# Cover sheet for submission of work for assessment

SWINBURNE UNIVERSITY OF TECHNOLOGY

## UNIT DETAILS

| | | | | | |
|---|---|---|---|---|---|
| Unit name | Finite Element Methods and Applications | | | Class day/time | Wednesday |
| Unit code | CVE80018 | Assignment no. | Group 07 | Due date | 02/06/2023 |
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# 1. Description of the problem

Analyzing Truss bridge consisting of primary beams, secondary beams, truss members, concrete slab and piers for the gravity loads and moving vehicle load (M1600) according to the Australian Standards using Strand 7 software

Designing the slab, secondary beam section (ULS & SLS), primary beam section (ULS & SLS), truss members (ULS), concrete pier column section and bored pile capacity for ULS & SLS is a complex process that requires a deep understanding of structural engineering principles. The following are some of the key considerations that were taken into account when designing these elements:

- The loads that the bridge will be subjected to, including dead loads, pressure loads, and moving loads (M1600)
- The material properties of the sections that are used, such as the strength and stiffness of the concrete and steel
- The allowable serviceability limits of the structures, such as deflection
- The ultimate load-carrying capacity of the sections

Once these factors have been considered, the appropriate design was developed. This process involved iterative calculations (manually) and analysis (using strand 07) to ensure that the element meets all of the design requirements.

The following were taken into account during the design of a truss bridge:

- **Slab:** The slab deck supports the weight of the moving load M1600 and distributes it to the primary and secondary beams. Therefore it must be designed to support the loads without cracking or deforming excessively.
- **Secondary beams:** The secondary beams are the vertical elements that support the weight of the slab and transfer it to the primary beams. It was designed to support these loads.
- **Primary beams:** The primary beams are the horizontal elements that support the weight of the secondary beams and transfer it to the columns. It was designed to support the loads without deflecting excessively.
- **Truss members:** They must be designed to support the axial loads without buckling or deflecting excessively for the axial loads both for tension and compression .
- **Concrete pier column section:** The concrete pier column section is the vertical element that supports the weight of the bridge and transfers it to the foundation. It is designed to support the loads without buckling or deflecting excessively.
- **Bored pile capacity:** The bored pile capacity is the load-carrying capacity of the bored pile. It is designed to support the weight of the building without buckling or deflecting excessively.

The analysis of a truss bridge is a critical step in ensuring the safety of the structure. By following the Australian Standards and using Strand 7 software, we have designed a bridge that will safely withstand the loads.

# 2. Identification and computation of the loading parameters.

Dead Load - Gravity Load on the structure

- Gravity load = 9.81m/s2 to account self weight of the structure

Moving Load - Pressure on the slab

- Global Face Pressure = (6kN/m)/(3.2m)=1.9 kPa

Moving load ( M1600)

- The slab will experience 4 sets of 360kN loads, as shown in Figure 01. Each set has 6 contact points, which will act as point loads when the vehicle's axles touch the slab deck. Therefore, each axle will apply a 60kN point load to the bridge deck. This will be taken into account in the analysis, according to the values entered in Figure 2.
- Standard Design lane length = 3.2m. Distance from each edge = 0.9m

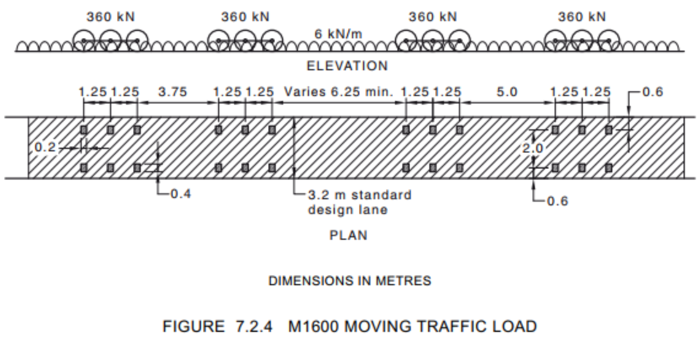


Figure 1: M1600 moving traffic load taken from AS5100

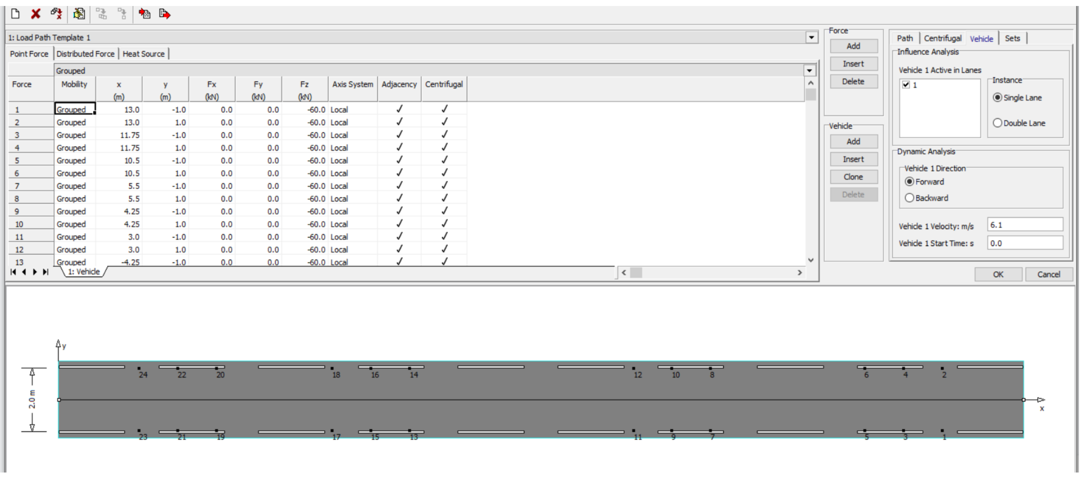

Figure 2: Corresponding Loads applied to the strand 07 for M1600 load

## 3. Statement of assumption and limitation in the design approaches

- The beams connecting the primary to secondary are assumed to be end-released in one direction, so it acts like a simple supported .
- The columns are assumed to have rotational end release. This means that the columns are free to rotate at their ends.
- Only vertical loads act on the structure (no other loads such as wind, earthquake, or impact). This means that the structure is not designed to withstand lateral loads, which can lead to a decrease in the overall safety of the structure.

It is important to note that these assumptions and limitations can lead to a decrease in the overall performance of the structure.

