Prince Mohammad Bin Fahd University
College of Engineering
Department of Civil Engineering

Comparative Design and Analysis of Post-Tension Concrete and Steel Bridges at Dhahran-Oqair-Salwa Road Dammam to Old Abqaiq Highway

Course Title: Learning Outcome Assessment III

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Abstract

To pursue with the civil rebirth that happened in the Kingdom of Saudi Arabia, and as a part of the vision of 2030 Kingdom of Saudi Arabia needs some focus to differentiate themselves from other countries worldwide. In our project, we selected the Eastern Province to create our comparative study which is (Comparative Design and Analysis of Post-Tensioned Concrete and Steel Bridge) in the Dammam to Abqaiq Highway (Dhahran-Oqair-Salwa Road). Moreover, this road is on the highway and it will help reduce the traffic from the Gulf Cooperative Council Road. Furthermore, there is cross section with Saudi Aramco pipelines. Most of the people utilize this road to reach Khobar City.

The design will be divided into parts depending on our coverage. In the structural design and analysis, we will use SAP2000 and CSI Bridge computer software's. Meanwhile, for our geotechnical part, we will design and analyse the foundation and piles using appropriate calculations. As a reference to our comparative study, we used the local Ministry of Municipal and Rural Affairs (MOMRA) and the American Association of State Highway and Transportation Officials (AASHTO) standards. Finally, our design and analysis are comprehended into different design constraints, and our process involves a raw material cost estimation.

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Notations

Symbol	Definition
c_{top}	Top Cover
c_{bottom}	Bottom Cover
f'_c	Concrete Compression Strength
p_e	Final Stress
p_i	Initial Stress
f_y	Yielding Strength of Concrete
f_{ci}	Initial Limit Compression Force
f_{ti}	Initial Limit Tension Force
f_{cs}	Final Limit Compression Force
f_{ts}	Final Limit Tension Force
s_b	Bottom Section Modulus
s_t	Top Section Modulus
r	Slenderness
e	Eccentricity
f_{top}	Top Force on Girder
f_{bottom}	Bottom Force on Girder

p_i	**Post-Tensioning Strength**
DL	Dead Load
LL	Live Load
F’	Asphalt + Concrete Slab + Girder Self-Weight + Bridge Railing Load on Pier Cap
F”	Truck Load on Pier Cap
F”’	Lane Load on Pier Cap
F_u	Factored Force on Pier Cap
P_D	Design Wind Pressure
P_B	Basic Wind Pressure
V_{DZ}	Design Wind Speed
V_0	Design Wind Speed at Hight 0
V_{30}	Design Wind Speed at Hight 30
V_B	Regional Basic Wind Speed
Z	Hight Above Average Ground Level
λ	Normal Weight of Concrete
PGA	Peak Ground Acceleration
γ	Unit Weight

q_{all}	**Allowable Bearing Capacity**
R.Q.D	Rock Quality Designation
q_u	Ultimate Bearing Capacity
C	Cohesion
$F_{cs}, F_{qs}, F_{\gamma s}$	Shape Factors
$F_{cd}, F_{qd}, F_{\gamma d}$	Depth Factors
$F_{ci}, F_{qi}, F_{\gamma i}$	Inclination Factors
N_q, N_γ, N_i	Bearing Capacity Factors
ϕ	Friction Angle
L'	Effective Length
B'	Effective width
I_z	Polar Moment of Inertia
E_s	Modulus of Soil

CHAPTER 1

Categories:

1. General
2. Project Objectives
3. Scope of The Report
4. Description of The Project
5. Design Constraints

CHAPTER 1: CATEGORIES

1. General:

Eastern province is one of the richest area with minerals. Also, it has a port. Which led to have growing industries. This made the Eastern province a major administrative center for the Saudi oil industry. Specifically, Dammam, Dhahran and Al Khobar form the heart of the eastern province. These three cities are known as the Greater Dammam. The population of these areas is 4,140,000 as of 2012. The oil Industry of eastern province will help the vision of 2030 to be a reality.

These cities growth is extraordinary, compared to other cites in the Kingdom, where it reached to 13% a year. the fastest in Saudi Arabia, the Gulf Cooperation Council, and the Arab world. In 2016 it was declared that the Greater Dammam is 4th largest area in size and population in the Gulf Cooperation Council (GCC). The Dammam metropolitan area and the Eastern Province as a whole are served by the King Fahd International Airport (KFIA), the largest airport in the world in terms of land area (roughly 780 km2), about 20 km to the northwest of the city. Dammam's King Abdul Aziz Sea Port is the largest on the Persian Gulf. Its import-export traffic in is second only to Jeddah Seaport in the Middle East and North Africa (MENA).

2. Project Objectives:

The objective of this project is to compare the cost of two bridges with the same design. However, one is made of Steel and the other is made of Superstructure Post-Tension I-Girder of Concrete. Also, bridges will be Doubling of Dhahran-Oqair-Salwa Road Dammam to old Abqaiq Highway. Furthermore, the design of those two bridge must link between Old Abqaiq Road with half-moon road (Road #5). In this project will meet several objectives:

- Design the project by using AASHTO and MOMRA standards, using SAP2000 software, and CSiBridge software, which contains the superstructure, substructure and foundation system.
- Avoiding Aramco’s oil piping system
- Geotechnical design for abutment piers, retaining walls, and foundation system.
- Comparative Design and Analysis of Concrete and Steel Bridges regarding their Structural design and Material costs.
- To significantly improve traffic efficiency.
- To connect between Old Abqaiq Rd and half-moon road (Road #5)

3. Scope of The Report:

This report consists of eight chapters. This report will present a detailed description of the design of the two bridges. Also, a brief description of the common types of bridges which will be mentioned in chapter two. In chapter three, the procedures which were used to complete the development of the two bridges design. In chapter four, the calculation of the two bridges design. In the fifth chapter, detailed soil profile is provided and geotechnical and foundation system. In the sixth chapter, the software that were used to insure calculation were correct for both design which were CSIBridge and SAP2000. Comparative Cost Estimation of the two bridges will be provided in the seventh chapter. In chapter eight the team will be providing a recommendation and conclusion of this project.

4. Description of The Project:

These two designs are using simply supported I-Girder Beam. This project is designing two Bridges one is made of I-Beam Girders and the other is made is concrete which is also I-Beam Girders. It consists of two spans only, three piers, two abutments, and MCM walls. The bridge consists of 11 girders carrying thee traffic lanes each intersect with Abqaiq Highway over Three of Aramco oil pipe lines, It has a total length of 60 m between abutments with equal 30 m spans, a minimum vertical clearance of 9.5 m, and a width of 16.5 m.

Figure 1 *Bridge Location*

(Google.Retrieved February 04, 2018, from https://www.google.com/maps)

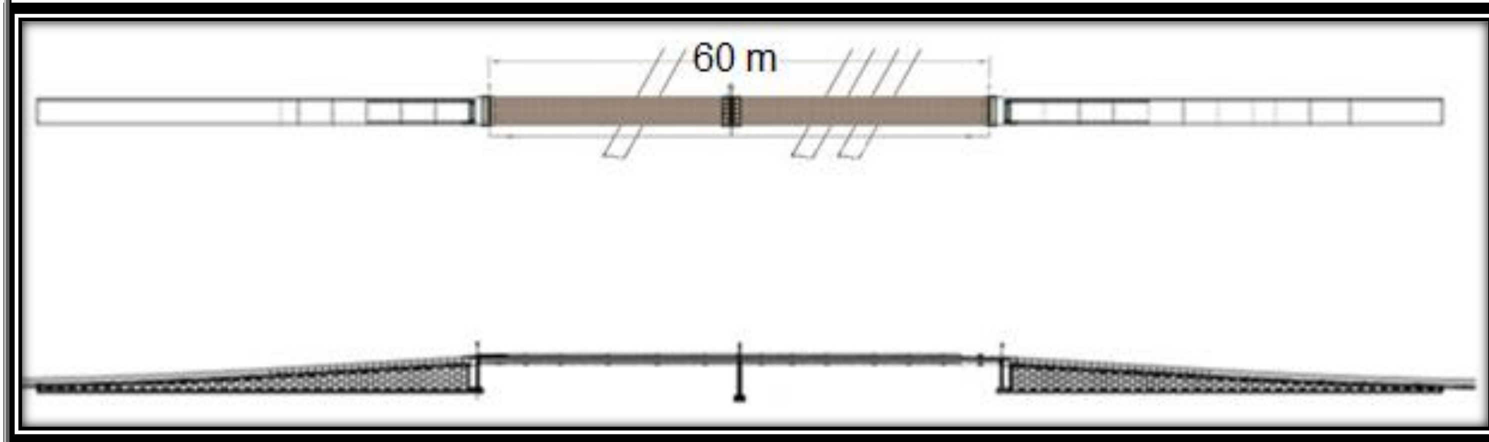


Figure 2 *Top and Side View of the Bridge*

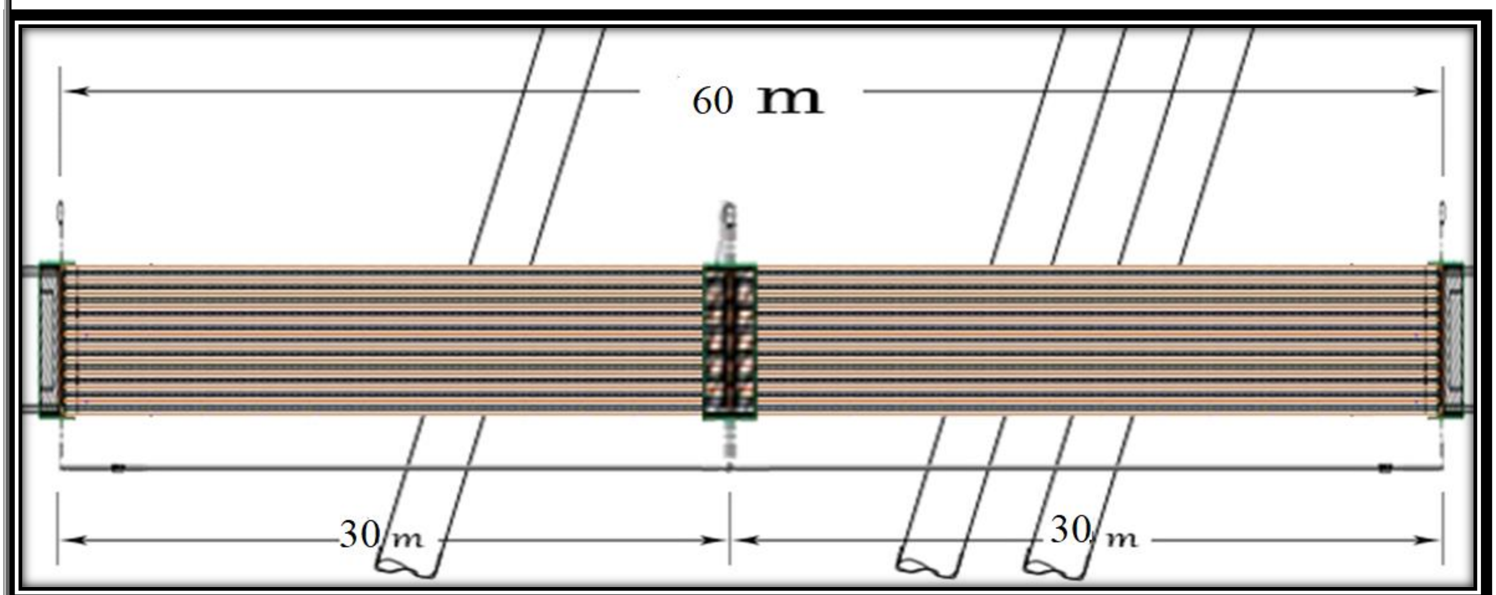


Figure 3 *Top View of the Bridge*

(Taken From Al-Shalawi International Holding Co. Trading & Contracting)

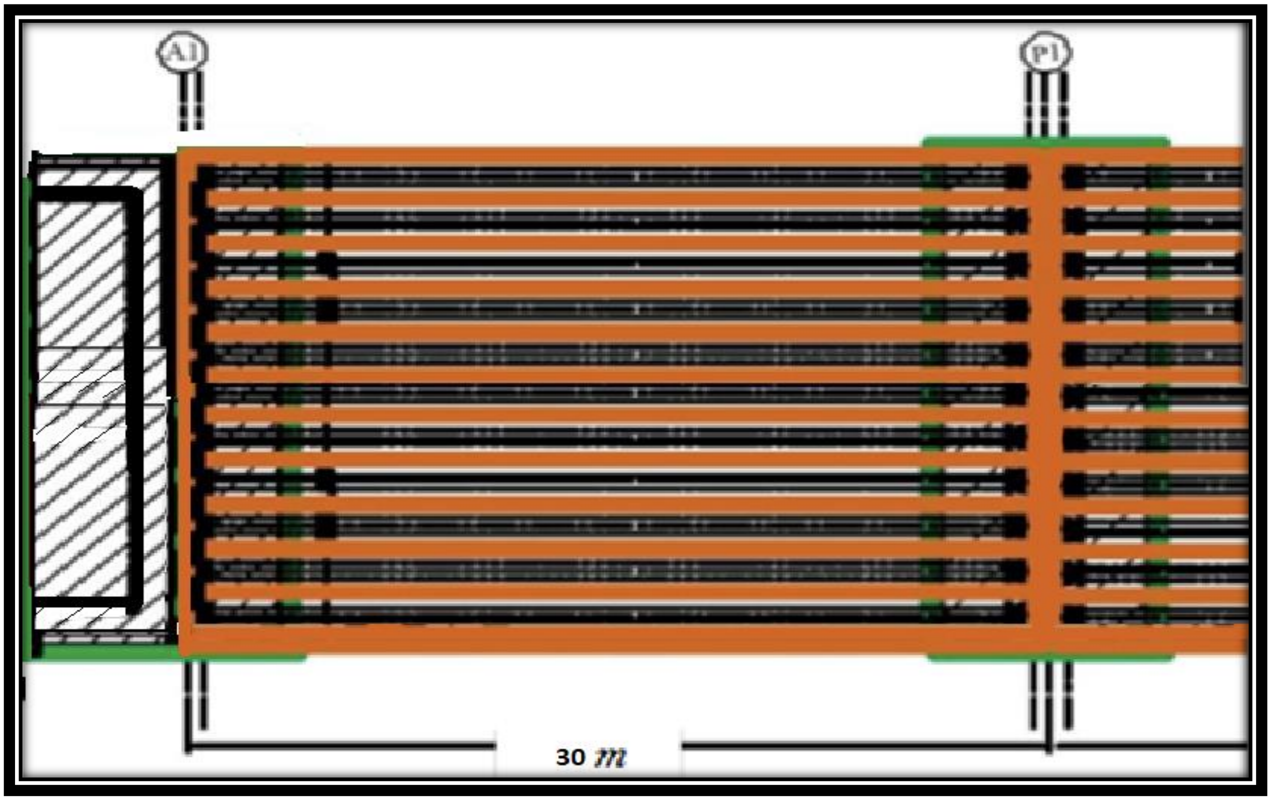
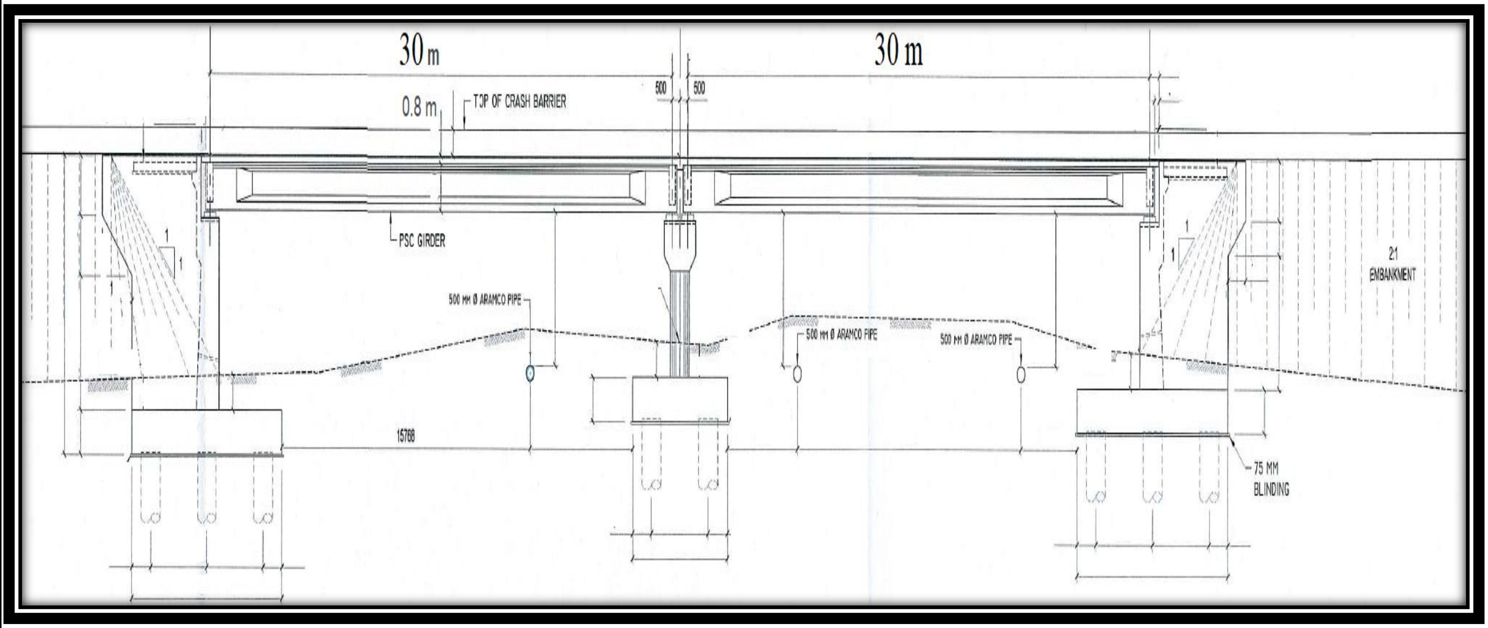


Figure 4 *Top View of the Bridge*



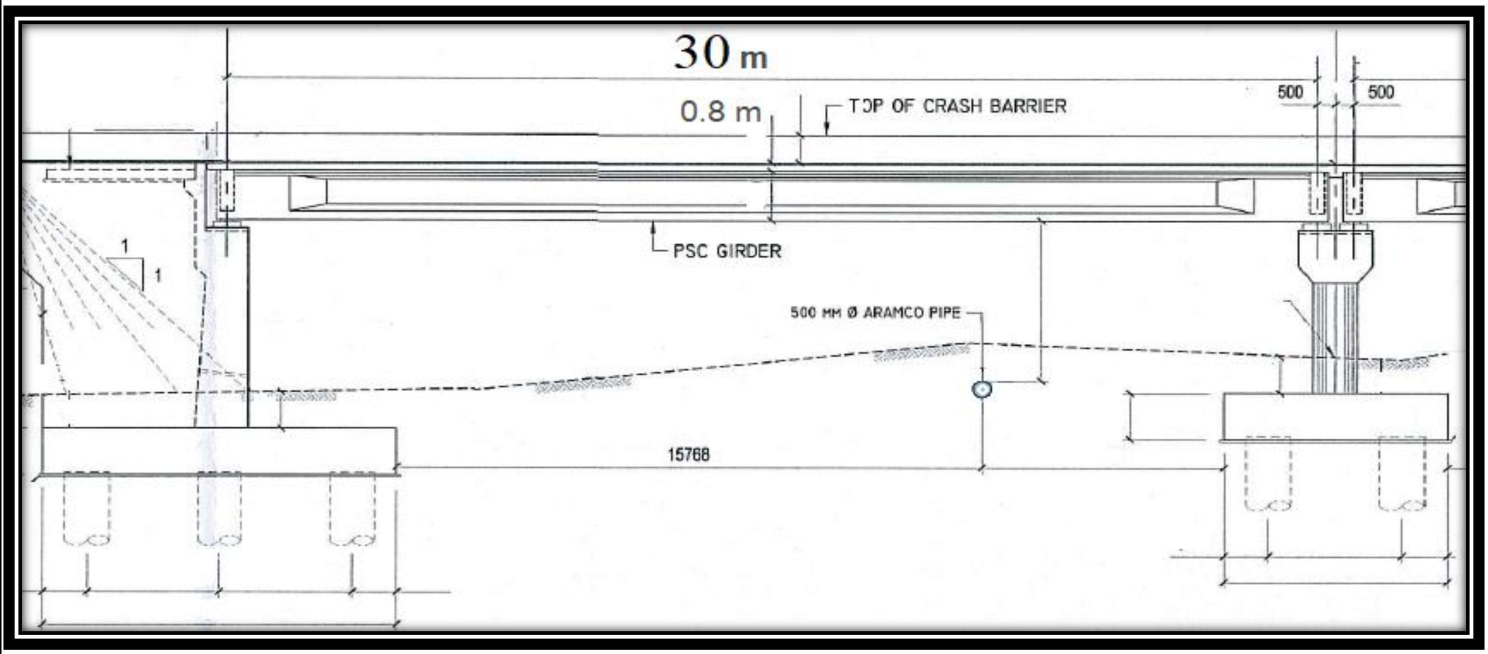


Figure 5 *Side View of the Bridge*

(Taken From Al-Shalawi International Holding Co. Trading & Contracting)

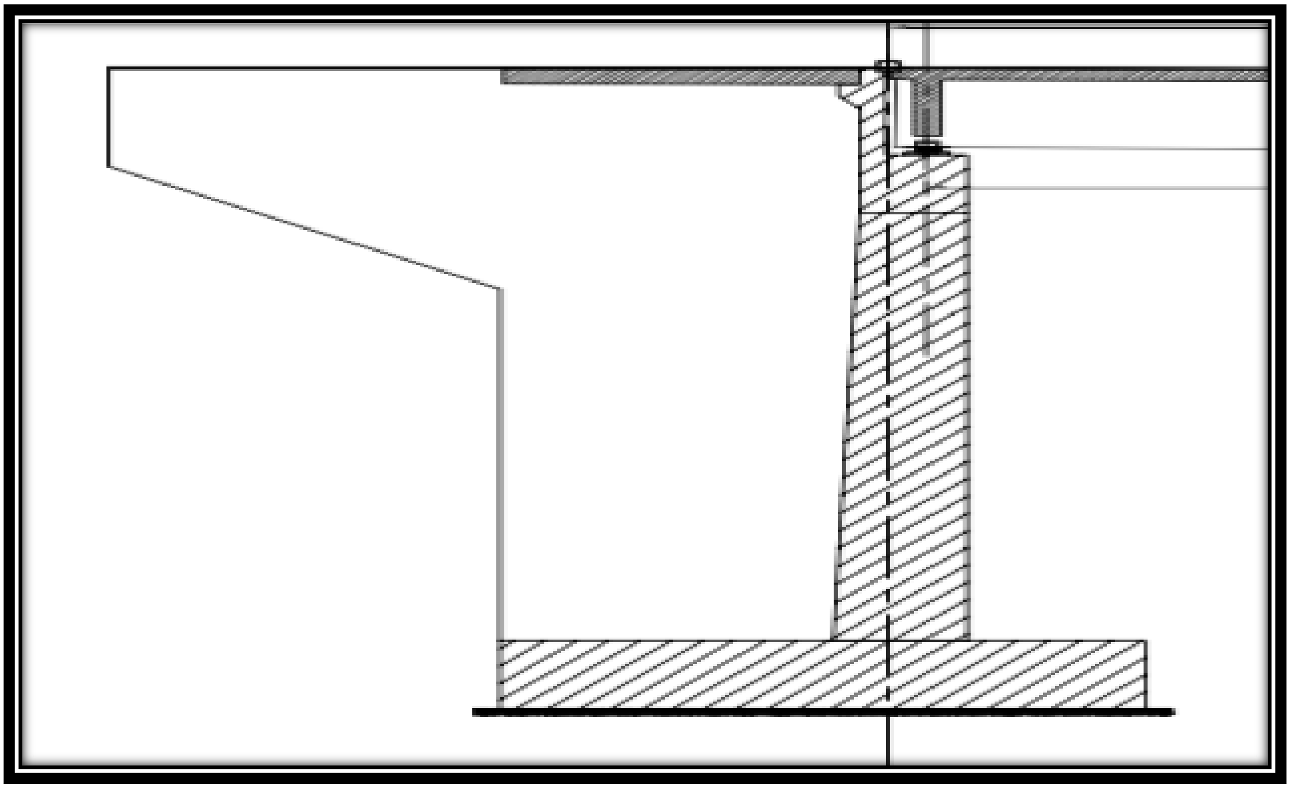


Figure 6 *Abutment Side View*

(Taken From Al-Shalawi International Holding Co. Trading & Contracting)

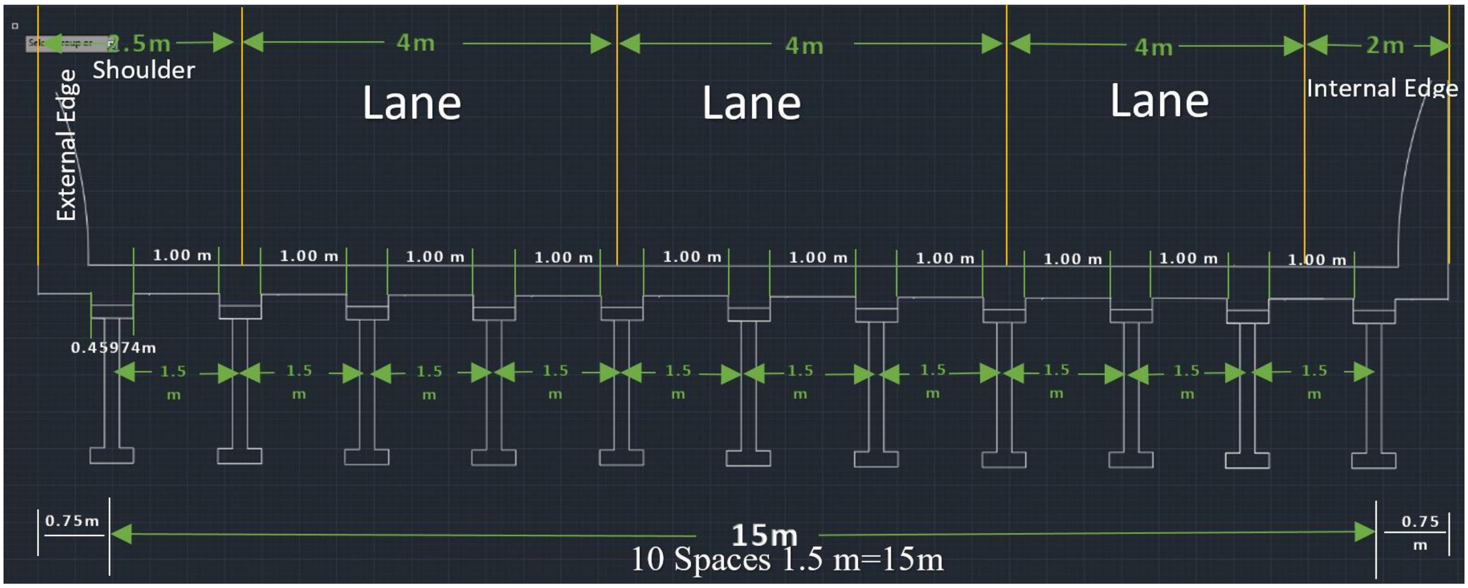


Figure 7 *Cross Section of* ***Steel*** *Bridge*

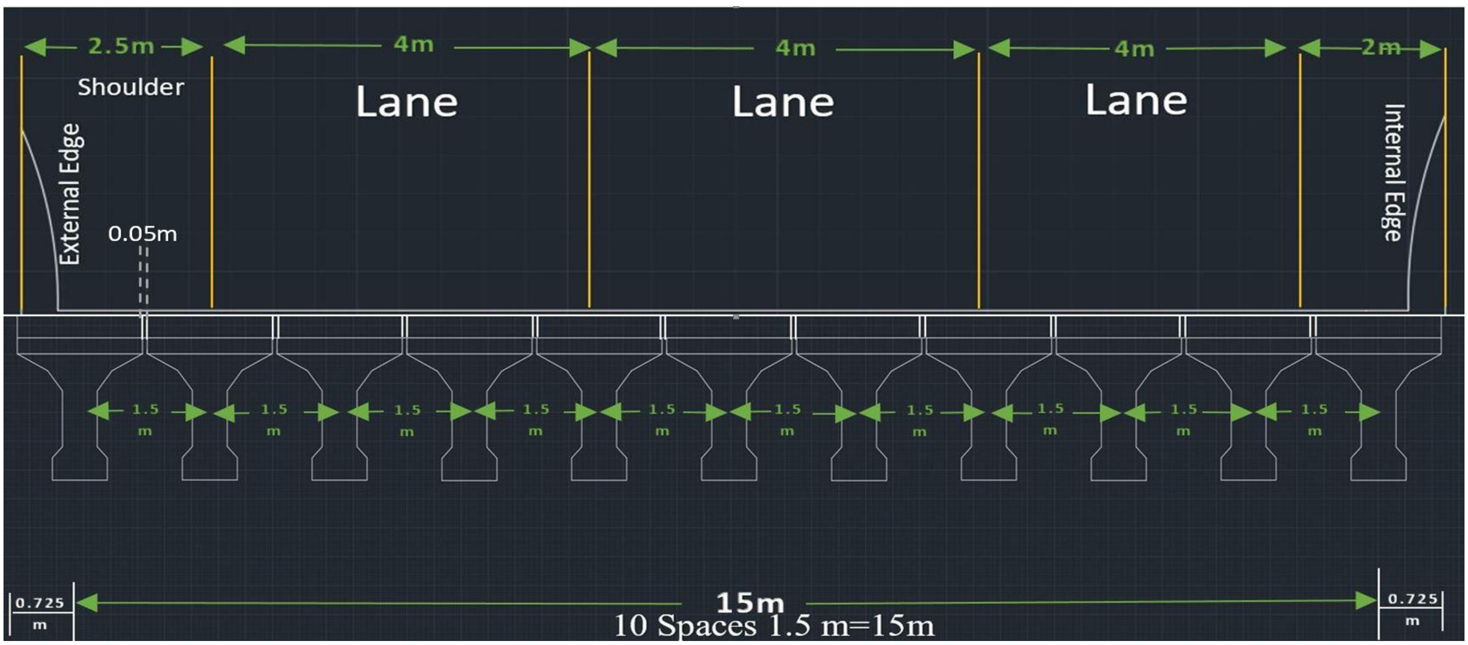


Figure 8 *Cross Section of* ***Post-Tensioned Concrete*** *Bridge*

5. Design Constraints

This project has several constraints just like any other project. The first the two bridges must have the same design with respect to their material. This is due to the cost com that will take place at the end of this project. Second, the oil pipes of Aramco must not be moved. Third, Due to the ground soil profile pile foundation must be used.

CHAPTER 2

Bridges In Brief:

1. Introduction
2. Bridge
3. Types of Bridges
4. Categorization Based On Construction Material
    - I. Concrete Bridges
    - II. Steel Bridges
    - III. Timber Bridge
5. Composite Bridges
6. Classification by Span Length
    - I. Short Span Bridges
    - II. Medium Span Bridges
    - III. Long Span Bridges
7. Classification By Structural Form
    - I. Slab Stringer Bridge
    - II. Truss Bridges
    - III. Rigid Frame Bridges
    - IV. Arch Bridge
    - V. Cable Stayed Bridge
    - VI. Suspension Bridges

2.8. Classification By The Span Type
- I. Simple Span Bridge
- II. Continuous Span Bridge

2.9. Classification of the Bridges According to their Utility

2.10. Classification According to the Deck Type of the Bridge

2.11. Bridge Structure
- I. Superstructure
- II. Bearings
- III. Substructure

2.12. Girder Bridge

2.13. Bracing

CHAPTER 2: BRIDGES IN BRIEF

1. Introduction:

This chapter discusses various types of bridges design depending on the known bridges classifications. This chapter is also concerned with the cataories of the bridges and how they are classified into short, miduim, and long span bridges.

2. Bridge:

Bridges are that type of important structure. When a road needs to extend across a river, valley, passing on top of obstacles or solve traffic a bridge is built to connect the two land masses. Since the average car cannot swim or fly, the bridge makes it possible for automobiles to continue driving from one land mass to another.

3. Types of Bridges:

The core structure of the bridge determines how it distributes the internal forces of tension, compression, torsion, bending, and sheer. While all bridges need to handle all those forces at all times, various types of bridges will dedicate more of their capacity to better handle specific types of forces. The handling of those forces can be centralized in only a few notable structure members (such as with cable or cable-stayed bridge where forces are distributed in a distinct shape or placement) or be distributed via truss across the almost entire structure of the bridge. Depending on the purpose of the bridge design and its construction all types of bridges can be categorized in different ways. Through the years and technology advancements types of bridges has risen to serve the need. Overall, bridges are usually categorized on the following details**:**

- Types of the material used in the construction.
- Span length.
- Construction shape.
- Span types.
- Load path Characteristics.
- Purpose and usage.
- Position.
- Deck type.

4. Categorization Based On Construction Material:

Generally, bridges can be categorized based on the type of the materials which are used in their superstructure which are built from:

- Concrete.
- Steel.
- Timber.

Therefore, bridges are named based on the material they are built from. Such as Steel Bridge, Concrete Bridge or Timber Bridge. Usually, the materials are combined to create the bridge. For example, the deck slab gets made by concrete and so does the foundation. However, the beams are usually made from steal or reinforced concrete despite the structure.

I. Concrete Bridges:

More bridges are built using concrete than any other material worldwide, demonstrating continued confidence in the material's performance and durability. Concrete bridges have a clear track record of flexibility and versatility in terms both of final forms and methods of construction that is hard to match. Concrete bridges are, mainly, composed of two types which are Pre-Stressed and Reinforced Concrete *RCC*. The Pre-Stressed concrete bridges contain reinforced concrete deck supported by pre-stressed concrete beams. However, concrete bridges, components of bridges including: deck, stringer and parapets are made of reinforced concrete.

II. Steel Bridges:

Steel is widely used around the world for the construction of bridges from the very large to the very small. It is a versatile and effective material that provides efficient and sustainable solutions. It dominates the markets for long span bridges, railway bridges, footbridges, and medium span highway bridges. Which are usually require superstructure that is based on steel to meet the requirements and the purpose of that building.

III. Timber Bridges:

A timber bridge or wooden bridge is a bridge that uses timber or wood as its main structural material. One of the first forms of bridge, those of timber have been used since ancient times. They are not used in big constructions.

5. Composite Bridges:

'Composite' means that the steel structure of a bridge is fixed to the concrete structure of the deck so that the steel and concrete act together, so reducing deflections and increasing strength. This is done using 'shear connectors' fixed to the steel beams and then embedded in the concrete. Shear connectors can be welded on, perhaps using a 'stud welder', or better still on export work, by fixing nuts and bolts. Most important, these composite materials don't show their full potential till they are mixed properly with steel and concrete. This type of bridges can handle high strength.

6. Classification by Span Length:

One of the most important factors that Civil Engineers consider is the span length of the bridge. Therefore, these bridges are classified upon: long, medium and short span length. There are no standards for the span lengths of bridge. Classification of span length varies upon several organizations practices and standards.

I. Short Span Bridges:

The kind of bridges what the engineers would believe to be the highest load that the bridge should handle is a medium sized car is known as a short span bridge. In case of lack of information regarding the details of the bridge, the following can be useful:

Short span bridges = ranging from 6 – 38 meters.

II. Medium Span Bridges:

For various kinds of bridges in which the capacity of the bridge is described by a train the sort of bridge is known as a medium span bridge. In case of lack of information regarding the details of the bridge, the following can be useful:

Medium span bridges= ranging from 38 – 122 meters.

III. Long Span Bridges:

For these various types of bridges that are planned to lift a high load, these bridges can take up a train and 2 direction roads. It is also needed to have a larger, more sophisticated kind of structure to receive a high load. Truss structured bridges are those used in such events like constructing sports complex, highways, etc.

7. Classification By Structural Form:

Based on engineering perspective, the design of the bridges based on its purpose classifies the type of bridges. All of which plays an important role at the end on the analysis and work design has to be done in order to make difference in final outcomes. In most cases, structural form of a bridge refers to the mechanism of resistance a bridge can handle.

I. Slab Stringer Bridge:

In a slab stringer bridge, the deck is backed up by stringers in which themselves backed up by abutments or on piers span or multiple span bridges. These kinds of bridges are often constructed from reinforced concretes. Stringers would be created from steel, reinforced concrete or Pre-Stressed concrete. The slab stringer system is often beneficial for short span bridges.

II. Truss Bridges:

Truss bridge is one of the various types of bridges, whom are allocated by the architecture of the researcher's estimation of organizing the components in the style of triangles, any pile group of similar components are merged of steel or wood. These bridges are constructed out of collections of metal structures and metal rods, which are composed of the most frequent kinds of straight chains of steel bars. Praises bridges journey softly along the limited roads such as mountain valleys, rivers and other major bridge features as continued greater than 300 m.

III. Rigid Frame Bridges:

The Rigid Frame Bridge is one of the bridges in which the superstructure and substructure are rigidly similar to operate as a non-stop unit. Frequently, the form is forged monolithically, creating the form non-stop from deck to foundation. The relations between people are rigid relations which mix bending moment, axial forces, and shear forces. A bridge blueprint is comprehensive of a rigid frame that can add extensive structural benefits, however this bridge may also be hard to blueprint and/or build.

IV. Arch Bridge:

The Arched Bridge which is one of the oldest kinds of bridges composed of components assembled at the end of the curved arch. These kinds of bridges start out with the movement of the weightage of the bridge moderately in parallel direction by the components on both directions. Bridges may be long arcs, composed of a sequence of arches. These bridges are conducted by the Central Powers because of the arcs ability to exercise pressure on the central axis powers. This type of bridges has many structures that differ by geographic region, revolving around the style of the engineering designer who selects the structure of the bridge.

V. Cable Stayed Bridge:

The Cable stayed bridge is a bridge composed of a tower or column of one or more surfaces through metal cables. There are two important kinds of cable stayed bridges: The first is the design of the harp, secondly is the design of the fan. The taut cables of the bridge are the most civilized bridges, containing endless girders towards the bridge and towers, metal cables moves at an angle to connect between the bridge and the body of the Balata camp. Usually the mean length of these kinds of bridges range from 500 to 2800 feet.

