STUDY ON STRUCTURAL DESIGN OF HIGHWAY BOX STRUCTURES

S.S.L.D.Chinthaka

(138729 J)

Degree of Master of Engineering in Structural Engineering Designs

Department of Civil Engineering
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University of Moratuwa
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Seethagala Subasinghage Lahiru Dulan Chinthaka

(138729 J)

Dissertation submitted in partial fulfilment of the requirements for the degree of
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DECLARATION

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Dr. K. Baskaran Date:

ABSTRACT

Box culverts are the highest in numbers from the list of structures in highway construction because of their advantages such as low ground bearing capacity requirement, low maintenance requirement and easy construction compared to bridge structures.

Box culverts in Sri Lanka are not standardized. People are still keep designing box culverts consuming lots of engineers valuable time, which can be used productively for the development process of the country. This research investigates typical box culverts that are used in Sri Lanka and then develops standard charts for various size box culverts with different overburden.

This study is carried out using numerical methods for different box culvert opening sizes with 1.5 x 1.5 m, 2.0 x 2.0 m and 3.0 x3.0 m

This dissertation presents analysis and design results of box culverts of varying numerical models of size 1.5x1.5m , 2.0x2.0m and 3.0x3.0m internal size with slab/wall thickness from 200mm to 400mm with 50mm gap as appropriate, for overburden of 0.5m, 1.0m, 2.0m, 4.0m, 6.0m, 8.0m and 10.0m

Total number of structures analyzed was 120

Final results are presented in both tabulated and graphical format

Observation shows that internal forces in the element of box culvert is less sensitive to bearing capacity of ground for thicker bases but sensitive for thin bases.

Every box culvert of given size and over burden has its own optimum thickness.

ACKNOWLEDGEMENT

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I also extend my sincere gratitude towards my employer, Road Development Authority (RDA) for granting leave to follow this course and other assistances provided for my research works. I would like to take this opportunity to convey my sincere gratitude to Mr.L.V.S.Weerakoon (Project Director, Central Expressway Project, RDA), Dr.Ruwan (Head , Structural design office, Central Expressway Project, RDA),for the assistance extended to me in numerous ways throughout, and Dr.Naveed Anwar (AIT,Thailand/International Consultant for Central Expressway Structural design works) for the guidance given in finite element modelling. Finally, I thank for all my colleagues and family members for the valued cooperation and encouragement received to complete my M. Eng. Program successfully.

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LIST OF SYMBOLS AND ABBREVIATIONS

ESE	Extension of Southern Expressway
OCH	Outer Circular Highway
CEP	Central Expressway
OAPI	Open Application Programming Interface
CSi	Computers and Structures.Inc.
Ka	Coefficient of Active earth pressure
Kp	Coefficient of Passive earth pressure
Ko	Coefficient of at rest earth pressure
φ	Friction angle of soil
D	Depth from ground to point under consideration
β	Super imposed dead load factor
Ks	Subgrade reaction
SF	Factor of safety
B.C	Allowable bearing capacity
Kt	Traction factor
F	Traction force
H'	Height of soil cover
W	Internal width of culvert
H	Internal height of culvert
t	Wall/Base/Top slab thickness

L_L	Overall length of structure perpendicular to wall
L	Length of culvert
M	Bending moment
M_{200}	Bending moment at 200kN/m^2 bearing capacity

1 INTRODUCTION

1.1 Background

Highway construction has become a major part of the current development of booming Sri Lanka.

There are few proposed expressways to various parts of Sri Lanka, two of them (Extension of Southern Expressway and Phase III of Outer Circular Road) are already started the construction, in addition to that Central Expressway and Ruwanpura Expressway is in the Design Stage.

Box structures play a major role in any road including expressways as an example the proposed cost for construction of all box structures in Central Expressway section III is Rs.2 Billion (total project cost for that is Rs.150 Billion).

Because of constant geometry (internal width and height) and similar conditions (fill height). box structures can be standardized easily, but in all projects in Sri Lanka still keep designing box culvert, which is costly to the country because it consumes considerable amount of engineering time for designing and also since there are no guideline to select initial thickness based on economy of box culvert different engineers end up in different ultimate design in terms of element thickness and amount of reinforcement, as an example for 3x3 box structure with 2m fill height different design engineers select different element thicknesses and end up in different designs. Therefore it is good to have a standardized box structure for each size and each fill height after a proper study.

Following traditional tedious design procedures to develop standardize chart for box structures is not practicable due to the high amount of time consumption. Therefore, it is necessary to automate analysis and design procedure

There are many different ways to automate the analysis of structures. In this project

Computers and Structures Inc. (CSi) Open Application Programming Interface (OAPI) is used, which is a powerful tool that allows users to automate many of the processes required to build, analyze and design models and to obtain customized analysis and design results. It also allows users to link SAP2000 with third-party software, providing a path for two-way exchange of model information with other programs (see Appendix A).

1.2 Aim and Objectives

- To study the sensitivity of internal forces in elements of reinforced box culvert for the specified bearing capacity used for the analysis
- To develop standard charts based on member thicknesses, reinforcements for different sizes and fill heights to find reinforcement requirement for selected thickness
- To identify the optimum thickness in terms of box size and fill height

1.3 Scope and Limitation of Study

Single cell reinforcement (RF) box structures are only considered for this study. Internal width to internal height ratio is limited to one.

1.4 Thesis Outline

This thesis begins with the importance of box structure and the current practice for the design, its disadvantages and requirement for the standardization. In the literature review, existing guideline and literature for load evaluation modelling, analysing and designing are explored. Furthermore in the methodology chapter from the geometry to analysis and design procedure are discussed.

All the Bending Moment and Shear Force results obtained in the analysis and amount of reinforcement required obtained in the design are presented under results and discussion chapter.

2 LITERATURE REVIEW

There are various guidelines, standards available for reinforced concrete box culvert designs in order to determine the parameters, analysis and design considerations.

These consist of practical guidelines and mathematical models, difficulties facing while following available standard and gaps in existing sources

2.1 Guideline for Selecting Analysing Parameters

2.1.1 Horizontal earth pressure coefficient

The earth exert pressure on the side wall of box culvert from a range minimum as active and maximum as passive, or in between called pressure at rest but it depends on the relative movement. Figure 1 shows how to differentiate the active, passive and at rest conditions and, below equations give values for active (K_a), passive (K_p) and at rest (K_o) lateral earth pressure coefficient (Bowels, 1997)

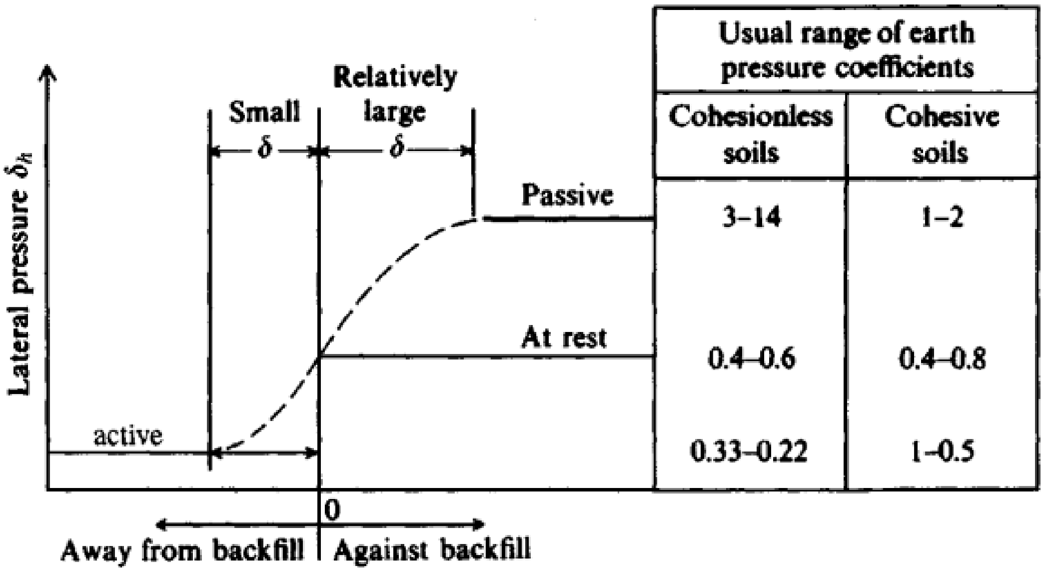


Figure 1: Illustration of active and passive pressure (Bowels, 1997)

$$Ka = (1 - \sin \emptyset)/(1 + \sin \emptyset)$$ **Equation 2-1**

$$Kp = (1 + \sin \emptyset)/(1 - \sin \emptyset)$$ **Equation 2-2**

$$ko = (1 - \sin \emptyset)$$ **Equation 2-3**

In the case of box, since it is confined with earth from both sides state of earth shall be at rest and co-efficient more than the active pressure is normally adapted in the design. Studies done by Pavan & Tande, (2015) have found that even though coefficient of earth pressure increases the combined effect with all other load combinations remain constant except for slight increases in the moments. Figure 2 shows some of the bending moment results obtained by their study.

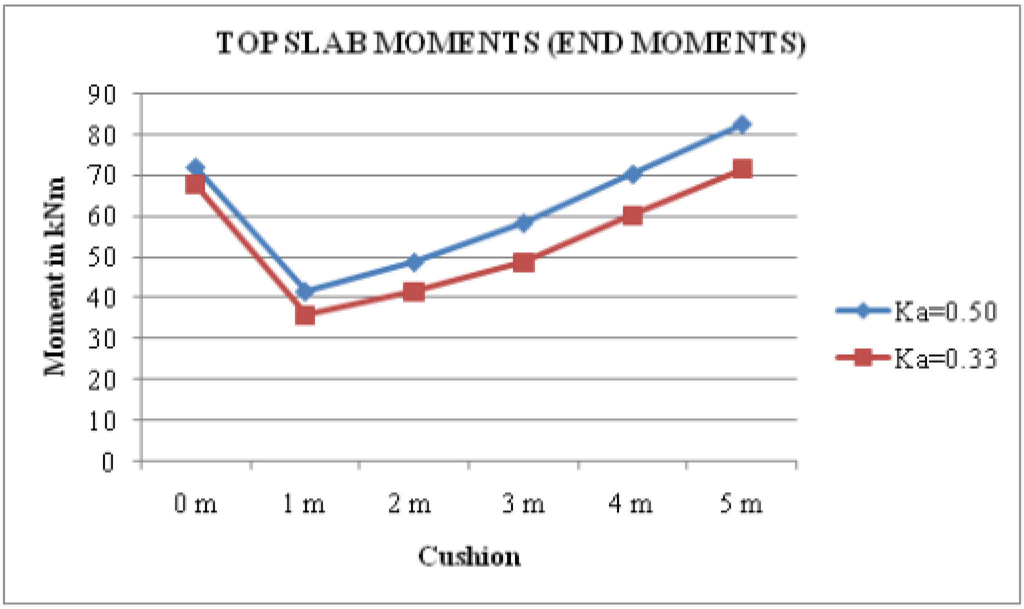


Figure 2: Variation of bending moment with cushion for top slab (Pavan & Tande, 2015)

The most popular document for the design of box culvert BD31/01 (2001) used by Sri Lankan designers, says the nominal pressure applied to the side walls of the structure at a depth D below ground level

For combination 1 loads

A maximum earth pressure equal to Ko ϒ D applied simultaneously on either side walls or a minimum earth pressure equal to 0.2 ϒ D applied simultaneously on both side walls

For combination 4 loads

A "disturbing" earth pressure equal to Ka ϒ D acting in the same direction as horizontal live load and a "restoring earth pressure equal to 0.6 ϒ D acting in the opposite direction to the horizontal live load.

Also if the backfill properties are not known the above document recommends to use following nominal default values

K min = 0.2

K a = 0.33

K o = 0.6

K p = 3.0

2.1.2 Super impose dead load

Nominal super impose dead load consists of the weight of soil cover and the road construction material above the structure. It shall be applied to the roof of the structure as a uniformly distributed load (BD31/01, 2001)

According to Lawson et al (2010) box culvert installed on existing soil fill and then covered by backfill as shown in Figure 3 are referred as embankment culvert. In such culverts even well compacted surrounding soil mass is less stiff than the combined culvert and soil column. Therefore, the back fill material around the culvert has tendency to settle more than the soil directly above the culvert.

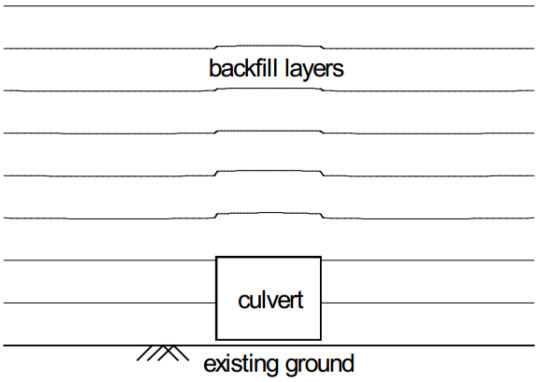


Figure 3: Embankment culvert (Lawson et al, 2010)

Figure 4 illustrates the trench installation. Trench installation culvert is mostly adopted in actual construction in the field. Here the backfill soil is less stiff than the surrounding in-situ soil and undergoes more settlement relative to the in-situ soil

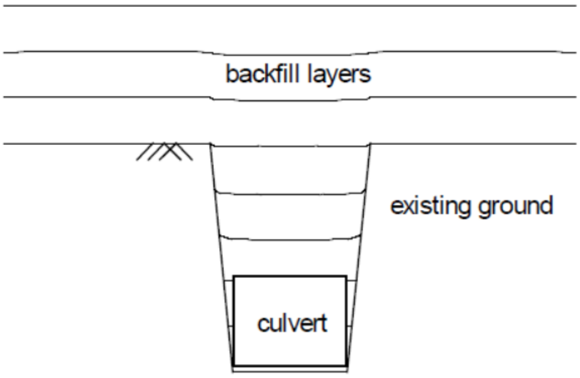


Figure 4: Trench culvert (Lawson et al, 2010)

In embankment installation culvert soil arching creates a negative arching effect as discussed above as surrounding soil settle more than the soil above the culvert, shear plane develop along the interface these shear forces transfer some of neighboring soil weight into the culvert, The net result is that the structure is required to carry the weight of the soil column as well as some surrounding soil weight. Figure 5 shows this effect

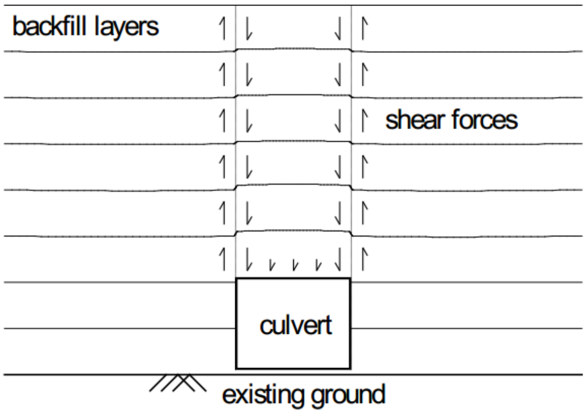


Figure 5: Negative soil arching (Lawson et al, 2010)

Trench culvert positive arching occur where the culvert and soil column are less stiff and experience greater settlement than the surrounding soil. Therefore shear stress and load change opposite direction the resulting load reduction can be half the weight of the soil column. Figure 6 shows this effect.

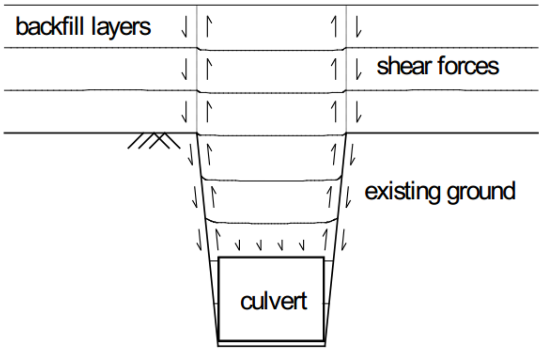


Figure 6: Positive soil arching (Lawson et al, 2010)

As stated in BD31/01 (2001) for box culvert the possible effect on positive arching reducing load can be ignored and negative arching of the fill above the roof, increased loading will be taken as maximum super impose dead (SID) load as "βϒ H" and minimum SID load as "ϒ H" and β factor can be taken from Figure 7.

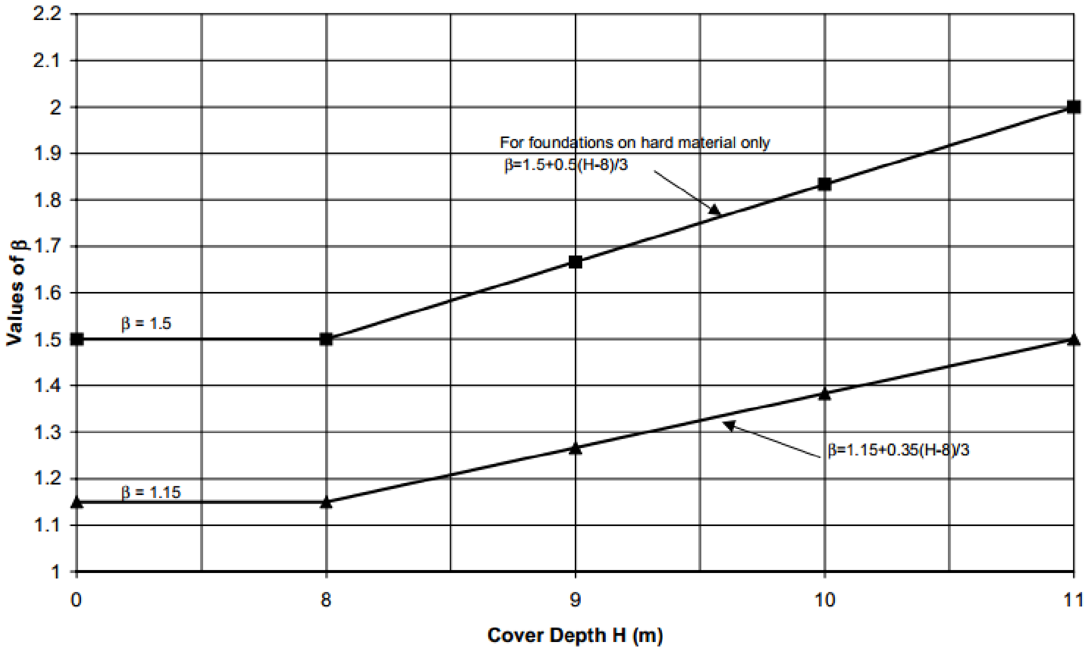


Figure 7: Factor for negative arching effect (BD31/01, 2001)

2.1.3 Soil sub grade reaction

According to Bowels (1997), the module of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members. It is shown in Figure 8

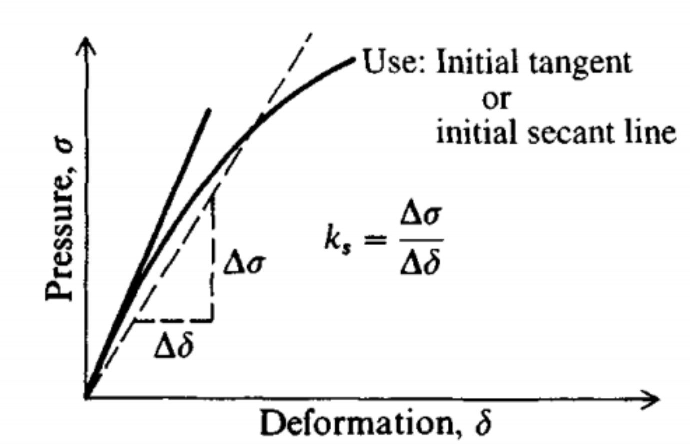


Figure 8: Modulus of subgrade reaction (Bowels, 1997)

There are many relationships presented in Bowels (1997). From that the most applicable relationship is the relationship between bearing capacity and subgrade reaction and it is presented below

$$ks = 40\,(SF)\,(B.C) \qquad \textbf{Equation 2-4}$$

Here,

ks = Subgrade reaction

SF = Factor of safety used for calculating bearing capacity

B.C = Allowable bearing capacity

There are no clear guidance for the values to be used for allowable bearing capacity for a box culvert, therefore it can be identified as a research gap

2.1.4 Vertical live load

According to BD31/01 (2001) for a box culvert depth of soil cover H is 0.6m or less HA load should be applied if the soil cover is exceeding, HA load should be replaced with 30 units of HB

For any structure HB load should apply

In Sri Lanka number of HB units considered is 30 (75kN per wheel) (RDA Bridge design manuel, 1997)

2.1.4.1 HA load

According to BS5400:Part2(2006) HA udl should be taken from Figure 9 and HA kel 120 kN/lane

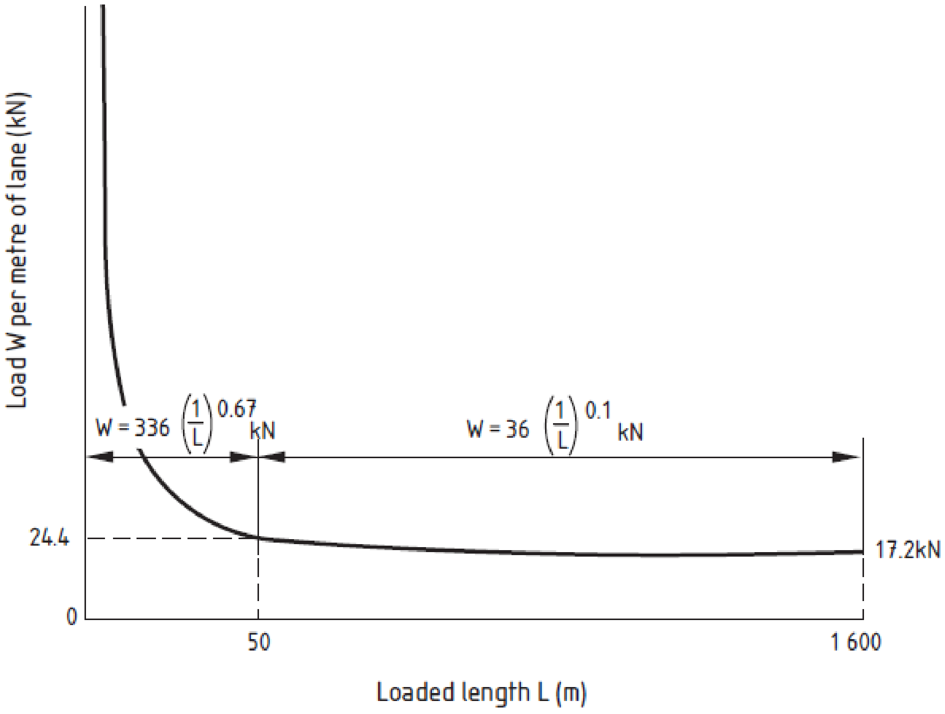


Figure 9: Loading curve HA udl (BS5400:Part2, 2006)

2.1.4.2 HB load

Wheel arrangement of HB Vehicle should be taken from Figure 10 and dispersion of wheel load through the fill at a slope of 2 vertically to 1 horizontally

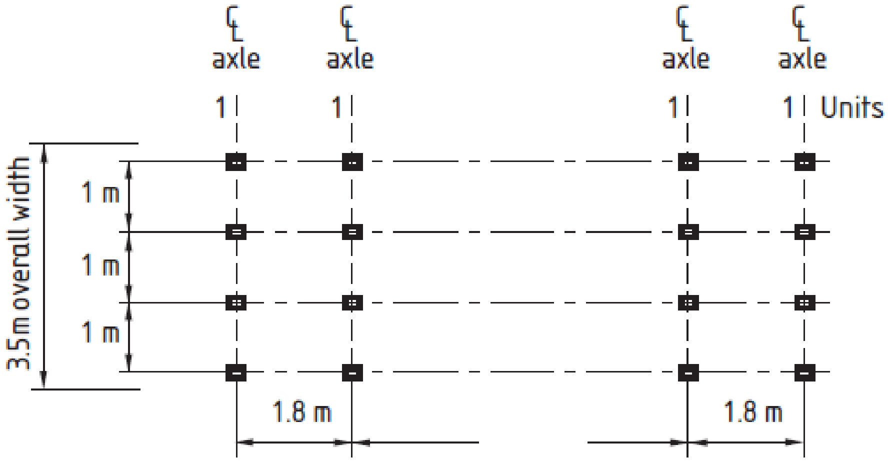


Figure 10: HB vehicle wheel arrangement (BS5400:Part2, 2006)

2.1.5 Traction load

According to BD31/01(2001) for a box culvert depth of soil cover H is 0.6m or less HA traction should apply if the soil cover exceeding, HA traction should be replaced with 30 units of HB traction, For any structure HB traction should apply

All traction forces shall be multiplied by "Kt" before they applied

$$\boldsymbol{K_t = (L_L - H')/(L_L - 0.6)} \qquad \textbf{Equation 2-5}$$

$but\ 1 \geq K_t \geq 0$

2.1.5.1 HA Traction (BS5400:Part2, 2006)

$$\boldsymbol{F = 250 + 8\ \ Loaded\ length} \qquad \textbf{Equation 2-6}$$

Applied to one notional lane only

2.1.5.2 HB Traction

$$\boldsymbol{F = 25\%\ of\ Total\ HB\ Load} \qquad \textbf{Equation 2-7}$$

= 0.25 x 1200 = 300 kN

Applied to two axel

2.1.6 Surcharge load

According to BD31/01(2001)

HA Surcharge = 10 kN/m^2

HB Surcharge = 12 kN/m^2

2.2 Guidelines for selecting design parameters and design equations

For the structural design of box culvert, the common method is philosophy of limit state design.

As described in (Clark, 1983) philosophy of limit state design is which target to ensure that the structure been designed will not become unfit for the use for which it is required during its design life.

