M.Tech (Structural Engineering)

DEVWRAT YADAV

2021

# EFFICACY STUDY OF DIFFERENT CONFIGURATION OF PRETENSIONED AND POST TENSIONED I-GIRDERS FOR HIGHWAY VIADUCT

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE
OF
MASTER OF TECHNOLOGY
IN
**STRUCTURAL ENGINEERING**

Submitted by:

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## CANDIDATE'S DECLARATION

I, Devwrat Yadav, Roll No. 2K18/STE/502 student of M.Tech (Structural Engineering), hereby declare that the project dissertation titled "**EFFICACY STUDY OF DIFFERENT CONFIGURATION OF PRETENSIONED AND POST TENSIONED I-GIRDERS FOR HIGHWAY VIADUCT**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **DEVWRAT YADAV**

Date: 11/08/2021

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# <u>CERTIFICATE</u>

I hereby certify that the Project Dissertation titled "**EFFICACY STUDY OF DIFFERENT CONFIGURATION OF PRETENSIONED AND POST TENSIONED I-GIRDERS FOR HIGHWAY VIADUCT**" which is submitted by Devwrat Yadav, Roll No. 2K18/STE/502, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Place: Delhi **Dr. SHILPA PAL**

Date: 11/08/2021 **Supervisor**

# ACKNOWLEDGEMENT

I sincerely take this opportunity to acknowledge the debt of gratitude, that I owe to my supervisor Dr. Shilpa Pal for her consistent guidance throughout the journey. She has helped me by means of her vast knowledge and expertise of the course content.

She provided the desired impetus when things were not turning in the favour, which really helped me to achieve the anticipated goals within a given time frame. It is my fortune that, I got an opportunity to work under her guidance for both of my Major Projects. I wish that my learning under her guidance continues forever.

At the last, I would like to extend a token of thanks to my parents, whose uninterrupted efforts have been a constant motivation throughout the journey.

Devwrat Yadav

# ABSTRACT

In today's world, there is a higher demand of roads and grade separated structures to avoid traffic congestion. Thus, a lot of elevated viaducts, flyovers and bridges are being constructed all over the world. The bridge superstructure is of various types and the type of superstructure to be adopted depends upon several factors. The most used superstructure type is beam slab system in which, generally, the beams are prestressed. Pre-Tensioned and Post Tensioned girders are the most used type of prestressed beams in beam slab bridges and the practice of Prestress I-Girder type bridges are gaining popularity in bridge engineering fraternity because of its structural efficiency, better stability, serviceability, elegance, economy, aesthetic appearance and shortened construction time.

Parametric study has been done with different configurations in terms of span length and the number of girders to evaluate the total quantities of Pretensioned and Post Tensioned girders. Finally, the cost comparison between the two types of girders is done considering the concrete quantity, reinforcement and prestressing steel quantity. The scheme of launching and logistics involved are also considered for the cost comparison between the two types of girders. The theoretical comparison is also done in order to understand the differences in bending moment & shear force between Pretensioned and Post tensioned I-Girders.

The design & analysis of prestressed concrete girders is carried out using IRC:112-2020 Concrete Road Bridges based on India Live Load as per IRC 6-2017. The IRC:112-2020 code is based on limit state design philosophy.

Based on the comparative study done, it has been found that the Pretensioned girders are very economical and time efficient primarily because more than 5 to 7 girders can be prestressed at the same time using the same equipment. Further, there is no requirement of anchorages, sheathing and grouting.

It has been found that Pretensioned Girders are more economical when compared to Post Tensioned Girders if the number of girders required in the project is more than 250 number of girders.

**TABLE OF CONTENTS**

# LIST OF FIGURES

## LIST OF TABLES

# CHAPTER 1

# INTRODUCTION

## 1.1 Concept & Principle of Prestressing

Concrete is strong in compression but weak in tension; However, with the help of Prestressing we can ensure that it maintains its tensile & compressive capacities under a variety of loading conditions.

Prestressing is the process by which a concrete element is compressed, generally by steel wires or strands. This method is cost effective, also it increases the quality & strength of the structure.

Prestressing is a method of reducing tensile stress in reinforced concrete sections by applying compressive force, usually by steel wires or strands, until the tensile stress is below the cracking tension. As a result, there are no cracks in the concrete. Concrete can thus be treated as an elastic material.

Prestress concrete has a high degree of elasticity due to its ability to fully recover from the impacts of sustained overloading without sustaining major damage. Due to the small stress variation in prestressing steel, prestress concrete has a higher fatigue strength than other materials and is therefore suggested for dynamically loaded constructions.

There have been significant developments in PSC over last 25 years, primarily due to number of reasons listed below:

- Availability of high-grade concrete & high grade of HTS.
- Development of specific construction methods.
- Improved proficiency in the design of structural concrete.
- Availability of innovative post tensioning technology.
- The yield strength of steel has evolved over the last 3 decades from around 415 Mpa to 600 Mpa.

- Concrete quality has evolved in terms of performance and strength over last 3 decades. High performance / High strength concretes are available now a days with strength as high as M100.
- Prestressing steel in the form of 7-wire strand has been available with a tensile strength of 1860 Mpa. Next generation of 7-wire strands is appearing in the market with 2160 Mpa strength.
- Galvanized strands are now available for better durability.
- PSC Bridges are possible now for a span length of 250m-300m, which was not possible earlier.
- Large projects have great influence on erection techniques due to their demand for fast paced construction.
- There is an increasing trend in use of external prestressing in bridges.

## 1.2 Prestressed Concrete Methods

There are basically two methods of applying prestress to a concrete member.

### i. Pretensioning:

This method is most often used in factory situations and it is a method in which the strands/tendons are tensioned before the casting of concrete. The tendons are cut away from the ends of the concrete once it has reached the necessary strength for prestressing. Because of the bond between them, the prestress is transferred from the tendons to the concrete.

Fig 1.1 & 1.2 shows the glimpse view of casting bed and preparation of reinforcement and casting of Pretensioned I Girder and Fig 1.3 & 1.4 shows the Anchor block wall and multi pull jacks from where prestressing shall be done in order to stress the girder strands.

Fig 1.1 Construction of Pretension I Girder in casting bed

Fig 1.2 Preparation of reinforcement of Pretension I Girder in casting yard

Fig 1.3 Anchor Block Wall & Multi pull jacks of Pretension I Girder

Fig 1.4 Anchor Block Wall of Pretension I Girder

**Staged involved in Pre-Tensioning Method**

- Stage 1 : Tendons & reinforcement are positioned in the beam mould.
- Stage 2 : Tendons are stressed to about 70% of their ultimate tensile strength (UTS).
- Stage 3: Concrete is poured into the beam mould and allowed to cure to the initial strength requirements.
- Stage 4 : The stressing force is released & the tendons fix themselves in the concrete when the concrete has cured.

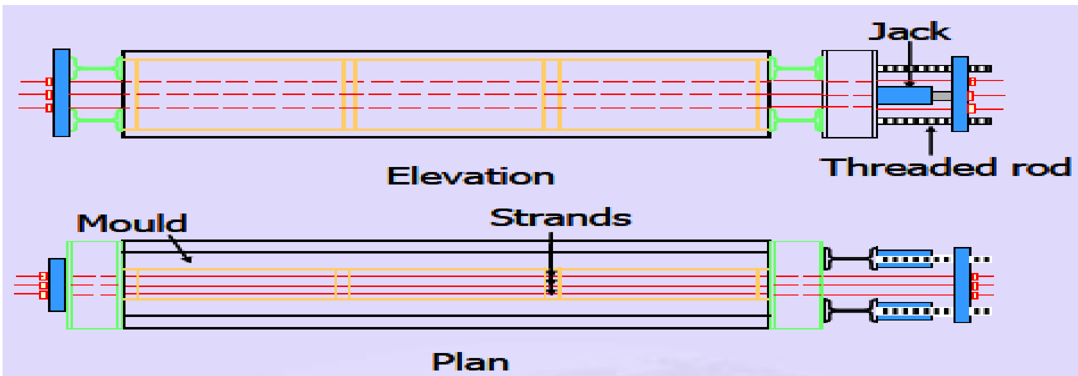



Fig 1.5 Elevation & Plan showing strands profile of I Girder before casting concrete ("Referred from Prestressed Concrete Structures by Dr. AK Sengupta and Prof. Devdas Menon")

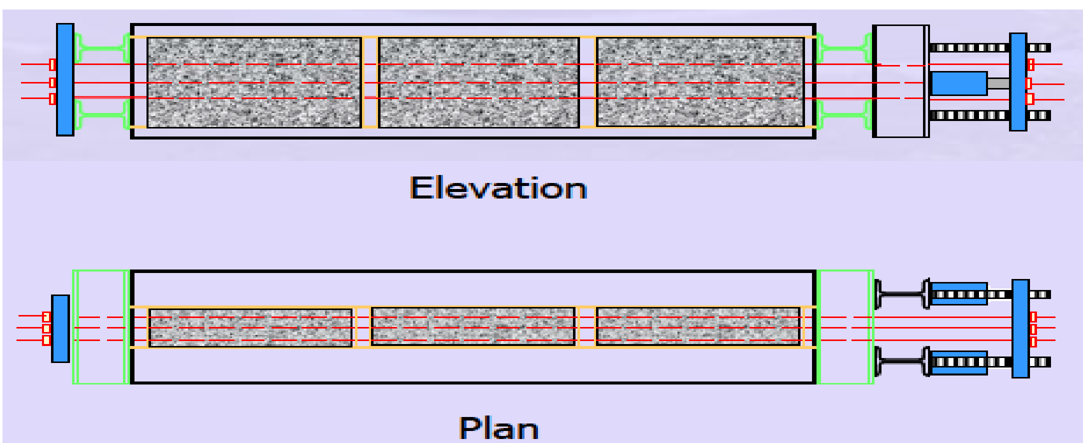



Fig 1.6 Elevation & Plan showing strands profile of I Girder after casting concrete ("Referred from Prestressed Concrete Structures by Dr. AK Sengupta and Prof. Devdas Menon")

ii. **Post-Tensioning**:

This process is widely used at site and in this method, the strands are tensioned after the concrete has hardened. Before casting, metal or plastic ducts are commonly placed inside the concrete. When the concrete had hardened and gained sufficient strength, the tendon was placed inside the duct, stressed & anchored against the concrete. Grouting may be injected into the duct once the whole stressing operation is completed.

Fig 1.7 Reinforcement Casting of Post-Tension I Girder

Fig 1.8 Constructed Post-Tension I Girder

**Post-Tensioning Method**

- Stage 1 - In the beam mould, cable ducts & reinforcement are placed. To reduce the eccentricity of the stressing force, the ducts are usually raised towards the neutral axis at the ends.
- Stage 2 - The beam mould is filled with concrete and allowed to cure to the necessary starting strength.
- Stage 3 - Tendons are inserted into cable ducts and tensioned to roughly 70% of their ultimate strength.
- Stage 4 - The tensioning force on the tendons is released by inserting wedges into the end anchorages. To protect the tendons, grout is injected into the ducts.

Below Fig 1.9 illustrating the different stages of Post-tensioning method, starting from casting of concrete to tensioning of tendons and till the wedges are locked in the end anchorages.

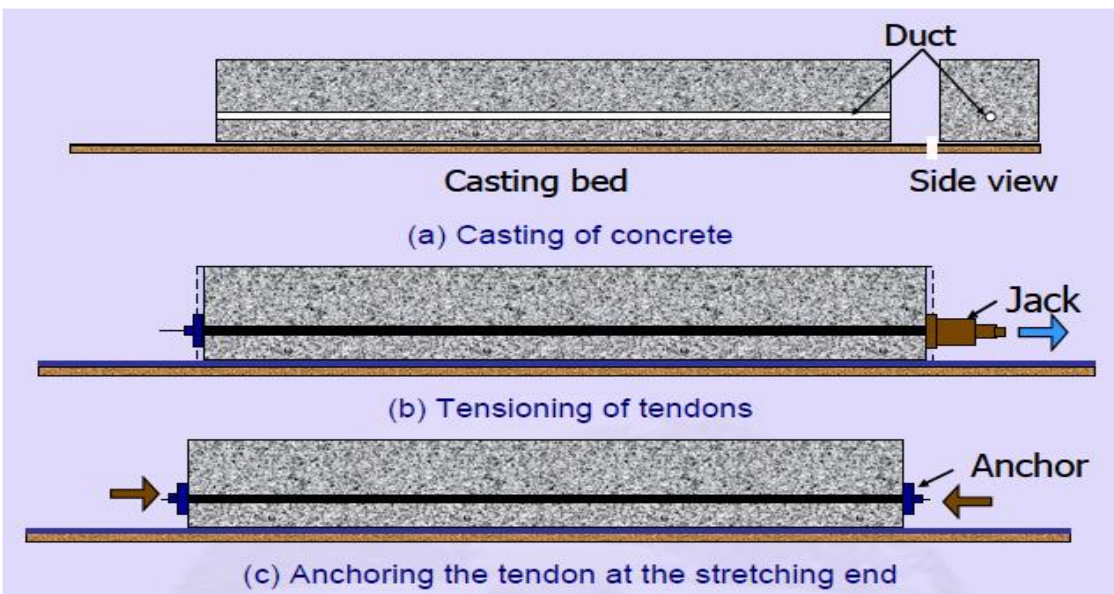



Fig 1.9 Stages of Post-Tensioning (“Referred from Prestressed Concrete Structures by Dr. AK Sengupta and Prof. Devdas Menon”)

## 1.3 Prestress Losses

Prestress losses are divided into two categories: Immediate and Time-Dependent.

The immediate losses occur when the tendons are prestressed and prestress is transferred to the concrete part. The time-dependent losses occur during the prestressed member's service life.

The losses due to friction at the tendon-concrete interface, slip of the anchorage and elastic shortening of the member are the immediate losses and the losses due to the creep, shrinkage & relaxation of the steel are the time dependent losses.

The causes of the various prestress losses are depicted in the following fig 1.10.

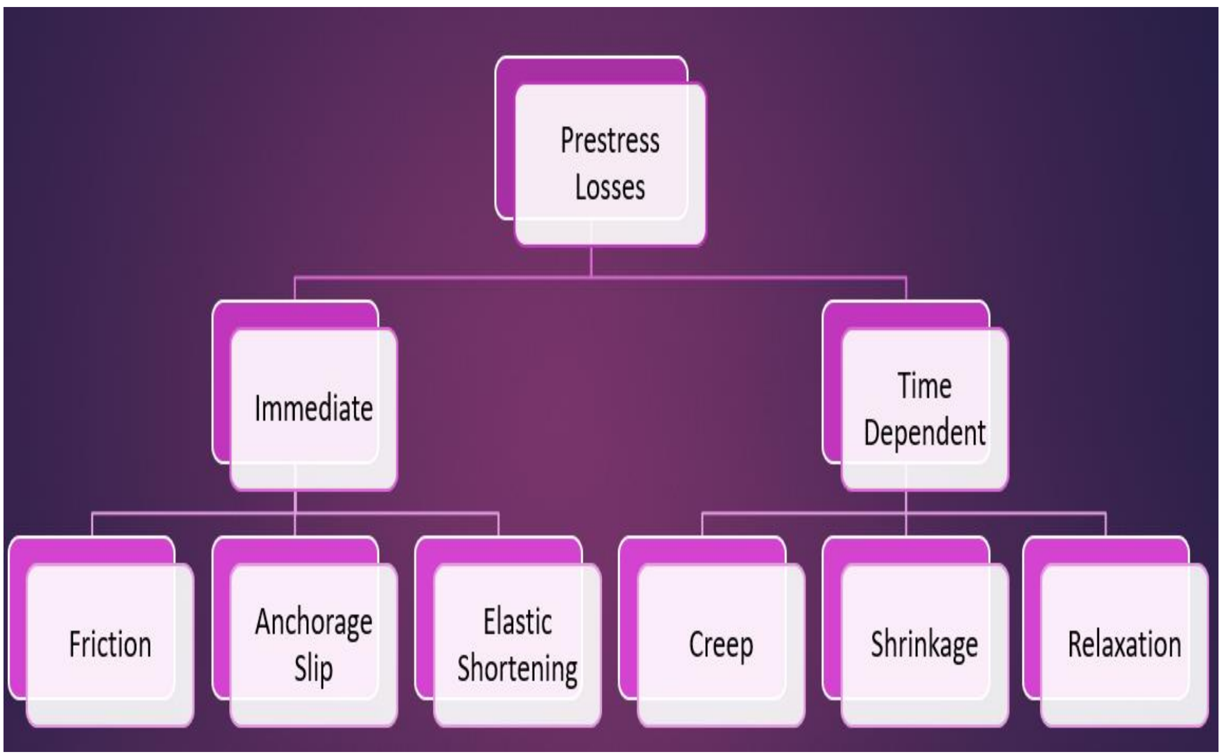



Fig 1.10 Different losses in prestress

Table 1.1 Losses in Various Prestressing Systems

| Sr. No. | Types of Loss | Pre-Tensioning | Post-Tensioning |
|---|---|---|---|
| 1 | Friction Loss | No | Yes |
| 2 | Anchorage Slip | No | Yes |
| 3 | Elastic Shortening | Yes | Yes |
| 4 | Creep | Yes | Yes |
| 5 | Shrinkage | Yes | Yes |
| 6 | Relaxation | Yes | Yes |

## 1.4 Advantages of Prestressing

- Prestressed concrete is lighter in weight comparatively to RCC sections.
- In PSC, section remains uncracked under service loads.
- Reduction of steel corrosion thus it increases the durability.
- PSC takes full advantages of high strength concrete & high strength steel.
- It uses smaller sections & depth, thus high span to depth ratios.
- Full section is utilized thus higher stiffness & better shear resistance.
- Long spans possible with prestressing found sustainable & economical.
- Quicker construction, better quality control, and lower maintenance costs.
- Suitable for multiple use of formwork and repetitious construction.
- More aesthetic appeal due to slender sections.

## 1.5 Limitations of Prestressing

- The use of high strength materials is costly.
- There is need for quality control and inspection.
- The cost of auxiliary equipment is higher.
- Prestressing requires skilled technology. As a result, it is not as widely used as reinforced concrete.

## 1.6 Objective of the Study

The following are the study's objectives:

i. To prepare a methodology for deciding the efficient configuration of Prestressed I-Girders for different span length of highway viaduct.

ii. To develop a methodology for evaluating the minimum number of girders required in order to go with the Pre-tensioned I girder system.

iii. To develop the cost & quantities comparison between Pre-tensioned and Post-tensioned I-girders.

## 1.7 Scope of the Study

This study deals with the detailed design and analysis of Pre-tensioned and Post-tensioned I-girders of span length 25m, 30m & 35m.

