.41	15720713889

COST DECREASE BY 10%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	1958401269		1958401269	0	0
2	2611201692		2611201692	0	0
3	1958401269		1958401269	0	0
4		97920063.46	97920063.46	1198210018	1100289955
5		102816066.6	102816066.6	1234156319	1131340252
6		107956870	107956870	1271181008	1163224138
7		113354713.5	113354713.5	1309316439	1195961725
8		119022449.1	119022449.1	1348595932	1229573483
9		124973571.6	124973571.6	1389053810	1264080238
10		131222250.2	131222250.2	1430725424	1299503174
11		137783362.7	137783362.7	1473647187	1335863824
12		144672530.8	144672530.8	1517856602	1373184072
13		151906157.4	151906157.4	1563392300	1411486143
14		159501465.2	159501465.2	1610294069	1450792604

15		167476538.5	167476538.5	1658602891	1491126353
16		175850365.4	175850365.4	1708360978	1532510613
17		184642883.7	184642883.7	1759611808	1574968924
18		193875027.9	193875027.9	1812400162	1618525134
19		203568779.3	203568779.3	1812400162	1608831383
20		213747218.2	213747218.2	1866772167	1653024948
21		224434579.1	224434579.1	1922775332	1698340753
22		235656308.1	235656308.1	1980458592	1744802284
23		247439123.5	247439123.5	2039872349	1792433226
24		259811079.7	259811079.7	2101068520	1841257440
25		272801633.6	272801633.6	2164100575	1891298942
26		286441715.3	286441715.3	2229023593	1942581877
27		300763801.1	300763801.1	2295894300	1995130499
28		315801991.1	315801991.1	2364771130	2048969138
29		331592090.7	331592090.7	2435714263	2104122173
30		348171695.2	348171695.2	2508785691	2160613996
Total		**5353204331**	**11881208561**	**48007041621**	**42653837290**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-1958401269	1748572562		-1748572562	-1748572562
2	-2611201692	2331430082		-2331430082	-4080002644
3	-1958401269	1748572562		-1748572562	-5828575206
4	1100289955	87428628.09	699254157.8	611825529.7	-5216749676
5	1131340252	91800059.49	718987183.1	627187123.6	-4589562553
6	1163224138	96390062.47	739249969.2	642859906.7	-3946702646
7	1195961725	101209565.6	760055297.4	658845731.8	-3287856914
8	1229573483	106270043.9	781416176.9	675146133.1	-2612710781
9	1264080238	111583546.1	803345843.9	691762297.8	-1920948483

10	1299503174	117162723.4	825857759.9	708695036.6	-1212253447
11	1335863824	123020859.5	848965610.5	725944750.9	-486308695.7
12	1373184072	129171902.5	872683302.4	743511399.9	257202704.2
13	1411486143	135630497.6	897024961.3	761394463.7	1018597168
14	1450792604	142412022.5	922004928	779592905.5	1798190073
15	1491126353	149532623.6	947637754.5	798105130.9	2596295204
16	1532510613	157009254.8	973938199.8	816928945	3413224149
17	1574968924	164859717.6	1000921224	836061506.5	4249285656
18	1618525134	173102703.4	1028601983	855499279.5	5104784935
19	1608831383	181757838.6	1022441429	840683590.1	5945468525
20	1653024948	190845730.5	1050527239	859681508.2	6805150034
21	1698340753	200388017.1	1079326252	878938234.5	7684088268
22	1744802284	210407417.9	1108853394	898445976.5	8582534245
23	1792433226	220927788.8	1139123719	918195930.6	9500730175
24	1841257440	231974178.3	1170152390	938178212	10438908387
25	1891298942	243572887.2	1201954669	958381782	11397290169
26	1942581877	255751531.5	1234545902	978794370.3	12376084539
27	1995130499	268539108.1	1267941501	999402393	13375486932
28	2048969138	281966063.5	1302156930	1020190866	14395677798
29	2104122173	296064366.7	1337207680	1041143313	15436821112
30	2160613996	310867585	1373109255	1062241670	16499062782
Total		**10608221930**	**27107284711**	**16499062782**	

Year	IRR	B/C ratio	NPV
10	5%	0.97	-1212253447
20	15.24%	1.88	6805150034
30	17%	2.56	16499062782

COST DECREASE BY 15%:

Year	**Cost**			**Benefit**	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	1849601199		1849601199	0	0
2	2466134932		2466134932	0	0
3	1849601199		1849601199	0	0
4		92480059.93	92480059.93	1198210018	1105729958
5		97104062.93	97104062.93	1234156319	1137052256
6		101959266.1	101959266.1	1271181008	1169221742
7		107057229.4	107057229.4	1309316439	1202259209
8		112410090.8	112410090.8	1348595932	1236185841
9		118030595.4	118030595.4	1389053810	1271023214
10		123932125.2	123932125.2	1430725424	1306793299
11		130128731.4	130128731.4	1473647187	1343518455
12		136635168	136635168	1517856602	1381221434
13		143466926.4	143466926.4	1563392300	1419925374
14		150640272.7	150640272.7	1610294069	1459653797
15		158172286.3	158172286.3	1658602891	1500430605
16		166080900.7	166080900.7	1708360978	1542280078
17		174384945.7	174384945.7	1759611808	1585226862
18		183104193	183104193	1812400162	1629295969
19		192259402.6	192259402.6	1812400162	1620140759
20		201872372.8	201872372.8	1866772167	1664899794
21		211965991.4	211965991.4	1922775332	1710809340
22		222564291	222564291	1980458592	1757894301
23		233692505.5	233692505.5	2039872349	1806179844
24		245377130.8	245377130.8	2101068520	1855691389
25		257645987.3	257645987.3	2164100575	1906454588
26		270528286.7	270528286.7	2229023593	1958495306
27		284054701	284054701	2295894300	2011839599
28		298257436.1	298257436.1	2364771130	2066513693
29		313170307.9	313170307.9	2435714263	2122543956

30		328828823.3	328828823.3	2508785691	2179956868
Total		**5055804090**	**11221141419**	**48007041621**	**42951237531**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-1849601199	1651429642		-1651429642	-1651429642
2	-2466134932	2201906189		-2201906189	-3853335831
3	-1849601199	1651429642		-1651429642	-5504765472
4	1105729958	82571482.08	702711378.3	620139896.3	-4884625576
5	1137052256	86700056.19	722617264.7	635917208.5	-4248708367
6	1169221742	91035059	743061554.9	652026495.9	-3596681872
7	1202259209	95586811.95	764057462.4	668470650.4	-2928211221
8	1236185841	100366152.5	785618450.2	685252297.6	-2242958923
9	1271023214	105384460.2	807758230.8	702373770.6	-1540585153
10	1306793299	110653683.2	830490766.2	719837083	-820748069.9
11	1343518455	116186367.3	853830267	737643899.7	-83104170.21
12	1381221434	121995685.7	877791191.8	755795506.1	672691335.9
13	1419925374	128095470	902388245.2	774292775.2	1446984111
14	1459653797	134500243.5	927636376	793136132.5	2240120244
15	1500430605	141225255.7	953550775	812325519.3	3052445763
16	1542280078	148286518.4	980146871.3	831860352.8	3884306116
17	1585226862	155700844.4	1007440329	851739484.7	4736045600
18	1629295969	163485886.6	1035447043	871961156.7	5608006757

19	1620140759	171660180.9	1029628742	857968561.1	6465975318
20	1664899794	180243190	1058073918	877830727.8	7343806046
21	1710809340	189255349.5	1087250264	897994915	8241800961
22	1757894301	198718116.9	1117173608	918455491.1	9160256452
23	1806179844	208654022.8	1147859944	939205920.8	10099462373
24	1855691389	219086723.9	1179325426	960238701.8	11059701075
25	1906454588	230041060.1	1211586356	981545296.3	12041246371
26	1958495306	241543113.1	1244659173	1003116060	13044362431
27	2011839599	253620268.8	1278560436	1024940168	14069302599
28	2066513693	266301282.2	1313306811	1047005529	15116308128
29	2122543956	279616346.3	1348915056	1069298710	16185606838
30	2179956868	293597163.6	1385402000	1091804836	17277411674
Total		**10018876267**	**27296287941**	**17277411674**	

Year	IRR	B/C ratio	NPV
10	6%	1.03	-820748069.9
20	16.22%	2.00	7343806046
30	17%	2.73	17277411674

COST DECREASE BY 20%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	1740801128		1740801128	0	0
2	2321068171		2321068171	0	0
3	1740801128		1740801128	0	0
4		87040056.41	87040056.41	1198210018	1111169962
5		91392059.23	91392059.23	1234156319	1142764260
6		95961662.19	95961662.19	1271181008	1175219346