Design for bending and shear is done for ultimate limit (ULS) state and check for crack width is done for serviceability limit (SLS) state (BS5400:Part4, 1990)

2.2.1 Design for bending

It is required to provide sufficient amount of reinforcement to avoid rupture of structure to calculate the amount of bending reinforcement following assumptions are made (Clark, 1983)

- Plane section remain plane
- Design stress strain curve for reinforcement and concrete are as shown in Figure 11 and Figure 12 respectively
- If a beam is singly reinforced the neutral axis depth is limited to half of effective depth to avoid over reinforced failure involving crushing of concrete
- Tensile strength of concrete is ignored
- Small axial thrust of up to 0.1 F_{cu} A_c are ignored, because they increase the calculated moment of resistance

As a result of stress strain curve shown in Figure 12 concrete compressive stress block is parabolic-rectangular, but code (BS5400:Part4, 1990) permit the simple stress block with a constant stress of 0.4 F_{cu} for simplicity it end up in same steel area as parabolic-rectangular curve (Clark, 1983)

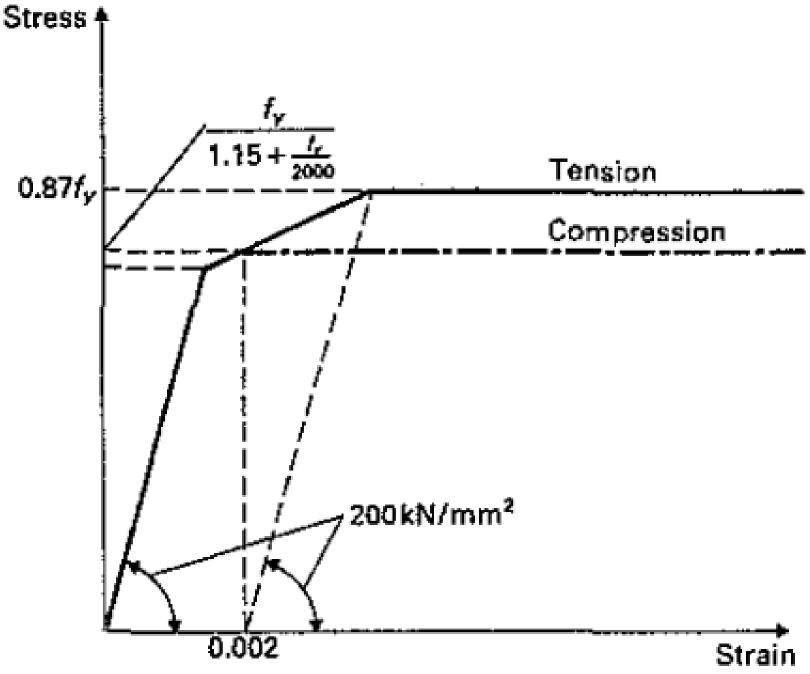


Figure 11: Stress strain curve for reinforcement (Clark, 1983)

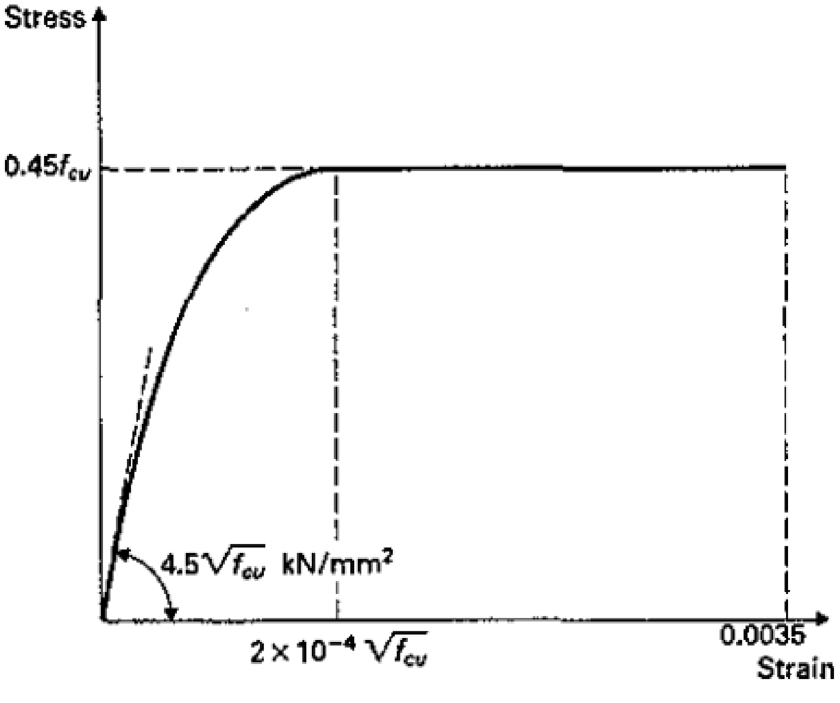


Figure 12: Stress strain curve for concrete (Clark, 1983)

Following design equations are given in the code (BS5400:Part4, 1990) for design of bending of singly reinforced sections as

$$\boldsymbol{M_u = (0.87f_y)A_s\, z}$$ **Equation 2-8**

$$\boldsymbol{M_u = 0.15\, f_{cu}bd^2}$$ **Equation 2-9**

And lever arm z can be written as below (Clark, 1983)

$$\boldsymbol{z = 0.5d[\ 1 + \sqrt{1 - 5M_u/f_{cu}bd^2}\ ]}$$ **Equation 2-10**

2.2.2 Design for shear

Shear stress (v) of slab should be less than $\xi_s v_c$ for a solid slab (BS5400:Part4, 1990)

$$\boldsymbol{v = V/bd}$$ **Equation 2-11**

$$\boldsymbol{v_c = \frac{0.27}{\gamma_m}\ [\frac{100\, A_s}{b_w d}]^{1/3}\ {f_{cu}}^{1/3}}$$ **Equation 2-12**

$$\boldsymbol{\xi_s = (500/d)^{0.25} \geq 0.7}$$ **Equation 2-13**

Critical location for shear is effective depth “d” from the inside edge of the fillets and if there are no fillet it should be “d” distance from internal corner (BD31/01, 2001)

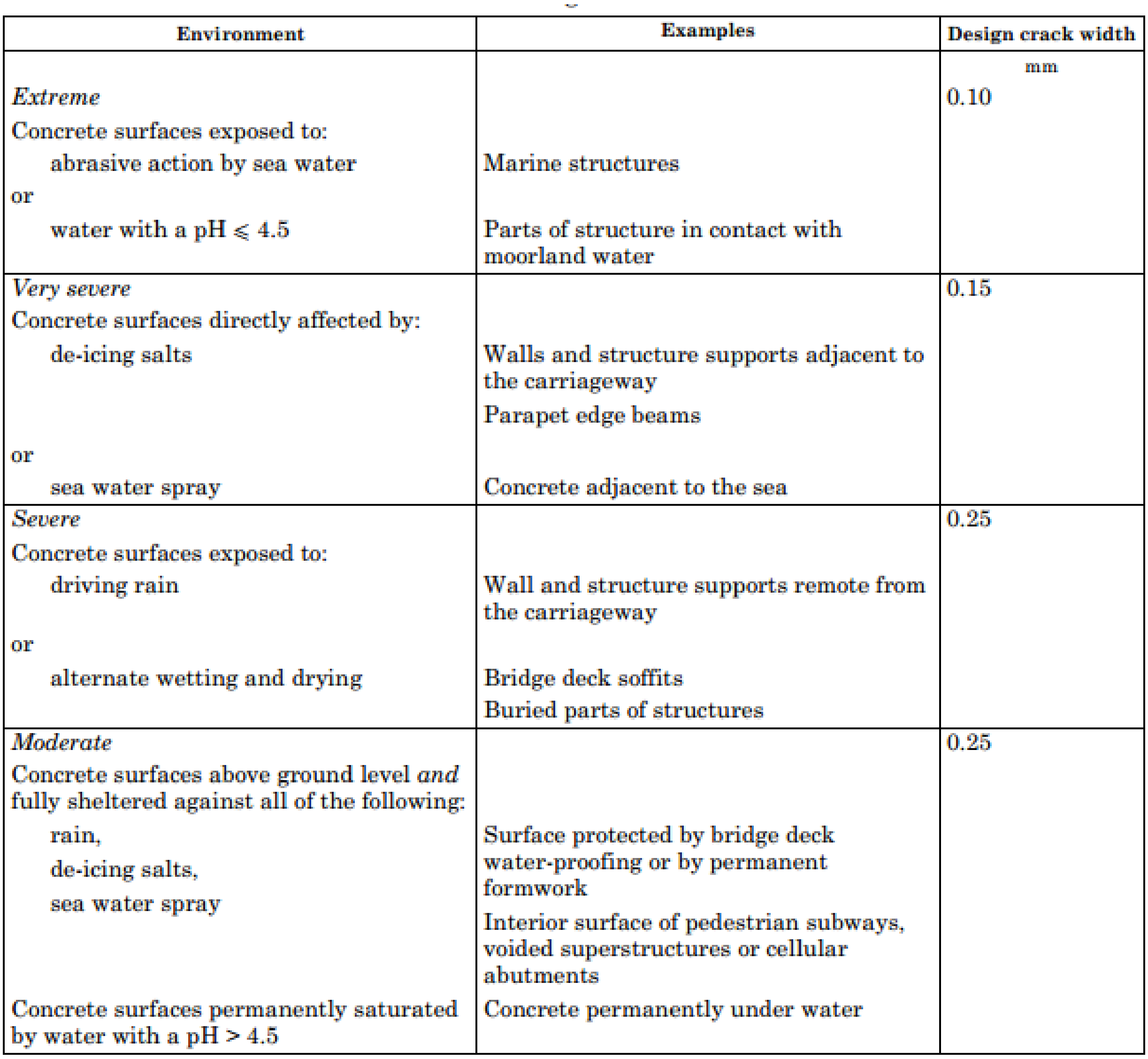
2.2.3 Design for crack width

Crack width should be calculated for serviceability limit state (SLS) from below equation (BS5400:Part4, 1990)

$$crackwidth = \frac{3\, a_{cr} \epsilon_m}{1+2(a_{cr}-c_{nom})/(h-d_c)} \qquad \textbf{Equation 2-14}$$

Calculated crack width at any point should be less than the value given in Table 1

Table 1: Design crack width (BS5400:Part4, 1990)



Environment	Examples	Design crack width mm
Extreme Concrete surfaces exposed to:		0.10
abrasive action by sea water	Marine structures	
or		
water with a pH ⩽ 4.5	Parts of structure in contact with moorland water	
Very severe Concrete surfaces directly affected by:		0.15
de-icing salts	Walls and structure supports adjacent to the carriageway Parapet edge beams	
or		
sea water spray	Concrete adjacent to the sea	
Severe Concrete surfaces exposed to:		0.25
driving rain	Wall and structure supports remote from the carriageway	
or		
alternate wetting and drying	Bridge deck soffits Buried parts of structures	
Moderate Concrete surfaces above ground level *and* fully sheltered against all of the following:		0.25
rain, de-icing salts, sea water spray	Surface protected by bridge deck water-proofing or by permanent formwork Interior surface of pedestrian subways, voided superstructures or cellular abutments	
Concrete surfaces permanently saturated by water with a pH > 4.5	Concrete permanently under water	

2.2.4 Design for thermal and shrinkage

According to (BS5400:Part4, 1990) to prevent cracking due to shrinkage and thermal crack reinforcement should be provided in the direction of restrains, the area of reinforcement As should be

$$\boldsymbol{A_s > \ k_r(A_c - 0.5\ A_{cor})} \qquad \textbf{Equation 2-15}$$

Kr = 0.005 for grade 460 reinforcement

Kr = 0.006 for grade 250 reinforcement

Ac = Area of gross concrete section

Acor = Area of the core of the concrete section Ac (portion of the section 250mm away from all concrete surfaces)

According to (BD28/87, 1987) amount of reinforcement (A_s) to prevent cracking due to shrinkage and thermal is given by maximum of following equations

$$\boldsymbol{A_s = [\frac{f_{ct}}{f_y}]A_c} \qquad \textbf{Equation 2-16}$$

$$\boldsymbol{A_s = \left[\frac{f_{ct}}{f_b}\right] A_c \frac{\emptyset}{2w} [R(\in_{sh} - \in_{th}) - 0.5 \in_{ult}]} \qquad \textbf{Equation 2-17}$$

Ac = area of concrete which lies within 250mm of the surface

fy = characteristic tensile strength of reinforcement.

fct = tensile strength of immature concrete which may be taken as 0.12 $(f_{cu})^{0.7}$

fcu = characteristic cube strength of concrete

Fb = average bond strength between the reinforcement and the immature concrete

Φ = bar size (nominal diameter)

W = permissible crack width

ε_{th} =Thermal strain

=0.8 α (T1+T2)

T1 = Short-term fall in temperature from hydration peak to ambient conditions

T2 = Long-term fall in temperature from ambient to the seasonal minimum

α = Coefficient of thermal expansion of concrete

= 12×10^{-6} per °c

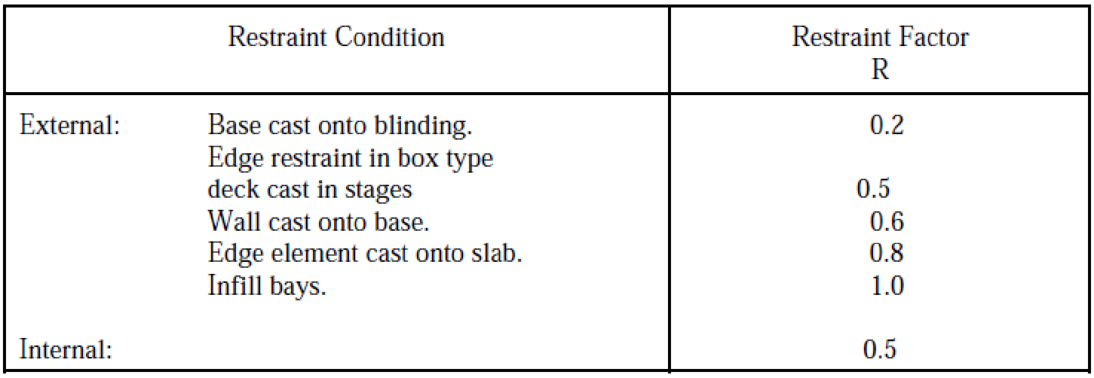
ε_{ult} =Ultimate tensile strain capacity of concrete which may be taken as 200 micro strain

ε_{sh} =Shrinkage strain

(For normal conditions $\varepsilon_{sh} = 0.5\ \varepsilon_{ult}$)

R =Restraint factor Table 2

Table 2: Restraint factor (BD28/87, 1987)



Restraint Condition		Restraint Factor R
External:	Base cast onto blinding.	0.2
	Edge restraint in box type deck cast in stages	0.5
	Wall cast onto base.	0.6
	Edge element cast onto slab.	0.8
	Infill bays.	1.0
Internal:		0.5

According to studies done by Nanayakkara & Wannigama(2003) T1 for the conditions prevailing in Sri Lanka given in the Table 3 and T2 given in Table 4

Table 3:T1 Values for Sri Lanka

Wall thickness (mm)	T1 C^o
250	33
300	35
400	38
500	40
600	42

Table 4: T2 Values for Sri Lanka

City	T2 C^o
Anuradhapura	11
Badulla	12
Bandarawela	11
Batticaloa	8
Colombo	8
Galle	7
Hambanthota	8
Katugasthota	12
Kurunagala	11
Mahailluppallama	11
Nuwaraeliya	12
Puttalam	10
Vavuniya	12
Average	10

2.2.5 Minimum requirement

According to BS5400:Part4(1990) Minimum area of tension reinforcement in slabs is 0.15 x width x effective depth for grade 460 reinforcement

2.3 Summary

This chapter explained all the parameters required to analyze the box culvert such as soil subgrade reaction, lateral earth pressure coefficient, live loads, surcharge load, soil loads and also the design requirement to meet

Next chapter describes the methodology followed to fill the research gap identified in literature review

3 METHODOLOGY

3.1 Fixing geometry

3.1.1 Culvert cross section

For this study culvert cross section for a given opening of height H and given width W, same thickness for base slab, top slab and side walls as shown in Figure 13 has been used, in addition standard chamfer section used which is chamfer size similar to slab thickness

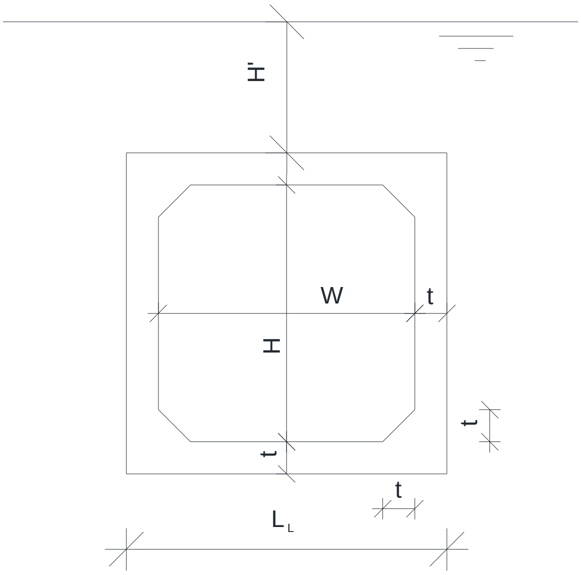


Figure 13: Culvert cross section

3.1.2 Length of culvert

The resultant internal forces depend on width of notional lane, applied traction force, the length of structure and position of traction force.

When the width of notional lane reduces the intensity of force increases and internal force increases.

When length of culvert reduce internal forces resulting from traction increase. For this analysis full length culvert to accommodate two notional lanes of 2.5m along the cross section are considered by avoiding joint in-between and length of culvert is L

This section can be used for any length (including expressway culvert) which carriage way length is greater than 5m

L= 5 + 3H’ Equation 3-1

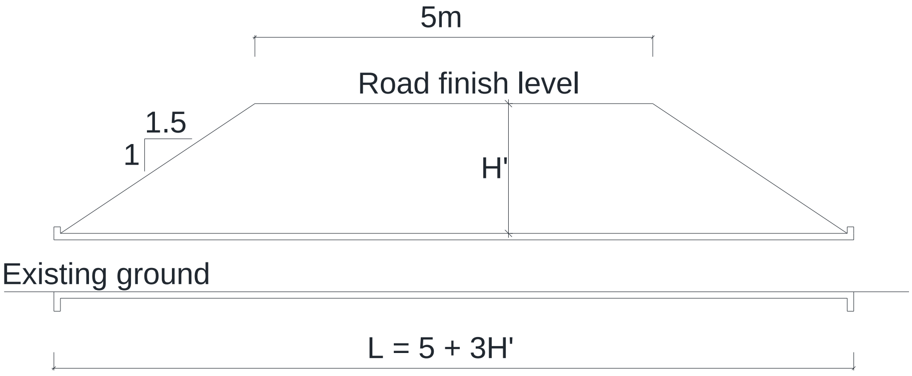


Figure 14: Culvert longitudinal section

3.2 Categorization of box culverts depending on geometry and sizes

Distribution of traction force along the culvert depends on geometry therefore it is necessary to do a “3D” analysis if culvert subjected to a traction force because the traction force apply to a one notional lane only according to BS5400:Part2(2006)

According to BD31/01(2001) the traction load will disappear beyond some fill height ($H' \geq L_L$) and problem become plain strain and can be used “2D” analysis

For other culverts it is necessary to do “3D” analysis

Therefore it is possible to identify two categories

1. Type 01-3D analysis required

2. Type 02 -2D analysis adequate

Table 5: Culvert types

<table>
<tr><th></th><th></th><th colspan="7">fill height(m)</th></tr>
<tr><th></th><th></th><th>0.5</th><th>1</th><th>2</th><th>4</th><th>6</th><th>8</th><th>10</th></tr>
<tr><td rowspan="3">box size</td><td>1.5 x 1.5</td><td colspan="2">Type 01</td><td colspan="5">Type 02</td></tr>
<tr><td>2 x 2</td><td colspan="3" rowspan="2"></td><td colspan="4" rowspan="2"></td></tr>
<tr><td>3 x 3</td></tr>
</table>

3.3 Numerical model development

Numerical modelling process involve identification of input data ,selection of modelling type (2D or 3D) based on input data and output (BM and SF) from FE analysis. The process is described in flow chart as follows

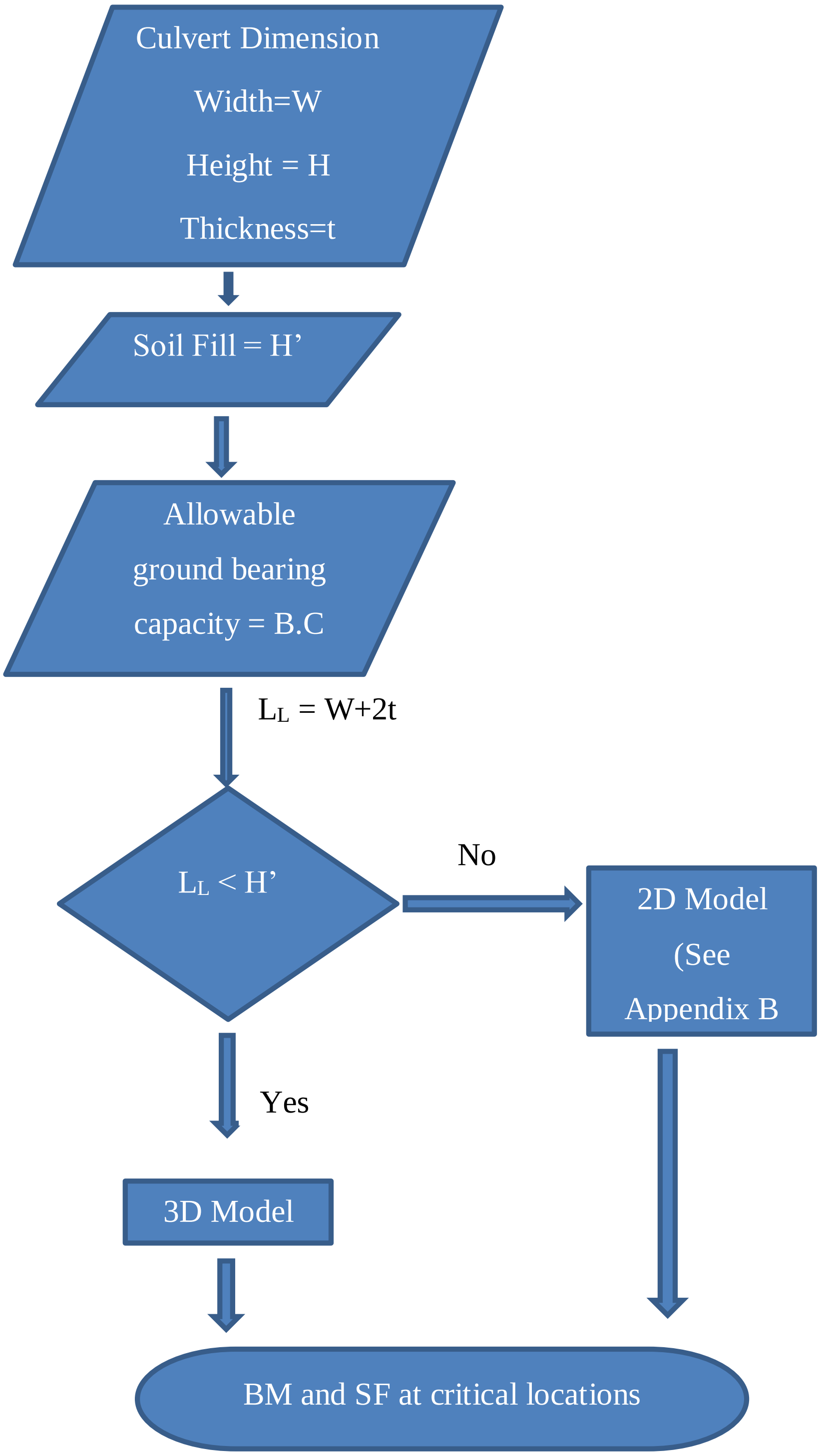


Figure 15: Numerical model flow chart

As explained in flow chart in figure 15, the basic inputs are culvert dimensions such as internal width, internal height and thickness. The fill height also a major input parameter .Subsequently the allowable ground bearing capacity also required to process the programme

The modelling technique (2D or 3D) is decided based on the overall culvert width (L_L) and the fill height (H')

- If L_L<H' , programme select the 2D modelling and analysis technique
- If L_L>H' , programme select the 3D modelling and analysis technique

In this programme 2D modelling analysis technique comprehensively describe with an example in Appendix B

3.4 Data collection

3.4.1 Study 1 (Effect of soil bearing capacity on structural design of box culvert)

By using the analytical model developed set of box culverts analysed for a constant height, width and fill height but varying bearing capacity and thickness to study the effect of bearing capacity and stiffness of slab on internal forces of the culvert

3.4.2 Study 2 (Optimizing the box culvert)

By using the analytical model developed set of culverts are analysed for a constant bearing capacity but varying height, width, and fill height and slab thickness.

Find internal forces at the critical locations for the optimization of the box culvert.