VI. Suspension Bridges:

The suspension bridge is a type of bridge in which the deck (the load-bearing portion) is hung below suspension cables on vertical suspenders. The first modern examples of this type of bridge were built in the early 1800s.[3][4] Simple suspension bridges, which lack vertical suspenders, have a long history in many mountainous parts of the world. This type of bridge has cables suspended between towers, plus vertical suspender cables that carry the weight of the deck below, upon which traffic crosses. This arrangement allows the deck to be level or to arc upward for additional clearance. Like other suspension bridge types, this type often is constructed without false work. The suspension cables must be anchored at each end of the bridge, since any load applied to the bridge is transformed into a tension in these main cables. The main cables continue beyond the pillars to deck-level supports, and further continue to connections with anchors in the ground. The roadway is supported by vertical suspender cables or rods, called hangers. In some circumstances, the towers may sit on a bluff or canyon edge where the road may proceed directly to the main span, otherwise the bridge will usually have two smaller spans, running between either pair of pillars and the highway, which may be supported by suspender cables or may use a truss bridge to make this connection. In the latter case there will be very little arc in the outboard main cables (Wikipedia, 2018).

8. Classification By The Span Type

Bridges are often classified similarly in accordance with their span in respect with the load this bridge will handle.

I. Simple Span Bridge

Simple span bridges cross from one support to another and can be joined together to create a longer span. Continuous span bridges cross from one side to the other with one structural beam truss, or arch. Cantilevered bridges are supported at one end or in the middle and are often held up by tensile suspension (next, 2018).

II. Continuous Span Bridge

The continuous span provides beam bridges the capability to cover various distances. A single beam bridge barely covers greater than 250 feet. In the Chesapeake Bay Bridge-Tunnel, various beam bridges may be connected together, constructing what is called a continuous span.

9. Classification of the Bridges According to their Utility

Besides the bridges that are created for highways and railways uses. There are bridges designed for non- vehicular uses like:

Pedestrians bridges.

Pipeline bridges.

Conveyor bridges.

10. Classification According to the Deck Type of the Bridge

Solid slab, steel girder, grid, simple beam and slab, multicellular, and Spaced beam and slab.

11. Bridge Structure

All bridges can be divided into 3 main criteria which are superstructure, bearings, and substructure.

I. Superstructure

This part of the bridge moves the capacity received from the carriageway into the floor.

II. Bearings:

Bearings used in bridge structure could be categorized into 2 groups which are metal and elastomeric. Both types are usable for different purposes and requirements.

III. Substructure:

It consists of piers and abutment shafts or walls, hammerhead, bed block, pedestals and bearings and various other components.

12. Girder Bridge:

A steel girder bridge is a bridge in which the main beams comprise girders in the shape of a I shape. A girder may be made of concrete or steel. Many shorter bridges, especially in rural areas where they may be exposed to water overtopping and corrosion, utilize concrete box beams. The term "girder" is typically used to refer to a steel girder. In a girder or beam bridge, the girders themselves are the primary support for the deck, and are responsible for transferring the load down to the foundation. Material type, shape, and weight all affect how much weight a beam can hold. Due to the properties of inertia, the height of a girder is the most significant factor to affect its load capacity (Wikipedia, 2018).

13. Bracing:

The structural members that are positioned transversely between the adjacent girders at suitable intervals are the bracing. The bracing used to provide the lateral distribution of live load at various adjacent girders.

CHAPTER 3

Investigative Procedure:

1. Introduction
2. Adopted Strategy For Analysis
    I. Selection of Cross Section
    II. Defining Loads
    III. Analysis and Design

CHAPTER 3: INVESTIGATIVE PROCEDURE

1. Introduction:

The below dialogue chapter outlines the mathematical and geometric simplifications required for calculating critical failure stresses due to the extreme situations that could increase in a bridge.

2. Adopted Strategy For Analysis:

The adopted strategy for the fulfillment of the bridge project was the following strategy.

I. Selection of Cross Section:

The empirical formulas established in engineering codes used in assuming the depth of the girder.

II. Defining Loads:

The factors of the dead loads and live loads have taken from AASHTO. Moving load has taken from Ministry of Municipality and Rural Affairs (MOMRA) code.

III. Analysis and Design:

The design and analysis of the bridge components is performed by using specific formula after the loads are assigned, SAP2000 and CSI Bridge civil engineering software are used for complex analysis finite element then the analysis results are used to design the element manually.

CHAPTER 4

Design Calculation for the Steel Bridge:

1. Limitations
2. Loads Calculation
3. Slab Design
4. Steel Girder Design
5. Bracing Design
6. Elastomeric Bearing Design
7. Pier Cap Design
8. Pier Design

CHAPTER 4: DESIGN CALCULATION FOR THE STEEL BRIDGE

1. Limitations

- Depth of I-Beam Steel Girder $\geq 0.040L$ (MOMRA, table 2.1, page 22)
- Assuming distance between girders (center to center) = 1.5 m
- Total number of girders = $\frac{16.5}{1.5}$= 11 girders
- Minimum concrete slab thickness $= 175\ mm$ (MOMRA 7.7.2.4 , page 760)
- Minimum $C_{Top} = 50\ mm$, $C_{bottom} = 25\ mm$, $Reinorced\ Core = 100\ mm$ (MOMRA Table 5.14 , page 356)
- Assuming Asphalt thickness = $75\ mm$ (AASHTO)
- Traffic Parapet, Height = 810 *mm*, Width = 430 *mm* (MOMRA 11.7.3.2 ,page 1171)
- Concrete not less than fc' 28 MPa (ACI 318 , page 227)
- Safety factors for dead and moving load are 1.3, 1.6
- Densities (MOMRA Table 3.4)
  - Density of Concrete = 2392 kg/m^3 = 23.92 kN/m^3
  - Density of Steel = 7850 kg/m^3 =78.50 kN/m^3
  - Bituminous wearing surface = 2250 kg/m^3 = 22.50 kN/m^3

2. Loads Calculation

note: Load is calculated for one typical girder

1- Dead Load:

- Asphalt = $(1.5\ m) \times (0.075\ m) \times (23.47\ \ kn/m^3) = 2.64\ kN/m$
- Concrete slap = $(1.5\ m) \times (0.175\ m) \times (23.47\ kn/m^3) = 6.16\ kN/m$
- Girder self-weight = $(0.16064\ m^2) \times \left(78.50\ \frac{kn^3}{m}\right) = 12.611\ kN/m$
- Bridge Railing = $(0.810\ m) \times (0.430\ m) \times (23.47\ \ kN/m^3) = 8.33\ kN/m$

Total Dead Load = 29.58 kN/m

2- Moving Load:

- Truck Load (MOMRA 3.6.1.2 / figure 3.1 , page 54)
- Design lane load
  - 20 kN/m^3 uniformly distributed in the longitude direction
  - Transversely, the design lane load shall be assumed to be uniformly over $3m$ widt.

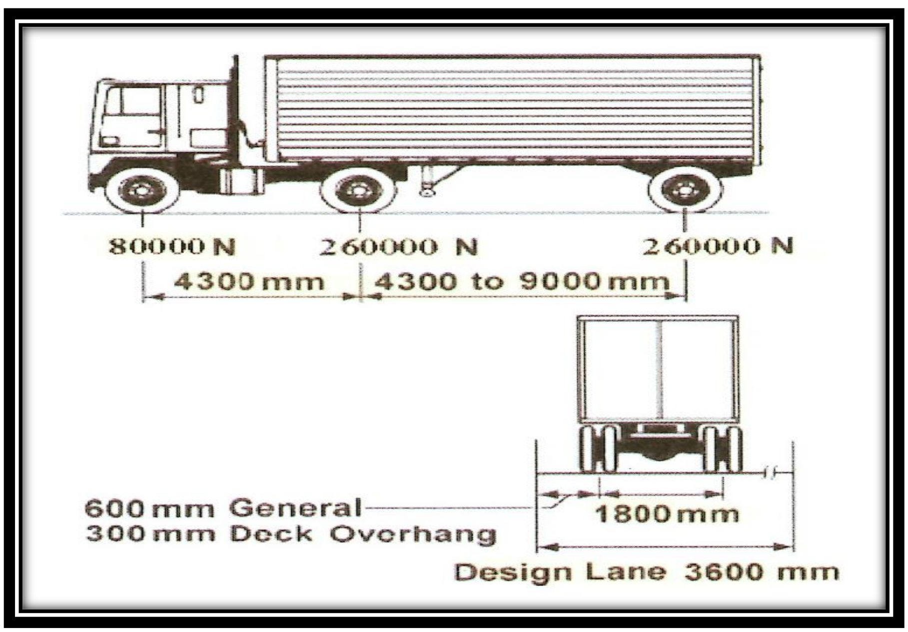


***Figure 9** Truck load*

3- Earthquake Load (AASHTO, ch3 , page 3.34)

<u>From AASHTO 3.9.10.2:</u>

Assume seismic zone = 1

Acceleration coefficient, as, ≤ 0.05

Horizontal design $\geq 0.15\times$vertical reaction due to permanent load.

Reaction 5969 kN "From CSi-Bridge"

Horizontal force = $0.15\times 5969 = 895.35$ kN

Moment on pier due to earthquake load is:

$M = 895.35 \text{ kN} \times 3.5 \text{ m} = 3133.725 \text{ kN-m}$

- Seismic zones – (AASHTO, Table 3.10.6.1):

  Assume acceleration coefficient, $S_{D1} = 0.1$

  ⇨ Seismic zone 1

- Site class – (AASHTO, Table 3.10.3.1.1):
  A: Hard rock with shear wave velocity, $\overline{V} > 5000$ ft/s

- Site Factor, F_{pga} at zero period on acceleration spectrum
  $PGA = 0.2 \rightarrow F_{pga} = 1$ →(AASHTO, Table 3.10.3.2.1 , Page 3-91)
  $S_S = 0.5 \rightarrow F_a = 1.0$ →(AASHTO, Table 3.10.3.2.2 , page 3-91)
  $S_1 = 0.5 \rightarrow F_v = 1.0$ →(AASHTO, Table 3.10.3.2.3 , page 3-91)

Assume period is greater than or equal to

$C_{ms} = S_{DS}$

$S_{DS} = Fa\ S_s = (1.0)(0.5) = 0.5$

⇨ $C_{ms} = 0.5$

4- Wind Load (AASHTO 3.10.9.2 , page 3-96)

Assume wind velocity = 100 mph

Table 3.8.1.2.1.1 →The base Pressure, P_B = 0.05 (AASHTO, Table 3.8.1.2.1-1, page 53)

Minimum wind load = 0.3 kips/ft

Table 3.8.1.3.1 →skew angle = 0

- ⇨ Normal component “Transvers” = 0.1 kips/ft
- ⇨ Parallel component “Long” = 0

The design wind pressure: (AASHTO, page 3.38)

$P_D = P_B \frac{V_{DZ}^2}{10,000}$

$V_{DZ} = 2.5\, V_o (\frac{V_{30}}{V_B}) \ln(\frac{Z}{Z_o})$

For structure in open country →V_o = 8.2

Z_o = 0.23

Assume V30 = V_B = 100 mph

$V_{DZ} = 2.5\,(8.2) \ln(\frac{31.49}{0.23}) = 101$ mph

$P_D = P_B \frac{(102)^2}{10,000} = 1.02\, P_B$

Long Area = $(\frac{30}{0.3048})(\frac{1.5}{0.3048})$ **= 484 ft²**

Transverse Area = $\left(\frac{16.5}{0.3048}\right)\left(\frac{1.0795}{0.3048}\right)$ **= 191.72 ft²**

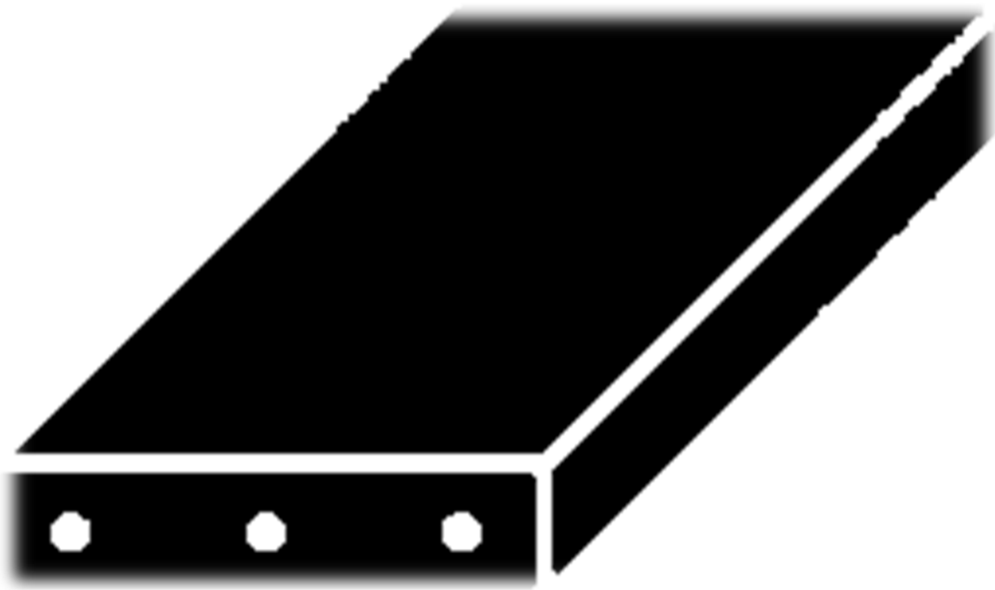
Zero degree skew Angle

V_{Long} = (484)(0)(1.02) = 0

$V_{Transvers}$ = (191.72)(0.04)(1.02) = 7.822176 kips => 34.7948kN

The moment due to wind on the pier is

M = 7.8 kips × 8 ft = 85.8 kips-ft = 116.33 k N-m



Steel Bridge

(Slab Design)

3. Slab Design for Steel Bridge

$M_{Max} = 80.25\ kN.m$ (From CSI-Bridge)

$f_c = 28\ MPa$

$f_y = 420\ MPa$

$$R_u = \frac{M_{Max}}{0.9bd^2} = \frac{80.25 \times 10^6}{0.9(1000)(175)^2} = 2.92\ N/mm^2$$

$$\rho = \frac{0.85f_c}{f_y}(1 - \sqrt{1 - \frac{2R_u}{0.85f_c}})$$

$$\rho = \frac{0.85(28)}{420}(1 - \sqrt{1 - \frac{2(2.057)}{0.85(28)}}) = 0.007441$$

$$A_s = \rho bd = 0.007441\ (1000)(175) = 1302.175\ mm^2$$

Use $\phi\ 16\ mm\ \rightarrow \#\ of\ bars = \frac{1302.175}{\frac{\pi}{4}(16)^2} = 6.476487$

Take 5 bars for each 1 m

$7\#\ 16\ mm$

Spacing between the bars ≈ 170 mm c/c

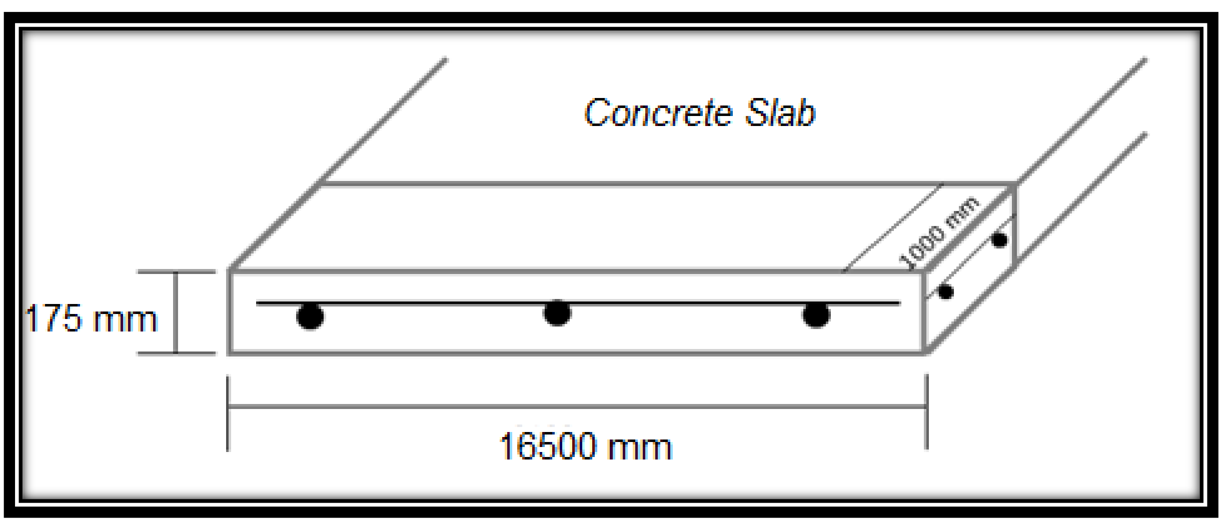
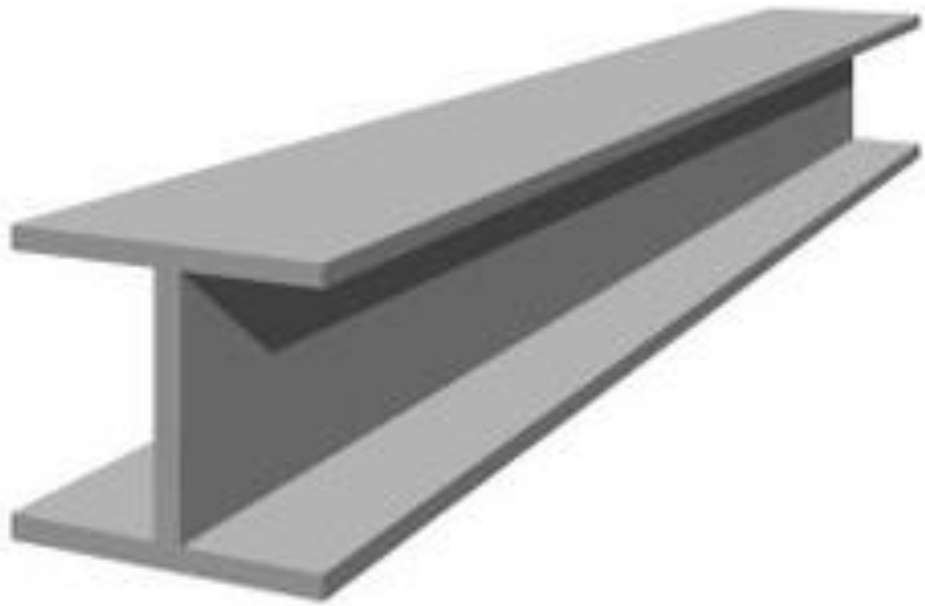


Figure 10 *Reinforced slab dimensions*



Steel Bridge

(Girder Design)

4. Steel Girder Design for Steel Bridge

Finding allowable deflection:

Modulus of Elasticity E = 200 GPa

$$\delta = \frac{5\,(w)(L)^4}{384\,E\,I} + \frac{Pb\,(L^2 - b^2)^{3/2}}{(9\sqrt{3})\,(L)EI} + \frac{Pb\,(L^2 - b^2)^{3/2}}{(9\sqrt{3})\,(L)EI} + \frac{Pb\,(L^2 - b^2)^{3/2}}{(9\sqrt{3})\,(L)EI}$$

$\delta = \frac{30 \times 1000}{800} =$ 37.5 mm = 0.0375 m

Determining moment of inertia:

$$0.0375 = \frac{5\,(16.68)(30)^4}{384\,(200 \times 10^6)(I)} + \frac{40\,(30^2 - 20.662^2)^{3/2}}{(9\sqrt{3})(30)(200 \times 10^6)(I)} + \frac{40\,(30^2 - 16.362^2)^{3/2}}{(9\sqrt{3})(25)(200 \times 10^6)(I)}$$

$$+ \frac{40\,(30^2 - 12.062^2)^{3/2}}{(9\sqrt{3})(30)(200 \times 10^6)(I)} + (0.0130) \times \frac{(20)(30)^3}{(200 \times 10^6)(I)}$$

I = 0.0015 m^4 = 3603.76 in^4

Largest W shape in Steel Construction Manual is:

W36×652:- I = 50,600 in^4

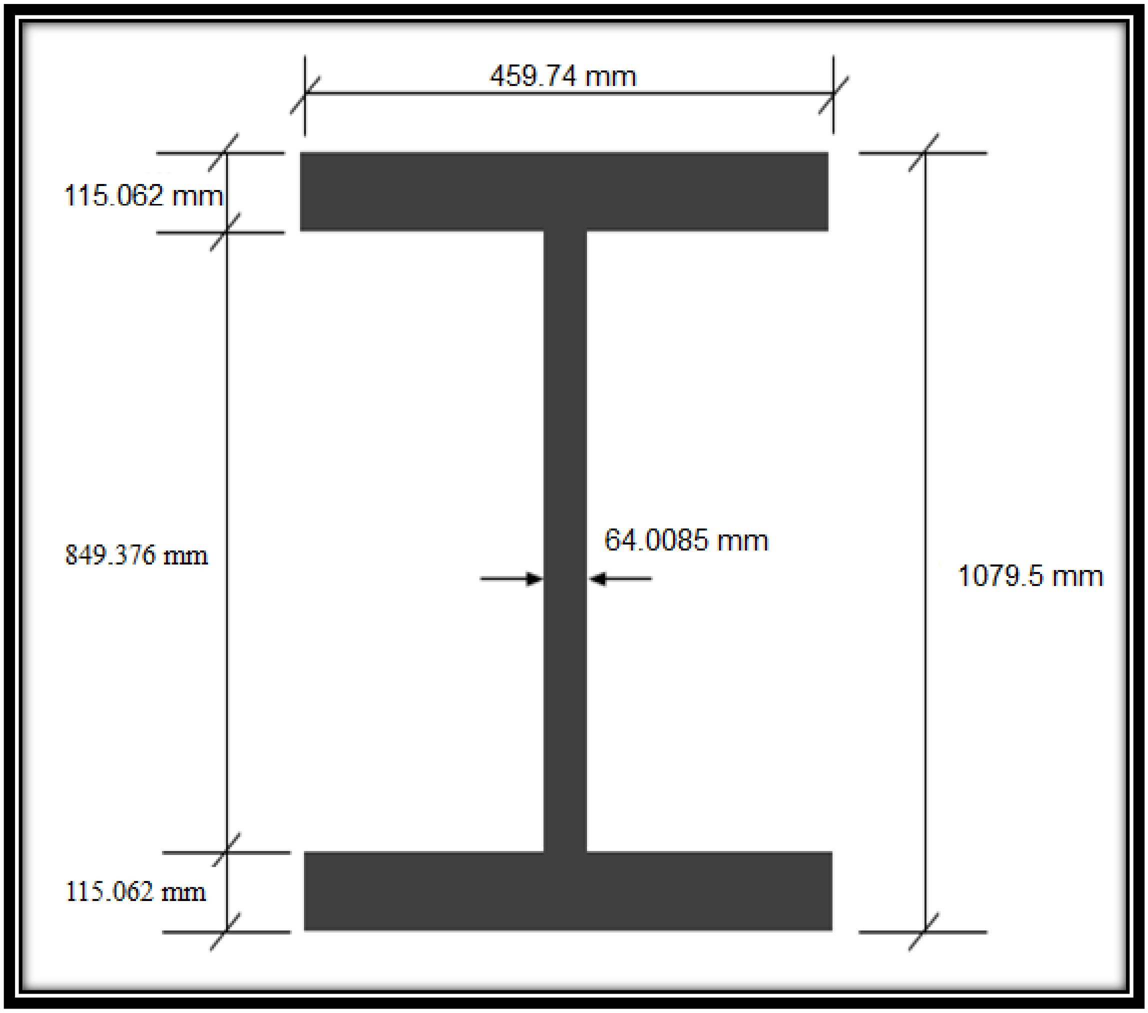


Figure 11 *Steel girder dimensions*

After Two Trials W36X848 section will work

Check for Moment of Inertia:

Modulus of Elasticity E = 200 GPa

$I_x = 67400\ in^4 > I = 3603.7\ in^4$ OK √

Check for Deflection:-

$$\delta = \frac{0.00088}{0.0280384} + \frac{0.000004}{0.0280384} + \frac{0.000007}{0.0280384} + \frac{0.000009}{0.0280384} + \frac{0.000035}{0.0280384}$$

$\boldsymbol{\delta = 0.0333} < 0.0375$ **Acceptable.** √

Finding Shear and Moment (DEAD LOAD):

Wearing surface (Asphalt + Concrete slab + Bridge Railing):

w = 2.64 + 6.2 + 8.2 = 16.973 kN/m

$V = \frac{wL}{2} = \frac{16.973 \times 30}{2} = 254.59$ kN

$M = \frac{wL^2}{8} = \frac{16.973(30)^2}{8} = 1909.42$ kN-m

Girder self-weight:-

Area Total = 249 in^2

A_{Total} = 0.16064484 m^2

w = (0.1606 m^2)(78.5 kn/m^3) = 12.611 kN/m

$V_{max} = \frac{(12.611)(30)^2}{2} = 5674.78$ kN

$M_{max} = \frac{(12.611)(30)^2}{8} = 1418.69$ kN-m

Concrete slab and girder self-weight:-

M_{total} = (1418.69) + (1909.42) = 3328.11 kN-m

V_{total} = (5674.78) + (254.59) = 5929.37 kN

Ultimate (Dead Load):

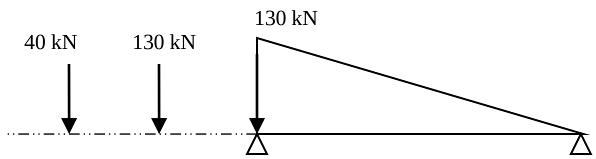
M_u = 1.3 × (3328.11) = 4326.55 kN-m

V_u = 1.3 × (5929.37) = 7708.19 kN

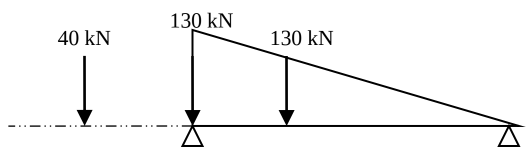
Finding Shear and Moment (MOVING LOAD):

*Note: to find the critical shear and moment due to movable load, influence line method has to be used.

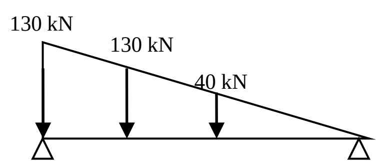
1. *Truck load*
   - Case-1 => $V_{max} = 130\times1 = 130$ kN



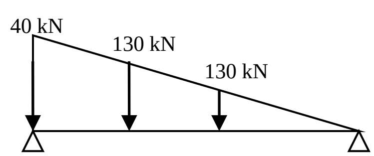
   - Case-2 => $V_{max} = (130\times1) + (130\times\frac{30-8.6}{30}) = 222.73$ kN



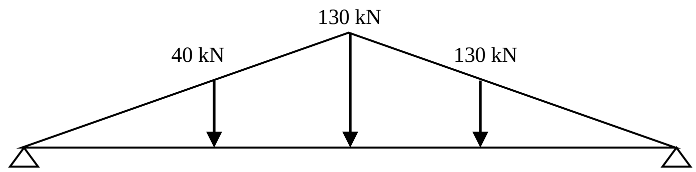
   - Case-3 => $V_{max} = (40\times1) + (130\times\frac{30-4.3}{30}) + (130\times\frac{30-8.6}{30}) = 244.1$ kN



   - Case-4 => $V_{max} = 130 + (130\times\frac{30-4.3}{30}) + (130\times\frac{30-8.6}{30}) = \boxed{334.1\text{ kN}}$



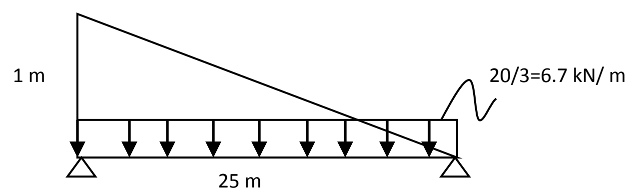
$V_{max} = 334.1$ kN

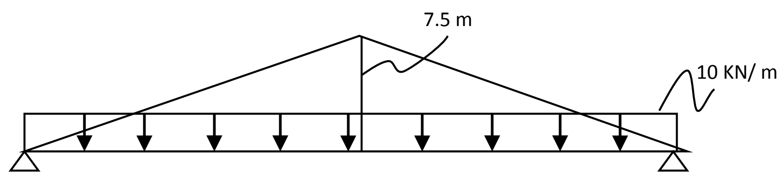


$(15-4.3)(\frac{7.5}{15}) = 5.35$ m

$M_{max} = (40\times5.35) + (130\times7.5) + (130\times5.35) = 1884.5$ kN-m

2. *Lane Load*





$V_{max} = \frac{1}{2}\times 30 \times 1 \times 6.7 = 100.5$ kN

$M_{max} = \frac{1}{2}\times 30 \times 7.5\times 6.7 = 753.75$ kN-m

Ultimate (Moving load)

$M_u = 1.6 \times (753.75 + 1884.5) = 4221.2$ kN-m

$V_u = 1.6 \times (334.1 + 100.5) = 695.36$ kN

Total Moment and Shear:-

$M_{u\ total} = 3802.929 + 3252.707 = \boxed{8547.75 \text{ kN-m}}$

$V_{u\ total} = 603.265 + 556.208 = \boxed{8403.55 \text{ kN}}$

Check for Moment:

F_y = 450 Mpa

$M_{plastic} = F_y \times Z$

$Z = 2\ (0.0.11506)\ (0.45974)\ (0.42469+0.05753) + 2(0.06401\times0.42469)\ (\frac{0.42469}{2})$

$Z = 0.06276246 m^3$

$M_{plastic} = (450\times10^3)\ (0.06276246) = 28243.107$ kN-m

$\emptyset M = (0.9)\ (9414.369) = 25418.7963$ kN-m

$M_{u\ total} = 25418.7963$ kN-m $< \emptyset M = 79951.072$ kN-m **acceptable** √

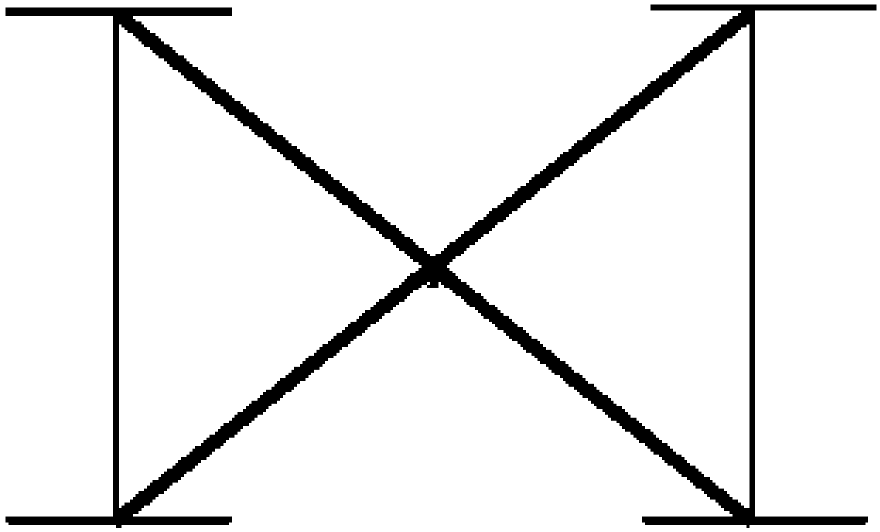
Check for Shear:

F_y = 450 Mpa

$\emptyset V_n = 0.6\ F_y\ A_w\ C_r$

$\emptyset V_n = 0.6 \times (450\times10^3)(\ 0.085\times0.9)(1) = 20639.84$ kN

$V_{u\ total} = 8403.545919512$ kN $< \emptyset V_n = 20639.84$ kN **acceptable** √



Steel Bridge

(Bracing Design)

5. Bracing Design for steel Bridge

$r_y = \sqrt{\frac{I_y}{A}}$

From Section Data sheet

$I_y = 0.0018928\ m^4$

$A = 0.160645\ m^2$

$r_y = \sqrt{\frac{(0.0018928)}{(0.160645)}} = 0.108547233\ m \rightarrow 4.27351311\ in$

$E = 29{,}000\ ksi$, $Fy = 50\ ksi$

$Lp = (1.76)(r_y)(\sqrt{\frac{E}{Fy}})$

$Lp = (1.76)(4.27351311)(\sqrt{\frac{29000}{50}}) = 181.14\ in \rightarrow 15.10\ ft$

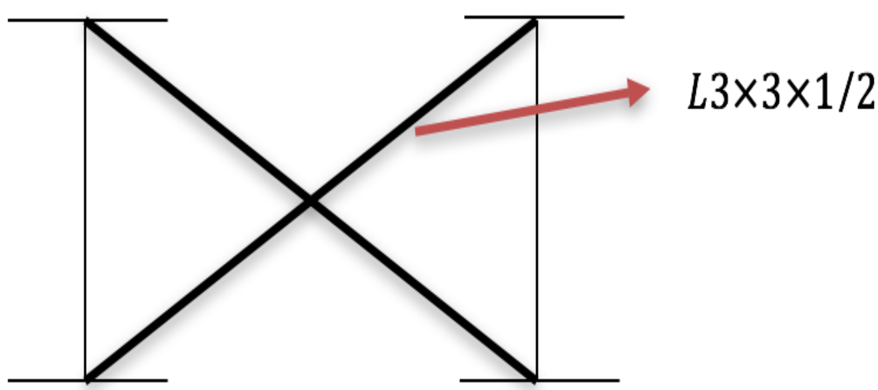
$Lp = 4.600927839\ m$, use => $\boxed{Lp = 5\ m}$

$\lambda = \frac{K\,L}{r}$

$V = 1029.46\ kN$

$P_n = 70\ kN \rightarrow P_n = 15.74\ kips$

Choose section L3×L3×1/2



$Ag = 2.76\ in^2$,

$P_n = 39.7\ kips$,

$r_y = 0.895\ in$

$\lambda = \frac{(1)(6)}{0.895} = 6.7 \rightarrow 7$

$F_{cr} = 32.3\ ksi$

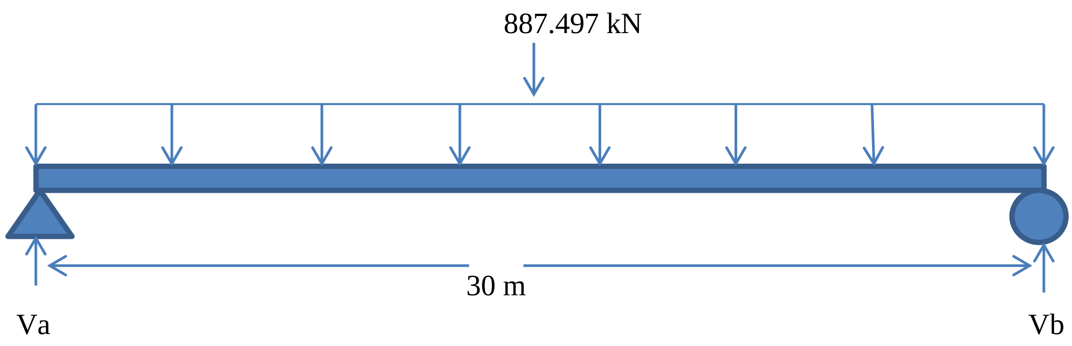
$P_{cr} = (32.3)(2.76) = 89.148\ kips > 15.7366\ kips$ √ ok!