In total, 6 girders are idealized in Staad.pro V8i software and their results; bending moment & shear forces are compared. Prestress loss calculation are also done, accordingly compressive force in the form of HTS strands is provided in the design in order to eliminate the tensile stresses.

After finalizing the reinforcement & HTS strands in the girder as per design requirements, their concrete quantity & steel quantity comparison is done in order to evaluate the total cost of 1 Girder in Pretensioned and Post-Tensioned systems.

## 1.8 Organization of Thesis

This Dissertation titled "**EFFICACY STUDY OF DIFFERENT CONFIGURATION OF PRETENSIONED AND POST TENSIONED I-GIRDERS FOR HIGHWAY VIADUCT**" is composed of six chapter and a bibliography. Following are the chapters included in this dissertation:

**Chapter 1** consist of the Introduction of the Prestressing systems, in which objective and scope of thesis is also given.

**Chapter 2** comprises of literatures which have been reviewed, during the study.

**Chapter 3** discusses in detail the comparative study between pre-tensioned & post-tensioned I girders.

**Chapter 4** comprises of the design & analysis of the different spans ranging from 25m to 35m of Pretensioned and Post-Tensioned girders and covering the design bending moments and shear forces.

**Chapter 5** comprises of the Quantity & Cost comparison of the Pretensioned and Post-Tensioned girders

**Chapter 6** consist of the conclusion for the case studies conducted.

**Bibliography** of the literatures which have been referred in the study is also provided

# CHAPTER 2

# LITERATURE REVIEW

**Nayal et al. (2010) :** The goal of this research was to identify the primary factors that influence the performance of a post-tensioned bridge system. The parametric research was then conducted to determine the scope and design restrictions in terms of post-tensioning stages, post-tensioning forces, and timing possibilities. Six inverted T-sections including IT 500, IT 600, IT 700, IT 800, IT 900, and IT 1000 were considered and the effect of different creep-and-shrinkage models was investigated. According to the findings, alternative creep and shrinkage models have little effect on the calculation of losses in pretensioned strands and post-tensioned tendons. Post-tensioned – Inverted T-section was investigated to overcome the drawbacks of conventional replacement methods, where pretensioned IT beams are post-tensioned to improve the system's capacity, longevity & durability of the system, increase the beam's span-to-depth ratio and eliminate deck cracks over the piers.

**Park et al. (2016) :** Five large post tensioned girders were evaluated in this study to see how high strength strands affected flexural behaviour based on concrete compressive strength and strand tensile strength. Five post tensioned PSC girders were fabricated and tested in total. The specimens were ductile, and the crack patterns were consistent over time. Regardless of the tensile strength of the prestressing strands, the crack patterns and crack spacing were similar in all specimens. Under full-service stress, the maximum fracture width in the specimen with high-strength strands slightly exceeded the allowable limit of ACI 318; however, this may be easily managed by arranging deformed bars in the right way.

**Markus and Gauvreau (2020) :** The results of a study of the efficiency of post-tensioned bridges are presented in this study. The study's main objectives were to find structural arrangements that meet design criteria for serviceability and safety while also reducing the reference depth for a given bridge type and span range. Also, to determine whether there are any significant relationships between design parameters and reference depth, as well as the practical relevance of reference depth as a measure of efficiency. The parameter limitations and trends in the efficient situations defined by reference depth were estimated in terms of their ability to be utilized in design to meet the study's major goals.

# CHAPTER 3

# COMPARATIVE STUDY BETWEEN PRE-TENSIONED & POST-TENSIONED I GIRDERS

## 3.1 Introduction

A comparative study between Pre-Tensioned and Post Tensioned I Girders was done to evaluate the efficacy of the structural system with respect to the span length and the number of girders required. The span length was varied from 25 m to 35 m and the number of girders was varied from 100 to 1000 to understand the financial implications of using two types of structural systems studied.

The principal objective of the study was to evaluate which of the two structural systems could lead to more length of grade separated structures or bridges for a specified allocated infrastructure budget. The study is very significant to the current scenario as the country is developing more and more elevated, congestion free roads.

## 3.2 Pre-Tensioned I Girders Methodology

This chapter pertains to design of pretensioned prestressed I girder for 25m, 30m & 35m straight span (c/c exp. Joint) for a deck width of 21.250m.

For analysis, the superstructure has been modeled as a grillage in STAAD Pro software. Design of both outer and inner girder is presented here. For design purpose, sections at every 1/16th span, at start and end of flaring have been considered.

The bending moment & shear force due to dead load of girder and slab has been calculated manually for each section. The bending moment & shear force due to SIDL and live load has been taken from Grillage output.

For live load analysis, trains of Class A, Class 70R wheeled & Special Vehicle are considered as per IRC: 6-2017.

The strands are debonded at few locations, hence design of girders are checked for both condition i.e. with and without strands.

It is proposed to use 15.2mm diameter strands of UTS 1860Mpa, jacking force is considered to 78% UTS. All losses in prestress are calculated as per IRC112-2011. The jacking force shall be transferred to the girders when concrete attains its 90% strength i.e. 45Mpa.

Precast beams are checked under different stages of loads. Stress check is carried out at the extreme fibers of the beams. For this purpose, appropriate section properties such as beam alone and composite are considered.

Ultimate bending moment & shear force is calculated by applying load factors as per IRC6:2017 and sections are checked for ultimate bending and shear as per section 10 of IRC112:2011.

The following sequence of operation has been considered in the design of Superstructure.

a) Cast Precast Girders at Casting Yard.

b) Release prestress after 5 days of casting or when concrete attains a minimum strength of 45Mpa, whichever is later.

c) Shift Precast Girders from Casting bed to Stacking Yard after cutting of strands.

d) Transport the girders from staking yard to the site, by using low-bedded trailer. Erect the Girders over temporary bearings using cranes.

e) Erect staging for casting of deck slab from the already erected girder. Suitable holes may be left in the girder web for fixing of staging & shuttering.

f) Cast deck slab & cross Girder after laying of reinforcement over staging. Girders shall be at least 28 days old at the time of casting of deck slab.

g) Remove staging after 15 days (Minimum) of casting of deck slab or when concrete attains a minimum strength of 30Mpa, whichever is later.

h) Shift the entire superstructure (i.e Precast girders, deck slab & diaphragm) to permanent bearings from temporary bearings.

i) Cast Crash barrier & lay wearing coat.

### 3.3 Schematic Arrangement of Pre-Tensioned I Girders

The following cross-section have been adopted for all the 3 spans of 25m, 30m & 35m having deck width of 21.250m. The superstructure comprises of 7 nos of pre-tensioned I girders with cast in-situ RCC deck slab of 120mm thickness and precast RCC plank of 120mm thickness. The superstructures are rested in diaphragm or hanging in diaphragm. Fig 3.1 shows the cross-section of the end cross girder having 3 nos of POT-PTFE bearings below diaphragm and Fig 3.2 shows the cross-section of the intermediate cross girder.

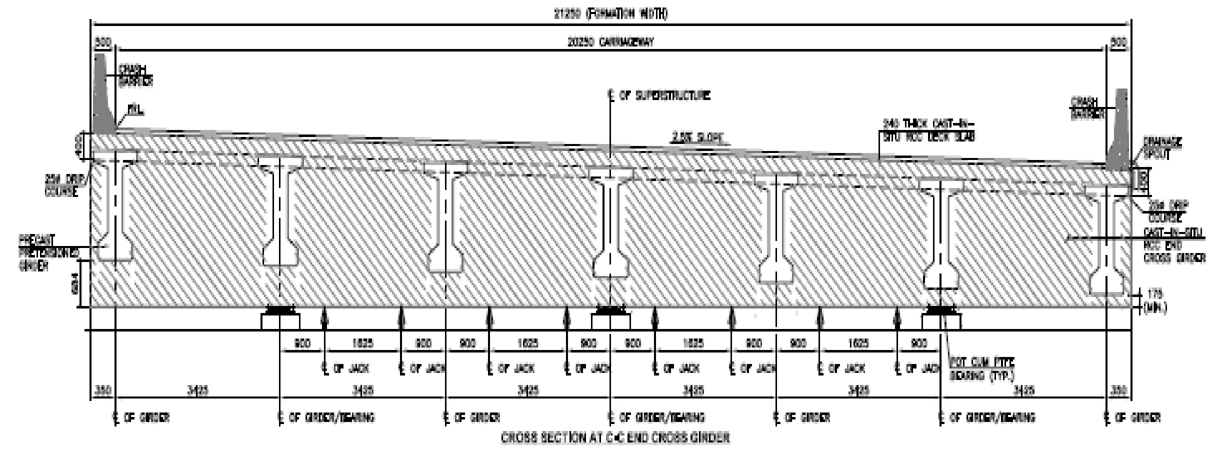



Fig 3.1 Cross-section of Diaphragm

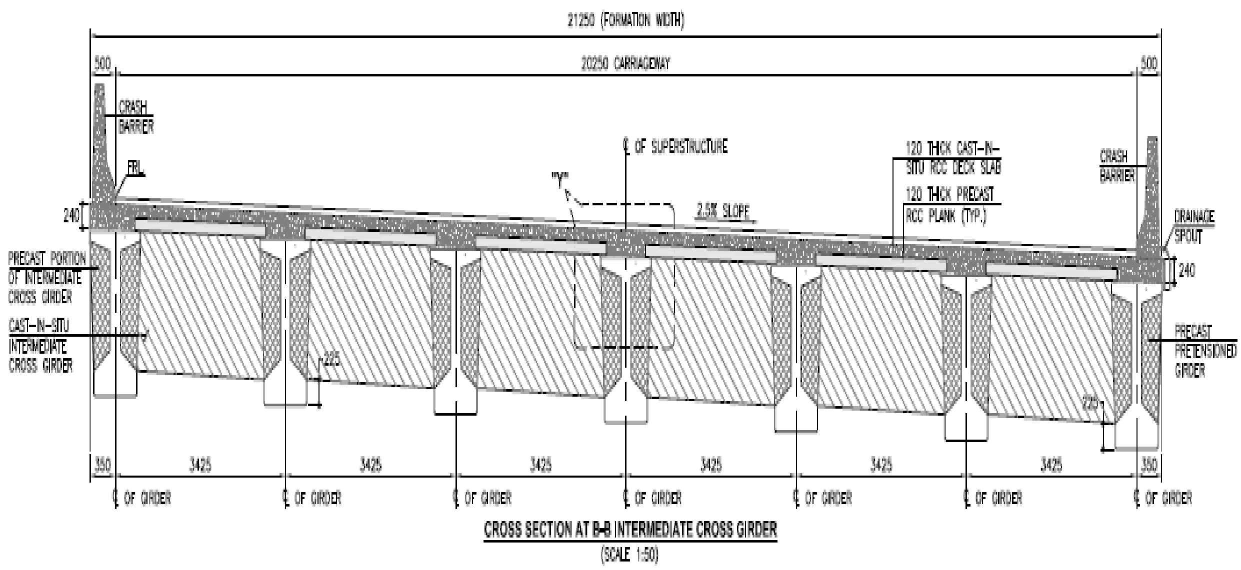



Fig 3.2 Cross-section of Intermediate Cross-Girder

### 3.3.1 Dimensional Details of Pre-Tensioned Superstructures

a) **For 25m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

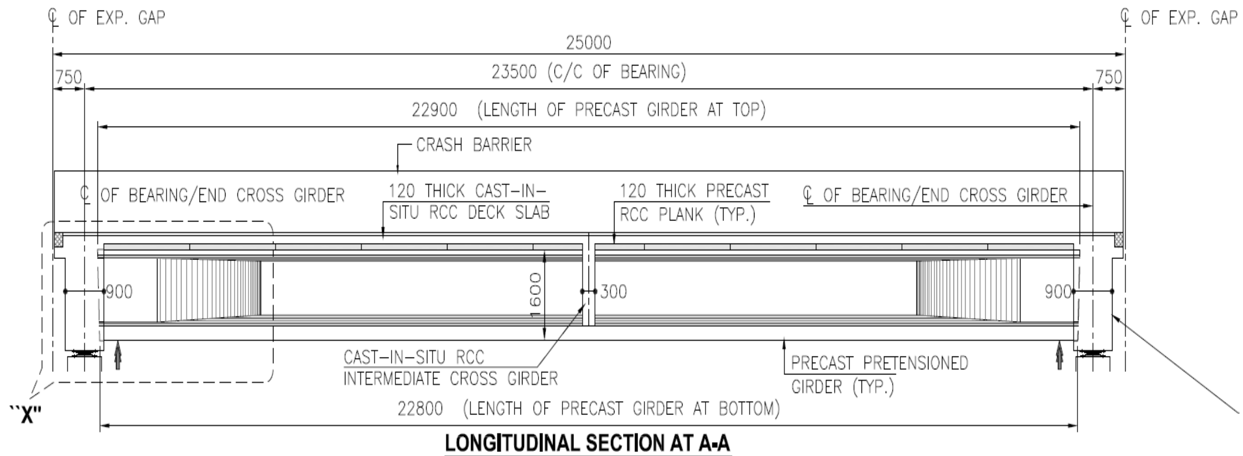
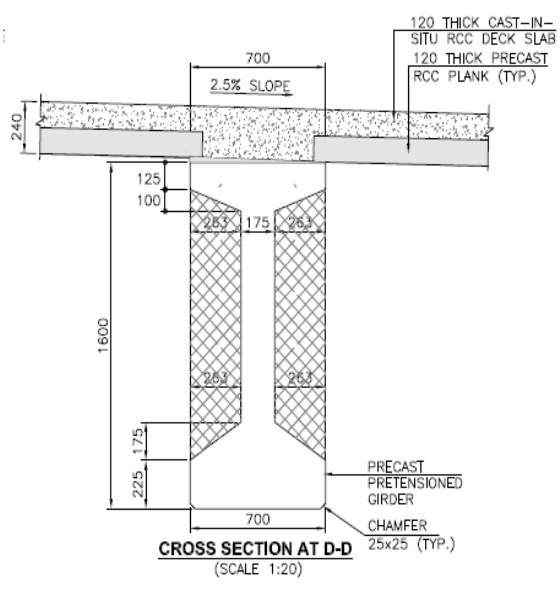



Fig 3.3 Longitudinal Girder Section of 25m c/c exp joint



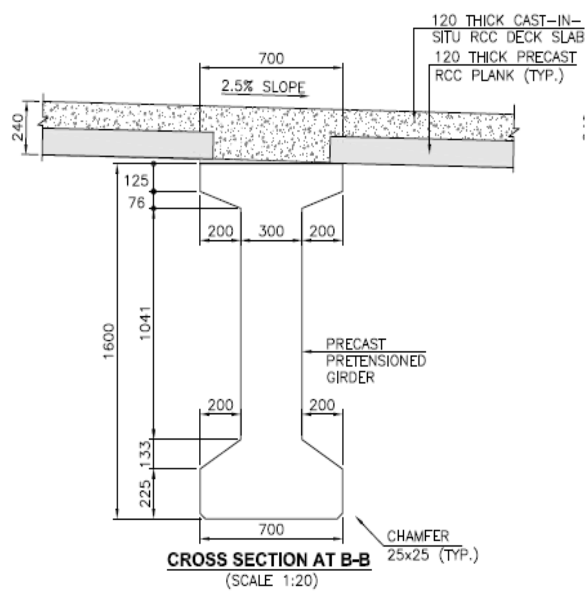




Fig 3.4 Section at Mid

Fig 3.5 Section at Support

**b) For 30m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

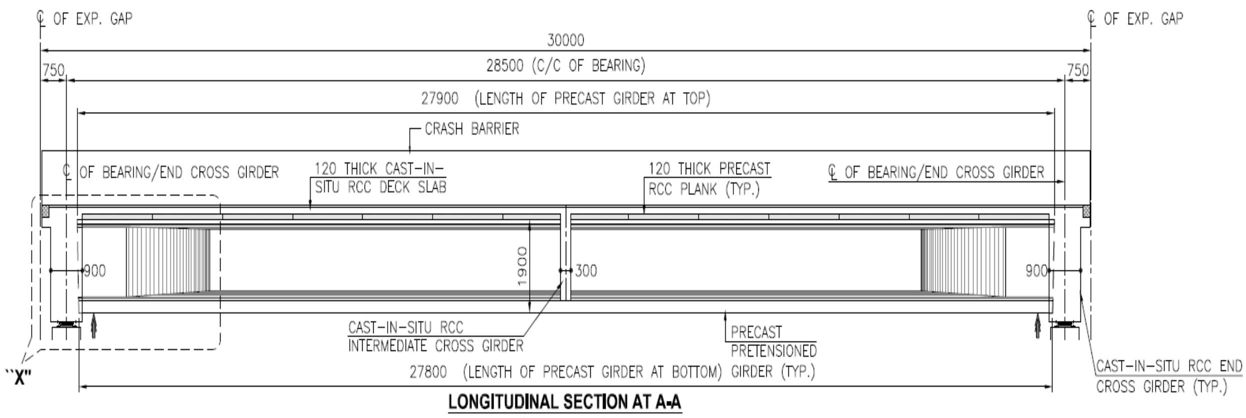
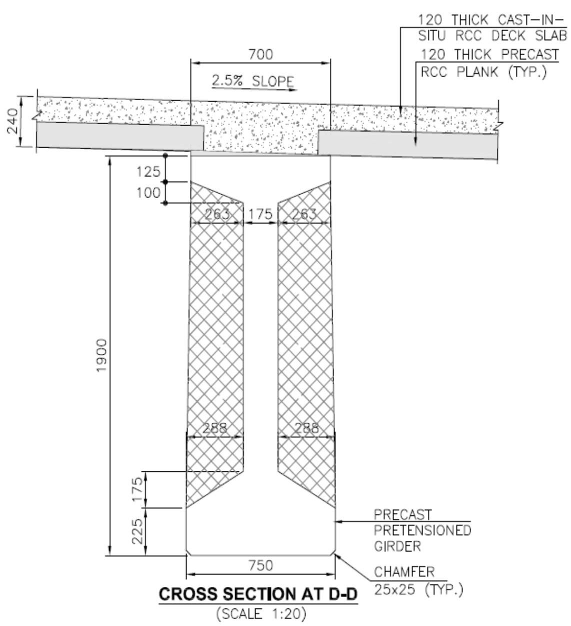