3.5 Design approach

3.5.1 Design for bending

It is possible to find reinforcement requirement for bending as described in 2.2.1. (See Appendix D1)

3.5.2 Design for shear

It is possible to find reinforcement requirement for shear as described in 2.2.2. (See Appendix D3)

3.5.3 Design for crack width

The amount of reinforcement required depends on the SLS bending moment, SLS Permanent bending moment, element thickness, cover, design crack width and spacing of reinforcement

For the purpose of this, it is assumed

Cover = 50 mm

Spacing = 150mm

Design crack width = 0.25mm (Severe exposure condition)

Crack width is calculated from 2.2.3. (See Appendix D5) for an assumed area of reinforcement and changed the amount of reinforcement until the design crack width is reached in trial and error basis

3.5.4 Design for thermal and shrinkage

The amount of reinforcement required is calculated as described in 2.2.4 . (See Appendix D4)

Restrained condition assumed as follows and restrained factor used for the calculation is given in Table 6

For

Bottom slab = base cast in to blinding,

Walls = wall cast on to base

Top slab = Deck cast in stages

Table 6: Restrained factors used for calculation

Element	Along the length of Box
Top Slab	0.5
Bottom slab	0.2
Wall	0.6

3.5.5 Minimum requirement

Minimum amount of reinforcement calculated according to 2.2.5(See Appendix D2)

4 RESULTS AND DISCUSSION

4.1 Effect of soil bearing capacity on structural design of box culvert

4.1.1 Input data for the numerical model

For this analysis following dimension considered

W =3m

H =3m

H' =6m

t/W =1/40, 1/20, 1/10, 1/5

B.C =50, 100, 150, 200, 250, 300, 350, 400 kN/m^2

4.1.2 Output from numerical model

Table 7 shows the span bending moment of the top slab for varying bearing capacity and also for varying thickness/span ratios

Table 8 shows the span bending moment of the bottom slab for varying bearing capacity and also for varying thickness/span ratios

Table 7: Top slab span bending moment (BM) (kNm/m)

Bearing capacity (kN/m^2)	Thickness			
	1/40	1/20	1/10	1/5
	75mm	150mm	300mm	600mm
50	124	133	147	182
100	120	132	146	182
150	118	131	146	182
200	117	130	146	182
250	116	129	145	182
300	115	128	145	182
350	115	127	145	182
400	114	127	145	181

Table 8: Bottom slab span bending moment (BM) (kNm/m)

Bearing capacity (kN/m^2)	Thickness			
	1/40	1/20	1/10	1/5
	75mm	150mm	300mm	600mm
50	79	130	158	212
100	53	121	156	212
150	37	112	154	211
200	27	105	152	211
250	23	98	151	210
300	20	92	149	210
350	17	87	147	210
400	15	82	146	209

4.1.3 Data interpretation

Sensitivity of the bending moment (BM) of the top slab and bottom slab can be interpreted from the plot of M/M_{200} against bearing capacity of ground for a given thickness to span ratio (t/W)

M =BM at given bearing capacity

M_{200} =BM at 200kN/m^2 bearing capacity

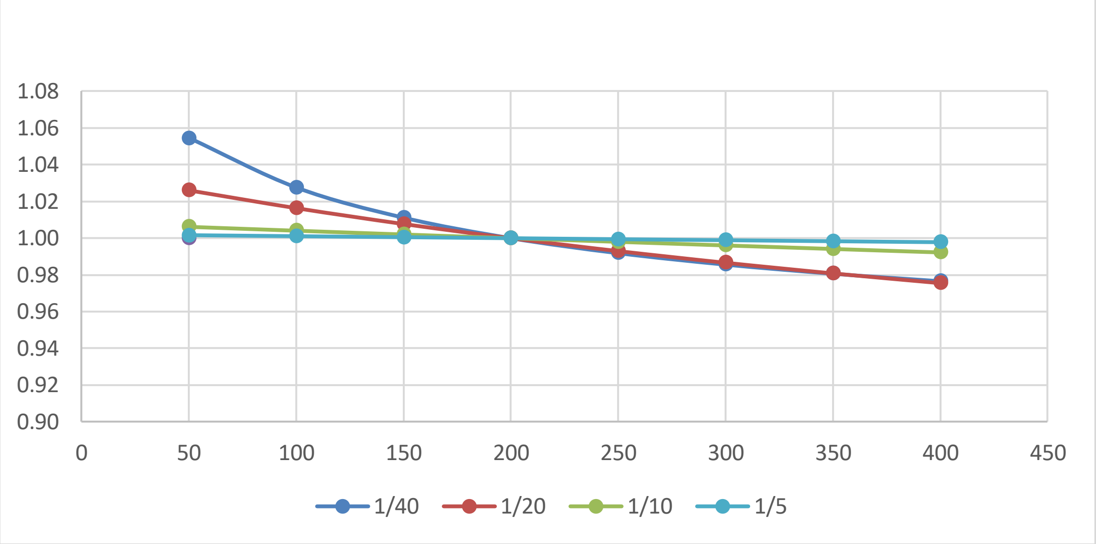


Figure 16: Variation of top slab span M/M_{200} with bearing capacity of ground

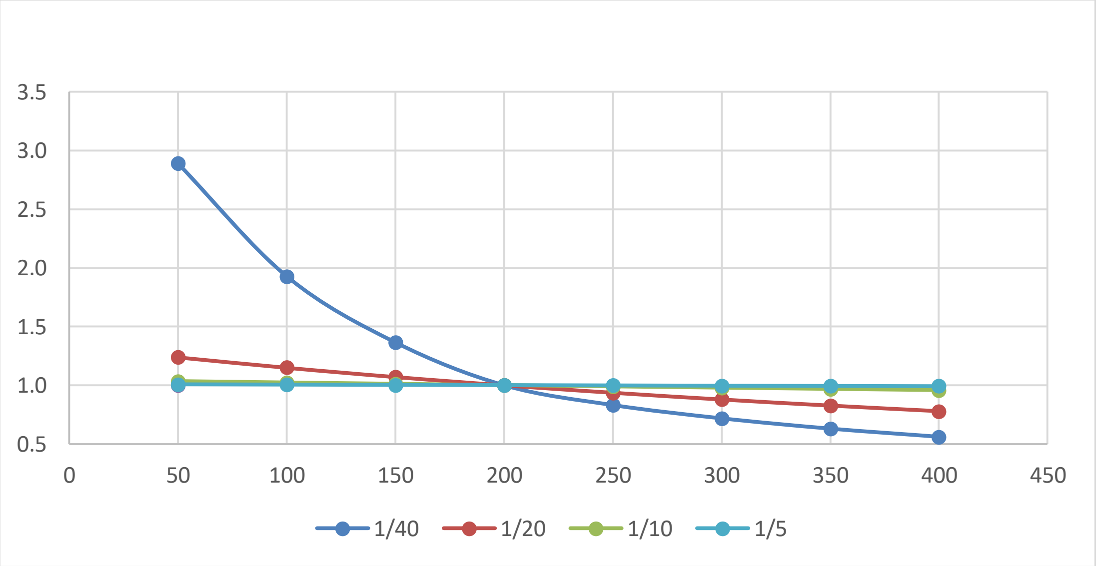


Figure 17: Variation of bottom slab span M/M_{200} with bearing capacity of ground

4.1.4 Discussion

- Top slab BM is less sensitive to bearing capacity of soil at low t/W ratios and not sensitive at high t/W ratios
- Bottom slab BM is highly sensitive to bearing capacity of soil at low t/W ratios and less sensitive at high t/W ratios
- Bottom slab BM increase when reducing ground bearing capacity for given t/W ratio
- Bottom slab BM increase when the thickness is increasing for a given bearing capacity
- Therefore it is conservative to assume less bearing capacity for the purpose of structural design
- Therefore in the next study bearing capacity is assumed as 100kN/m^2

4.2 Optimizing the box structure

According to LRFD (2013) critical locations for the design of box culvert shown in Figure 18 and Figure 19.

By analysing the box culvert, bending moment and shear forces results at critical locations is found