7		100759745.3	100759745.3	1309316439	1208556693
8		105797732.6	105797732.6	1348595932	1242798199
9		111087619.2	111087619.2	1389053810	1277966191
10		116642000.2	116642000.2	1430725424	1314083424
11		122474100.2	122474100.2	1473647187	1351173087
12		128597805.2	128597805.2	1517856602	1389258797
13		135027695.4	135027695.4	1563392300	1428364605
14		141779080.2	141779080.2	1610294069	1468514989
15		148868034.2	148868034.2	1658602891	1509734857
16		156311435.9	156311435.9	1708360978	1552049542
17		164127007.7	164127007.7	1759611808	1595484800
18		172333358.1	172333358.1	1812400162	1640066804
19		180950026	180950026	1812400162	1631450136
20		189997527.3	189997527.3	1866772167	1676774639
21		199497403.7	199497403.7	1922775332	1723277928
22		209472273.9	209472273.9	1980458592	1770986318
23		219945887.5	219945887.5	2039872349	1819926462
24		230943181.9	230943181.9	2101068520	1870125338
25		242490341	242490341	2164100575	1921610234
26		254614858.1	254614858.1	2229023593	1974408735
27		267345601	267345601	2295894300	2028548700
28		280712881	280712881	2364771130	2084058248
29		294748525.1	294748525.1	2435714263	2140965738
30		309485951.3	309485951.3	2508785691	2199299740
Total		**4758403850**	**10561074277**	**48007041621**	**43248637772**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-1740801128	1554286722		-1554286722	-1554286722
2	-2321068171	2072382295		-2072382295	-3626669017
3	-1740801128	1554286722		-1554286722	-5180955739
4	1111169962	77714336.08	706168598.9	628454262.8	-4552501476

5	1142764260	81600052.88	726247346.3	644647293.4	-3907854182
6	1175219346	85680055.53	746873140.6	661193085.1	-3246661097
7	1208556693	89964058.3	768059627.4	678095569.1	-2568565528
8	1242798199	94462261.22	789820723.4	695358462.2	-1873207066
9	1277966191	99185374.28	812170617.7	712985243.4	-1160221823
10	1314083424	104144643	835123772.4	730979129.4	-429242693.2
11	1351173087	109351875.1	858694923.6	749343048.4	320100355.3
12	1389258797	114819468.9	882899081.2	768079612.3	1088179968
13	1428364605	120560442.3	907751529	787191086.7	1875371054
14	1468514989	126588464.5	933267824.1	806679359.6	2682050414
15	1509734857	132917887.7	959463795.4	826545907.7	3508596322
16	1552049542	139563782.1	986355542.7	846791760.7	4355388082
17	1595484800	146541971.2	1013959434	867417463	5222805545
18	1640066804	153869069.7	1042292104	888423033.8	6111228579
19	1631450136	161562523.2	1036816055	875253532.1	6986482111
20	1676774639	169640649.4	1065620597	895979947.4	7882462058
21	1723277928	178122681.8	1095174277	917051595.5	8799513654
22	1770986318	187028815.9	1125493822	938465005.6	9737978660
23	1819926462	196380256.7	1156596168	960215911.1	10698194571
24	1870125338	206199269.6	1188498461	982299191.6	11680493762
25	1921610234	216509233.1	1221218044	1004708811	12685202573
26	1974408735	227334694.7	1254772445	1027437750	13712640323
27	2028548700	238701429.4	1289179371	1050477942	14763118265

28	2084058248	250636500.9	1324456693	1073820192	15836938458
29	2140965738	263168326	1360622432	1097454106	16934392564
30	2199299740	276326742.3	1397694745	1121368002	18055760566
Total		**9429530604**	**27485291170**	**18055760566**	

Year	IRR	B/C ratio	NPV
10	8%	1.10	-429242693.2
20	17.28%	2.14	7882462058
30	18%	2.92	18055760566

REVENUE INCREASE BY 5%:

Year	**Cost**			**Benefit**	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1258120519	1149320449
5		114240074	114240074	1295864135	1181624061
6		119952077.7	119952077.7	1334740059	1214787981
7		125949681.6	125949681.6	1374782261	1248832579
8		132247165.7	132247165.7	1416025728	1283778563
9		138859524	138859524	1458506500	1319646976
10		145802500.2	145802500.2	1502261695	1356459195
11		153092625.2	153092625.2	1547329546	1394236921
12		160747256.5	160747256.5	1593749432	1433002176
13		168784619.3	168784619.3	1641561915	1472777296
14		177223850.2	177223850.2	1690808773	1513584923
15		186085042.8	186085042.8	1741533036	1555447993
16		195389294.9	195389294.9	1793779027	1598389732
17		205158759.6	205158759.6	1847592398	1642433638
18		215416697.6	215416697.6	1903020170	1687603472
19		226187532.5	226187532.5	1903020170	1676832637
20		237496909.1	237496909.1	1960110775	1722613866
21		249371754.6	249371754.6	2018914098	1769542344

22		261840342.3	261840342.3	2079481521	1817641179
23		274932359.4	274932359.4	2141865967	1866933607
24		288678977.4	288678977.4	2206121946	1917442968
25		303112926.3	303112926.3	2272305604	1969192678
26		318268572.6	318268572.6	2340474772	2022206200
27		334182001.2	334182001.2	2410689016	2076507014
28		350891101.3	350891101.3	2483009686	2132118585
29		368435656.3	368435656.3	2557499977	2189064320
30		386857439.2	386857439.2	2634224976	2247367537
Total		**5948004812**	**13201342846**	**50407393702**	**44459388890**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1149320449	97142920.1	730413923	633271002.9	-5842923670
5	1181624061	102000066.1	750943452.5	648943386.3	-5193980284
6	1214787981	107100069.4	772019723.4	664919654	-4529060630
7	1248832579	112455072.9	793655680.8	681200607.9	-3847860022
8	1283778563	118077826.5	815864485.2	697786658.7	-3150073363
9	1319646976	123981717.8	838659510.5	714677792.6	-2435395571
10	1356459195	130180803.7	862054341.1	731873537.3	-1703522033
11	1394236921	136689843.9	886062768.8	749372924.9	-954149108.5
12	1433002176	143524336.1	910698789.2	767174453.1	-186974655.4
13	1472777296	150700552.9	935976597.2	785276044.2	598301388.8

14	1513584923	158235580.6	961910581.5	803675001	1401976390
15	1555447993	166147359.6	988515319.8	822367960.2	2224344350
16	1598389732	174454727.6	1015805571	841350843.6	3065695194
17	1642433638	183177464	1043796270	860618805.8	3926313999
18	1687603472	192336337.2	1072502516	880166178.7	4806480178
19	1676832637	201953154	1065657456	863704301.5	5670184480
20	1722613866	212050811.7	1094752254	882701442.2	6552885922
21	1769542344	222653352.3	1124576150	901922797.6	7454808719
22	1817641179	233786019.9	1155143829	921357809.3	8376166529
23	1866933607	245475320.9	1186470059	940994737.8	9317161266
24	1917442968	257749087	1218569671	960820583.8	10277981850
25	1969192678	270636541.3	1251457547	980821005.4	11258802855
26	2022206200	284168368.4	1285148598	1000980230	12259783085
27	2076507014	298376786.8	1319657748	1021280961	13281064046
28	2132118585	313295626.1	1354999906	1041704280	14322768326
29	2189064320	328960407.4	1391189950	1062229543	15384997869
30	2247367537	345408427.8	1428242698	1082834271	16467832139
Total		**11786913255**	**28254745395**	**16467832139**	

Year	IRR	B/C ratio	NPV
10	4%	0.90	-1703522033
20	14.29%	1.76	6552885922
30	16%	2.40	16467832139

REVENUE INCREASE BY 10%:

Year	Cost			Benefit	
	Capital Cost	O&M cost	Total cost	Total Benefit	Net Benefit
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1318031020	1209230950
5		114240074	114240074	1357571951	1243331877
6		119952077.7	119952077.7	1398299109	1278347031
7		125949681.6	125949681.6	1440248082	1314298401
8		132247165.7	132247165.7	1483455525	1351208359
9		138859524	138859524	1527959191	1389099667
10		145802500.2	145802500.2	1573797966	1427995466
11		153092625.2	153092625.2	1621011905	1467919280
12		160747256.5	160747256.5	1669642263	1508895006
13		168784619.3	168784619.3	1719731530	1550946911
14		177223850.2	177223850.2	1771323476	1594099626
15		186085042.8	186085042.8	1824463181	1638378138
16		195389294.9	195389294.9	1879197076	1683807781
17		205158759.6	205158759.6	1935572988	1730414229
18		215416697.6	215416697.6	1993640178	1778223480
19		226187532.5	226187532.5	1993640178	1767452645
20		237496909.1	237496909.1	2053449383	1815952474
21		249371754.6	249371754.6	2115052865	1865681110
22		261840342.3	261840342.3	2178504451	1916664108
23		274932359.4	274932359.4	2243859584	1968927225
24		288678977.4	288678977.4	2311175372	2022496394
25		303112926.3	303112926.3	2380510633	2077397707
26		318268572.6	318268572.6	2451925952	2133657379
27		334182001.2	334182001.2	2525483731	2191301729
28		350891101.3	350891101.3	2601248242	2250357141
29		368435656.3	368435656.3	2679285690	2310850033
30		386857439.2	386857439.2	2759664260	2372806821
Total		**5948004812**	**13201342846**	**52807745783**	**46859740971**