Fig 3.6 Longitudinal Girder Section of 30m c/c exp joint



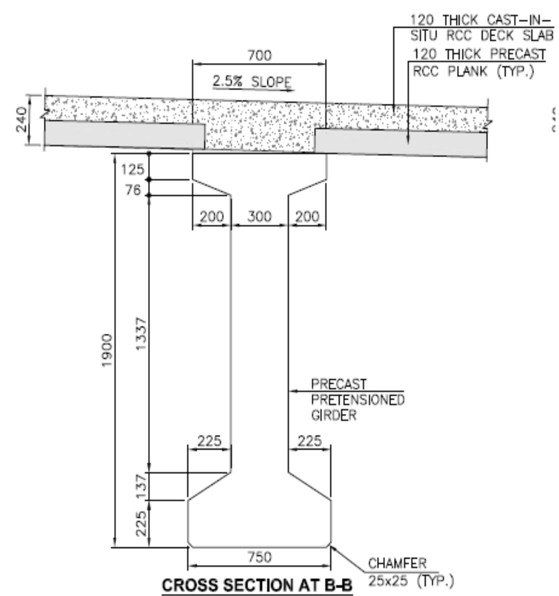




Fig 3.7 Section at Mid

Fig 3.8 Section at Support

**c) For 35m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

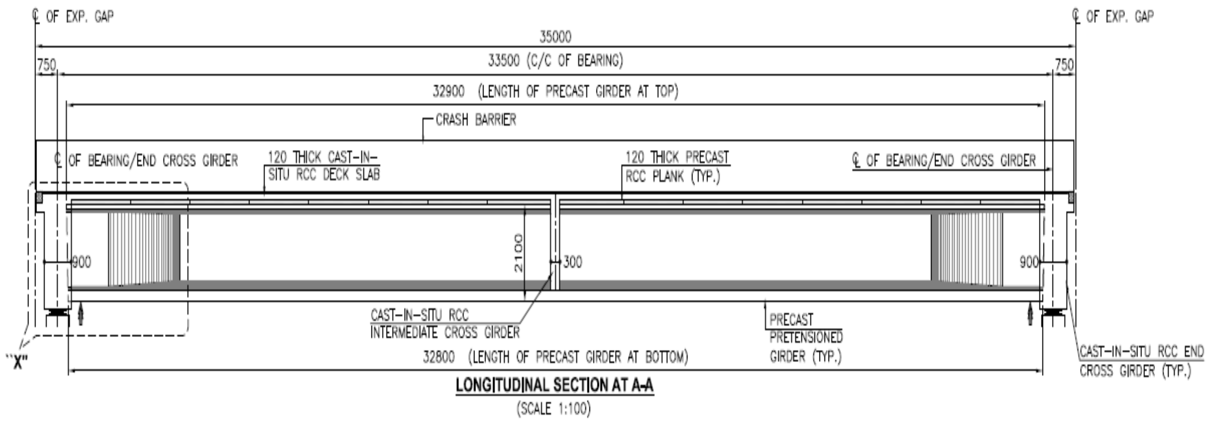



Fig 3.9 Longitudinal Girder Section of 35m c/c exp joint

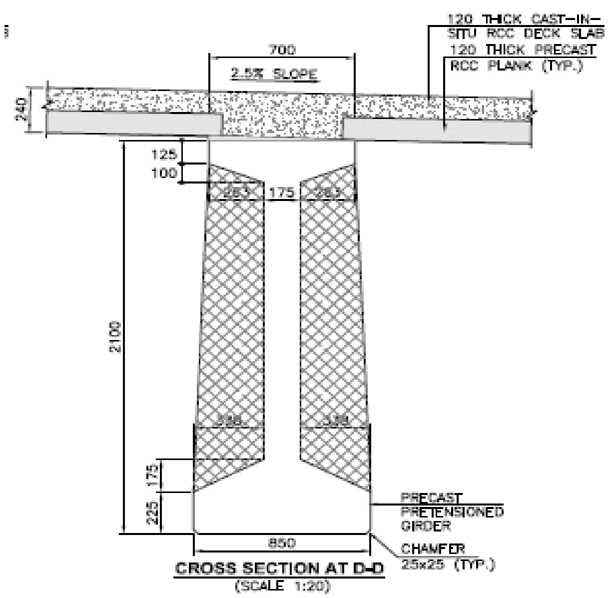



Fig 3.10 Section at Mid

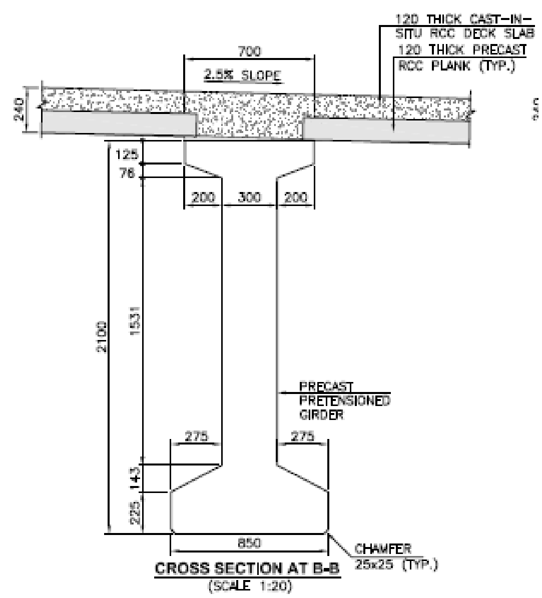



Fig 3.11 Section at Support

### 3.4 Post-Tensioned I Girders Methodology

This chapter pertains to design of post-tensioned prestressed I girder for 25m, 30m & 35m straight span (c/c exp. Joint) for a deck width of 21.250m.

For analysis, the superstructure has been modeled as a grillage in STAAD Pro software. Design of both outer and inner girder is presented here. For design purpose, sections at every 1/8th span, at start and end of flaring have been considered.

The bending moment and shear force due to dead load of girder and slab has been calculated manually for each section. The bending moment and shear force due to SIDL and live load has been taken from Grillage output.

For live load analysis, trains of Class A, Class 70R wheeled & Special Vehicle are considered as per IRC: 6-2017.

Precast beams are checked under different stages of loads. Stress check is carried out at the extreme fibers of the beams. For this purpose, appropriate section properties such as beam alone and composite are considered.

Ultimate bending moment and shear force is calculated by applying load factors as per IRC6:2017 and sections are checked for ultimate bending and shear as per section 10 of IRC112:2011.

The girders are prestressed in single stage before lifting the girder. After girders attaining the age of 28 days, it shall be lifted/transported & erected on the abutment/pier cap. The staging for casting of deck slab shall be erected with support from erected girder itself.

Table 3.1 Stages of Post-Tensioned Girder

| **STAGES** | Girder Age | Deck Age |
|---|---|---|
| Casting of concrete at day | 0 | - |
| Transfer of pre-stress at day stage-I | 14 | - |
| Transfer of pre-stress at day stage -Stage II | 28 | - |
| Casting of deck -III | 35 | 0 |
| Transfer over permanent Brg. - Stage IV | 63 | 28 |
| Placing of SIDL - Stage V | 64 | 29 |
| Open to LL - Stage -VI | 92 | 57 |
| At ∞ | 36500 | 36465 |

## 3.5 Schematic Arrangement of Post-Tensioned I Girders

The following cross-section have been adopted for all the 3 spans of 25m, 30m & 35m having deck width of 21.250m. The superstructure comprises of 7 nos of pre-tensioned I girders with cast in-situ RCC deck slab of 120mm thickness and precast RCC plank of 120mm thickness. The superstructures are rested in diaphragm or hanging in diaphragm. Fig 3.12 shows the cross-section of the end cross girder having 3 nos of POT-PTFE bearings below diaphragm and Fig 3.13 shows the cross-section of the intermediate cross girder.

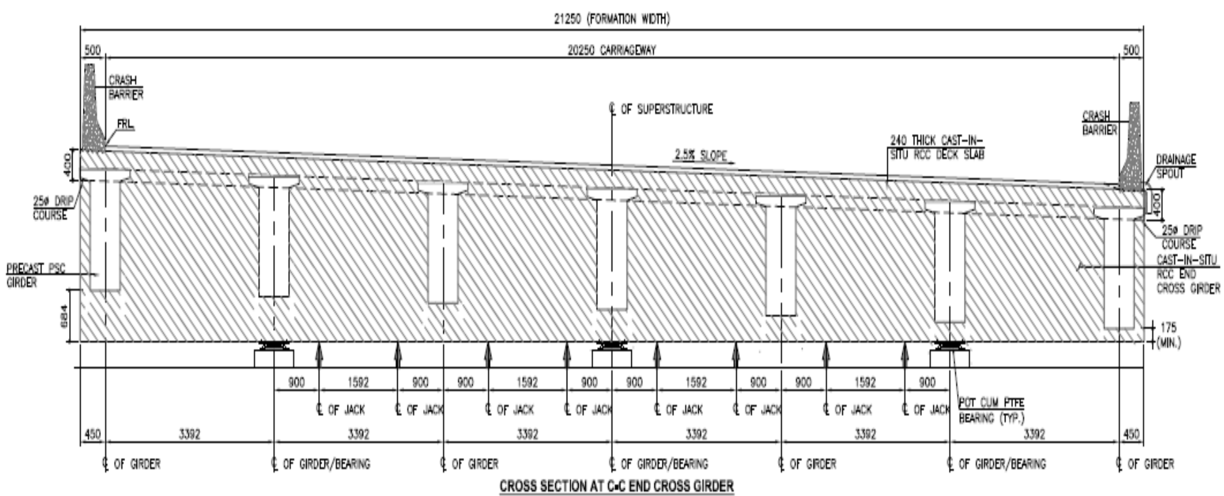



Fig 3.12 Cross-section of Diaphragm

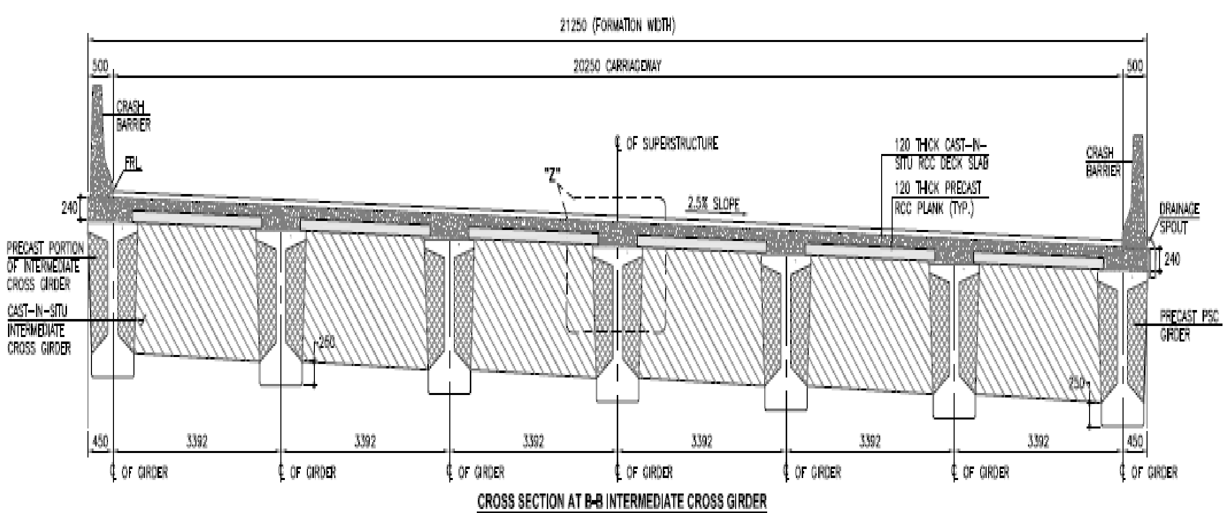



Fig 3.13 Cross-section of Intermediate Cross-Girder

### 3.5.1 Dimensional Details of Post-Tensioned Superstructures

**a) For 25m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

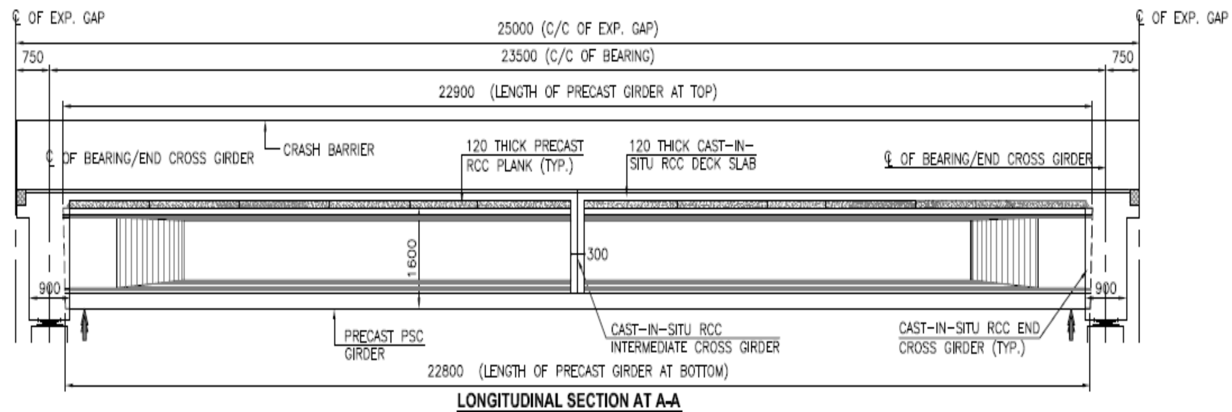



Fig 3.14 Longitudinal Girder Section of 25m c/c exp joint

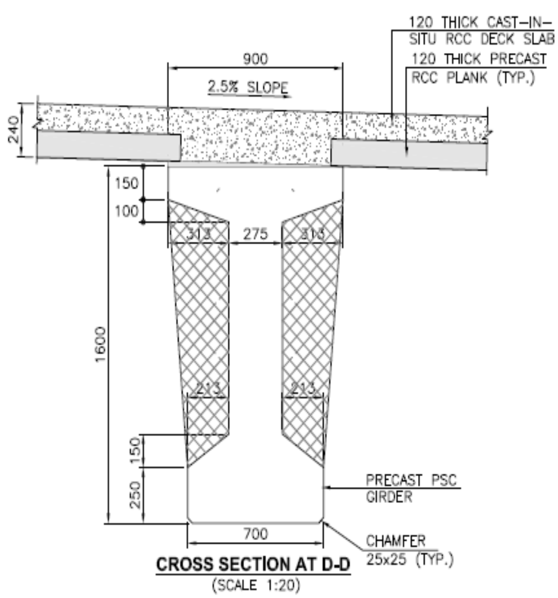



Fig 3.15 Section at Mid

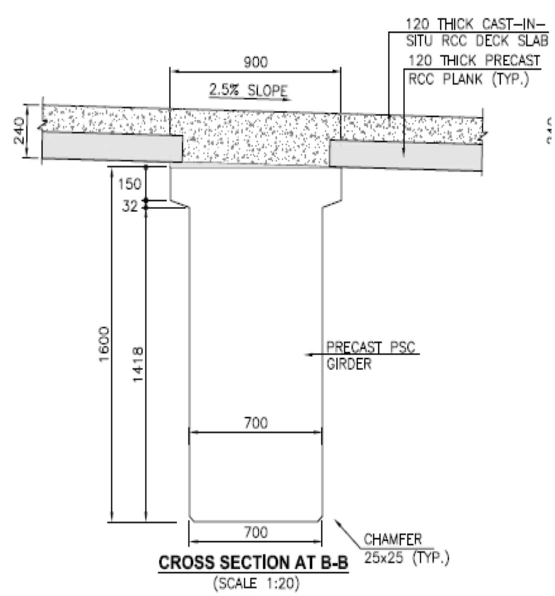



Fig 3.16 Section at Support

**b) For 30m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

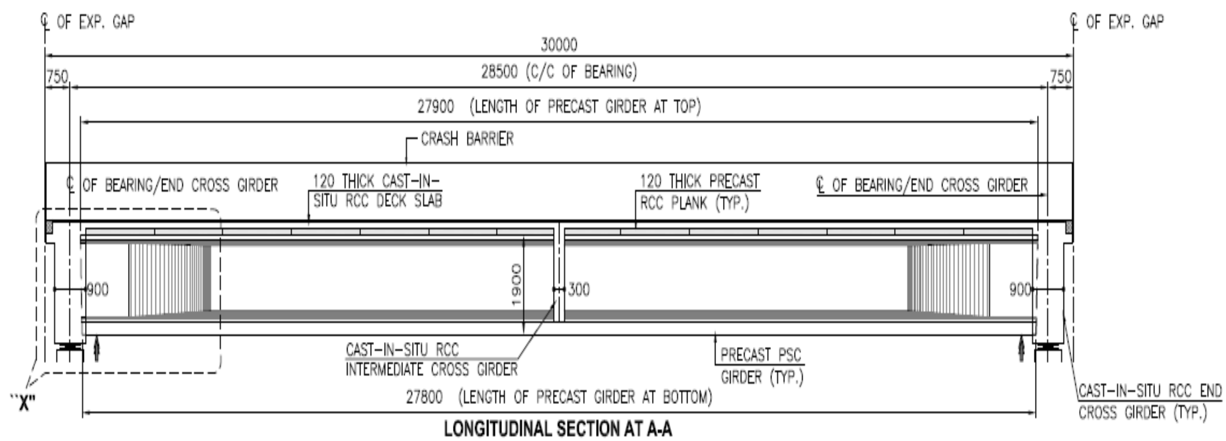



Fig 3.17 Longitudinal Girder Section of 30m c/c exp joint

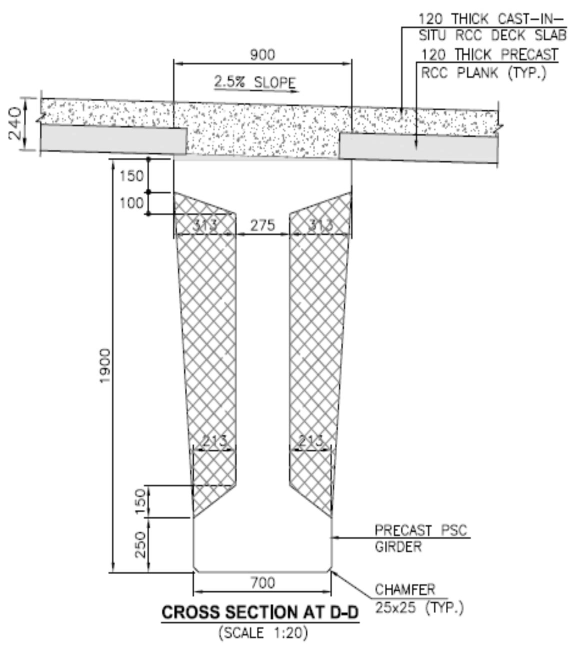



Fig 3.18 Section at Mid

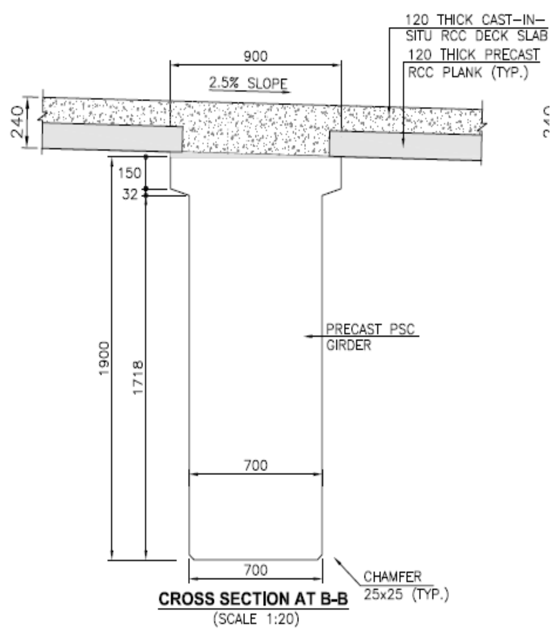



Fig 3.19 Section at Support

**c) For 35m Span- Dimensional Details of Superstructure:** Following longitudinal section and cross-sections are adopted for the detailed design.