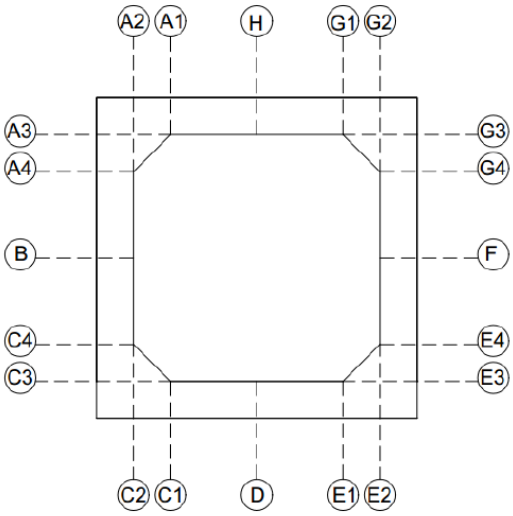


Figure 18: Critical locations for flexural design

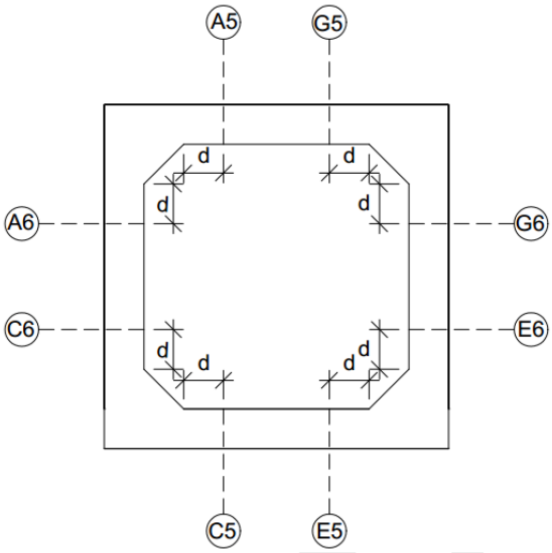


Figure 19: Critical location for shear design

4.2.1 Box culvert of 1.5 m x 1.5 m

4.2.1.1 Soil fill 0.5m

Input data for the numerical model

W =1.5 m H =1.5 m H' =0.5 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

For analysis results refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

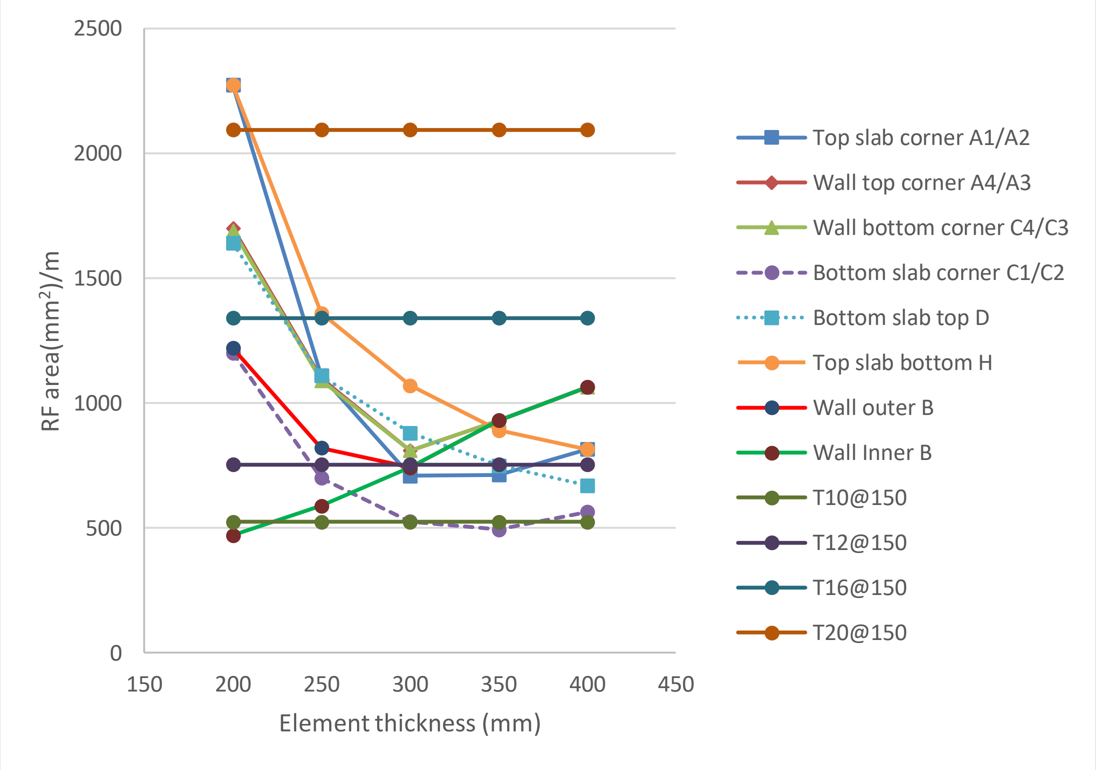


Figure 20: Box culvert 1.5x1.5 with 0.5m fill

4.2.1.2 Soil fill 1.0m

Input data for the numerical model

W =1.5 m H =1.5 m H' =1.0 m

B.C =100 kN/m^2

t =150, 200, 250, 300, 350 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

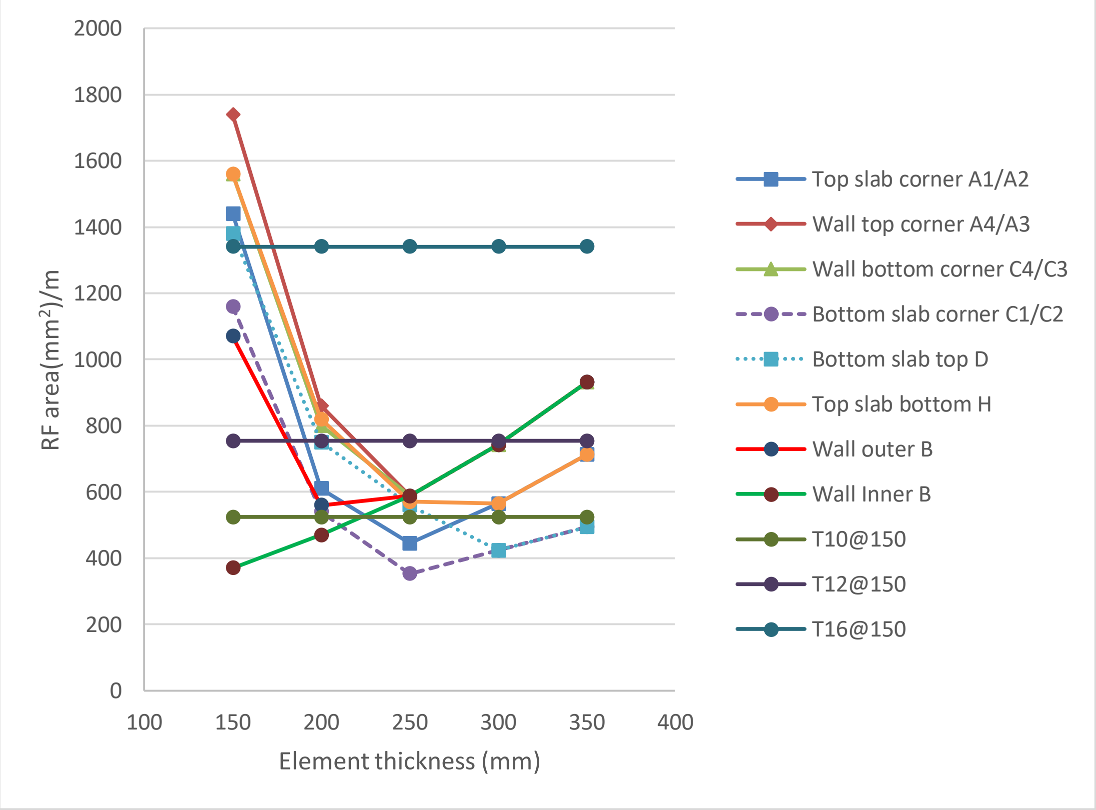


Figure 21: Box culvert 1.5mx1.5m with 1m fill

4.2.1.3 Soil fill 2.0m

Input data for the numerical model

W =1.5 m H =1.5 m H' =2.0 m

B.C =100 kN/m^2

t =150, 200, 250, 300, 350 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

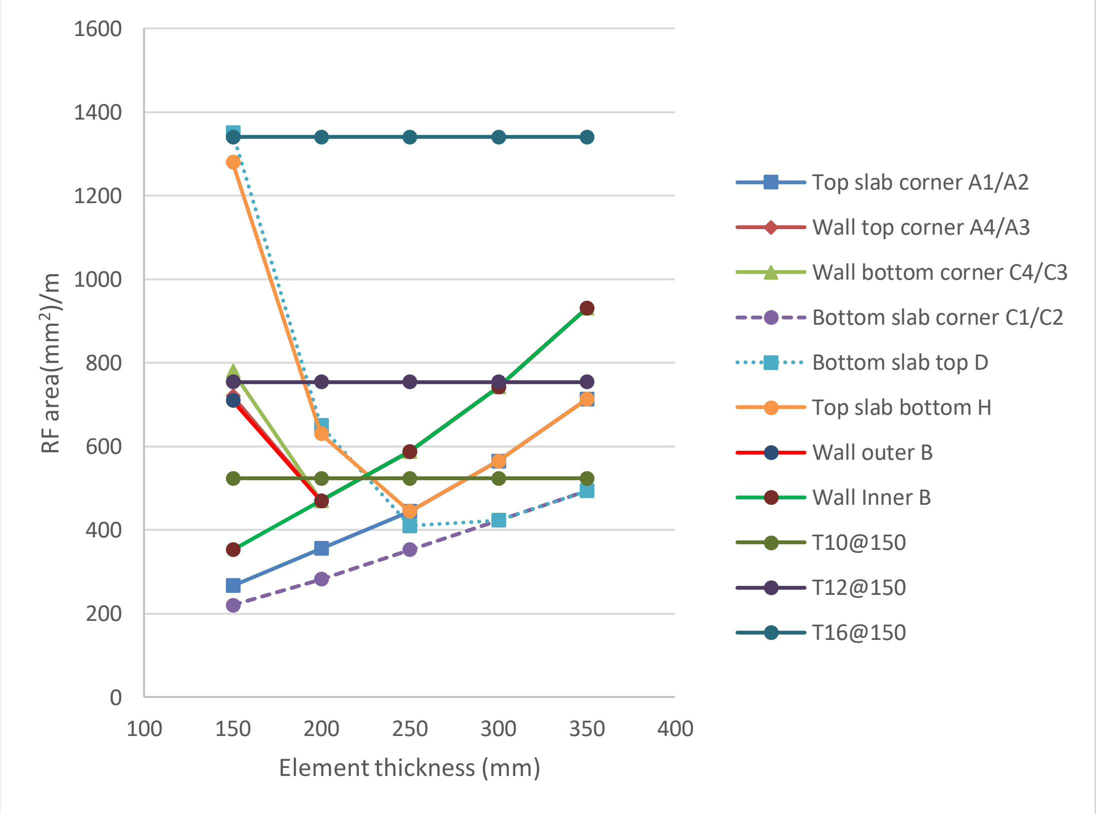


Figure 22: Box culvert 1.5mx1.5m with 2m fill

4.2.1.4 Soil fill 4.0m

Input data for the numerical model

W =1.5 m H =1.5 m H' =4.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

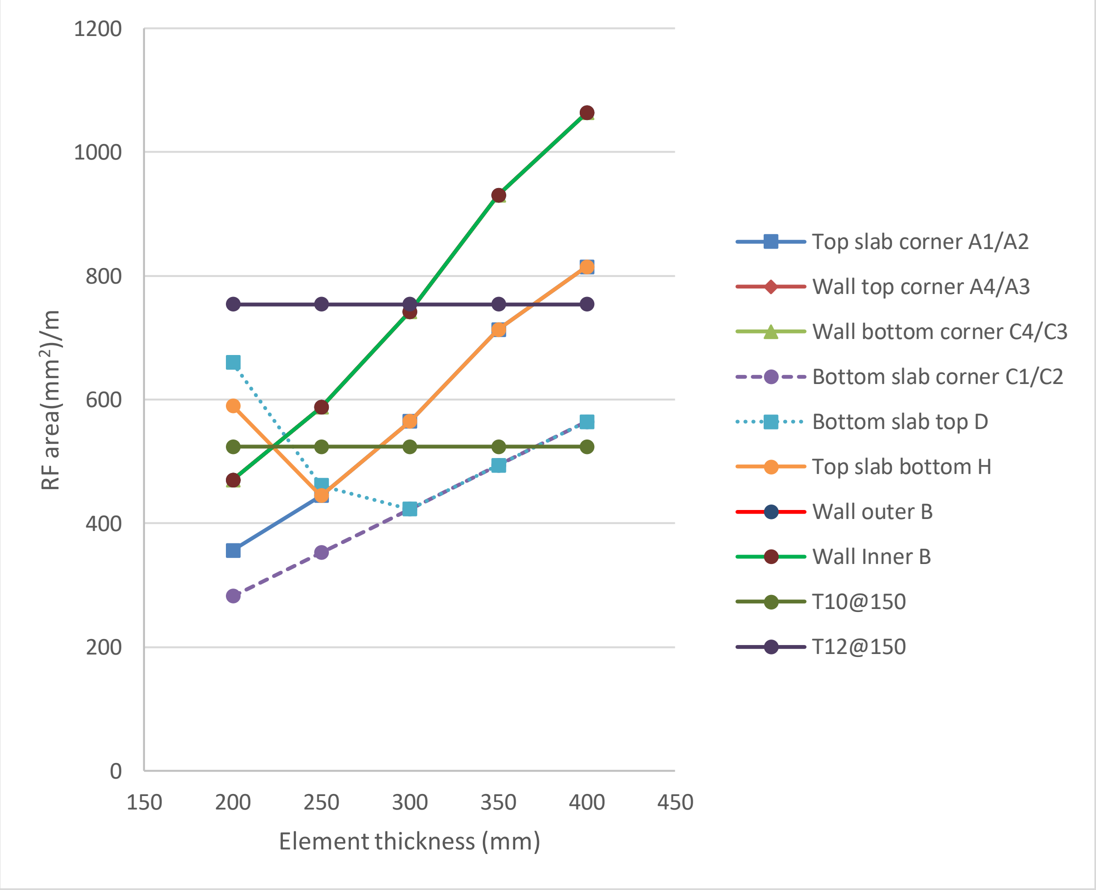


Figure 23: Box culvert 1.5mx1.5m with 4m fill

4.2.1.5 Soil fill 6.0m

Input data for the numerical model

W =1.5 m H =1.5 m H' =6.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

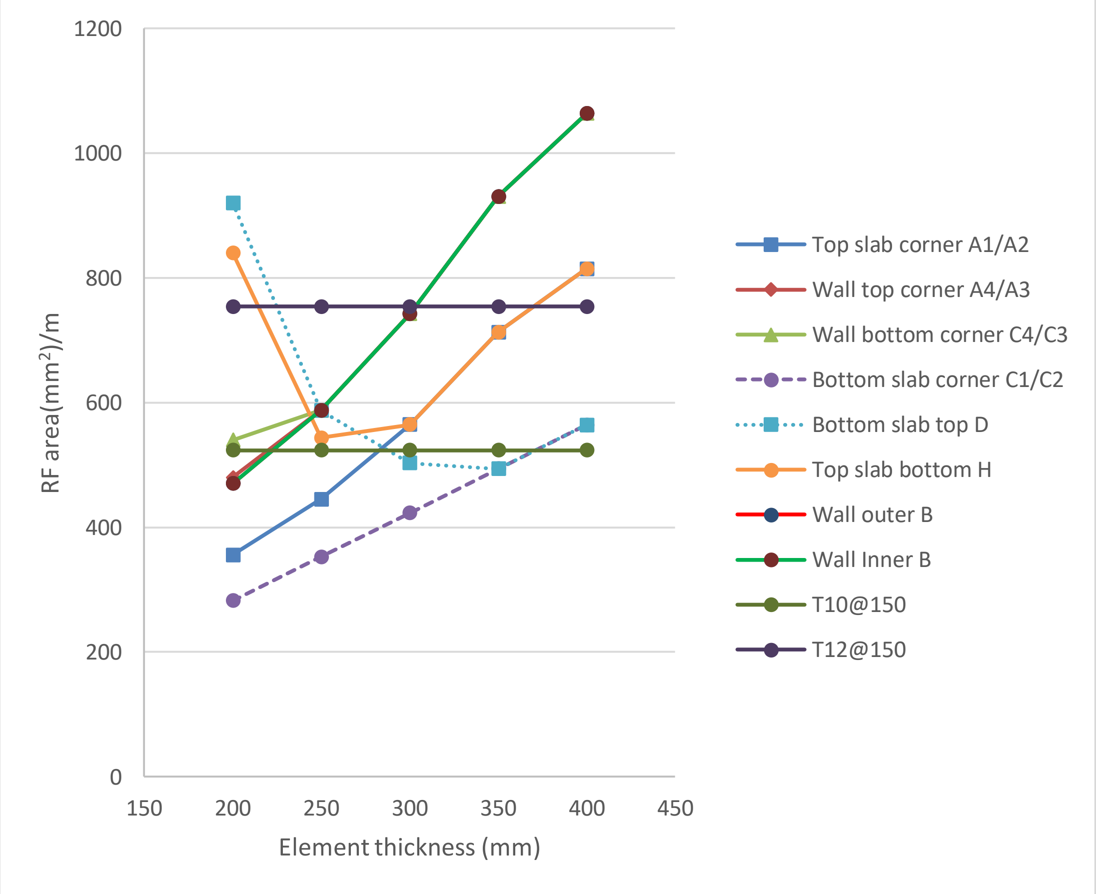


Figure 24: Box culvert 1.5mx1.5m with 6m fill

4.2.1.6 Soil fill 8.0m

Input data for the numerical model

W =1.5 m H =1.5 m H’ =8.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

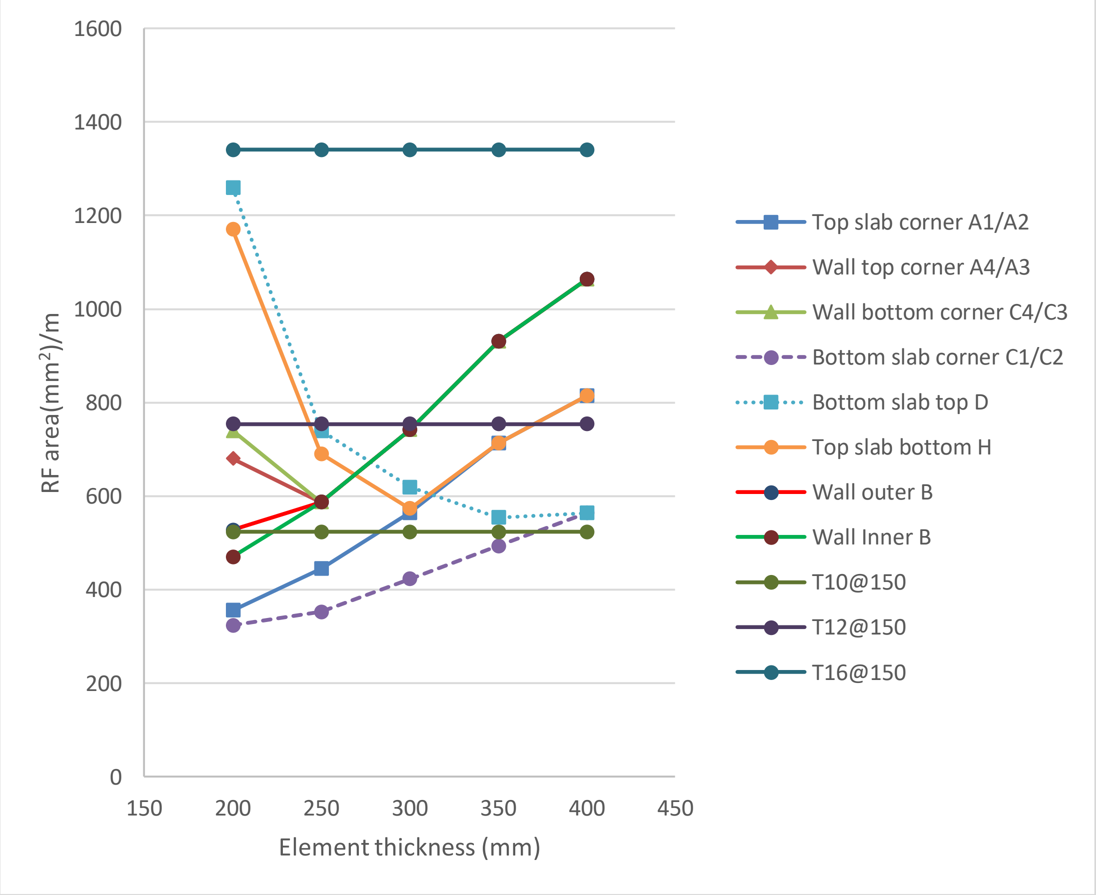


Figure 25: Box culvert 1.5mx1.5m with 8m fill

4.2.1.7 Soil fill 10.0m

Input data for the numerical model

W =1.5 m H =1.5 m H' =10.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C1

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

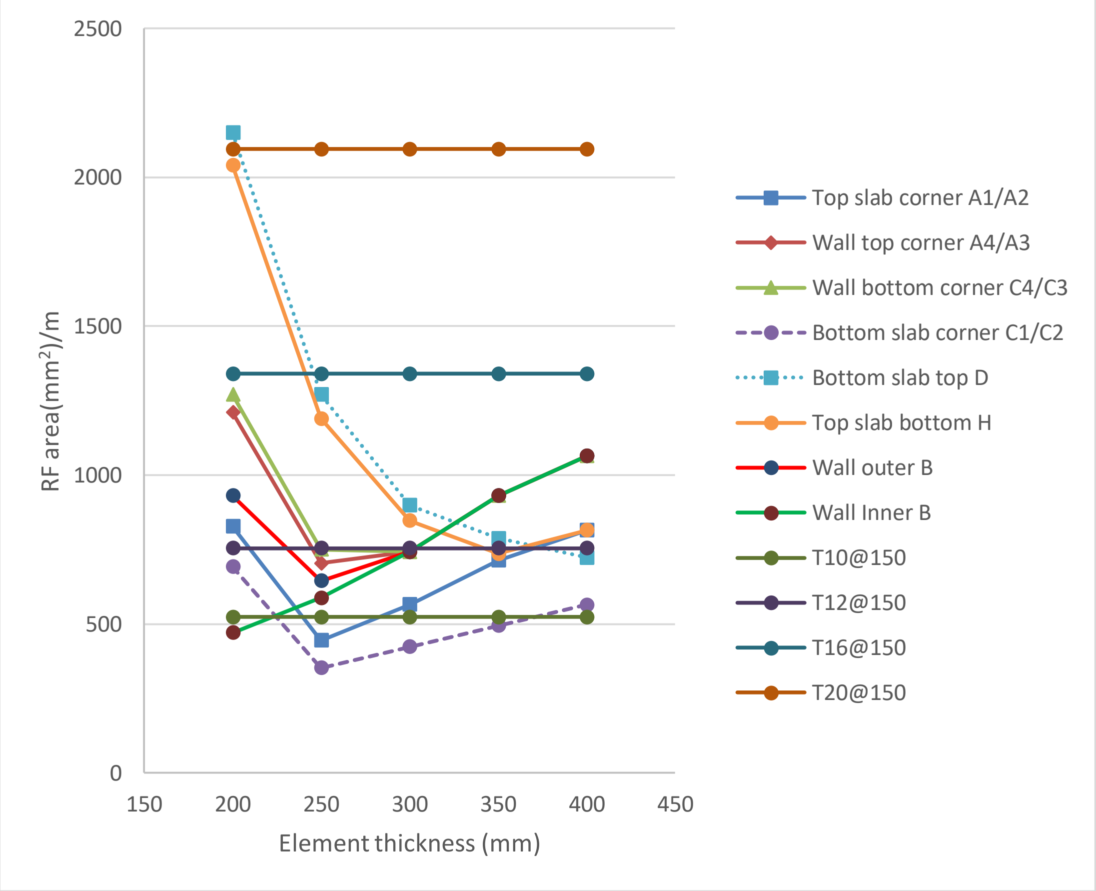


Figure 26: Box culvert 1.5mx1.5m with 10m fill

4.2.2 Box culvert of 2.0 m x 2.0 m

4.2.2.1 Soil fill 0.5m

Input data for the numerical model

W =2.0 m H =2.0 m H' =0.5 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

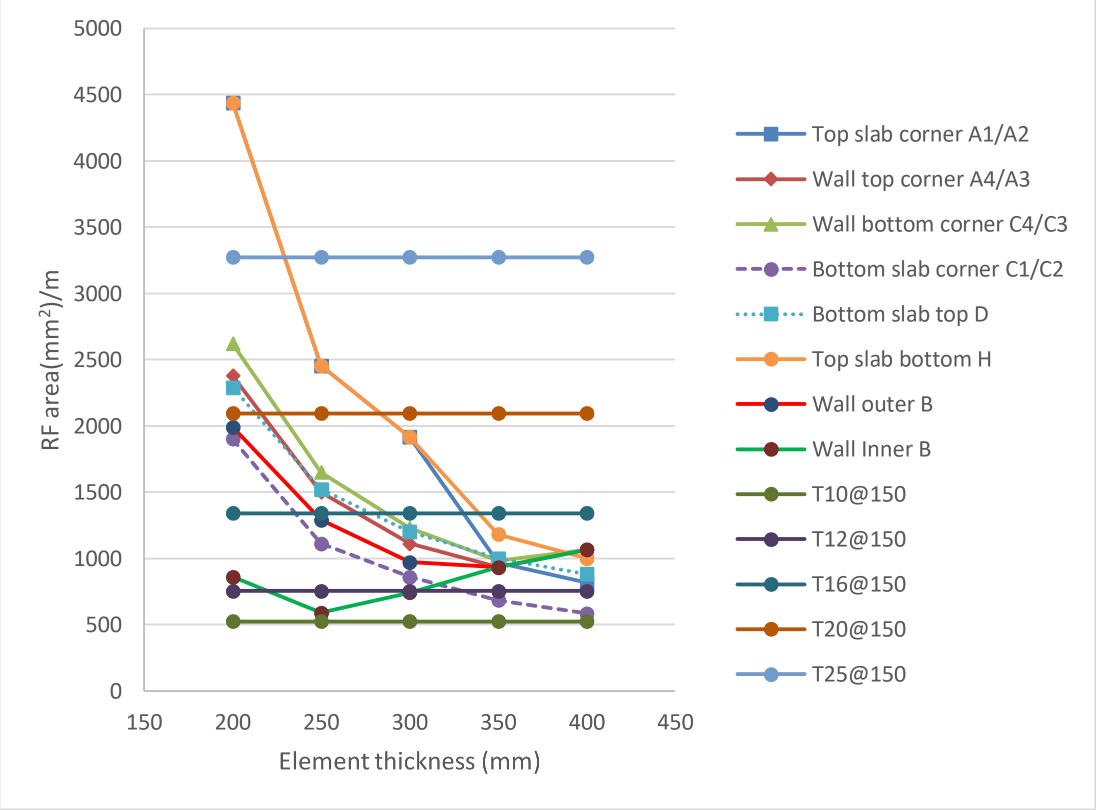


Figure 27: Box culvert 2.0mx2.0m with 0.5m fill

4.2.2.2 Soil fill 1.0m

Input data for the numerical model

W =2.0 m H =2.0 m H’ =1.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

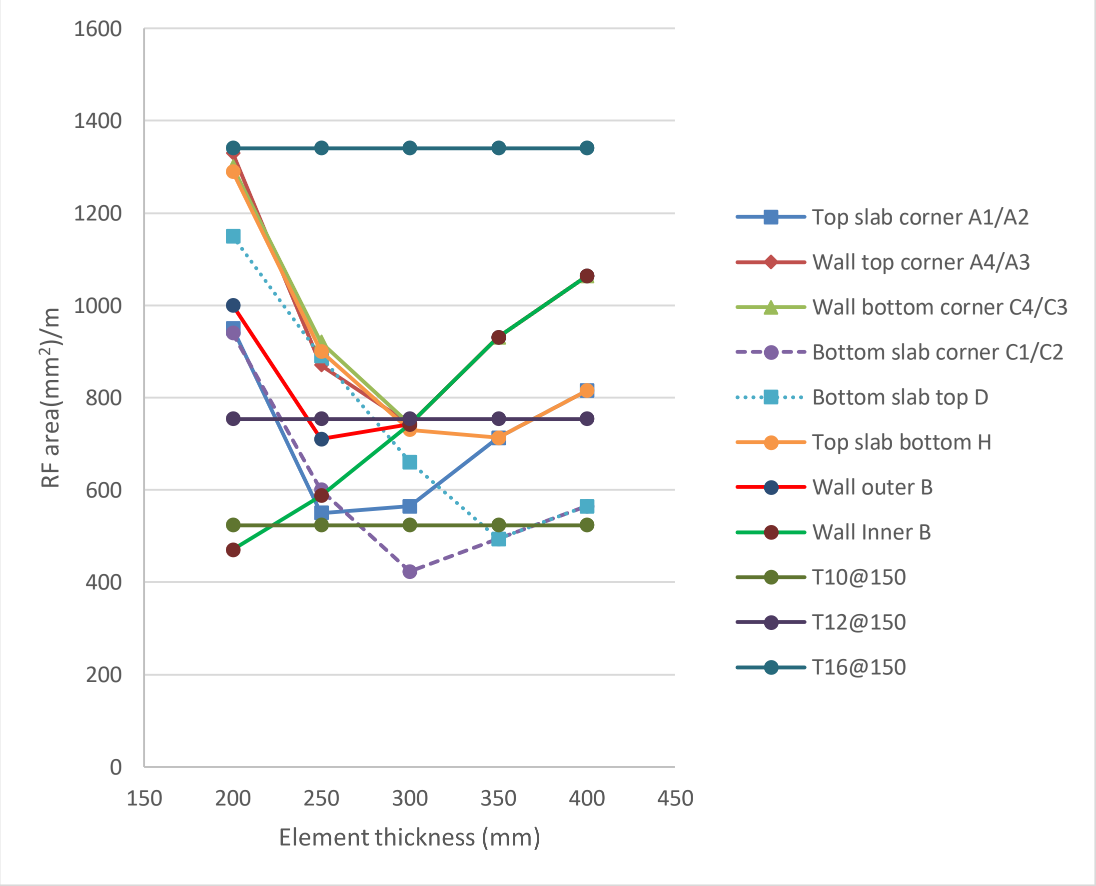


Figure 28: Box culvert 2.0mx2.0m with 1m fill

4.2.2.3 Soil fill 2.0m

Input data for the numerical model

W =2.0 m H =2.0 m H' =2.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

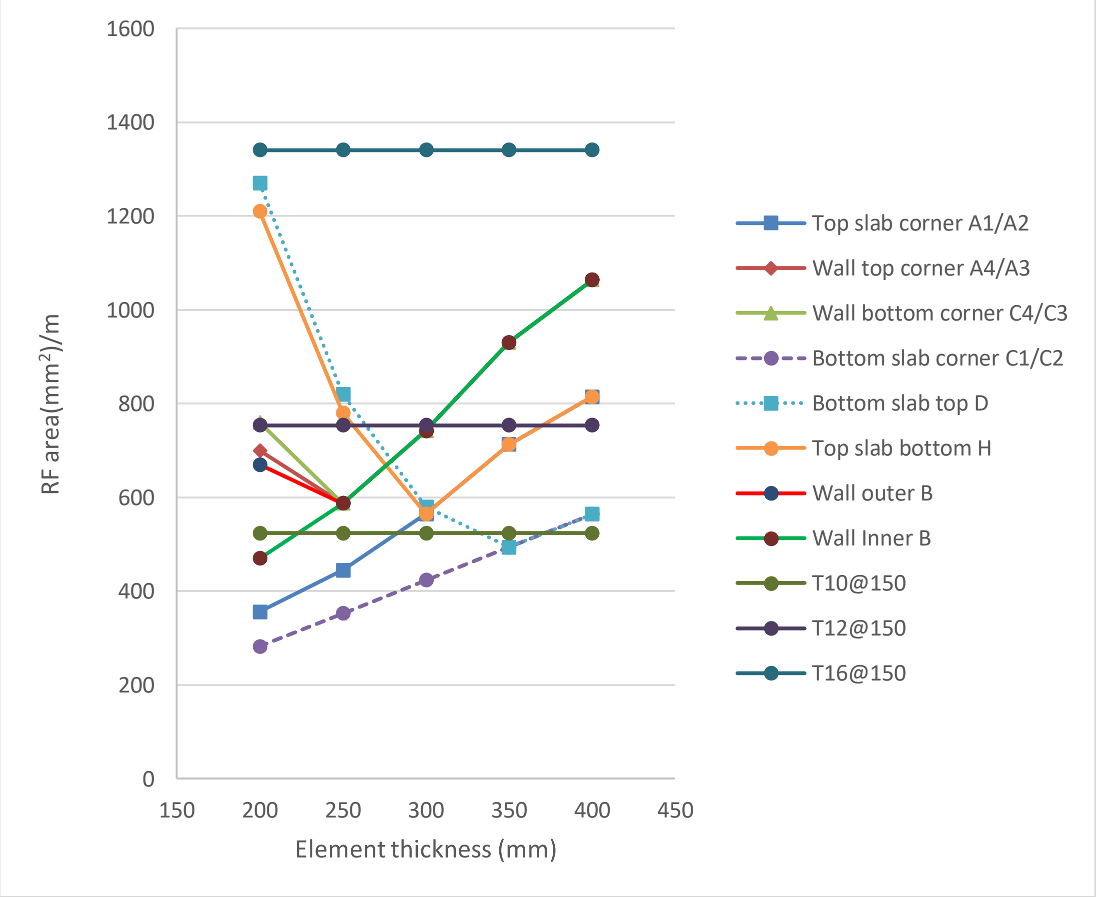


Figure 29: Box culvert 2.0mx2.0m with 2m fill

4.2.2.4 Soil fill 4.0m

Input data for the numerical model

W =2.0 m H =2.0 m H' =4.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

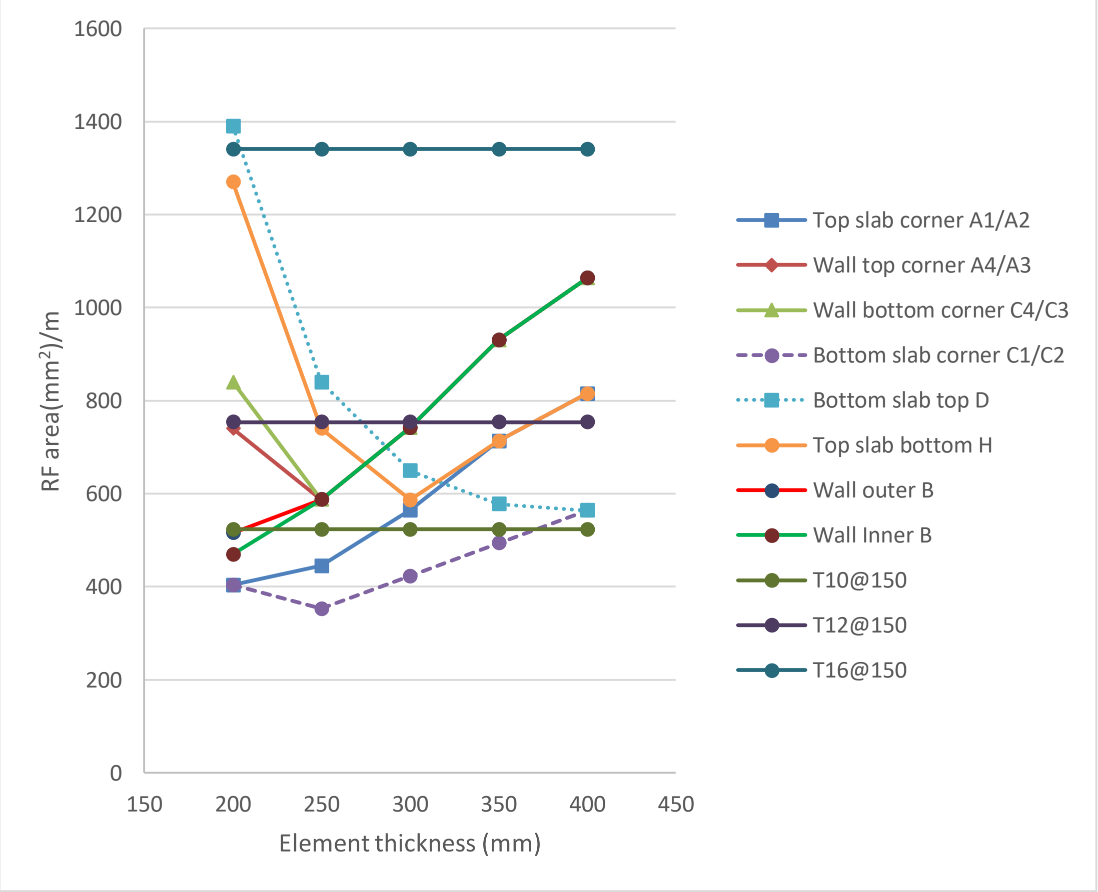


Figure 30: Box culvert 2.0mx2.0m with 4m fill

4.2.2.5 Soil fill 6.0m

Input data for the numerical model

W =2.0 m H =2.0 m H’ =6.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

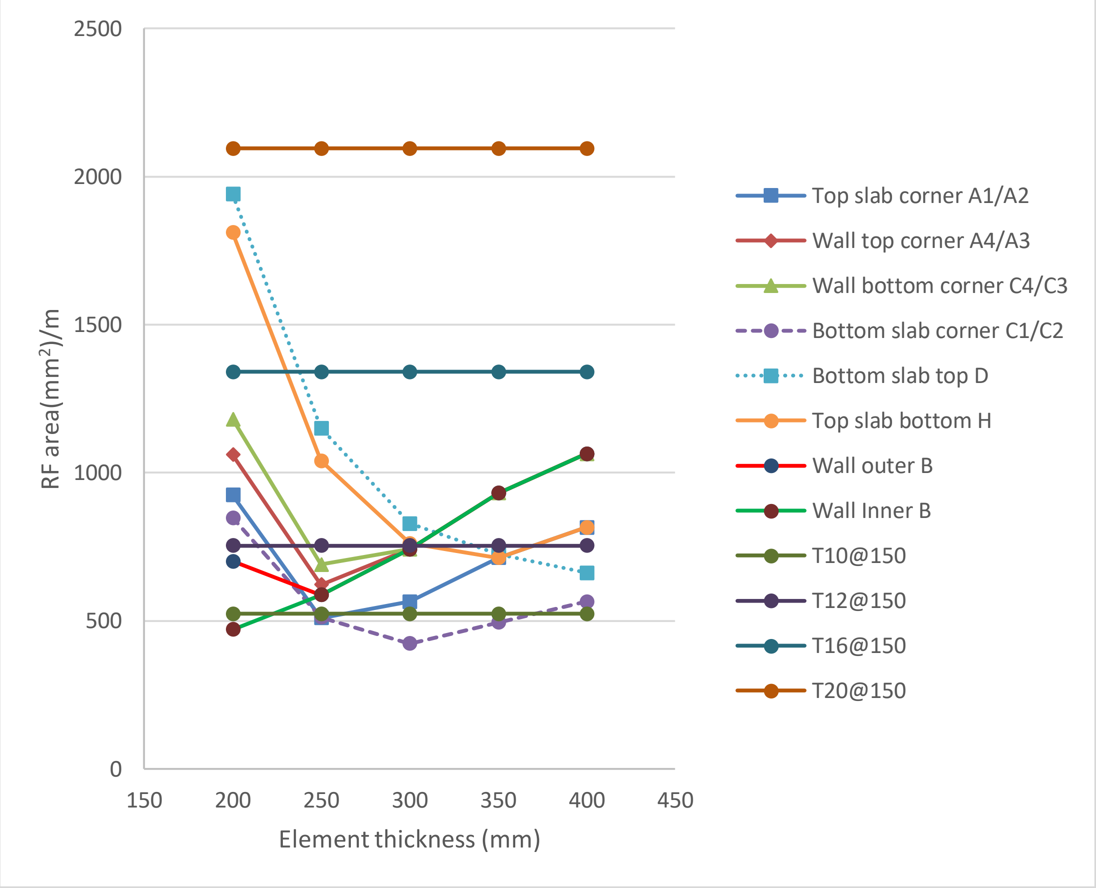


Figure 31: Box culvert 2.0mx2.0m with 6m fill

4.2.2.6 Soil fill 8.0m

Input data for the numerical model

W =2.0 m H =2.0 m H' =8.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

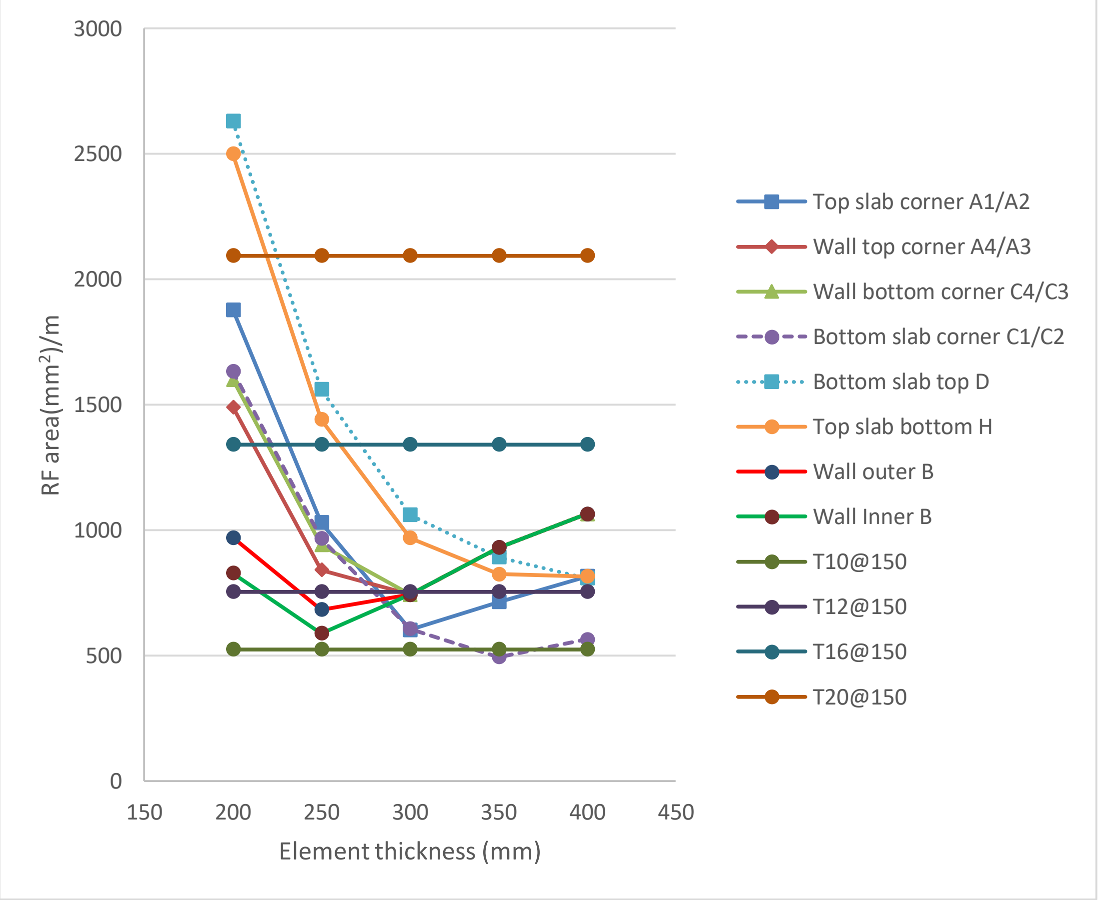


Figure 32: Box culvert 2.0mx2.0m with 8m fill

4.2.2.7 Soil fill 10.0m

Input data for the numerical model

W =2.0 m H =2.0 m H’ =10.0 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C2