Steel Bridge

(Elastomeric Bearing Design)

6. Elastomeric Bearing Design for steel Bridge

Dead Load:-



$Va = 936 \div 2 = 443.75\ kn$

$Vb = 936 \div 2 = 443.75\ kn$

Live Load:-

1- Truck Load:

F''= 334.1 KN "From movable load and influence line''

2- Lane Load:

F'''= 100.5 KN "From influence line shown previously"

$Mgr = (r_{skew}) \times (mg) = 0.826$

$Mgr = (0.826) \times (1) = 0.826$

$VLL = (0.826) \times (100.5 + 334.1) = 358.98\ kN$

$VDL = 443.75\ kN$

$VT = 802.73\ kN$

$\Delta T = 20 — 12 = 32°C$

The thermal coefficient $(\alpha) = 10.8 \times 10^{-6}\ m/mm/°c$ for normal density of concrete (for Abutment)

$$\varepsilon iemp = \alpha\Delta T = 10.8 \times 10^{-6}(32) = \ 0.000346$$

$\varepsilon su = 0.0002\ For\ 28\ days\ and\ 0.0005\ For\ 1\ year$

$\varepsilon su = 0.0005 - 0.0002 = 0.0003$

$rTv = 1.2\ (Table\ A3.4.1 - 1)$

Max $\Delta s = \gamma Fu\ le\ (\varepsilon\ temp + \ \varepsilon\ Jh)$

M $\Delta s = (1.2)(30 \times\times 10^3\ )(0.000346 + 0.0003) = 23.256\ mm$

$hrt \geq 2\Delta s = 2(23.256) = 46.512\ mm$

Design:

$hrt = 100\ mm, hri = 25\ mm, L = 400\ mm, B = 500\ mm$

$$\sigma_s = \frac{R}{LW} = \frac{802728.2467}{(500)(400)} = 4.014\ Mpa < 11\ Mpa\ Ok$$

$$S = \frac{LW}{2hri(L+W)} = \frac{(400)(500)}{2(25)(400+500)} = 8.89$$

$$= (1.66)(0.95)(8.89) = 14.02\ Mpa > 6.3\ Mpa\ Ok$$

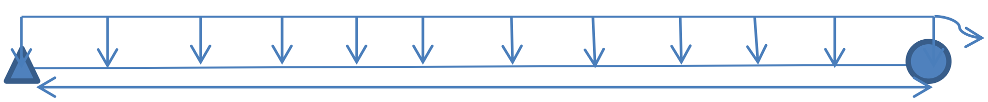
$$\sigma_L = \frac{358979.60}{(500)(400)} = 1.79\ Mpa < 11\ Mpa\ Ok$$

$$= (0.66)(0.95)(8.89) = 5.57\ Mpa > 2.4\ Mpa$$

$$\delta = \sum \mathcal{E}_i hri = 4(0.05)(25) = 5\ mm$$

$$\theta_{Max} = \frac{2\delta}{L} = \frac{2(5)}{400} = 0.025\ rad$$

-Dead Load:



$$M_D = \frac{Wl^2}{8} = \frac{29.58\ (30^2)}{8} = 3328.11\ KN.m = 3328.\times 10^6\ N.mm$$

$$\theta_{D1} = \frac{Wl^3}{24EI} = \frac{(29.58\ )(30000^3)}{24(10128 \times 10^{12})} = 0.003286053\ rad$$

$$\theta_{D2} = \frac{M_D L}{6EI} = \frac{(3328.11 \times 10^6)(30,000)}{6\ (10128 \times 10^{12})} = 0.001203\ rad$$

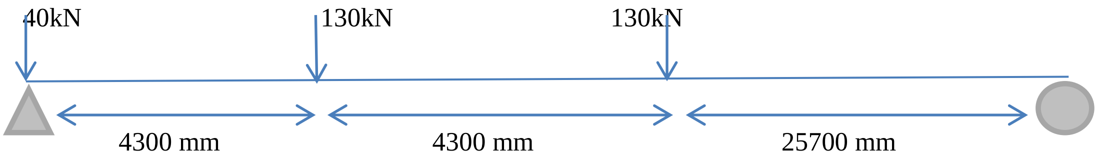
$$\theta_{Di} = \theta_{D1} - \theta_{D2} = 0.003286053 - 0.001643024 = 0.001643029$$

$$\theta_{Dc} = -(\theta_{Di} + \lambda\theta_{Di}) = -(1+\lambda)\theta_{Di}$$

$$\lambda = 1\ (\ creep\ factor\ )$$

$$\theta_{Dc} = -(1+1)(0.001643029) = -0.003286058\ rad$$

- Moving Load:



$$\theta_{L1} = \frac{Pab}{6EIl}(a+2b) = \frac{(130\times10^3)(4300)(25700)}{6(10128\times10^{12})(30000)}\big(4300+2(25700)\big) = 0.000438939\,rad$$

$$\theta_{L2} = \frac{(130\times10^3)(8600)(21400)}{6(10128\times10^{12})(30000)}\big(8600+2(21400)\big) = 0.000674563\,rad$$

$$M = 1722\,KN.m = 1722\times10^6 N.mm$$

$$\theta_{L3} = \frac{-ML}{6EI} = \frac{-(1722\times10^6)(30000)}{6(10128\times10^{12})} = -0.000850118\,rad$$

$$\theta_L = mgr(\textstyle\sum\theta_i) = (0.746)(0.000438939 + 0.000674563 - 0.000850118)$$

$$= 0.000196484\,rad$$

$$\theta_s = \theta_{DS} + \theta_L \pm \theta_{unk}$$

$$\theta_{unk} = \pm 0.005\,rad$$

$$\theta_s = -0.00293 + 0.000169 \pm 0.005$$

$$\theta_s = -0.001873516\,rad\ or\ \theta_s = 0.008126484\,rad$$

$$\theta_s = 0.001873516\,rad < \theta_{Max} = 0.008126484\,rad\ Ok$$

$$\sigma_{up\,min} = 1(G)(S)(\frac{\theta_s}{n})(\frac{B}{hri})^2$$

$$\sigma_{up\,min} = 1(1.2)(1.2)(4.3)(\frac{0.0.00813}{3})(\frac{400}{25})^2 = 4.294\,Mpa\ < \sigma_s = 8.8\,Mpa\ Ok$$

$$\sigma_{cMax} = (1.875)(G)(S)(1-0.2(\frac{\theta_s}{n})(\frac{L}{hri})^2$$

$$\sigma_{cMax} = (1{,}875)(0.95)(4.3)(1-0.2(\frac{0.00813}{3})(\frac{400}{25})^2 = 6.6\,Mpa > \sigma_s = 4.014\,Mpa\ \boldsymbol{Ok}$$

Stability of Elastomeric Bearings:

$\sigma_s \leq \sigma_{cr} = \frac{G}{2A-B}$ G=0.95

$$A = \frac{1.92\frac{hrt}{L}}{S\sqrt{1+\frac{2.0L}{W}}} = \frac{1.92\frac{100}{400}}{4.9\sqrt{1+\frac{2(400)}{500}}} = 0.061$$

$$B = \frac{2.67}{S(S+2)(1+\frac{L}{4.0W})} = \frac{2.67}{4.9(4.9+2)(1+\frac{400}{4(500)})} = 0.0658$$

$$\sigma_{cr} = \frac{0.95}{2(0.0658)-0.0658} = 13.41\ Mpa$$

$$\sigma_s = 4.012\ Mpa \leq \sigma_{cr} = 13.41\ Mpa$$

Reinforcement:

At service limit state

$$hs \geq \frac{3h_{Max\ \sigma_s}}{Fy} = \frac{3(20)(4.012)}{345} = 0.6977\ \text{mm}$$

At fatigue limit state

$$hs \geq \frac{3h_{Max\ \sigma_L}}{\Delta F_{TH}} = \frac{2(20)(2.4)}{165} = 0.58\text{mm}$$

- Summary:

The total thickness of the bearing pad is:

$3\ interior\ layers \times 20mm = 60\ mm$

$2\ exterior\ layers\ \times 10mm = 20\ mm$

$4\ reinforcement\ \times 1.1mm = 4.4\ mm$

$The\ Total\ Thickness = 84.4\ mm$

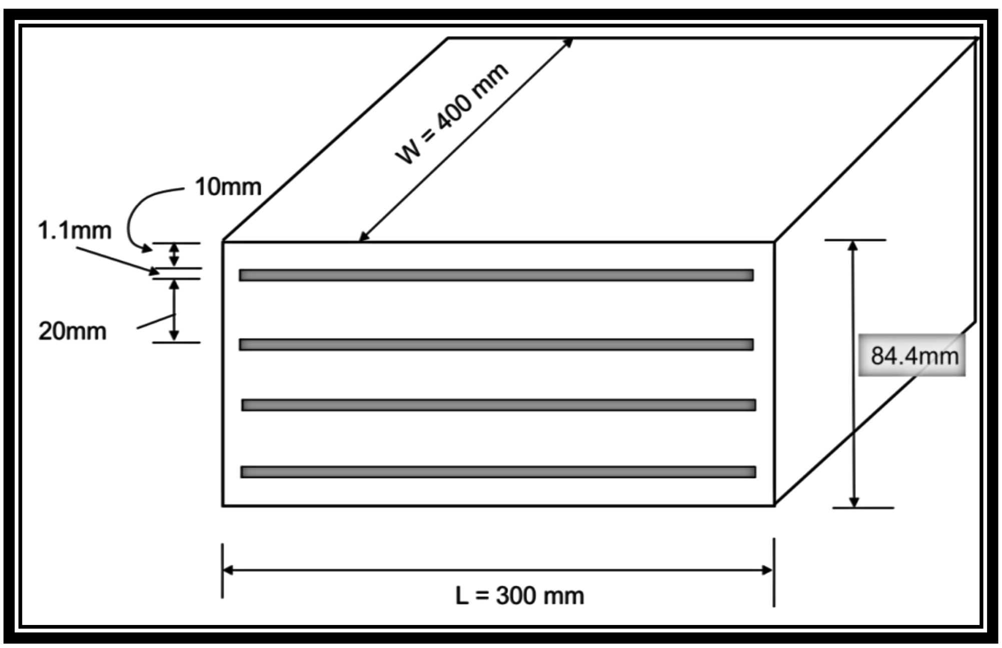
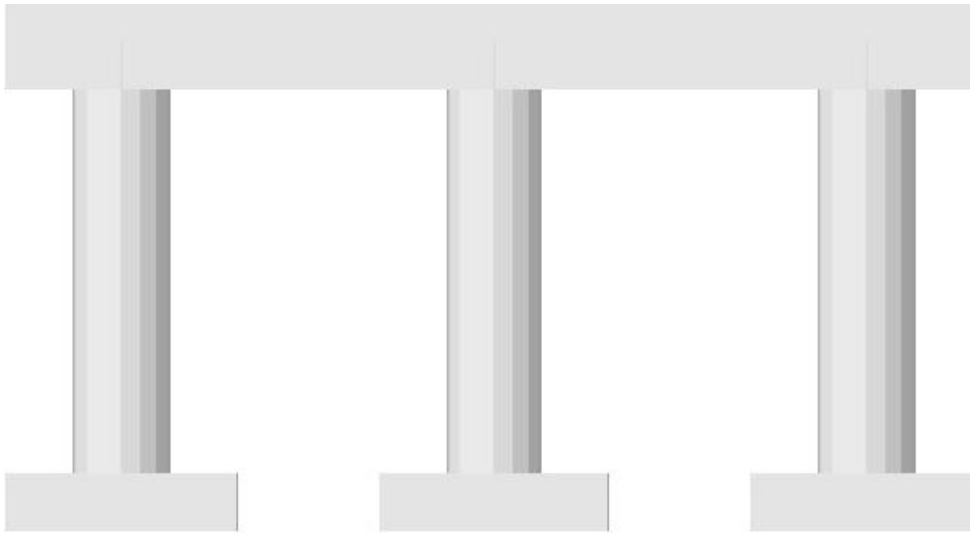


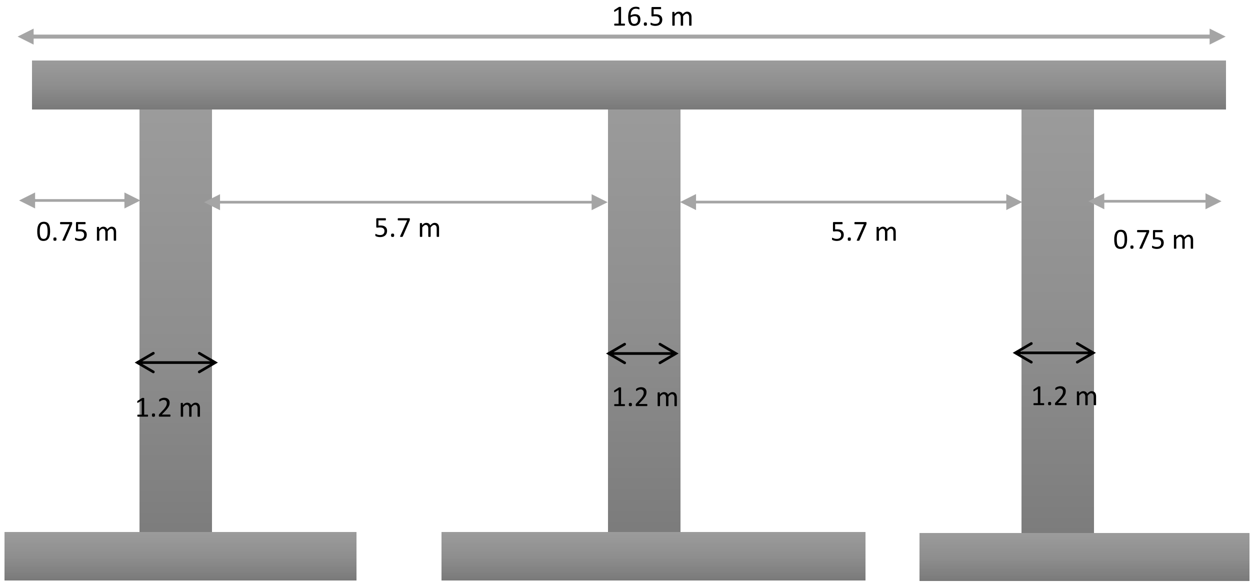
Figure 12 *Bearing dimensions*



Steel Bridge

(Pier Cap Design)

7. Pier Cap Design for Steel Bridge



- **Dead load:**

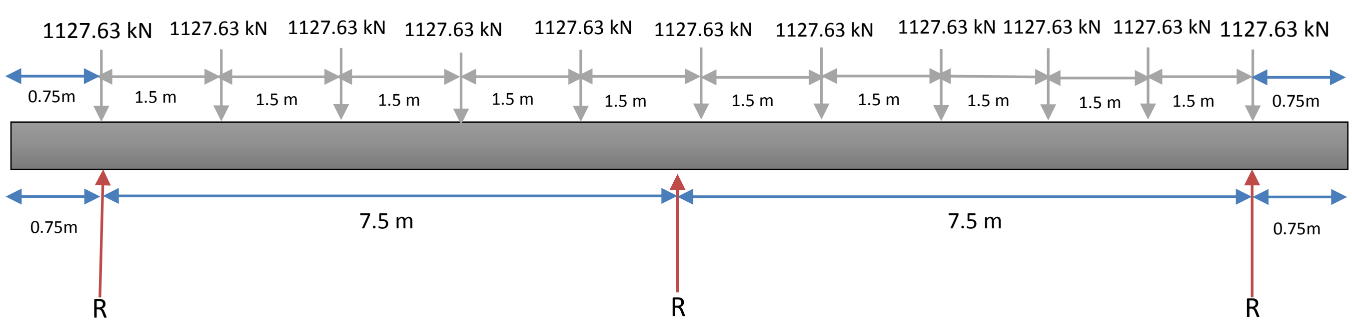
$F = 443.748\ KN$
$Fu = (443.748)(1.2) = 561.6\ kN$

- **Truck load:**

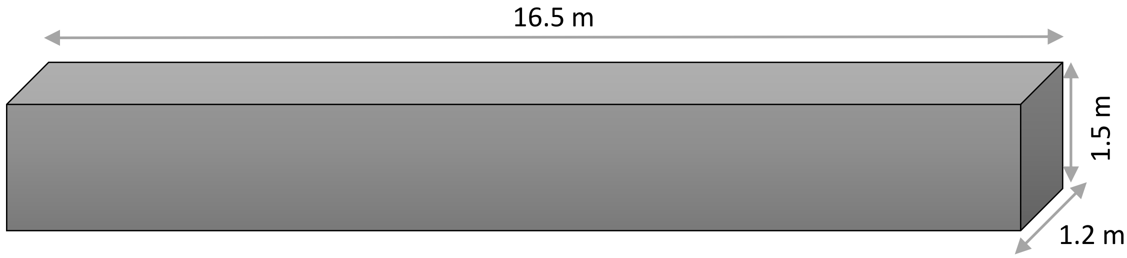
$F = 263.88\ kN$
$Fu = (263.88)(1.6) = 434.33\ kN$

- **Land load:**

$F = 334.1kN$
$Fu = (100.5)(1.6) = 160.8\ kN$
$Fu = (532.50 + 434.33 + 160.80) = 1127.63\ kN$

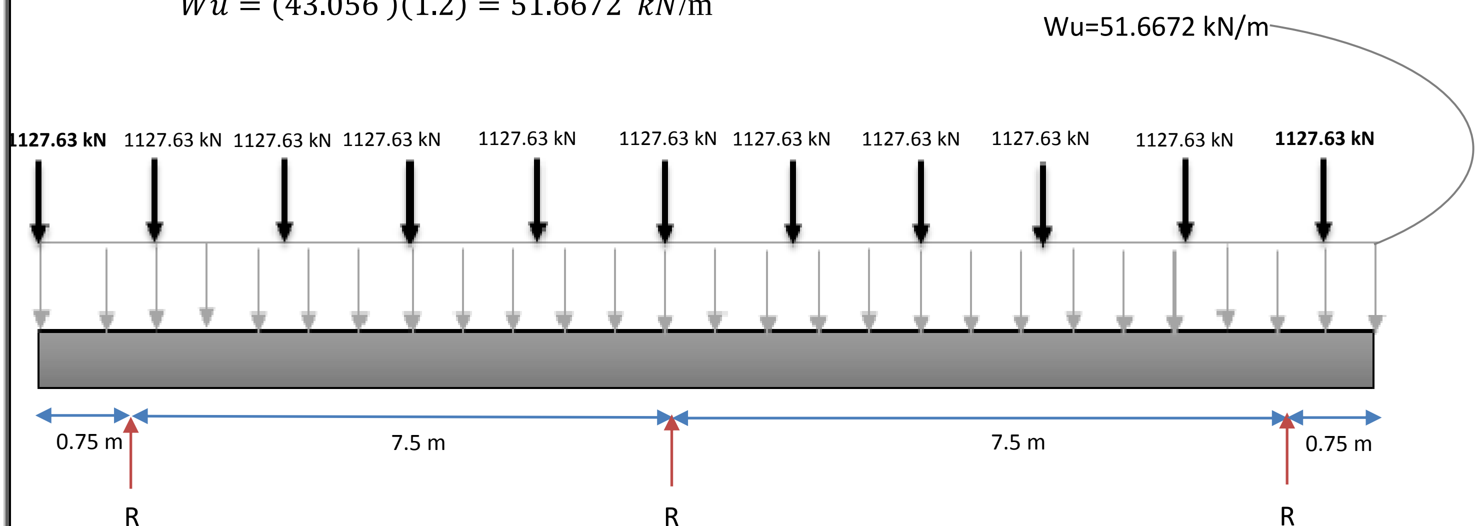


Design the cap:



- Self-weight:

$$W = (1.2)(1.5)(23.92) = 43.056\ kN/\mathrm{m}$$
$$Wu = (43.056\ )(1.2) = 51.6672\ \ kN/\mathrm{m}$$



- From CSi-Bridge:

$$Mmax = -1360.13\ kN.m$$
$$Mmax = 1207.72\ kN.m$$
$$Vmax = 2690.26\ kN$$
R = 5969 kN

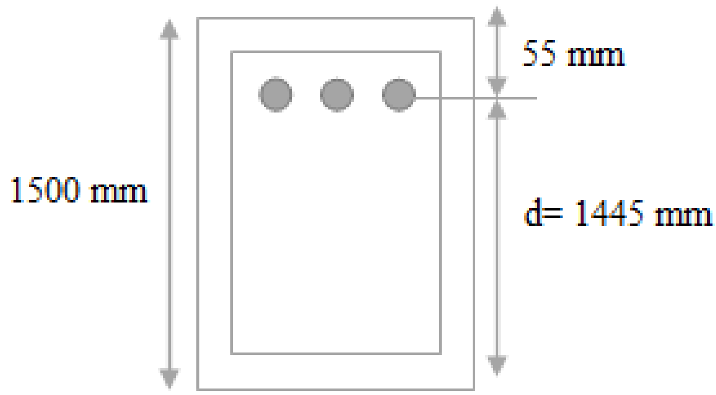
- **<u>Design The cap:</u>**

$$Mmax = -1360.13\ \ kN.m$$

$$Mmax = 640\ \ kN.m$$

$$Vmax = 1400\ kN$$

Design the top reinforcement base on the negative moment:



$M = \emptyset A_S fy(d - \frac{a}{2})$

$M = 1360.13 \times 10^6\ N.mm$

$$a = \left(\frac{A_s fy}{0.85(fc)(b)}\right) = \frac{(420)(A_s)}{(0.85)(28)(800)} = 0.02206A_s$$

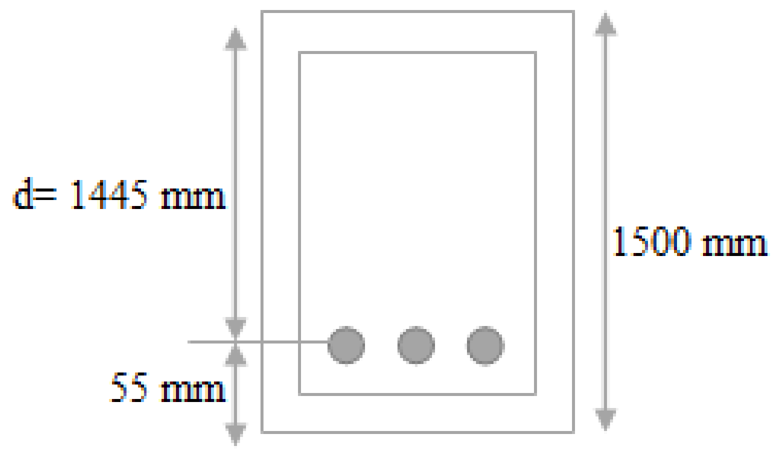
$$1360 \times 10^6 = (0.9)(A_s)(420)\left(1445 - \frac{0.02206A_S}{2}\right)$$

$A_s = 2539.096\ mm^2$

$$use\ \emptyset\ 25 \rightarrow \#\ \text{of bars} = \frac{2539.096}{\left(\frac{\pi}{4}\right)(25)^2} = 5.17 \cong 6\ bars$$

$use\ 6\ \#\ 25mm\ bars\ of\ the\ top\ of\ the\ piers.$

Design the bottom reinforcement based on the positive moment:



$a = 0.02206A_s$

$M_{Max} = 1207.72 \times 10^6$

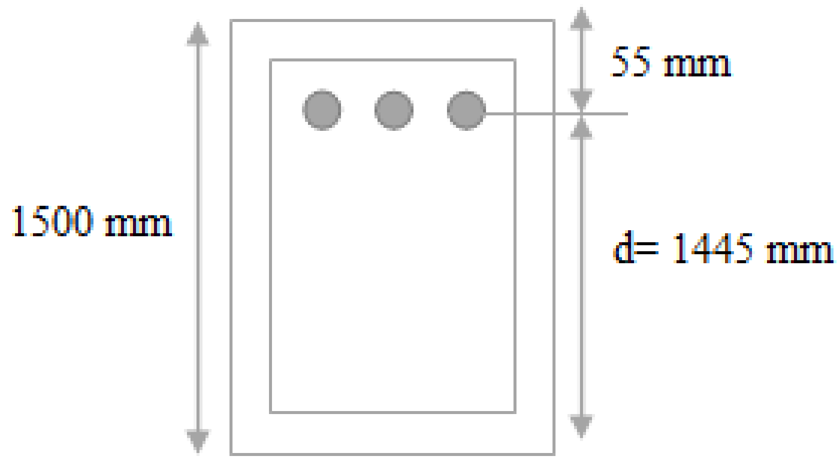
$$1207.72 = (0.9)(A_s)(420)\left(1445 - \frac{0.02206A_s}{2}\right)$$

$A_s = 3680.55mm^2$

$$use\ \emptyset\ 25 \rightarrow \#\ \text{of bars} = \frac{2249.72}{\left(\frac{\pi}{4}\right)(30)^2} = 3.18270\ \cong 5\ bars$$

$use\ 5\ \#\ 25mm\ bars\ of\ the\ bottom\ of\ the\ piers.$

Design for shear force "cap":



$Vmax = 2690.26. kN$
$fc = 28\ Mpa$
$fy = 420\ Mpa$

- **Concrete shear capacity:**

$\emptyset V_c = \emptyset(1.7)(\lambda)(\sqrt{fc})(b)(d)$

$\lambda = 1$ (normal weight concrete) , $\emptyset = 0.75$

$$V_c = \frac{(0.17)(1)(\sqrt{28})(1000)(1445)}{1000} = 1299.857\ kN$$

$\emptyset V_c = (0.75)(536.14) = 974.893214\ kN$

$Vmax = 2690.26\ KN\ > 974.893214\ kN$

So, stirrups are needed here.
$\emptyset 12$ mm $\rightarrow A_b = \left(\frac{\pi}{4}\right)(10)^2 = 79\ mm^2$
$A_u = 2A_b = 2(79) = 158\ mm^2$

Design he spacing between two adjacent stirrups:

$$S = \frac{(A_u)(fy)(d)}{\frac{V_u}{\emptyset} - V_c}$$

$$S = \frac{(158)(420)(745)}{\frac{2690.26 \times 10^3}{0.75} - 1299.857.14 \times 10^3} = 41.93\, mm$$

$$S_{Max} \leq \frac{d}{2} = \frac{1445}{2} = 722.5\, mm$$

$$S_{Max} = 1390\, mm \;\geq 722.5\, mm$$

$$S_{Max} = 722.5\, mm$$

$$use\; S = 42\, mm$$

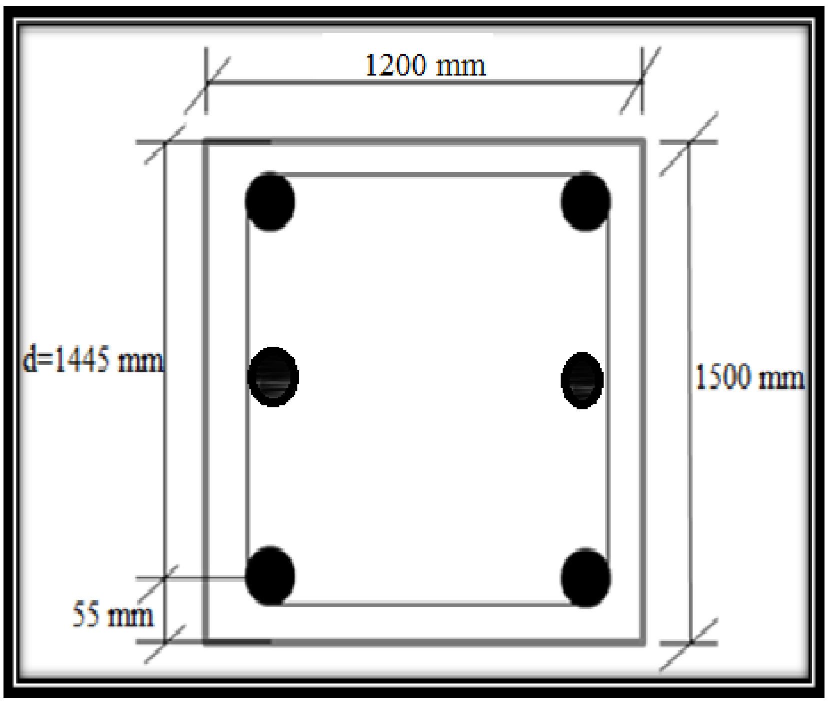


Figure 13 *Cap cross section*

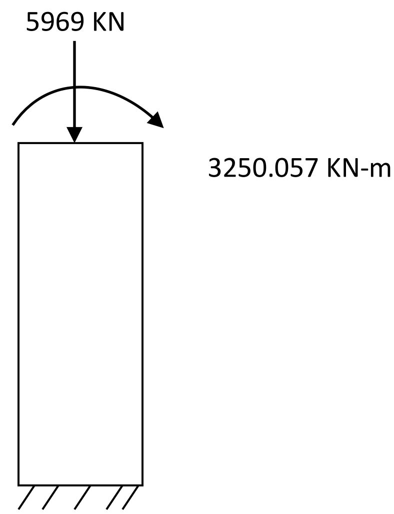
Steel Bridge

(Pier Design)

8. Pier Design for steel bridge

Axial Compression → P = 5969 kN (From CSi-Bridge)

Wind and Earthquake moment → M = 3133.725 + 116.33 = 3250.057 KN-m



Design the pier as a column subjected to axial compression and bending.

→ Use circular cross section

→ fc' = 28 MPa

→ F_y = 420 MPa

$$Ag = \frac{\pi}{4}(1.2)^2 = 1.131\ m^2$$

$$ɣh = 1.2 - 0.04 - 0.01 - 0.01 = 1.14\ mm$$

$$ɣ = \frac{ɣh}{D} = \frac{1.14}{1.2} = 0.95$$

$$K_n = \frac{P}{fc' \times Ag} = \frac{5969 \times 10^3}{(28MPa)(1.2 \times 10^6 mm^2)} = 0.188486801$$

$$R_n = \frac{M}{fc' \times Ag \times h} = \frac{6377.92 \times 10^6 N-mm}{(28MPa)(1.2 \times 10^6 mm^2)(1.2 \times 10^3 m)} = 0.161754$$

Use chart:

fc' = 28 MPa
Fy = 420 MPa → Percentage of Steel = 2 %

As = ρ × Ag = 0.02 × 1.2×10^{6} = 24000 mm^{2}

# of bars = $\frac{As}{Area\ of\ one\ bar} = \frac{24000}{\frac{\pi}{4}(20)^2}$ = 76.394 ≅ 77 bars

⇨ Use 77 ϕ 20 mm bar

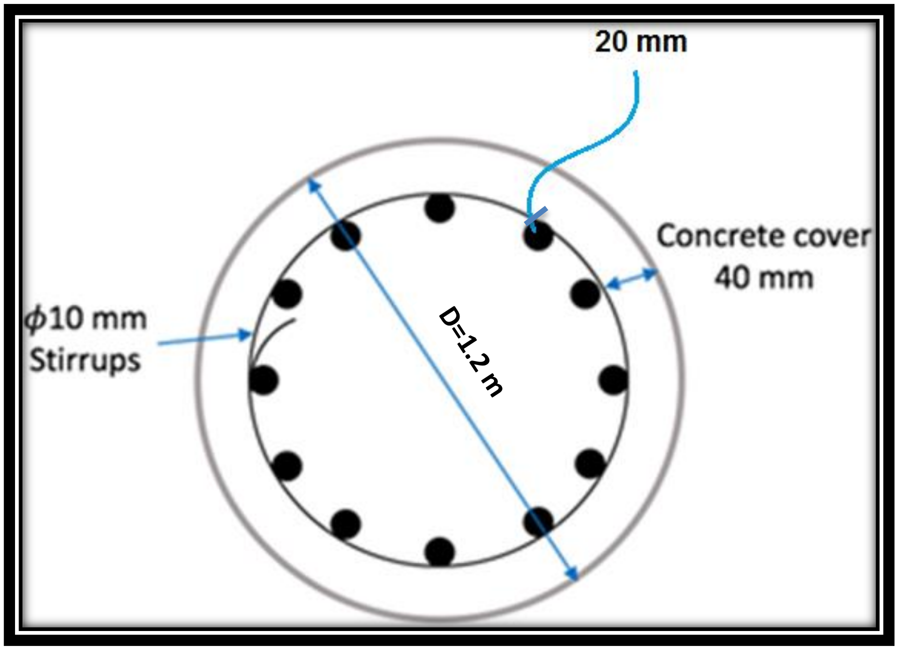


Figure 14 *Pier cross section*

CHAPTER 5

Design Calculation for Post-Tension Concrete Bridge:

1. Limitations
2. Loads Calculation
3. Slab Design
4. Girder Design
5. Stress Design
6. Elastomeric Bearing Design
7. Pier Cap Design
8. Pier Design
9. Losses in Pre-Stress

CHAPTER 5: DESIGN CALCULATION FOR POST-TENSION CONCRETE BRIDGE

1. Limitations

- Depth of I-Beam Girder $\geq 0.045L$ (MOMRA, table 2.1, page 22)
- Assuming distance between girders (center to center) = 1.5 m
- Total number of girders = $\frac{16.5}{1.5}$ = 11 girders
- Minimum concrete slab thickness $= 200\ mm$ (MOMRA 7.7.2.4 , page 760)
- Minimum $C_{Top} = 50\ mm$, $C_{bottom} = 25\ mm$, $Reinorced\ Core = 100\ mm$ (MOMRA Table 5.14 , page 356)
- Assuming Asphalt thickness = 75 mm (AASHTO)
- Traffic Parapet, Height = 810 *mm*, Width = 430 *mm* (MOMRA 11.7.3.2 ,page 1171)
- Concrete not less than fc' 28 MPa (ACI 318 , page 227)
- Safety factors for dead and moving load are 1.3, 1.6
- Loss in Pre-stress = 17% (MoMRA, Table 5.12 , page 350)
- Final Pre-stress = 83% (Pe = 0.83 Pi)
- Reinforcement Strength (Fy= 420). (ACI 318-14 , Page 509)
- Pre-stress "Post-tension" Concrete stress limits (MOMRA 5.18.2.3 , page 346)
  - Initial limits: Compression $fci = 0.6fc'i = 0.6(20) = 12\ MPa$
  - Initial Limits: Tension $fti = 0.25\sqrt{fc'i} = 0.25\sqrt{20} = 1.11\ MPa$
  - Finial Limits: Compression $fcs = 0.45fc' = 0.45(28) = 12.6\ MPa$
  - Finial Limits: Tension $fti = 0.5\sqrt{fc'} = 0.5\sqrt{28} = 2.65\ MPa$
- Densities (MOMRA Table 3.4)
  - Density of Concrete = 2392 kg/m^3 = 23.92 kN/m^3
  - Bituminous wearing surface = 2250 kg/m^3 = 22.50 kN/m^3

2. Load alculation *note: Load is calculated for one typical girder*

1- Dead Load:

- Asphalt = $(1.5\ m) \times (0.075\ m) \times (22.5\ kN/m^3) = 2.53\ kN/m$
- Concrete slab = $(1.5\ m) \times (0.200\ m) \times (23.92\ kN/m^3) = 7.176\ kN/m$
- Girder self-weight = $(0.765\ m^2) \times \left(23.92\ \frac{kN^3}{m}\right) = 18.30\ kN/m$
- Bridge Railing = $(0.810\ m) \times (0.430\ m) \times (23.92\ kN/m^3) = 8.33\ kN/m$

2- Moving Load:

- Truck Load (MOMRA 3.6.1.2 / figure 3.1 , page 54)
- Design lane load
  - $20\ kN/m^3$ uniformly distributed in the longitude direction
  - Transversely, the design lane load shall be assumed to be uniformly over $3m$ width.

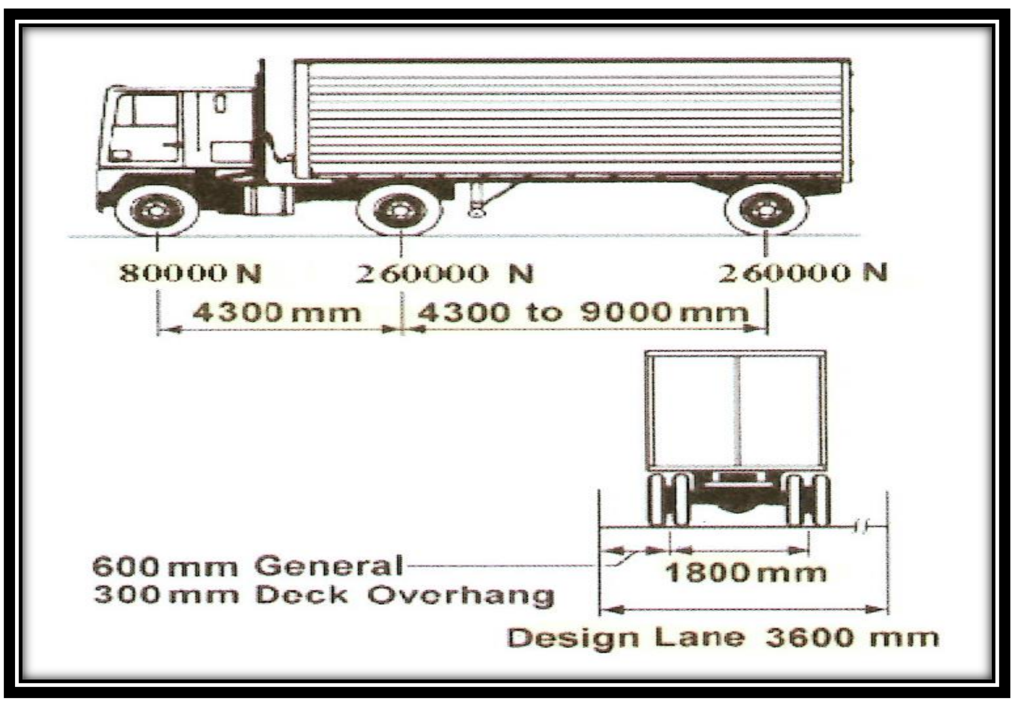


Figure 15 *Truck load*

3- Earthquake Load (AASHTO, ch3 , page 3.34)

<u>From AASHTO 3.9.10.2:</u>

Assume seismic zone = 1

Acceleration coefficient, as, ≤ 0.05

Horizontal design $\geq 0.15 \times$ vertical reaction due to permanent load.