## 4. Description of the Strand7 finite element model developed and used to analyze the problem

### 4.1 Geometry

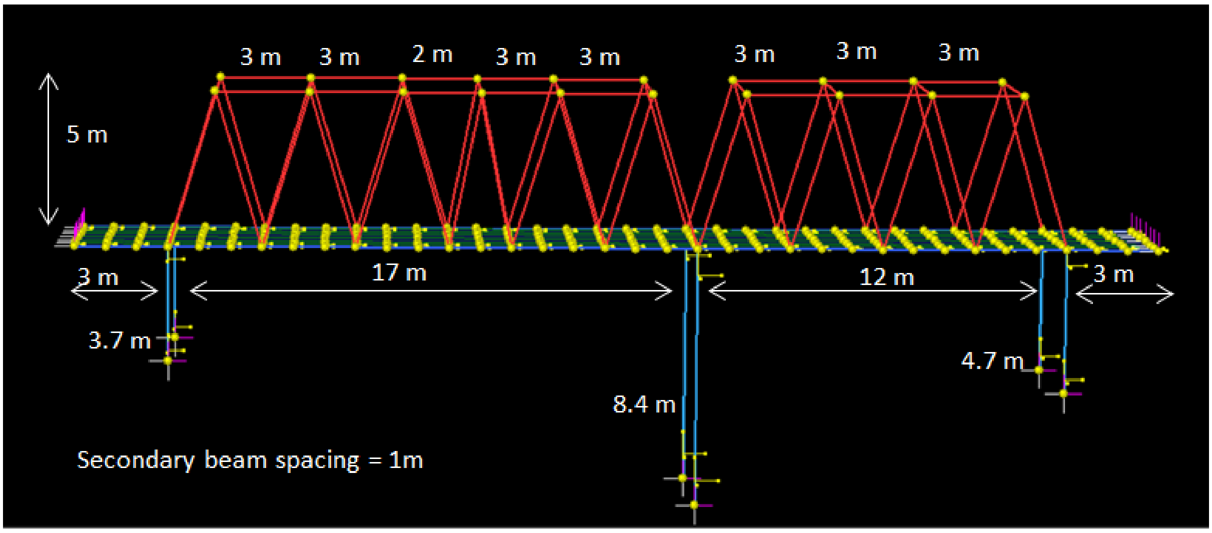


Figure 3 Geometry used for analyzed the truss bridge in strand 07

Figure 3 shows the geometry used in strand 07 to analyze the truss bridge. All dimensions are mentioned in meters. Width of the slab is 5m and the length is 35m. Longest span is 17m and the other span is 12m. Secondary beam spacing was taken as 1m. Column dimensions are 3.7m, 8.4m and 4.7m as shown in the figure 3.

### 4.2 Restrains

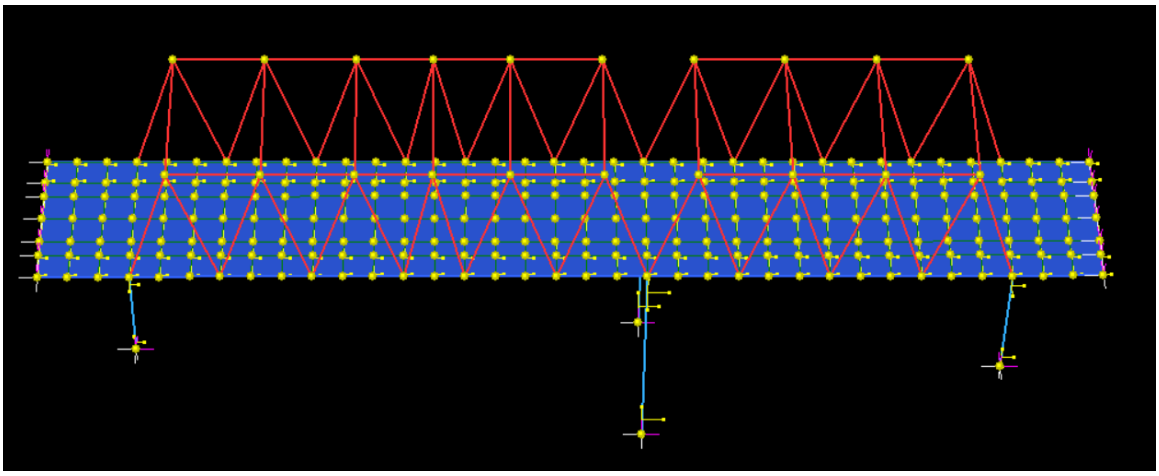

Figure 4 Restraint used for the model

- The edges of the slab deck of the bridge are roller supported.
- The beams connecting the primary to secondary are end-released.
- The columns are end-released for rotation.

## 4.3 Material Properties

The material properties were selected through trial and error. This was done by changing the sections of the strand 07 software and carrying out manual check calculations to check whether it adhered to the Australian standard requirements. The trial and error process was necessary because there is no one-size-fits-all solution for selecting material properties. The specific properties that are needed will vary depending on the specific application. Also when changing one section according to the Australian standard requirement, all the axial forces and bending moments will change. Therefore the process was repeated till we got the best section. The manual check calculations were necessary to ensure that the selected material properties met the Australian standard requirements.

- Primary Beam - OneSteel: Universal Beam 300PLUS 360UB56.7
- Secondary Beam OneSteel: Universal Beam 300PLUS 360UB50.7
- Truss member - OneSteel: TUBELINE C350L0 125x125x9.0 SHS
- Slab thickness - 410mm
- Columns Dimensions - 400mm x 450mm

More details on these material properties are explained in design part

## 4.4 Loads

The loads were applied to strand 07 as per the values in section 2.

Gravity Load on the structure

- Gravity load = 9.81m/s2 to account self weight of the structure

Pressure on the slab

- Global Face Pressure = (6kN/m)/(3.2m)=1.9 kPa

Moving load ( M1600)

- The slab will experience 4 sets of 360kN loads. Each set has 6 contact points, which will act as point loads when the vehicle's axles touch the slab deck. Therefore, each axle will apply a 60kN point load to the bridge deck.

It was assumed that only above-mentioned vertical loads act on the structure. No other loads such as wind, earthquake, or impact are considered for this project.

### 4.4.1 Moving load analysis

This analysis was done to the 4 sets of 360kN loads to determine the maximum deflection, axial force and bending moment values using the Linear Transient dynamic analysis for these loads. Loads were applied to the load path according to figure 2. 5% damping was used for the analysis as shown in figure 5. And also 1000 steps were used to enable all 4 moving loads to pass the entire bridge length as shown in figure 6. Then was solved using linear transient dynamic analysis.