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

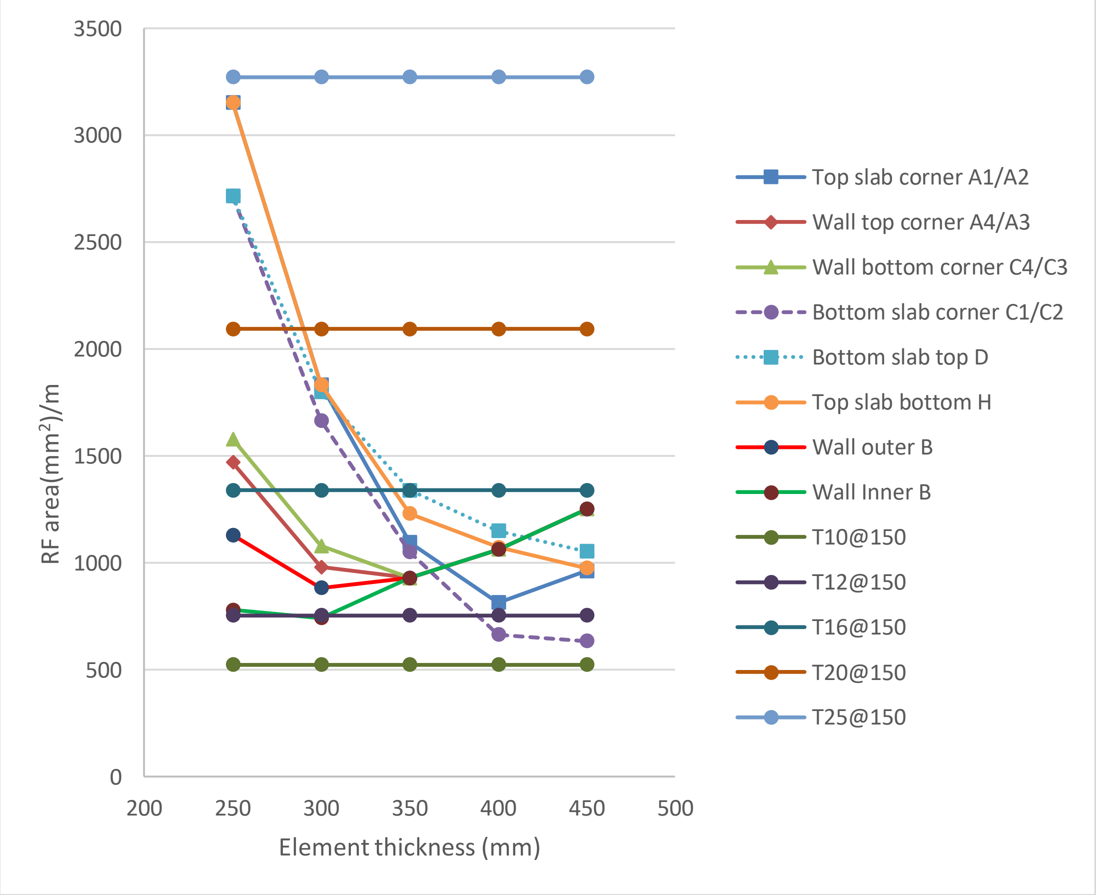


Figure 33: Box culvert 2.0mx2.0m with 10m fill

4.2.3 Box culvert of 3.0 m x 3.0 m

4.2.3.1 Soil fill 0.5m

Input data for the numerical model

W =3.0 m H =3.0 m H’ =0.5 m

B.C =100 kN/m^2

t =250, 300, 350, 400, 450 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

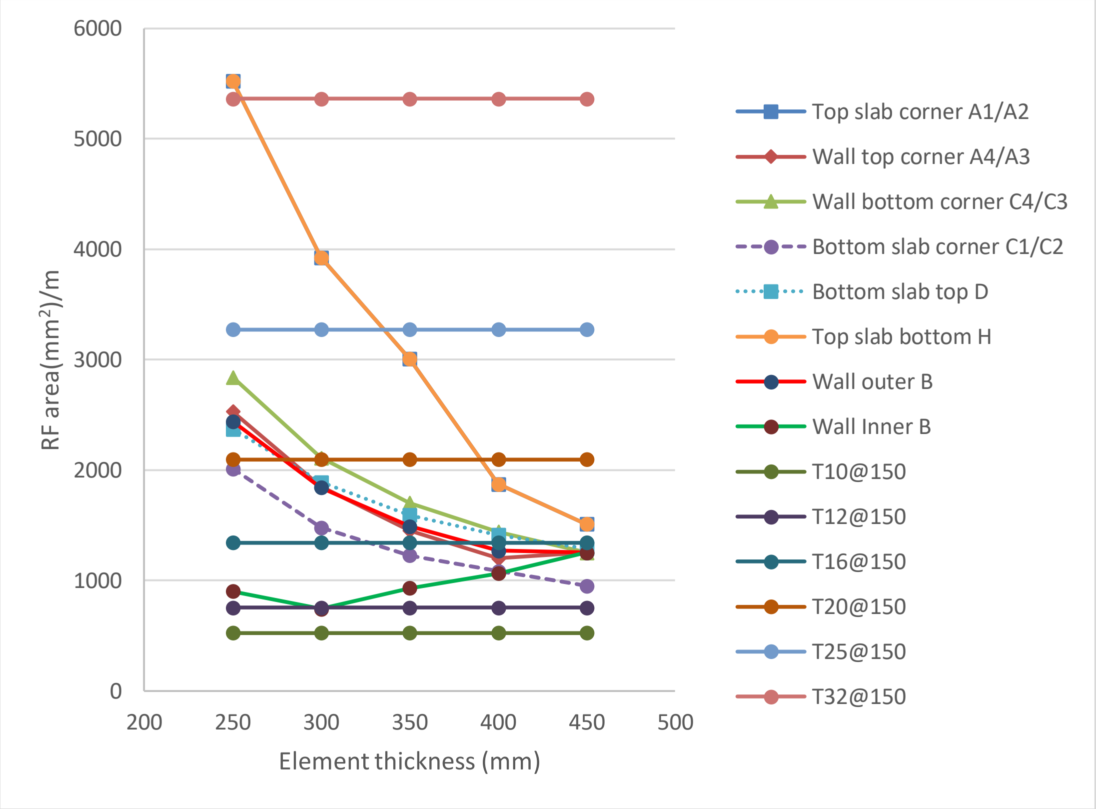


Figure 34: Box culvert 3.0mx3.0m with 0.5m fill

4.2.3.2 Soil fill 1.0m

Input data for the numerical model

W =3.0 m H =3.0 m H’ =1 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

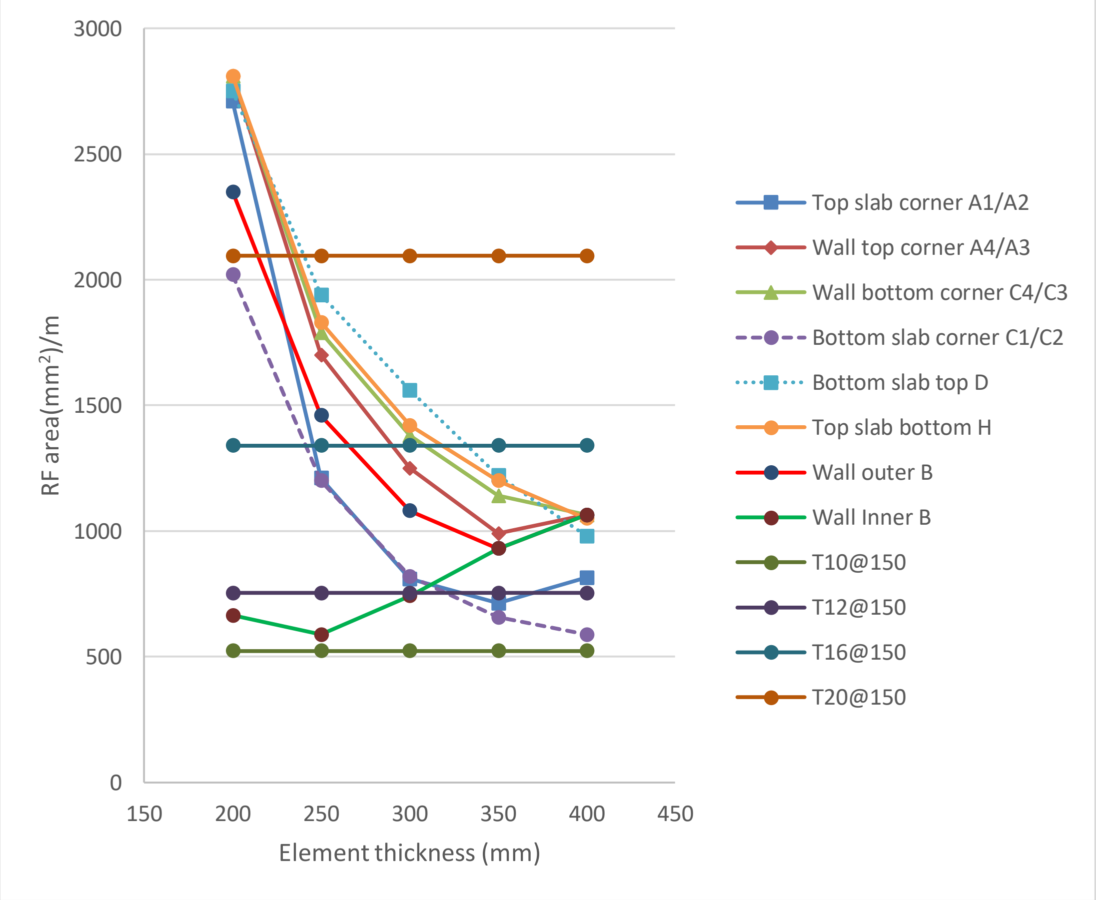


Figure 35: Box culvert 3.0mx3.0m with 1m fill

4.2.3.3 Soil fill 2.0m

Input data for the numerical model

W =3.0 m H =3.0 m H' =2 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

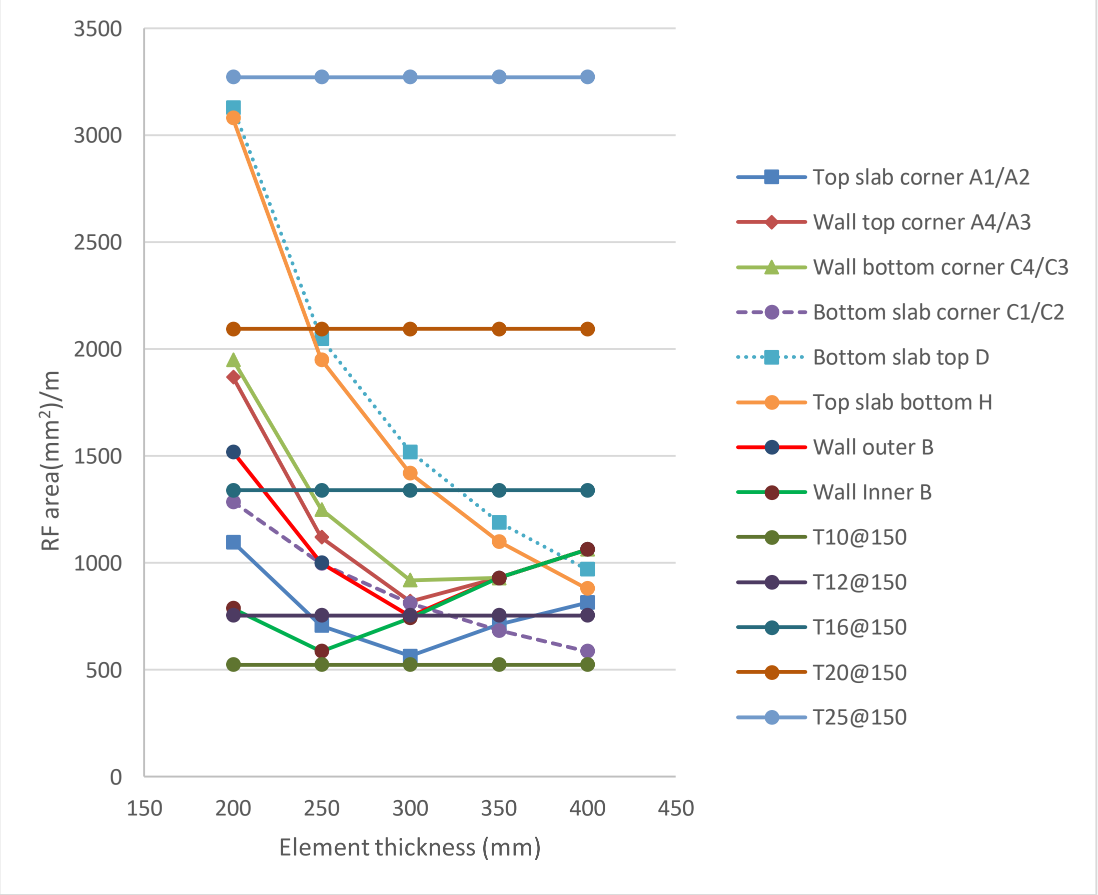


Figure 36: Box culvert 3.0mx3.0m with 2m fill

4.2.3.4 Soil fill 4.0m

Input data for the numerical model

W =3.0 m H =3.0 m H’ =4 m

B.C =100 kN/m^2

t =200, 250, 300, 350, 400 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

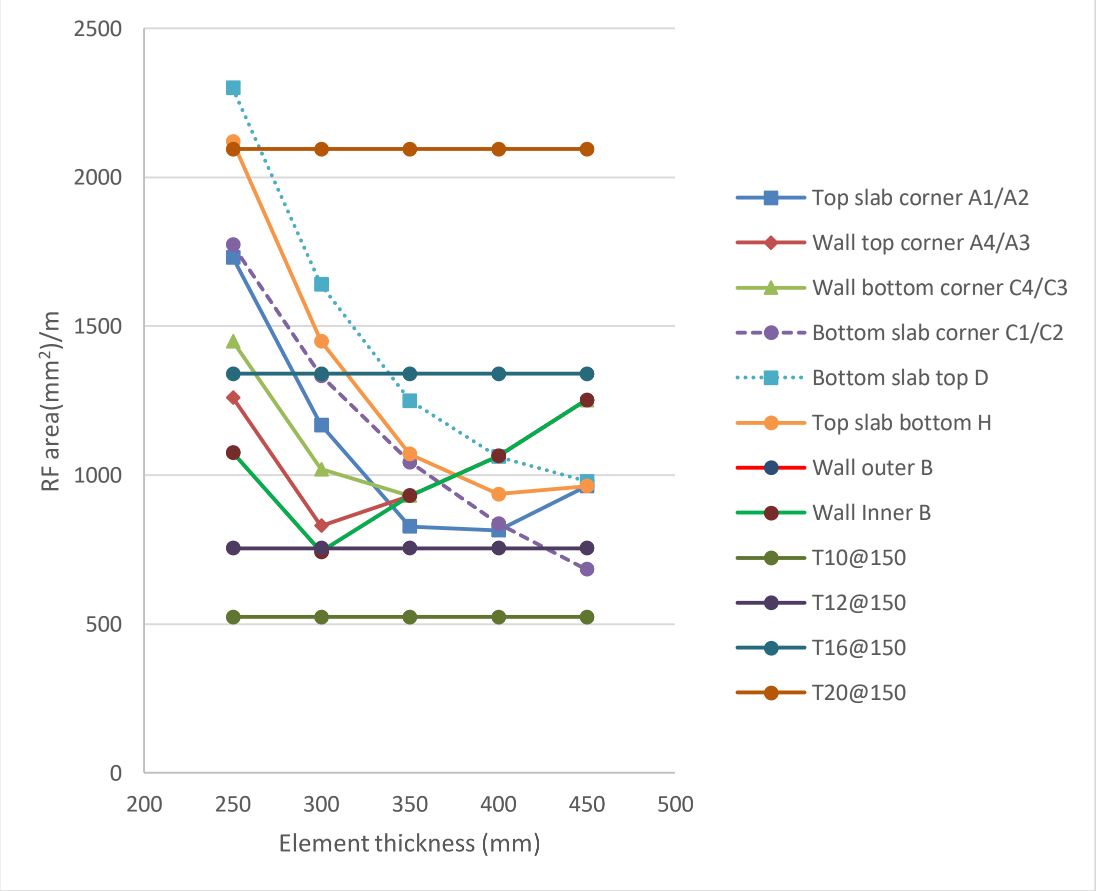


Figure 37: Box culvert 3.0mx3.0m with 4m fill

4.2.3.5 Soil fill 6.0m

Input data for the numerical model

W =3.0 m H =3.0 m H' =6 m

B.C =100 kN/m^2

t =250, 300, 350, 400, 450 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

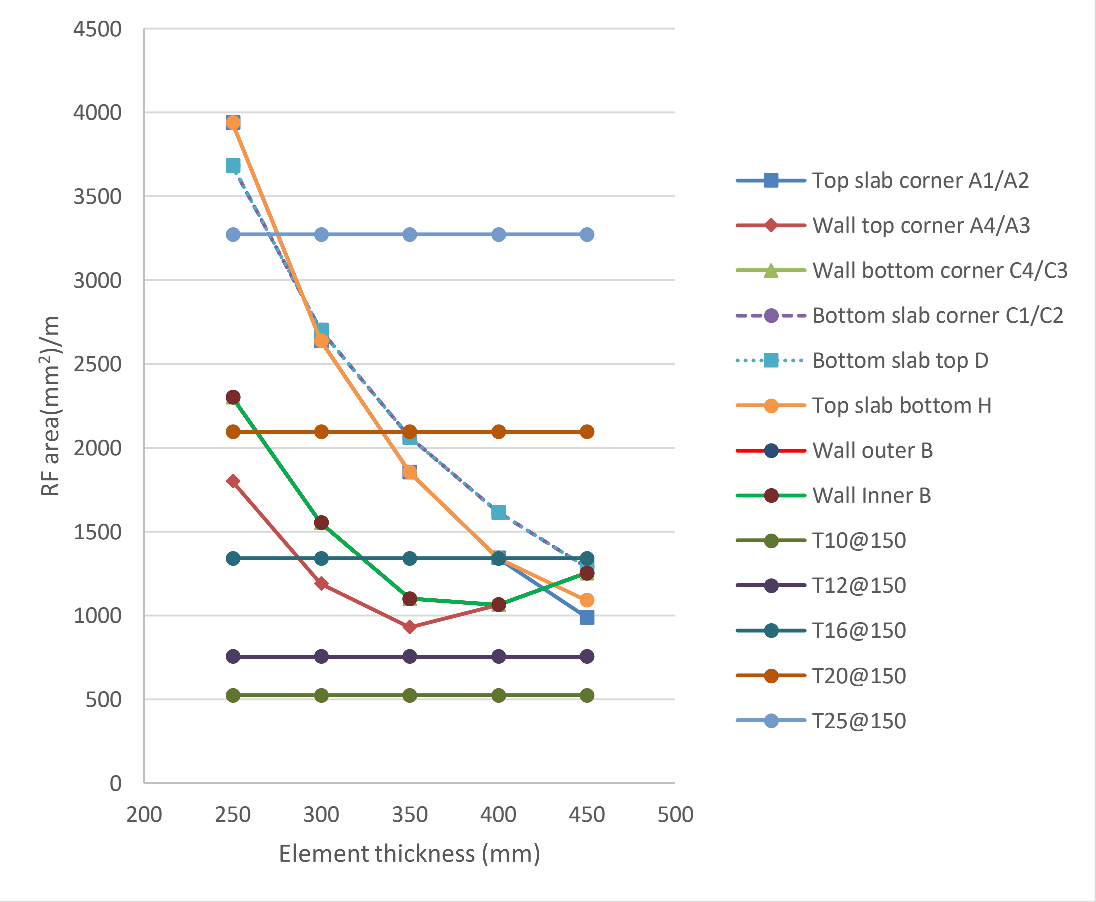


Figure 38: Box culvert 3.0mx3.0m with 6m fill

4.2.3.6 Soil fill 8.0m

Input data for the numerical model

W =3.0 m H =3.0 m H' =8 m

B.C =100 kN/m^2

t =300, 350, 400, 450, 500 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

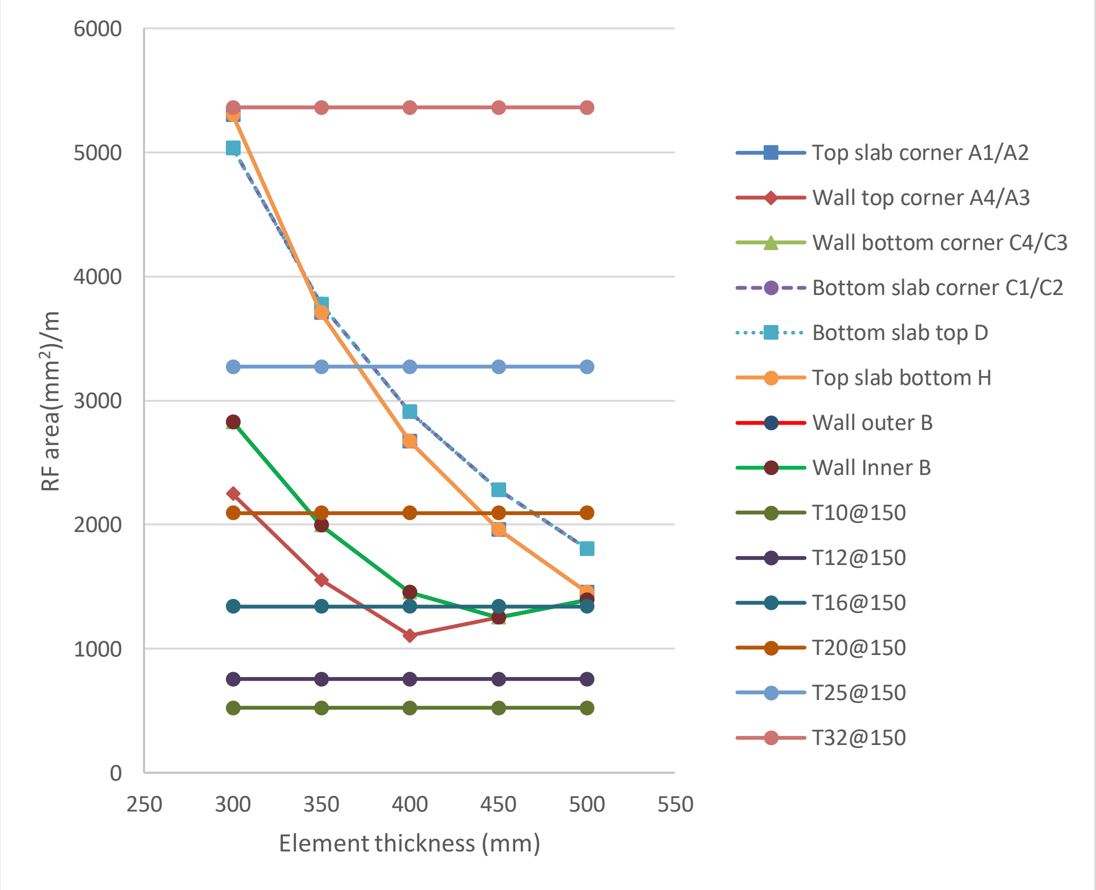


Figure 39: Box culvert 3.0mx3.0m with 8m fill

4.2.3.7 Soil fill 10.0m

Input data for the numerical model

W =3.0 m H =3.0 m H’ =10 m

B.C =100 kN/m^2

t =350, 400, 450, 500, 550 mm

Output from numerical model

Refer Appendix C3

Data interpretation

Amount of reinforcement requirement for each location can be plotted against thickness of the section

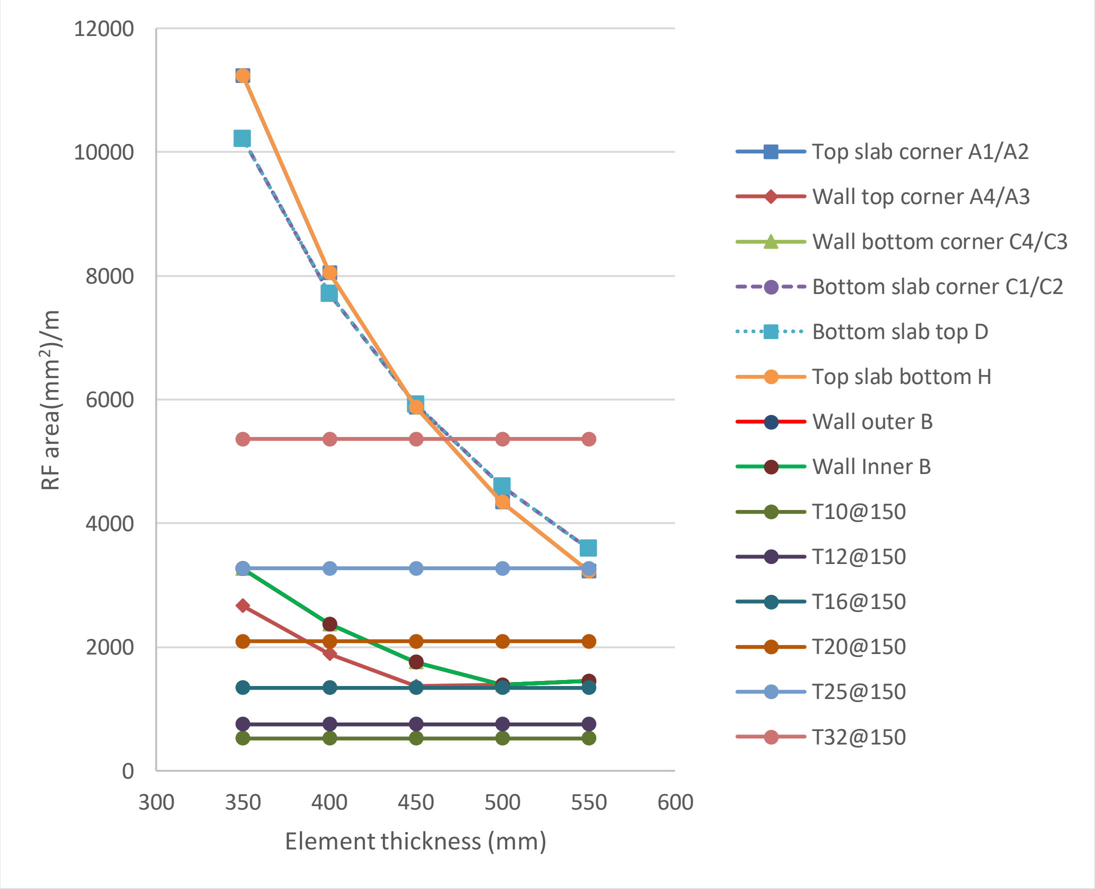


Figure 40: Box culvert 3.0mx3.0m with 10m fill

4.3 Optimum thickness of box culvert

From the analysis done in 4.2 it can be identified optimum thickness range (exact thickness depend on reinforcement to concrete cost ratio) and reported in Table 9, Table 10 and Table 11

Table 9: Optimum thicknesses for 1.5mx1.5m box culvert

Fill height (H') m	Optimum Thickness(t_o) mm	W/t
0.5	250-300	5.0- 6.0
1	250	6.0
2	200-250	6.0- 7.5
4	200-250	6.0- 7.5
6	250	6.0
8	250-300	5.0- 6.0
10	250-300	5.0- 6.0

Table 10: Optimum thicknesses for 2.0mx2.0m box culvert

Fill height (H') m	Optimum Thickness(t_o) mm	W/t
0.5	300-350	6.7 - 5.7
1	300	6.7
2	250-300	8.0 - 6.7
4	250-300	8.0 - 6.7
6	250-300	8.0 - 6.7
8	300-350	6.7 - 5.7
10	350	5.7

Table 11: Optimum thicknesses for 3.0mx3.0m box culvert

Fill height (H') m	Optimum Thickness(t_o) mm	W/t
0.5	350-400	8.6 - 7.5
1	350	8.6
2	300-350	10-8.6
4	350	8.6
6	350	8.6
8	400	7.5
10	500	6.0

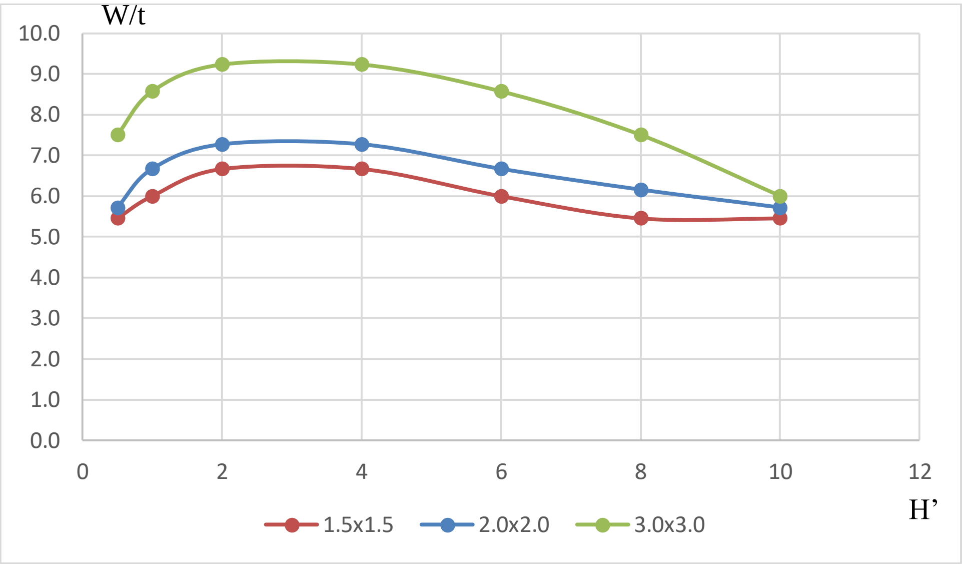


Figure 41: Variation of optimum width to thickness (W/t) ratio against soil cover thickness H’

It is not possible to identify constant W/t ratio for optimum thickness of the box culvert but it vary largely

For 1.5 x 1.5 optimum W/t ratio vary between 5.0 and 7.5

For 2.0 x 2.0 optimum W/t ratio vary between 5.7 and 8.0

For 3.0 x 3.0 optimum W/t ratio vary between 6.0 and 10.0

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

First objective of the research is to investigate the sensitivity of internal forces in the element of box culvert to the bearing capacity used for the analysis

For t/W ratio< 1/20 top slab bending moment is less sensitive and bottom slab bending moment is much sensitive to bearing capacity of ground

For t/W ratio > 1/10 top slab bending moment is not sensitive and bottom slab bending moment is less sensitive to bearing capacity of ground and also bending moment inversely proportional to bearing capacity of ground

Second objective is to develop standard chart including member thickness and reinforcement for different sizes and fill height given on section 4.2(See 5.3, for the procedure to follow the proposed design chart)

Third objective is to find optimum thickness for box culvert for different sizes and thicknesses, given in 4.3

5.2 Recommendation for future research

- Need to develop standard chart for box sizes greater than 3x3
- Need to develop standard chart for multi cell boxes
- Need to study the capability of optimization using different thickness for different members

5.3 How to follow proposed design chart

Step 1: Select correspond chart for the specific culvert size depending on internal dimension and fill height

Example: Height =2.0m

Width =2.0m

Fill height =2.0m

For this example corresponding chart is in page no 38

In the chart horizontal axis is element thickness and vertical axis is reinforcement area per unit length

Horizontal line represent possible arrangement of reinforcement (i.e T16@150)