Year	Cash flow	Present Value			Cumulative Discounted Cash Flow
		PV cost	PV Benefit	NPV	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1209230950	97142920.1	768488129.4	671345209.3	-5804849464
5	1243331877	102000066.1	790159885.1	688159819	-5116689645
6	1278347031	107100069.4	812412649	705312579.6	-4411377065
7	1314298401	112455072.9	835260394.2	722805321.3	-3688571744
8	1351208359	118077826.5	858717340	740639513.5	-2947932231
9	1389099667	123981717.8	882797950.9	758816233	-2189115998
10	1427995466	130180803.7	907516934.7	777336130.9	-1411779867
11	1467919280	136689843.9	932889240.2	796199396.3	-615580470.3
12	1508895006	143524336.1	958930054.8	815405718.7	199825248.3
13	1550946911	150700552.9	985654800.7	834954247.8	1034779496
14	1594099626	158235580.6	1013079131	854843550.6	1889623047
15	1638378138	166147359.6	1041218926	875071566.3	2764694613
16	1683807781	174454727.6	1070090285	895635557.9	3660330171
17	1730414229	183177464	1099709525	916532061.5	4576862232
18	1778223480	192336337.2	1130093169	937756832.1	5514619064
19	1767452645	201953154	1123248109	921294954.9	6435914019

20	1815952474	212050811.7	1154070627	942019815.2	7377933835
21	1865681110	222653352.3	1185674074	963020721.8	8340954556
22	1916664108	233786019.9	1218074691	984288671.2	9325243228
23	1968927225	245475320.9	1251288846	1005813526	10331056753
24	2022496394	257749087	1285333022	1027583935	11358640688
25	2077397707	270636541.3	1320223799	1049587257	12408227946
26	2133657379	284168368.4	1355977838	1071809469	13480037415
27	2191301729	298376786.8	1392611864	1094235077	14574272492
28	2250357141	313295626.1	1430142646	1116847020	15691119512
29	2310850033	328960407.4	1468586973	1139626565	16830746078
30	2372806821	345408427.8	1507961631	1162553204	17993299281
Total		**11786913255**	**29780212537**	**17993299281**	

Year	IRR	B/C ratio	NPV
10	5%	0.94	-1411779867
20	15.07%	1.85	7377933835
30	16%	2.53	17993299281

REVENUE INCREASE BY 15%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1377941521	1269141450
5		114240074	114240074	1419279767	1305039693
6		119952077.7	119952077.7	1461858160	1341906082

7		125949681.6	125949681.6	1505713904	1379764223
8		132247165.7	132247165.7	1550885322	1418638156
9		138859524	138859524	1597411881	1458552357
10		145802500.2	145802500.2	1645334238	1499531737
11		153092625.2	153092625.2	1694694265	1541601640
12		160747256.5	160747256.5	1745535093	1584787836
13		168784619.3	168784619.3	1797901145	1629116526
14		177223850.2	177223850.2	1851838180	1674614330
15		186085042.8	186085042.8	1907393325	1721308282
16		195389294.9	195389294.9	1964615125	1769225830
17		205158759.6	205158759.6	2023553579	1818394819
18		215416697.6	215416697.6	2084260186	1868843488
19		226187532.5	226187532.5	2084260186	1858072654
20		237496909.1	237496909.1	2146787992	1909291083
21		249371754.6	249371754.6	2211191631	1961819877
22		261840342.3	261840342.3	2277527380	2015687038
23		274932359.4	274932359.4	2345853202	2070920842
24		288678977.4	288678977.4	2416228798	2127549820
25		303112926.3	303112926.3	2488715662	2185602735
26		318268572.6	318268572.6	2563377132	2245108559
27		334182001.2	334182001.2	2640278446	2306096444
28		350891101.3	350891101.3	2719486799	2368595698
29		368435656.3	368435656.3	2801071403	2432635747
30		386857439.2	386857439.2	2885103545	2498246106
Total		**5948004812**	**13201342846**	**55208097865**	**49260093052**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1269141450	97142920.1	806562335.8	709419415.7	-5766775257

5	1305039693	102000066.1	829376317.7	727376251.6	-5039399006
6	1341906082	107100069.4	852805574.6	745705505.1	-4293693501
7	1379764223	112455072.9	876865107.5	764410034.6	-3529283466
8	1418638156	118077826.5	901570194.7	783492368.2	-2745791098
9	1458552357	123981717.8	926936391.3	802954673.4	-1942836424
10	1499531737	130180803.7	952979528.3	822798724.5	-1120037700
11	1541601640	136689843.9	979715711.6	843025867.7	-277011832.2
12	1584787836	143524336.1	1007161320	863636984.2	586625152
13	1629116526	150700552.9	1035333004	884632451.3	1471257603
14	1674614330	158235580.6	1064247681	906012100.2	2377269704
15	1721308282	166147359.6	1093922532	927775172.4	3305044876
16	1769225830	174454727.6	1124375000	949920272.2	4254965148
17	1818394819	183177464	1155622781	972445317.2	5227410465
18	1868843488	192336337.2	1187683823	995347485.5	6222757951
19	1858072654	201953154	1180838762	978885608.3	7201643559
20	1909291083	212050811.7	1213389000	1001338188	8202981747
21	1961819877	222653352.3	1246771998	1024118646	9227100393
22	2015687038	233786019.9	1281005553	1047219533	10274319927
23	2070920842	245475320.9	1316107634	1070632313	11344952240
24	2127549820	257749087	1352096374	1094347287	12439299526
25	2185602735	270636541.3	1388990051	1118353509	13557653036
26	2245108559	284168368.4	1426807077	1142638709	14700291745
27	2306096444	298376786.8	1465565981	1167189194	15867480939

28	2368595698	313295626.1	1505285386	1191989760	17059470699
29	2432635747	328960407.4	1545983995	1217023588	18276494287
30	2498246106	345408427.8	1587680565	1242272137	19518766423
		11786913255	**31305679679**	**19518766423**	

Year	IRR	B/C ratio	NPV
10	6%	0.98	-1120037700
20	15.83%	1.94	8202981747
30	17%	2.66	19518766423

REVENUE INCREASE BY 20%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1437852022	1329051951
5		114240074	114240074	1480987583	1366747509
6		119952077.7	119952077.7	1525417210	1405465132
7		125949681.6	125949681.6	1571179726	1445230045
8		132247165.7	132247165.7	1618315118	1486067952
9		138859524	138859524	1666864572	1528005048
10		145802500.2	145802500.2	1716870509	1571068009
11		153092625.2	153092625.2	1768376624	1615283999
12		160747256.5	160747256.5	1821427923	1660680666
13		168784619.3	168784619.3	1876070760	1707286141
14		177223850.2	177223850.2	1932352883	1755129033
15		186085042.8	186085042.8	1990323470	1804238427
16		195389294.9	195389294.9	2050033174	1854643879
17		205158759.6	205158759.6	2111534169	1906375409
18		215416697.6	215416697.6	2174880194	1959463497
19		226187532.5	226187532.5	2174880194	1948692662
20		237496909.1	237496909.1	2240126600	2002629691
21		249371754.6	249371754.6	2307330398	2057958643

22		261840342.3	261840342.3	2376550310	2114709968
23		274932359.4	274932359.4	2447846819	2172914460
24		288678977.4	288678977.4	2521282224	2232603246
25		303112926.3	303112926.3	2596920691	2293807764
26		318268572.6	318268572.6	2674828311	2356559739
27		334182001.2	334182001.2	2755073161	2420891159
28		350891101.3	350891101.3	2837725355	2486834254
29		368435656.3	368435656.3	2922857116	2554421460
30		386857439.2	386857439.2	3010542830	2623685390
Total		**5948004812**	**13201342846**	**57608449946**	**51660445133**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1329051951	97142920.1	844636542.2	747493622.1	-5728701051
5	1366747509	102000066.1	868592750.3	766592684.2	-4962108367
6	1405465132	107100069.4	893198500.1	786098430.7	-4176009936
7	1445230045	112455072.9	918469820.9	806014748	-3369995188
8	1486067952	118077826.5	944423049.5	826345223	-2543649965
9	1528005048	123981717.8	971074831.7	847093113.8	-1696556851
10	1571068009	130180803.7	998442121.9	868261318.1	-828295533.2
11	1615283999	136689843.9	1026542183	889852339.1	61556805.94
12	1660680666	143524336.1	1055392586	911868249.8	973425055.7
13	1707286141	150700552.9	1085011208	934310654.8	1907735711