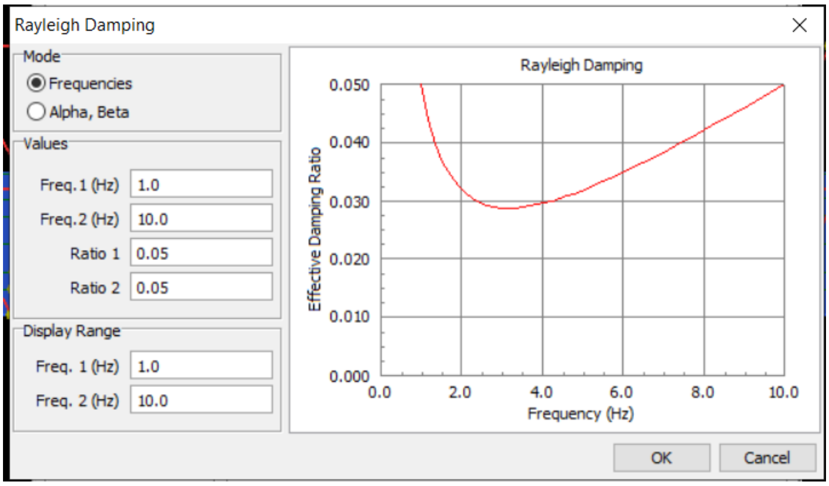


Figure 5 Rayleigh Damping used for the model

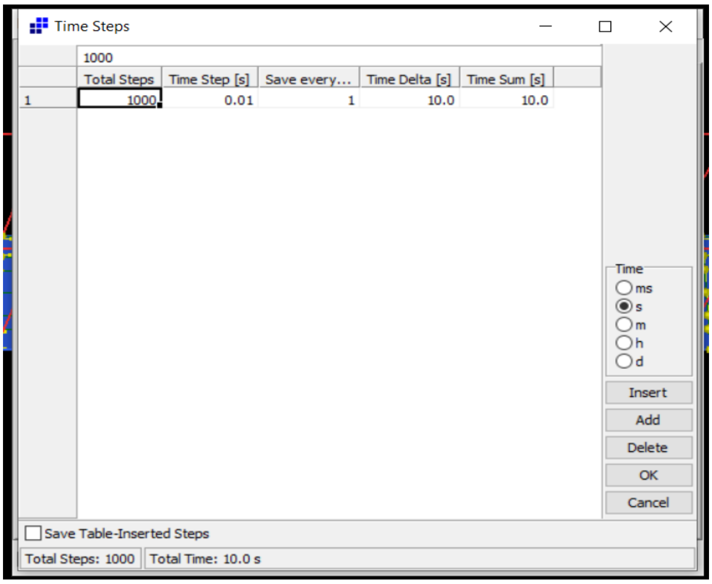


Figure 6 Total time steps

### 4.5 Analysis

Following the verification of the Strand 07 model's geometry, restraints, material properties, and loadings, the below mentioned 3 analyses were performed to validate the material properties selected initially, from the manual calculation process in order to meet Australian standards.

- Linear static analysis for pressure and gravity
- Linear Transient Dynamic Analysis for Moving load
- Linear Buckling analysis for calculation verifications

## 5. Results

**Deflections - Serviceability limit state**

AS5100.2 (Clause 7.11)

- Deflection not more than 1/600 of the span or 1/300 of the cantilever projection

- No Sag deflection under permanent load
- Hog deflection does not exceed 1/300 span

Span = 17m & 12m. Therefore deflection must be less than 28.3mm and 20mm for span

**The deflections obtained from strand 07 analysis are as follows;**

Deflection in the middle node at the 17 m span

- Due to Gravity load = 5.2 mm (figure 07)
- Due to Pressure load = 0.5 mm (figure 08)
- Due to Moving load =5.35 mm (figure 09)

Deflection in the middle node at the 12 m span

- Due to Gravity load = 2.17 mm (figure 07)
- Due to Pressure load = 0.22 mm (figure 08)
- Due to Moving load =2.7 mm (figure 10)

| | Displacements (mm) | Factor | Factored displacement (mm) |
|---|---|---|---|
| Dead load | 5.21 | 1 | 5.21 |
| Pressure | 0.5 | 1.35 | 0.675 |
| Moving load | 5.4 | 1.35 | 7.29 |
| Total | | | 13.175 |

Allowable deflections 28.3 mm from AS5100 > Actual deflections 13. 18 mm. Therefore the sections are okay for SLS.