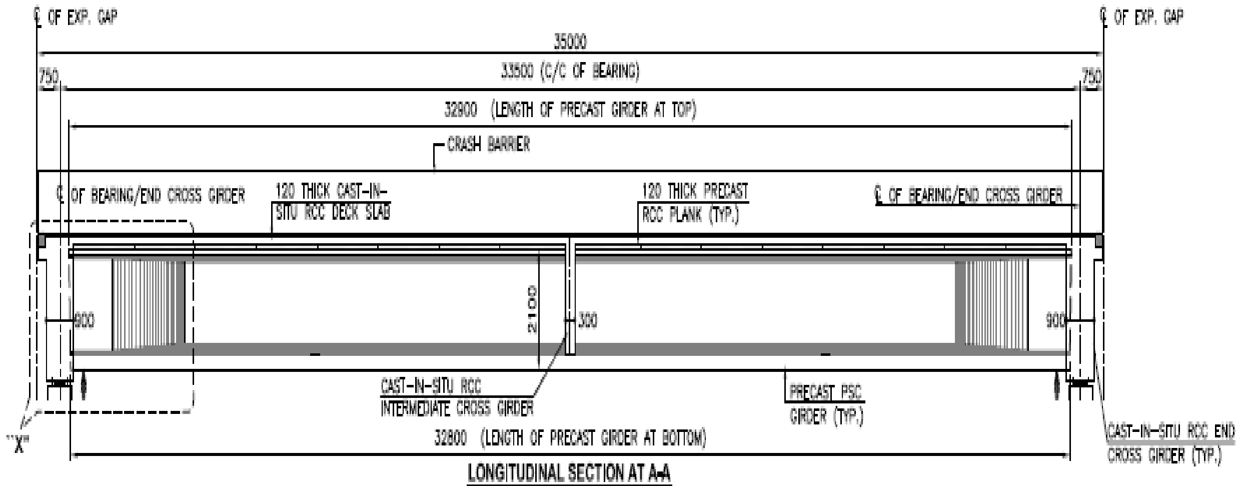



Fig 3.20 Longitudinal Girder Section of 35m c/c exp joint

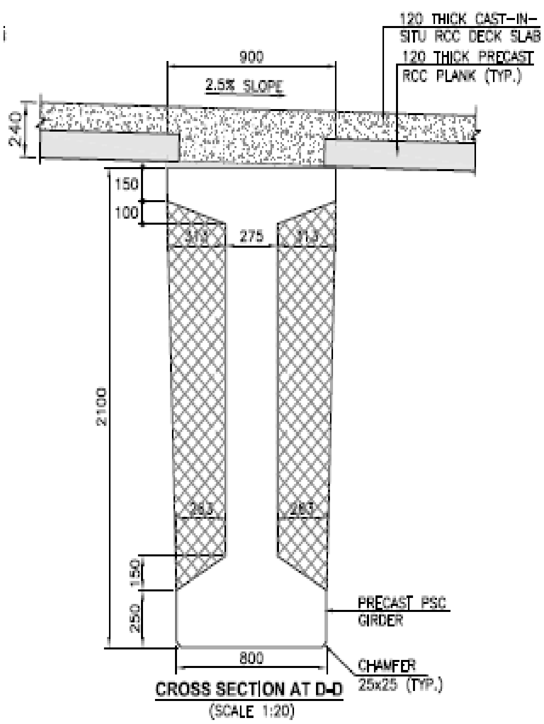



Fig 3.21 Section at Mid

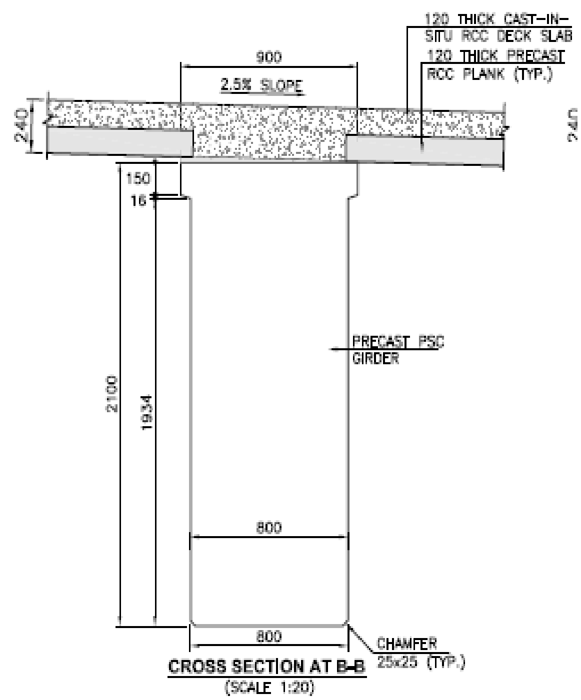



Fig 3.22 Section at Support

# CHAPTER 4

# DESIGN & ANALYSIS

## 4.1 Introduction

In this research, a simply supported PSC I girder bridge is modelled to investigate their respective reactive behavior. A prestressed I girder bridge of 25 m, 30 m, & 35 m span c/c exp joint and carriageway width of 21.250 m is considered for the analysis. Live loads are taken as per IRC:6-2017. Cross section of I girder is shown in Fig 3.1, 3.2, 3.12 & 3.13 and Plan of I-Girder is shown in Figure 4.1. The deck slab thickness is 0.24 m comprises of 0.12 m of RCC precast plank in addition of 0.12 m cast in situ RCC deck slab.

Material properties used are M45 & M50 grade of concrete and Fe500 grade steel. The tendon profile considered is linear in pretensioned girder and parabolic in post-tensioned girder. All the tendons are stressed from one end in Pretensioned girder and all the tendons/strands are stressed from both ends in Post-Tensioned girder. The bridge was examined for various span-to-depth ratios (L/d) ranging from 15 to 19.

For analysis, the superstructure has been modeled as a grillage in STAAD Pro software. Design of both outer and inner girder is presented here. IRC 6-2017 specifies the numerous types of loads, forces and stresses that must be considered in the study and design of bridge components.

The superstructure has been idealized as a mesh of longitudinal and transverse members and the loading has been applied as per the construction sequence.

Transverse analysis of deck has been done using Staad software and excel for dispersion, 65mm thick wearing coat has been assumed but load due to wearing coat has been assumed as 0.2 t/m2 assuming future overlay.

Fig 4.2, 4.3 & 4.4 represents the static (dead load) and super imposed dead load (crash barrier & wearing course) over the girders.

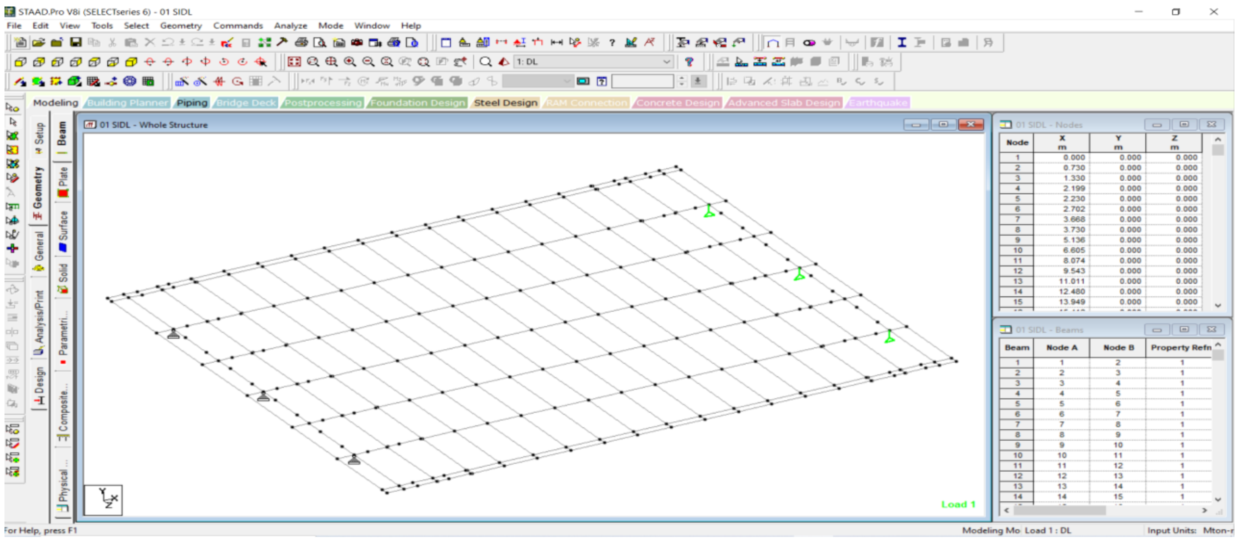



Fig 4.1 Grillage model of Superstructure

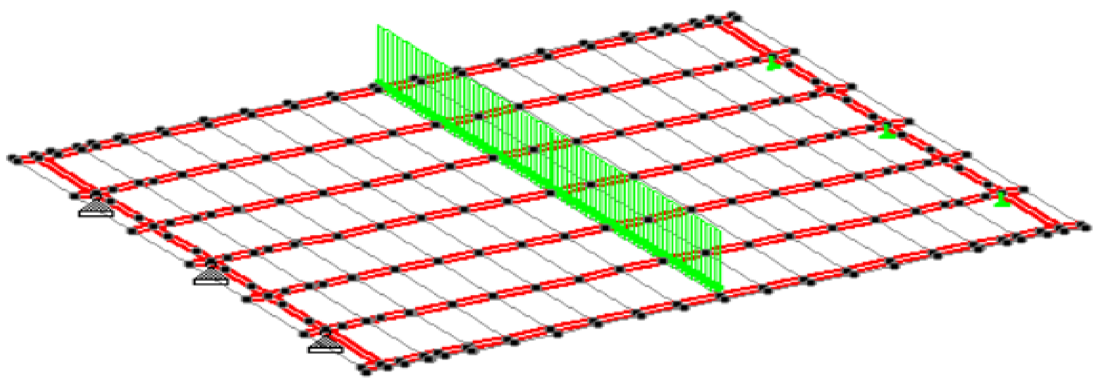


Fig 4.2 Self-weight load of PSC I-Girder

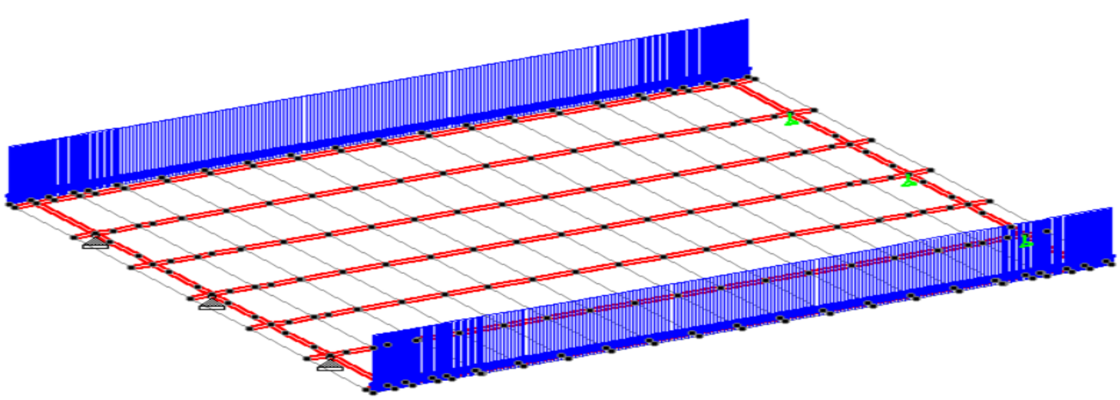


Fig 4.3 Crash barrier load on design model

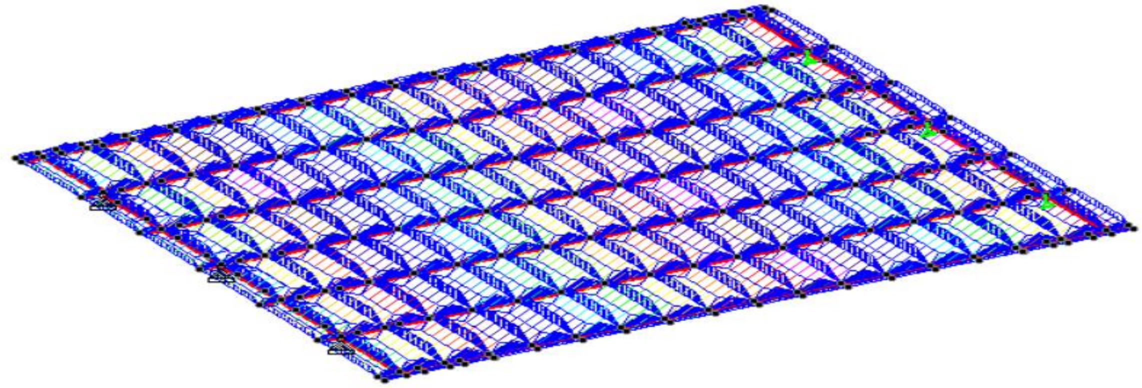


Fig 4.4 Wearing coarse load on design model

### 4.1.1 Vehicle Live Loads as per IRC 6-2017:

The position of the wheels for Class A Vehicle, 70R Wheeled Vehicle, 70R Tracked, and SV Loading as per IRC6-2017 is shown in figure 4.5, 4.6 & 4.8.

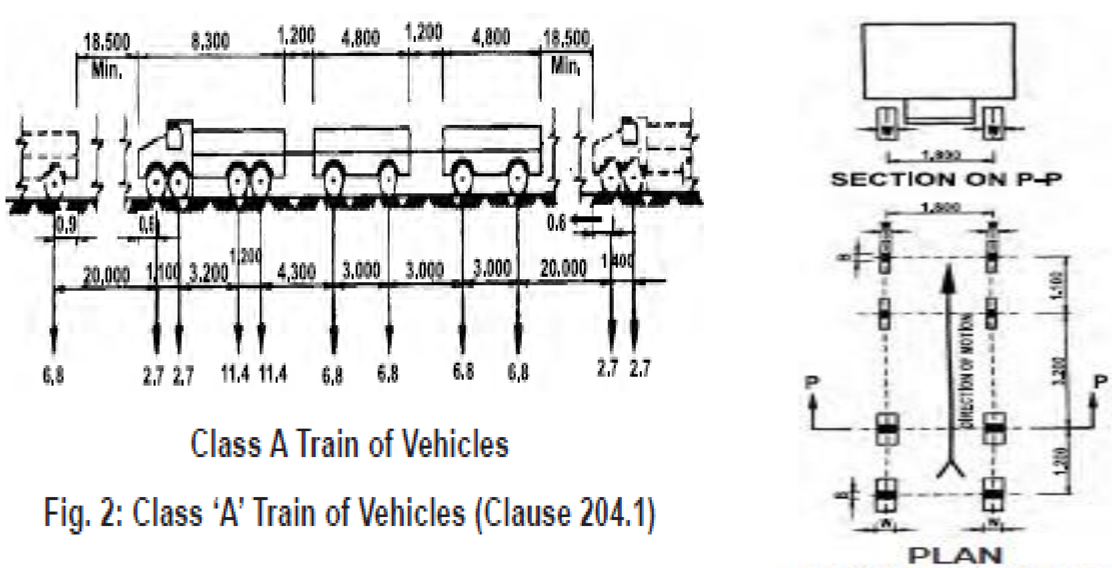



Fig 4.5 Class A Vehicles ("Referred from IRC 6-2017")

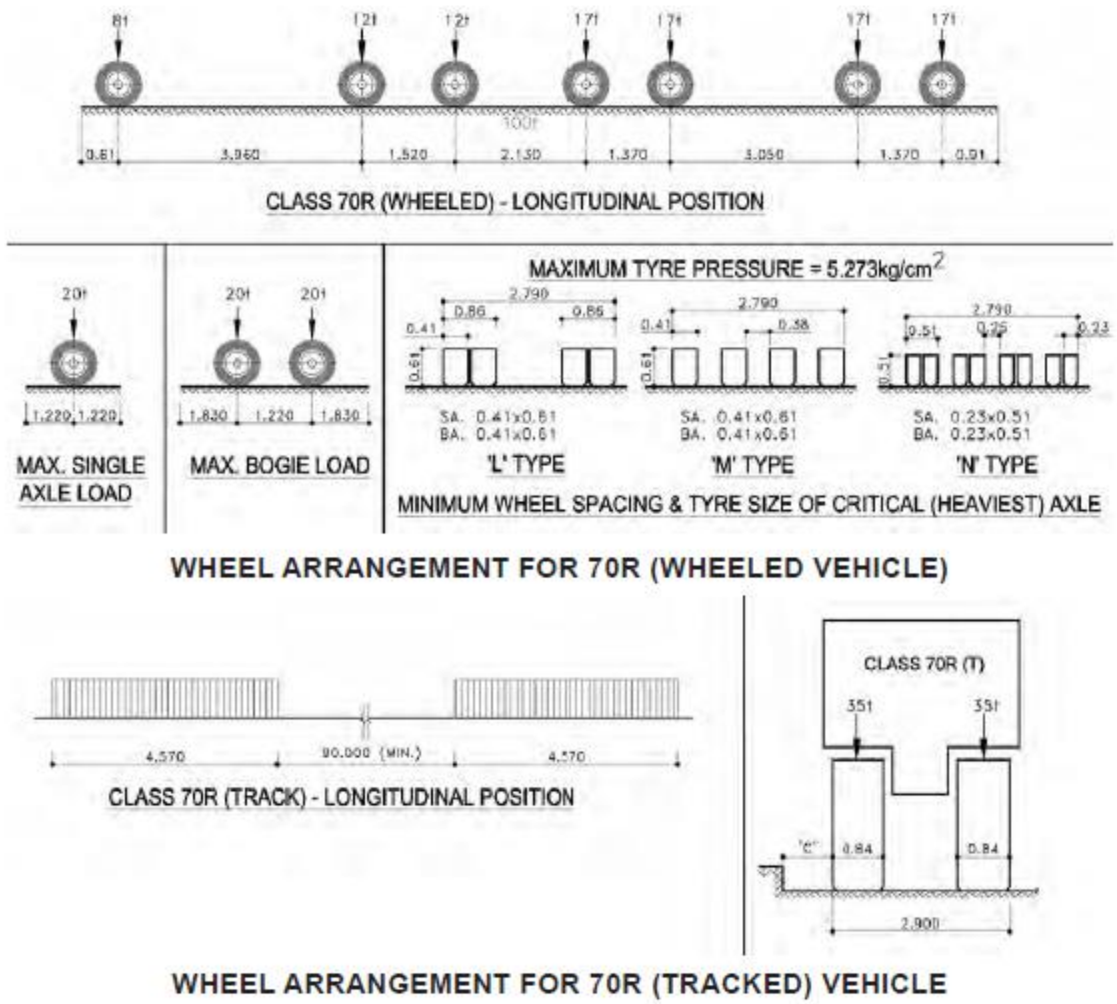



Fig 4.6 Class 70R Wheeled and Tracked Vehicles ("Referred from IRC 6-2017")