14	1755129033	158235580.6	1115416230	957180649.9	2864916360
15	1804238427	166147359.6	1146626138	980478778.5	3845395139
16	1854643879	174454727.6	1178659714	1004204987	4849600125
17	1906375409	183177464	1211536037	1028358573	5877958698
18	1959463497	192336337.2	1245274476	1052938139	6930896837
19	1948692662	201953154	1238429416	1036476262	7967373099
20	2002629691	212050811.7	1272707373	1060656561	9028029660
21	2057958643	222653352.3	1307869923	1085216570	10113246230
22	2114709968	233786019.9	1343936415	1110150395	11223396625
23	2172914460	245475320.9	1380926422	1135451101	12358847727
24	2232603246	257749087	1418859725	1161110638	13519958365
25	2293807764	270636541.3	1457756303	1187119761	14707078126
26	2356559739	284168368.4	1497636317	1213467948	15920546074
27	2420891159	298376786.8	1538520098	1240143311	17160689385
28	2486834254	313295626.1	1580428126	1267132500	18427821885
29	2554421460	328960407.4	1623381018	1294420610	19722242496
30	2623685390	345408427.8	1667399498	1321991070	21044233565
Total		11786913255	32831146821	21044233565	

Year	IRR	B/C ratio	NPV
10	7%	1.02	-828295533.2
20	16.56%	2.04	9028029660
30	18%	2.79	21044233565

REVENUE DECREASE BY 5%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1138299517	1029499447
5		114240074	114240074	1172448503	1058208429
6		119952077.7	119952077.7	1207621958	1087669880
7		125949681.6	125949681.6	1243850617	1117900935
8		132247165.7	132247165.7	1281166135	1148918969
9		138859524	138859524	1319601119	1180741595
10		145802500.2	145802500.2	1359189153	1213386653
11		153092625.2	153092625.2	1399964827	1246872202
12		160747256.5	160747256.5	1441963772	1281216516
13		168784619.3	168784619.3	1485222685	1316438066
14		177223850.2	177223850.2	1529779366	1352555516
15		186085042.8	186085042.8	1575672747	1389587704
16		195389294.9	195389294.9	1622942929	1427553634
17		205158759.6	205158759.6	1671631217	1466472458
18		215416697.6	215416697.6	1721780154	1506363456
19		226187532.5	226187532.5	1721780154	1495592621
20		237496909.1	237496909.1	1773433558	1535936649
21		249371754.6	249371754.6	1826636565	1577264811
22		261840342.3	261840342.3	1881435662	1619595320
23		274932359.4	274932359.4	1937878732	1662946372
24		288678977.4	288678977.4	1996015094	1707336116
25		303112926.3	303112926.3	2055895547	1752782620
26		318268572.6	318268572.6	2117572413	1799303840
27		334182001.2	334182001.2	2181099585	1846917584
28		350891101.3	350891101.3	2246532573	1895641472
29		368435656.3	368435656.3	2313928550	1945492894
30		386857439.2	386857439.2	2383346407	1996488968
Total		**5948004812**	**13201342846**	**45606689540**	**39658684728**

Year	Cash flow	Present Value			Cumulative Discounted Cash Flow
		PV cost	**PV Benefit**	**NPV**	
0					

1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	1029499447	97142920.1	654265510.2	557122590.1	-5919072083
5	1058208429	102000066.1	672510587.2	570510521.1	-5348561562
6	1087669880	107100069.4	691233872.2	584133802.8	-4764427759
7	1117900935	112455072.9	710446254.1	597991181.2	-4166436578
8	1148918969	118077826.5	730158775.7	612080949.2	-3554355629
9	1180741595	123981717.8	750382629.7	626400911.9	-2927954717
10	1213386653	130180803.7	771129153.8	640948350.1	-2287006367
11	1246872202	136689843.9	792409826	655719982	-1631286385
12	1281216516	143524336.1	814236258.1	670711922	-960574462.8
13	1316438066	150700552.9	836620190.1	685919637.2	-274654825.6
14	1352555516	158235580.6	859573482.3	701337901.7	426683076.1
15	1389587704	166147359.6	883108107.5	716960747.9	1143643824
16	1427553634	174454727.6	907236142.6	732781415	1876425239
17	1466472458	183177464	931969758.3	748792294.3	2625217533
18	1506363456	192336337.2	957321209	764984871.8	3390202405
19	1495592621	201953154	950476148.7	748522994.7	4138725400
20	1535936649	212050811.7	976115507.9	764064696.1	4902790096
21	1577264811	222653352.3	1002380302	779726949.2	5682517045

22	1619595320	233786019.9	1029282105	795496085.5	6478013131
23	1662946372	245475320.9	1056832483	811357162.2	7289370293
24	1707336116	257749087	1085042968	827293881	8116664174
25	1752782620	270636541.3	1113925043	843288501.5	8959952675
26	1799303840	284168368.4	1143490119	859321750.8	9819274426
27	1846917584	298376786.8	1173749514	875372727.3	10694647153
28	1895641472	313295626.1	1204714425	891418799.3	11586065953
29	1945492894	328960407.4	1236395905	907435498	12493501451
30	1996488968	345408427.8	1268804832	923396404.4	13416897855
Total		**11786913255**	**25203811110**	**13416897855**	

Year	IRR	B/C ratio	NPV
10	2%	0.82	-2287006367
20	12.67%	1.58	4902790096
30	14%	2.15	13416897855

REVENUE DECREASE BY 10%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1078389016	969588946
5		114240074	114240074	1110740687	996500612.9
6		119952077.7	119952077.7	1144062908	1024110830
7		125949681.6	125949681.6	1178384795	1052435113
8		132247165.7	132247165.7	1213736339	1081489173
9		138859524	138859524	1250148429	1111288905
10		145802500.2	145802500.2	1287652882	1141850381
11		153092625.2	153092625.2	1326282468	1173189843

12		160747256.5	160747256.5	1366070942	1205323686
13		168784619.3	168784619.3	1407053070	1238268451
14		177223850.2	177223850.2	1449264662	1272040812
15		186085042.8	186085042.8	1492742602	1306657560
16		195389294.9	195389294.9	1537524880	1342135586
17		205158759.6	205158759.6	1583650627	1378491867
18		215416697.6	215416697.6	1631160146	1415743448
19		226187532.5	226187532.5	1631160146	1404972613
20		237496909.1	237496909.1	1680094950	1442598041
21		249371754.6	249371754.6	1730497799	1481126044
22		261840342.3	261840342.3	1782412732	1520572390
23		274932359.4	274932359.4	1835885114	1560952755
24		288678977.4	288678977.4	1890961668	1602282690
25		303112926.3	303112926.3	1947690518	1644577592
26		318268572.6	318268572.6	2006121233	1687852661
27		334182001.2	334182001.2	2066304870	1732122869
28		350891101.3	350891101.3	2128294017	1777402915
29		368435656.3	368435656.3	2192142837	1823707181
30		386857439.2	386857439.2	2257907122	1871049683
Total		**5948004812**	**13201342846**	**43206337459**	**37258332647**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	969588945.9	97142920.1	616191303.7	519048383.7	-5957146290
5	996500612.9	102000066.1	633294154.6	531294088.5	-5425852201
6	1024110830	107100069.4	650840946.6	543740877.2	-4882111324
7	1052435113	112455072.9	668841540.7	556386467.9	-4325724856

8	1081489173	118077826.5	687305921	569228094.4	-3756496761
9	1111288905	123981717.8	706244189.3	582262471.5	-3174234290
10	1141850381	130180803.7	725666560.2	595485756.5	-2578748534
11	1173189843	136689843.9	745583354.5	608893510.6	-1969855023
12	1205323686	143524336.1	766004992.6	622480656.4	-1347374367
13	1238268451	150700552.9	786941986.6	636241433.6	-711132932.9
14	1272040812	158235580.6	808404932.6	650169352.1	-60963580.79
15	1306657560	166147359.6	830404501.4	664257141.8	603293561
16	1342135586	174454727.6	852951428.3	678496700.7	1281790262
17	1378491867	183177464	876056502.5	692879038.6	1974669300
18	1415743448	192336337.2	899730555.6	707394218.4	2682063519
19	1404972613	201953154	892885495.3	690932341.3	3372995860
20	1442598041	212050811.7	916797134.8	704746323.1	4077742183
21	1481126044	222653352.3	941282377.3	718629025	4796371208
22	1520572390	233786019.9	966351243.5	732565223.5	5528936432
23	1560952755	245475320.9	992013695.3	746538374.4	6275474806
24	1602282690	257749087	1018279617	760530529.5	7036005336
25	1644577592	270636541.3	1045158791	774522249.5	7810527585
26	1687852661	284168368.4	1072660880	788492511.3	8599020096
27	1732122869	298376786.8	1100795397	802418610.6	9401438707
28	1777402915	313295626.1	1129571685	816276059.1	10217714766
29	1823707181	328960407.4	1158998883	830038475.6	11047753242
30	1871049683	345408427.8	1189085899	843677471.3	11891430713

Total		11786913255	23678343968	11891430713	

Year	IRR	B/C ratio	NPV
10	0%	0.78	-2578748534
20	11.81%	1.49	4077742183
30	14%	2.02	11891430713