Reaction = 6791.669 kN "From CSi-Bridge"

Horizontal force = 0.15×6791.669 = 1018.75 kN

Moment on pier due to earthquake load is:

M = 1018.75 kN × 3.5 m = 3565.625 kN-m

- Seismic zones – (AASHTO, Table 3.10.6.1):

  Assume acceleration coefficient, $S_{D1} = 0.1$

  ⇨ Seismic zone 1

- Site class – (AASHTO, Table 3.10.3.1.1):
  A: Hard rock with shear wave velocity, $\overline{V} > 5000$ ft/s

- Site Factor, F_{pga} at zero period on acceleration spectrum
  PGA = 0.2 => $F_{pga} = 1$ => (AASHTO, Table 3.10.3.2.1 , Page 3-91)
  $S_S = 0.5$ => $F_a = 1.0$ => (AASHTO, Table 3.10.3.2.2 , page 3-91)
  $S_1 = 0.5$ => $F_v = 1.0$ => (AASHTO, Table 3.10.3.2.3 , page 3-91)

Assume period is greater than or equal to

$C_{ms} = S_{DS}$

$S_{DS} = Fa\ S_s = (1.0)(0.5) = 0.5$

⇨ $C_{ms} = 0.5$

4- Wind Load (AASHTO 3.10.9.2 , page 3-96)

Assume wind velocity = 100 mph

Table 3.8.1.2.1.1 => the base Pressure, P_B = 0.05 (AASHTO, Table 3.8.1.2.1-1, page 53)

Minimum wind load = 0.3 kips/ft

AASHTO, Table 3.8.1.3.1, page 56 => skew angle = 0

- ⇨ Normal component "Transvers" = 0.1 kips/ft
- ⇨ Parallel component "Long" = 0

The design wind pressure: (AASHTO, page 3.38)

$P_D = P_B \frac{V_{DZ}^2}{10{,}000}$

$V_{DZ} = 2.5\, V_o (\frac{V_{30}}{V_B}) \ln(\frac{Z}{Z_o})$

For structure in open country => V_o = 8.20

Z_o = 0.23

Assume V30 = V_B = 100 mph

$V_{DZ} = 2.5\,(8.2) \ln(\frac{31.49}{0.23}) = 101$ mph

$P_D = P_B \frac{(101)^2}{10{,}000} = 1.02\, P_B$

Long Area = $(\frac{30}{0.3048})(\frac{1.5}{0.3048})$ = 484 ft^2

Transverse Area = $\left(\frac{16.5}{0.3048}\right)\left(\frac{1.5}{0.3048}\right)$ = 266 ft^2

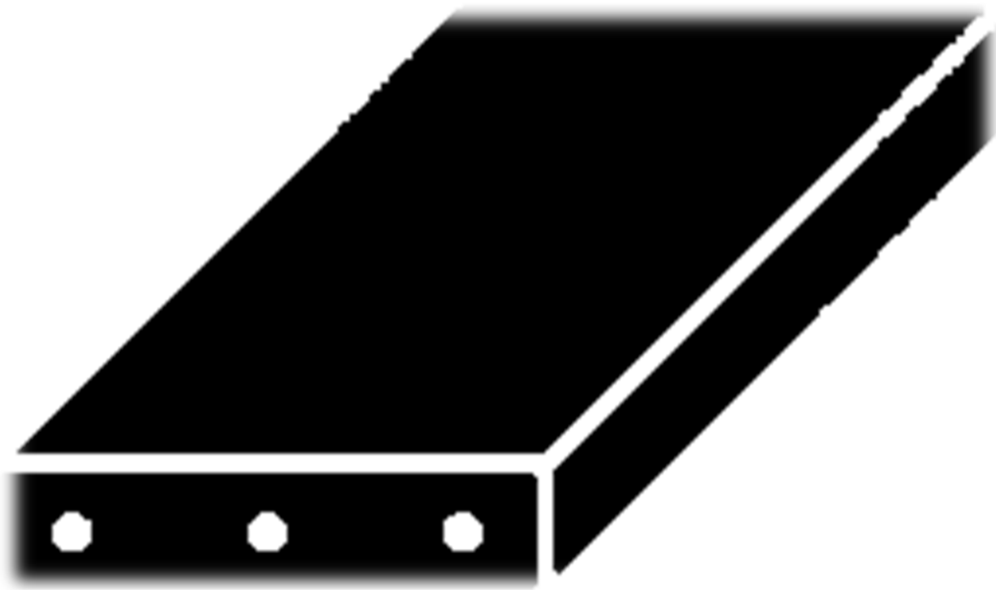
Zero degree skews Angle

V_{Long} = (484)(0)(1.02) = 0

$V_{Transvers}$ = (266)(0.04)(1.02) = 11 kips

The moment due to wind on the pier is

$M = 11^k \times 8^{ft}$ = 88 kips-ft = 119 kN-m



Post-Tension Concrete Bridge

(Slab Design)

3. Slab Design for Post-Tension Concrete Bridge

$M_{Max} = 82.982 kN.m$ (From CSI-Bridge)

$f_c = 28\ MPa$

$f_y = 420\ MPa$

$$R_u = \frac{M_{Max}}{0.9bd^2} = \frac{82.982 \times 10^6}{0.9(1000)(200)^2} = 2.305\ N/mm^2$$

$$\rho = \frac{0.85f_c}{f_y}(1 - \sqrt{1 - \frac{2R_u}{0.85f_c}}\ )$$

$$\rho = \frac{0.85(28)}{420}(1 - \sqrt{1 - \frac{2(2.305)}{0.85(28)}}\ ) = 0.00578$$

$$A_S = \rho bd = 0.00578(1000)(200) = 1174\ mm^2$$

Use $\phi\ 16\ mm\ \rightarrow \#\ of\ bars = \frac{1174}{\frac{\pi}{4}(16)^2} = 5.6$

Take 5 bars for 1 m

5# 16 *mm*

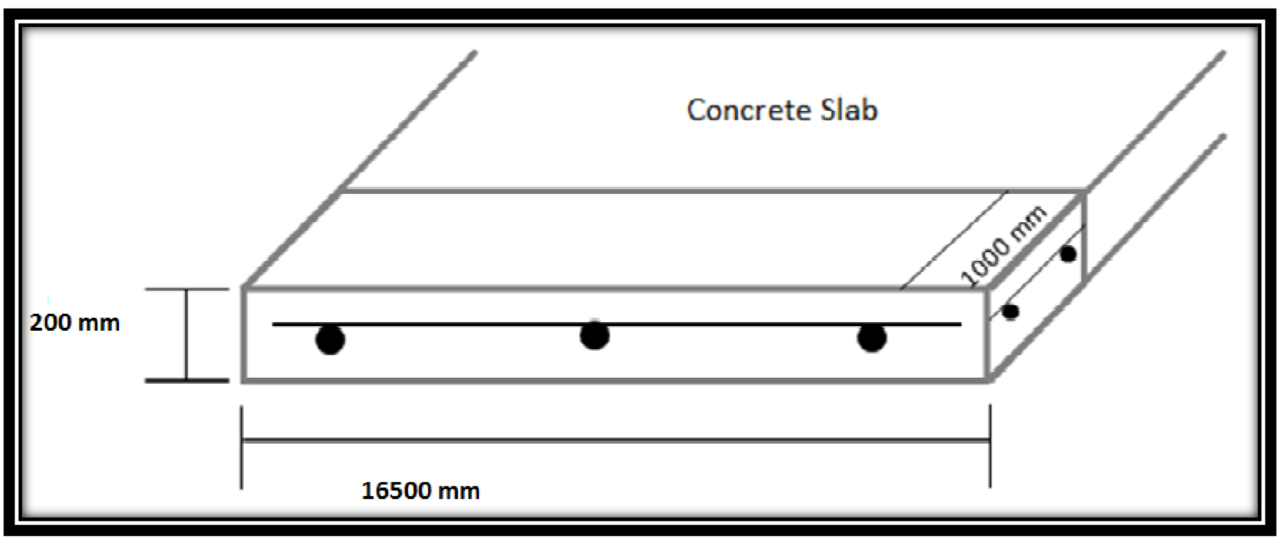
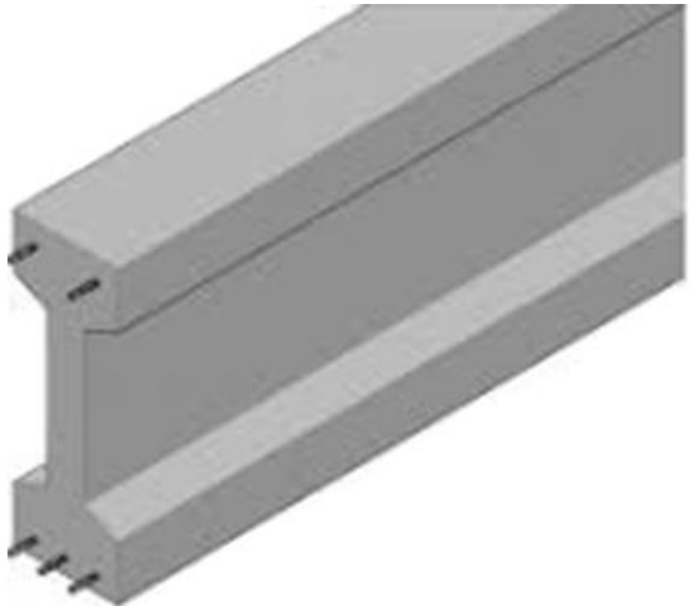


Figure 16 *Reinforced slab dimensions*



Post-Tension Concrete Bridge

(Girder Design)

4. Girder Design for Post-Tension Concrete Bridge (AASHTO, page 96 , PCI standard products, Appendix B -7)

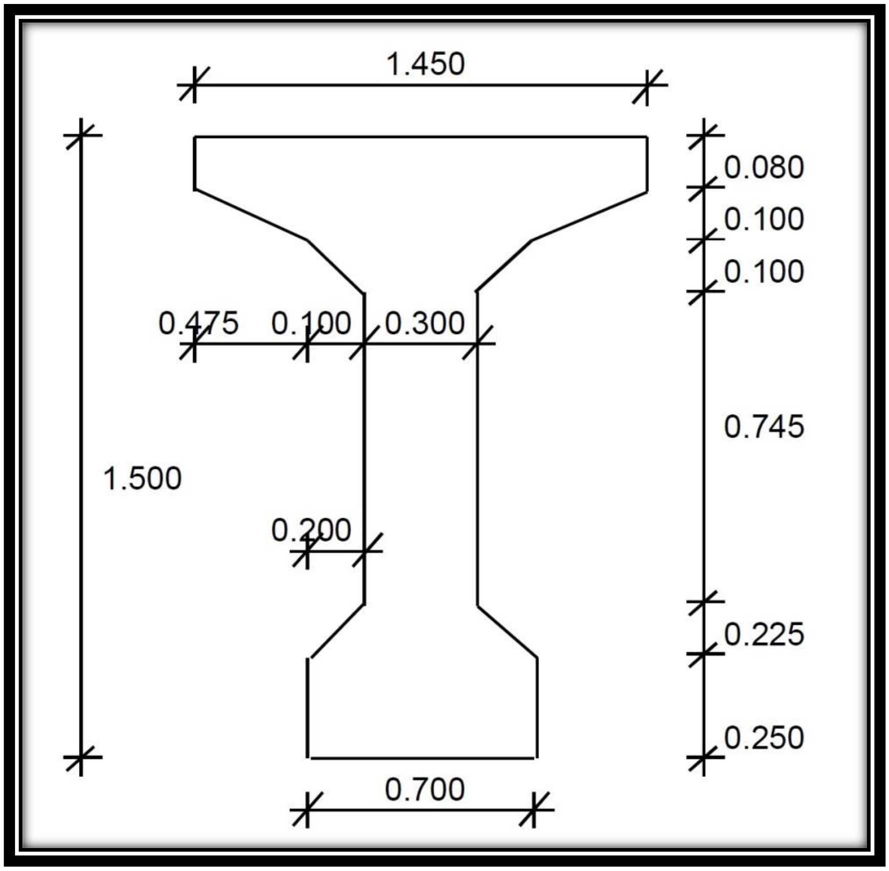


Figure 17 *Concrete girder dimensions*

- Gross Area = (0.080) (1.450) + (0.5) (0.475) (0.100) + (0.5) (0.475) (0.100) + (0.5) (0.100) + (0.5) (0.100) (0.100) +(0.5) (0.100) (0.100) +(0.300) (0.100) +(0.300) (0.745) +(0.5) (0.225) (0.200) + (0.5) (0.225) (0.200) + (0.225) (0.3) + (0.700) (0.250)
  = **0.765 m²**
- Centroid (Datum is at the top)
- $Y = (0.080)(1.450)\left(\frac{0.080}{2}\right) + 2\left(\frac{1}{2}(0.475)(0.100)\left(\frac{0.100}{3} + 0.080\right)\right) + (0.1)(0.5)\left(0.080 + \frac{0.1}{2}\right) + 2\left(\left(\frac{1}{2}\right)(0.1)(0.1)\left(\frac{0.1}{3}\right)(0.1 + 0.80)\right) + (0.745)(0.300)\left(0.080 + 0.1 + 0.1 + \frac{0.745}{2}\right) + 2((\frac{1}{2})(0.225)(0.200)\left(0.080 + 0.1 + 0.1 + 0.745 + \frac{2(0.225)}{3}\right) + (0.225)(0.300)\left(0.080 + 0.1 + 0.1 + 0.745 + \frac{0.225}{2}\right) + (0.700)(0.250)\left(0.080 + 0.1 + 0.1 + 0.745 + 0.225 + \frac{0.250}{2}\right) / 0.765$

$$= \mathbf{0.6989\ m}$$

- Distance from the neutral axis to extreme fibers
  - C bottom = 1.5 – 0.6989 = 0.8011 m
  - C top = Y = 0.6989 m
- Moment of inertia about neutral axis:
- $I_x = [\frac{1}{12}(1.450)(0.080)^3 + (1.450\times0.08)(0.6989 - (\frac{0.080}{2})^2] + 2[\frac{1}{36}(0.475)(0.1)^3 +$

  $(0.475)(0.1)(0.6989 -$

  $0.1133)^2] + [\frac{1}{12}(0.5)(0.1)^3 + (0.5)(0.1)(0.6989 - 0.13)^2] + 2[\frac{1}{36}(0.1)(0.1)^3 +$

  $(0.1)(0.1)(0.6989 - 0.213)^2] + [\frac{1}{12}(0.3)(0.1)^3 + (0.3)(0.1)(0.6989 - 0.23)^2]$

  $+ [\frac{1}{12}(0.3)(0.745)^3 + (0.3)(0.745)(0.6989 - 0.6525)^2] +$

  $2[\frac{1}{36}(0.2)(0.225)^3 + (0.2)(0.225)(0.8011 - 0.4)^2] + [$

  $\frac{1}{12}(0.3)(0.225)^3 + (0.3)(0.225)(0.8011 - 0.3625)^2] +$

  $[\frac{1}{12}(0.7)(0.250)^3 + (0.7)(0.250)(0.8011 - 0.125)^2] = 0.231\ m^4$

  $I_x = 0.231\ m^4$

Secton Properties – Gross composite section:

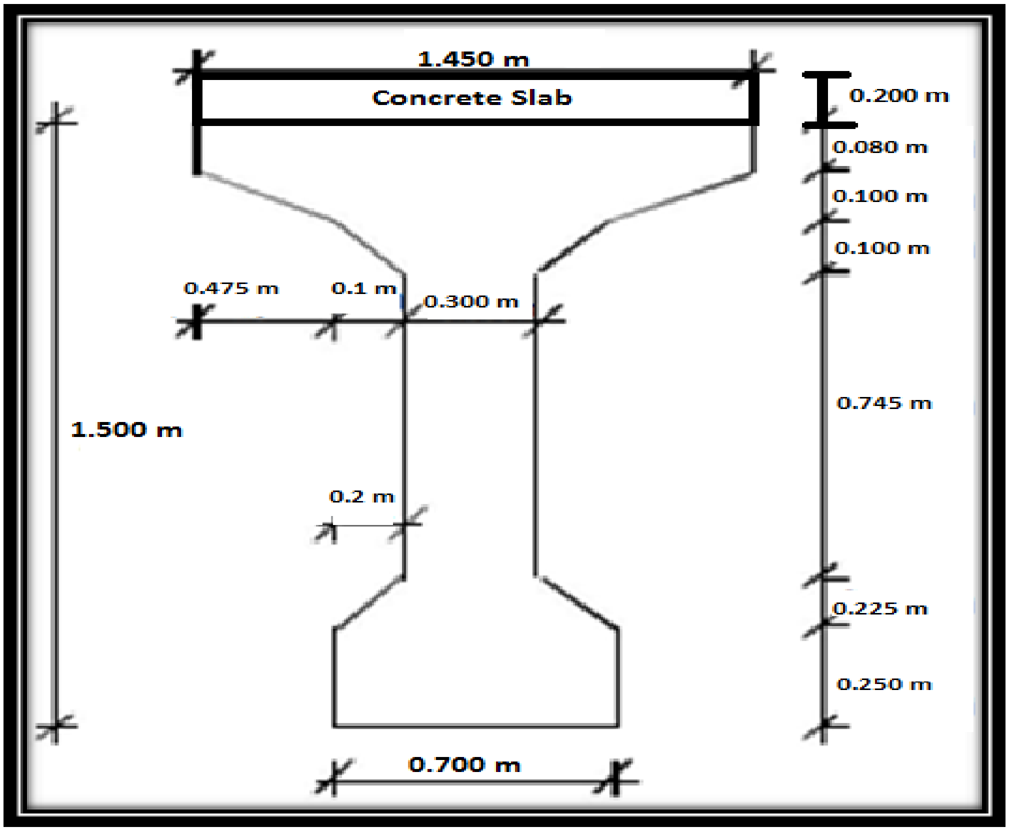


Figure 18 *Concrete girder dimensions with concrte slab*

- Gross Area = (1.450)(0.200)+(0.745)(0.300)+($\frac{1}{3}$)(0.2)(0.225)+($\frac{1}{3}$) (0.200)(0.225) +(0.300)(0.225)+(0.700)(0.250) = 0.786 m^2
- Centroid (Datum is at the bottom)
- Y =(0.700)(0.250)($\frac{0.250}{2}$)+(0.300)(0.225)($\frac{0.225}{2}$+0.250)+(2)($\frac{1}{3}$)(0.225)(0.200)($\frac{0.225}{3}$ +0.250)+(0.745)(0.300)($\frac{0.745}{2}$)+0.225+0.250)+(2)($\frac{1}{3}$)(0.1)(0.1)($\frac{0.1}{3}$+0.745+0.225+0.250)+(0.300)(0.100)($\frac{0.1}{2}$+0.745+0.225+0.250)+(1.450)(0.28)($\frac{0.28}{2}$+0.1+0.1+0.745+0.225+0.250)+(2)($\frac{1}{3}$)(0.1)(0.475)($\frac{0.2}{3}$+0.1+0.745+0.225+0.250)+(0.5)(0.100)($\frac{0.100}{2}$ +0.1+0.745+0.225+0.250) = **1.037 m**

Distance from the neutral axis to extreme fibers

- C top = 1.7 - 1.037 = 0.663 m
- C bottom = 1.037 m

- Moment of inertia about neutral axis:
- $I_x = [\frac{1}{12}(1.450)(0.28)^3 + (1.450)(0.28)(1.037 - 0.14)^2] +$

$2[\frac{1}{36}(0.475)(0.100)^3 + (0.475)(0.100)(1.037 - 0.3467)^2] +$

$[\frac{1}{12}(0.5)(0.100)^3 + (0.5)(0.100)(1.037 - 0.33)^2] +$

$2[\frac{1}{36}(0.100)(0.100)^3 + (0.100)(0.100)(1.037 - 0.413)^2] +$

$[\frac{1}{12}(0.300)(0.100)^3 + (0.300)(0.100)(1.037 - 0.413)^2] +$

$[\frac{1}{12}(0.300)(0.745)^3 + (0.300)(0.745)(1.037 - 0.8525)^2] +$

$2[\frac{1}{36}(0.200)(0.225)^3 + (0.200)(0.225)(0.663 - 0.325)^2] +$

$[\frac{1}{12}(0.300)(0.225)^3 + (0.300)(0.225)(0.663 - 0.3625)^2] +$

$[\frac{1}{12}(0.700)(0.250)^3 + (0.700)(0.250)(0.663 - 0.125)^2] = 0.507\ m^4$

$\mathbf{I_x = 0.507\ m^4}$

- **I-Section**

$$Sb = \frac{I}{C\ bottom} = \frac{0.321}{0.6989} = 0.459\ m^3$$

$$St = \frac{I}{C\ top} = \frac{0.321}{0.8011} = 0.401\ m^3$$

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.321}{0.765}} = 0.648\ m$$

- **Composite section**

$$Sb = \frac{I}{C\ bottom} = \frac{0.507}{0.663} = 0.765\ m^3$$

$$St = \frac{I}{C\ top} = \frac{0507}{1.037} = 0.489\ m^3$$

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.507}{0.786}} = 0.803\ m$$

Finding Shear and Moment (DEAD LOAD)

- Girder self-weight = $(0.765\ m^2) \times \left(23.92\ \frac{kN^3}{m}\right) = 18.298\ kN/m$
- Concrete slap = $(1.5\ m) \times (0.200\ m) \times (23.92\ kN/m^3) = 7.176\ kN/m$

Loads on the non-composite girder:

$V_{max} = \frac{wL}{2} = \frac{18.298(30)}{2} = 274.47$ kN

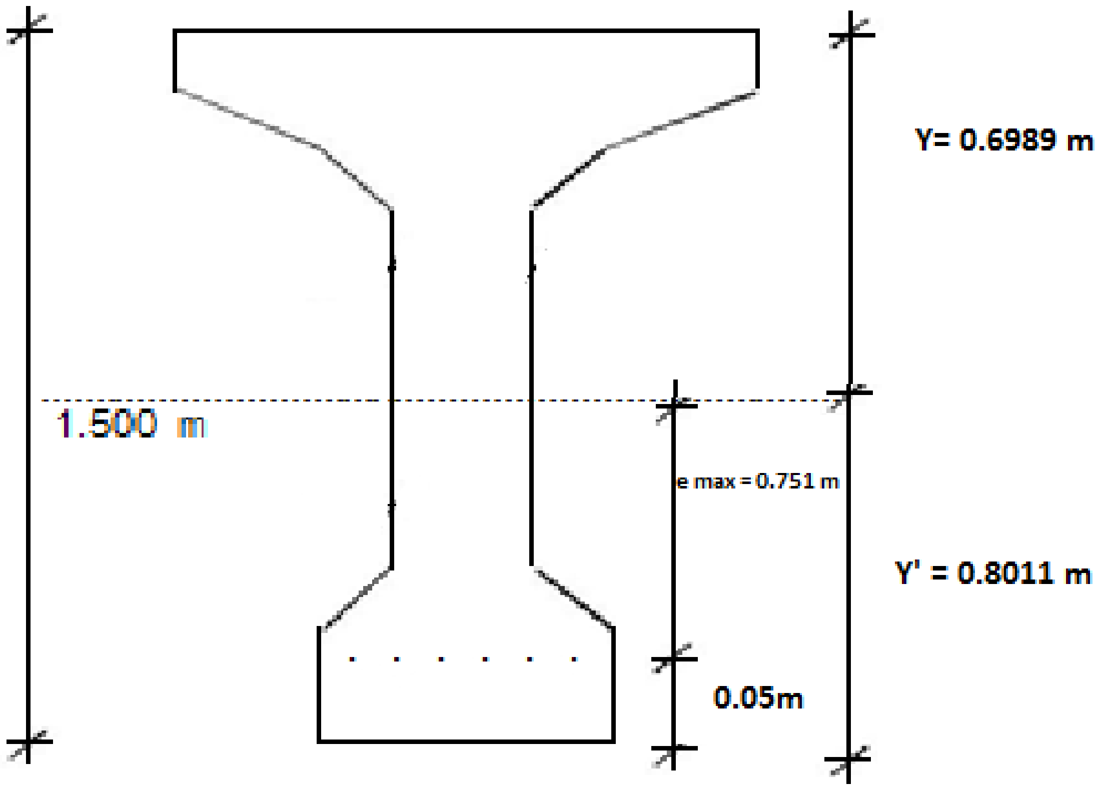
$M_{max} = \frac{wL^2}{8} = \frac{18.298(30)^2}{8} = 2058.5$ kN.m

Loads on the composite girder:

$V_{max} = \frac{(25.47)(30)}{2} = 382.05$ kN

$M_{max} = \frac{(25.47)(30)^2}{8} = 2865.37$ kN.m

5. Stress Calculation: from (Paint program)



- Maximum eccentricity is: e_{max} = Y – Bottom cover
  e_{max} = 0.8011 – 0.05 = 0.7511 m
- Maximum eccentricity to minimize the required Pre-stressed steel

Stresses $= -\frac{P}{A} \pm \frac{Pe}{S} \pm \frac{M}{S}$

Initial Stage (Non-composite Girder):

- $f\ top = -\frac{Pi}{A} + \frac{Pe}{St} - \frac{M_{self\ weight}}{St} \leq fti$

$$= -\frac{Pi}{0.765} + \frac{Pi(0.7511)}{0.401} - \frac{2058.5}{0.401} \leq 1.11 \times 10^3 KPa$$

$$Pi \leq 11033.15\ KN$$

- $f\ bottom = -\frac{Pi}{A} - \frac{Pe}{Sb} + \frac{M_{self\ weight}}{Sb} \geq -fci$

$$= -\frac{Pi}{0.765} - \frac{Pi(0.7511)}{0.459} + \frac{2058.5}{0.459} \geq -12 \times 10^3 KPa$$

$$Pi \leq 5600.25\ kN$$

Final Stage (Non-composite Girder):

- $f\ top = -\frac{0.85Pi}{A} + \frac{0.85Pe}{St} - \frac{M_{self\ weight+Slab\ deck}}{St} \geq -fcs$

$$= -\frac{0.85Pi}{0.765} + \frac{0.85Pi(0.7511)}{0.401} - \frac{2865.37}{0.401} \geq 12600$$

$$Pi \geq -11339.88\ KN$$

- $f\ bottom = -\frac{0.85Pi}{A} - \frac{0.85Pe}{Sb} + \frac{M_{self\ weight+Slab\ deck}}{Sb} \leq fts$

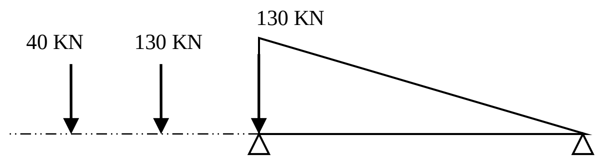
$$= -\frac{0.85Pi}{0.765} - \frac{0.85Pi(0.7511)}{0.459} + \frac{2865.37}{0.459} \leq 2650$$

$$Pi \leq 1435.88\ kN$$

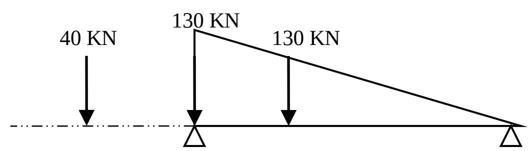
Finding Shear and Moment (MOVING LOAD)

*Note: to find the critical shear and moment due to movable load, influence line method has to be used.

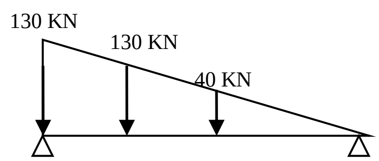
3. *Truck load*
   - Case-1 => V_{max} = 130×1 = 130 kn



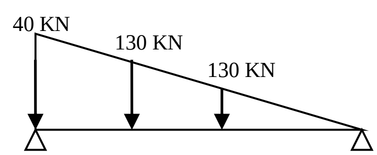
   - Case-2 => $V_{max} = (130\times1) + (130\times\frac{30-10}{30}) = 216.67$ KN



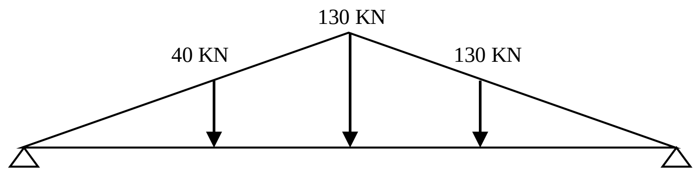
   - Case-3 => $V_{max} = (40\times1) + (130\times\frac{30-5.2}{30}) + (130\times\frac{30-10}{30}) = 234.13$kN



   - Case-4 => $V_{max} = 130 + (130\times\frac{30-5.2}{30}) + (130\times\frac{30-10}{30}) = \boxed{324.13 \text{ kN}}$



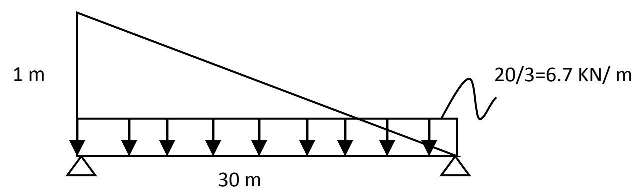
V_{max} = 324.13 KN

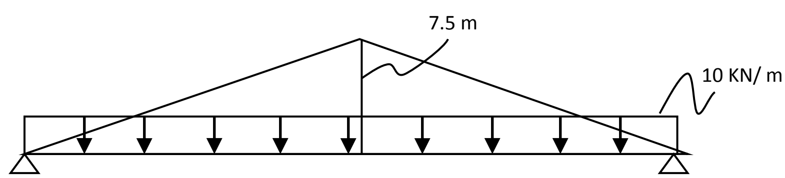


$(15-5.2)(\frac{7.5}{15}) = 4.9$ m

$M_{max} = (40×4.9) + (130×7.5) + (130×4.9) = 1808$ kN-m

4. *Lane Load*





$V_{max} = \frac{1}{2} × 30 × 1 × 6.7 = 100.5$ kN

$M_{max} = \frac{1}{2} ×30 × 7.5 × 6.7 = 753.75$ kN-m

Ultimate (Moving load)

$M_u = 1.6 × (1808 + 753.75) = 4098.8$ kN-m

$V_u = 1.6 × (324.13 + 100.5) = 679.408$ kN

Inital Stage (composite Girder):

M = Girder self-wight + Slab deck = 2865.37 kN.m

- $f\ top = -\frac{Pi}{A} + \frac{Pie}{St} - \frac{M}{St} \leq fti$

$$= -\frac{Pi}{0.786} + \frac{Pi(0.9511)}{0.489} - \frac{2865.37}{0.489} \leq 1.11 \times 10^3 KPa$$

$$Pi \leq 10360.33\ kN$$

- $f\ bottom = -\frac{Pi}{A} - \frac{Pie}{Sb} + \frac{M}{Sb} \geq -fci$

$$= -\frac{Pi}{0.489} - \frac{Pi(0.9511)}{0.765} + \frac{2865.37}{0.765} \geq -12 \times 10^3 KPa$$

$$Pi \leq 4788.43\ kN$$

Final Stage (Non-composite Girder):

M = 2538.3 + Asphalt + Truck load + Lane load = 4966.58 kN.m

- $f\ top = -\frac{0.85Pi}{A} + \frac{0.85Pe}{St} - \frac{M}{St} \geq -fcs$

$$= -\frac{0.85Pi}{0.765} + \frac{0.85Pi(0.9511)}{0.489} - \frac{4966.58}{0.489} \geq -12 \times 10^3 KPa$$

$$Pi \geq -3400.28$$

- $f\ bottom = -\frac{0.85Pi}{A} - \frac{0.85Pe}{Sb} + \frac{M}{Sb} \leq fts$

$$= -\frac{0.85Pi}{0.786} - \frac{0.85Pi(0.9511)}{0.765} + \frac{4966.58}{0.765} \leq 2.650 \times 10^3 KPa$$

$$Pi \leq 1796.96\ kN$$

The appropriate range of Pi to satisfy both initial and final stresses of both composite and non-composite girder are:

$$1796.96\ kN \leq Pi\ \leq 5600.25\ kN$$

Let $Pi = 1796.96\ kN$

MOMRA, Table 5.3, Use strand 1860 MPa (Grade 270)

$$fpu = 1860\ MPa$$

$$fpy = 0.9(1860) = \ 1674\ MPa$$

$$Diameter = 9.53\ mm\ to\ 15.24\ mm$$

Number of Wires = 7 wires.

Yield Strength, fpy (MPa) is 85% of fpu, except 90% of fpu for low-relaxation strand.

Area of strands = 140 mm^2

Required area of steel = $\frac{1055}{\frac{\pi}{4}(15.24)^2}$ = 6 strands

Width of girder = 700 mm

Thickness of deck slab = 200 mm

dc = 50 mm

Fc = 28 Mpa

Mc = 6×10^8 (From CSI Bridge)

Fy= 420 Mpa

K = 0.159 (From CSI Bridge)

J = 1-(1/3) (0.159) = 0.947

Area of steel = 618 mm^2 (From CSI Bridge)

Provide 4 bars φ 20 mm (From CSI Bridge)

Area of steel required = 1256.64 mm^2 (From CSI Bridge)

The spacing **S** of reinforcing bars in the layer closest to the tension face shall satisfy the following: (MOMRA, 5.7.3.4, Page 308)

$$s \leq \frac{123000\, ye}{\beta s\, fss} - 2dc$$

$$\beta s = 1 + \frac{dc}{0.7\,(h - dc)}$$

Where:

γe = Exposure factor

= 1.00 for Class 1 exposure condition

= 0.75 for Class 2 exposure condition

dc = Thickness of concrete cover measured from extreme tension fiber to center of the flexural reinforcement located closest thereto (mm)

fss = Tensile stress in steel reinforcement at the service limit state (MPa)

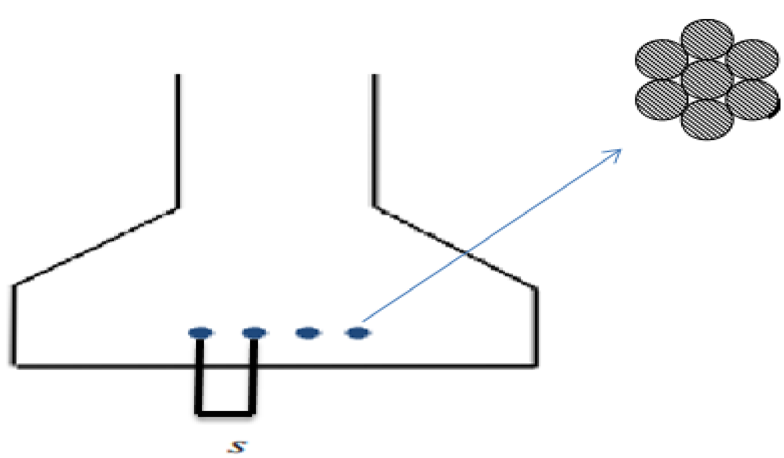
h = overall thickness or depth of the component (mm)

K = Assuming steel does not yielding

$$\beta s = 1 + \frac{50}{0.7\,(1500 - 50)} = 1.05\, mm$$

$$fss = \frac{Mc}{J\, As\, d} = \frac{6.10^{8}}{0.947 \times 618 \times 1450} = 707.04 \text{ Mpa}$$

$$s \leq \frac{123000 \times 0.75}{1.05 \times 707.04} - 2(50) = 33.35\, mm$$



Post-Tension Concrete Bridge

(Elastomeric Bearing Design)

6. Elastomeric Bearing Design for Post-Tension Concrete Bridge

- From superstructure Analysis: (AASHTO LRFD, Cl: 3.12.2.3)

DL= 382.05 kN

LL= 100.5 + 324.13 = 424.63 kN

θ = 0.0121 rad (rotation about transverse axis)

- Steel reinforced elastomeric bearing is selected:
  $\Delta T = \alpha L (T_{MaxDesign} - T_{MinDesign})$ (MOMRA LRFD, Table 3.28, page 135)
  Where: L = expansion length (in.)
  α = coefficient of thermal expansion (in./in./ºF)

Temperature Movement = $\alpha L(T_{MaxDesign} - T_{MinDesign}) = (1.1*10^{-5})(6000)(45-0) =$ 29.7mm

Concrete Shrinkage = $\beta\times\mu\times L = (0.0002)\times(0.50)\times(60000) = 6$ mm

Minimum Thickness of Pad= 2 × horizontal movement

= 2 × (29.7 + 6)

= 71.4mm

Try T= 71.4mm (elastomer only)

Maximum Pressure = $\frac{DL+LL}{W\times L} = \frac{382.05\times10^3+424.63\times10^3}{W\times L} = 7\ MPa$

$\longrightarrow$ W×L= $\frac{(382.55\times10^3)+(424.63\times10^3)}{7}$ = 115240 mm^2 ≈ 340×340 mm

Trial Pad: 71.4mm × 340 mm × 340 mm

Maximum Thickness of Pad $\longrightarrow \frac{1}{3}$ of length or width $\longrightarrow \frac{340}{3}$ = 113 mm

T = 71.4 mm < max = 113 mm (*Its ok)*

Compressive Stress = $\frac{DL+LL}{W\times L} = \frac{(382.05\times10^3)+(424.63\times10^3)}{330\times330}$ = 6.9 < 7 MPa *(It's ok)*

Compressive Stress (Dead Load Only) = $\frac{DL}{W \times L} = \frac{382.05 \times 10^3}{330 \times 330}$ = 3.31 MPa > 1.4 MPa *(It's ok)*

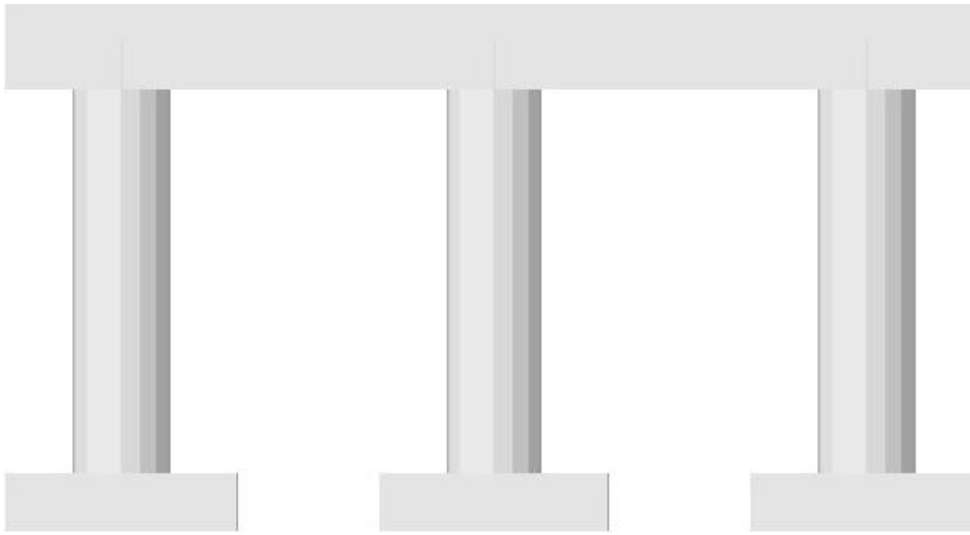
Shape Factor = $\frac{W \times L}{W + L} = \frac{340 \times 340}{340 + 340}$ = 170

Maximum Shear force at Slippage:

Fs(Max) = $\frac{DL}{5} = \frac{382.05}{5}$ = 76.41 kN

Actual Design Shear force = $\frac{Modulus \times\ Area \times\ Movement}{Pad\ Thickness\ \times 1000}$

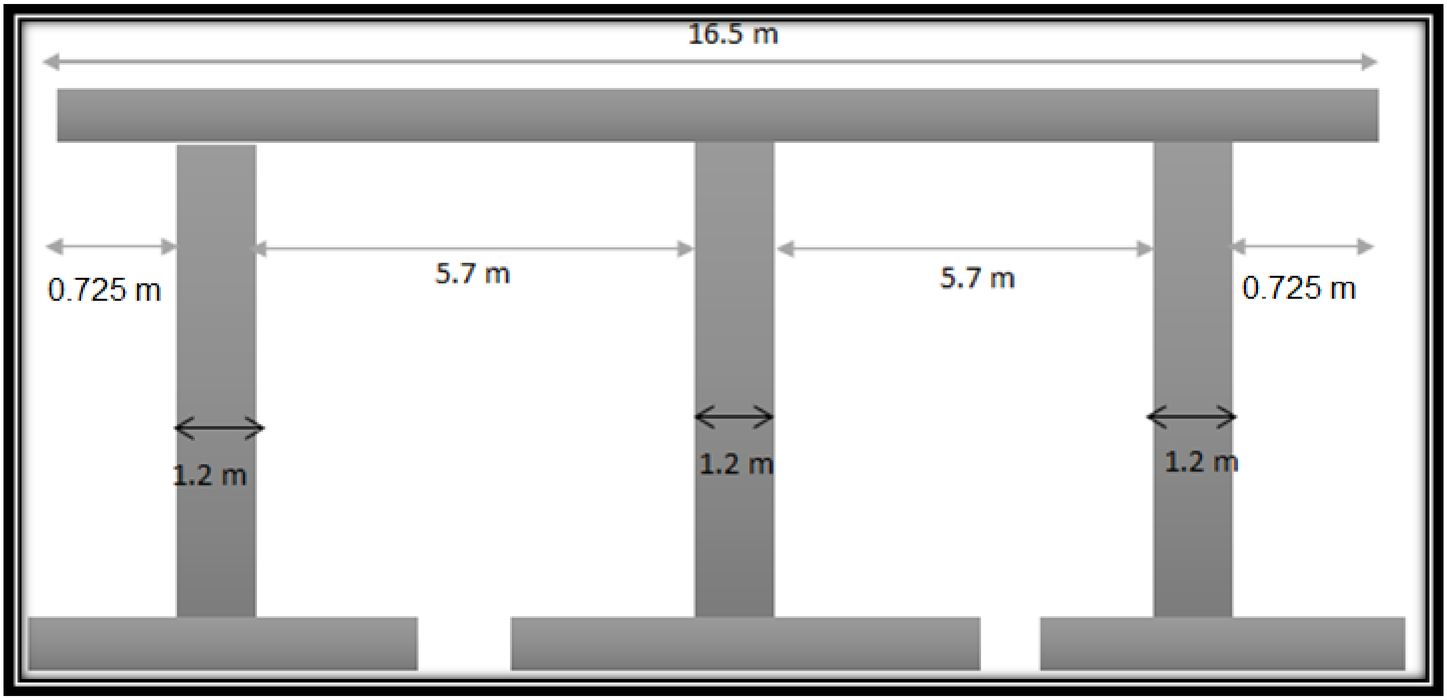
= 60.73 kN < 76.41 kN (It's ok)



Post-Tension Concrete Bridge

(Pier Cap Design)

7. Pier Cap Design for Post-Tension Concrete Bridge



- Dead load:

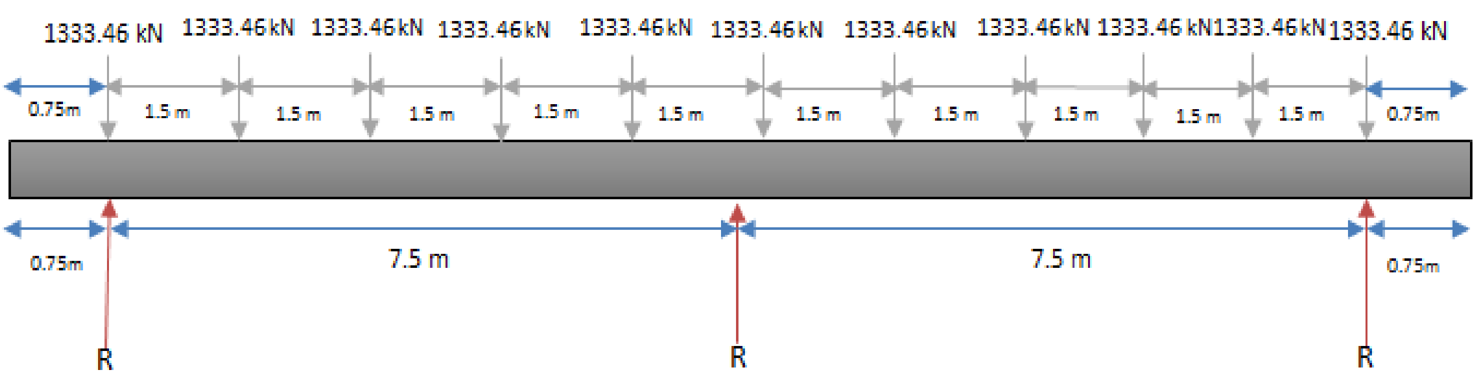
$$F = 545.04kN$$
$$Fu = (545.04)(1.2) = 654.048\ kN$$

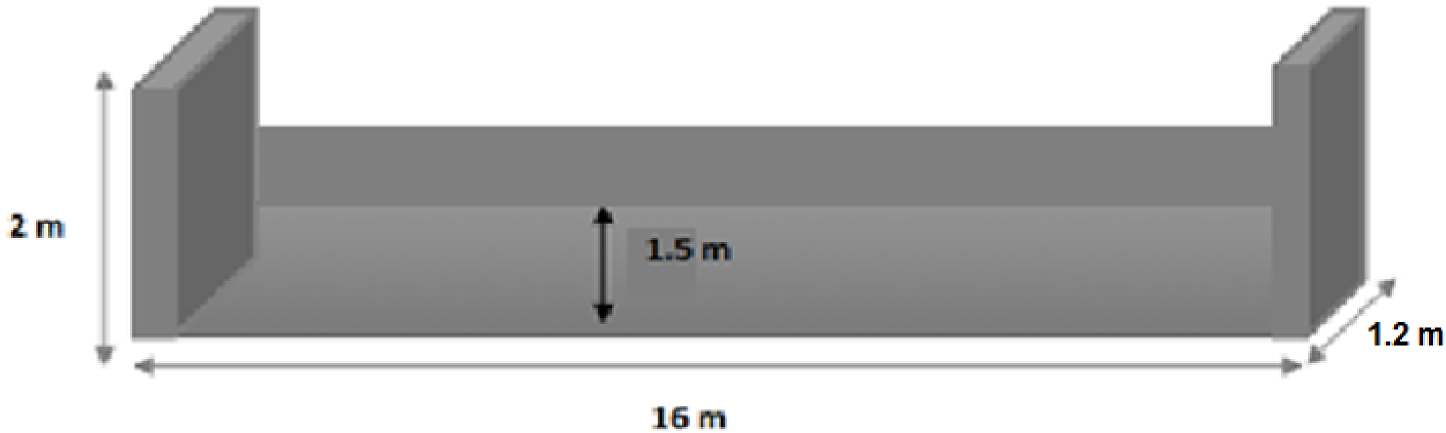
- Truck load:

$$F = 324.13\ kN$$
$$Fu = (324.13)(1.6) = 518.608\ kN$$

- Lane load:

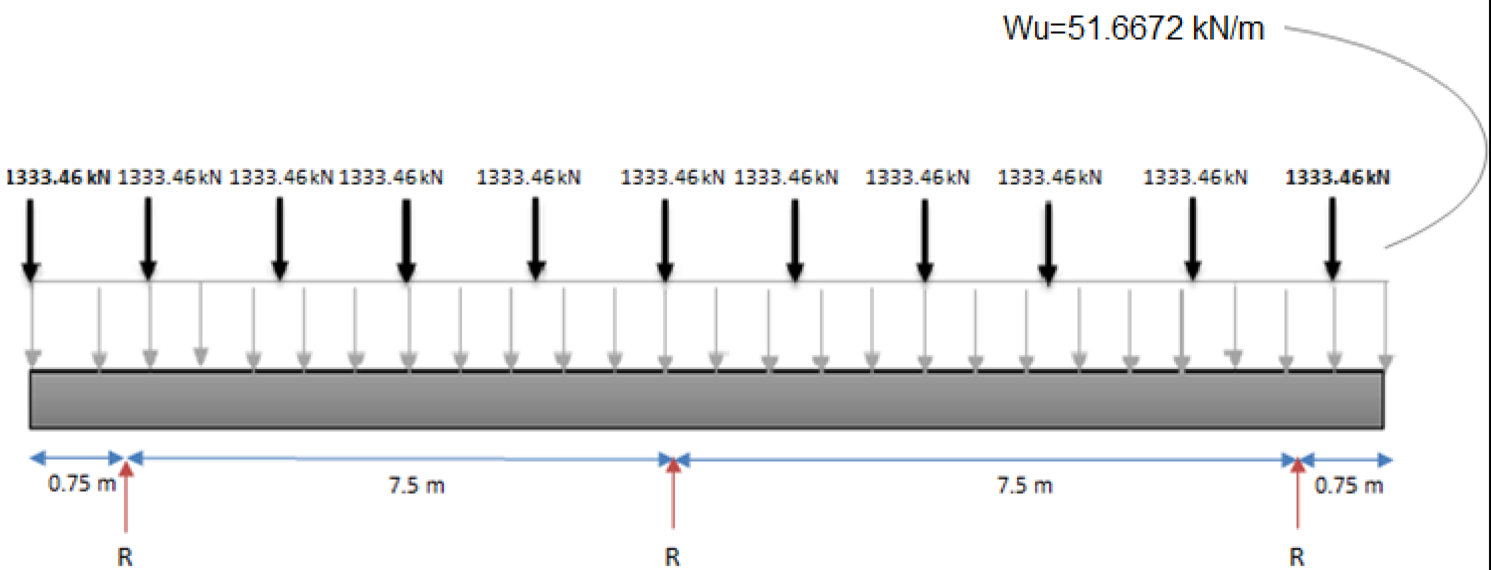
$$F = 100.5\ kN$$
$$Fu = (100.5)(1.6) = 160.8\ kN$$
$$Fu = (654.048 + 518.608 + 160.8) = 1333.46\ kN$$





- Self-weight:

$W = (1.5)(1.2)(23.92) = 43.056\ kN/\text{m}$
$Wu = 43.056\ (1.2) = 51.6672\ kN/\text{m}$



- From CSi-Bridge:

$M + max = 2733.30\ kN.m$

$M - max = 3475.85\ kN.m$

$Vmax = 2690.26kN$

R = 6791.669 kN

- **Design the top reinforcement base on the negative moment:**

$M = \emptyset A_S f y(d - \frac{a}{2})$

$M = 3475.85\ kN.m$

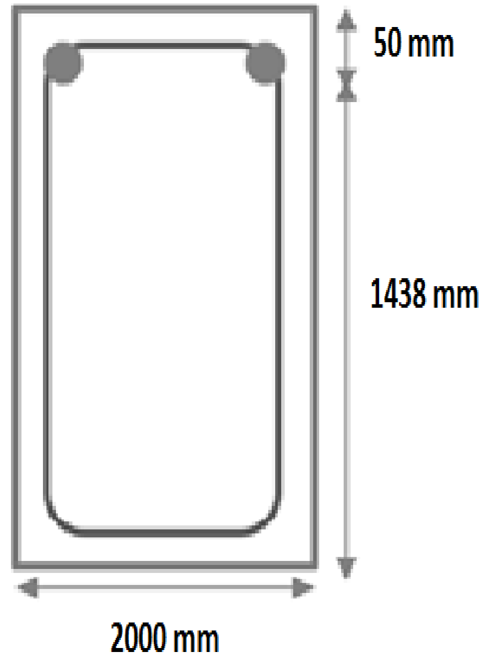
$a = \left(\frac{A_s f y}{0.85(fc)(b)}\right) = \frac{(420)(A_s)}{(0.85)(28)(2000)} = 0.00882 A_s$

$3475.85 \times 10^6 = (0.9)(A_s)(420)\left(1438 - \frac{0.00882 A_s}{2}\right)$

$A_s = 6501\ mm^2$

$use\ \emptyset\ 25 \rightarrow \#\ \text{of bars} = \frac{6501}{\left(\frac{\pi}{4}\right)(25)^2} = 13.24$

$use\ 13\ \#\ 25mm\ bars\ of\ the\ top\ of\ the\ piers.$



- **Design the bottom reinforcement based on the positive moment:**

$a = 0.00882 A_s$

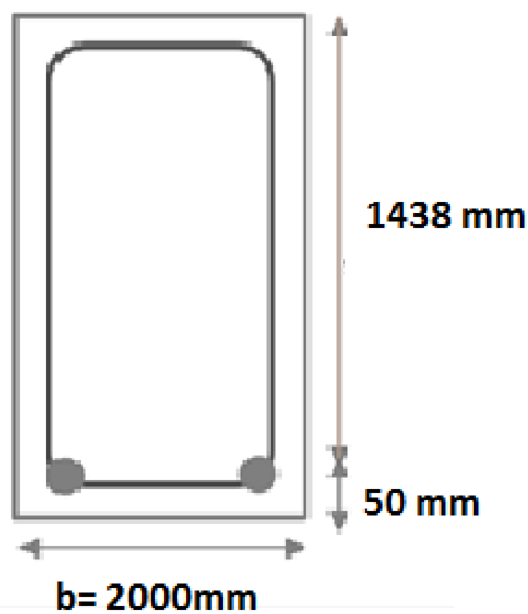
$M_{Max} = 2733.30\ kN\ .m$

$2733.30 \times 10^6 = (0.9)(A_s)(420)\left(1438 - \frac{0.00882 A_s}{2}\right)$

$A_s = 5138\ mm^2$

$use\ \emptyset\ 25 \rightarrow \#\ \text{of bars} = \frac{5138}{\left(\frac{\pi}{4}\right)(25)^2} = 10.5$

$use\ 10\ \#\ 25mm\ bars\ of\ the\ bottom\ of\ the\ piers.$



- **Design for shear force "cap"** **(ACI 318-5, section 11.3.2.1)**

$Vmax = 1870kN$
$fc = 28MPa$
$fy = 420MPa$

- Concrete shear capacity:

$$\emptyset V_c = \emptyset(0.17)(\lambda)\left(\sqrt{fc}\right)(b)(d)$$

λ= 1 (normal weight concrete) , $\emptyset = 0.75$

$$V_c = \frac{(0.17)(1)\left(\sqrt{28}\right)(2000)(1438)}{1000} = 2587.12kN$$

$$\emptyset V_c = (0.75)(2587.12) = 1940.34kN$$

$$Vmax = 2690.26\ KN\ > 1940.34\ kN$$

So, stirrups are needed here. (AASHTO LRFD, Cl: 5.13.2.4.2-6)
Ø12mm → $A_b = \left(\frac{\pi}{4}\right)(12)^2 = 79mm^2$
$A_u = 2A_b = 2(79) = 158mm^2$

- Design the spacing between two adjacent stirrups (ACI 318-05 Section)

$$S = \frac{(A_u)(fy)(d)}{\frac{V_u}{\emptyset} - V_c}$$

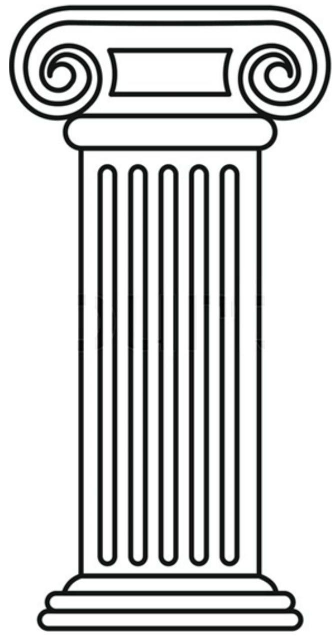
$$S = \frac{(158)(420)(1438)}{\frac{2690.26\times10^3}{0.75} - 2587.12\times10^3} = 95\ mm$$

$$S_{Max} \le \frac{d}{2} = \frac{1438}{2} = 719\ mm$$

$$S_{Max} = 803\ mm\ \ge 719\ mm$$

$$S_{Max} = 719\ mm$$

$$use\ S = 95\ mm$$



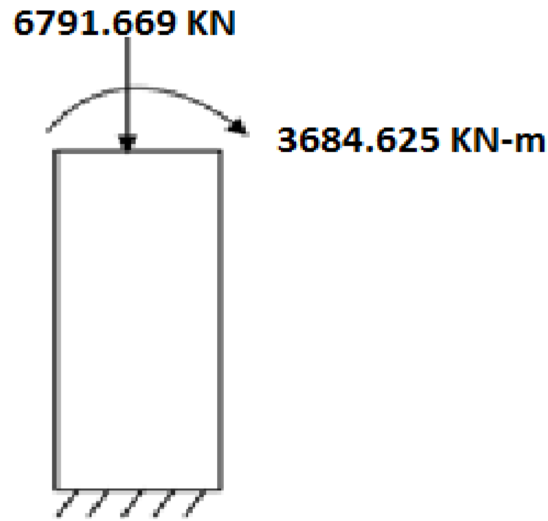
Post-Tension Concrete Bridge

(Pier Design)

8. Pier Design for Post-Tension Concrete Bridge

Axial Compression → P = 6791.669 KN (From CSi-Bridge)

Wind and Earthquake moment → M = 3565.625 + 119 = 3684.625 KN-m



Design the pier as a column subjected to axial compression and bending.

→ Use circular cross section

→ *fc'* = 28 MPa, F_y = 420 MPa

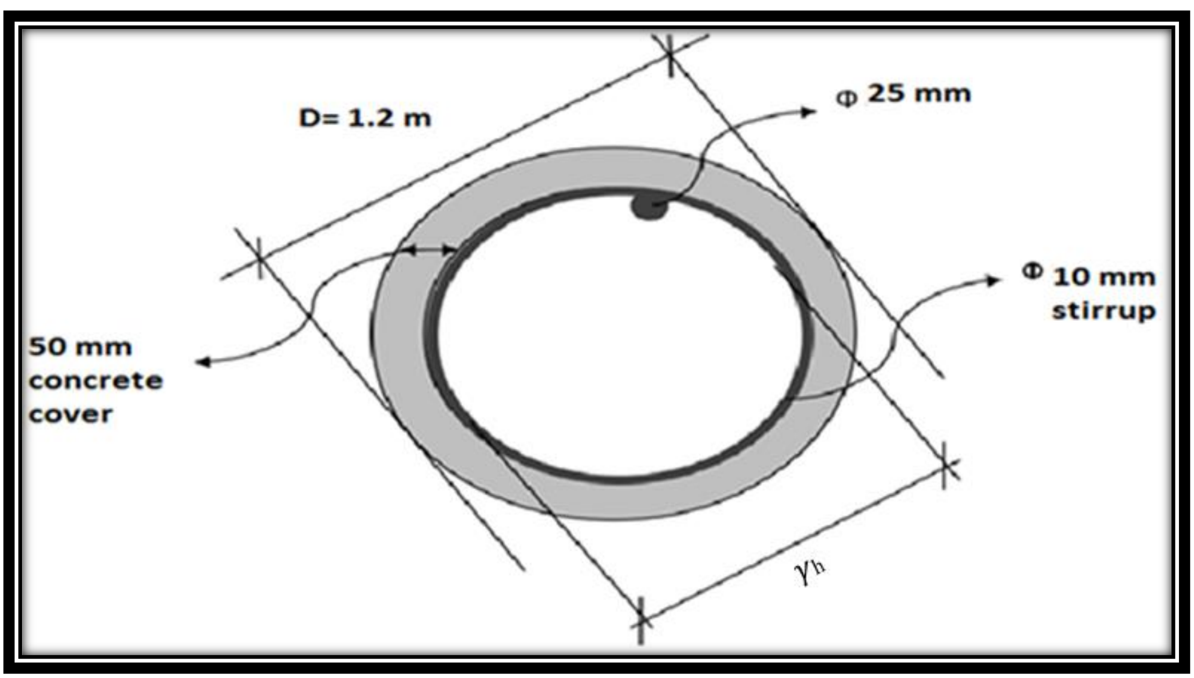


Figure 19 *Pier cross section*

Ag = $\frac{\pi}{4}$ $(1.2)^2$ = 1.13 m^2

ɣh = 1.2 – (2) 0.05 – (2)0.01 – 0.025 = 1.055 mm

ɣ = $\frac{ɣh}{D} = \frac{1.055}{1.2} \cong 0.88$

$K_n = \frac{P}{fc' \times Ag} = \frac{6791.669 \times 10^3}{(28MPa)(1.13 \times 10^6 mm^2)} = 0.215$

$R_n = \frac{M}{fc' \times Ag \times h} = \frac{1529 \times 10^6 N-mm}{(28MPa)(1.13 \times 10^6 mm^2)(1.2 \times 10^3 m)} = 0.040$

Use chart:

fc' = 28 MPa

Fy = 420 MPa → Percentage of Steel = 2 %

As = ρ × Ag = 0.02 × 1.13×10^6 = 22,600 mm^2

# of bars = $\frac{As}{Area\ of\ one\ bar} = \frac{22,600}{\frac{\pi}{4}(25)^2}$ = 46.1 bars

⇨ **Use 46 ϕ 25 mm bars**

Post-Tension Concrete Bridge

(Losses in Pre-Stress)

9. Losses in Pre-Stress for Post-Tension Concrete Bridge

1. **Loss due to Elastic Shortening** (Ref: AASHTO LRFD, Cl:5.9.5.2.3b) page 131

The loss due to elastic shortening may be calculated using Eq. C5.9.5.2.3a1:

Where:

$e_{54.5}$ = average eccentricity of pre-stressing steel at mid-span(in).

f_{pbt} = stress in pre-stressing steel immediately prior to transfer as specified in table S5.9.3-1; $0.75f_{pu}$.

M_g = mid-span moment due to member self-weight.

$$\Delta f_{Pes} = \frac{44(0.153)[0.75(270)]\left[733320+31.38^2(1085)\right]-31.38(20142)(1085)}{44(0.153)[733320+31.38^2(1085)]+\frac{1085(733320)(4200)}{28500}}$$

$$\Delta f_{Pes} = 13.7 \text{ ksi}$$

- Calculate the pre-stressing stress at transfer:

F_{pt} = stress immediately prior to transfer - Δf_{pES}

= 202.5-13.7

= 188.8 ksi

- Calculate the pre-stressing force at transfer:

$P_t = N_{strands}\,(A_{ps})\,(f_{pt})$

= 44(0.153) (188.8)

= 1271 kips (initial loss = 6.77 %)

2. **Loss due to Shrinkage of Concrete** (Ref: AASHTO LRFD, Cl:5.9.5.4.2a-1) page 132

$$\Delta \boldsymbol{f}_{\mathbf{pSR}} = \boldsymbol{\varepsilon}_{\mathbf{bid}} \; \boldsymbol{E}_{\mathbf{P}} \, \boldsymbol{K}_{\mathbf{id}}$$

Where:

εbid = concrete shrinkage strain of girder between the time of transfer and deck placement per Eq. 5.4.2.3.3-1.

Kid = transformed section coefficient that accounts for time-dependent interaction between concrete and bonded steel in the section being considered for time period between transfer and deck placement.

To determine the value of εbid the shrinkage strain of the girder must be determined at the time of deck placement. The basic equation for shrinkage is:

$$\varepsilon sh = -kvs\, khs\, kf\, ktd\, 0.48\, x\, 10 - 3\, kvs = 1.45 - 0.13(V/S) = 1.45 - 0.13(3.89) = 0.944$$

A humidity of 40 percent is used for this design.

$$khs = 2.00 - 0.014H = 2.00 - 0.014(40) = 1.440$$

$$K_{\mathrm{td}} = \frac{t}{61 - 4\, f'ci + t}$$

The time of deck placement, assumed at 60 days:

$$k_{\mathrm{td}} = \frac{60}{61-(4)(4.7)+60} = 0.587$$

$$\varepsilon_{\mathrm{bid}} = -(0.944)(1.440)(0.877)(0.587)(0.48\times10^{-3}) = -0.336\times10^{-3}$$

$$\Delta f_{\mathrm{PSR}} = 0.0210\ ksi$$

Loss due to Shrinkage of Concrete is 2.1%

3. **Loss due to Creep of Concrete** (Ref: AASHTO LRFD, Cl: 5.9.5.4.2b-1) page 133

$$\Delta f_{pCR} = \frac{Ep}{Eci} \times f_{cgp} \times \psi (t_d, t_t) K_{id}$$

To determine the value of K_{id} the girder creep must be determined at final age as follows:

$\psi b(tf, ti)$ = girder creep coefficient at final time due to loading introduced at transfer per Eq. 5.4.2.3.2-1

t_f = final age = (50 years)(365 days / year) = 18,250 days

t_i= age at transfer = 1 day.

$\psi_b (t_f, t_i) = 1.9\, k_{vs}\, k_{he}\, k_f\, k_{td}\, t_i^{-0.118}$

$k_{he} = 1.56 - 0.008H = 1.56 - (0.008)(40) = 1.240$

$K_{td} = \frac{18{,}250}{61-(4)(4.7)+18{,}250} = 0.998$ Use 1.0 for design.

$\psi_b (t_f, t_i) = (1.9)(0.944)(1.240)(0.877)(1.0)(1)^{-0.118} = 1.951$

Use gross section properties to determine k_{id}

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}} \frac{A_{ps}}{A_g}\left(1 + \frac{A_g e_{pg}^2}{I_g}\right)\left[1 + 0.7\psi_b(t_f, t_i)\right]} \quad (5.9.5.4.2a\text{-}2)$$

$$= \frac{1}{1 + \frac{28500}{3946} \frac{7.344}{941} \left(1 + \frac{(941)(30.939)^2}{671108}\right)[1 + (0.7)(1.951)]}$$

$k_{id} = 0.00762$

The pre-stress loss due to shrinkage between the time of transfer and the time of deck placement can be determined as follows:

$\Delta f_{pSR} = (0.000336)(28500)(0.00762) = 0.0729\ ksi$

The pre-stress loss due to creep of girder concrete between time of transfer and deck placement is determined as follow:

$$\Delta \boldsymbol{f}_{\mathbf{pCR}} = \frac{\boldsymbol{Ep}}{\boldsymbol{Eci}} \times \boldsymbol{f}_{\mathbf{cgp}} \times \boldsymbol{\psi}\ (\mathbf{t_d}, \mathbf{t_t})\ \boldsymbol{K}_{\mathbf{id}}$$

f_{cgp} = concrete stress at center of gravity of pre-stressing tendons.

$\psi b(tf, ti)$= girder creep coefficient at time of deck placement due to loading introduced at transfer per Eq 5.4.2.3.2-1

$\psi b(tf, ti)$= $1.9\ k_{vs}\, k_{he}\, k_f\, k_{td}\, t_i^{-0.118}$

$\psi b(tf, ti)$= (1.9) (0.944) (1.240) (0.877) (0.587) $(1)^{-0.118}$ = 1.145

The effective pre-stress force is the jacking stress minus the relaxation loss from time of stressing till time of transfer.

$p_t = [(0.75)(270) - 2.23](7.344) = 1470.78\ k\text{si}$

The concrete stress at the centroid of the pre-stress steel is calculated as follows using the transformed section properties at transfer.

$f_{cgp} = (1470.78)\left[\frac{1}{986.68} + \frac{(29.507)^2}{712{,}809}\right] - \frac{(1503)(12)(29.507)}{712{,}809} = 4.640\ ksi$

All the remaining variables have already been determined. The Pre-Stress loss due to creep is calculated as follows:

$\Delta f_{pCR} = \frac{28500}{3946} \times (4.640) \times (1.145) \times (0.00762) = 0.0292\ ksi$

Loss due to Creep of Concrete is 2.9%

4. **Loss due to Creep in steel (Relaxation of steel)** (Ref: AASHTO LRFD, Cl: 5.9.5.4.2c-1) page 135

$$\Delta f_{pR1} = \frac{f_{pt}}{K_L}\left(\frac{f_{pt}}{f_{py}} - 0.55\right)$$

f_{PRl} = stress in pre-stressing strands immediately after transfer but shall not be less than $0.55f_{py}$ = 0.55(243) = 133.65 ksi. The stress after transfer includes the relaxation loss prior to transfer and the elastic shortening loss.

$\Delta f_{PES} = \frac{Ep}{KL}\, fcgp = \frac{28500}{3946} \times 2.540 = 18.35\ ksi$

$f_{pt} = (0.75)(310) - 2.23 - 18.35 = 212 ksi$

$K_L = 30\ for\ low\ relaxation\ strands.$

$\Delta f_{PR1} = \frac{212}{30}\left(\frac{212}{243} - 0.55\right) \div 100 = 0.0230\ Ksi$

. Loss due to Creep in steel (Relaxation of steel) is 2.30%

5. The losses due to friction $\Delta P\mu(x)$ (Ref: AASHTO LRFD, Cl: 5.9.5.4.2c-1)

$$\Delta p_{\mu}(x) = p_{max}\,(1 - e^{-\mu\,(\Theta+Kx)})$$

Θ: is the sum of the angular displacements over a distance x (irrespective of direction or sign)

μ: is the coefficient of friction between the tendon and its duct

k: is an unintentional angular displacement for internal tendons (per unit length)

x: is the distance along the tendon from the point where the pre-stressing force is equal to Pmax (the force at the active end during tensioning)

Where,

ηx = μα + kx

For cable ym = 0.1 m.

For the cables, L = 15 m

Substituting the values of ym and L

η_x = 0.0029

ηL e = 0.971

Percentage loss due to friction = (1 – e–ηL) × 100% = 3%

Area of cable = 1820 mm^2

Number of cable = 3

Total area of three cables = 5460 mm^2

Diameter for wire = 15.24 mm^2

Area of pre-stressing wire (A_P) = $3 \times \left(\frac{\pi}{4}\right) \times (15.24)^2$ = 547.244 mm^2

$P_e = N_{strands}(A_{ps})(f_{pe})$ (Ref:AASHTO LRFD, Cl:5.4.4.2)

Type of

$N_{strands}$= 13

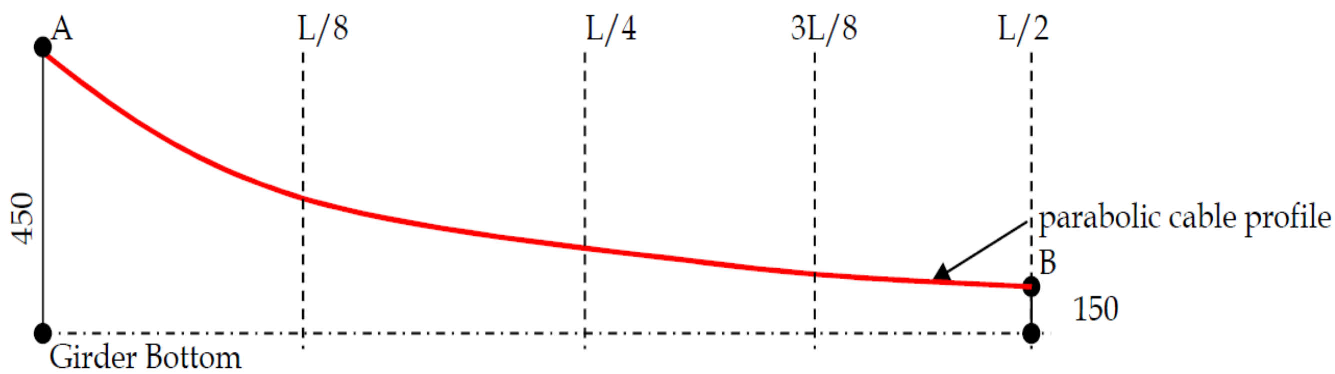
A_{ps} = 5320 mm^2

$f_{pe} = 0.75f_{pu} - \Delta f_{pT}$ = 336 N/mm^2

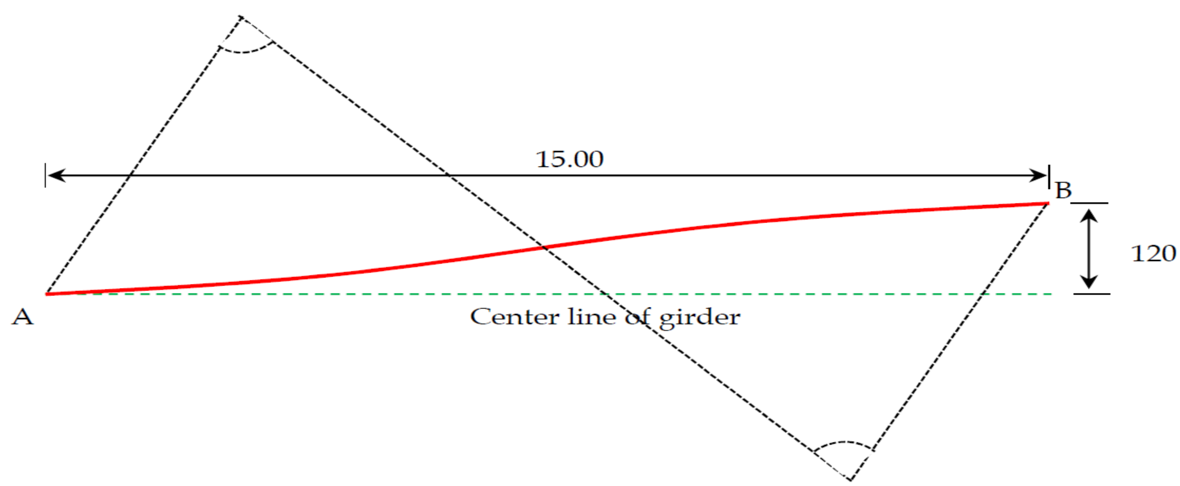
P_e = 1699.006 kips

Total percentage for losses of pre-stresses is 17%

Cable

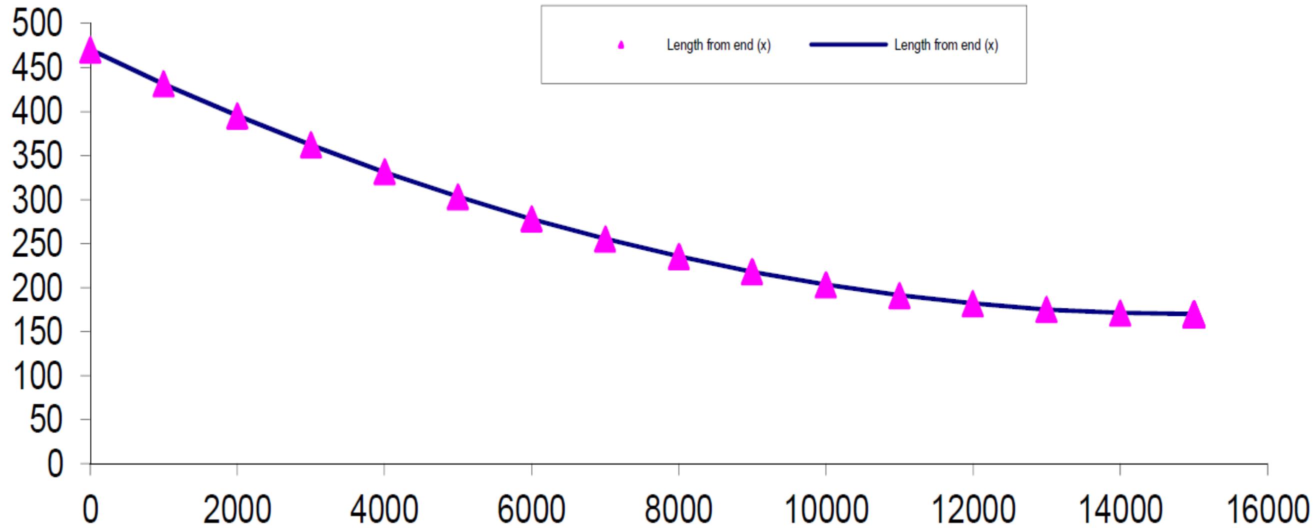


Elevation showing Cable profile



Plan showing sway between point A & B

Ordinates of cable at different sections from bottom of girder



Section	0	L/16	L/8	L/4	3L/8	L/2

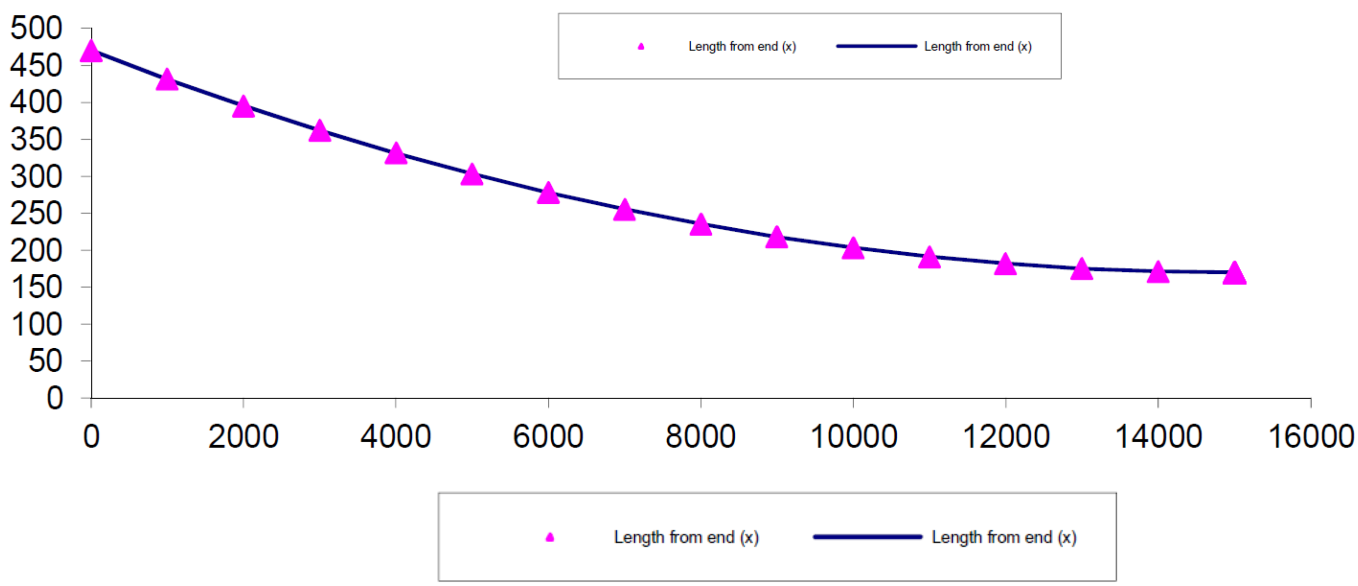
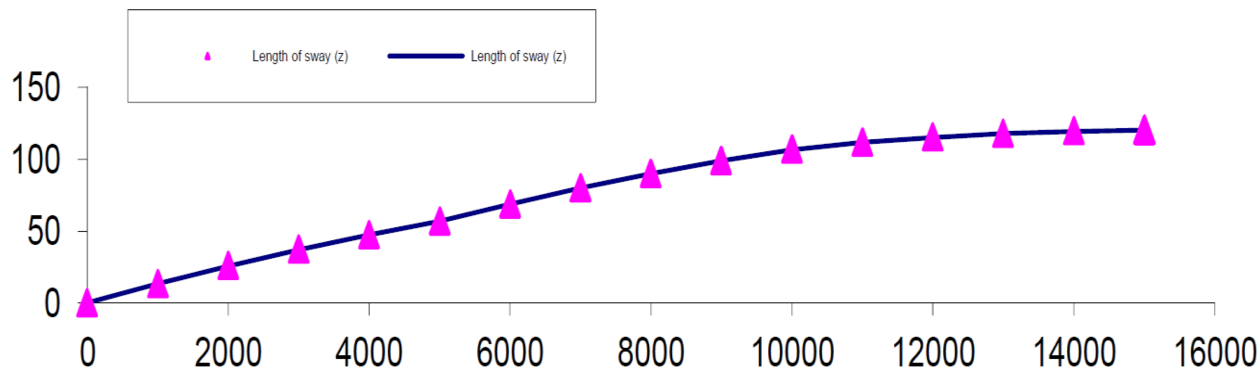


Figure 20 *Points of moment in the cable*



Vertical angle turning = 0.0400 ° = 0.03998 rad

Horizontal angle turning = $2 \times \tan^{-1} \dfrac{24.63}{937.50}$ = 0.05252 rad

Stresses at various points

A = = 1377.99 N/mm^2

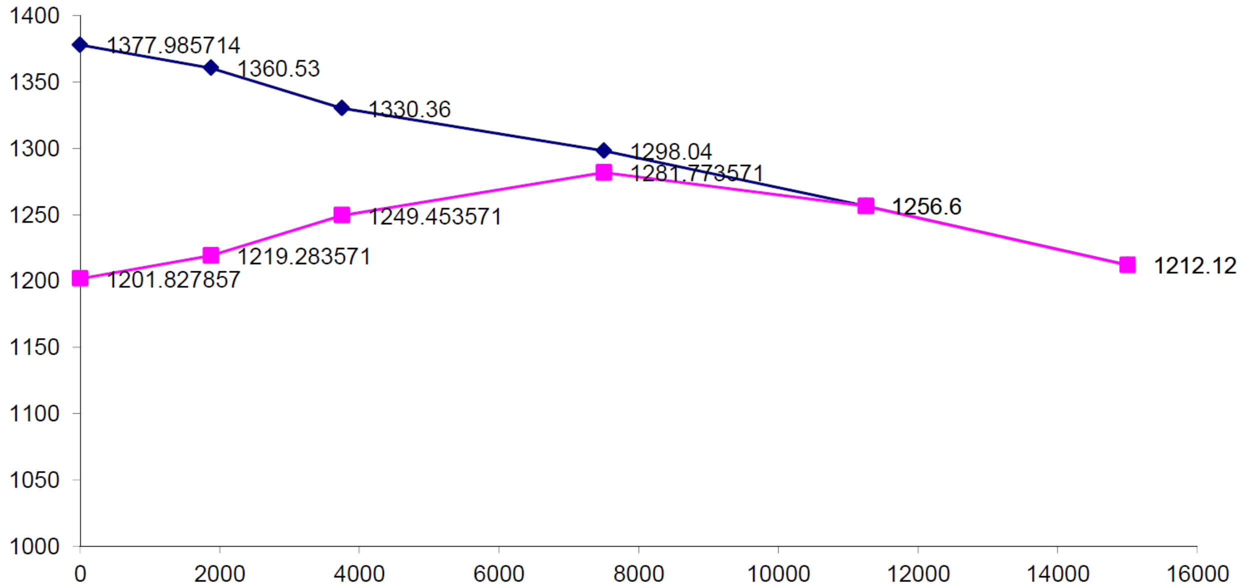
L/16 = $1377.99 \times e^{-(0.0007 \times 1.8820 + 0.20 \times 0.058)}$ = 1360.53 N/mm^2

L/8 = $1360.53 \times e^{-(0.0007 \times 1.8803 + 0.20 \times 0.106)}$ = 1330.36 N/mm^2

L/4 = $1330.36 \times e^{-(0.0007 \times 3.7562 + 0.20 \times 0.111)}$ = 1298.04 N/mm^2

3L/8 = $1298.04 \times e^{-(0.0007 \times 3.7522 + 0.20 \times 0.150)}$ = 1256.60 N/mm^2

L/2 = $1256.60 \times e^{-(0.0007 \times 3.7511 + 0.20 \times 0.168)}$ = 1212.12 N/mm^2


1400
1350
1300
1250
1200
1150
1100
1050
1000
0
2000
4000
6000
8000
10000
12000
14000
16000
1377.985714
1360.53
1330.36
1298.04
1281.773571
1256.6
1249.453571
1219.283571
1201.827857
1212.12

CHAPTER 6

Soil Report and Foundation System Design:

1. Introduction
2. Soil Investigation
3. Design of piers foundation for (Steel Bridge)
4. Design of piers foundation for (Post-Tensioned Concrete Bridge)

CHAPTER 6: SOIL REPORT AND FOUNDATION SYSTEM DESIGN

1. Introduction

This chapter is stated to explain the investigation of the site and the labarotory, ground profile and soil report of the field of the bridge. All information are combined in sequence to design and analyze the system of foundation for various types of the bridge. Furthermore, the system of foundation design and analysis will be explained in this chapter.