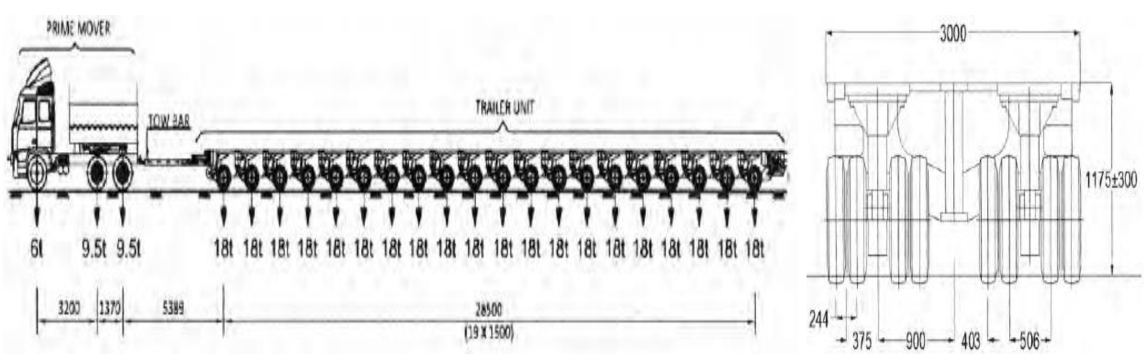



Fig 4.7 Special Vehicle Loading ("Referred from IRC 6-2017")

**Live Load combination as per IRC 6- 2017:**

Table 4.1 Live Load Combination for different Lane Width

<table>
<tr><th>Carriageway width</th><th>Number of lanes for design purposes</th><th>Load Combination</th></tr>
<tr><td>1. Less than 5.3m</td><td>1</td><td>One lane of Class A considered to occupy 2.3m. The remaining width of carriageway shall be loaded with 500Kg/m$^2$.</td></tr>
<tr><td>2. 5.3m and above but less than 9.6m</td><td>2</td><td>One lane of class 70R OR two lanes of Class A</td></tr>
<tr><td>3. 9.6m and above but less than 13.1m</td><td>3</td><td>One lane of Class 70R for every two lanes with one lane of class A on the remaining lane OR 3 lanes of Class A</td></tr>
<tr><td>4. 13.1m and above but less than 16.6m</td><td>4</td><td rowspan="3">One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes, if any, OR one lane of Class A for each lane.</td></tr>
<tr><td>5. 16.6m and above but less than 20.1m</td><td>5</td></tr>
<tr><td>6. 20.1m and above but less than23.6m</td><td>6</td></tr>
</table>

Since, the carriageway width is 21.25 m, so according to the above recommendation One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes or six lanes of Class A will be considered.

Below Fig 4.8, 4.9, 4.10 & 4.11 shows the Live load of Class A- 6 Lane, 70RW- 2 Lane, Class A- 4 Lane + One lane of 70RW and Special Vehicle Loading.

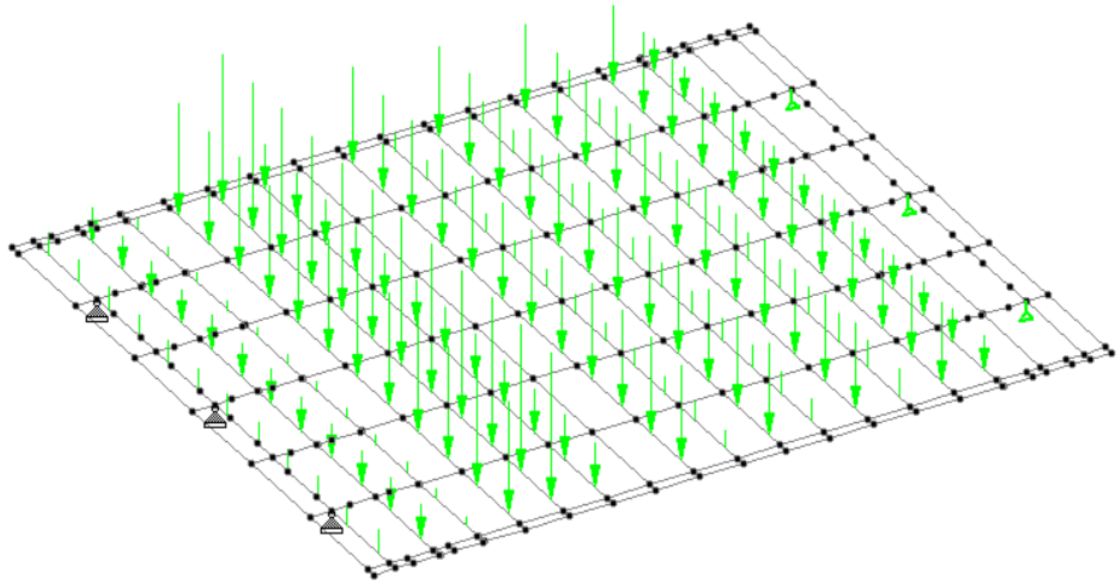


Fig 4.8 Live load (Class A- 6 Lane)

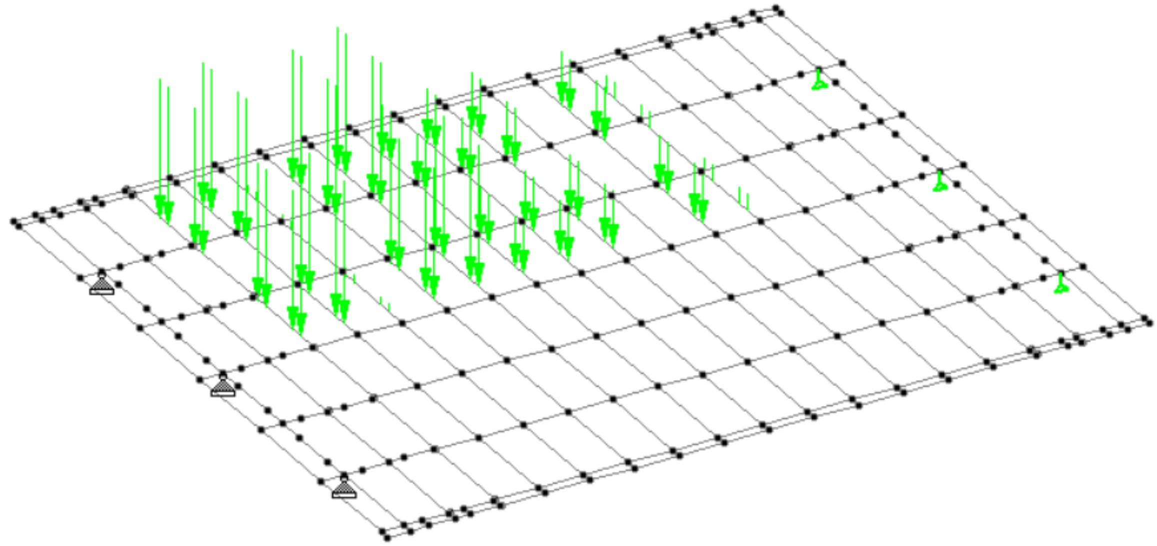


Fig 4.9 Live load (70RW- 2 Lane)

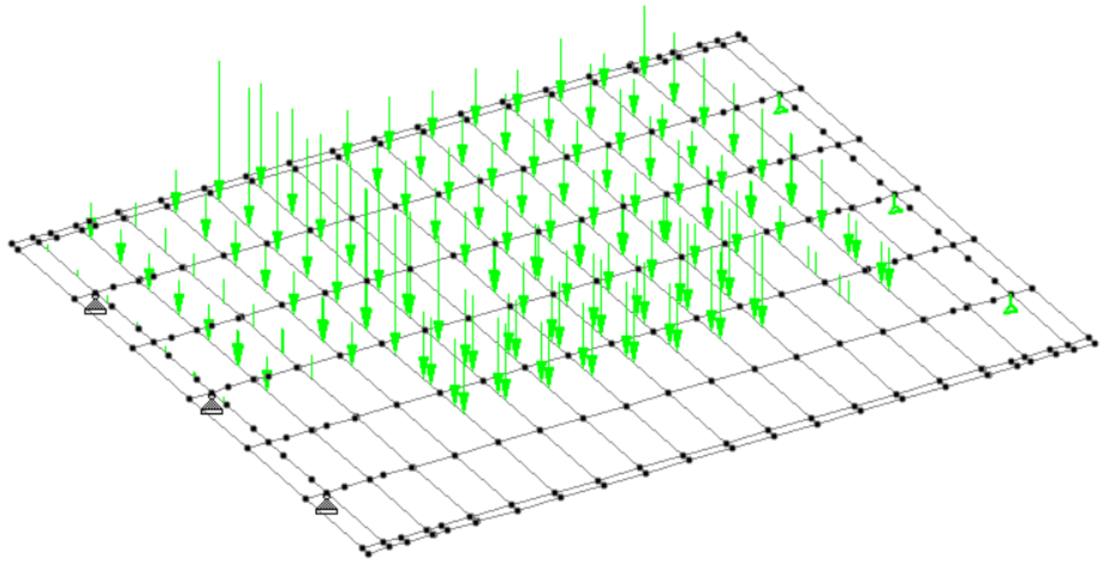


Fig 4.10 Live load (4 Lane of Class A + 70RW)

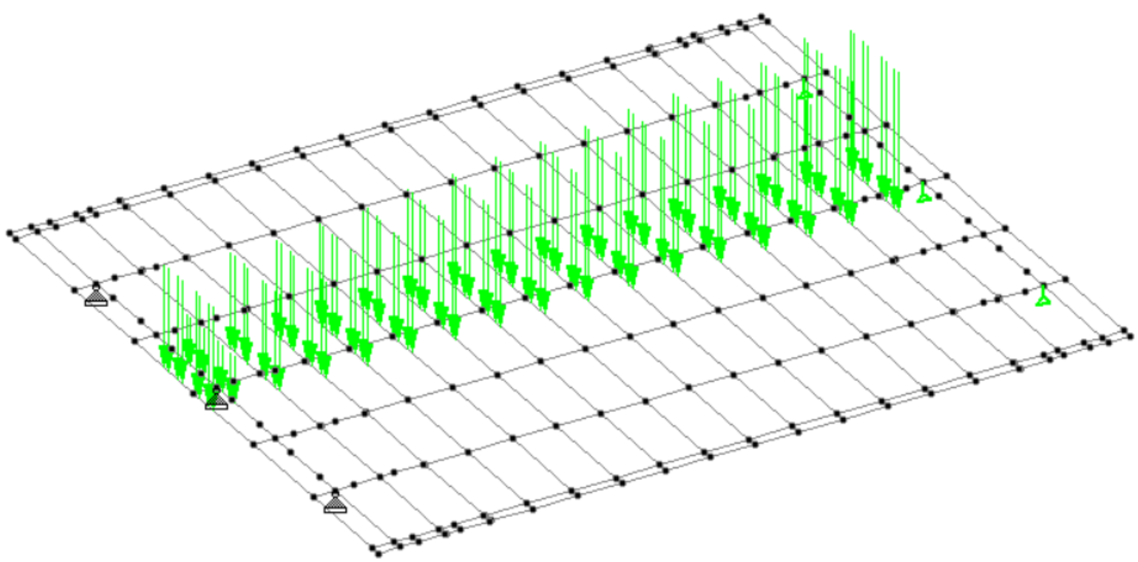


Fig 4.11 Live load (Special Vehicle Loading)

## 4.2 Design Comparison of Pretensioned & Post-Tensioned for 25m Span

The maximum Bending Moment is considered at L/2 of the span and maximum Shear Force is considered at deffective distance from the face of the support.

**4.2.1** The comparison for Outer Girder is shown in Table 4.2

Table 4.2 Comparison of Bending Moment & Shear Forces for Outer Girder- 25m span

| **Sr. No.** | **Loads** | **Pretensioned Girder** | | **Post Tensioned Girder** | |
|---|---|---|---|---|---|
| | | Bending Moment (t-m) | Shear Force (t) | Bending Moment (t-m) | Shear Force (t) |
| 1 | Dead Load of Girder | 93 | 13 | 124 | 19 |
| 2 | Deck Slab | 89 | 13 | 104 | 15 |
| 3 | Crash Barrier | 35 | 7 | 38 | 8 |
| 4 | Wearing Course | 33 | 4 | 32 | 1 |
| 5 | Maximum Live Load | 201 | 25 | 198 | 24 |
| | **Summation of Loads** | **451** | **62** | **496** | **67** |

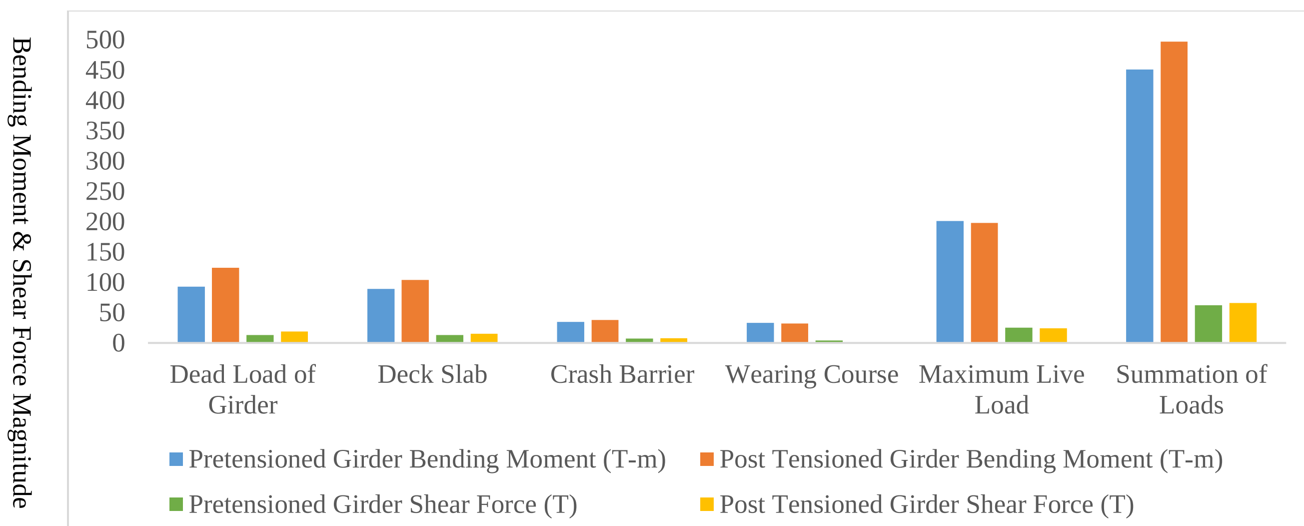



Fig 4.12 Comparison of Bending Moment & Shear Forces for Outer Girder – 25m span

**4.2.2** The comparison for Inner Girder is shown in Table 4.3

Table 4.3 Comparison of Bending Moment & Shear Forces for Inner Girder- 25m span

| **Sr. No.** | **Loads** | **Pretensioned Girder** | | **Post Tensioned Girder** | |
|---|---|---|---|---|---|
| | | Bending Moment (t-m) | Shear Force (t) | Bending Moment (t-m) | Shear Force (t) |
| 1 | Dead Load of Girder | 93 | 13 | 124 | 19 |
| 2 | Deck Slab | 147 | 13 | 167 | 24 |
| 3 | Crash Barrier | 5 | 2 | 32 | 2 |
| 4 | Wearing Course | 47 | 6 | 48 | 7 |
| 5 | Maximum Live Load | 234 | 41 | 240 | 45 |
| | **Summation of Loads** | **526** | **75** | **611** | **97** |