REVENUE DECREASE BY 15%:

Year	Cost			Benefit	
	Capital Cost	**O&M cost**	**Total cost**	**Total Benefit**	**Net Benefit**
0					
1	2176001410		2176001410	0	0
2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	1018478516	909678445
5		114240074	114240074	1049032871	934792796.9
6		119952077.7	119952077.7	1080503857	960551779.4
7		125949681.6	125949681.6	1112918973	986969291.2
8		132247165.7	132247165.7	1146306542	1014059376
9		138859524	138859524	1180695738	1041836214
10		145802500.2	145802500.2	1216116610	1070314110
11		153092625.2	153092625.2	1252600109	1099507484
12		160747256.5	160747256.5	1290178112	1129430856
13		168784619.3	168784619.3	1328883455	1160098836
14		177223850.2	177223850.2	1368749959	1191526109
15		186085042.8	186085042.8	1409812458	1223727415
16		195389294.9	195389294.9	1452106832	1256717537
17		205158759.6	205158759.6	1495670036	1290511277
18		215416697.6	215416697.6	1540540138	1325123440
19		226187532.5	226187532.5	1540540138	1314352605
20		237496909.1	237496909.1	1586756342	1349259433
21		249371754.6	249371754.6	1634359032	1384987277
22		261840342.3	261840342.3	1683389803	1421549461
23		274932359.4	274932359.4	1733891497	1458959138
24		288678977.4	288678977.4	1785908242	1497229264
25		303112926.3	303112926.3	1839485489	1536372563
26		318268572.6	318268572.6	1894670054	1576401481

27		334182001.2	334182001.2	1951510155	1617328154
28		350891101.3	350891101.3	2010055460	1659164359
29		368435656.3	368435656.3	2070357124	1701921468
30		386857439.2	386857439.2	2132467838	1745610398
Total		**5948004812**	**13201342846**	**40805985378**	**34857980566**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	PV Benefit	NPV	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271
3	-2176001410	1942858402		-1942858402	-6476194673
4	909678445	97142920.1	578117097.3	480974177.2	-5995220496
5	934792796.9	102000066.1	594077722	492077655.9	-5503142840
6	960551779.4	107100069.4	610448021	503347951.6	-4999794888
7	986969291.2	112455072.9	627236827.4	514781754.5	-4485013134
8	1014059376	118077826.5	644453066.2	526375239.7	-3958637894
9	1041836214	123981717.8	662105748.9	538124031.1	-3420513863
10	1070314110	130180803.7	680203966.6	550023162.9	-2870490700
11	1099507484	136689843.9	698756883.1	562067039.2	-2308423661
12	1129430856	143524336.1	717773727	574249390.9	-1734174270
13	1160098836	150700552.9	737263783.1	586563230.1	-1147611040
14	1191526109	158235580.6	757236383	599000802.4	-548610237.7
15	1223727415	166147359.6	777700895.3	611553535.7	62943298.02
16	1256717537	174454727.6	798666714	624211986.4	687155284.4

17	1290511277	183177464	820143246.8	636965782.8	1324121067
18	1325123440	192336337.2	842139902.2	649803565	1973924632
19	1314352605	201953154	835294841.9	633341687.9	2607266320
20	1349259433	212050811.7	857478761.8	645427950.1	3252694270
21	1384987277	222653352.3	880184453.1	657531100.8	3910225371
22	1421549461	233786019.9	903420381.5	669634361.6	4579859733
23	1458959138	245475320.9	927194907.6	681719586.6	5261579319
24	1497229264	257749087	951516265.1	693767178.1	5955346497
25	1536372563	270636541.3	976392538.9	705755997.5	6661102495
26	1576401481	284168368.4	1001831640	717663271.8	7378765767
27	1617328154	298376786.8	1027841281	729464493.9	8108230261
28	1659164359	313295626.1	1054428945	741133318.9	8849363580
29	1701921468	328960407.4	1081601861	752641453.2	9602005033
30	1745610398	345408427.8	1109366966	763958538.2	10365963571
Total		11786913255	22152876826	10365963571	

Year	IRR	B/C ratio	NPV
10	-1%	0.74	-2870490700
20	10.93%	1.39	3252694270
30	13%	1.89	10365963571

REVENUE DECREASE BY 20%:

Year	Cost			Benefit	
	Capital Cost	O&M cost	Total cost	Total Benefit	Net Benefit
0					
1	2176001410		2176001410	0	0

2	2901335214		2901335214	0	0
3	2176001410		2176001410	0	0
4		108800070.5	108800070.5	958568015	849767944
5		114240074	114240074	987325055	873084981
6		119952077.7	119952077.7	1016944807	896992728.9
7		125949681.6	125949681.6	1047453151	921503469.3
8		132247165.7	132247165.7	1078876745	946629579.7
9		138859524	138859524	1111243048	972383523.8
10		145802500.2	145802500.2	1144580339	998777839
11		153092625.2	153092625.2	1178917749	1025825124
12		160747256.5	160747256.5	1214285282	1053538025
13		168784619.3	168784619.3	1250713840	1081929221
14		177223850.2	177223850.2	1288235256	1111011405
15		186085042.8	186085042.8	1326882313	1140797270
16		195389294.9	195389294.9	1366688783	1171299488
17		205158759.6	205158759.6	1407689446	1202530686
18		215416697.6	215416697.6	1449920129	1234503432
19		226187532.5	226187532.5	1449920129	1223732597
20		237496909.1	237496909.1	1493417733	1255920824
21		249371754.6	249371754.6	1538220265	1288848511
22		261840342.3	261840342.3	1584366873	1322526531
23		274932359.4	274932359.4	1631897879	1356965520
24		288678977.4	288678977.4	1680854816	1392175838
25		303112926.3	303112926.3	1731280460	1428167534
26		318268572.6	318268572.6	1783218874	1464950302
27		334182001.2	334182001.2	1836715440	1502533439
28		350891101.3	350891101.3	1891816904	1540925802
29		368435656.3	368435656.3	1948571411	1580135754
30		386857439.2	386857439.2	2007028553	1620171114
Total		**5948004812**	**13201342846**	**38405633297**	**32457628485**

Year	**Cash flow**	**Present Value**			**Cumulative Discounted Cash Flow**
		PV cost	**PV Benefit**	**NPV**	
0					
1	-2176001410	1942858402		-1942858402	-1942858402
2	-2901335214	2590477869		-2590477869	-4533336271

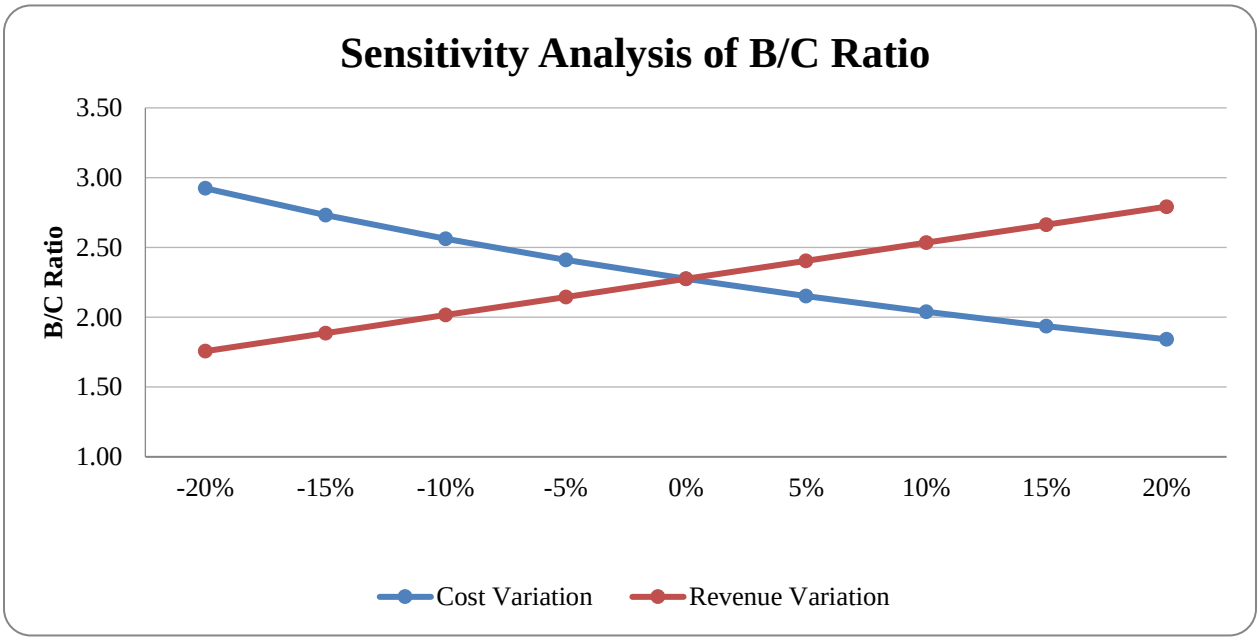
3	-2176001410	1942858402		-1942858402	-6476194673
4	849767944.1	97142920.1	540042890.9	442899970.8	-6033294702
5	873084981	102000066.1	554861289.4	452861223.3	-5580433479
6	896992728.9	107100069.4	570055095.4	462955026	-5117478453
7	921503469.3	112455072.9	585632114	473177041.2	-4644301412
8	946629579.7	118077826.5	601600211.5	483522384.9	-4160779027
9	972383523.8	123981717.8	617967308.5	493985590.7	-3666793436
10	998777839	130180803.7	634741373	504560569.3	-3162232867
11	1025825124	136689843.9	651930411.7	515240567.8	-2646992299
12	1053538025	143524336.1	669542461.4	526018125.3	-2120974174
13	1081929221	150700552.9	687585579.5	536885026.6	-1584089147
14	1111011405	158235580.6	706067833.4	547832252.8	-1036256895
15	1140797270	166147359.6	724997289.2	558849929.6	-477406965
16	1171299488	174454727.6	744381999.7	569927272.1	92520307.1
17	1202530686	183177464	764229991.1	581052527.1	673572834.2
18	1234503432	192336337.2	784549248.8	592212911.6	1265785746
19	1223732597	201953154	777704188.5	575751034.5	1841536780
20	1255920824	212050811.7	798160388.8	586109577.1	2427646357
21	1288848511	222653352.3	819086528.9	596433176.6	3024079534
22	1322526531	233786019.9	840489519.6	606703499.7	3630783034
23	1356965520	245475320.9	862376119.8	616900798.9	4247683833
24	1392175838	257749087	884752913.7	627003826.7	4874687659