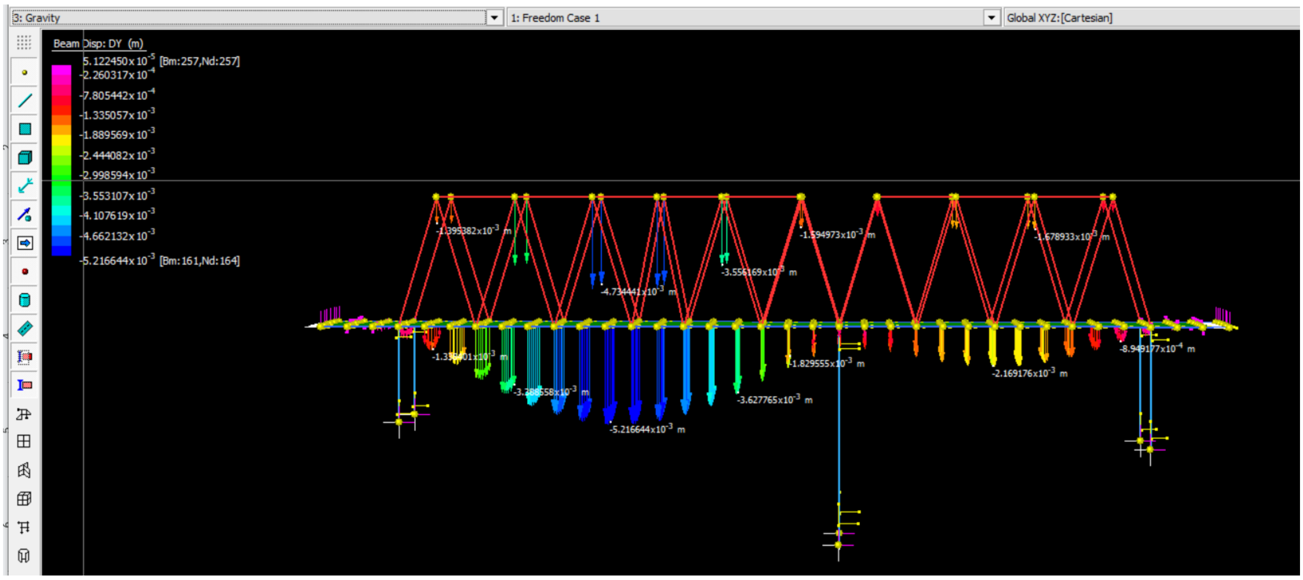


Figure 07 Deflections due to gravity load

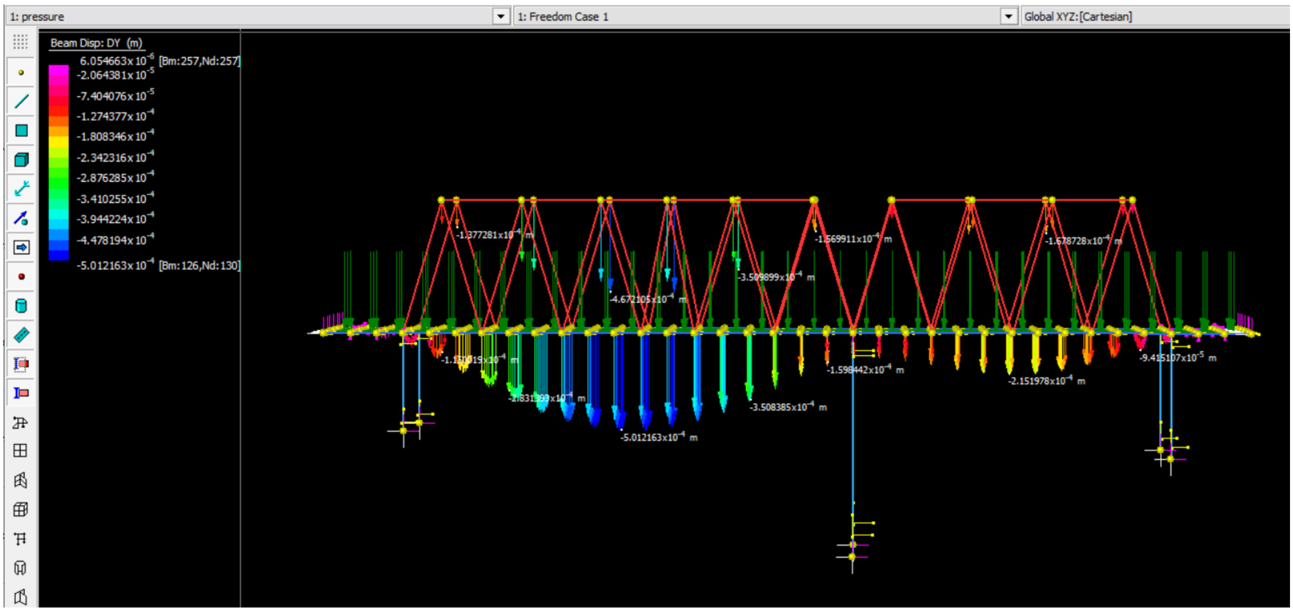


Figure 08 Deflections due to pressure load

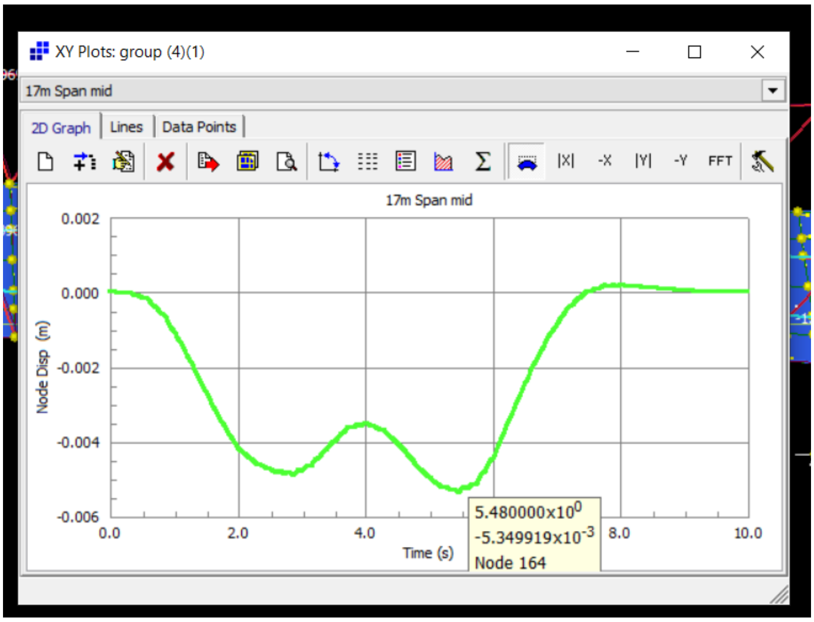


Figure 09 Deflections due to moving load in 17m span

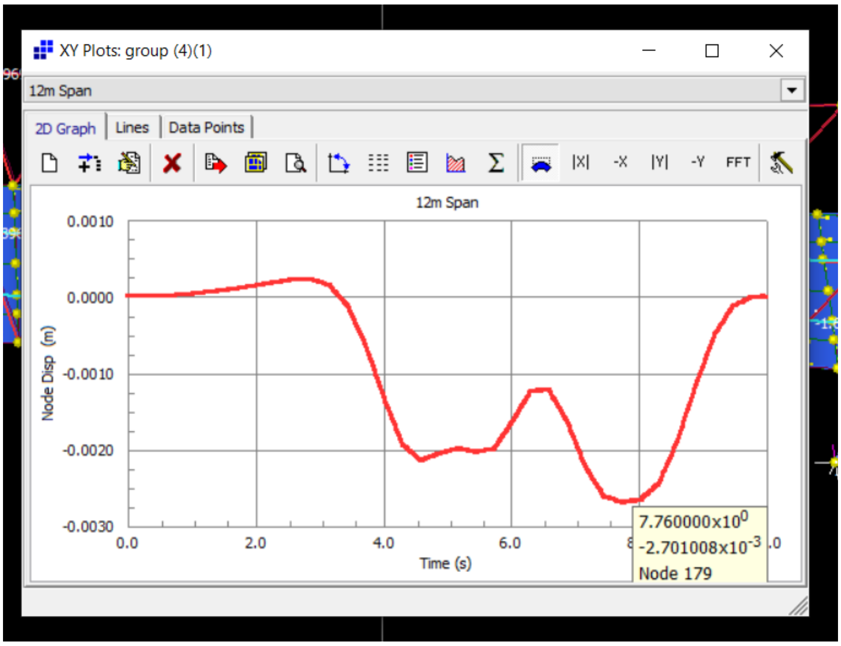


Figure 10 Deflections due to moving load in 12m span

## Design of slab deck of the bridge for Ultimate limit state

| | | |
|---|---|---|
| Slab thickness | 410 | mm |
| Kv | 0.12 | |
| Bv | 1000 | mm |
| Dv | 410 - 50 = 360 | mm |
| fc | 40 | mpa |
| ϕ | 0.7 | |

| | | | |
|---|---|---|---|
| Dead load | 25kN/m3 * 1m * 5m * 0.41m | 51.25 | kN |
| Moving load | 60kN * 2 + 6kN/m * 1m | 126 | kN |

| | | | |
|---|---|---|---|
| Vuc | Vuc=kvbvdv √fc | | |
| ϕ Vuc | 0.7 * 0.12 * 1000mm * 360mm * √40 | 191254.5529 | N |
| ϕ Vuc | | 191.2545529 | kN |

| | | | |
|---|---|---|---|
| V* | 1.2*Dead load + 1.35*1.8*Moving load | | |
| | 1.2 * 51.25 kN + 1.35*1.8 * 126 | 367.68 | kN |

| | | | |
|---|---|---|---|
| | kN | | |
| | 367.68/2 | 183.84 | kN |

ϕ Vuc (191.25 kN) > V* (183.84 kN). Therefore the slab thickness of 410mm is satisfactory for the slab deck to carry the above loads.