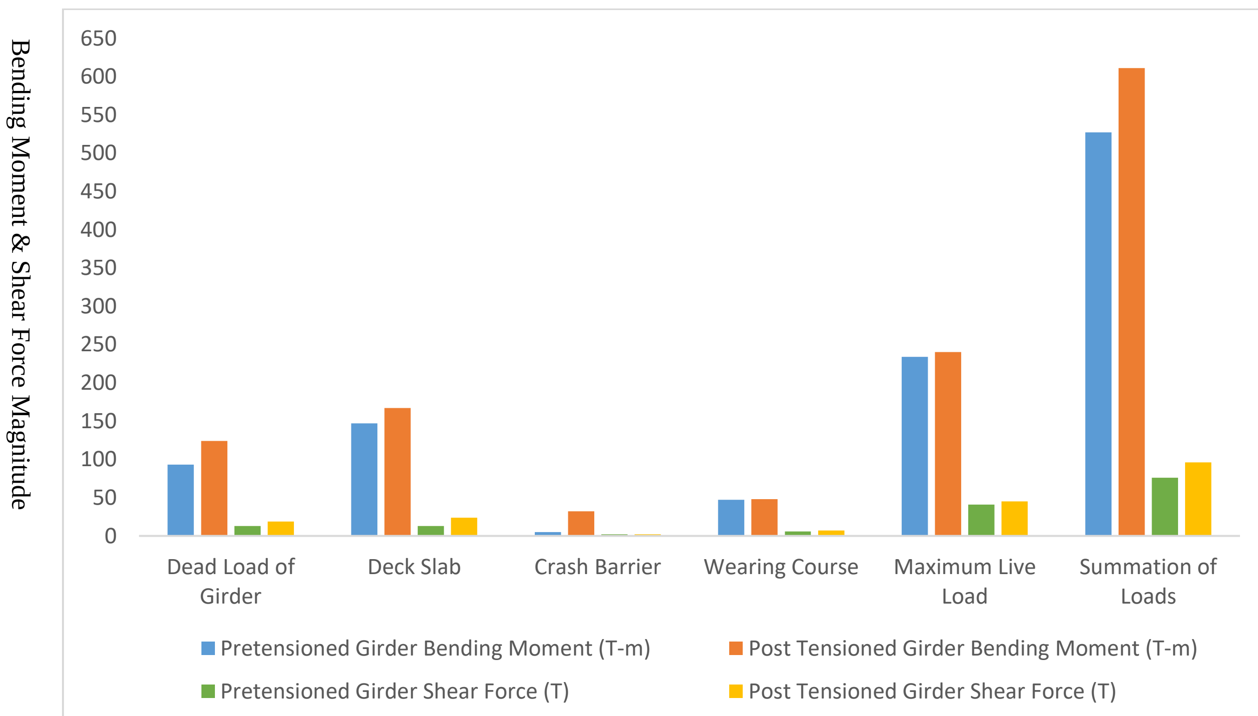



Fig 4.13 Comparison of Bending Moment & Shear Forces for Inner Girder – 25m span

### 4.3 Design Comparison of Pretensioned & Post-Tensioned for 30m Span

4.3.1 The comparison for Outer Girder is shown in Table 4.4

Table 4.4 Comparison of Bending Moment & Shear Forces for Outer Girder- 30m span

| Sr. No. | Loads | Pretensioned Girder | | Post Tensioned Girder | |
|---|---|---|---|---|---|
| | | Bending Moment (T-m) | Shear Force (T) | Bending Moment (T-m) | Shear Force (T) |
| 1 | Dead Load of Girder | 154 | 18 | 203 | 25 |
| 2 | Deck Slab | 131 | 15 | 155 | 18 |
| 3 | Crash Barrier | 38 | 8 | 44 | 9 |
| 4 | Wearing Course | 52 | 5 | 51 | 6 |
| 5 | Maximum Live Load | 268 | 26 | 261 | 28 |
| | **Summation of Loads** | **643** | **72** | **714** | **86** |

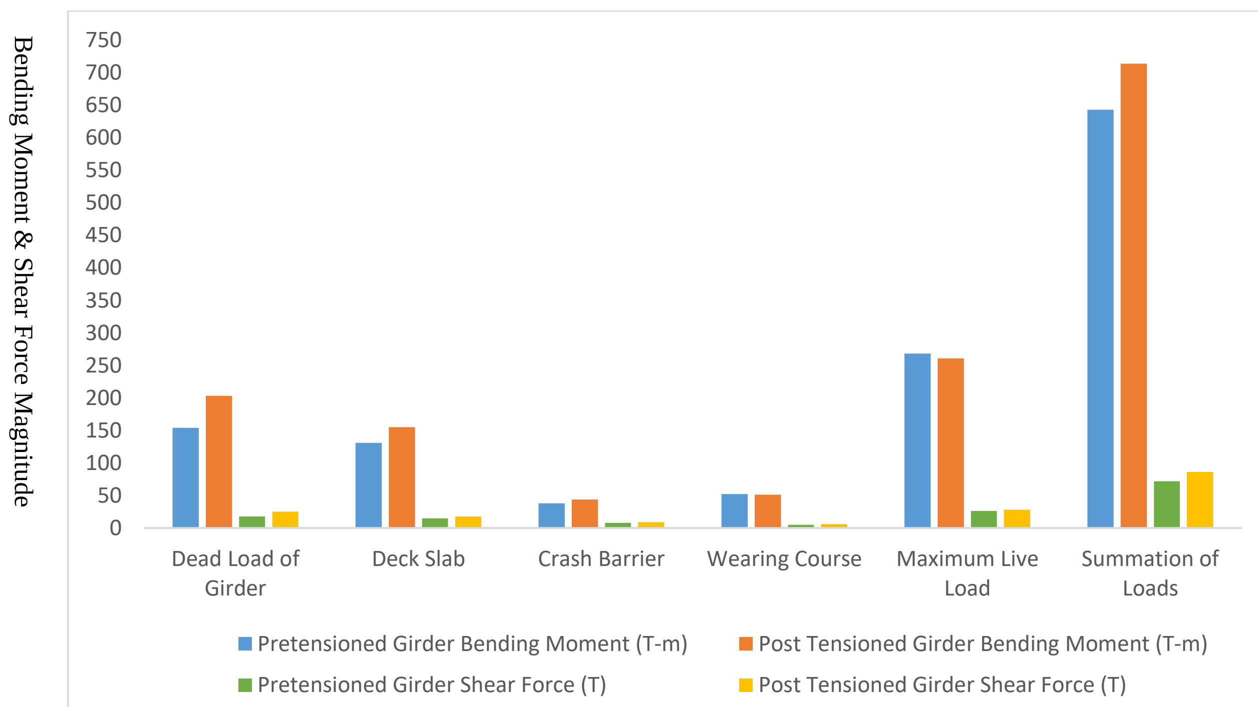



Fig 4.14 Comparison of Bending Moment & Shear Forces for Outer Girder- 30m span

4.3.2 The comparison for Inner Girder is shown in Table 4.5

Table 4.5 Comparison of Bending Moment & Shear Forces for Inner Girder- 30m span

| **Sr. No.** | **Loads** | **Pretensioned Girder** | | **Post Tensioned Girder** | |
|---|---|---|---|---|---|
| | | Bending Moment (T-m) | Shear Force (T) | Bending Moment (T-m) | Shear Force (T) |
| 1 | Dead Load of Girder | 154 | 18 | 203 | 25 |
| 2 | Deck Slab | 217 | 15 | 245 | 28 |
| 3 | Crash Barrier | 16 | 3 | 46 | 2 |
| 4 | Wearing Course | 68 | 8 | 69 | 8 |
| 5 | Maximum Live Load | 276 | 43 | 277 | 50 |
| | **Summation of Loads** | **731** | **87** | **840** | **113** |

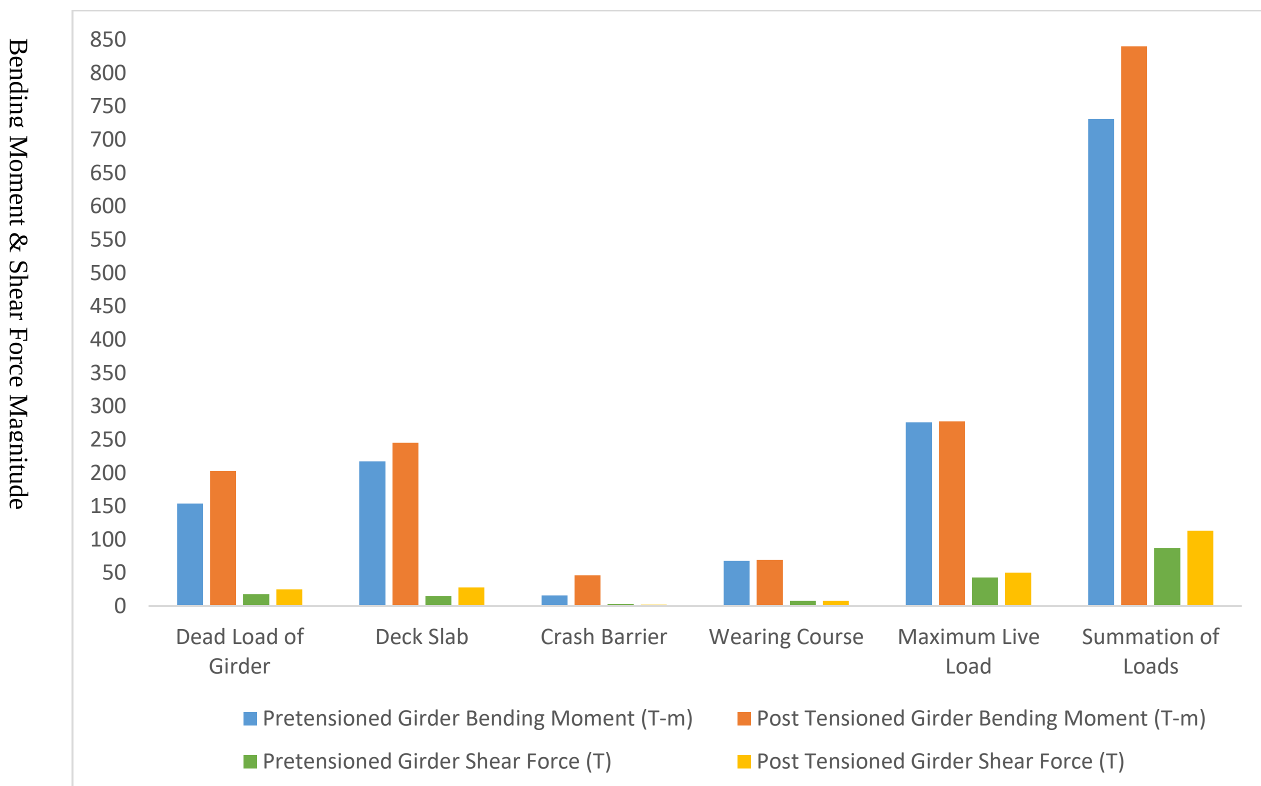



Fig 4.15 Comparison of Bending Moment & Shear Forces for Inner Girder- 30m span

**4.4 Design Comparison of Pretensioned & Post-Tensioned for 35m Span**

4.4.1 The comparison for Outer Girder is shown in Table 4.6

Table 4.6 Comparison of Bending Moment & Shear Forces for Outer Girder- 35m span

| Sr. No. | Loads | Pretensioned Girder | | Post Tensioned Girder | |
|---|---|---|---|---|---|
| | | Bending Moment (T-m) | Shear Force (T) | Bending Moment (T-m) | Shear Force (T) |
| 1 | Dead Load of Girder | 236 | 24 | 311 | 33 |
| 2 | Deck Slab | 180 | 18 | 214 | 22 |
| 3 | Crash Barrier | 39 | 8 | 49 | 10 |
| 4 | Wearing Course | 75 | 7 | 73 | 7 |
| 5 | Maximum Live Load | 329 | 28 | 324 | 30 |
| | **Summation of Loads** | **859** | **85** | **971** | **102** |

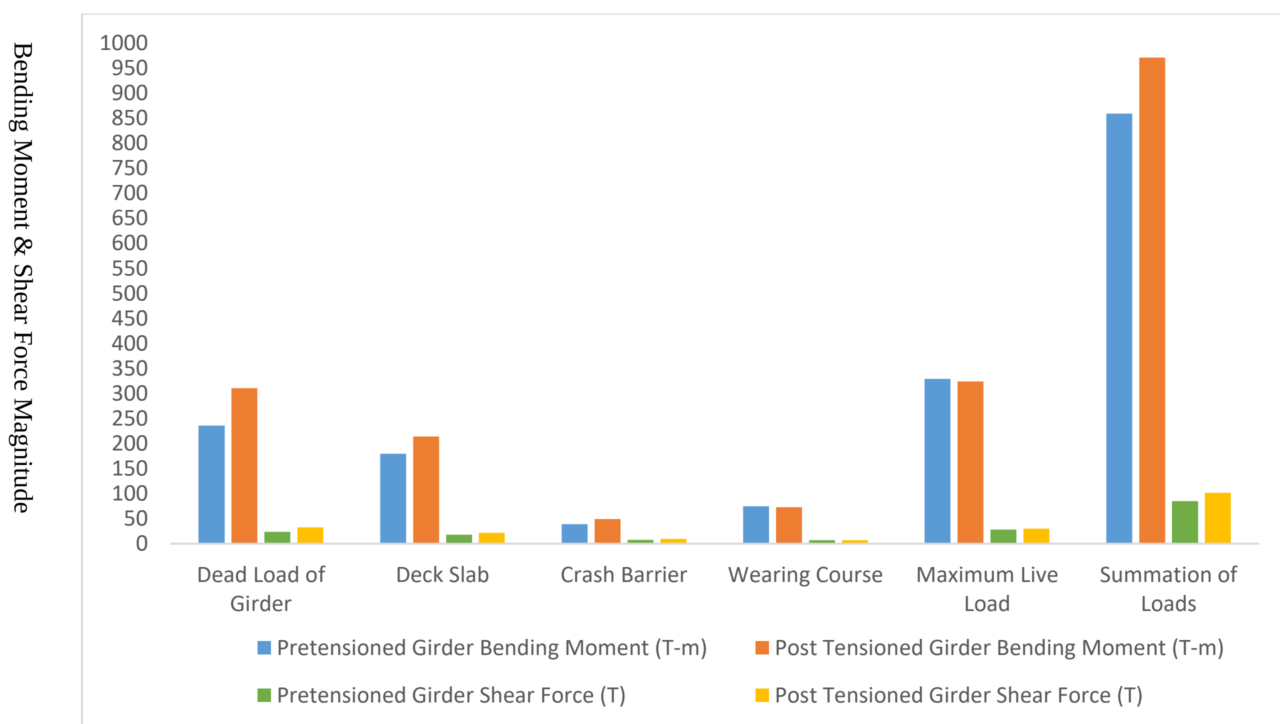



Fig 4.16 Comparison of Bending Moment & Shear Forces for Outer Girder- 35m span

4.4.2 The comparison for Inner Girder is shown in Table 4.7

Table 4.7 Comparison of Bending Moment & Shear Forces for Inner Girder- 35m span

| **Sr. No.** | **Loads** | **Pretensioned Girder** | | **Post Tensioned Girder** | |
|---|---|---|---|---|---|
| | | Bending Moment (T-m) | Shear Force (T) | Bending Moment (T-m) | Shear Force (T) |
| 1 | Dead Load of Girder | 236 | 24 | 311 | 33 |
| 2 | Deck Slab | 300 | 18 | 336 | 33 |
| 3 | Crash Barrier | 31 | 3 | 61 | 3 |
| 4 | Wearing Course | 92 | 9 | 93 | 10 |
| 5 | Maximum Live Load | 324 | 45 | 320 | 52 |
| | **Summation of Loads** | **983** | **99** | **1121** | **131** |

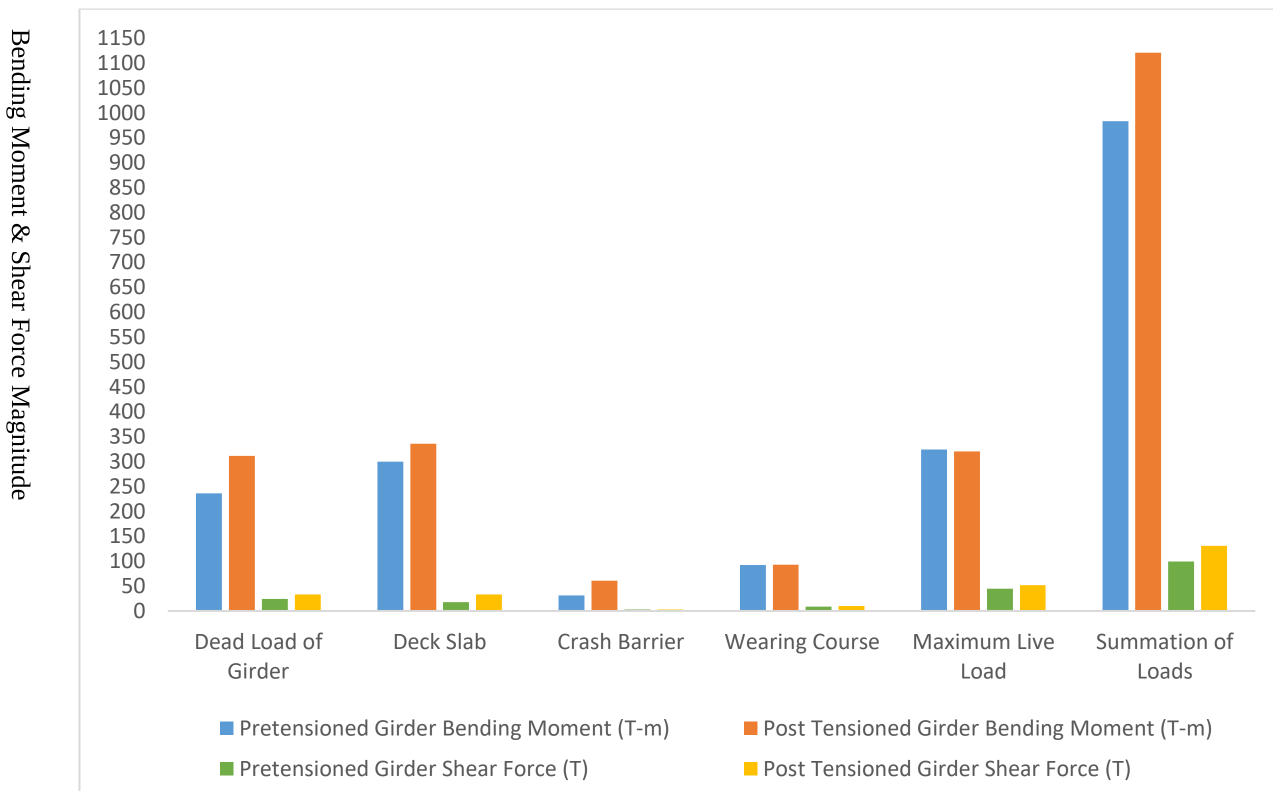



Fig 4.17 Comparison of Bending Moment & Shear Forces for Inner Girder- 35m span

# CHAPTER 5

# QUANTITY & COST COMPARISON

## 5.1 Introduction

The detailed analysis was done for Pretensioned & Post Tensioned Girder of different span arrangements 25 m, 30 m and 35 m in order to determine their concrete quantities, HTS, TMT and overall construction cost.

The study is done considering number of Girders varied from 100 to1000 in a highway project, accordingly casting bed cost of pretensioned girder is calculated and similarly auxiliary items like HDPE duct, anchor cone, wedges and bearing plate is considered in Post-tensioned girder.

After evaluation it has been found that Pretensioned girders are quite economical than post-tensioned girders due to numerous reasons, the same has been tabulated in the below comparisons for 25 m, 30 m and 35 m.

## 5.2 Comparison Between Pretensioned & Post Tensioned Girder for 25 m Span

From the table 5.1, it can be noted that there are huge savings in choosing the Pretensioned Girders and the net difference in cost of 1 girder is found to be Rs 92,359 in addition there will be massive savings of time as well.

Cumulatively the cost of Pretensioned Girder is found to be 31% lesser than Post tensioned girder for a comparison of 1000 number of girders.