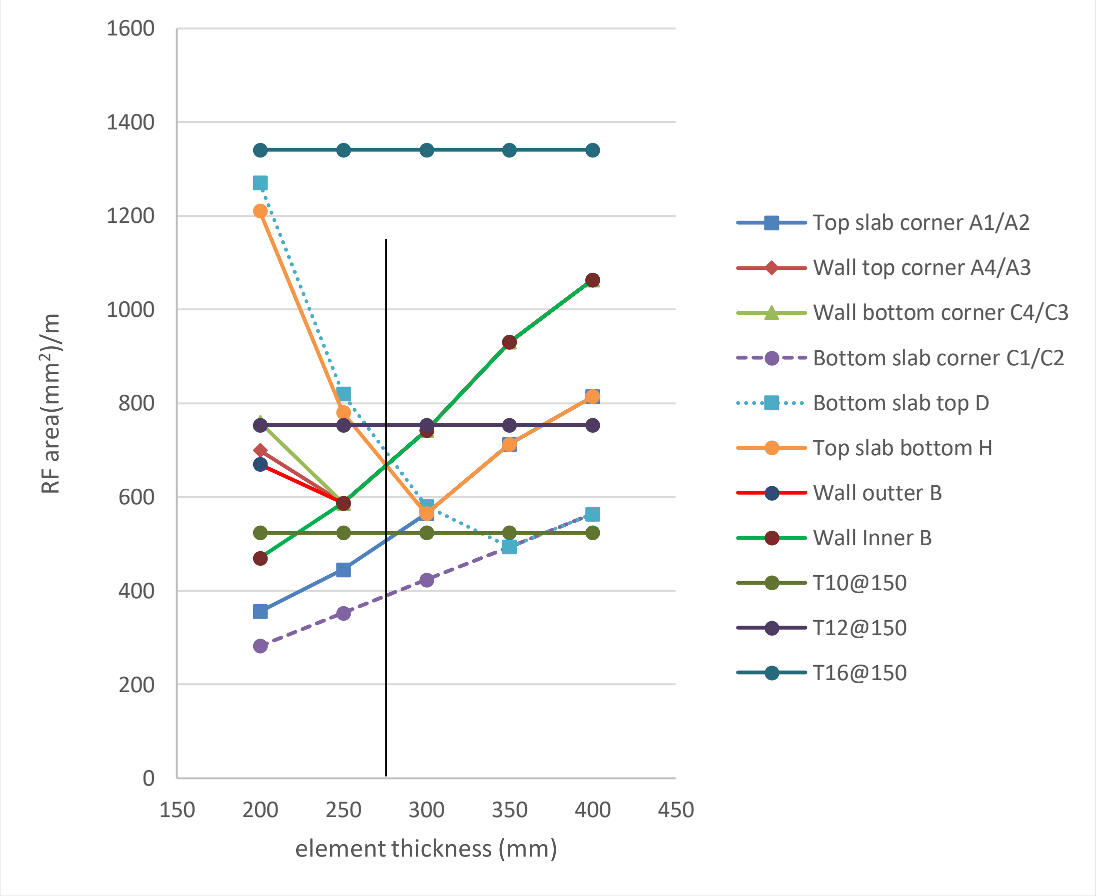
Curve represent the amount of reinforcement required depending on design requirement

Step 2: Select thickness

Example: According to design chart it can be identified optimum thickness is between 250mm and 300mm

Therefor select thickness as 275mm (if you have predetermined thickness use it)

Step 3: Find RF for each element and each location



Draw a vertical line at 275mm thickness

Find the possible reinforcement arrangement for each location. In this example

Top slab top corner = T10@150

Bottom slab bottom corner = T10@150

Wall top corner outer = T12@150

Wall top bottom outer = T12@150

Wall inner/outer at mid height = T12@150

Bottom slab top = T12@150

Top slab bottom mid = T12@150

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APPENDIX A - USAGE OF OAPI FOR THE STUDY

OAPI facility given in SAP2000 allows 3rd party software to create models, run analysis and extract analysis results by using specific set of commands given in SAP2000

In this project Microsoft Excel (EXCEL) together with Visual Basic (VB) use as 3rd party software

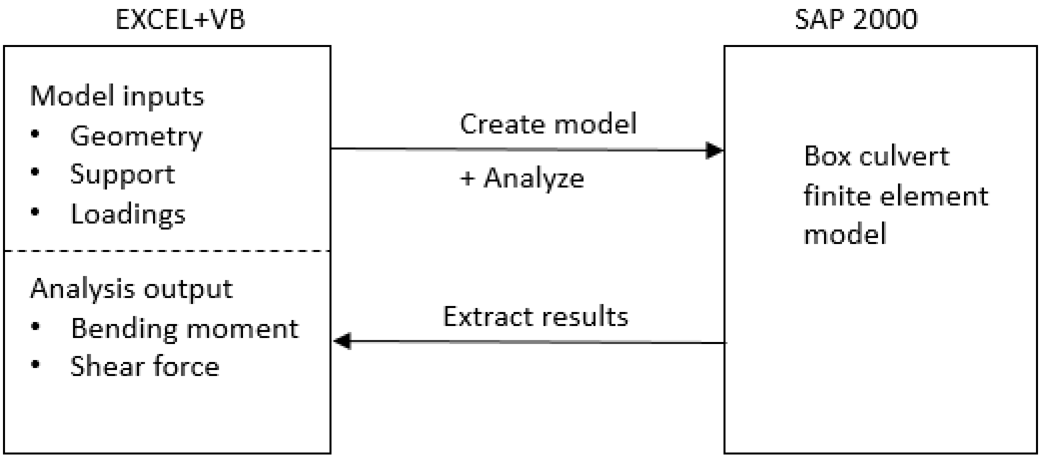


Figure A.1: Usage of OAPI

All the VB codes required to modelling analysis and extracting the results are given in CSi OAPI Documentation which is available in SAP2000 installed folder

APPENDIX B - ANALYSIS DETAILS

2D Model

2D model develop only for the cases which is traction force not apply ($H'>L_L$), to explain the modelling procedure use following example

W =3.0m

H =3.0m

H' =6.0m

t =0.3m

Soil unit weight (γ_s) = 18 kN/m^3

Road construction material unit weight (γ_r) = 23 kN/m^3

1.1 Model geometry details

Center to center width of culvert = internal width of culvert + slab thickness

= 3.0 +0.3

=3.3m

Center to center height of culvert = internal height of culvert + slab thickness

= 3.0 +0.3

=3.3m

1.2 Box culvert geometry modelling

Draw 3.3m height and 3.3m width box using frame element as shown in figure

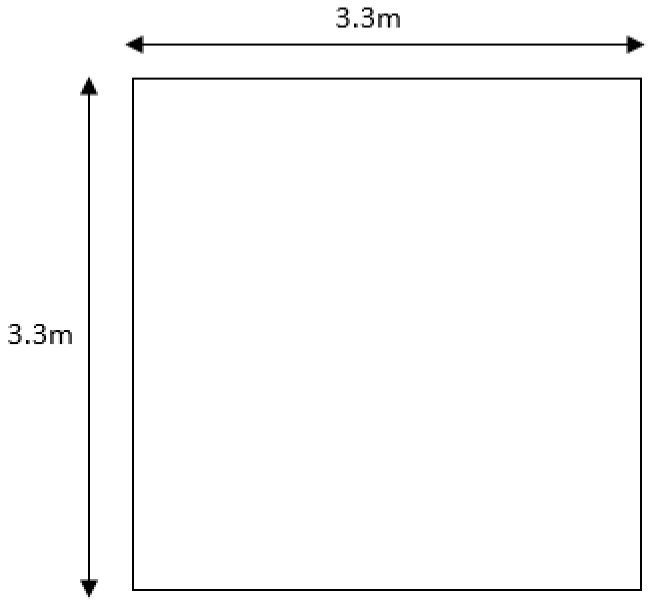


Figure B.1: Centerline model of box culvert

Frame mesh at main results interesting location as shown in figure 18 and figure 19 and further meshed as maximum element size is not more than 150mm

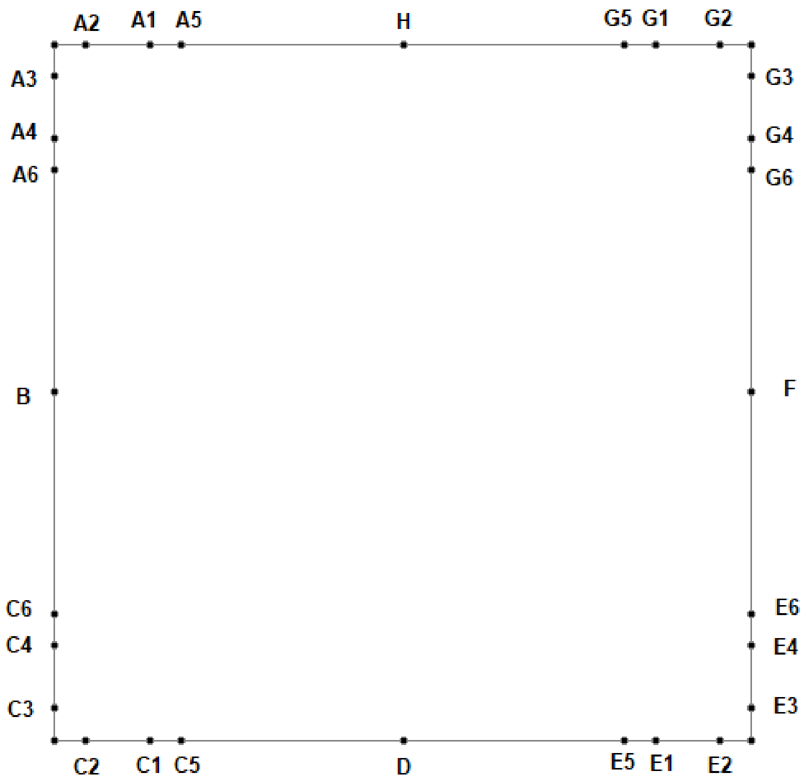


Figure B.2: FEM Mesh of box culvert

1.3 Define material property

For concrete G30

Strength = 30 N/mm^2

Elastic module = 28 kN/mm^2

Poisson's ration = 0.2

Coefficient of thermal expansion = 12x10^{-6}

1.4 Define section property

Stiff section inside the wall =2t =0.60m (height) x 1.0m (width)

Chamfer =1.5t =0.45m (height) x 1.0m (width)

Normal section =t =0.30m (height) x 1.0m (width)

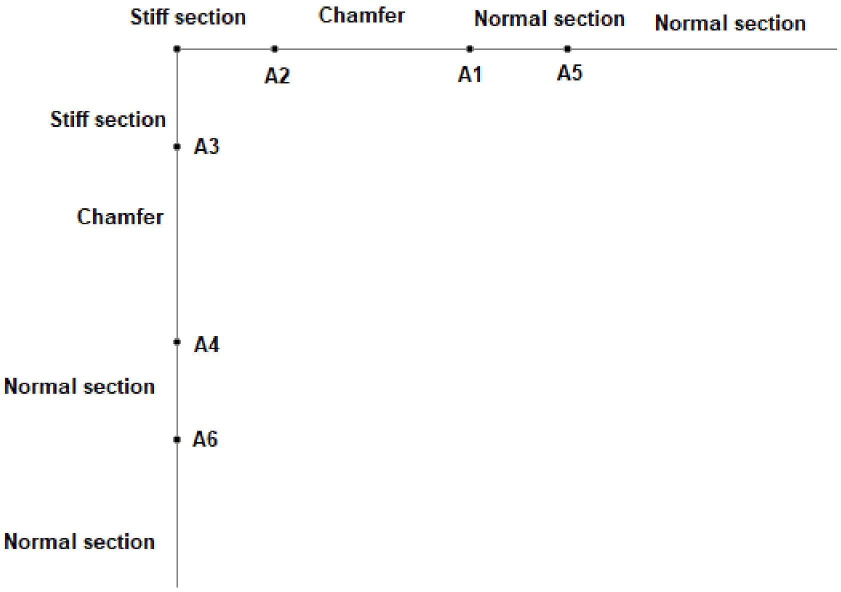


Figure B.3: Section property assignment

1.5 Support conditions

For bottom slab assign line spring

Soil subgrade module = 40 x F.O.S x Allowable bearing capacity

= 40 x 2.5 x 100

= 10000 kN/m^2/m

Line spring = 10000 x 1

= 10000 kN/m/m

1.6 Assign loads

Modelling step 6

Dead load –Self weight automatically generated by the software

Soil horizontal (k=1)

Soil load on top edge of wall = (H'+t/2-0.2) x γ_s+ 0.2 x γ_r

= (6+0.15-0.2) x 18+ 0.2 x 23

= 111.7 kN/m^2

Soil load on bottom edge of wall = (H'+H+1.5t-0.2) x γ_s+ 0.2 x γ_r

= (6+3+0.45-0.2) x 18+ 0.2 x 23

= 171.1 kN/m^2

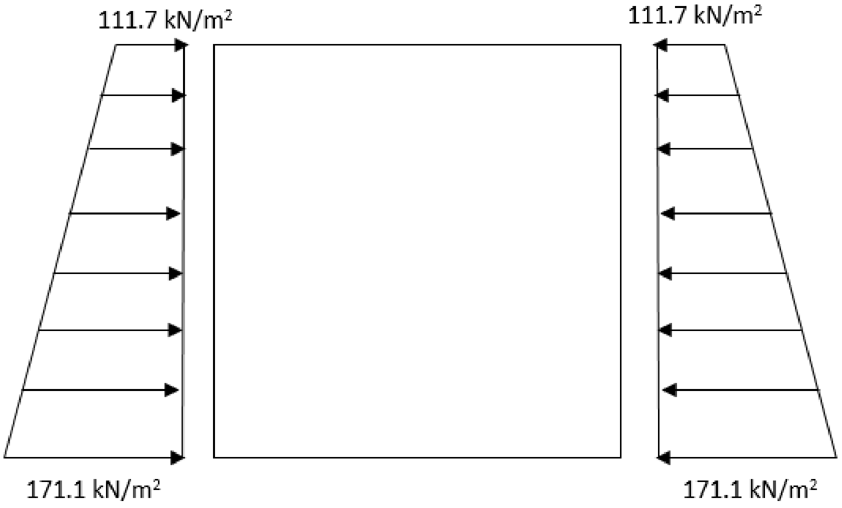


Figure B.4: Horizontal soil load on culvert

HA Surcharge (k=1) = 10 kN/m^2

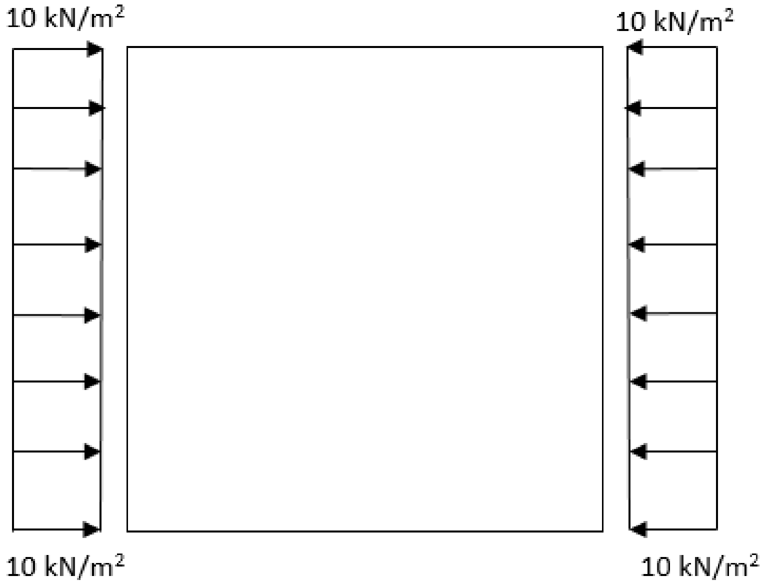


Figure B.5: Horizontal HA surcharge load on culvert

HB Surcharge (k=1) = 12 kN/m^2

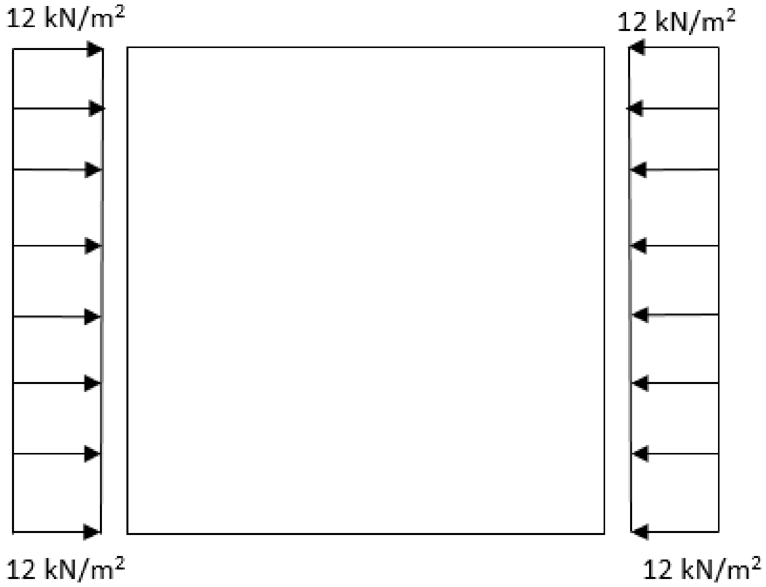


Figure B.6: Horizontal HB surcharge load on culvert

HB vertical load

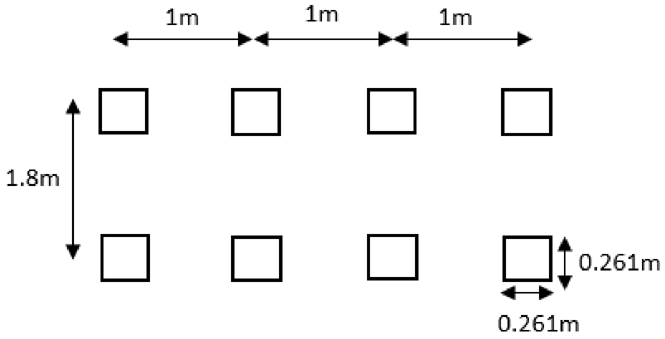


Figure B.7: Wheel arrangement of HB vehicle that load transfer on to culvert

Dispersion of wheel load through the fill is vertical 2 to horizontal 1, since fill height is 6m dispersion area of all wheel overlap therefore can consider as one unit

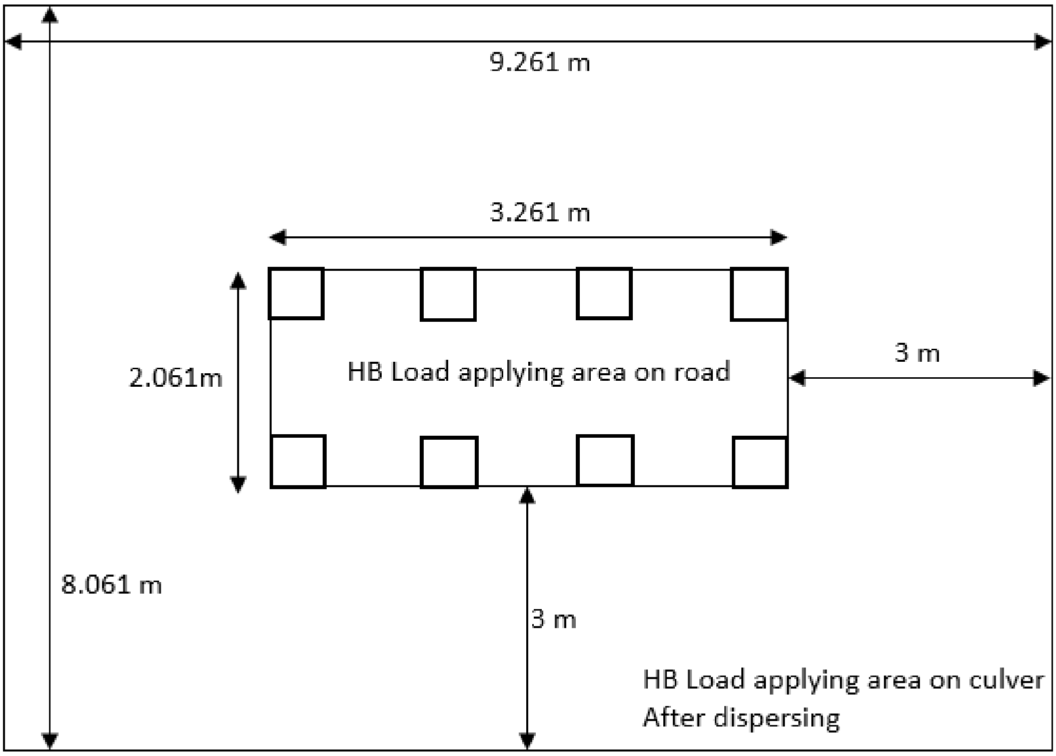


Figure B.8: Effective area of HB wheel on culvert top slab level

HB load by 8 wheels =75 x 8

=600 kN

HB Vertical load as a pressure =600 / (8.061 x 9.261)

=8.03kN/m^2

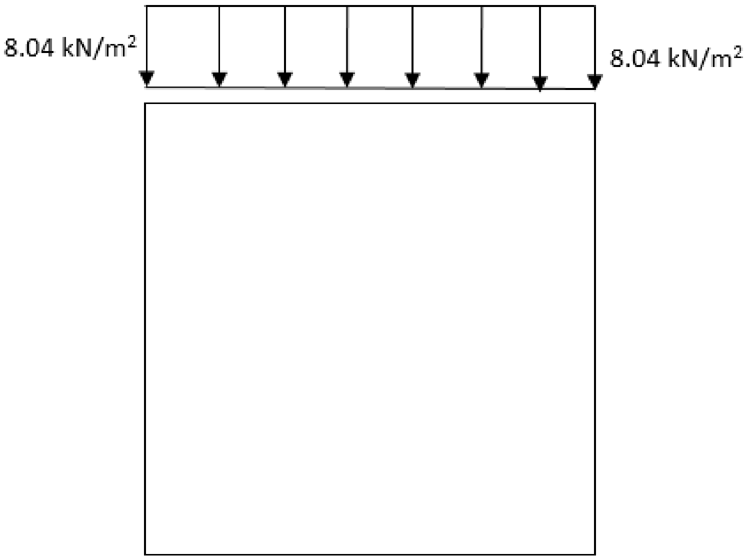


Figure B.9: HB vertical load on culvert

HA vertical load

Since fill height is greater than 0.6m HA load replaced by HB load value

Therefore

HA Vertical load as a pressure =8.03kN/m^2

SID load due to road construction material

SID load on top slab = 0.2 x γ_r = 0.2 x 23 = 4.6 kN/m^2

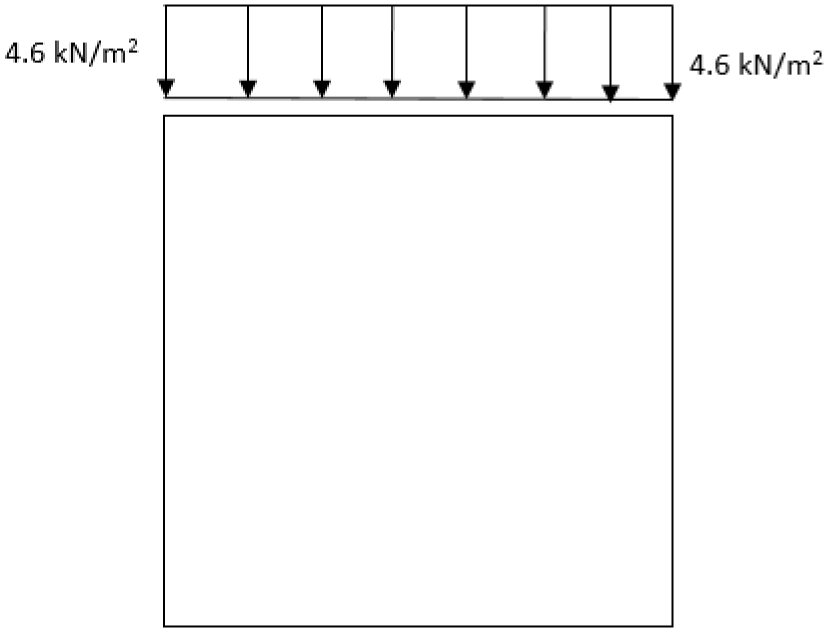


Figure B.10: SID road load on culvert

SID load due to soil fill

SID load on top slab = (H’-0.2) x γ_r = 5.8 x 18 = 104.4 kN/m^2

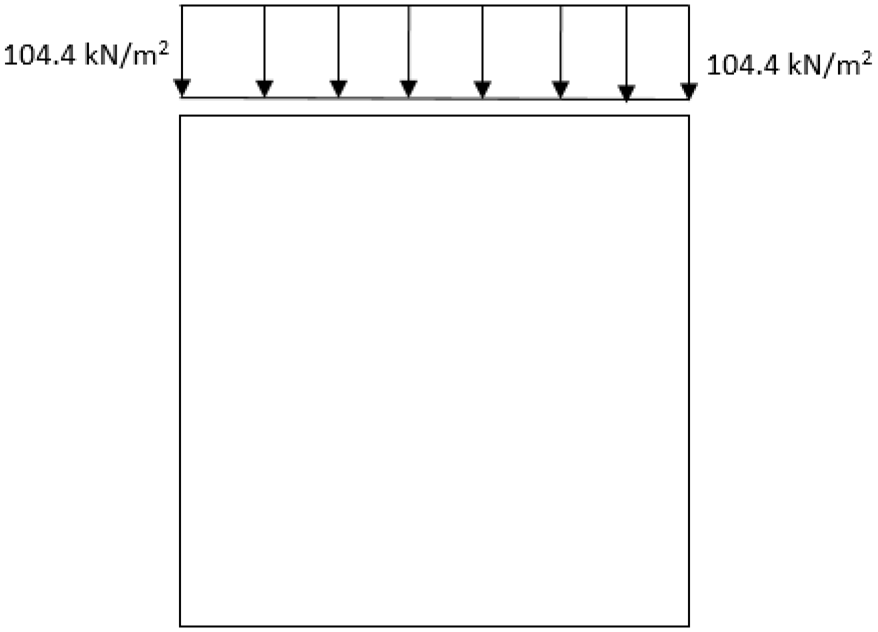
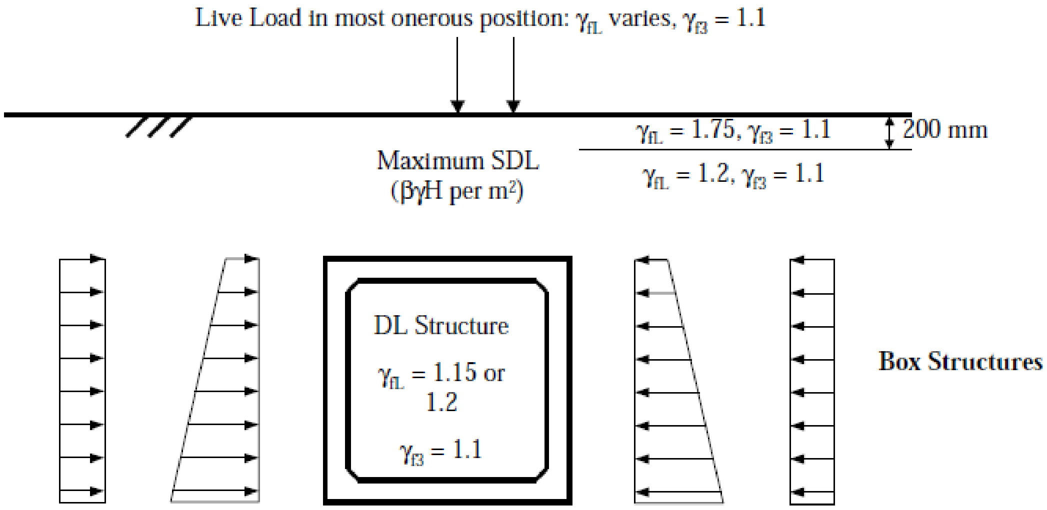