## 6. Design of secondary beam section

### Ultimate limit state

| | | | |
|---|---|---|---|
| Bending moment | 63 kN * 2.5m + 60 kN * 1m | 97.5 | kNm |
| factored bending moment | 1.8 * 97.5 kNm | 175.5 | kNm |
| yield stress | | 300 | MPa |
| Z | Bending Moment/ Yield stress | | |
| Z | 175.5 * 10^3 / 0.9 * 300 * 10^6 | 0.00065 | m3 |

Selected section for Strand 07
OneSteel: Universal Beam 300 PLUS 360UB50.7

| | | | |
|---|---|---|---|
| I | | 0.000142 | m4 |
| Y | | 0.178 | m |
| Z | Z = I / Y | 0.000797752809 | m3 |

Selected section Z = 0.000798 m3 > Required Z = 0.00065 m3. Therefore the selected section is okay for ULS

## 7. Design of primary beam section

### Ultimate limit state

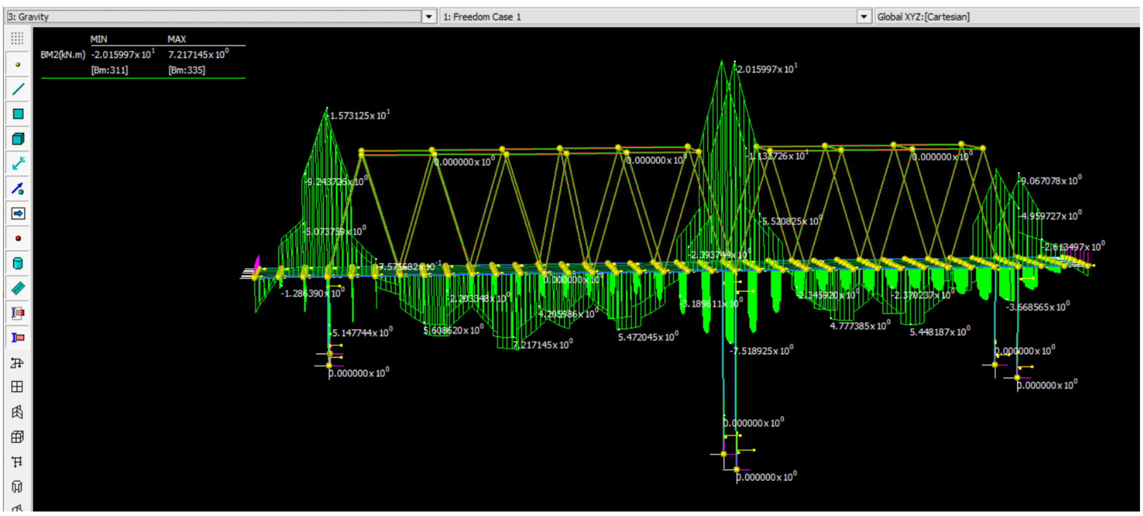


Figure 11 Bending Moment diagram for gravity load

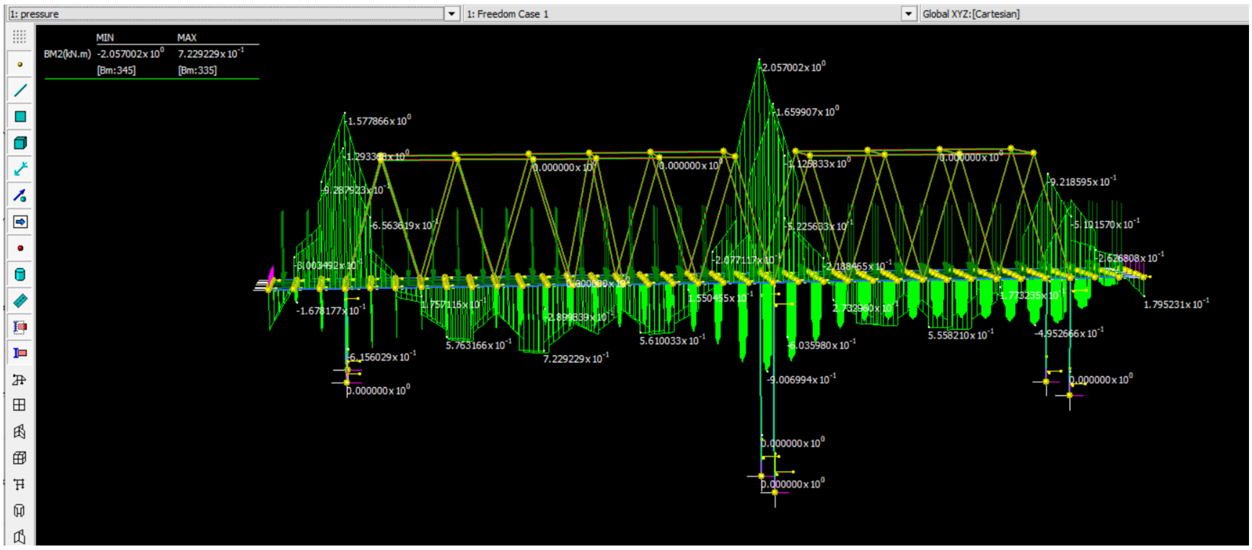


Figure 12 Bending moment diagram for pressure load

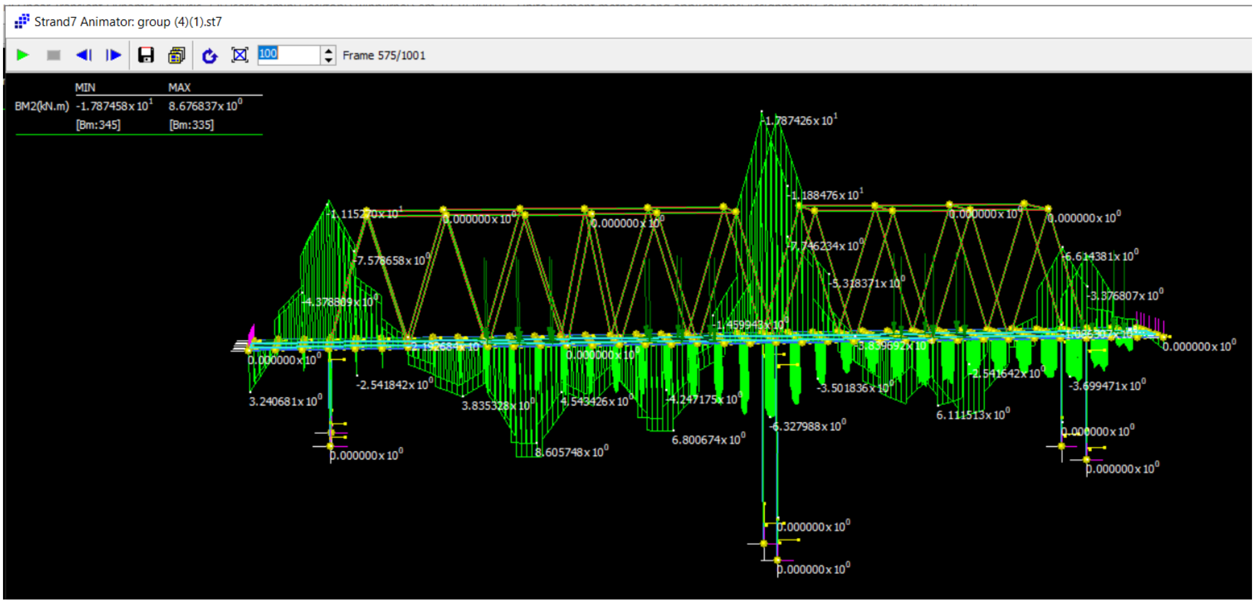


Figure 13 Bending moment diagram for Moving load

From figure 11, figure 12 and figure 13

| | Bending Moment (kNm) | Factor | Factored BM (kNm) |
|---|---|---|---|
| Dead load | 20.2 | 1.1 | 22.22 |
| Moving load | 17.9 + 2.06 | 2.43 | 43.497 + 5.0058 |
| Total | | | 70.7228 |

| | | |
|---|---|---|
| Bending moment | 70.7228 | kNm |
| yield stress | 300 | MPa |
| Z | Bending Moment/ Yield stress | |
| Z | 0.0002619362963 | m3 |