2. Soil Investigation

According to the laboratory report, it was found that there are two different soil profiles in our site. After digging few boreholes in the site, it was found that the right side of the railway (section A in figure 21) has the rock on 3 m below ground. On the other hand, it was found that the left side of the railway (section B in figure 21) has the rock on 4.5 m below ground. The best way to fix this problem is to excavate the 4.5 m from section B and compact it with granular soil of 1.5 m I order to have similar soil profile throughout the whole site.

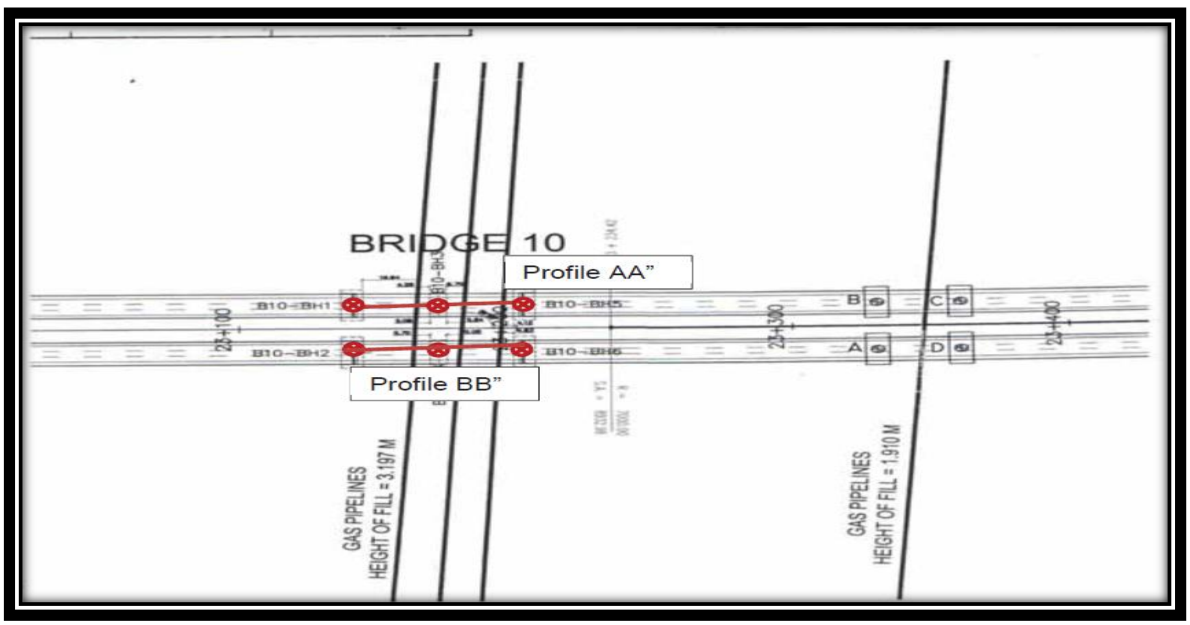
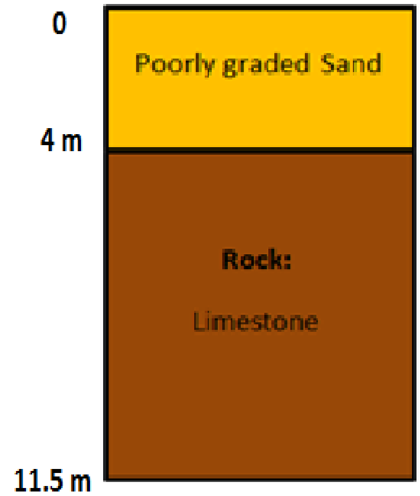


Figure 21 *Bridge layout and boreholes locations*

3. Design of piers foundation for (Steel Bridge)

S-Section (A):-



Section A

For Rock, the following was used method to find allowable bearing capacity:

$$q_{all} = \frac{(Rc)(0.8)}{10} \times R.Q.D$$

From soil profile we have these data:

R.Q.D = 50 % (by average)

Rc = 30.00 MPa = 3000 kN/m^2

$$q_{all} = \frac{(3000)(0.8)}{10} \times (0.50)$$

$$\mathbf{q_{all} = 120\ kN/m^2}$$

$Qp = A\ q_p = \pi \times (0.15)^2 \times 120 = 8.478$ KN

$Q_s = 2\pi R(L1f1 + L2f2 + L3f3\ )$ {Length of pile L=11.5 m}

$L_1 = 1.5$ m, $L_2 = 5.5$ m, $L_3 = 4.5$ m (DAS, 1997)

The unit frictions for the difficult soil layers are taken as follow:

$f1 = 15\ kpa$ $f3 = 20\ kpa$ $f2 = \alpha\ C2 = 0.30 \times 150 = 45\ kpa$

R = 15 cm = 0.15 m

$Q_s = 2 \times \pi \times 0.15\ (1.5 \times 15 + 5.5 \times 45 + 4.5 \times 20) = 339.29\ KN$

$Qpile = \frac{Qp+Qs}{Fs}$

$Qpile = \frac{8.478+339.29}{4} = 86.94\ KN$

$Q_{pile} = \frac{Qpile}{A} = \frac{86.94}{\pi(0.15)^2} = 1230$ KN/m^2

$Q_{Group} = \mathcal{E}\ Q_{pile}$ n

$\eta = \frac{2(n1+n2-2)d+4D}{P\ n1\ \ n2}$ (DAS, 1997)

$n_1 = 2$ (number of piles horizontal), $n_2 = 2$ (Number of piles vertical), d =Diameter for pile,

D = Spacing between piles, P = π D

$\eta = \frac{2(2+2-2)(0.30)+4(0.90)}{(0.9425)(2)(2\ )} = 1.27 \quad (So\ \eta = 1)$

$Q_{Group} = (1)\ (1359.36)\ (4) = 5437.45$ KN/m^2

Section (B):-

For compacted layer we have to use Terzaghi formula to find the ultimate bearing capacity:

$$q_u = 1.3C\, N_c + q\, N_q + 0.4\, \gamma\, B\, N_\gamma \quad \text{(Square Footing)}$$

From soil profile we have these data:

$\emptyset = 35°$ $\gamma = 20\ kN/m^3$ c = 0 D = 4 m. B = 1.5 m

$q = \gamma \times D = 20 \times 4 = 80\ kN/m^2$

$$From\ table\ 3.1,\ N_\gamma = 45.41$$

$$From\ table\ 3.1,\ Nq = 41.44$$

$$From\ table\ 3.1,\ Nc = 57.75$$

$$q_u = 1.3C\, N_c + q\, N_q + 0.4\, \gamma\, B\, N_\gamma \quad \text{(Square Footing)}$$

$q_u = (1.3)(0)(57.75) + (80)(41.44) + (0.4)(20)(1.5)(45.41) = 3860.12 KN/m^2$,

$$q_{all} = \frac{3860.12}{3} = 1286.71\ KN/\text{m}^2$$

Load and moment acting on the piers: (Superstrucure)

Q = 5969.10 kN, M = 2×3250.057 kN-m =6500.114 KN-m

$$e = \frac{M}{Q} = \frac{6500.114}{5969.10} = 1.0889 \approx 1.1\ m$$

$$q_{max} = \frac{Q}{BL} + \frac{6M}{B^2L} = \frac{5969.10}{(2.10)(2.10)} + \frac{6(6500.114)}{(2.10)^2(2.10)} = 5564.82\ kN/m^2$$

Verified:

$Q_{Group} + q_{all} = 6724.16 > q_{max} = 5564.82\ kN/m^2$ (verified)

Verified so:

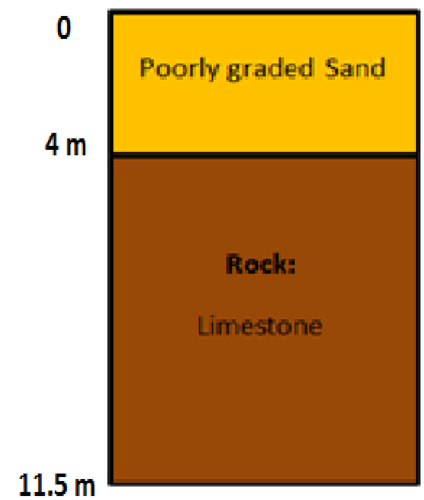
B= 1.5 m (footing)

N= 4 piles

d = 30 cm, L=11.5 m

4. Design of piers foundation for (Post-Tensioned Concrete Bridge)

S-Section (A):-



Section A

For Rock, the following was used method to find allowable bearing capacity:

$$q_{all} = \frac{(Rc)(0.8)}{10} \times R.Q.D$$

From soil profile we have these data:

R.Q.D = 50 % (by average)

Rc = 30.00 MPa = 3000 kN/m^2

$$q_{all} = \frac{(3000)(0.8)}{10} \times (0.50)$$

$$\mathbf{q_{all} = 120\ kN/m^2}$$

$Qp = A\ q_p = \pi \times (0.15)^2 \times 120 = 8.478$ KN

$Q_s = 2\pi R(L1f1 + L2f2 + L3f3\ )$ {Length of the pile L=11.5 m}

$L_1 = 1.5$ m, $L_2 = 5.5$ m, $L_3 = 4.5$ m {DAS, 1997}

The unit frictions for the difficult soil layer are taken as follow:

$f1 = 15\ kpa$ $f3 = 20\ kpa$ $f2 = \alpha\ C2 = 0.30 \times 150 = 45\ kpa$

R = 15 cm = 0.15 m

$Q_s = 2 \times \pi \times 0.15\ (1.5 \times 15 + 5.5 \times 45 + 4.5 \times 20) = 339.29\ KN$

$Qpile = \frac{Qp+Qs}{Fs}$

$$Qpile = \frac{8.478 + 339.29}{4} = 86.94\ KN$$

$Q_{pile} = \frac{Qpile}{A} = \frac{86.94}{\pi(0.15)^2} = 1230$ KN/m^2

$Q_{Group} = Ɛ\ Q_{pile}\ n$

$\eta = \frac{2(n1+n2-2)d+4D}{P\ n1\ n2}$ {DAS, 1997}

$n_1 = 2$ (number of piles horizontal), $n_2 = 2$ (Number of piles vertical), d =Diameter for pile,

D = Spacing between piles, P = π D

$\eta = \frac{2(2+2-2)(0.30)+4(0.90)}{(0.9425)(2)(2)} = 1.27 \quad (so\ \eta = 1)$

$Q_{Group} = (1)\ (1359.36)\ (4) = 5437.45$ KN/m^2

Section (B):-

For compacted layer we have to use Terzaghi formula to find the ultimate bearing capacity:

$$q_u = 1.3C\, N_c + q\, N_q + 0.4\, \gamma\, B\, N_\gamma \quad \text{(Square Footing)}$$

From soil profile we have these data:

$\emptyset = 35°$ $\quad \gamma = 20\ kN/m^3$ $\quad$ c = 0 $\quad$ D = 4 m. $\quad$ B= 2.10 m

$q = \gamma \times D = 20 \times 4 = 80\ kN/m^2$

$$From\ table\ 3.1\ ,\ N_\gamma = 45.41$$

$$From\ table\ 3.1\ ,Nq = 41.44$$

$$From\ table\ 3.1\ ,Nc = 57.75$$

$$q_u = 1.3C\, N_c + q\, N_q + 0.4\, \gamma\, B\, N_\gamma \quad \text{(Square Footing)}$$

$$q_u = (1.3)(0)(57.75) + (80)(41.44) + (0.4)(20\ )(2.10)(45.41) = 4078.088\ KN/m2$$

$$q_{all} = \frac{4078.088}{3} = 1359.36\ KN/m^2$$

Load and moment acting on the piers: (Superstructure)

Q = 6791.669 kN, M = 2×3684.625 kN-m =7369.25 KN-m

$$e = \frac{M}{Q} = \frac{7369.25}{6791.669} = 1.08\ m$$

$$q_{max} = \frac{Q}{BL} + \frac{6M}{B^2L} = \frac{6791.669}{(2.10)(2.10)} + \frac{6(7369.25)}{(2.10)^2(2.10)} = 6314.437\ kN/m^2$$

Verified:

$Q_{Group} + q_{all}$ = 5437.45+1359.36 = 6796.81 > q_{max} = 6314.437 (verified)

Verified so:

B= 2.10 m (footing)

N= 4 piles

D= 30 cm, L = 11.5 m

Pile foundation dimensions

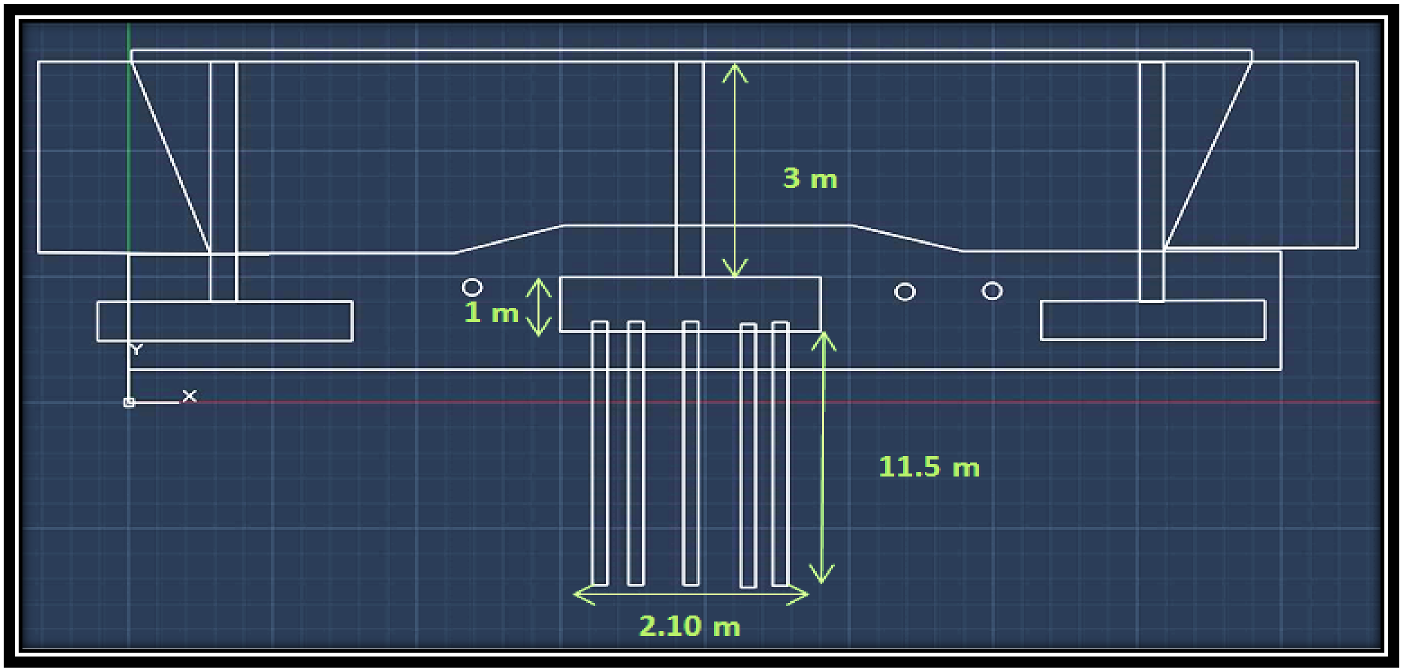


Figure 22 *Side view of pile foundation*

Footing dimensions

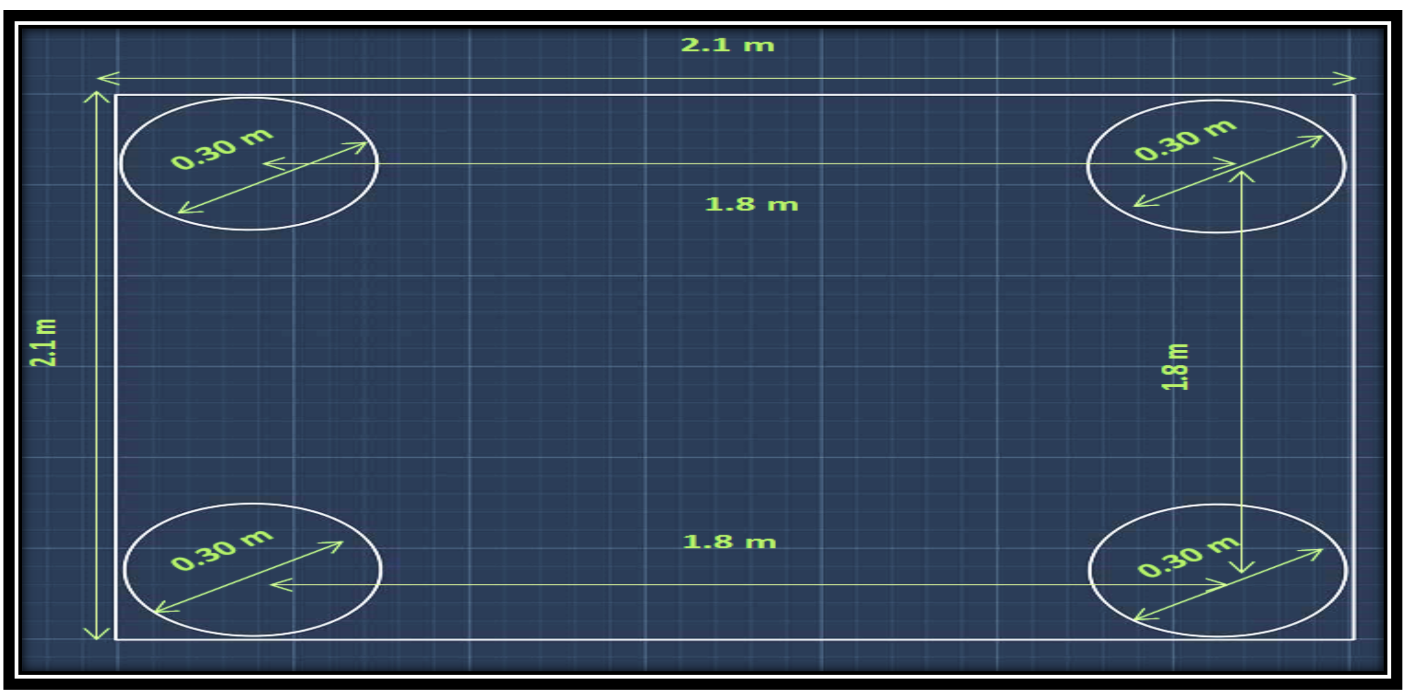


Figure 23 *Footing Cross section*

CHAPTER 7

Introduction To Modeling:

1. Introduction to CSiBridge
2. Initializing a Model
   - I Units
   - II Templates
   - III Objectives and Elements
   - IV Grid Systems
   - V Properties
   - VI Loading
   - VII Analysis
   - VIII Loads Combination
   - IX Design
   - X Output and Display
3. Result for **<u>(Steel Bridge)</u>**
   - I Steel 3D Model:
   - II Deflection
   - III Moment
   - IV Shear
4. Result for **<u>Post-Tensioned Concrete Bridge</u>**
   - I Post-Tensioned 3D Model:
   - II Deflection
   - III Moment
   - IV Shear

CHAPTER 7: Introduction To Modeling

1. Introduction to CSiBridge

In order to create the ultimate in computerized engineering tools, the modeling, analysis and design of bridge structures have been combined into CSiBridge. The ease of carrying out all these tasks makes CSiBridge the most adaptable and functional software in the market today.

Engineers can easily define complex bridge geometries, boundary conditions and load cases using CSiBridge. The bridge models are parametrically defined using terms familiar to bridge engineers such as layout lines, spans, bearings, abutments, bents and hinges and post-tensioning. The software creates models for spine, shell or solid objects that automatically refresh the bridge definition parameters..

The CSiBridge design enables fast and easy design and retrofitting of bridges in steel and concrete. The parametric model allows the user to create simple or complex bridge models and make efficient changes while maintaining complete control over the design process. Runways and vehicles can be quickly defined and have wide effects. Simple and practical Gantt charts are available for simulating the modeling and scheduling of construction sequences. Furthermore, AASHTO LRFD design comprises automated load combinations, superstructure design and the latest seismic design.

2. Initializing a Model

CSiBridge is unified with a large user interface with a wide range of design and analysis options. This interface enables structural models to be generated with immediate apprehension and eliminates fast process curve delays. CSiBridge provides step - by - step procedures with advanced analytical strategy. The user interface factors include:

- Units
- Templates
- Objects and elements
- Grid systems
- Properties
- Loading
- Analysis
- Load combinations
- Design
- Output and display

In a structural analysis, several classics can take time and it is difficult to explore the influence of a particular structural parameter without the effective method of modernized programs such as CSiBridge. The CSiBridge user interface has such features to initialize a model. The user can improve the model by using the steps and factors to create stronger structures for every model. The procedures and the factors are explained below step by step:

I. Units

CSiBridge handles various units. The units that are used to begin a new model becomes the basic units for that model. Every material dimension and constant is defined as similar with basic units. Newton and Kip are used to define Force, millimeter and inches are used for length. Time is measured in seconds and Mass is used only to compute accelerating objects for loads. Like others force loads weight also can be applied to the load. For angular measurements like geometry, Degree is used for measurement. Hertz (Hz) is used for frequency measurement or in cycles/second.

II. Templates

CSiBridge has different templates for a quick start of a new model. Parametric templates are used for 3D frames, 3D trusses, storage vessels, simple beams, staircases, pipes and dam structures. A beneficial decision of templates can boost up the overall modeling process in many cases. There are also various options available regarding the structure type.

III. Objectives and Elements

There are four types of objects and some are subdivided into various types. To define a model of the physical structural members and loads to the objects any geometrical figure can be drawn by assigning properties.

There are four kinds of objects, some of which are divided into different types. To define a model of the physical structural components and loads to the objects, any geometric figure can be drawn using assigned properties.The main objects are:

- **Point objects**: Subdivided into two grounded linked objects and Joint objects. Joint objects are automatically created and can be added in a definite manner. Objects based on the link accelerate support behavious such as gaps, insulators, multi-linear springs, dampers and others.

- **Line objects:** Subdivided into two as Frame objects and the Connecting link objects. Frame cable objects are used to model columns, trusses, braces and beams. The Connecting Objects are used to model gaps, insulators, multi-linear springs, dampers and others with zero length.

- **Solid objects:** Used to model 3D solids.
- **Area objects:** Used to model 2D solids and thin-walled members.

IV. Grid Systems

There are no limits of grid systems in a model and the grids can be rotated or placed inside the model in any direction. The CSiBridge is complemented by the 3D, right and Cartesian system of coordinates. Each grid could be a basic rectangular and cylindrical type. A 3D grid system with construction lines can locate objects in the model . The right - hand rule are three axes identified by X, Y, and Z. The direction of + Z is perpendicular to each other and the gravity implied by –Z direction globally.

V. Properties

A model may have CONCRETE, RECT, CIRC and SLAB properties. CONCRETE is a material property and can be enforced to the object automatically. RECT is the property of a rectangular frame section, a circular section is called CIRC and an area section is called SLAB.

These properties are assigned to determine the structural behaviour of objects in the model.

VI. Loading

The wave loading feature of CSiBridge generates the loading on the structures that result from current flow, waves, wind, and buoyancy. Static linear loading can be generated with multiple steps to stimulate the wave moving through the structure. Moreover, the dynamic loading is to include inertial effects as the wave moves through the structure.

CSIBridge generates and applies wind loads spontaneously on the basis of different national and international codes. It has a moving load generator which enables users to move loads on shell and frame elements to lanes.

The CSiBridge wave loading feature generates loading on structures resulting from current flow, waves, wind and boom. Static linear loading can be achieved by several steps to stimulate the movement of the wave through the structure. In addition, the dynamic loading must include inertial effects as the wave crosses the structure.

User loads are defined to model a wide range of loading conditions using the integrated user loading options of CSiBridge.

VII. Analysis

The analysis is the method for applying structural loads and calculating structural reactions. Several types of analysis are available such as Static, Dynamic, Buckling, P-Delta and Pushover.

CSiBridge is able to perform both static and linear multi-step analysis. Dynamic analysis capabilities include the vibration calculation with Ritz or Eigen. Linear modes of buckling of a structure remain under loads

P-Delta analysis captures the soft effect of the compression and the harshening effect of the tension. The Pushover analysis performs the performance of the FEMA-356 and also includes the hinge option based on stress.

VIII. Loads Combination

There are several combinations of loads. Linear addictive, envelope, absolute add, SRSS and range combinations are included.

- Linear addictive: linear additves generate combos and cases and then it adds them
- Envelope: it is the responsibility of adding the results to find the maximum and minimum values envelope combination.
- SRSS: This type calculates the square root sum of the analytical case and combo squares.

The model design is not based directly on analysis, but instead on combinations. Additional combinations can be created for design and other purposes.

IX. Design

Some settings affect the design of a particular model. In areas where the properties are based on steel, concrete or aluminum materials, design features can be applied to frame objects. Two frames are briefly explained:

- Steel frame: Steel frame can be used for member size optimization and implementation of design codes. The program allows users to view the results of the design via any frame.
- Concrete frame: The concrete frame design includes member sizing auto-select lists, steel calculation area, overwriting capacity and interactive design.

X. Output and Display

This feature offers many options for displaying sets, views, formats and model function plots. Users can easily display deformed geometry based on load and mode animation combinations.

The force diagrams show the inner shear moments, forces and dislocations at each frame element location. The CSI bridge provides the option to scroll along the way to display values at the maximum and minimum value location.

Virtual Work diagrams are the other type. It can be used to determine the elements to be hardened in order to control the structure most efficiently.

3. Result for **(Steel Bridge)**

In CSiBridge software, we have defined the bridge components and their dimensions. After the loads were assigned, we carried out the analysis and obtained the following results:

I. Steel 3D Model:

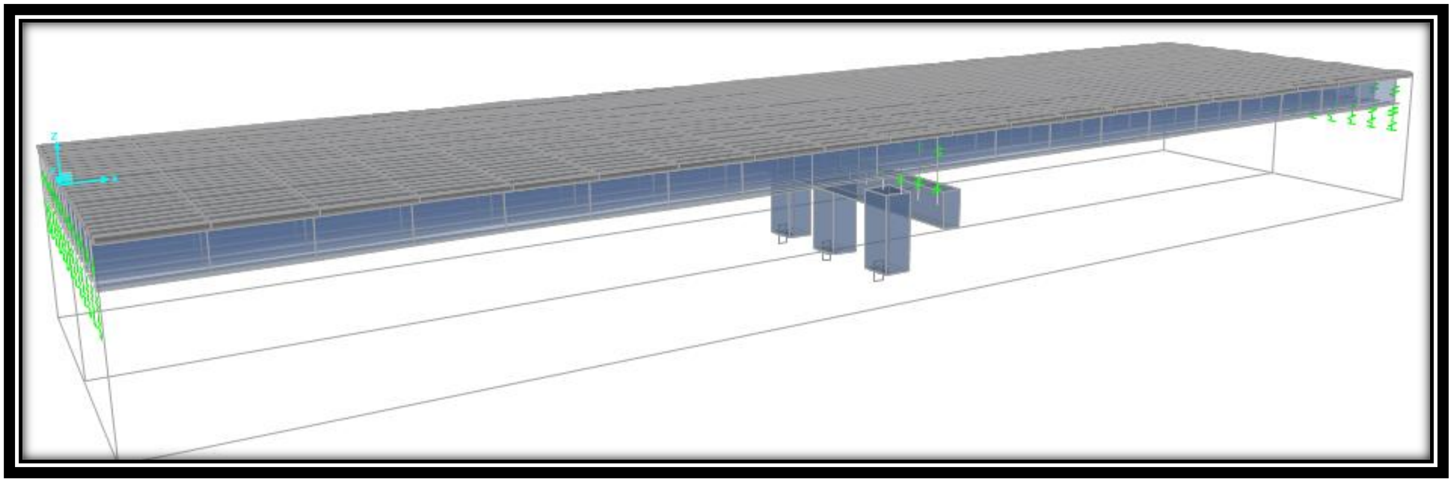


Figure 24 *3D Model*

II. Deflection

The Allowable Deflection : $\frac{\text{L}}{800} = 31.3$ mm (MOMRA)

The Software Result = 28.56 mm

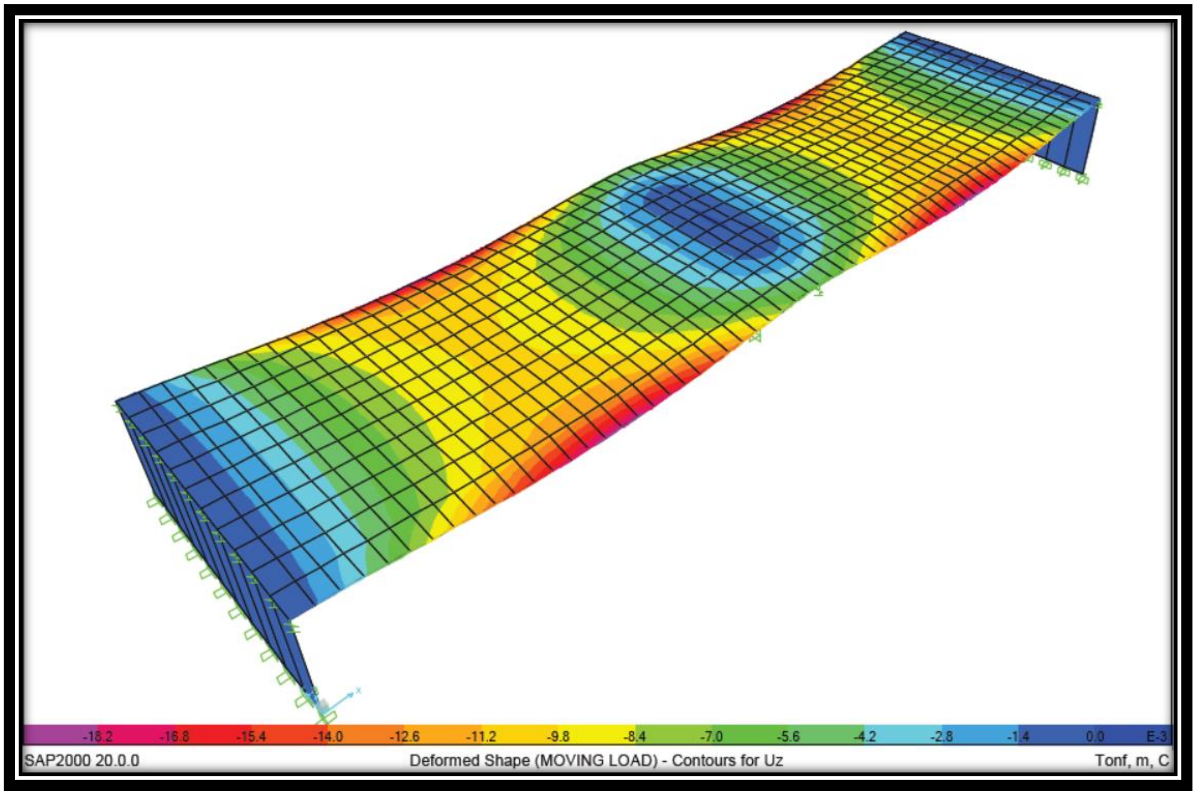


Figure 25 *Deformation shape*

III. Moment

Maximum Moment = 25418.7963 kN-m (AISC)

Software Result = 32991.34 kN-m

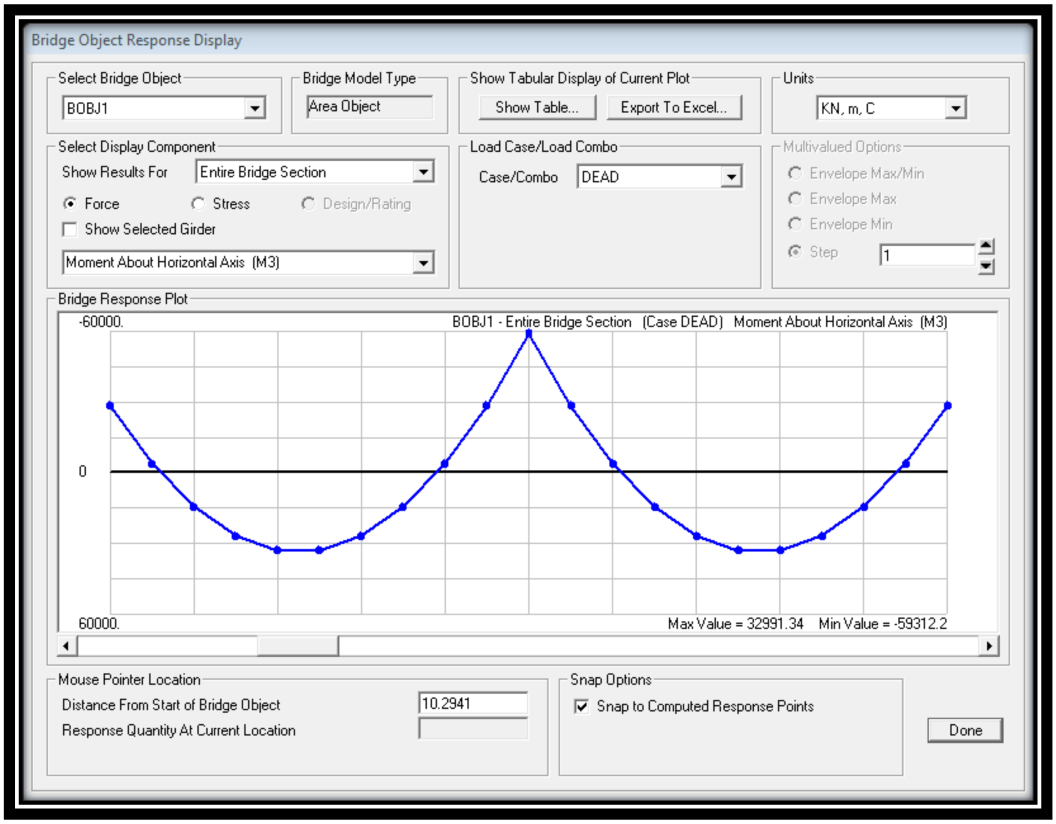


Figure 26 *Moment Result*

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IV. Shear

Maximum Shear = 20639.84 KN (AISC)

Software Result = 11,277.495 kN

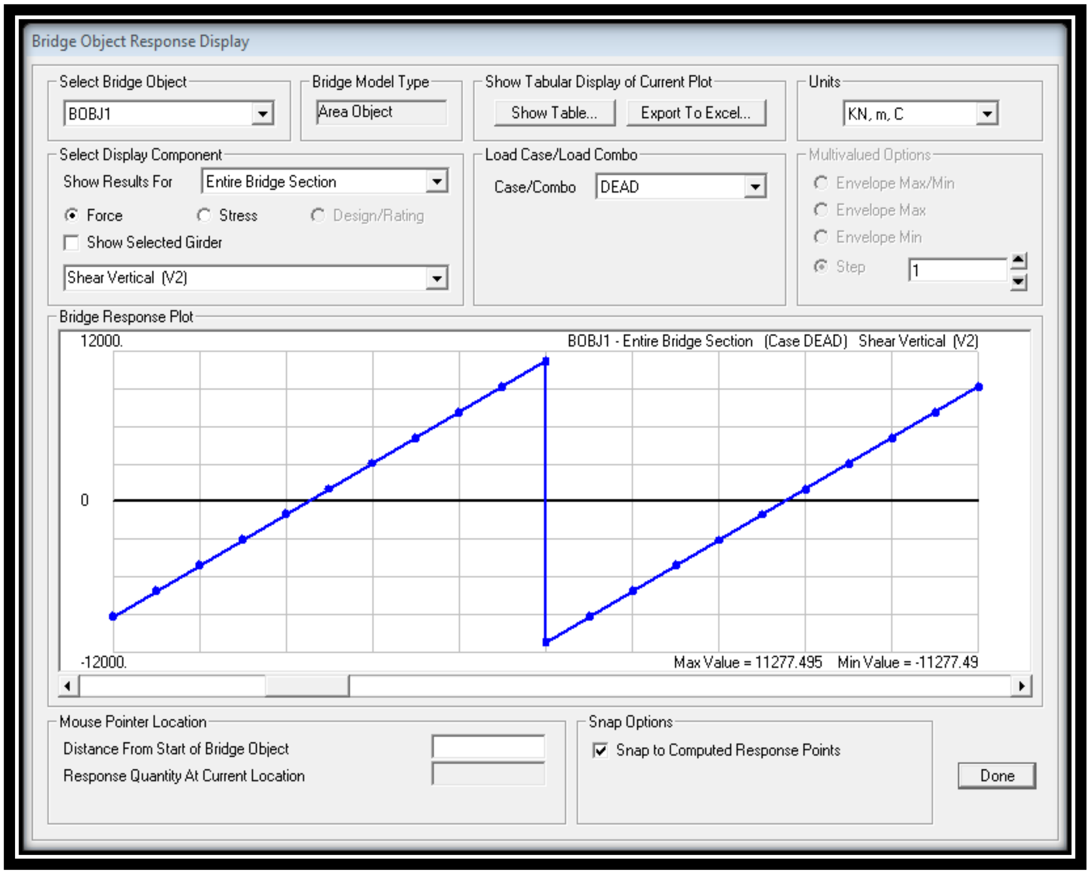

Figure 27 *Shear Result*

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4. Result for **(Post-Tensioned Concrete Bridge)**