Figure B.11: SID soil load on culvert

1.7 Define Load combinations

Combination A1



LLSC	Earth		Earth	LLSC
K = 0.6 $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	K = 0.6 $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	Default values	K = 0.6 $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	K = 0.6 $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$
$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	BS 8002 coefficients	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$

Figure B.12: Combination A1

Combination A1 HA ULS

Name	factors notations	factors values	final load factor
DEAD	Υ_{fl} x Υ_{f3}	1.15 x 1.1	1.265
SID top 200	Υ_{fl} x Υ_{f3} x β	1.75 x 1.1 x 1.15	2.214
SID Soil	Υ_{fl} x Υ_{f3} x β	1.20 x 1.1 x 1.15	1.518
Soil horizontal	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA surcharge	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HB surcharge			
HA Vertical	Υ_{fl} x Υ_{f3}	1.50 x 1.1	1.650
HB Vertical			

Combination A1 HA SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.60
HA surcharge	ϒfl x Ko	1.00 x 0.60	0.60
HB surcharge			
HA Vertical	$ϒ_{fl}$	1.20	1.20
HB Vertical			

Combination A1 HB ULS

Name	factors notations	factors values	final load factor
DEAD	$ϒ_{fl}$ x $ϒ_{f3}$	1.15 x 1.1	1.265
SID top 200	$ϒ_{fl}$ x $ϒ_{f3}$ x β	1.75 x 1.1 x 1.15	2.214
SID Soil	$ϒ_{fl}$ x $ϒ_{f3}$ x β	1.20 x 1.1 x 1.15	1.518
Soil horizontal	$ϒ_{fl}$ x $ϒ_{f3}$ x K_o	1.50 x 1.1 x 0.60	0.990
HA surcharge			
HB surcharge	$ϒ_{fl}$ x $ϒ_{f3}$ x K_o	1.50 x 1.1 x 0.60	0.990
HA Vertical			
HB Vertical	$ϒ_{fl}$ x $ϒ_{f3}$	1.30 x 1.1	1.430

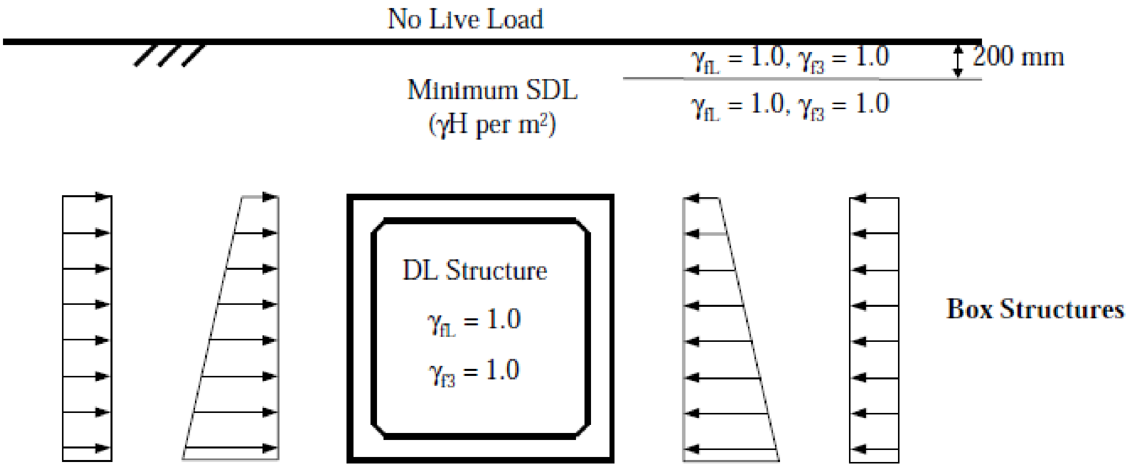
Combination A1 HB SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.6
HA surcharge			
HB surcharge	ϒfl x Ko	1.00 x 0.60	0.6
HA Vertical			
HB Vertical	$ϒ_{fl}$	1.10	1.10

Combination A1 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	Ɣfl	1.00	1.00
SID top 200	Ɣfl x β	1.20 x 1.15	1.38
SID Soil	Ɣfl x β	1.00 x 1.15	1.15
Soil horizontal	Ɣfl x Ko	1.00 x 0.60	0.60
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Combination A2



LLSC	Earth		Earth	LLSC
$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	Default values	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = 0.6$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$
$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	BS 8002 coefficients	$K = K_o$ $\gamma_{fL} = 1.2$ $\gamma_{f3} = 1.1$	$K = K_o$ $\gamma_{fL} = 1.5$ $\gamma_{f3} = 1.1$

Figure B.13: Combination A2

Combination A2 HB ULS

Name	factors notations	factors values	final load factor
DEAD	Υ_{fl} x Υ_{f3}	1.00 x 1.00	1.265
SID top 200	Υ_{fl} x Υ_{f3} x β	1.00 x 1.00 x 1.00	2.214
SID Soil	Υ_{fl} x Υ_{f3} x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA surcharge			
HB surcharge	Υ_{fl} x Υ_{f3} x K_o	1.50 x 1.1 x 0.60	0.990
HA Vertical			
HB Vertical			

Combination A2 HB SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00 x 1.00	1.265
SID top 200	ϒfl x β	1.00 x 1.00 x 1.00	2.214
SID Soil	ϒfl x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.6
HA surcharge			
HB surcharge	ϒfl x Ko	1.00 x 0.60	0.6
HA Vertical			
HB Vertical			

Combination A2 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00 x 1.00	1.265
SID top 200	ϒfl x β	1.00 x 1.00 x 1.00	2.214
SID Soil	ϒfl x β	1.00 x 1.00 x 1.00	1.518
Soil horizontal	ϒfl x Ko	1.00 x 0.60	0.6
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Combination A3

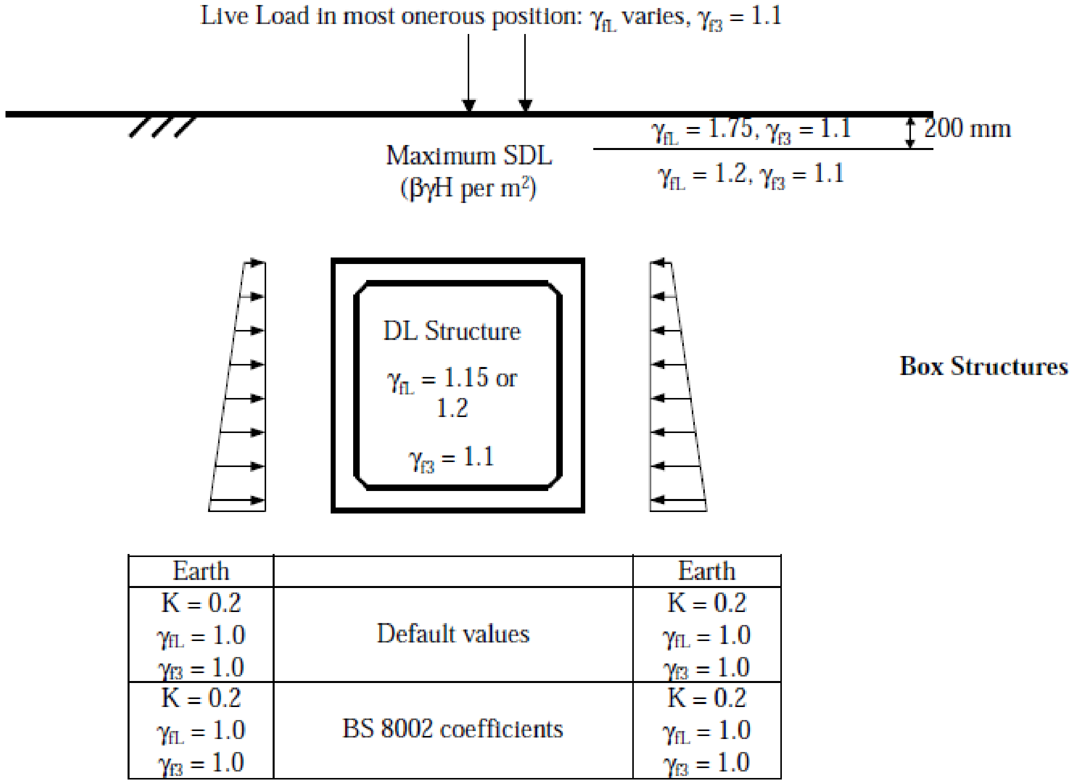


Figure B.14: Combination A3

Combination A3 HA ULS

Name	factors notations	factors values	final load factor
DEAD	γ_{fl} x γ_{f3}	1.15 x 1.1	1.265
SID top 200	γ_{fl} x γ_{f3} x β	1.75 x 1.10 x 1.15	2.214
SID Soil	γ_{fl} x γ_{f3} x β	1.20 x 1.10 x 1.15	1.518
Soil horizontal	γ_{fl} x γ_{f3} x K_o	1.00 x 1.00 x 0.20	0.200
HA surcharge			
HB surcharge			
HA Vertical	γ_{fl} x γ_{f3}	1.50 x 1.1	1.650
HB Vertical			

Combination A3 HA SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical	Υ_{fl}	1.20	1.20
HB Vertical			

Combination A3 HB ULS

Name	factors notations	factors values	final load factor
DEAD	Υ_{fl} x Υ_{f3}	1.15 x 1.1	1.265
SID top 200	Υ_{fl} x Υ_{f3} x β	1.75 x 1.1 x 1.15	2.214
SID Soil	Υ_{fl} x Υ_{f3} x β	1.20 x 1.1 x 1.15	1.518
Soil horizontal	Υ_{fl} x Υ_{f3} x K_o	1.00 x 1.00 x 0.20	0.200
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical	Υ_{fl} x Υ_{f3}	1.30 x 1.1	1.430

Combination A3 HB SLS

Name	factors notations	factors values	final load factor
DEAD	ϒfl	1.00	1.00
SID top 200	ϒfl x β	1.20 x 1.15	1.38
SID Soil	ϒfl x β	1.00 x 1.15	1.15
Soil horizontal	ϒfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical	Υ_{fl}	1.10	1.10

Combination A3 SLS Permanent

Name	factors notations	factors values	final load factor
DEAD	Ɣfl	1.00	1.00
SID top 200	Ɣfl x β	1.20 x 1.15	1.38
SID Soil	Ɣfl x β	1.00 x 1.15	1.15
Soil horizontal	Ɣfl x Ko	1.00 x 0.20	0.20
HA surcharge			
HB surcharge			
HA Vertical			
HB Vertical			

Create envelope for ULS, SLS and SLS permanent load combinations

Appendix C -(1.5X1.5)

																		outter T			inner T																				
		A1	**A5**	**A1**	**A1**	**A4**	**A6**	**A4**	**A4**	**C4**	**C6**	**C4**	**C4**	**C1**	**C5**	**C1**	**C1**	**B**	**B**	**B**	**B**	**B**	**B**	**H**	**H**	**H**	**D**	**D**	**D**	**A2**	**A2**	**A2**	**A3**	**A3**	**A3**	**C3**	**C3**	**C3**	**C2**	**C2**	**C2**
fill height	**thickness**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**
0.5	200	32	153	22	1	50	27	35	2	50	33	35	4	38	120	26	1	38	26	3	15	10	0	56	41	4	49	34	5	58	41	3	63	44	3	64	45	6	59	40	5
0.5	**250**	26	136	18	0	49	25	35	3	49	31	34	5	34	117	23	0	38	26	4	13	8	0	58	42	4	50	35	7	57	40	3	65	46	4	67	46	7	59	40	6
0.5	300	21	129	15	0	48	23	34	3	48	32	34	6	31	117	20	0	37	26	5	10	6	0	61	44	5	54	36	8	56	40	2	66	47	4	70	49	8	61	41	6
0.5	350	17	128	11	0	48	20	33	4	47	30	33	7	26	112	16	0	38	28	6	8	4	1	63	45	6	56	38	10	55	39	2	68	48	4	72	50	10	60	41	7
0.5	**400**	13	125	8	0	47	17	33	5	46	29	33	8	21	109	11	0	40	29	7	5	2	2	65	47	7	60	41	11	53	38	2	69	49	5	75	52	11	61	41	7
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1	**200**	20	72	14	1	28	22	19	4	27	18	18	5	21	66	12	1	20	13	4	8	4	0	25	18	6	26	17	7	38	26	4	37	25	5	36	24	8	33	21	7
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1	300	12	63	7	0	28	15	18	5	27	17	18	7	18	68	9	0	19	13	6	6	2	0	28	20	7	29	19	10	33	23	4	40	27	6	41	28	10	37	23	8
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2	150	7	36	4	3	14	21	10	6	16	22	12	7	8	39	4	3	14	10	6	8	2	1	22	16	9	23	17	10	16	10	7	19	13	8	21	15	10	18	12	9
2	**200**	6	32	2	1	16	18	11	6	18	20	13	8	7	37	3	2	16	11	7	7	2	0	24	17	10	26	19	11	15	10	7	20	14	9	23	17	11	18	12	9
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2	**350**	2	22	2	0	20	9	15	9	24	14	17	12	2	31	3	0	22	16	10	7	0	0	30	21	13	34	25	16	13	8	6	24	16	10	31	22	16	19	13	10
4	200	9	45	3	2	19	31	14	12	22	33	16	14	9	45	4	2	17	12	10	10	1	0	29	21	17	31	22	19	23	15	13	27	19	16	30	21	19	26	17	15
4	**250**	7	39	1	0	21	27	15	13	24	29	17	15	7	41	1	0	20	14	12	9	0	0	31	22	19	34	24	21	23	15	13	28	20	17	32	23	20	26	17	15
4	300	5	33	0	0	23	22	16	14	26	25	19	16	5	36	0	0	22	15	13	9	0	0	33	24	20	37	27	23	22	14	12	29	21	18	34	25	22	26	17	16
4	350	3	26	0	0	24	17	17	15	28	21	20	18	2	30	0	0	24	17	15	9	0	0	35	25	22	40	29	26	21	13	12	30	22	19	36	27	24	26	17	15
4	**400**	1	20	0	0	26	12	19	16	30	17	22	19	0	23	0	0	27	19	16	9	0	0	38	27	23	44	32	28	21	12	11	31	22	19	38	29	25	26	17	15
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6	**250**	9	51	0	0	27	36	20	19	30	39	22	21	9	52	0	0	25	17	16	12	0	0	40	29	27	43	31	29	31	20	18	37	27	25	41	30	28	34	23	21
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6	**400**	1	26	0	0	33	16	24	22	37	22	27	25	0	28	0	0	34	24	22	11	0	0	48	35	33	55	40	38	28	17	16	40	30	28	47	35	34	33	21	20
8	200	15	75	5	4	32	54	24	23	34	55	25	24	15	72	5	4	28	19	19	15	0	0	47	34	33	50	36	35	40	26	25	45	32	31	48	35	33	42	28	27
8	**250**	11	64	0	0	34	46	25	24	37	48	27	26	11	64	0	0	31	22	21	14	0	0	50	36	35	53	39	38	39	26	24	47	34	32	51	37	36	43	28	27
8	300	7	54	0	0	37	38	26	26	40	41	29	28	7	55	0	0	35	24	24	14	0	0	53	38	37	57	42	40	39	25	23	48	35	34	53	39	38	43	28	26
8	350	4	43	0	0	39	29	28	27	42	34	31	30	2	45	0	0	38	27	26	14	0	0	56	41	40	62	45	44	38	24	22	49	36	35	55	41	40	42	27	26
8	**400**	0	32	0	0	41	21	30	29	45	26	32	32	0	34	0	0	41	29	28	14	0	0	60	43	42	67	49	48	36	22	21	50	37	36	57	43	42	41	26	24
10	200	17	109	6	4	48	65	35	35	49	66	37	36	18	103	6	5	42	30	29	17	0	0	70	51	50	72	53	52	52	35	33	64	46	45	66	48	47	54	36	35
10	**250**	13	94	0	0	51	55	37	37	53	58	39	39	13	90	0	0	47	33	33	17	0	0	73	54	53	77	56	55	51	34	32	66	48	47	69	51	50	54	36	34
10	300	9	78	0	0	54	46	39	39	57	49	42	41	8	76	0	0	51	36	36	16	0	0	77	56	56	82	60	59	50	32	31	68	50	49	73	54	53	53	35	34
10	350	4	62	0	0	57	36	41	41	61	40	44	44	2	62	0	0	56	39	39	16	0	0	82	60	59	87	64	63	48	30	29	70	52	51	76	56	55	52	34	32
10	**400**	0	46	0	0	61	26	44	43	64	31	46	46	0	47	0	0	60	42	42	16	0	0	87	63	63	94	69	68	45	28	27	72	53	52	78	59	58	49	31	30
12	200	20	150	6	5	66	76	49	49	68	77	50	50	21	140	6	5	60	42	42	20	0	0	97	71	71	100	73	73	66	44	43	85	62	61	87	63	62	68	46	44
12	**250**	15	129	0	0	71	65	52	52	73	67	54	53	15	122	0	0	66	47	47	19	0	0	102	75	74	105	78	77	64	43	41	89	65	64	92	67	67	67	45	43
12	300	10	108	0	0	75	54	55	55	78	57	57	57	9	103	0	0	72	51	51	19	0	0	107	79	78	112	82	82	62	40	39	92	68	67	96	71	70	65	43	41
12	350	5	86	0	0	80	42	58	58	83	46	60	60	3	83	0	0	77	55	55	18	0	0	113	83	83	119	88	87	59	38	36	95	70	69	100	75	74	62	40	39
12	**400**	0	64	0	0	84	31	61	61	87	35	64	63	0	63	0	0	83	59	59	19	0	0	119	88	87	127	94	94	55	34	33	98	73	72	104	78	77	58	37	36

Appenndix C(2.0X2.0)

outter T inner T

		A1	A5	A1	A1	A4	A6	A4	A4	C4	C6	C4	C4	C1	C5	C1	C1	B	B	B	B	B	B	H	H	H	D	D	D	A2	A2	A2	A3	A3	A3	C3	C3	C3	C2	C2	C2
fill height	**thickness**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**
0.5	200	51	191	35	3	68	38	47	4	74	48	51	7	60	133	39	4	58	40	5	29	19	2	75	54	6	68	45	9	79	55	6	83	58	6	92	63	10	86	57	10
0.5	**250**	44	178	31	2	67	35	46	4	73	46	50	8	54	134	35	3	57	40	7	27	17	1	79	57	7	69	47	10	78	54	6	85	59	6	95	65	12	87	58	11
0.5	300	39	180	27	1	66	33	45	5	72	46	50	10	51	138	33	2	57	40	8	24	15	1	84	60	8	73	49	12	78	54	5	87	60	7	99	68	14	90	60	12
0.5	350	33	155	23	0	65	29	44	6	71	45	50	11	46	138	28	0	56	40	10	21	13	0	82	59	9	75	51	15	75	52	5	87	61	7	102	70	16	90	60	13
0.5	**400**	28	152	18	0	63	26	43	7	70	45	49	13	41	140	24	0	56	40	11	19	10	0	83	60	11	78	53	17	74	52	5	88	61	8	106	73	19	92	61	14
1	200	31	89	21	3	43	33	28	6	43	34	28	9	36	84	21	5	34	22	7	16	8	2	38	27	9	38	25	12	50	34	8	53	36	9	54	35	13	52	32	12
1	**250**	27	88	18	2	43	31	28	7	44	34	29	11	35	90	19	4	34	23	9	16	7	1	40	29	10	42	28	14	50	34	8	55	37	10	60	39	15	56	35	13
1	300	24	87	15	1	42	28	27	7	45	32	30	12	32	92	17	2	35	23	10	14	6	0	42	30	12	45	31	16	50	34	8	57	39	10	64	41	17	58	36	14
1	350	20	84	12	0	42	25	27	8	45	31	30	14	29	92	13	0	35	24	12	13	5	0	44	32	13	46	33	18	50	34	8	59	40	11	67	44	20	59	36	15
1	**400**	17	84	9	0	42	22	27	9	46	30	31	16	25	93	10	0	36	25	14	11	3	0	47	34	15	50	36	21	49	33	7	61	41	11	72	47	22	61	37	16
2	200	13	63	7	5	28	37	19	11	31	40	22	14	15	72	8	7	27	19	12	15	4	2	40	29	16	43	31	19	29	19	13	35	24	15	40	28	19	34	23	17
2	**250**	12	60	5	3	30	34	20	11	33	38	24	15	14	73	6	5	30	22	13	14	4	1	42	30	17	46	34	21	29	19	13	38	25	16	45	31	22	35	24	18
2	300	10	58	3	1	31	31	21	12	36	36	26	17	12	73	4	2	33	24	15	14	2	0	45	32	19	50	36	23	28	18	13	41	26	17	50	34	24	37	25	19
2	350	9	55	1	0	32	28	23	13	39	34	28	19	10	73	1	0	37	26	17	13	1	0	47	34	20	54	39	26	27	18	13	43	28	17	54	36	26	39	25	20
2	**400**	7	51	0	0	34	24	24	14	42	32	31	21	7	72	0	0	40	29	19	13	0	0	50	37	22	59	43	29	27	17	12	46	29	18	59	39	29	40	26	21
4	200	20	86	10	8	33	62	24	20	36	66	27	23	22	86	12	10	28	19	16	19	4	1	49	35	30	52	38	32	42	28	24	47	33	28	51	36	32	47	31	28
4	**250**	17	80	7	5	34	57	25	21	39	62	29	25	19	83	8	6	31	21	18	19	3	0	51	37	31	56	40	35	42	28	24	48	34	29	55	39	34	48	32	29
4	300	15	74	4	2	36	52	26	22	42	58	31	27	16	79	4	2	34	24	20	18	1	0	54	39	33	60	43	38	42	27	23	50	35	30	58	42	37	50	33	30
4	350	12	68	0	0	39	47	28	24	46	54	33	29	13	75	0	0	38	26	22	17	0	0	57	41	35	64	47	41	41	26	23	51	37	31	62	45	40	51	34	30
4	**400**	9	61	0	0	41	42	30	25	49	50	36	31	9	71	0	0	41	29	25	17	0	0	60	43	37	69	50	44	41	26	22	53	38	33	65	48	43	51	34	30
6	200	26	113	14	12	43	83	32	30	46	88	34	32	28	110	15	13	36	24	23	24	3	1	64	46	43	67	49	46	56	38	35	62	44	41	66	47	44	61	41	38
6	**250**	23	105	9	7	45	77	33	31	50	82	37	35	24	105	10	8	40	27	25	23	2	0	67	48	45	71	52	49	56	37	34	64	45	42	70	51	47	63	42	39
6	300	19	97	4	2	48	70	35	32	53	76	39	37	20	100	5	3	44	30	28	22	0	0	70	51	47	76	55	52	56	37	34	66	47	44	74	54	51	64	43	40
6	350	15	89	0	0	50	64	36	34	57	70	42	39	16	94	0	0	48	33	31	22	0	0	73	53	50	81	59	55	56	36	33	68	49	45	78	57	54	65	43	40
6	**400**	11	80	0	0	53	57	38	36	61	65	44	42	11	87	0	0	52	36	34	21	0	0	77	56	52	86	63	59	55	35	32	69	50	47	81	60	57	65	43	40
8	200	33	143	17	15	54	105	41	39	57	109	43	41	35	137	18	16	45	30	30	29	3	0	81	59	57	83	61	59	71	48	45	79	56	53	83	59	57	76	51	48
8	**250**	28	133	11	9	57	97	42	41	62	102	46	44	30	130	12	10	49	34	33	28	1	0	84	61	59	88	64	62	72	47	45	81	58	55	87	63	60	78	52	49
8	300	23	122	5	3	60	88	44	42	66	94	48	47	24	123	5	3	54	37	36	27	0	0	88	64	62	93	68	66	71	47	44	83	60	57	91	66	64	79	52	50
8	350	18	112	0	0	63	80	46	44	70	87	51	50	19	115	0	0	59	41	40	26	0	0	92	66	64	99	72	70	71	46	43	85	61	59	95	70	67	80	53	50
8	**400**	13	101	0	0	66	71	48	46	74	79	54	53	13	106	0	0	64	44	43	25	0	0	96	70	68	105	77	75	70	44	42	87	63	61	99	73	71	80	52	50
10	250	34	193	13	11	84	116	62	61	88	121	65	64	35	184	14	12	74	52	51	32	0	0	123	90	89	128	94	92	94	63	60	113	81	79	118	86	84	99	67	64
10	**300**	28	178	5	3	88	107	65	64	94	112	69	68	29	172	6	4	80	56	56	31	0	0	128	94	93	134	98	97	93	61	59	116	84	82	124	90	88	100	67	64
10	350	22	162	0	0	92	97	68	67	99	103	73	72	22	159	0	0	87	61	61	30	0	0	133	98	96	141	104	102	91	60	57	119	87	85	129	95	93	100	66	64
10	400	16	146	0	0	97	86	71	70	105	94	77	76	14	146	0	0	93	66	65	29	0	0	139	102	101	149	109	108	89	58	55	122	90	88	134	99	97	99	65	63
10	**450**	10	130	0	0	102	76	74	73	110	85	80	79	7	132	0	0	99	70	70	29	0	0	146	107	105	157	116	114	87	55	52	125	92	90	139	104	102	98	64	61
12	300	32	244	6	4	122	125	90	90	128	130	95	94	33	232	6	4	113	80	80	35	0	0	178	131	130	184	135	135	116	78	75	155	113	112	163	119	118	123	83	81
12	**350**	25	222	0	0	128	113	95	94	135	119	100	99	25	214	0	0	121	86	86	34	0	0	185	136	135	192	142	141	114	75	73	160	117	116	170	125	123	122	82	79
12	400	18	200	0	0	135	101	99	98	142	108	104	104	16	195	0	0	129	93	92	34	0	0	192	142	141	202	149	148	110	72	69	165	121	120	176	131	129	120	79	77
12	450	11	178	0	0	141	89	103	103	149	97	109	109	8	176	0	0	137	99	98	33	0	0	201	148	147	212	157	156	106	68	66	169	125	123	182	136	134	117	76	74
12	**500**	4	155	0	0	148	77	107	107	156	86	114	113	0	155	0	0	145	104	104	33	0	0	209	154	153	224	166	165	102	64	62	173	128	127	188	141	140	113	73	70