Selected section for Strand 07
OneSteel: Universal Beam 300 PLUS 360UB56.7

| | | | |
|---|---|---|---|
| I | | 0.000161 | m4 |
| Y | | 0.1795 | m |
| Z | Z = I / Y | 0.000896935933 | m3 |

Selected section Z = 0.000897 m3 > Required Z = 0.0002 m3. Therefore, the selected section is okay for ULS.
The higher section was selected as the primary beam because it had a larger cross-sectional area than the secondary beam. This means that it could support more weight and was therefore more suitable for carrying the load of the structure.

## 8. Design compression members of the truss structure for ultimate limit state

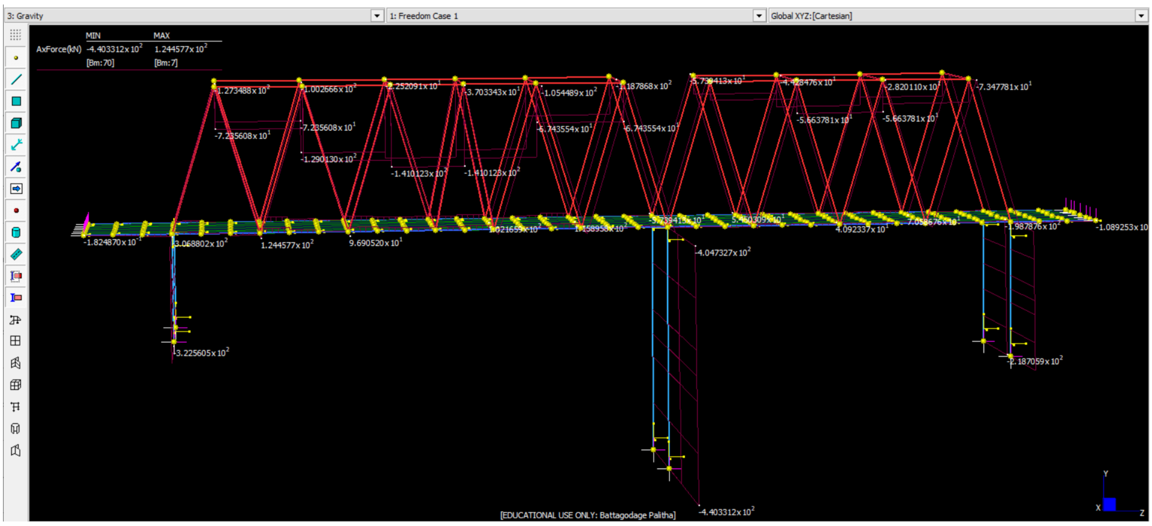


Figure 14 Axial force diagram for Gravity load

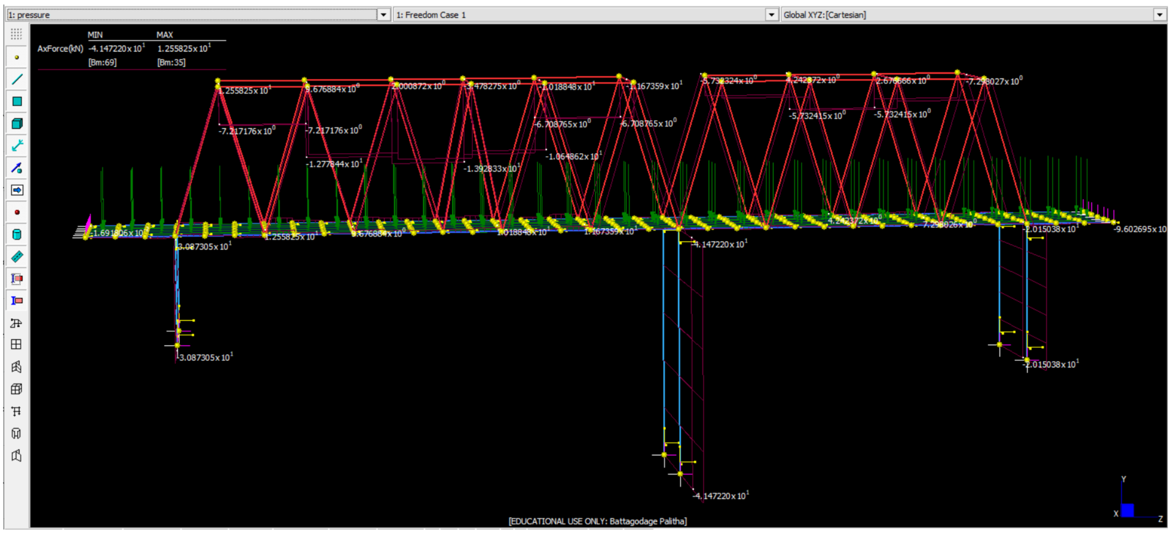


Figure 15 Axial force diagram for Pressure load

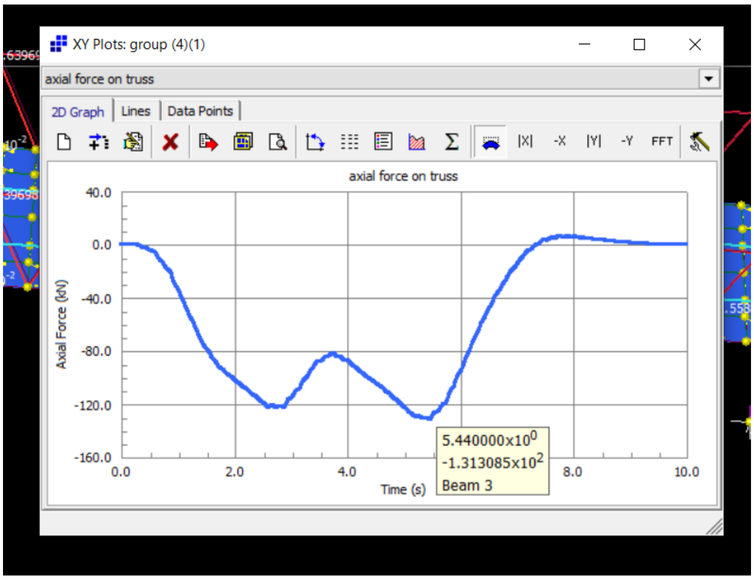


Figure 16 Axial force graph for Moving load

From figure 14, figure 15 and figure 16

| | From strand 07 | Factors | Factored axial force (kN) |
|---|---|---|---|
| Dead loads | 141 kN | 1.1 | 155.1 |
| Moving loads | (13.9 + 131.3) kN | 1.8 * 1.35 | 352.836 |
| Total | | | 507.936 |

| | | |
|---|---|---|
| E | 200000000 | kPa |
| I | 9.42^10-6 | m4 |
| L | 3.8 | m |
| ke | 0.7 | |
| Pcr | π^2 * E * I / (L*ke)^2 = 2628.44 | kN |