Also, in Pretensioned girder, the concrete quantity is 39.8%, TMT is 29% and HTS is 23.6% lesser than Post tensioned girder.

Table 5.1 Quantity & Cost comparison of Pretensioned & Post-tensioned for 25 m span

| Sr. No. | Item | Unit | Pretensioned Girder | | | Post-Tensioned Girder | | | Difference in Rupees for 1 Girder |
|---|---|---|---|---|---|---|---|---|---|
| | | | Qty | Rate | Amount | Qty | Rate | Amount | |
| **25m Span Girder** | | | | | | | | | |
| 1 | Concrete | Cum | 12.766 | 6000 | 76599 | 17.859 | 6000 | 107155 | **92,359** |
| 2 | TMT | MT | 1.660 | 60000 | 99578 | 2.143 | 60000 | 128586 | |
| 3 | HTS | MT | 0.858 | 110000 | 94382 | 1.061 | 110000 | 116750 | |
| 4 | HDPE Duct | Rm | | | 0 | 119.500 | 127 | 15177 | |
| 5 | Anchor Cone | EA | | | 0 | 10.000 | 720 | 7200 | |
| 6 | Bearing Plate | EA | | | 0 | 10.000 | 608 | 6080 | |
| 7 | Wedges | Pair | | | 0 | 110.000 | 50 | 5500 | |
| 8 | Casting Yard | Per Cum | 12.766 | 2109 | 26924 | | | 0 | |
| 9 | Shuttering | EA | | | | 17.859 | 190 | 3393 | |
| | **Total Amount** | | | | **2,97,483** | | | **3,89,841** | |

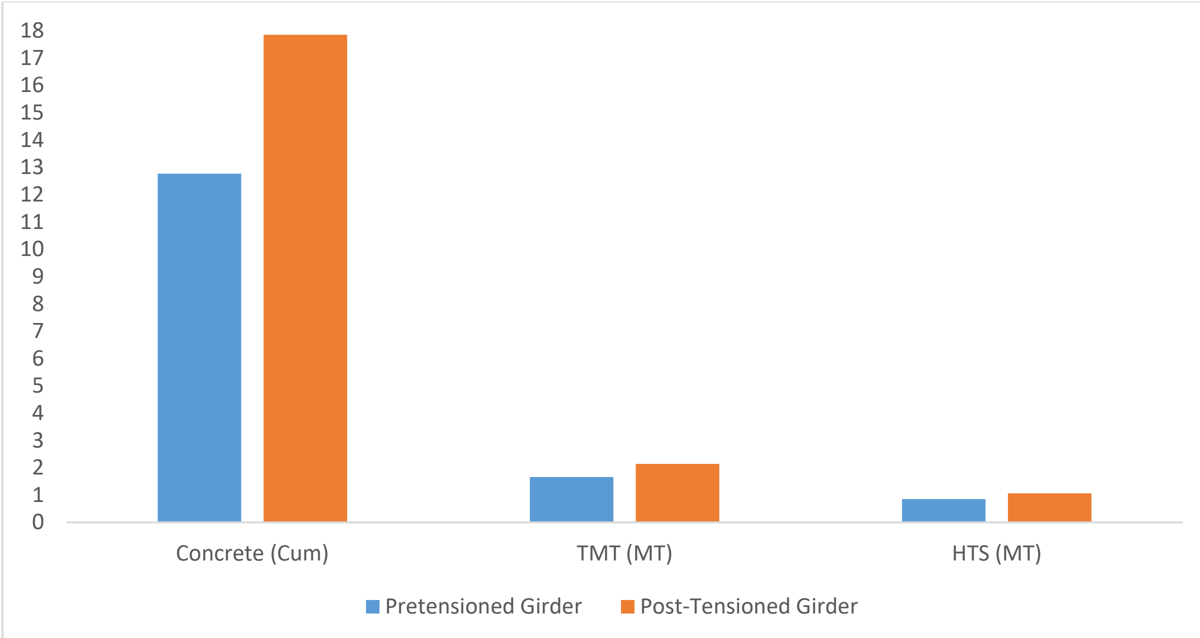



Fig 5.1 Graphical Quantity comparison of Concrete, TMT & HTS for 25 m span

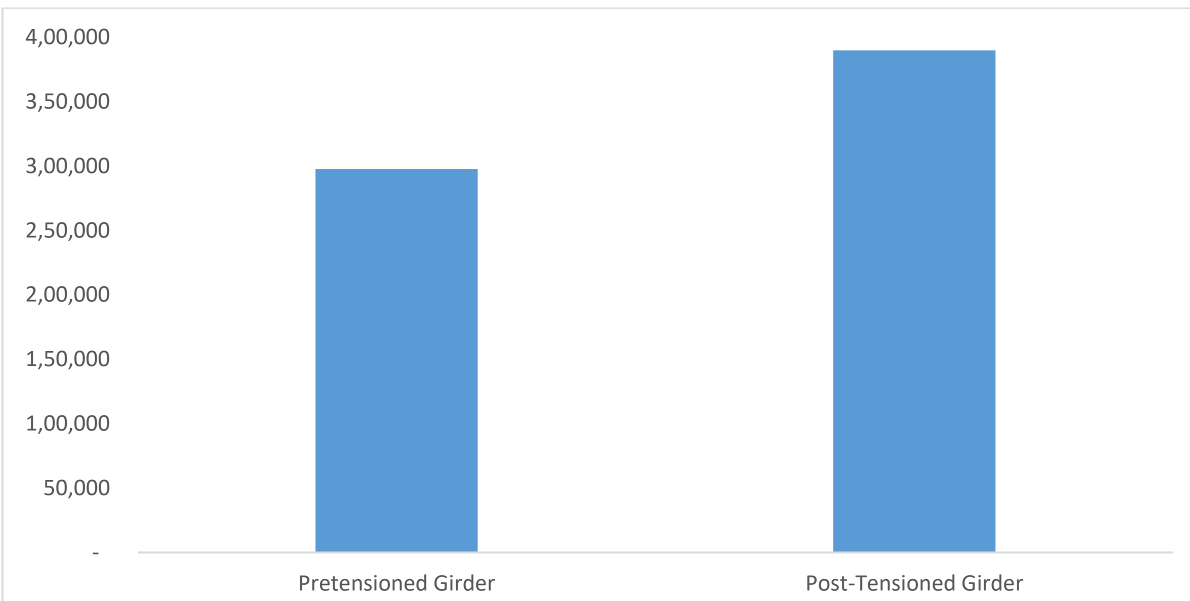



Fig 5.2 Cost comparison of Pretensioned & Post-tensioned Girder of 25 m span

### 5.3 Comparison Between Pretensioned & Post Tensioned Girder for 30 m Span

From the table 5.2, it can be noted that there are huge savings in choosing the Pretensioned Girders and the net difference in cost of 1 girder is found to be Rs 1,28,205 in addition there will be massive savings of time as well.

Cumulatively the cost of Pretensioned Girder is found to be 31% lesser than Post tensioned girder for a comparison of 1000 number of girders.

Also, in Pretensioned girder, the concrete quantity is 38.2%, TMT is 27.5% and HTS is 28.1% lesser than Post tensioned girder.

Table 5.2 Quantity & Cost comparison of Pretensioned & Post-tensioned for 30 m span

| **Sr. No.** | **Item** | **Unit** | **Pretensioned Girder** | | | **Post-Tensioned Girder** | | | **Difference in Rupees for 1 Girder** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Qty** | **Rate** | **Amount** | **Qty** | **Rate** | **Amount** | |
| **30m Span Girder** | | | | | | | | | |
| 1 | Concrete | Cum | 17.493 | 6000 | 104959 | 24.174 | 6000 | 145047 | **1,28,205** |
| 2 | TMT | MT | 2.274 | 60000 | 136447 | 2.901 | 60000 | 174056 | |
| 3 | HTS | MT | 1.230 | 110000 | 135282 | 1.576 | 110000 | 173330 | |
| 4 | HDPE Duct | Rm | | | 0 | 173.400 | 127 | 22022 | |
| 5 | Anchor Cone | EA | | | 0 | 12.000 | 720 | 8640 | |
| 6 | Bearing Plate | EA | | | 0 | 12.000 | 608 | 7296 | |
| 7 | Wedges | Pair | | | 0 | 136.000 | 50 | 6800 | |
| 8 | Casting Yard | Per Cum | 17.493 | 2109 | 36892 | | | 0 | |
| 9 | Shuttering | EA | | | | 24.174 | 190 | 4593 | |
| 10 | **Total Amount** | | | | **4,13,580** | | | **5,41,784** | |

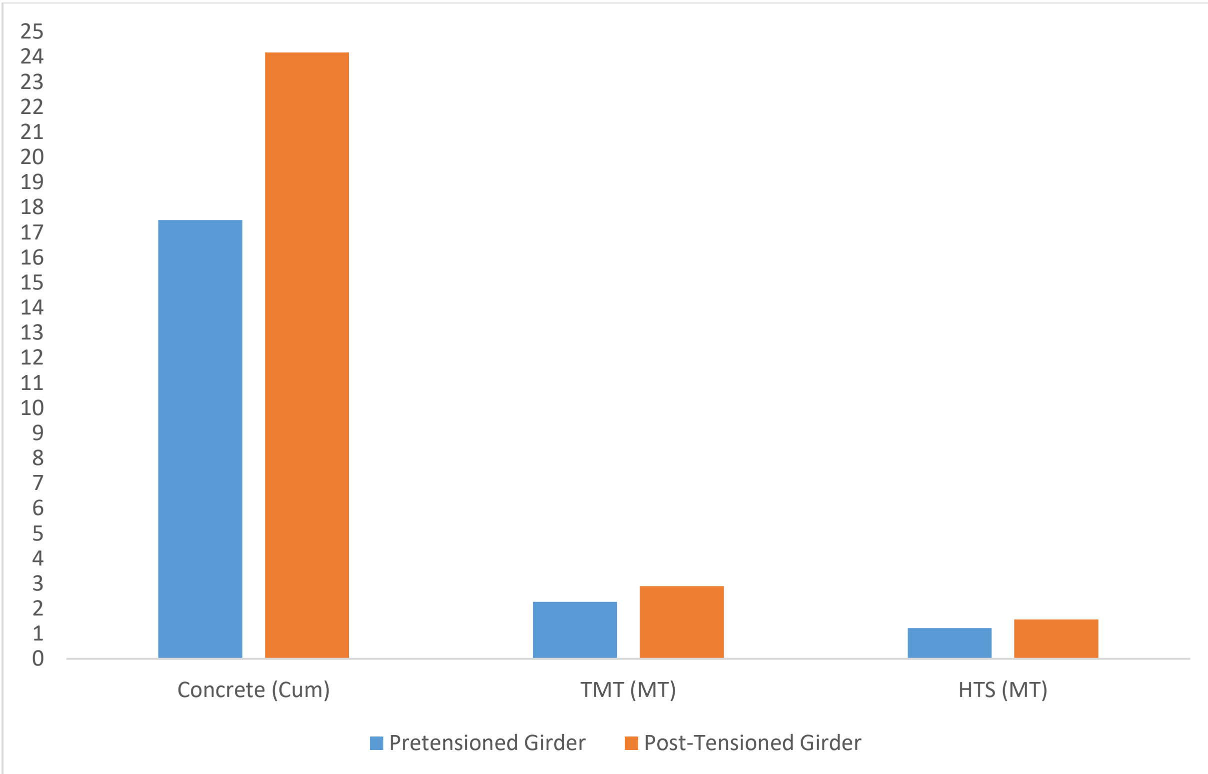



Fig 5.3 Graphical Quantity comparison of Concrete, TMT & HTS for 30 m span

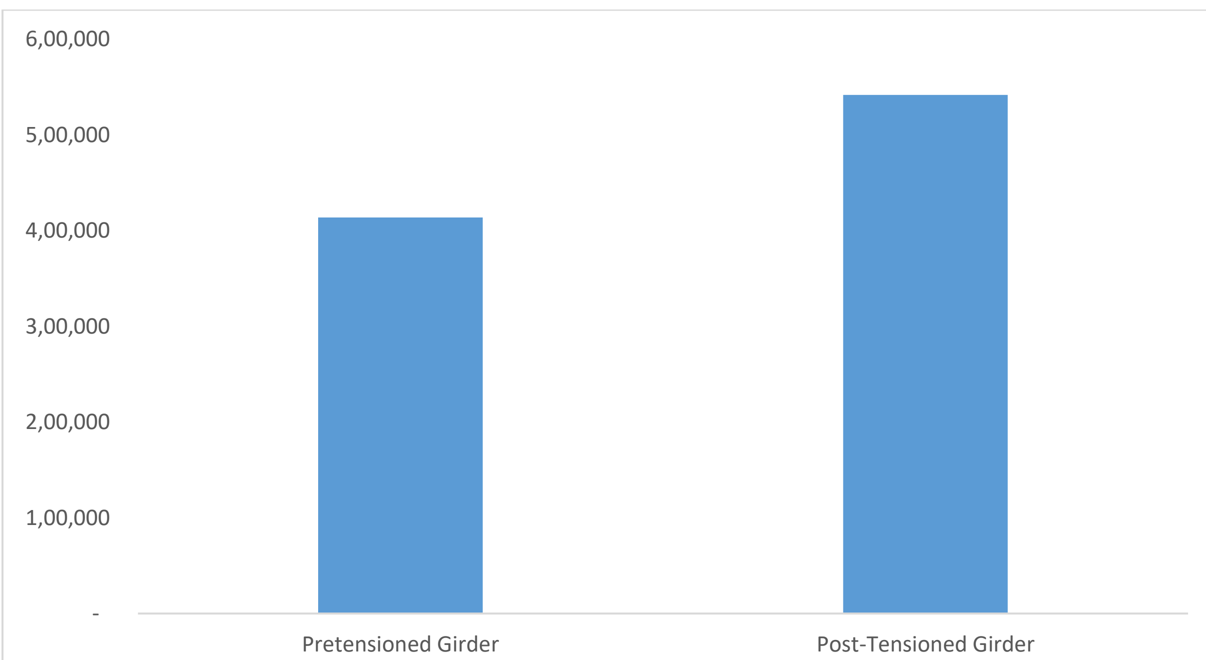



Fig 5.4 Cost comparison of Pretensioned & Post-tensioned Girder of 30 m span

### 5.4 Comparison Between Pretensioned & Post Tensioned Girder for 35m Span

From the table 5.3, it can be noted that there are huge savings in choosing the Pretensioned Girders and the net difference in cost of 1 girder is found to be Rs 1,53,457 in addition there will be massive savings of time as well.

Cumulatively the cost of Pretensioned Girder is found to be 27.3% lesser than Post tensioned girder for a comparison of 1000 number of girders.

Also, in Pretensioned girder, the concrete quantity is 40%, TMT is 29.3% and HTS is 19.3% lesser than Post tensioned girder.

Table 5.3 Quantity & Cost comparison of Pretensioned & Post-tensioned for 35 m span

| **Sr. No.** | **Item** | **Unit** | **Pretensioned Girder** | | | **Post-Tensioned Girder** | | | **Difference in Rupees for 1 Girder** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Qty** | **Rate** | **Amount** | **Qty** | **Rate** | **Amount** | |
| **35m Span Girder** | | | | | | | | | |
| 1 | Concrete | Cum | 22.790 | 6000 | 136742 | 31.938 | 6000 | 191627 | **1,53,457** |
| 2 | TMT | MT | 2.963 | 60000 | 177765 | 3.833 | 60000 | 229953 | |
| 3 | HTS | MT | 1.813 | 110000 | 199407 | 2.164 | 110000 | 238018 | |
| 4 | HDPE Duct | Rm | | | 0 | 203.400 | 127 | 25832 | |
| 5 | Anchor Cone | EA | | | 0 | 12.000 | 720 | 8640 | |
| 6 | Bearing Plate | EA | | | 0 | 12.000 | 608 | 7296 | |
| 7 | Wedges | Pair | | | 0 | 160.000 | 50 | 8000 | |
| 8 | Casting Yard | Per Cum | 22.790 | 2109 | 48064 | | | 0 | |
| 9 | Shuttering | EA | | | | 31.938 | 190 | 6068 | |
| 10 | **Total Amount** | | | | **5,61,977** | | | **7,15,434** | |