I. Post-Tensioned 3D Model

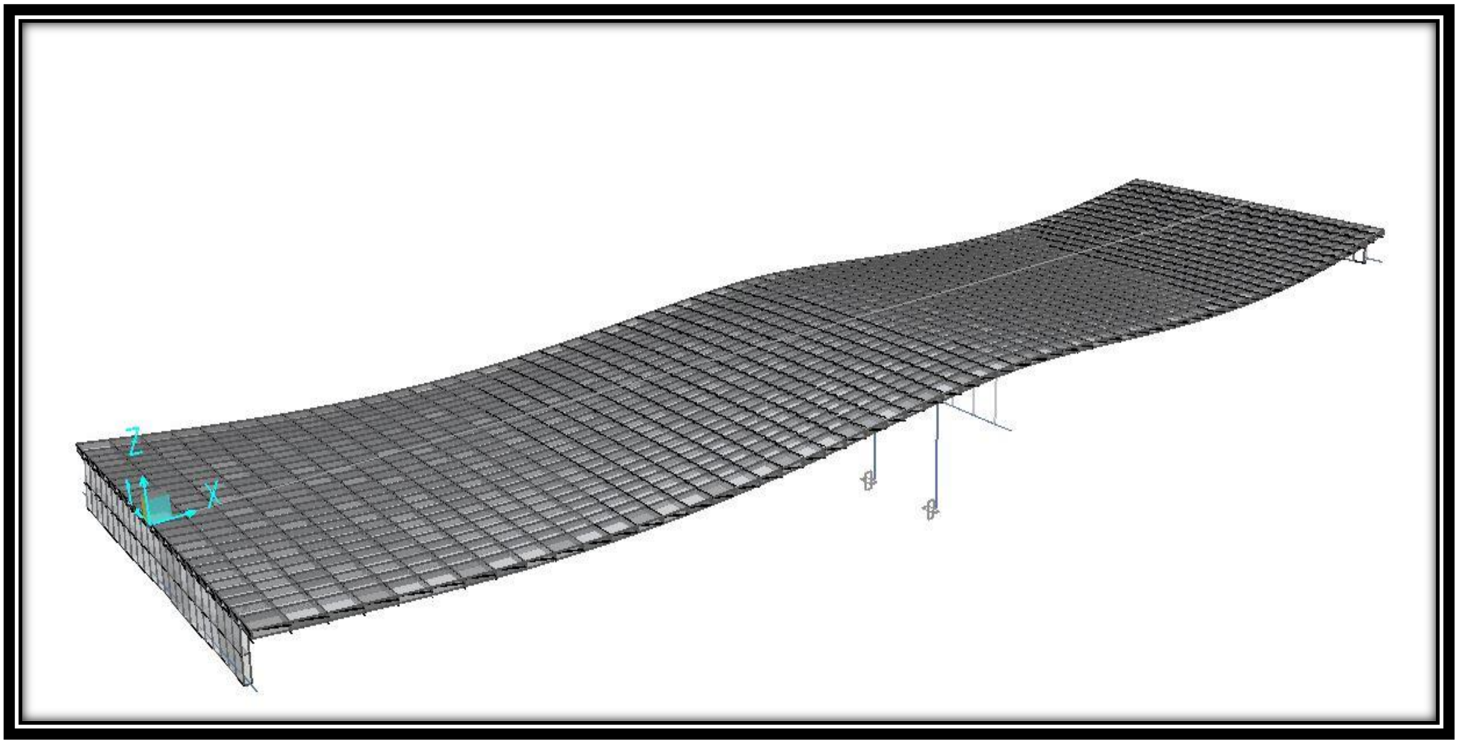

Figure 28 *3D Model*

II. Deflection

The Allowable Deflection : $\frac{L}{800} = 31.3$ mm (MOMRA)

The Software Result = 25.96 mm

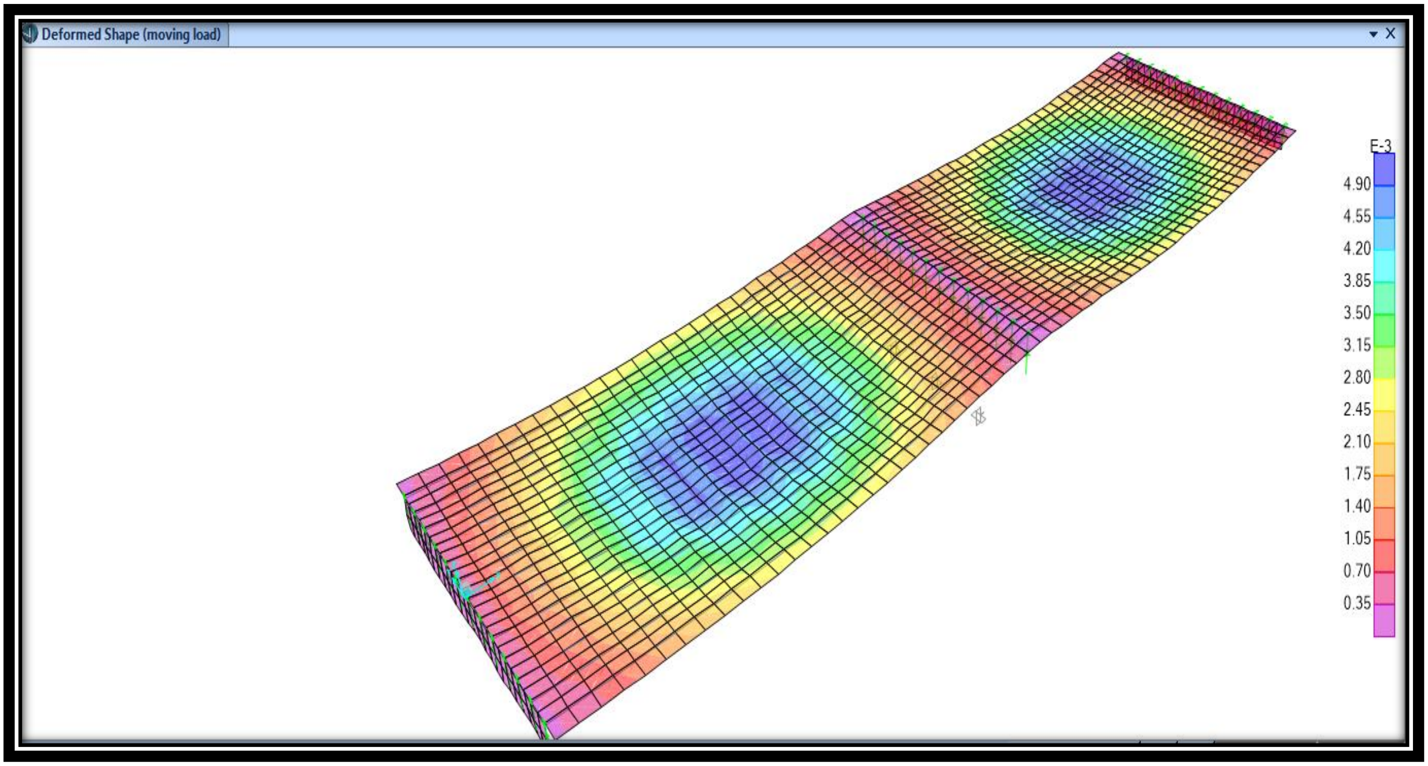

Figure 29 *Deformation shape*

III. Moment

Maximum Moment = 27915.61 kN-m (AISC)

Software Result = 19,915.602 kN-m

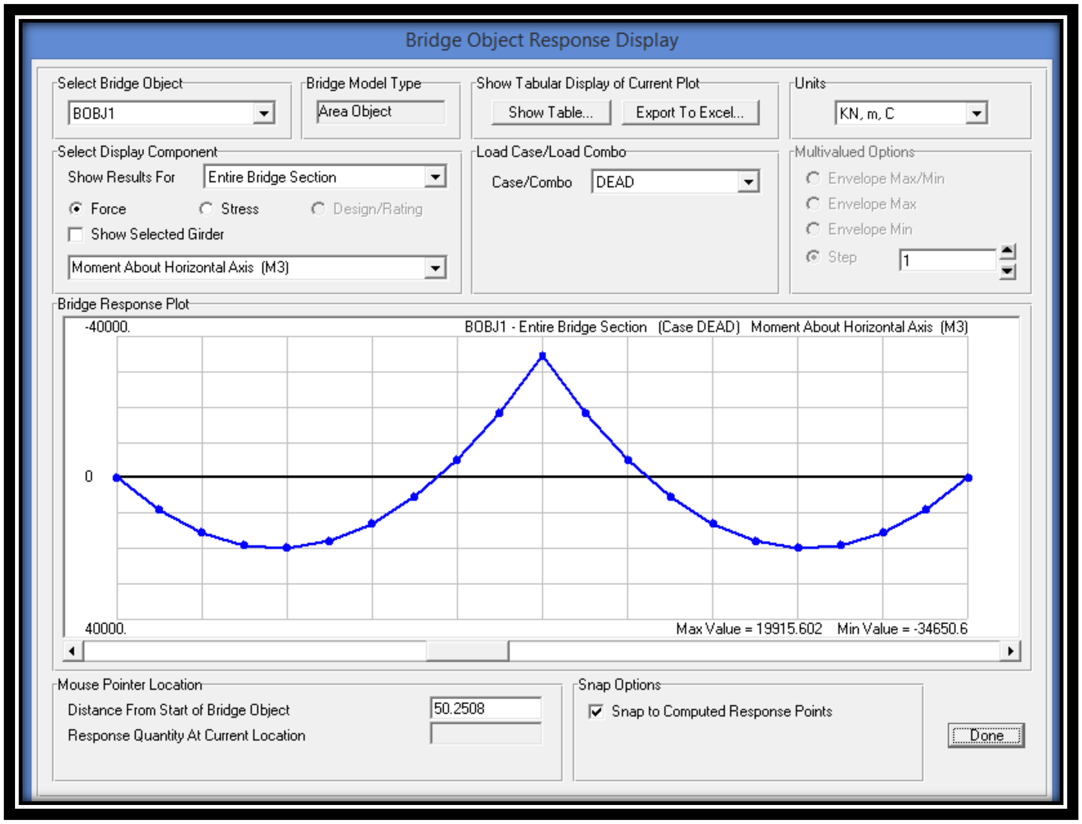

Figure 30 *Moment Result*

IV. Shear

Maximum Shear = 16951 kN (AISC)

Software Result = 5853.26 kN

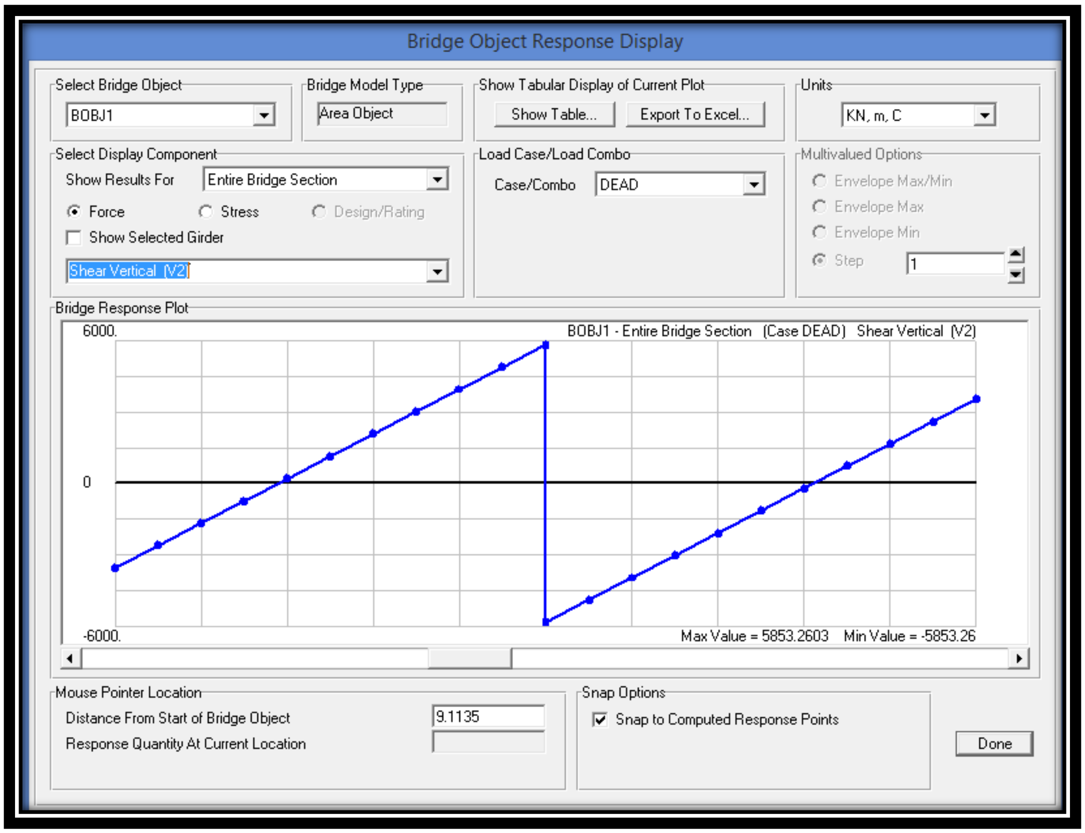

Figure 31 *Shear Result*

CHAPTER 8

Cost Estimation:

1. Introduction
2. Resources (4Ms)
3. The Factors
4. The Techniques
   - I Expert Judgment
   - II Analogous Estimating
   - III Parametric Estimating
   - IV Bottom-up Estimating
5. Process (Analogous Technique)
   - I (Post-Tensioned Concrete Bridge)
   - II Final Cost
   - III (Steel Bridge)
   - IV Final Cost

CHAPTER 8: COST ESTIMATION

1. Introduction

The cost estimate is the practice of forecasting the cost of a defined scope project. It is the main element of project cost management, an area of knowledge involving the planning, monitoring and control of the monetary costs of a project. An accurate cost estimate is essential to decide whether to undertake a project, to determine the possible scope of a project and to ensure that projects remain financially feasible and avoid overhead costs. Moreover, an estimate of costs is more than just a list of costs: it also describes the assumptions underlying each cost. These assumptions (in addition to cost accuracy estimates) are compiled into a report called the estimate basis, which also details the exclusion and inclusion of costs. The estimate report allows project stakeholders to interpret project costs and how and where actual costs could differ from approximate costs.

2. Resources (4Ms)

In addition to the broad cost classification, project expenditure falls into more specific categories. Common expenditure types include:

a) **M**anpower: The cost of human effort was spent on project goals.
b) **M**aterials: The cost of resources for producing products.
c) **M**achine(Equipment): The cost of purchasing and maintaining project equipment.
d) **M**oney(Contingency costs): Costs added to the project budget to deal with particular risks.

3. The Factors

Factors should be considered by the estimator:

1. Quantity of work
2. Productivity, weather and strikes, marking and profit, market conditions and contingency, etc.
3. Quality of data, which results in estimation accuracy.
4. R.S., selling good quality data to owners, contractors, designers and consultants.

4. The Techniques

There are four commonly used techniques for cost estimation that most of professional estimators use:

Four commonly used cost estimation techniques are used by most professional estimators:

1- Expert judgment
2- Analogous estimating
3- Parametric estimating
4- Bottom-up estimating

These four estimation techniques represent a hierarchical structure where analogous estimating represents the least accurate technique, and bottom-up estimating represents the most accurate technique.

These four estimation techniques represent a hierarchical structure in which analogous estimation is the least accurate and bottom-up estimation is the most accurate technique.

I. Expert Judgment:

Is widely used in the production of cost estimates. Cost estimators must make many expectations and intuition about the cost of a new product. However, the use of expert judgment in a concurrent engineering environment is often ignored, not well accepted or understood by non-cost estimators.

II. Analogous Estimating:

Uses a comparable previous project to estimate the time or expenditure of the current project and thus the word root: analogy. Used when your current project has limited information, an analog estimate is considered " top down " and is generally not as accurate as other estimation techniques. In addition, because the project manager and possibly the teams, experience and judgements are applied to the estimation process, historical information and expert judgment are considered to be a combination.

III. Parametric Estimating:

A more precise cost and duration estimation technique uses the relationship between variables to calculate the costs or duration. However, a parametric estimate is essentially determined by identifying the cost or duration of the unit and the number of units required for the project or business. The measurement must be scalable to be precise. In addition, parametric estimates are more similar to analog estimates, and parametric estimates use historical data to estimate costs.

IV. Bottom-up Estimating:

Is a technique also referred to as the “definitive technique ". This estimation technique is the most accurate, time-consuming and expensive method to estimate the project cost. In this technique, the cost of each individual activity is determined at the bottom level with the highest level of detail and then rolls up to calculate the total project cost.

5. Process (Analogous Technique)

Step 1: Comparing the projects
Step 2: Find the size factor (S.F)
Step 3: Find the area factor (A.F)
Step 4: Find the location factor (L.F)
Step 5: Find the Interest rate (T.F)
Step 6: Find the Quality factor (Q.F)
Step7: Find the overhead risk factor
Step 8: Determining the final estimation

I. (Post-Tensioned Concrete Bridge)

Step 1: Comparing the projects (Post-Tensioned Concrete Bridge)

We will compare our concrete bridge project with Prince Naif concrete bridge intersection with King Fahad Road. The bridge is consisting of two traffic lanes for each direction. The bridge is located in Dammam City.

Factors/data	Original project	Our project
Cost (SAR)	34,472,000 SAR	Unknown
Area (m^2)	12490	1980
Start of construction	Finished In 2008	In 2020
Interest Rate (i)	3.72%	3.72%
Location	Dammam	Khobar

Step 2: Determine the size factor (S.F)

In size factor, we will compare the size factor by using number of lane in the bridge.

$$Size\ factor(S.F) = \frac{3}{2} = 1.5$$

Step 3: Determine the area factor (A.F)

In area factor, we will compare the area factor by using area of bridge.

$$Area\ factor(A.F) = \frac{1980}{12490} = 0.1585$$

Step 4: Determine the location factor (L.F)

In location factor, we need to get the cost live in the bridge region, so we need to use Numbeo" Web-site to find the cost of living between these two regions.

$$Location\ factor = \frac{9856.67}{9100} = 1.0831$$

Step 5: Determine the Interest rate (T.F)

To do that, we need to find the market interest rate to determine the future interest rate that will be used in year 2020.

Where we can determine the marked interest rate using:

i= i' + f +(i') (f)

Where:

i: market interest rate

i': real interest rate = 3.72% from (1992-2018)

f: inflation rate = 3.51% from (2012-2016)

Therefore, i = 0.0372+0.0351+(0.0372) (0.0351) = 7.36%

Now, we use the market interest rate to determine the future factor. Which we will use F/P formula to find it:

F = P(1 + i)^n

Where n= 2020-2008 = 12

$F = 1(1 + 0.0736)^{12} = 2.3448$

Step 6: Determine the Quality factor (Q.F)

Simple, the quality of our project is 150%

Step7: Determine the overhead risk factor

We assumed that the overhead risk factor will equal 2.5 Million.

Step 8: Finding the final estimation

Using this formula given below, we can find the cost of the new project

Cost of new project= (Cost of the old project x S.F x A.F x L.F x T.F x Q.F) + overhead risk.

Factor	Result
Size (**S.F**)	1.5
Area (**A.F**)	0.1585
Location (**L.F**)	1.0831
Interest Rate (**T.F**)	2.3448
Quality (**Q.F**)	150%
Overhead Risk	2.5 Million

II. Final Cost

Cost = (34,472,000x1.5x0.1585x1.0831x 2.3448x1.5) + 2,500,000

The New Cost = 33,721,418.23 SAR

III. (Steel Bridge)

Step 1: Comparing the projects (<u>Steel Bridge</u>)

We will compare our steel bridge project with king Salman steel bridge intersection with King Fahad Road. The bridge is combined of two bridges oppose to each other connected by an intersection in the mid distance of those two bridges where both bridges have equal spans.

Factors/data	Original project	Our project
Cost (SAR)	78,000,000 SAR	Unknown
Area (m^2)	22800	1980
Start of construction	Finished In 2010	In 2020
Interest Rate (i)	3.72%	3.72%
Location	Khobar	Khobar

Step 2: Determine the size factor (S.F)

In size factor, we will compare the size factor by using number of lane in the bridge.

$$Size\ factor(S.F) = \frac{3}{6} + \frac{3}{4} = 1.25$$

Step 3: Determine the area factor (A.F)

In area factor, we will compare the area factor by using area of bridge.

$$Area\ factor(A.F) = \frac{1980}{22800} = 0.0868$$

Step 4: Determine the location factor (L.F)

In location factor, we need to get the cost live in the bridge region, so we need to use Numbeo” Web-site to find the cost of living between these two regions.

$$Location\ factor = \frac{9856.67}{9856.67} = 1$$

Step 5: Determine the Interest rate (T.F)

To do that, we need to find the market interest rate to determine the future interest rate that will be used in year 2020.

Where we can determine the marked interest rate using:

$i = i' + f + (i')(f)$

Where:

i: market interest rate

i': real interest rate = 3.72% from (1992-2018)

f: inflation rate = 3.51% from (2012-2016)

Therefore, i = 0.0372+0.0351+(0.0372) (0.0351) = 7.36%

Now, we use the market interest rate to determine the future factor. Which we will use F/P formula to find it:

F = P(1 + i)^n

Where n= 2020-2010 = 10

$F = 1(1 + 0.0736)^{10} = 2.0343$

Step 6: Determine the Quality factor (Q.F)

Simple, the quality of our project is 150%

Step7: Determine the overhead risk factor

We assumed that the overhead risk factor will equal 2.5 Million.

Step 8: Finding the final estimation

Using this formula given below, we can find the cost of the new project

Cost of new project= (Cost of the old project x S.F x A.F x L.F x T.F x Q.F) + overhead risk.

Factor	Result
Size (**S.F**)	1.25
Area (**A.F**)	0.0868
Location (**L.F**)	1
Interest Rate (**T.F**)	2.0343
Quality (**Q.F**)	150%
Overhead Risk	2.5 Million

IV. Final Cost

Cost = (78,000,000x1.25x0.0868x1x 2.0343x1.5) + 2,500,000

The New Cost = 28,324,421.35 SAR

CHAPTER 9

CONCLUSION

CHAPTER 9: CONCLUSION

To conclude, this project's main objective was to design a steel bridge and post tension concrete bridge then the two bridge will be compared with regard to their materials prices. The bridge was initially designed manually by hand calculations for the reinforced concrete slab, steel girders, bracing, bearing, pier cap, piers, foundation, and finally with the ASHTO LRFD design specifications and MOMRA design manual. The CSIBridge software was then used to complete the design for the both bridges.

The foundation system was developed in accordance with the obtained geotechnical report. In addition, the cost estimation process was calculated and done to get an idea of the project cost comparison between steel and concrete post-tensioned bridge. It was obtained that, the Steel bridge is cheaper compare to post-tensioned bridge, Particulary with respect to material cost.

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Appendix A: Sections Extracted from Ministry of Municipal and Rural Affairs

LOAD FACTORS AND LOAD COMBINATIONS:

Table 3.1: Load Combinations and Load Factors

Load Combination Limit State	*DC DD DW EH EV ES EL*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU CR SH*	*TG*	*SE*	Use One of These at a Time			
										EQ	*IC*	*CT*	*CV*
STRENGTH I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—
STRENGTH V	γ_p	1.35	1.00	0.40	1.00	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
EXTREME EVENT I	γ_p	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00	—	—	—
EXTREME EVENT II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00
SERVICE I	1.00	1.00	1.00	0.30	1.00	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—
SERVICE II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—
SERVICE III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—
SERVICE IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—
FATIGUE—LL, IM & CE ONLY	—	0.75	—	—	—	—	—	—	—	—	—	—	—

Table 3.2: Load Factors for Permanent Loads, γ_p.

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor	
		Maximum	Minimum
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles, λ Method	1.05	0.30
	Drilled shafts, O'Neill and Reese (1999) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• AEP for anchored walls		1.35	N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures other than Metal Box Culverts		1.95	0.90
• Flexible Metal Box Culverts		1.50	0.90
ES: Earth Surcharge		1.50	0.75

Dead Loads:

Dead load shall include the weight of all structural components, appliances and utilities, earth cover, wearing surface, future overlays and planned expansion. The densities specified in Table 3.4 may be used for dead loads in the absence of more accurate information.

The traditional densities shown in Table 3.4. The density of granular materials depends on the compactness and water content of the material. The concrete density is primarily affected by the aggregate density, which varies according to geological location and increases with the compressive strength of the concrete. The reinforced concrete density is generally assumed to be 72 kg / m3 higher than the plain concrete density. The wood values include the mass of mandatory preservatives. The weight of transit rails, etc. should only be used for preliminary design. The densities shown with the kg / m3 and kg / mm units are in the units of mass, not force. To convert the units of N / m3 to force by constant gravitation g = 9.8066 m/sec.2 and collect the units kgm/sec2 as a Newton.

Table 3.4: Densities

Material		Density (kg/m^3)
Aluminum Alloys		2800
Bituminous Wearing Surfaces		2250
Cast Iron		7200
Cinder Filling		960
Compacted Sand, Silt, or Clay		1925
Concrete	Low-density	1775
	Sand-low-density	1925
	Normal Density with $f'_c \leq 35$ MPa	2320
	Normal Density with $35 < f'_c \leq 105$ MPa	$2240 + 2.29 f'c$
Loose Sand, Silt, or Gravel		1600
Soft Clay		1600
Rolled Gravel, Macadam, or Ballast		2250
Steel		7850
Stone Masonry		2725
Wood	Hard	960
	Soft	800
Water	Fresh	1000
	Salt	1025
Item		Mass per Unit Length (kg/mm)
Transit Rails, Ties, and Fastening per Track		0.30

Design Vehicular Live Load

1. General

The MOMRA designated live vehicle loading on the roads of bridges or incidental structures shall consist of a combination of:

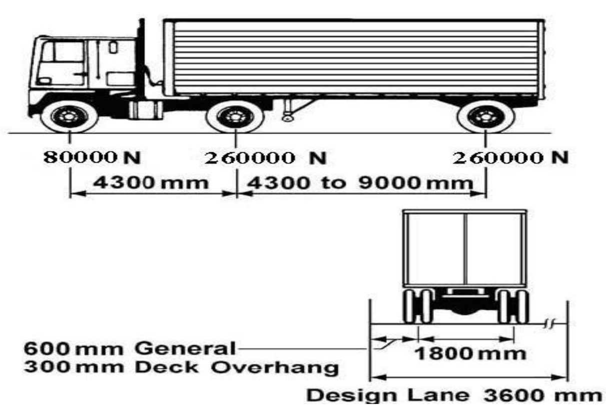
- Design truck or design tandem, and
- Design lane load.

Except as modified in Article 3.6.1.3.1, each design lane under consideration shall be occupied by either the design truck or tandem, coincident with the lane load, where applicable. The loads shall be assumed to occupy 3 m transversely within a design lane.

Except as corrected in Article 3.6.1.3.1, each design lane under consideration shall, where applicable, be occupied by the design truck or tandem, in line with the lane load. The loads are assumed to be 3 m across a design lane.

2. Design Truck

The weights and distances of the axles and wheels for the design truck shall be as specified in Figure 3.1 and the dynamic load allowance as specified in Article 3.6.2 shall be considered. The spacing between the two 260 kN axles, except as specified in Articles 3.6.1.3.1 and 3.6.1.4.1, shall vary between 4.3 and 9 m to produce extreme force effects.



Design Tandem:

The design tandem shall be a pair of axles of 250 kN with a distance of 1.2 m. The transverse wheel spacing shall be taken as 1.8 m. The dynamic load allowance laid down in Article 3.6.2 shall be considered.

Design Lane Load:

The design load of the lane shall consist of a load of 20 kN /m in the uniformly distributed in the longitudinal direction. The design load of the lane is assumed to be distributed uniformly over a width of 3 meters. The force effects of the lane load of the design are not subject to a dynamic load allowance.

WIND LOAD:

General:

The pressure specified herein is assumed to be caused by a wind speed of 160 km / h in the base design, VB. The wind load is assumed to be distributed uniformly in the area exposed to the wind. The exposed area comprises the sum of all components

including floor system and railing, as seen in elevation taken perpendicular to the assumed wind direction. This direction shall be varied to determine the extreme force effect in the structure or in its components. Areas that do not contribute to the extreme force effect under consideration may be neglected in the analysis. For bridges or parts of bridges more than 10 m above low ground or water level, the design wind velocity, *VDZ*, should be adjusted according to:

$$V_{DZ} = 2.5V_0\left(\frac{V_{10}}{V_B}\right)\ln\left(\frac{Z}{Z_0}\right)$$

***V10* may be established from:**

Basic wind speed charts available in ASCE 7-88 for different recurrence intervals, site-specific wind surveys and the assumption that V10= VB= 160 km / h in the absence of a better criterion.

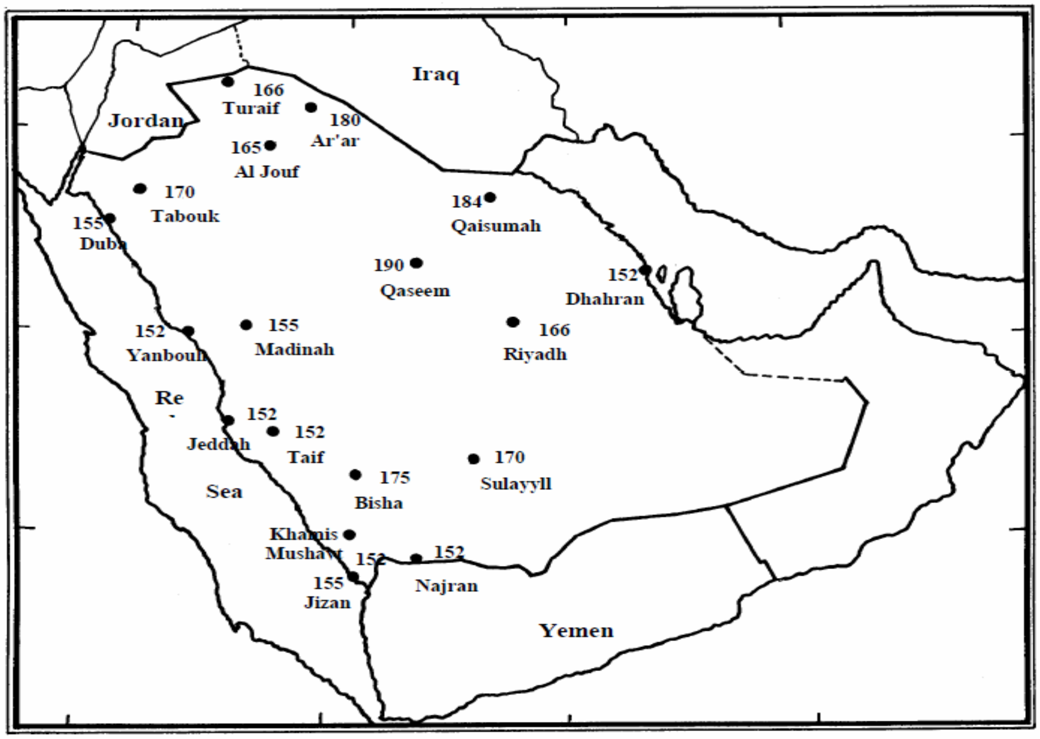


FIGURE 6.4-1
BASIC 3-SECOND GUST WIND SPEED IN km/h FOR SELECTED CITIES OF SAUDI ARABIA.
ADOPTED FROM SAUDI ARAMCO DATA SAES A-112.

EARTHQUAKE EFFECTS: EQ

General:

Earthquake loads are given by the product of the elastic seismic response coefficient *Csm* and the equivalent weight of the superstructure. The equivalent weight is a function of the actual weight and bridge configuration and is automatically included in both the single-mode and multimode methods of analysis specified in Article 4.7.4. Design and detailing provisions for bridges to minimize their susceptibility to damage from earthquakes are contained in Section 3, Section 4, Section 5, Section 6, Section 8, and Section 9. Bridges shall be designed to have a low probability of collapse but may suffer significant damage and disruption to service when subject to earthquake ground motions that have a 2% probability of exceedance in 50 years. Partial or complete replacement may be required. Higher levels of performance may be used with the authorization of the bridge owner.

Earthquake loads shall be taken to be horizontal force effects determined in accordance with the provisions of Article 4.7.4 on the basis of the elastic response coefficient, *Csm*, specified in Article 3.9.4, and the equivalent weight of the superstructure, and adjusted by the response modification factor, *R*, specified in Article 3.9.7.1. The provisions herein shall apply to bridges of conventional slab, beam girder, box girder, and truss superstructure construction with spans not exceeding 150 m. For other types of construction and bridges with spans exceeding 150 m, the Owner shall specify and/or approve appropriate provisions. Unless otherwise specified by the Owner, these provisions need not be applied to completely buried structures. Seismic effects for box culverts and buried structures need not be considered, except where they cross active faults. The potential for soil liquefaction and slope movements shall be considered. C These Specifications establish design and detailing provisions for bridges to minimize their susceptibility to damage from earthquakes. C The design earthquake motions and forces specified in these provisions are based on a low probability of their being exceeded during the normal life expectancy of a bridge. Bridges that are designed and detailed in accordance with the provisions may suffer damage, but should have low probability of collapse due to seismically induced ground shaking. The principles used for the development of these Specifications are:

- Small to moderate earthquakes should be resisted within the elastic range of the structural components without significant damage.
- Realistic seismic ground motion intensities and forces should be used in the design procedures; and
- Exposure to shaking from large earthquakes should not cause collapse of all or part of the bridge. Where possible, damage that does occur should be readily detectable and accessible for inspection and repair.

These Specifications are considered to be "force-based" wherein a bridge is designed to have adequate strength (capacity) to resist earthquake forces (demands).

Seismic Hazard:

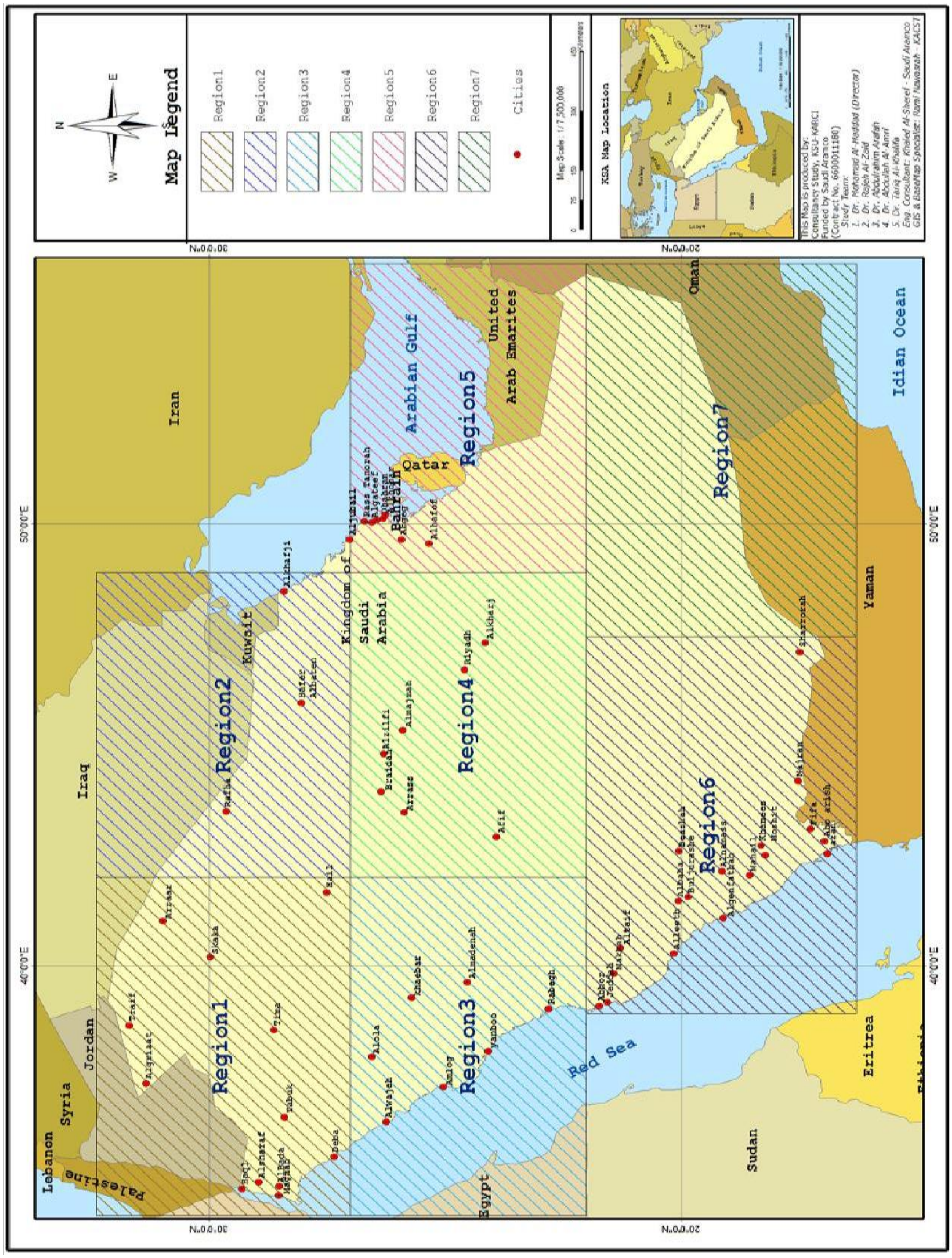
The seismic hazard at a bridge site shall be characterized by the acceleration response spectrum for the site and the site factors for the relevant site class. The acceleration spectrum shall be determined using either the General Procedure specified in Article 3.9.2.1 or the Site Specific Procedure specified in Article 3.9.2.2.

A Site-Specific Procedure shall be used if any one of the following conditions exists:

- The site is located within 10 kilometers of an active fault,
- The site is classified as Site Class F (Article 3.9.3.1),
- Long-duration earthquakes are expected in the region,
- The importance of the bridge is such that a lower probability of exceedance (and therefore a longer return period) should be considered. If time histories of ground acceleration are used to characterize the seismic hazard for the site, they shall be determined in accordance with Article 4.7.4.3.4.b.