Selected section for Strand 07
OneSteel: TUBELINE C350L0 125x125x9.0 SHS

AS4100 clause 6.1

| | | |
|---|---|---|
| kf | 1 | |
| An | (125 * 125) - (125-9)^2 = 2169 | mm2 |
| fy | 300 | MPa |
| Ns | Ns = kf * An * fy => 650.7 | |
| Factor ϕ | 0.9 | |
| ϕ Ns | 585.630 | kN |

AS4100 clause 6.2

$\alpha_c$ = member slenderness reduction factor

$$= \xi\left[1 - \sqrt{\left[1 - \left(\frac{90}{\xi\lambda}\right)^2\right]}\right]$$

$$\xi = \frac{\left(\frac{\lambda}{90}\right)^2 + 1 + \eta}{2\left(\frac{\lambda}{90}\right)^2}$$

$$\lambda = \lambda_n + \alpha_a\alpha_b$$

$$\eta = 0.00326(\lambda - 13.5) \geq 0$$

$$\lambda_n = \left(\frac{l_e}{r}\right)\sqrt{(k_f)}\sqrt{\left(\frac{f_y}{250}\right)}$$

$$\alpha_a = \frac{2100\left(\lambda_n - 13.5\right)}{\lambda_n^2 - 15.3\lambda_n + 2050}$$

$\alpha_b$ = appropriate member section constant given in Table 6.3.3(A) or 6.3.3(B)

Figure 17 equations taken from AS4100 for the compression truss member calculations

| | | |
|---|---|---|
| le | Le = (ke * L) * 1000 = 2660 | mm |
| r | r = √(I / An) = 65.907685 | mm |
| λn | 44.211597 | |
| αa | 19.352279 | |
| αb | -1 | |
| λ | 24.859318 | |
| η | 0.0370314 | |
| ε | 7.2962368 | |
| αc, calc | 0.9615725 | |
| Nc | 625.69523 | kN |
| ϕ Nc | 563.1257 | kN |

Critical axial load 507.936kN < Design Section capacity ϕ Ns 585.63kN and Design member capacity ϕ Nc 563.13 kN. Therefore, the selected section is okay for ULS for compression.

## 9. Design of concrete pier column section (use axial-bending interaction diagram for all load combinations).

Selected section for Strand 07

- Column size 400mm x 450mm
- Steel reinforcement 8 N 18
- Strut reinforcement N 10 @ 300mm

From strand 07 maximum axial force values in columns as in figures 14, figure 15, figure 17, figure 18 and figure 19.

Where N* = 1.2 x Static load + 1.8 x 1.35 Dynamic load

M* = 0.05 x 450mm x 0.001 x N*

| | **3.7m col** | | **8.4m Column** | | **4.7m Column** | |
|---|---|---|---|---|---|---|
| | Static | Dynamic | Static | Dynamic | Static | Dynamic |
| | 322.56 | 323.79 | 440.34 | 360.9 | 218.7 | 250.35 |
| **N*** | 1173.8817 | | 1405.395 | | 870.7905 | |
| **M*** | 26.412 | | 31.621 | | 19.592 | |

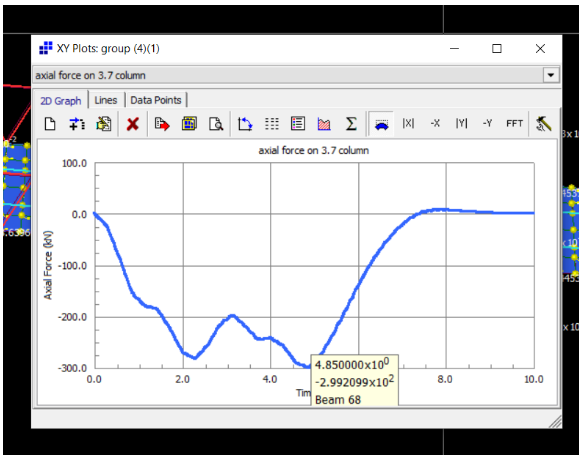


Figure 17 Axial force graph for Moving load for 3.7m column

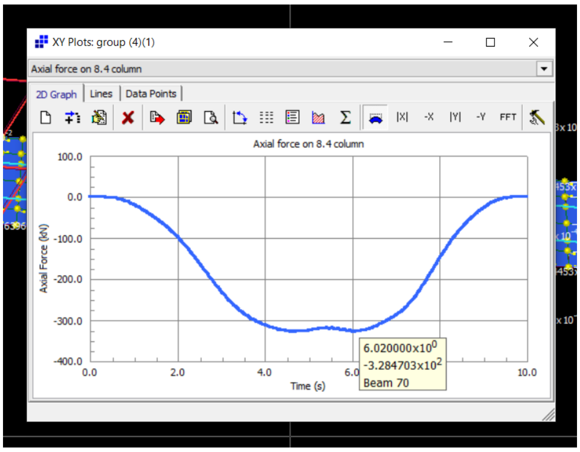


Figure 18 Axial force graph for Moving load for 8.4m column

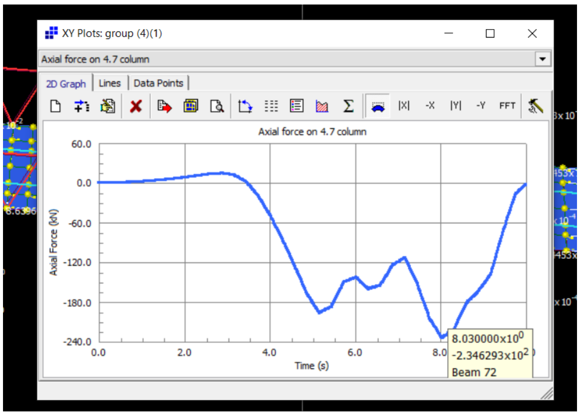


Figure 19 Axial force graph for Moving load for 4.7m column

| | | |
|---|---|---|
| fc' | 40 | MPa |
| fsy | 500 | MPa |
| c | 40 | mm |
| E | 200 | GPa |
| Section Properties | | |
| I | 1/12 (bh3) = 3.04*10^9 | mm4 |
| Z | I /y = 13500000 | mm3 |
| Ag | b * d =180000 | mm2 |
| Check for minimum reinforcement ratio | | |
| Ast | No of bars *π * r^2 = 2035.752 | mm2 |
| Ast/Ag | 0.0113097 | |
| 0.01 ≤ Ast/Ag ≤ 0.04; Therefore the size is okay | | |
| Calculate squash load capacity | | |
| 0.72 ≤ $\alpha$1 ≤ 0.85 | | |
| $\alpha$1 | 1-0.003*fc = 0.88 | >0.85 |
| $\alpha$1(adjusted) | 0.85 | |
| Nuo | Ast * fsy + (Ag - Ast) $\alpha$1 *fc | |
| Nuo | 7068.660.5 | kN |
| $\phi$ | 0.6 | |
| $\Phi$ Nuo | 4241.2 | kN |