25	1428167534	270636541.3	907626286.9	636989745.6	5511677405
26	1464950302	284168368.4	931002400.6	646834032.2	6158511437
27	1502533439	298376786.8	954887164	656510377.2	6815021814
28	1540925802	313295626.1	979286204.9	665990578.7	7481012393
29	1580135754	328960407.4	1004204838	675244430.8	8156256824
30	1620171114	345408427.8	1029648033	684239605.2	8840496429
Total		**11786913255**	**20627409684**	**8840496429**	

Year	IRR	B/C ratio	NPV
10	-2%	0.70	-3162232867
20	10.01%	1.30	2427646357
30	12%	1.76	8840496429

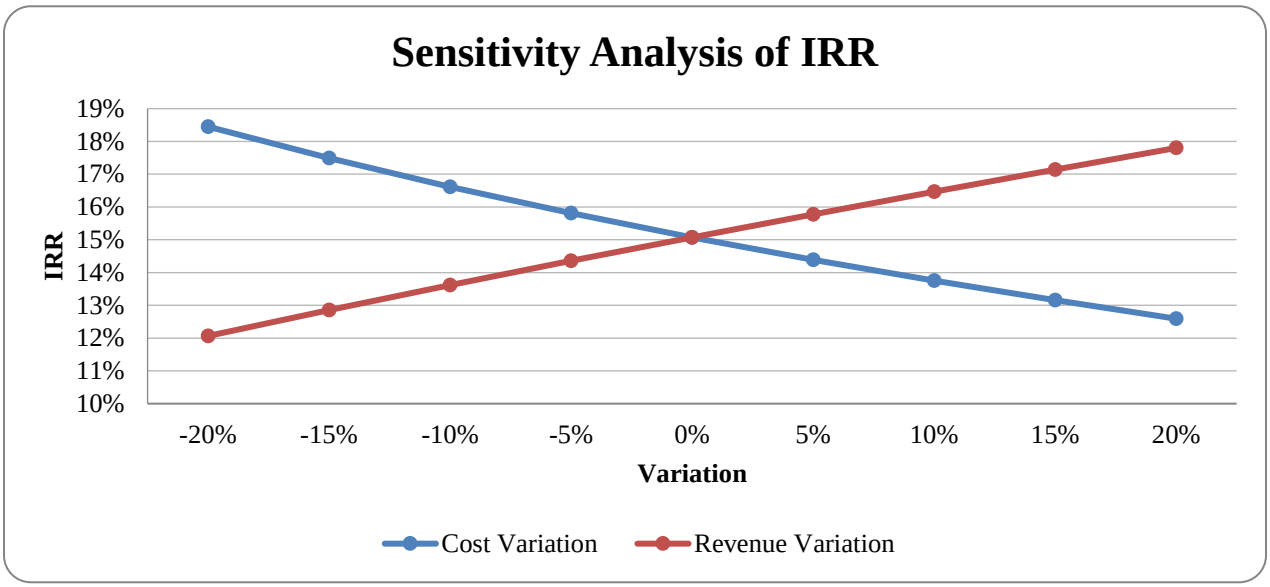
SENSITIVITY ANALYSIS OF BC RATIO:

B/C Ratio		
Variation	**Cost Variation**	**Revenue Variation**
-20%	2.92	1.76
-15%	2.73	1.89
-10%	2.56	2.02
-5%	2.41	2.15
0%	2.27	2.27
5%	2.15	2.40
10%	2.04	2.53
15%	1.94	2.66
20%	1.84	2.79



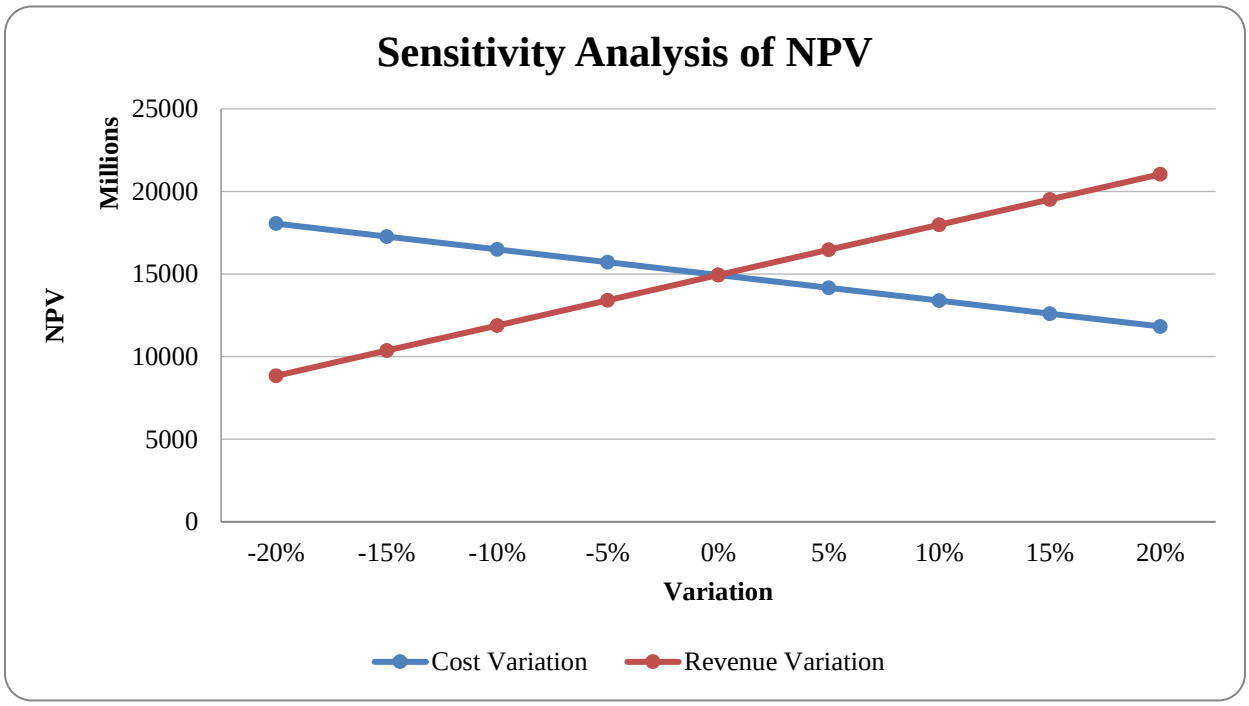
SENSITIVITY ANALYSIS OF IRR:

IRR		
Variation	**Cost Variation**	**Revenue Variation**
-20%	18.45%	12.07%
-15%	17.49%	12.85%
-10%	16.62%	13.61%
-5%	15.82%	14.35%
0%	15.08%	15.08%
5%	14.39%	15.78%
10%	13.75%	16.47%
15%	13.15%	17.14%
20%	12.59%	17.80%