General Procedure

The General Procedure shall use the short and long period spectral acceleration coefficients (*SS* and *S1* respectively) to calculate the spectrum as specified in Article 3.9.4. Values of *SS*, *S1* shall be determined from either Figure 3.5 to Figure 3.21 as appropriate, or from region ground motion maps approved by the owner. Linear interpolation shall be used for sites located between contour lines or between a contour line and a local maximum or minimum. The effect of site class on the seismic hazard shall be as specified in Article 3.9.3.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Region2
Region3
Region4
Region5
Region6
Region7
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Palestine
Egypt
Sudan
Eritrea
Yaman
Oman
Qatar
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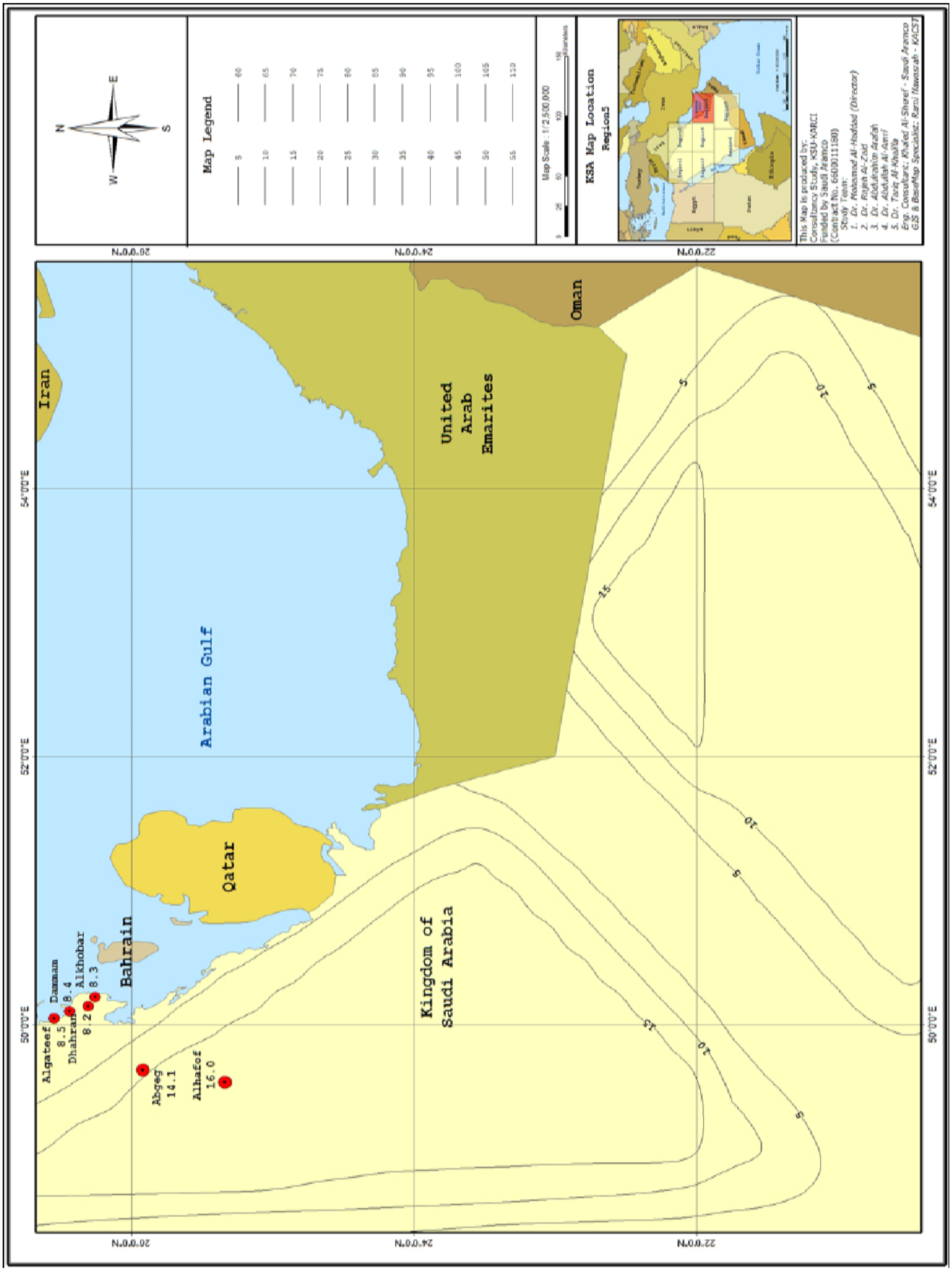
Region3
Region4
Region5
Region6
Region7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Oman
Qatar
Bahrain
Kingdom of Saudi Arabia
Algateef 8.5
Dammam 8.4
Dhahran 8.2
Alkhobar 8.3
Abqeq 14.1
Alhafof 16.0
26°0'0"N
24°0'0"N
22°0'0"N
54°0'0"E
52°0'0"E
50°0'0"E

Criteria for Deflection:

In the absence of other criteria, the following deflection limits may be considered for steel or concrete construction:

- Vehicular load, general Span/800
- Vehicular and/or pedestrian loads Span/1000
- Vehicular load on cantilever arms Span/300
- Vehicular and/or pedestrian loads on cantilever arms Span/375

For steel I-shaped beams and girders, and for steel box and tub girders, the provisions of Articles 6.10.4.2 and 6.11.4, respectively, regarding the control of permanent deflections through flange stress controls, shall apply. The following provisions shall apply to orthotropic plate decks:

- Vehicular load on deck plate Span/300
- Vehicular load on ribs of orthotropic metal decks Span/1000
- Vehicular load on ribs of orthotropic metal decks (extreme relative deflection between adjacent ribs) 2.5 mm.

Optional Criteria for Span-to-Depth Ratios:

Unless otherwise specified herein, if an Owner chooses to invoke controls on spanto-depth ratios, the limits in Table 2.1, in which S is the slab span length and L is the bridge span length, both in mm, may be considered in the absence of other criteria. Where used, the limits in Table 2.1 shall be taken to apply to overall depth unless noted. For curved steel girder systems, the span-to-depth ratio, Las/D, of each steel girder should not exceed 25 when the specified minimum yield strength of the girder in regions of positive flexure is 345 MPa or less, and:

- When the specified minimum yield strength of the girder is 485 MPa or less in regions of negative flexure, or
- When hybrid sections satisfying the provisions of Article 6.10.1.3 are used in regions of negative flexure.

Table 2.1: Traditional Minimum Depths for Constant Depth Superstructures.

Superstructure		Minimum Depth (Including Deck) When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections (*S* is the slab span length and *L* is the bridge span length)	
Material	Type	Simple Spans	Continuous Spans
Reinforced Concrete	Slabs with main reinforcement parallel to traffic	$\frac{1.2(S+3000)}{30}$	$\frac{S+3000}{30} \geq 165mm$
	T-Beams	0.070L	0.065L
	Box Beams	0.060L	0.055L
	Pedestrian Structure Beams	0.035L	0.033L
Prestressed Concrete	Slabs	0.030L > 165 mm	0.027L > 165 mm
	Cast In Place Box Beams	0.045L	0.040L
	Precast I-Beams	0.045L	0.040L
	Pedestrian Structure Beams	0.033L	0.030L
	Adjacent Box Beams	0.030L	0.025L
Steel	Overall Depth of Composite I-Beam	0.040L	0.032L
	Depth of I-Beam Portion of Composite I-Beam	0.033L	0.027L
	Trusses	0.100L	0.100L

APPENDIX B:
Project Management

B.1 Project Plan

Table B.1 Project Plan

Task	Assigned Team Members	Duration (Weeks)
Data Collection	All	3
Proposal	All	3
Structural design	All	8
Software Modeling and Analysis	All	4
Geotechnical Design	All	4
Mid Term	All	3
Cost Estimation	All	3
Final Report	All	8
Final Report Correction	All	2
Final Presentation	All	3

B.2 Contribution of Team Members

- **Hamed Al Kaltham**
    - ✓ Setting Objectives
    - ✓ Collecting Data
    - ✓ Literature review
    - ✓ Feasibility study
    - ✓ Selecting Structural system
    - ✓ Preliminary design
    - ✓ CSIBridge modeling
    - ✓ Checking for Adjustments if any
    - ✓ Check soil capacity
    - ✓ Selecting foundation system
    - ✓ Design Foundation
    - ✓ Preparing Technical Report

- **Azzam Al Harthi**
    - ✓ Setting Objectives
    - ✓ Collecting Data
    - ✓ Literature review
    - ✓ Feasibility study
    - ✓ Selecting Structural system
    - ✓ Preliminary design
    - ✓ ETABS modeling
    - ✓ Checking for Adjustments if any
    - ✓ Check soil capacity
    - ✓ Selecting foundation system
    - ✓ Design Foundation
    - ✓ Preparing Technical Report

- **Ziad Al Harthi**

  - ✓ Setting Objectives
  - ✓ Collecting Data
  - ✓ Literature review
  - ✓ Feasibility study
  - ✓ Selecting Structural system
  - ✓ Preliminary design
  - ✓ CSIBridge modeling
  - ✓ Checking for Adjustments if any
  - ✓ Check soil capacity
  - ✓ Selecting foundation system
  - ✓ Design Foundation
  - ✓ Preparing Technical Report

- **Hisham Al Mousa**

  - ✓ Setting Objectives
  - ✓ Collecting Data
  - ✓ Literature review
  - ✓ Feasibility study
  - ✓ Selecting Structural system
  - ✓ Preliminary design
  - ✓ CSIBridge modeling
  - ✓ Checking for Adjustments if any
  - ✓ Check soil capacity
  - ✓ Selecting foundation system
  - ✓ Design Foundation
  - ✓ Preparing Technical Report

B.3 Project Execution and Monitoring

- Meeting daily, to speak and continue the assignment that we have to do together
- 1 meeting a week with the advisors to evaluate our work and performance.

B.4 Challenges and Decision Making

• Choosing an adequate structural system that meets all architectural and security requirements, as well as keeping feasibility and costs within a reasonable range. To overcome this challenge, we have carried out several investigations concerning various structural members.

• One of the challenges facing us is also the selection of the foundation system. Due to the geotechnical constraints of the project we decided to use the pile foundation. Even though it is expensive.

APPENDIX C:
Project Analysis

C.1 Life-long Learning

• Time management is a key to our project. We have learned how to divide our project into smaller activities and how to allocate time for each activity.

• Literature review plays an important role in these projects because you can learn about past mistakes and how to avoid making the same mistakes. Literature reviews can also introduce you to a wide range of resources and links.

• Important decisions are taken on a daily basis on such large - scale projects. We learned that we should take into account everything, because these sequences of decisions will build the whole project.

• The work organized flows smoothly. However, if you do not follow a well-organized plan, sooner or later you are going to mess up.

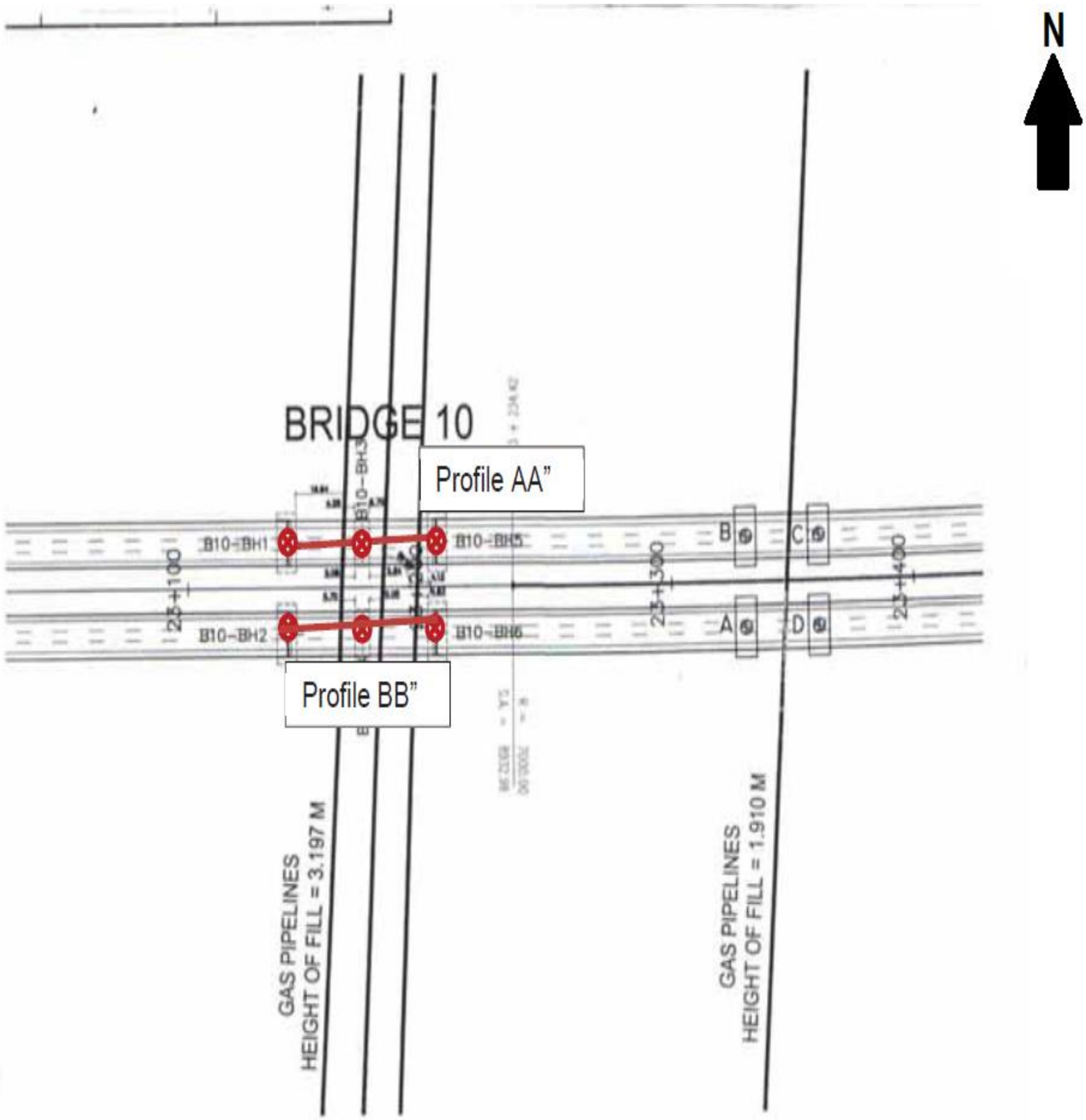
• We were able to work on computer - aided software such as CSIBridge, SAP2000 and AutoCAD.

• The completion of any interdisciplinary project depends on multiple knowledge sources ' cooperation, coordination and combined efforts.

C.2 Impact of Engineering Solutions

There are various methods to dertermine the structural and Foundation systems in construction. However, any other approach, if not well analyzed, will be problem-oriented, and a lot of money will be spent to maintain the problem-centered structure. To overcome such complications, the engineers came up with solutions. With some construction problems, we had to double reinforce the pier cap due to the high load that the pier cap design entailed.

APPENDIX D:
Soil Report



BRIDGE NO. 10
STA 23+171.74
BORE HOLES LOCATION

I.D. No.	Northing (m)	Easting (m)
B10-BH1	2891476.264	393321.365
B10-BH2	2891453.524	393299.639
B10-BH3	2891454.752	393343.881
B10-BH4	2891432.012	393322.155
B10-BH5	2891433.241	393366.396
B10-BH6	2891410.501	393344.671

Arab Company for Laboratories and Soil (ACES)

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-01

Sheet 1 of 3

ACES

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 9.885	Boring Started: 15-Feb-16	Boring Dia. (mm): 101.3 — Core Dia. (mm): 101.2
Coordinates: N= 2,891,476.00	Boring Completed: 16-Feb-16	Casing Dia. (mm): NE — Casing Depth (m): NE
E= 393,321.00	Rig: RK-07 Driller: HAMEED	Water Depth (m): 1.35

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	Core Recovery TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	P	0 - 1.5										Medium dense, brown, fine to medium grained,Silty SAND.			
1													(3)		
	SPT	1.5 - 1.95	6	12	18	30									
2	P	1.95 - 3											3	6.89	
3	SPT	3 - 3.45	8	15	20	35						Hard, brown to green, fine to medium grained, calcareous Sandy Lean CLAY.			
4	P	3.45 - 4.5													
	SPT	4.5 - 4.95	10	40	45	85									
5	P	4.95 - 6													
6	SPT	6 - 6.45	12	33	42	75							(6)		
7	P	6.45 - 7.5													
	SPT	7.5 - 7.95	25	38	45	83									
8	P	7.95 - 9											9	0.89	
9	SPT	9 - 9.45	27	40	47	87						Very dense, green, fine to medium grained, Silty SAND with gravel.			

Undisturbed Sample Key:
- CS: Core Sample
- DB: Drive Barrel
- SH: Shelby Tube

Disturbed Sample Key:
- P:Percussion
- SPT:Standard Penetration Test
- AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-01** Sheet 2 of 3	ACES

Total Depth (m): 25 Ground Level (m): 9.885 Coordinates: N= 2,891,476.00 E= 393,321.00	Drilling Method: Conventional Boring Started: 15-Feb-16 Boring Completed: 16-Feb-16 Rig: RK-07 Driller: HAMEED	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.35	Core Dia. (mm): 101.2 Casing Depth (m): NE

Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)
P	9.45 - 10.5										Very dense, green, fine to medium grained, Silty SAND with gravel.	(4.5)	
SPT	10.5 - 10.8	30	50/15		REF								
P	10.8 - 12												
SPT	12 - 12.3	23	50/15		REF								
P	12.3 - 13.5											13.5	-3.62
CS	13.5 - 15					60	0	16			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.	(11.5)	
CS	15 - 16.5					65	0	18					
CS	16.5 - 18					70	0	20					
CS	18 - 19.5					75	0	22					

Scale (m): 11, 12, 13, 14, 15, 16, 17, 18, 19

Undisturbed Sample Key: CS: Core Sample; DB: Drive Barrel; SH: Shelby Tube

Disturbed Sample Key: P:Percussion; SPT:Standard Penetration Test; AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-01

Sheet 3 of 3

ACES

Total Depth (m): 25
Ground Level (m): 9.885
Coordinates: N= 2,891,476.00
E= 393,321.00

Drilling Method: Conventional
Boring Started: 15-Feb-16
Boring Completed: 16-Feb-16
Rig: RK-07 Driller: HAMEED

Drilling Medium: WATER
Boring Dia. (mm): 101.3
Casing Dia. (mm): NE
Water Depth (m): 1.35
Core Dia. (mm): 101.2
Casing Depth (m): NE

Scale (m)	Samples		SPT Records				Core Recovery				UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	Type and Number	Depth (m)	Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI					
	CS	19.5 - 21					78	0	25			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			
21	CS	21 - 22.5					80	0	28						
22															
23	CS	22.5 - 24					85	0	29						
24	CS	24 - 25					88	0	30						
25													25	-15.12	

End of Boring 25M.

Undisturbed Sample Key:
CS: Core Sample
DB: Drive Barrel
SH: Shelby Tube

Disturbed Sample Key:
P:Percussion
SPT:Standard Penetration Test
AU:Auger

Abbreviations:
Ground Water Table
TCR: Total Core Recovery
SCR: Solid Core Recovery
RQD: Rock Quality Designation
FI: Fracture Index
UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-02** Sheet 1 of 3	ACES

Total Depth (m): 25 Ground Level (m): 9.885 Coordinates: N= 2,891,454.00 E= 393,300.00	Drilling Method: Conventional Boring Started: 17-Feb-16 Boring Completed: 20-Feb-16 Rig: RK-07 Driller: AHSAN	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.4	Core Dia. (mm): 101.2 Casing Depth (m): NE

Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)
SPT	0 - 0.45	3	4	4	8					
P	0.45 - 1.5									
SPT	1.5 - 1.95	4	8	10	18					
P	1.95 - 3									
SPT	3 - 3.45	25	20	15	35					
P	3.45 - 4.5									
SPT	4.5 - 4.95	18	30	35	65					
P	4.95 - 6									
SPT	6 - 6.27	35	50/12		REF					
P	6.27 - 7.5									
SPT	7.5 - 7.55	50/5			REF					
P	7.55 - 9									
SPT	9 - 9.1	50/10			REF					
P	9.1 - 10.5									

Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
Loose to medium dense, brown, fine to medium grained, Silty SAND.	(3) 3	6.89	
Hard, brown to green, creamy to grayish creamy, fine to medium grained, Sandy Lean CLAY.	(3) 6	3.89	
Very dense, green, fine to medium grained, Silty SAND with gravel.	(1.5) 7.5	2.39	
Decomposed Coral LIMESTONE, transformed into very dense, gray, poorly graded gravel with Silty SAND.	(3)		

Scale (m): 1, 2, 3, 4, 5, 6, 7, 8, 9

Undisturbed Sample Key: CS: Core Sample; DB: Drive Barrel; SH: Shelby Tube

Disturbed Sample Key: P:Percussion; SPT:Standard Penetration Test; AU:Auger

Abbreviations:
Ground Water Table
TCR: Total Core Recovery
SCR: Solid Core Recovery
RQD: Rock Quality Designation
FI: Fracture Index
UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-02** Sheet 2 of 3	ACES

Total Depth (m): 25 Ground Level (m): 9.885 Coordinates: N= 2,891,454.00 E= 393,300.00	Drilling Method: Conventional Boring Started: 17-Feb-16 Boring Completed: 20-Feb-16 Rig: RK-07 Driller: AHSAN	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.4	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	P												10.5	-0.62	
11	CS	10.5 - 12					30	0	8			Very weak, dark grey to light grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.	(3)		
12–13	CS	12 - 13.5					32	0	10				13.5	-3.62	
14	CS	13.5 - 15					35	0	12			Very weak, yellowish creamy to brownish creamy, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			
15–16	CS	15 - 16.5					45	0	20						
17	CS	16.5 - 18					50	0	25						
18–19	CS	18 - 19.5					52	0	26				(11.5)		

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample DB: Drive Barrel SH: Shelby Tube	P:Percussion SPT:Standard Penetration Test AU:Auger	Ground Water Table TCR: Total Core Recovery SCR: Solid Core Recovery RQD: Rock Quality Designation FI: Fracture Index UCS:Unconfined Comp. Strength	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-02

Sheet 3 of 3

ACES

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 9.885	Boring Started: 17-Feb-16	Boring Dia. (mm): 101.3 — Core Dia. (mm): 101.2
Coordinates: N= 2,891,454.00	Boring Completed: 20-Feb-16	Casing Dia. (mm): NE — Casing Depth (m): NE
E= 393,300.00	Rig: RK-07 Driller: AHSAN	Water Depth (m): 1.4

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	Core Recovery TCR (%)	Core Recovery SCR (%)	Core Recovery RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	CS	19.5 - 21					54	0	28			Very weak, yellowish creamy to brownish creamy, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			
21	CS	21 - 22.5					60	0	30						
22															
23	CS	22.5 - 24					62	0	32						
24	CS	24 - 25					64	0	32						
25													25	-15.12	

End of Boring 25M.

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample	P:Percussion	Ground Water Table	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).
DB: Drive Barrel	SPT:Standard Penetration Test	TCR: Total Core Recovery	
SH: Shelby Tube	AU:Auger	SCR: Solid Core Recovery	
		RQD: Rock Quality Designation	
		FI: Fracture Index	
		UCS:Unconfined Comp. Strength	

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-03

Sheet 1 of 3

ACES

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 11.095	Boring Started: 23-Feb-16	Boring Dia. (mm): 101.3
Coordinates: N= 2,891,455.00	Boring Completed: 23-Feb-16	Casing Dia. (mm): NE
E= 393,344.00	Rig: RK-05 Driller: HAMEED	Water Depth (m): 2.0
		Core Dia. (mm): 101.2
		Casing Depth (m): NE

Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	Core Recovery TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)
P	0 - 1.5										Medium dense to very dense, brown, fine to medium grained, Silty SAND.	(6) 6	5.10
SPT	1.5 - 1.95	5	6	8	14								
P	1.95 - 3												
SPT	3 - 3.45	7	11	15	26								
P	3.45 - 4.5												
SPT	4.5 - 4.95	8	14	22	36								
P	4.95 - 6												
SPT	6 - 6.45	28	36	28	64						Hard, creamy to grayish creamy, fine to medium grained, calcareous Fat CLAY.	(0.5) 6.5	4.60
P	6.45 - 7.5										Weak, greyish green, Silty SANDSTONE mixed with gypsum, moderately weathered, moderately fractured.	(2.5) 9	2.10
CS	7.5 - 9					32	0	7					
CS	9 - 10.5					35	0	8			Weak, dark grey to light grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.		

Undisturbed Sample Key:
- CS: Core Sample
- DB: Drive Barrel
- SH: Shelby Tube

Disturbed Sample Key:
- P:Percussion
- SPT:Standard Penetration Test
- AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-03** Sheet 2 of 3	ACES

Total Depth (m): 25 Ground Level (m): 11.095 Coordinates: N= 2,891,455.00 E= 393,344.00	Drilling Method: Conventional Boring Started: 23-Feb-16 Boring Completed: 23-Feb-16 Rig: RK-05 Driller: HAMEED	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 2.0	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	Core Recovery: TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
11	CS	10.5 - 12					40	0	0			Weak, dark grey to light grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.			
12	CS	12 - 13.5					42	0	0				(6)		
13, 14	CS	13.5 - 15					45	0	9				15	-3.91	
15	CS	15 - 16.5					48	0	0			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			
16, 17	CS	16.5 - 18					50	0	0						
18, 19	CS	18 - 19.5					52	0	0						

Undisturbed Sample Key:
- CS: Core Sample
- DB: Drive Barrel
- SH: Shelby Tube

Disturbed Sample Key:
- P:Percussion
- SPT:Standard Penetration Test
- AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	Borehole No. BH-03 Sheet 3 of 3	ACES

Total Depth (m): 25 Ground Level (m): 11.095 Coordinates: N= 2,891,455.00 E= 393,344.00	Drilling Method: Conventional Boring Started: 23-Feb-16 Boring Completed: 23-Feb-16 Rig: RK-05 Driller: HAMEED	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 2.0	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	Core Recovery: TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	CS	19.5 - 21					63	0	0			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.	(10)		
21	CS	21 - 22.5					55	0	13						
22															
23	CS	22.5 - 24					58	0	0						
24	CS	24 - 25					60	0	0						
25													25	-13.91	

End of Boring 25M.

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample DB: Drive Barrel SH: Shelby Tube	P:Percussion SPT:Standard Penetration Test AU:Auger	Ground Water Table TCR: Total Core Recovery SCR: Solid Core Recovery RQD: Rock Quality Designation FI: Fracture Index UCS:Unconfined Comp. Strength	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-04** Sheet 1 of 3

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 11.095	Boring Started: 20-Feb-16	Boring Dia. (mm): 101.3 — Core Dia. (mm): 101.2
Coordinates: N= 2,891,432.00	Boring Completed: 20-Feb-16	Casing Dia. (mm): NE — Casing Depth (m): NE
E= 393,322.00	Rig: RK-05 Driller: HAMEED	Water Depth (m): 2.0

Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)
P	0 - 1.5									
SPT	1.5 - 1.95	4	8	11	19					
P	1.95 - 3									
SPT	3 - 3.45	6	10	13	23					
P	3.45 - 4.5									
SPT	4.5 - 4.95	12	20	34	54					
P	4.95 - 6									
SPT	6 - 6.15	32	50/0		REF					
P	6.15 - 7.5									
SPT	7.5 - 7.65	28	50/0		REF					
P	7.65 - 9									
SPT	9 - 9.15	29	50/0		REF					
P	9.15 - 10.5									

Description of Strata	Depth (Thickness) (m)	Reduced Level (m)
Medium dense to very dense, brown, fine to medium grained, Silty SAND.	(4.65) 4.65	6.45
Hard, creamy to grayish creamy, fine to medium grained, calcareous Fat CLAY.	(1.85) 6.5	4.60
Decomposed Coral LIMESTONE, transformed into very dense, gray, poorly graded gravel with Silty SAND.	(4)	

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample	P:Percussion	Ground Water Table	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).
DB: Drive Barrel	SPT:Standard Penetration Test	TCR: Total Core Recovery	
SH: Shelby Tube	AU:Auger	SCR: Solid Core Recovery	
		RQD: Rock Quality Designation	
		FI: Fracture Index	
		UCS:Unconfined Comp. Strength	

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-04

Sheet 2 of 3

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 11.095	Boring Started: 20-Feb-16	Boring Dia. (mm): 101.3 / Core Dia. (mm): 101.2
Coordinates: N= 2,891,432.00	Boring Completed: 20-Feb-16	Casing Dia. (mm): NE / Casing Depth (m): NE
E= 393,322.00	Rig: RK-05 Driller: HAMEED	Water Depth (m): 2.0

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
													10.5	0.60	
11	SPT	10.5 - 10.65	30	50/0		REF						Very dense, green, fine to medium grained, Silty SAND with some gravel at some places	(1.5)		
	P	10.65 - 12											12	-0.90	
12–13	CS	12 - 13.5					35	0	18			Weak, yellowish green to green, SANDSTONE intercalated with thin layer of calcareous Siltstone, moderately weathered, slightly to highly fractured.			
14	CS	13.5 - 15					36	0	19				(4.5)		
15–16	CS	15 - 16.5					38	0	0				16.5	-5.41	
17	CS	16.5 - 18					40	0	22			Very weak, grey to yellowish grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.			
18–19	CS	18 - 19.5					45	0	25						

Undisturbed Sample Key:
- CS: Core Sample
- DB: Drive Barrel
- SH: Shelby Tube

Disturbed Sample Key:
- P:Percussion
- SPT:Standard Penetration Test
- AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-04

Sheet 3 of 3

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 11.095	Boring Started: 20-Feb-16	Boring Dia. (mm): 101.3 — Core Dia. (mm): 101.2
Coordinates: N= 2,891,432.00	Boring Completed: 20-Feb-16	Casing Dia. (mm): NE — Casing Depth (m): NE
E= 393,322.00	Rig: RK-05 Driller: HAMEED	Water Depth (m): 2.0

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Records: Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	Core Recovery: TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	CS	19.5 - 21					46	0	26			Very weak, grey to yellowish grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.	(8.5)		
21	CS	21 - 22.5					47	0	27						
22															
23	CS	22.5 - 24					49	0	29						
24	CS	24 - 25					50	0	0						
25													25	-13.91	

End of Boring 25M.

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample	P:Percussion	Ground Water Table	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).
DB: Drive Barrel	SPT:Standard Penetration Test	TCR: Total Core Recovery	
SH: Shelby Tube	AU:Auger	SCR: Solid Core Recovery	
		RQD: Rock Quality Designation	
		FI: Fracture Index	
		UCS:Unconfined Comp. Strength	

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-05

Sheet 1 of 3

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 10.743	Boring Started: 21-Feb-16	Boring Dia. (mm): 101.3 / Core Dia. (mm): 101.2
Coordinates: N= 2,891,433.00	Boring Completed: 21-Feb-16	Casing Dia. (mm): NE / Casing Depth (m): NE
E= 393,366.00	Rig: RK-07 Driller: MUNSOUR	Water Depth (m): 1.8

Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)
P	0 - 1.5										Medium dense, brown, fine to medium grained, poorly SAND wiht Silt.	(4.5) 4.5	6.24
SPT	1.5 - 1.95	2	3	5	8								
P	1.95 - 3												
SPT	3 - 3.45	3	5	7	12								
P	3.45 - 4.5												
SPT	4.5 - 4.95	10	10	22	32						Very Stiff to hard, creamy to grayish creamy, fine to medium grained, calcareous Sandy Fat CLAY.	(1.5) 6	4.74
P	4.95 - 6												
CS	6 - 7.5					30	0	0			Very weak, yellowish green to green, SANDSTONE intercalated with thin layer of calcareous Siltstone, moderately weathered, slightly to highly fractured.	(6)	
CS	7.5 - 9					64	38	33					
CS	9 - 10.5					63	33	38					

Undisturbed Sample Key: CS: Core Sample; DB: Drive Barrel; SH: Shelby Tube

Disturbed Sample Key: P:Percussion; SPT:Standard Penetration Test; AU:Auger

Abbreviations:
Ground Water Table
TCR: Total Core Recovery
SCR: Solid Core Recovery
RQD: Rock Quality Designation
FI: Fracture Index
UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	**Borehole No. BH-05** Sheet 2 of 3	ACES

Total Depth (m): 25 Ground Level (m): 10.743 Coordinates: N= 2,891,433.00 E= 393,366.00	Drilling Method: Conventional Boring Started: 21-Feb-16 Boring Completed: 21-Feb-16 Rig: RK-07 Driller: MUNSOUR	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.8	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples		SPT Records				Core Recovery				UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	Type and Number	Depth (m)	Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI					
11	CS	10.5 - 12					60	27	12			Very weak, yellowish green to green, SANDSTONE intercalated with thin layer of calcareous Siltstone, moderately weathered, slightly to highly fractured.	12	-1.26	
12	CS	12 - 13.5					64	22	0			Very weak, dark grey to light grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.			
13, 14	CS	13.5 - 15					55	20	0				(6)		
15, 16	CS	15 - 16.5					57	23	0						
17	CS	16.5 - 18					61	26	0				18	-7.26	
18, 19	CS	18 - 19.5					43	0	0			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample DB: Drive Barrel SH: Shelby Tube	P:Percussion SPT:Standard Penetration Test AU:Auger	Ground Water Table TCR: Total Core Recovery SCR: Solid Core Recovery RQD: Rock Quality Designation FI: Fracture Index UCS:Unconfined Comp. Strength	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	Borehole No. BH-05 Sheet 3 of 3	ACES

Total Depth (m): 25 Ground Level (m): 10.743 Coordinates: N= 2,891,433.00 E= 393,366.00	Drilling Method: Conventional Boring Started: 21-Feb-16 Boring Completed: 21-Feb-16 Rig: RK-07 Driller: MUNSOUR	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.8	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Records: Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	Core Recovery: TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	CS	19.5 - 21					37	0	11			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.	(7)		
21	CS	21 - 22.5					52	0	0						
22															
23	CS	22.5 - 24					60	0	10						
24	CS	24 - 25					63	0	0						
25													25	-14.26	

End of Boring 25M.

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample	P:Percussion	Ground Water Table	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).
DB: Drive Barrel	SPT:Standard Penetration Test	TCR: Total Core Recovery	
SH: Shelby Tube	AU:Auger	SCR: Solid Core Recovery	
		RQD: Rock Quality Designation	
		FI: Fracture Index	
		UCS:Unconfined Comp. Strength	

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	Borehole No. BH-06 Sheet 1 of 3	ACES

Total Depth (m): 25 Ground Level (m): 10.743 Coordinates: N= 2,891,410.00 E= 393,345.00	Drilling Method: Conventional Boring Started: 29-Feb-16 Boring Completed: 29-Feb-16 Rig: RK-07 Driller: MUNSOUR	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.8	Core Dia. (mm): 101.2 Casing Depth (m): NE

Type and Number	Depth (m)	0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)
P	0 - 1.5										Medium dense, brown, fine to medium grained, poorly SAND wiht Silt.	(4.5)	
SPT	1.5 - 1.95	8	10	12	22								
P	1.95 - 3												
SPT	3 - 3.45	9	12	15	27								
P	3.45 - 4.5											4.5	6.24
SPT	4.5 - 4.95	10	13	18	31						Very Stiff to hard, creamy to grayish creamy, fine to medium grained, calcareous Sandy Fat CLAY	(3)	
P	4.95 - 6												
SPT	6 - 6.45	15	32	37	69								
P	6.15 - 7.5											7.5	3.24
CS	7.5 - 9					64	40	36			Very weak, yellowish green to green, SANDSTONE intercalated with thin layer of calcareous Siltstone, moderately weathered, slightly to highly fractured.		
CS	9 - 10.5					64	38	53				(4.5)	

Undisturbed Sample Key: CS: Core Sample; DB: Drive Barrel; SH: Shelby Tube

Disturbed Sample Key: P:Percussion; SPT:Standard Penetration Test; AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10 Project No.: SK16000011 Location: Dammam, KSA Client: Al-Shalawi Intl Holding Co. Trad & Cont	Borehole No. BH-06 Sheet 2 of 3	ACES

Total Depth (m): 25 Ground Level (m): 10.743 Coordinates: N= 2,891,410.00 E= 393,345.00	Drilling Method: Conventional Boring Started: 29-Feb-16 Boring Completed: 29-Feb-16 Rig: RK-07 Driller: MUNSOUR	Drilling Medium: WATER Boring Dia. (mm): 101.3 Casing Dia. (mm): NE Water Depth (m): 1.8	Core Dia. (mm): 101.2 Casing Depth (m): NE

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
11	CS	10.5 - 12					66	33	0			Very weak, yellowish green to green, SANDSTONE intercalated with thin layer of calcareous Siltstone, moderately weathered, slightly to highly fractured.	12	-1.26	
12	CS	12 - 13.5					66	25	16			Very weak, dark grey to light grey, Coral LIMESTONE, intercalated with thin layer of calcareous Siltstone, highly weathered, highly fractured.			
13, 14	CS	13.5 - 15					67	22	0						
15	CS	15 - 16.5					66	24	0				(6)		
16, 17	CS	16.5 - 18					68	25	0				18	-7.26	
18, 19	CS	18 - 19.5					45	0	0			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.			

Undisturbed Sample Key:
- CS: Core Sample
- DB: Drive Barrel
- SH: Shelby Tube

Disturbed Sample Key:
- P:Percussion
- SPT:Standard Penetration Test
- AU:Auger

Abbreviations:
- Ground Water Table
- TCR: Total Core Recovery
- SCR: Solid Core Recovery
- RQD: Rock Quality Designation
- FI: Fracture Index
- UCS:Unconfined Comp. Strength

Remarks:
* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).

Project Name: Salwa-Oqair Project- Bridge No.10
Project No.: SK16000011
Location: Dammam, KSA
Client: Al-Shalawi Intl Holding Co. Trad & Cont

Borehole No. BH-06

Sheet 3 of 3

ACES

Total Depth (m): 25	Drilling Method: Conventional	Drilling Medium: WATER
Ground Level (m): 10.743	Boring Started: 29-Feb-16	Boring Dia. (mm): 101.3 / Core Dia. (mm): 101.2
Coordinates: N= 2,891,410.00	Boring Completed: 29-Feb-16	Casing Dia. (mm): NE / Casing Depth (m): NE
E= 393,345.00	Rig: RK-07 Driller: MUNSOUR	Water Depth (m): 1.8

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	SPT Field Records 15-30 (cm)	SPT Field Records 30-45 (cm)	N Blows	TCR (%)	SCR (%)	RQD (%)	FI	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
	CS	19.5 - 21					50	0	16			Very weak, grey to yellowish grey, Coral LIMESTONE intercalated with Marlstone, moderately weathered, slightly to moderately fractured.	(7)		
21	CS	21 - 22.5					57	0	0						
22															
23	CS	22.5 - 24					63	0	18						
24	CS	24 - 25					66	0	0						
25													25	-14.26	

End of Boring 25M.

Undisturbed Sample Key:	Disturbed Sample Key:	Abbreviations:	Remarks:
CS: Core Sample	P:Percussion	Ground Water Table	* The samples were described in accordance with appropriate standards (BS 5930; ASTM D2488).
DB: Drive Barrel	SPT:Standard Penetration Test	TCR: Total Core Recovery	
SH: Shelby Tube	AU:Auger	SCR: Solid Core Recovery	
		RQD: Rock Quality Designation	
		FI: Fracture Index	
		UCS:Unconfined Comp. Strength	

APPENDIX E: CSiBridge Report For STEEL

APPENDIX F: CSiBridge Report For Post-Tensioned Concrete