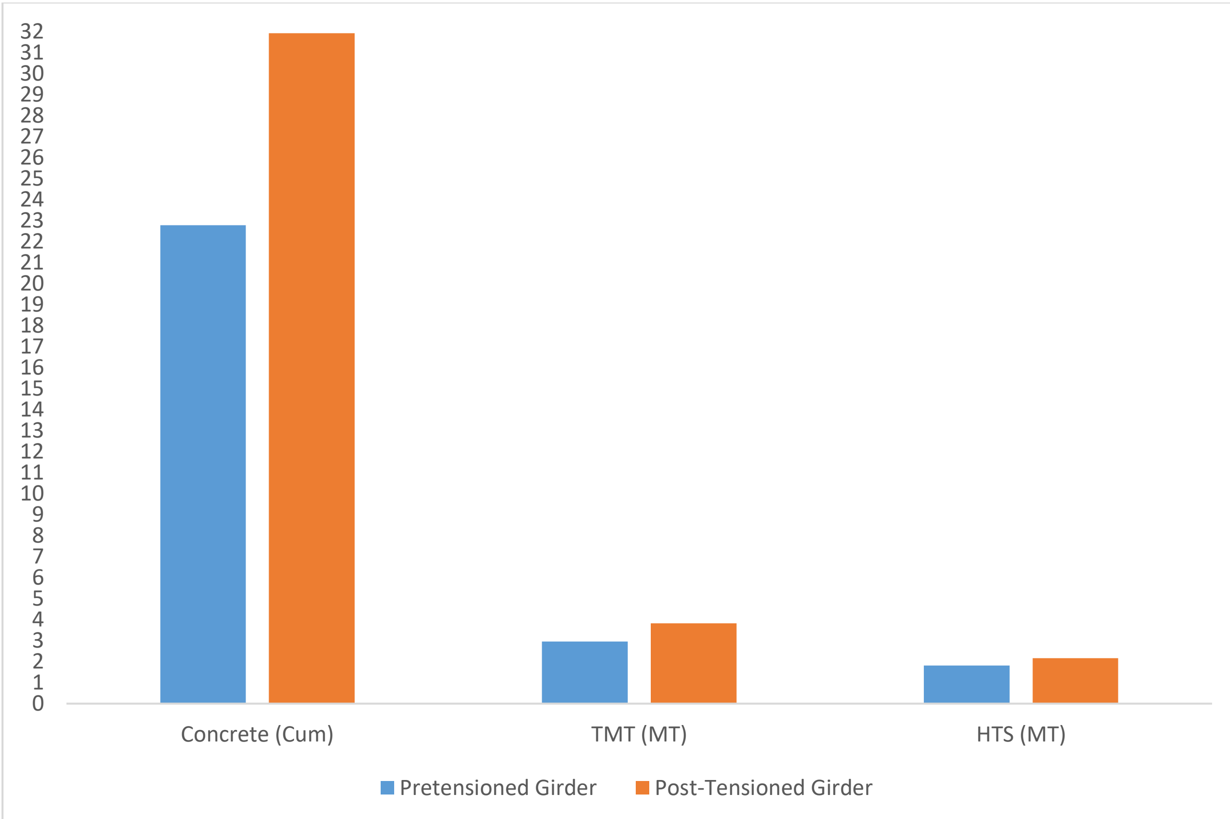



Fig 5.5 Graphical Quantity comparison of Concrete, TMT & HTS for 35 m span

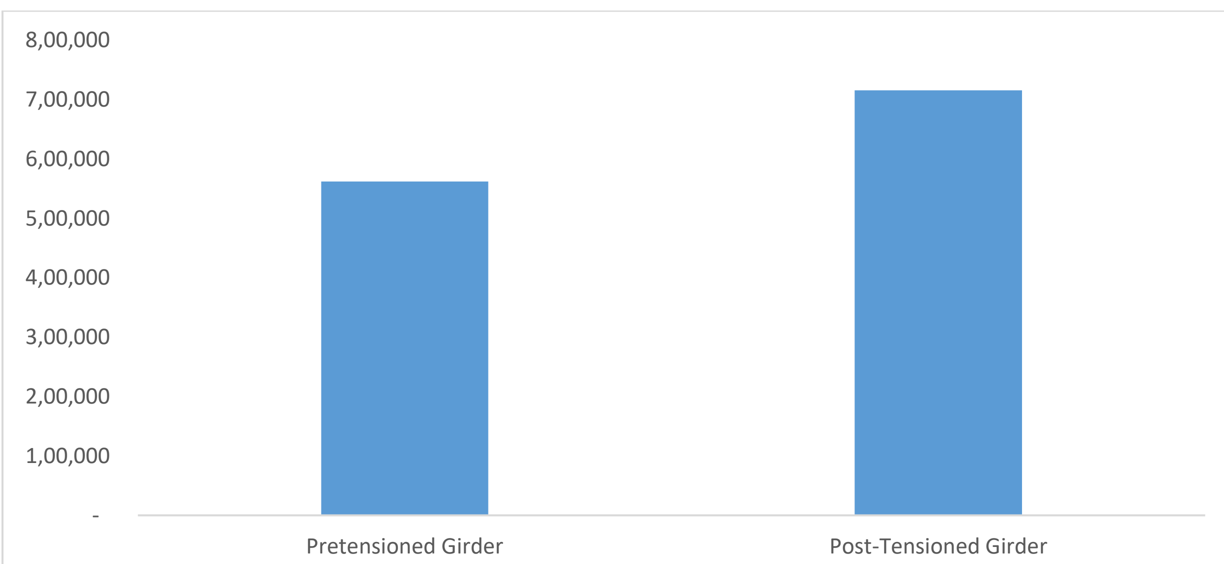



Fig 5.6 Cost comparison of Pretensioned & Post-tensioned Girder of 35 m span

## 5.5 Comparative Study Between Pretensioned & Post Tensioned Girder

A comparative study is done between Pre-Tensioned and Post Tensioned I Girders to estimate the efficacy of the structural system with respect to the span length and the number of girders required.

The span length is varied from 25 m to 35 m and the number of girders are varied from 100 to 1000 number of girders to understand the financial implications of using two types of structural systems studied.

### 5.5.1 Comparative Study for 25 m Span

Girders are varying from 100 to 1000 number of girders and accordingly the cost per girder is fluctuating in between Pretensioned & Post-tensioned girders.

From the results stated in Table 5.4, we can clearly say that when the girders are more than 250 numbers, the cost of Pretensioned girder is lesser than Post-tensioned girders.

Table 5.4 Cost comparison for 25 m span

| For 25m Span | | | | |
|---|---|---|---|---|
| **Sr. No.** | **No. of Girders** | **Pretensioned Cost for 1 no. Girder** | **Post Tensioned Cost for 1 no. Girder** | **Cost Difference in Rupees for 1 Girder (Pretensioned - Post Tensioned)** |
| 1 | 100 | 539798 | 389841 | -149956 |
| 2 | 200 | 405178 | 389841 | -15337 |
| 3 | 300 | 360305 | 389841 | 29536 |
| 4 | 400 | 337869 | 389841 | 51973 |
| 5 | 500 | 324407 | 389841 | 65435 |
| 6 | 600 | 315432 | 389841 | 74410 |
| 7 | 700 | 309022 | 389841 | 80820 |
| 8 | 800 | 304214 | 389841 | 85628 |
| 9 | 900 | 300474 | 389841 | 89367 |
| 10 | 1000 | 297483 | 389841 | 92359 |

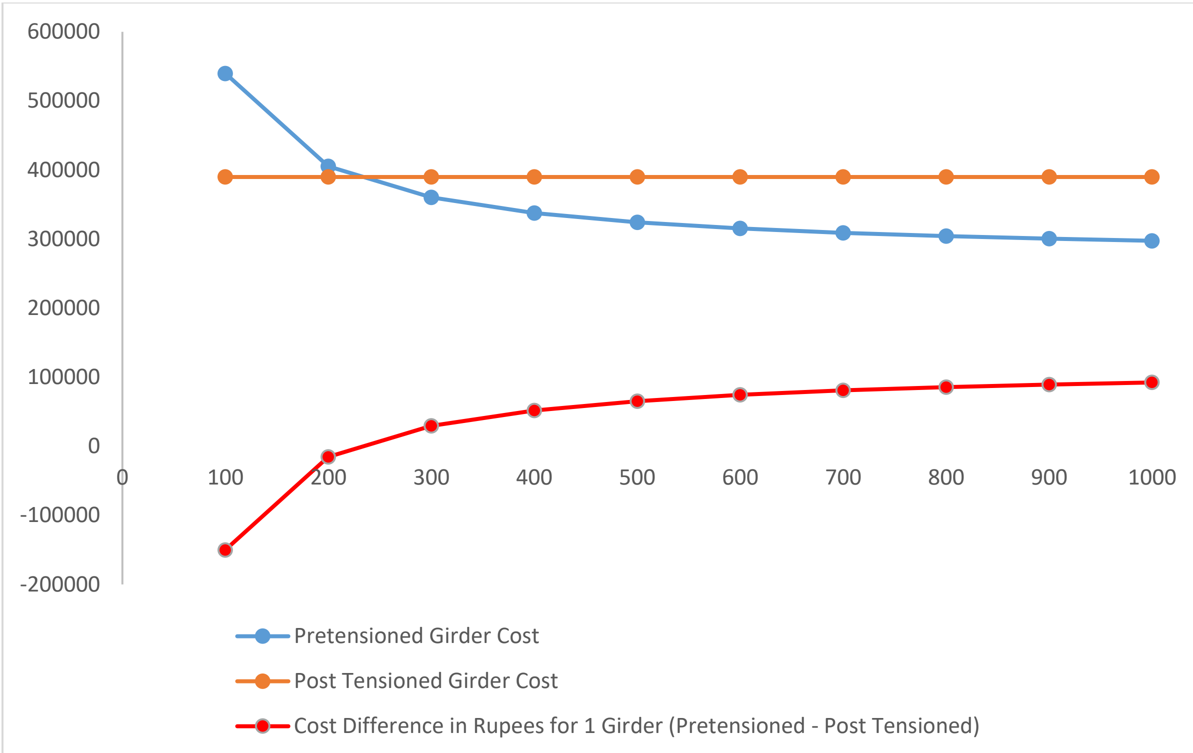



Fig 5.7 Graphical Cost comparison for 25 m span upto 1000 number of Girders

### 5.5.2 Comparative Study for 30 m Span

Girders are varying from 100 to 1000 number of girders and accordingly the cost per girder is fluctuating in between Pretensioned & Post-tensioned girders.

From the results stated in Table 5.5, we can clearly say that when the girders are more than 250 numbers, the cost of Pretensioned girder is lesser than Post-tensioned girders.

Table 5.5 Cost comparison for 30 m span

| For 30m Span | | | | |
|---|---|---|---|---|
| **Sr. No.** | **No. of Girders** | **Pretensioned Cost for 1 no. Girder** | **Post Tensioned Cost for 1 no. Girder** | **Cost Difference in Rupees for 1 Girder (Pretensioned - Post Tensioned)** |
| 1 | 100 | 745611 | 541784 | -203826 |
| 2 | 200 | 561149 | 541784 | -19365 |
| 3 | 300 | 499662 | 541784 | 42123 |
| 4 | 400 | 468918 | 541784 | 72866 |

| | | | | |
|---|---|---|---|---|
| 5 | 500 | 450472 | 541784 | 91312 |
| 6 | 600 | 438175 | 541784 | 103610 |
| 7 | 700 | 429391 | 541784 | 112394 |
| 8 | 800 | 422803 | 541784 | 118982 |
| 9 | 900 | 417679 | 541784 | 124106 |
| 10 | 1000 | 413580 | 541784 | 128205 |

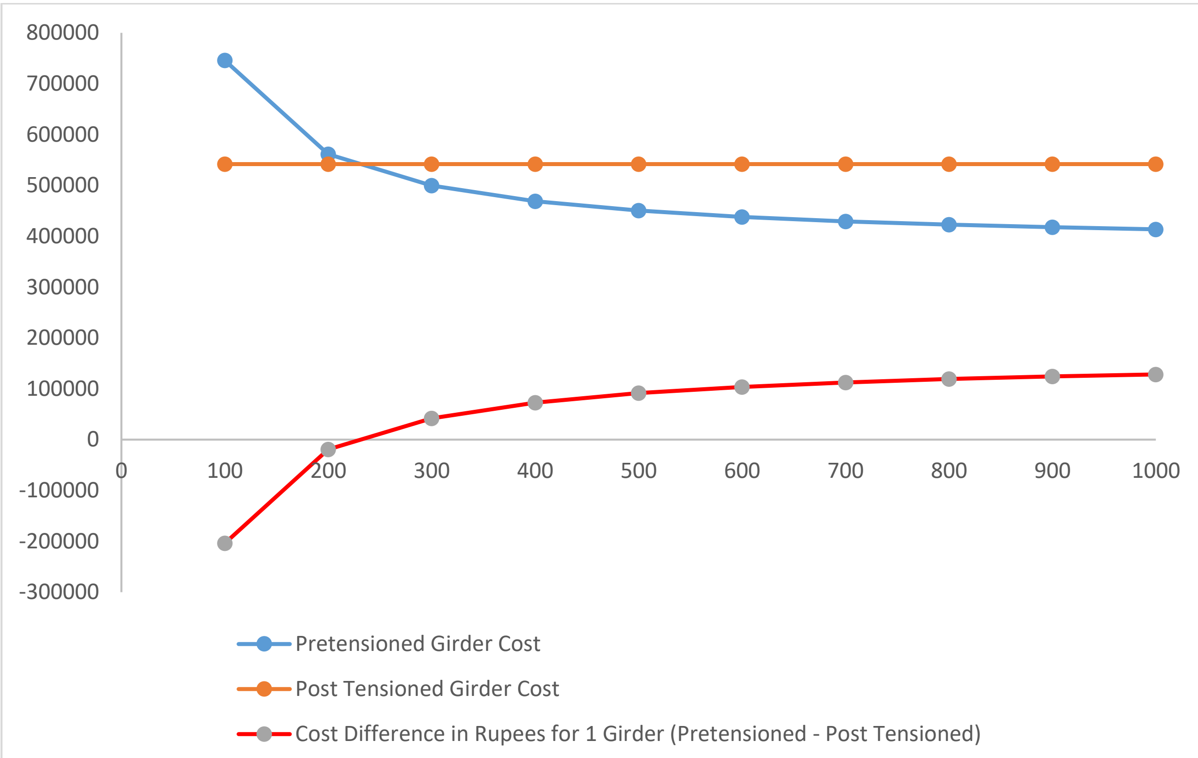



Fig 5.8 Graphical Cost comparison for 30 m span upto 1000 number of Girders

### 5.5.3 Comparative Study for 35 m Span

Girders are varying from 100 to 1000 number of girders and accordingly the cost per girder is fluctuating in between Pretensioned & Post-tensioned girders.

From the results stated in Table 5.6, we can clearly say that when the girders are more than 250 numbers, the cost of Pretensioned girder is lesser than Post-tensioned girders.

Table 5.6 Cost comparison for 35 m span

| For 35m Span | | | | |
|---|---|---|---|---|
| **Sr. No.** | **No. of Girders** | **Pretensioned Cost for 1 no. Girder** | **Post Tensioned Cost for 1 no. Girder** | **Cost Difference in Rupees for 1 Girder (Pretensioned - Post Tensioned)** |
| 1 | 100 | 994551 | 715434 | -279117 |
| 2 | 200 | 754232 | 715434 | -38798 |
| 3 | 300 | 674126 | 715434 | 41308 |
| 4 | 400 | 634073 | 715434 | 81361 |
| 5 | 500 | 610041 | 715434 | 105393 |
| 6 | 600 | 594020 | 715434 | 121414 |
| 7 | 700 | 582576 | 715434 | 132858 |
| 8 | 800 | 573993 | 715434 | 141441 |
| 9 | 900 | 567318 | 715434 | 148116 |
| 10 | 1000 | 561977 | 715434 | 153457 |

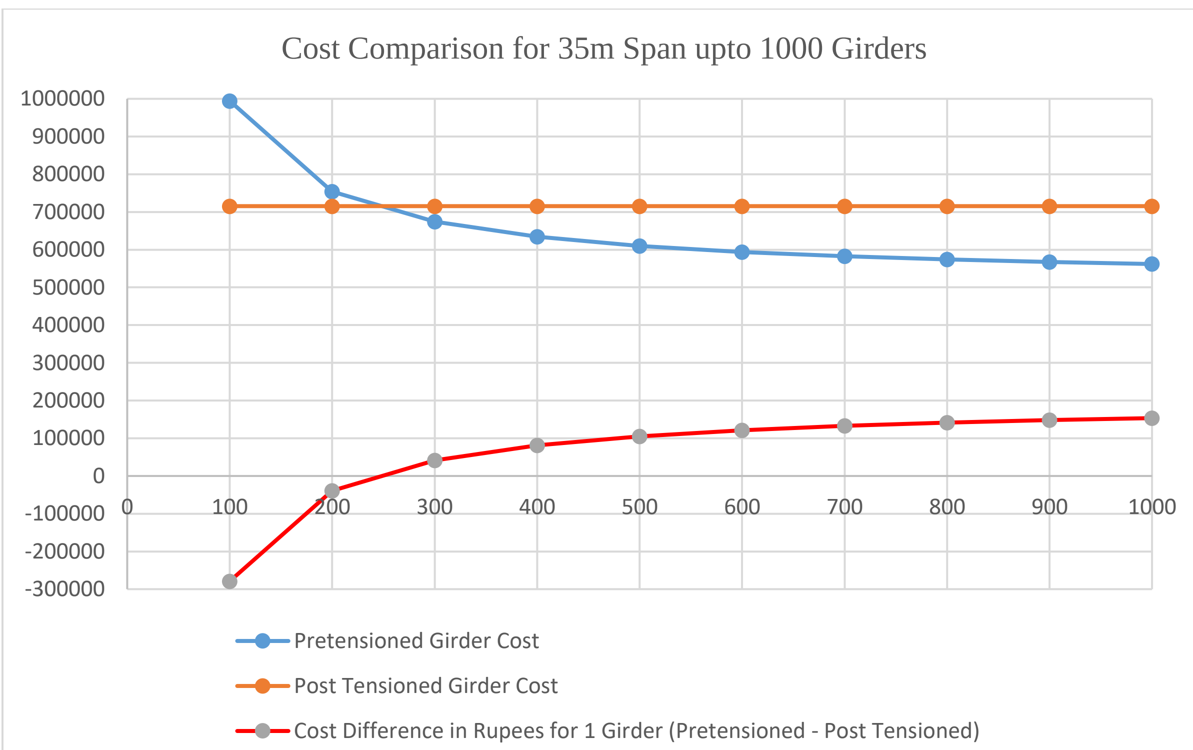



Fig 5.9 Graphical Cost comparison for 35 m span upto 1000 number of Girders

# CHAPTER 6

# CONCLUSION AND FUTURE SCOPE

## 6.1 Conclusion

A comparative study between Pre-Tensioned and Post Tensioned I Girders was done to evaluate the efficacy of the structural system with respect to the span length and the number of girders required. The span length was varied from 25 m to 35 m and the number of girders was varied from 100 to 1000 to understand the financial implications of using two types of structural systems studied.

The prime driver of the study was to evaluate which of the two structural systems could lead to more length of grade separated structures or bridges for a specified allocated infrastructure budget. The study is very significant to the current scenario as the country is developing more and more elevated, congestion free roads. The following conclusions can be drawn based on the study conducted:

Pretensioned Girders are lighter compared to the Post Tensioned Girders as the requirement of web thickness in the Post Tensioned Girders is higher due to the presence of the prestressing cable ducts.

Post Tensioned Girders offer more flexibility in construction as the post tensioned girders do not need an elaborate prestressing mechanism requirement. They can be cast at the construction site itself if the weight and length of girders pose challenge to transportation.

The prestressing and reinforcement arrangement in the Pretensioned Girders is congestion free at all locations along the girders. The reinforcement arrangement in the anchorage regions of the Post Tensioned Girders is congested.

The choice of adopting Pretensioned or Post Tensioned girders depends on the following factors:

- Number of Girders
- Distance of Casting Yard from Site

- Seismic Zone
- Time Restrictions

Based on the comparative study done, it has been found that the Pretensioned girders are very economical and time efficient primarily because more than 5-7 girders can be prestressed at the same time using the same equipment. Further, there is no requirement of anchorages, sheathing and grouting.

It has been found that Pre Tensioned Girders are more economical when compared to Post Tensioned Girders if the number of girders required in the project is more than 250.

Pre Tensioned Girders lead to lesser weight per square meter of the bridge. Thus, the Seismic Forces for the Design of Substructure and foundation are lesser leading to a cascading effect on the economy of the project.

Upon visiting several Casting yard locations around India, it has been observed that the quality control in pre tensioned girders is much more compared to the post tensioned girders leading to high durability and reliability of the structure.

## 6.2 Future Scope

The future scope of the study is as follows:

1. Design and optimization of these structures to validate the assumptions made on economic point of view.

2. Changing the depth of the PSC I girder and comparing the behavior of the structure to evaluate the effect of depth and design of the same.

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