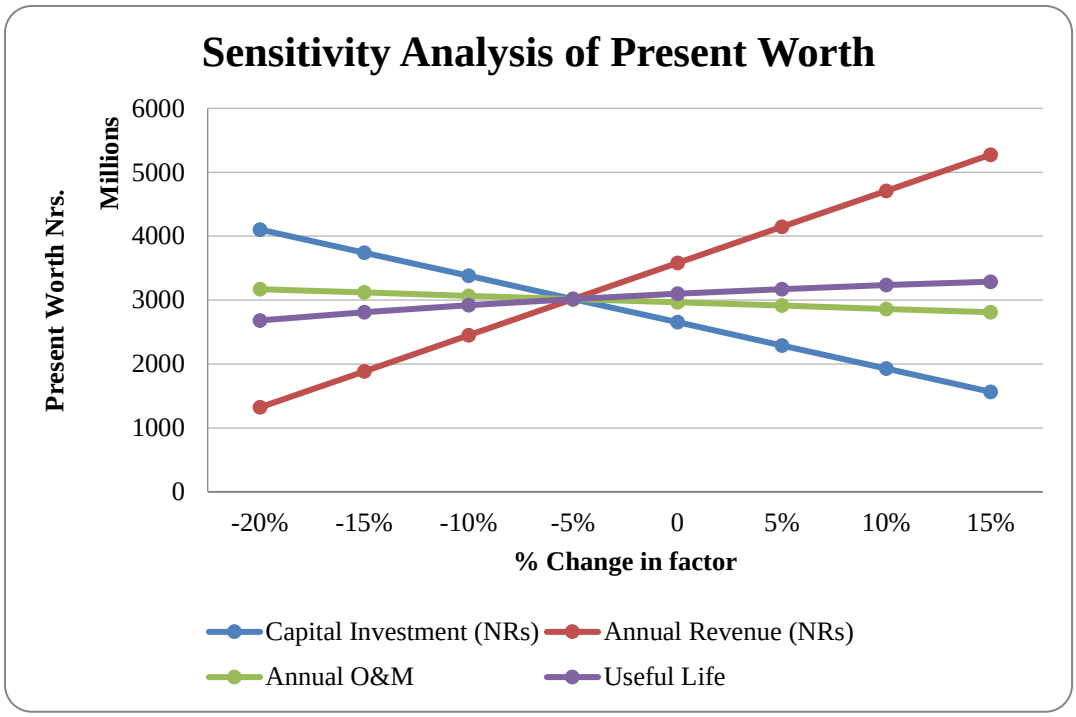
SENSITIVITY ANALYSIS OF NPV:

NPV		
Variation	**Cost Variation**	**Revenue Variation**
-20%	18055760566	8840496429
-15%	17277411674	10365963571
-10%	16499062782	11891430713
-5%	15720713889	13416897855
0%	14942364997	14942364997
5%	14164016105	16467832139
10%	13385667213	17993299281
15%	12607318321	19518766423
20%	11828969428	21044233565



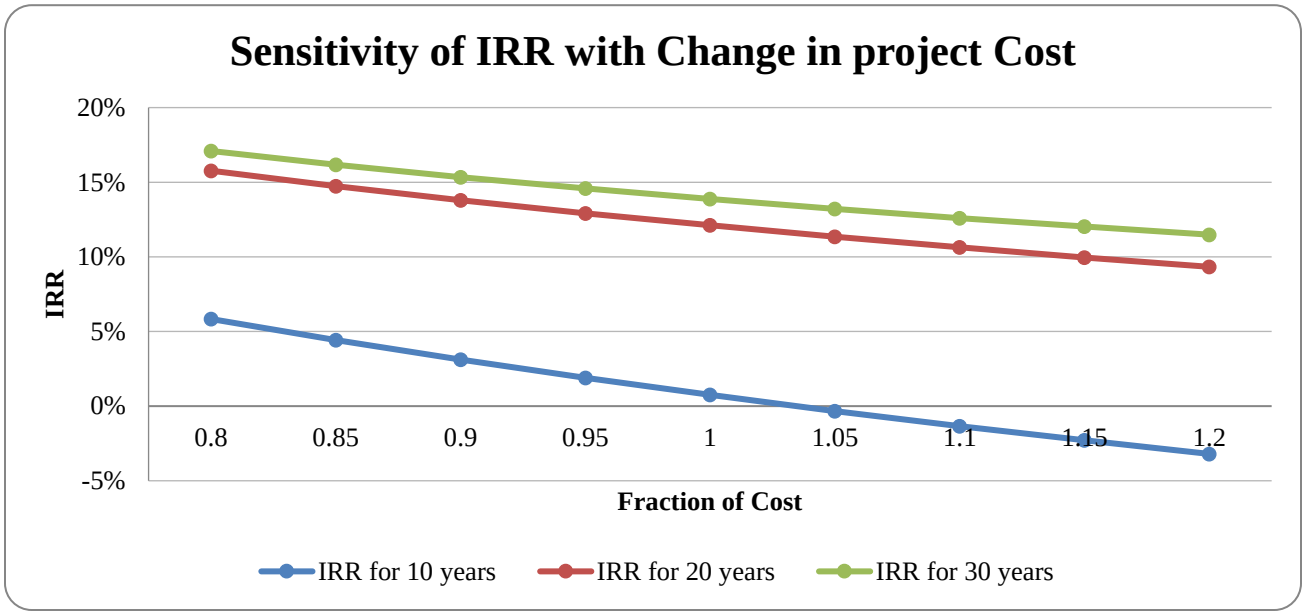
Sensitivity Analysis of Present Worth:

%Change in Factor	Capital Investment (NRs)	Annual Revenue (NRs)	Annual O&M	Useful Life
-20%	4467103969.63	757351691.74	3221566154.58	2534731479.35
-15%	4104437067.93	1322122859.52	3170283706.64	2682072176.76
-10%	3741770166.23	1886894027.29	3119001258.71	2809784761.17
-5%	3379103264.53	2451665195.06	3067718810.77	2920484007.91
0	3016436362.84	3016436362.84	3016436362.84	3016436362.84
5%	2653769461.14	3581207530.61	2965153914.90	3099606345.36
10%	2291102559.44	4145978698.39	2913871466.97	3171696769.80
15%	1928435657.75	4710749866.16	2862589019.03	3234183608.66
20%	1565768756.05	5275521033.93	2811306571.10	3288346211.55



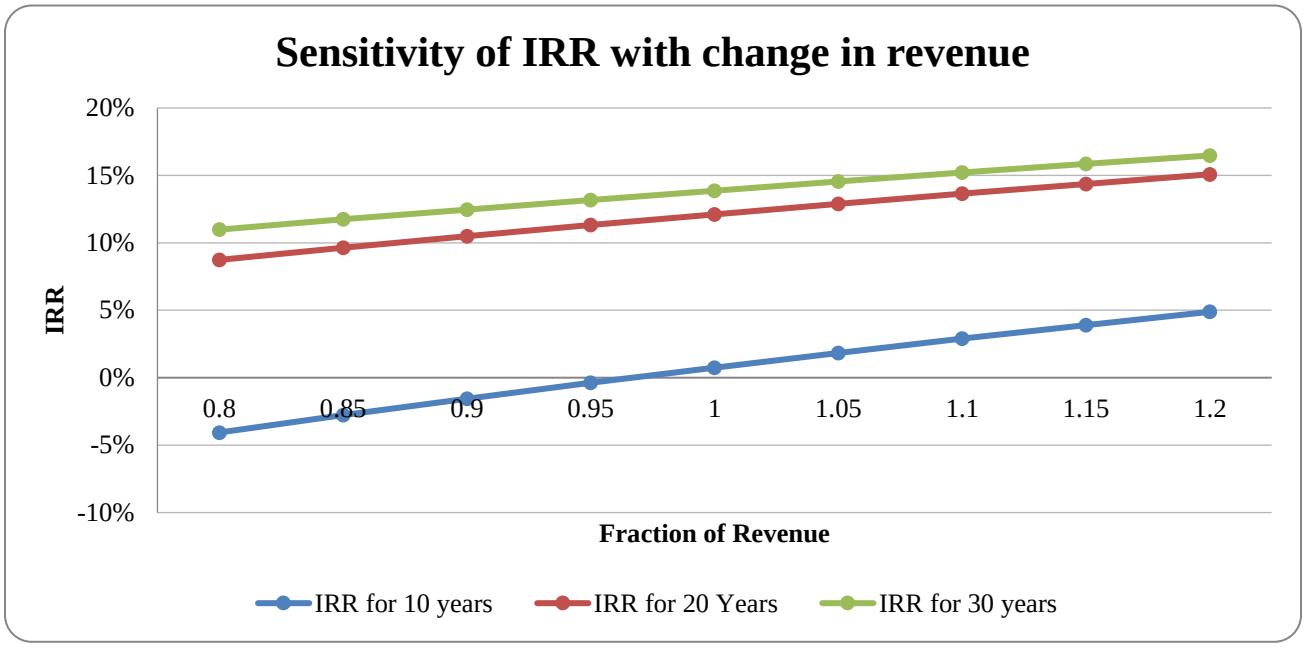
Sensitivity Analysis of IRR for change in project cost:

Sensitivity of IRR with Change in project Cost					
% Change of Project Cost	**Project Cost**	**Fraction of Cost**	**IRR for 10 years**	**IRR for 20 years**	**IRR for 30 years**
-0.2	5802670427	0.8	5.84%	15.77%	17.09%
-0.15	6165337329	0.85	4.43%	14.75%	16.18%
-0.1	6528004231	0.9	3.11%	13.80%	15.35%
-0.05	6890671132	0.95	1.89%	12.92%	14.58%
0	7253338034	1	0.75%	12.11%	13.87%
0.05	7616004936	1.05	-0.32%	11.35%	13.21%
0.1	7978671837	1.1	-1.34%	10.64%	12.60%
0.15	8341338739	1.15	-2.29%	9.97%	12.03%
0.2	8704005641	1.2	-3.20%	9.33%	11.49%



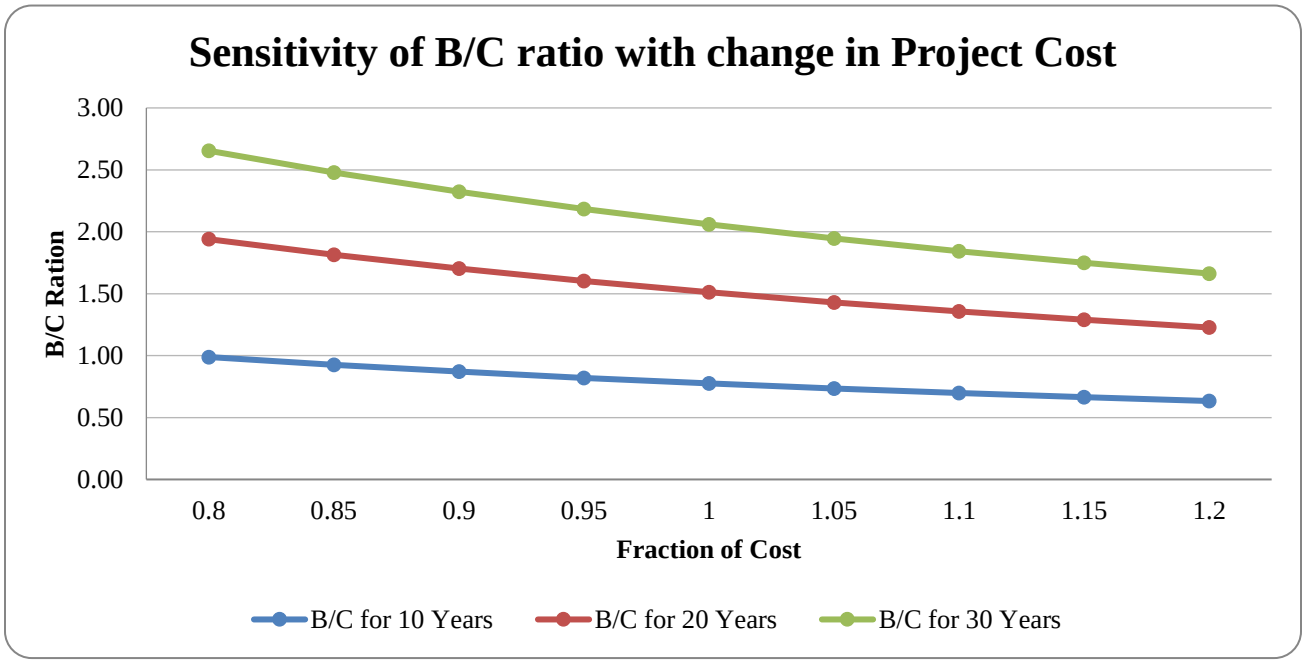
Sensitivity Analysis of IRR for change in revenue:

Sensitivity of IRR with change in revenue					
% Change of Revenue	**Revenue**	**Fraction of revenue**	**IRR for 10 years**	**IRR for 20 Years**	**IRR for 30 years**
-0.2	958568014.6	0.8	-4.07%	8.73%	10.98%
-0.15	1018478516	0.85	-2.78%	9.63%	11.74%
-0.1	1078389016	0.9	-1.55%	10.49%	12.47%
-0.05	1138299517	0.95	-0.38%	11.31%	13.18%
0	1198210018	1	0.75%	12.11%	13.87%
0.05	1258120519	1.05	1.84%	12.88%	14.54%
0.1	1318031020	1.1	2.89%	13.64%	15.20%
0.15	1377941521	1.15	3.90%	14.37%	15.85%
0.2	1437852022	1.2	4.88%	15.08%	16.48%



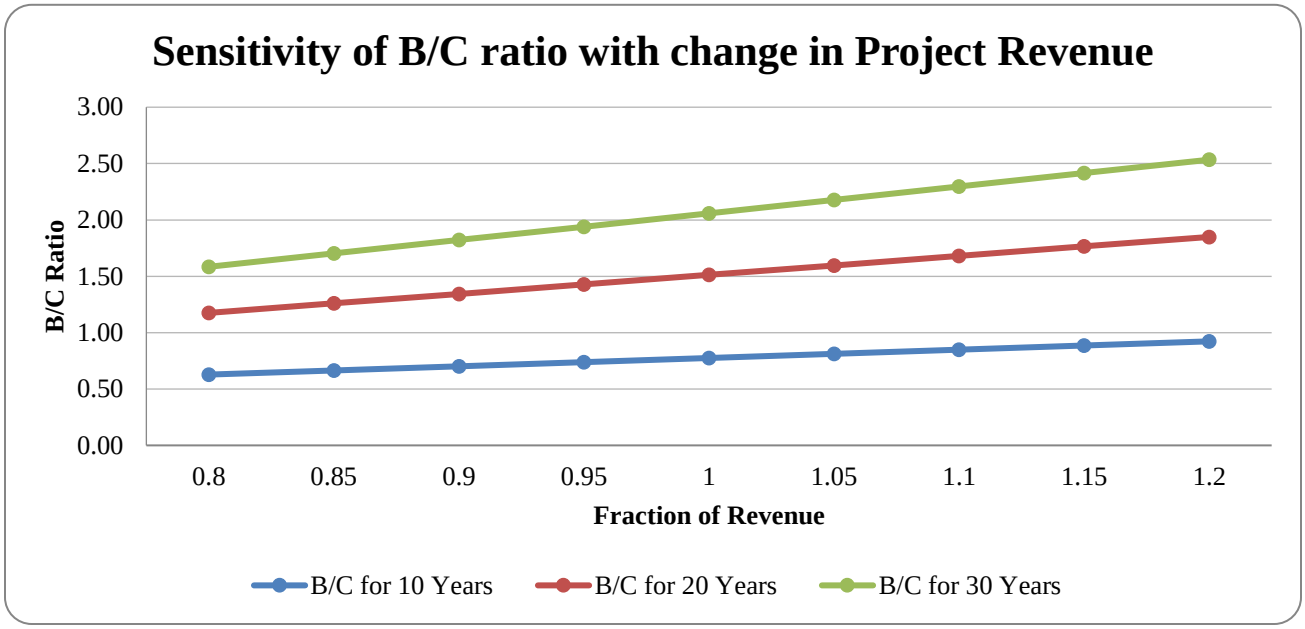
Sensitivity Analysis of B/C Ratio for change in project cost:

Sensitivity of B/C ratio with change in Project Cost					
% Change of Cost	**Cost**	**Fraction of Cost**	**B/C for 10 Years**	**B/C for 20 Years**	**B/C for 30 Years**
-0.2	5802670427	0.8	0.99	1.94	2.65
-0.15	6165337329	0.85	0.93	1.81	2.48
-0.1	6528004231	0.9	0.87	1.70	2.32
-0.05	6890671132	0.95	0.82	1.60	2.18
0	7253338034	1	0.78	1.51	2.06
0.05	7616004936	1.05	0.73	1.43	1.95
0.1	7978671837	1.1	0.70	1.36	1.84
0.15	8341338739	1.15	0.66	1.29	1.75
0.2	8704005641	1.2	0.63	1.23	1.66



Sensitivity Analysis of B/C Ratio for change in revenue:

Sensitivity of B/C ratio with change in Project Revenue					
% Change of Revenue	**Revenue**	**Fraction of revenue**	**B/C for 10 Years**	**B/C for 20 Years**	**B/C for 30 Years**
-0.2	958568014.6	0.8	0.63	1.18	1.58
-0.15	1018478516	0.85	0.66	1.26	1.70
-0.1	1078389016	0.9	0.70	1.34	1.82
-0.05	1138299517	0.95	0.74	1.43	1.94
0	1198210018	1	0.78	1.51	2.06
0.05	1258120519	1.05	0.81	1.60	2.18
0.1	1318031020	1.1	0.85	1.68	2.30
0.15	1377941521	1.15	0.89	1.76	2.42
0.2	1437852022	1.2	0.92	1.85	2.53


Sensitivity of B/C ratio with change in Project Revenue
3.00
2.50
2.00
1.50
1.00
0.50
0.00
B/C Ratio
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Fraction of Revenue
B/C for 10 Years
B/C for 20 Years
B/C for 30 Years

ANNEX VI - DESIGN DRAWINGS