| | | |
|---|---|---|
| Calculate decompression point capacity | | |
| y1 | 59 | mm |
| y2 | 225 | mm |
| y3 | 391 | mm |
| Ast,1 | 763.407 | mm2 |
| Ast,2 | 508.938 | mm2 |
| Ast,3 | 763.407 | mm2 |
| $\alpha$2 | 0.85 - 0.0015 fc ; $\alpha$2 > 0.67 | |
| $\alpha$2 | 0.79 | OK |
| $\gamma$ | 0.97 - 0.0025 fc ; $\gamma$ > 0.67 | |
| $\gamma$ | 0.87 | OK |
| ku | b / y3 = 1.0230179 | |
| Force of Concrete in Compression | | |
| Cconc | ($\alpha$2 * fc) * ($\gamma$ * D) * B | |

| | | |
|---|---|---|
| Cconc | 4948.56 | kN |
| Strain in Compression Steel | | |
| εs<εsy | | |
| εsy | 2.5 | |
| εs1 | 0.002607 | OK |
| εs2 | 0.0015 | OK |
| εs3 | 0.000393 | OK |
| Where εs = (D - y) D | | |
| -Force in Compression Steel | | |
| Csteel,1 | 398 | kN |
| Csteel,2 | 152.7 | kN |
| Csteel,3 | 60.1 | kN |
| Total Compression Force  Cconc + Csteel | | |
| Ctotal | 5559.3 | kN |
| Bending Capacity (Taking midpoint as rotation point) | | |
| Concrete | 144.7 | kNm |
| Steel 1 | 66.1 | kNm |
| Steel 2 | 0 | kNm |
| Steel 3 | -10 | kNm |
| Total Bending | 200.8 | kNm |
| Φ Nu | 3335.6 | kN |
| Φ Mu | 120.5 | kNm |
| Calculate Balance Point | | |
| Only Row 1 steel is in compression | | |
| (0.003 / kud) = (0.0025 / (y3 - kud)) and ku = kud / y3 | | |
| kud | 213.27273 | |
| ku | 0.545 | |
| Force in Concrete in Compression | | |
| Cconc | (α * fc) * (γ * kud) * B | |
| Cconc , Nu | 2345.3175 | kN |
| Strain in Steel in Tension | | |
| Row 2 | 0.0006379 | |
| Row 3 | 0.0025 | |
| Force in Steel in Tension | | |

| | | |
|---|---|---|
| Tsteel,2 | -64.9 | kN |
| Tsteel,3 | -343.5 | kN |
| Bending Capacity | | |
| Concrete | 310.1 | kNm |
| Steel, 2 | 0 | |
| Steel, 3 | 57 | kNm |
| Total Bending Mu | 367.1 | kNm |
| ΦNu | 1407.2 | kN |
| ΦMu | 220.3 | kNm |
| <u>6. Calculate Pure Bending</u> | | |
| For simplicity, considering only row 3 for tension steel | | |
| Kud = (Ast*fsy) / (α2 * γ * fc * B) | | |
| kud | 34.71 | |
| Mu = Ast * fsy (d - γ * kud/2) | | |
| Mu | 143.48 | kNm |
| ku = kud / y3 | | |
| ku | 0.09 | |
| Φ calc | 1.24 - (13 * ku)/12 = 1.14 | >0.85 |
| Φ adjusted | 0.85 | |
| Φ Mu= | 122 | kNm |

Plot Axial-Bending Interaction Diagram

| **Φ Mu** | **Φ Nu** |
|---|---|
| 0 | 4241.2 |
| 120.5 | 3335.6 |
| 220.3 | 1407.2 |
| 122 | 0 |

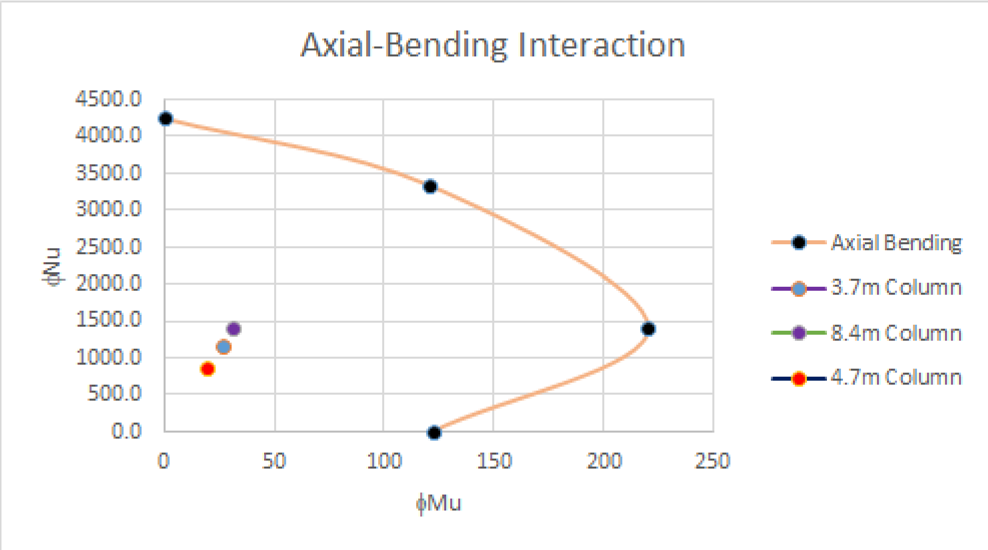


Figure 20 Axial Bending Interaction curve

The chosen column dimensions of 400 mm x 450 mm meet Australian standards. A smaller dimension, such as 300 mm x 350 mm, would also be sufficient, but it would not be practical because our columns are designed to withstand impact loads, which are not considered in this problem. We are only considering vertical loads, such as those from gravity and moving loads.

## 10. Check the maximum load carried by one bored pile for ULS

From section 9,
Maximum axial load in 3.7m column = 1173.882 kN
Maximum axial load in 8.4m column = 1405.395 kN
Maximum axial load in 4.7m column = 870.7905 kN

Since there are 4 bored piles for each concrete pier column
Maximum load carried by one bored pile in 3.7m column = 1173.882 kN / 4 = 293.47 kN
Maximum load carried by one bored pile in 8.4m column = 1405.395 kN / 4 = 351.35 kN
Maximum load carried by one bored pile in 4.7m column = 870.7905 kN / 4 = 217.70 kN