Appendx C (3.0X3.0)

																		outer T			inner T																				
		A1	**A5**	**A1**	**A1**	**A4**	**A6**	**A4**	**A4**	**C4**	**C6**	**C4**	**C4**	**C1**	**C5**	**C1**	**C1**	**B**	**B**	**B**	**B**	**B**	**B**	**H**	**H**	**H**	**D**	**D**	**D**	**A2**	**A2**	**A2**	**A3**	**A3**	**A3**	**C3**	**C3**	**C3**	**C2**	**C2**	**C2**
fill height	**thickness**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**ULS SF**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**	**ULS BM**	**SLS BM**	**SLS P BM**
0.5	250	84	233	57	9	111	63	74	10	124	78	82	17	100	162	60	15	108	72	18	49	29	8	127	91	14	106	70	20	126	86	15	133	90	16	153	100	26	144	91	26
0.5	**300**	78	229	53	7	111	60	74	10	125	78	83	20	97	165	57	13	109	73	20	48	27	7	134	96	15	112	75	24	126	86	15	135	91	16	160	105	30	149	94	29
0.5	350	70	226	47	6	109	56	72	11	125	76	84	23	90	168	52	12	110	74	21	46	25	5	133	96	18	116	79	28	124	84	15	137	93	17	166	110	34	152	96	32
0.5	400	63	206	42	4	109	53	72	12	127	76	85	26	85	172	48	9	111	76	23	44	23	4	135	97	20	121	84	32	122	83	15	139	94	18	173	115	38	156	98	34
0.5	**450**	57	203	37	2	108	50	71	13	128	75	87	29	79	174	42	6	113	77	27	41	20	2	141	102	22	126	89	37	121	82	15	142	95	18	180	119	43	159	99	37
1	200	80	138	52	13	85	71	54	15	88	74	54	19	75	126	41	18	75	47	24	35	16	10	76	54	19	74	53	24	104	69	21	100	66	22	106	65	29	103	61	29
1	**250**	59	133	38	11	82	63	52	15	87	72	54	22	71	127	37	17	75	47	25	34	14	8	77	55	21	81	58	28	92	61	21	100	65	23	110	67	33	104	61	32
1	300	53	131	34	9	81	61	51	15	89	71	56	25	68	132	34	15	77	49	26	34	13	7	81	58	23	87	63	32	93	61	21	102	67	23	116	72	37	108	63	35
1	350	49	128	30	7	81	58	51	16	91	69	58	28	65	136	30	13	79	51	28	33	11	5	84	60	25	93	68	36	92	60	21	105	68	24	123	77	41	112	65	37
1	**400**	44	126	26	5	81	55	50	17	93	68	60	32	62	140	27	10	81	53	29	32	10	4	88	63	28	100	72	40	92	60	21	107	70	25	130	82	45	116	67	40
2	200	39	120	24	19	69	76	42	26	72	87	45	29	47	126	28	24	61	41	36	41	16	10	85	61	34	87	63	38	70	47	33	81	53	35	88	60	42	79	53	41
2	**250**	35	117	20	16	70	74	42	25	75	85	48	32	43	132	25	22	65	45	37	40	14	8	89	64	36	95	69	42	70	47	33	84	55	36	96	65	47	84	56	44
2	300	33	115	17	13	70	71	43	25	78	83	53	35	40	135	23	19	68	49	39	39	12	6	92	66	38	102	74	47	70	46	33	88	57	38	103	70	51	88	59	46
2	350	31	112	14	10	71	68	45	27	82	81	57	39	38	138	20	15	74	54	40	38	11	5	97	70	41	109	80	51	70	46	33	91	59	39	111	75	55	91	61	49
2	**400**	29	109	11	6	72	65	47	28	85	79	62	42	35	140	16	11	80	58	41	37	9	3	101	73	44	117	85	56	69	45	33	94	61	40	119	81	60	95	64	51
4	250	52	158	30	26	72	120	54	45	80	135	60	52	59	159	35	31	58	39	32	51	14	8	108	78	66	115	83	71	98	66	57	107	74	64	118	83	73	111	75	67
4	**300**	48	153	25	21	75	115	55	47	86	131	64	56	55	160	30	26	64	43	36	49	11	5	113	81	69	123	89	77	99	65	57	109	77	66	125	89	79	115	78	69
4	350	45	147	19	15	78	110	57	48	92	126	68	60	51	159	25	20	70	47	40	48	9	3	117	84	72	130	95	82	99	65	57	112	79	68	131	94	84	119	80	72
4	400	41	142	14	10	81	105	59	50	99	122	73	64	46	158	19	14	76	52	44	47	6	0	122	88	75	138	100	88	99	65	56	114	81	70	138	100	89	123	82	74
4	**450**	36	136	9	4	85	100	62	52	105	118	77	68	41	156	12	7	82	56	48	45	4	0	127	92	78	146	107	93	99	64	56	117	83	72	145	106	95	126	84	76
6	250	69	208	40	36	95	159	71	66	101	174	76	72	75	203	44	40	75	50	47	62	13	7	142	103	96	147	107	100	131	88	81	141	99	92	151	107	100	143	96	90
6	**300**	63	200	32	28	98	153	73	68	109	168	81	76	70	202	37	33	82	55	52	60	10	4	146	106	99	156	114	107	132	87	81	144	101	94	159	113	106	147	99	93
6	350	58	193	25	21	102	146	75	70	116	162	86	81	64	200	30	26	89	60	57	58	7	1	151	110	103	164	120	113	132	87	80	147	104	97	166	119	112	151	102	95
6	400	52	185	17	13	106	139	77	72	123	156	91	86	57	197	22	17	96	66	62	57	4	0	157	114	106	173	126	119	132	86	80	150	107	99	173	126	118	155	104	97
6	**450**	46	177	10	5	110	132	80	75	130	150	96	90	50	193	13	8	103	71	67	55	1	0	163	118	110	182	133	125	132	85	79	153	109	102	181	132	125	158	106	99
8	300	78	253	40	36	124	190	92	89	134	205	100	97	85	249	45	41	102	69	68	70	9	3	184	134	130	193	141	137	166	110	104	181	128	123	196	140	134	181	122	116
8	**350**	71	243	30	26	128	182	95	92	142	197	105	102	77	244	35	31	110	75	73	69	6	0	190	138	134	202	148	143	166	110	104	185	131	126	204	146	141	185	124	118
8	400	63	232	21	16	133	173	98	95	150	190	111	108	69	239	25	20	118	81	79	67	2	0	196	142	138	212	155	150	166	109	103	188	134	129	212	153	148	189	126	120
8	450	56	222	11	6	138	165	101	98	157	182	116	113	60	233	14	9	126	87	85	65	0	0	202	147	143	221	162	158	165	108	102	192	137	132	220	160	155	192	128	122
8	**500**	48	211	1	0	143	156	104	101	165	174	121	118	50	227	2	0	135	94	91	63	0	0	209	152	148	232	170	165	165	106	100	195	140	135	228	167	161	194	129	123
10	350	84	351	36	31	187	217	139	137	200	233	149	147	90	340	40	36	164	114	114	79	4	0	277	203	200	289	212	210	216	145	139	255	183	179	273	197	193	234	158	153
10	**400**	75	336	24	19	194	207	143	141	210	223	156	154	80	331	28	23	175	122	121	77	0	0	285	209	206	301	221	218	215	143	137	261	188	183	283	206	201	237	159	154
10	450	65	320	12	7	201	197	148	146	220	214	163	161	69	321	15	10	185	130	129	75	0	0	294	215	212	312	230	227	213	141	135	266	192	188	293	214	210	239	160	155
10	500	56	304	0	0	208	186	153	151	230	205	169	167	58	310	1	0	196	138	137	73	0	0	303	222	219	325	239	236	211	138	133	271	197	193	303	223	218	240	160	155
10	**550**	46	288	0	0	215	175	158	156	240	195	176	174	46	298	0	0	207	146	145	71	0	0	312	229	226	338	249	246	209	135	129	276	201	197	313	231	227	241	160	154
12	400	86	461	27	23	268	241	199	198	283	257	211	209	91	442	31	26	244	173	173	87	0	0	395	291	289	409	302	301	270	181	176	347	251	248	368	268	265	291	197	192
12	**450**	75	439	13	9	278	229	206	204	296	246	220	218	79	427	16	11	258	184	183	84	0	0	405	298	297	424	313	311	267	178	173	355	258	254	380	279	275	291	196	191
12	500	64	417	0	0	288	217	212	211	309	235	228	227	66	410	0	0	272	194	194	82	0	0	417	307	305	439	324	323	263	174	169	362	264	261	393	289	286	291	195	190
12	550	52	394	0	0	298	204	219	218	321	224	237	236	52	393	0	0	286	204	204	80	0	0	429	316	314	455	336	334	259	169	164	370	270	267	405	299	296	289	193	188
12	**600**	41	372	0	0	308	191	226	225	333	212	246	244	38	375	0	0	299	214	214	79	0	0	442	325	323	472	349	347	253	164	159	377	277	273	417	310	306	287	191	185

APPENDIX D CALCULATION OF REINFORCEMENT REQUIRMENT

This section explain the procedure followed in the calculation of reinforcement for each requirment

Top slab bottom reinforcement calculation is presented

D-1 BENDING REINFORCEMENT REQUIREMENT

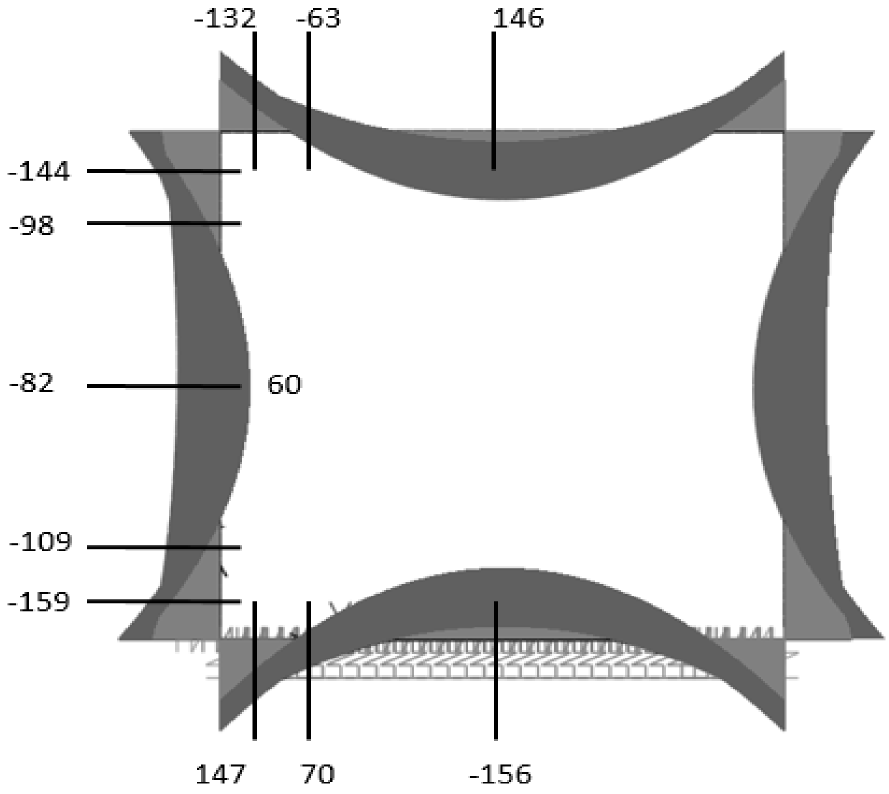
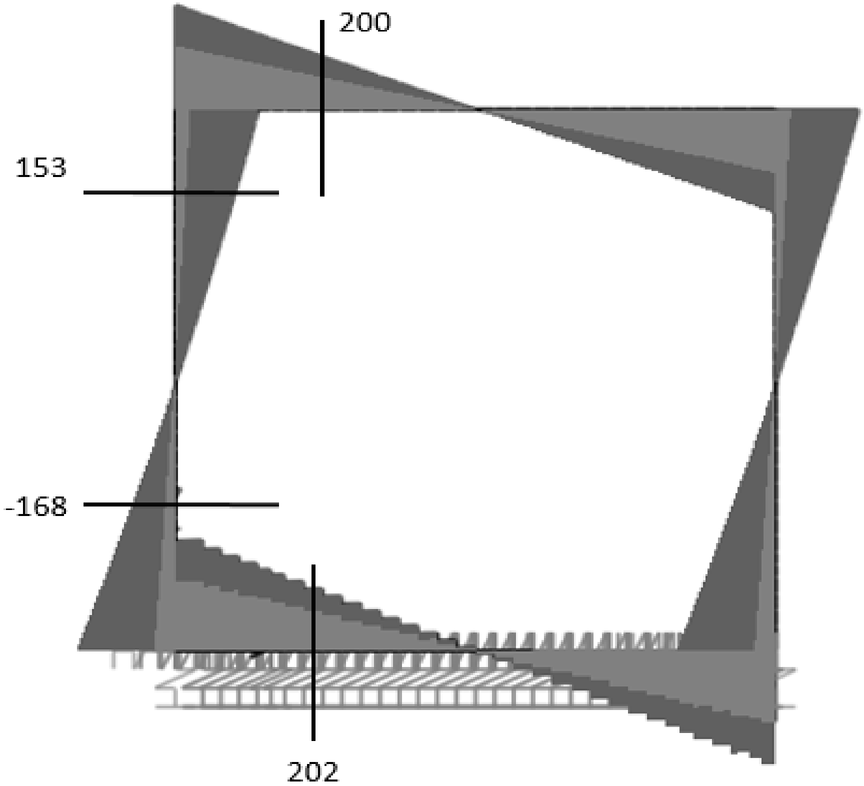
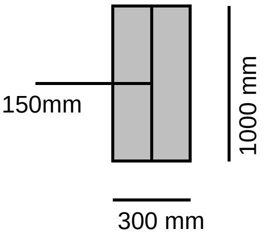


Figure D.1:ULS bending moment (kNm/m) diagram

Reference	Calculation	Output
	Characteristic strength of concrete, f_{cu} = 30 N/mm^2	
	Characteristic strength of reinforcement, f_y = 460 N/mm^2	
	Thickness of top slab, h = 300 mm	
	ULS Bending moment from analysis = 146 kNm/m	
RDA Bridge Design Manual:1997	Cover = 50 mm	Cover = 50 mm
	Assume diametre of main reinforcement = 20 mm	
	Effective depth, d = 300-50-20/2 = 240.0 mm	d = 240.0 mm
BS 5400 Part 4: 1990 5.3.2.3	$M = (0.87f_y)A_sz$ equation 1 $z = (1 - 1.1f_yA_s/ f_{cu}bd)\ d$ equation 5 from these two equations	
	$z = 0.5d\ [1+ (1-5M/f_{cu}bd^2)^{1/2}\ ]$ $z = 0.5d\ [1+ (1-5x146x10^6/30x1000x240^2)^{1/2}\ ]$ $= 0.880\ d < 0.950\ d$ $Z = 0.880\ d$ $= 0.95x240 = 211.2$ mm	

Reference	Calculation	Output
	Main reinforcement	
equation 1	A_s = M / 0.87f_yz	
	= 146×10^6 / 0.87x460x211.2 = 1727 mm^2/m	$A_{s\ req}$ = 1727 mm^2/m
	D-2 MINIMUM REINFORCEMENT REQUIREMENT	
BS 5400 Part 4: 1990 5.8.4.1	$100A_s / b_a d$ = 0.15 A_s = 0.15 X 240 X 1000 / 100 = 360 mm^2/m	
	D-3 SHEAR REINFORCEMENT REQUIREMENT	
	to find the reinforcement requirment for shear , assume a amount for reinforcement and calculate shear capacity	
	then change the assumed amount of reinforcement until shear capacity reach actual shear strength of the section	
	 Figure D.2:ULS Shear force (kN/m) diagram	
	Characteristic strength of concrete, f_{cu} = 30 N/mm^2	
	Characteristic strength of reinforcement, f_y = 460 N/mm^2	
BS 5400 Part 4:1990 Table 13	Thickness of approch slab, h = 300 mm	
RDA Bridge Design Manual:1997	Cover = 50 mm	Cover = 50 mm

Reference	Calculation	Output
	Shear force from analysis = 200 kN/m	V = 200 kN/m
	Effective depth, d = 240.0 mm	
BS 5400	Design shear stress, V = V / bd	
Part 4: 1990	= $(200x10^3)/(1000x240)$	
5.3.3.1	= 0.83 N/mm^2	v =
equation 8	$0.75X(f_{cu})^{1/2}$ = $0.75x(30)^{1/2}$ = 4.108 N/mm^2	0.833 N/mm^2
	Design shear stress, v = 0.83 < $0.75x(f_{cu})^{1/2}$ or 4.75 N/mm^2	
	Hence O.K	
	Assume longitudanal tension reinforcement	
	$A_{s\ pro}$ = 2637 mm^2/m	
BS 5400	Allow. shear resistance ,$x_s v_c$ = $(0.27/g_m)(100A_s/b_w d)^{1/3}\ (f_{cu})^{1/3}\ x_s$	
Part 4: 1990		
5.3.3.2	Where, depth ratio, ξ_s = $(500/d)^{1/4}$	
	= $(500/240)^{1/4}$	
	= 1.20 or 0.7 (greater value)	
	$\xi_s v_c$ = $(0.27/1.25)x(100x2637/1000x240)^{1/3}x(30)^{1/3}x1.20$	
	= 0.83 N/mm^2	$\xi_s v_c$
	= actual shear stress	= 0.83 N/mm^2
B/D 28/87	**D-4 SHRINKAGE AND TEMPERATURE REINFORCEMENT REQUIREMENT**	
Incorporating		
Amendment		
No.1 1989	f_{cu} = 30 N/mm^2	
	f_y = 460 N/mm^2	
	Ac = 1000 x 150	
	= 150000 mm^2	
5.1	f_{ct} = $0.12\ (f_{cu})^{0.7}$ = $0.12\ (30)^{0.7}$	
	= 1.30 N/mm^2	
5.3	As = $(f^{ct} \div f_y) \times Ac$ = $\frac{1.30}{460} \times 150000$	
	As = 423 mm^2	
5.3	As = $\frac{f_{ct} \times A_c \times \phi}{f_b \times 2w}\ [\ R(\ \varepsilon_{sh} + \varepsilon t_h) - 0.5\ \varepsilon_{ult}\ )\ ]$	
BS 5400		
Part 4: 1990		
Table 1	w = 0.25 mm	
B/D 28/87	ε_{ult} = 200×10^{-6}	
Incorporating	$f_{ct} \div f_b$ = 0.67	
Amendment	ε_{sh} = $0.5 \times \varepsilon_{ult}$ = 100×10^{-6}	
No.1 1989	ϕ = 20 mm	
Table 2	R = 0.5	
Table 1	T_1 = 35	
5.9	T_2 = 12	
5.7	α = 12×10^{-6}	

Reference	Calculation	Output

ε_{th} = 0.8 α (T1 + T2)

= 0.8 x 12 x 10^{-6} (35 + 12)

= 451.2 x 10^{-6}

As = 706 mm^2

Maximum r/f required = 706 mm^2

D-5 FLEXURAL CRACK WIDTH REINFORCEMENT REQUIREMENT

to find the reinforcement requirment for crack width , assume a amount for reinforcement and calculate crack width

then change the assumed amount of reinforcement until crack width reach to design crack width (0.25mm)

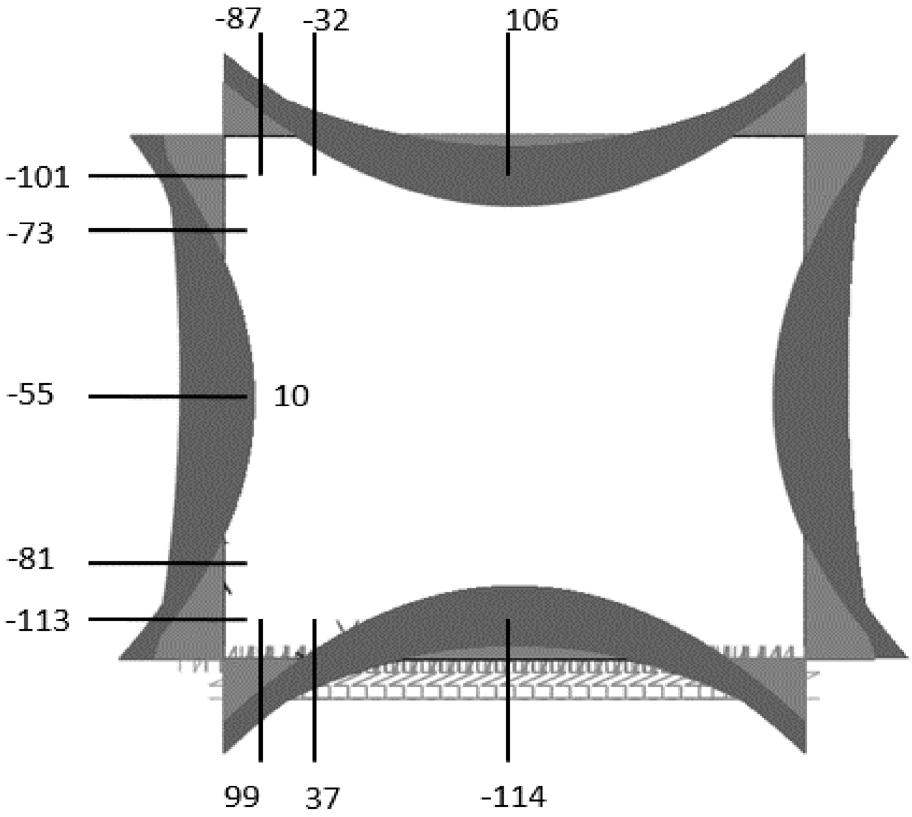


Figure D.3:SLS bending moment (kNm/m) diagram

Reference	Calculation	Output

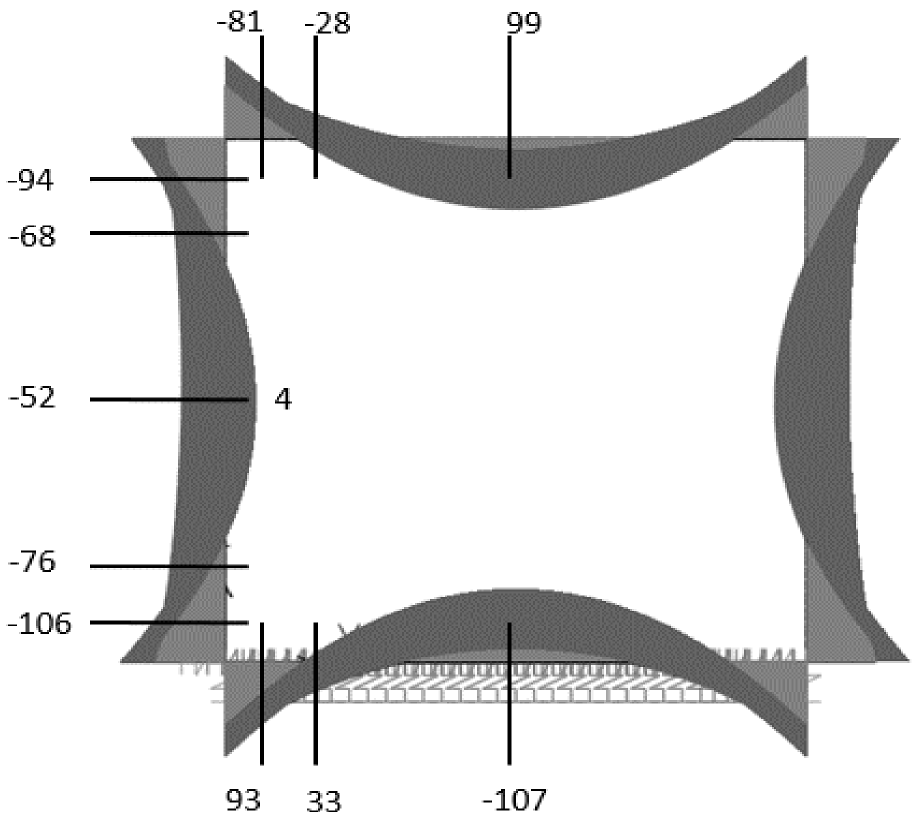


Figure D.4:SLS permanent bending moment (kNm/m) diagram

Bending moment at SLS	M	=	106	kNm
Bending moment due to permanent loads	M_g	=	99	kNm
Bending moment due to live loads	M_q	=	7	kNm
Elastic modulus of concrete (long term)	E_c	=	14	kN/mm^2
Elastic modulus of reinforcement	E_S	=	200	kN/mm^2
Moduli ratio	$\alpha_e = E_S/E_c$	=	14.29	

BS 5400
Part 4
5.8.8.2
eq 24

Design crack width $= \dfrac{3a_{cr}€_m}{1+2(a_{cr}\text{-}c_{nom})/(h-d_c)}$

d_c = depth to neutral axis
d = effective depth
h = overall depth
$€_c$ = strain of concrete at compression face
$€_s$ = strain at reinforcement
$€_1$ = strain of concrete at tensile surface

Above figure shows the strain variation of the section under SLS loading

d_c can be calculated considering the force equilibrium of the section and strain compatibility.

$d_c/d = \alpha_e\rho\,[(1+2/\alpha_e\rho)^{1/2}-1]$ Where $\rho = A_s/(bd)$

Depth of the wing wall section, h	=	300	mm
Breadth considered, b	=	1000	mm
Main r/f size	=	20	mm

Reference	Calculation	Output
	Assume amount of reinforcement ,As = 2013 mm^2/m	
	Cover to r/f = 50 mm	
	Effective depth, d = 240 mm	
	$\rho = A_s/(bd)$ = 0.0084	
	$\alpha_e\rho$ = 0.1198	
	d_c/d , from above equation = 0.384	
	d_c = 92 mm	
	Then the lever arm, $Z = d - d_c/3$ = 209.3 mm	
	Check for stress levels	
	Bending moment at	
	Serviceability limit state (M_s) = 106 kNm/m	
	$s_c = 2M_s/bzd_c$	
BS 5400	$s_c = 10.99$ N/mm^2 $<$ $s_a = 15$ N/mm^2	
Part 4	Hence ok	
Table 2		
	$s_{se} = M_s/zA_s$	
	$= 251.6$ N/mm^2 $<$ $s_s = 345$ N/mm^2	
	Hence ok	
	$\varepsilon_m = \varepsilon_1 - \Delta\varepsilon$	
	$\Delta\varepsilon = \frac{[(3.8).b_t.h.(a'-d_c)]}{\varepsilon_s.A_s.(h-d_c)} \times [(1-M_q/M_g).10^{-9}]$	
	$\varepsilon_1 = \frac{(h-dc)}{(d-dc)} \times \frac{s_{se}}{E_s}$	
BS 5400 5.8.8.2 eq : 25	$= \frac{300 - 92}{240 - 92} \times \frac{252}{200 \times 10^3}$	
	$\varepsilon_1 = 1.769 \times 10^{-3}$	
	$\varepsilon_s = \frac{s_{se}}{E_s}$	
	$= 1.258 \times 10^{-3}$	
	$\Delta\ \varepsilon_s = 0.418 \times 10^{-3}$	
	$\varepsilon_m = \varepsilon_1 - \Delta\varepsilon$	
	$= 1.350 \times 10^{-3}$	
	$a_{cr} = (d'^{\,2} + a'^{\,2})^{1/2} - \varphi/2$	
	a' = Centre to centre distance of nearest tension r/f	
	d' d' = h - d	
	ϕ = diametre of tension r/f	

Reference	Calculation	Output

2.a' = Spacing of reinforcement

= 150 mm

a_1 = 75 mm

d' = 60 mm

a_{cr} = 86.05 mm

BS 5400
5.8.8.2
eq : 24

Design crack width = $$\frac{3a_{cr}\text{€}_m}{1+2(a_{cr}-c_{nom})/(h-d_c)}$$

= 0.25 mm

D-6 SUMMARY OF REINFORCEMENT REQUIREMENT

Criteria	Amount of RF required (mm^2/m)
Bending	1727
Minimum	360
Shear	2637
Thermal and Shrinkage	706
Crack width	2013
Final amount of RF required	2637