EFFICACY STUDY OF POST-TENSIONED I GIRDER MADE OF ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE AND ORDINARY CONCRETE FOR IRC LOADING

A Thesis Submitted
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY

in
Structural Engineering

by

Ayush Satija
(2K21/STE/503)

Under the Supervision of
Dr. Ritu Raj

Assistant Professor, Department of Civil Engineering

Delhi Technological University

Department of Civil Engineering

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

May, 2024

ACKNOWLEDGEMENT

I, **AYUSH SATIJA** would like to express my deepest gratitude for the guidance, expertise and unwavering support provided by my supervisor, Dr. Ritu Raj. Their mentorship, value feedback and encouragement were instrumental in shaping the direction of this research. I am very much obliged for their detailed comments, suggestions and continuous motivation throughout the work.

I am grateful to the faculty and staff of Delhi Technological University, especially the Civil Engineering Department, for providing a conducive academic environment and necessary resources for carrying out this research. The access to the laboratory facilities and library resources has greatly facilitated the experimental work and literature review.

I would like to acknowledge my parent organization Louis Berger India Private Limited, Gurugram, Haryana, India, for allowing me to pursue postgraduate study at Delhi Technological University, Delhi.

I would also like to thank almighty as well as my friends and family for their steadfast support and understanding during this journey. Their encouragement, motivation, and unwavering belief in my capabilities have consistently bolstered me.

This thesis would not have been possible without the support, guidance, and contributions of all those mentioned above. I am truly grateful for their invaluable assistance, and their involvement has played a significant role in the successful completion of this research.

AYUSH SATIJA

2K21/STE/503

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CANDIDATE'S DECLARATION

I, **Ayush Satija, Roll No. 2K21/STE/503**, student of M. Tech (Structural Engineering), hereby certify that the work which is being presented in the thesis entitled **"Efficacy Study of Post-Tensioned I Girder Made of Ultra High Performance Fiber Reinforced Concrete and Ordinary Concrete for IRC Loading"** in partial fulfillment of the requirements for the award of the Degree of Master of Technology, submitted in the Department of **Civil Engineering**, Delhi Technological University is an authentic record of my own work carried out during the period from **January 2024 to May 2024** under the supervision of **Dr. Ritu Raj (Assistant Professor, DTU).**

The Matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Candidate's Signature

This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

Signature of Supervisor **Signature of External Examiner**

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CERTIFICATE BY THE SUPERVISOR

Certified that **Ayush Satija, (Roll No. 2K21/STE/503)** has carried out their research work in this thesis **entitled "Efficacy Study of Post-Tensioned I Girder Made of Ultra High Performance Fiber Reinforced Concrete and Ordinary Concrete for IRC Loading"** for the award of **Master of Technology** from Department of Civil Engineering, Delhi Technological University, Delhi under my supervision. The thesis embodies results of original work studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institute.

(Dr. Ritu Raj)
(Assistant Professor)
Department Of Civil Engineering
Delhi Technological University, Delhi-110042

Date:

Efficacy Study of Post-Tensioned I Girder Made of Ultra High Performance Fiber Reinforced Concrete and Ordinary Concrete for IRC Loading

Ayush Satija

ABSTRACT

In the contemporary era, there's an increased need for elevated structures to alleviate traffic congestion. Consequently, numerous viaducts, flyovers, and bridges are being erected globally. The design of bridge superstructures varies based on numerous factors, with the beam slab system, typically utilizing prestressed beams, being the most commonly employed type. Post-tensioned I-girder superstructures are rising in popularity due to their structural efficiency, enhanced stability, cost-effectiveness, ease of construction, and quicker erection.

In recent times, Ultra-high-performance fiber reinforced concrete (UHPFRC) has emerged as a groundbreaking material in the construction of bridges, revolutionizing the way we conceptualize and engineer infrastructure. This advanced concrete variant offers exceptional mechanical properties, including high compressive and tensile strength, enhanced durability. In bridge construction, the utilization of UHPFRC brings numerous benefits. Firstly, its remarkable strength-to-weight ratio allows for the design of lighter and more slender structural elements, facilitating longer spans and reduced material consumption. This not only enhances the aesthetic appeal of bridges but also minimizes environmental impact.

Despite its numerous advantages, the widespread adoption of UHPFRC in bridge construction is still evolving, primarily due to factors such as cost, availability of materials, and standardization of design guidelines. Therefore, it is necessary to assess the practicality of using ultra-high-performance fiber-reinforced concrete instead of ordinary concrete in bridges, particularly regarding economic considerations.

The objective of this research is to conduct a comparative efficacy study between post-tensioned I-girders fabricated from ultra-high-performance fiber-reinforced concrete and ordinary concrete. This assessment is based on the costs related to concrete production, prestressed steel reinforcement, shear reinforcement, interface shear reinforcement, untensioned steel reinforcement, erection, and RE panels in approaches for a standard flyover with a clearance of 5.5 meters and a total carriageway width of 16.0 meters.

Parametric modelling has been executed in MIDAS Civil to analyse and design superstructures across a range of span lengths, including 25m, 30m, 35m, 40m, and 45m. Subsequently, a comparative cost assessment between post-tensioned I-girders constructed from ordinary concrete and those fabricated from ultra-high-performance fiber-reinforced concrete has been conducted.

The analysis of prestressed concrete girders is carried out for the standard loading specifications outlined in IRC:6-2017 for road bridges, while the design of

post-tensioned girders adheres to IRC:112-2020 guidelines. In cases where relevant Indian codes for ultra-high-performance fiber-reinforced concrete are unavailable, NF P18-710 (French standard) is selectively utilized.

The research findings indicate that post-tensioned I-girders constructed from ultra-high-performance fiber-reinforced concrete become cost-effective for spans exceeding 40.0m. This is attributed to several factors, including reduced depth of UHPFRC girder, elimination of untensioned steel requirements, reduced need for shear reinforcement owing to the contribution of steel fibers to shear strength, shallower depths resulting in decreased erection costs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RCC- Reinforced cement concrete

PSC- Prestressed concrete

OC- Ordinary concrete

UHPFRC- Ultra-high-performance fiber reinforced concrete

CHAPTER 1
INTRODUCTION

1.1. General

Concrete is a fundamental building material which primarily comprises of cement, water, and aggregates such as sand and gravel. It's renowned for its versatility, durability, and strength. Thus, making it a cornerstone of modern construction. Initially, concrete appears as a workable mixture which can be molded into various shapes and forms before hardening into a robust solid. This transformation is known as hydration which occurs as the cement particles react with water and bind together to form a solid matrix.

Concrete's ability to adapt to diverse construction needs makes it versatile for use. It can be poured into molds to make foundations, walls, columns, and other structural elements. Additionally, it can be reinforced with steel bars or fibers to increase its tensile strength, enabling it to withstand bending forces. Beyond its structural capabilities, concrete offers various advantages including fire-resistance, weather-resistance and provides excellent thermal properties, contributing significantly to energy efficient buildings. However, concrete has its own limitations. It is relatively heavy, which can pose transportation challenges during construction. Additionally, its production contributes enormously to carbon emissions and makes way for more sustainable alternatives.

1.2. Types of concrete

1.2.1. Ordinary concrete

Ordinary concrete, commonly referred to as plain concrete, is the most widely used type of concrete in construction. It serves as the fundamental building material for various structures due to its versatility, ease of construction, and relatively low cost. In this document, we'll explore the composition, properties, applications, and limitations of ordinary concrete.

Composition:

- Ingredients:
  - Cement: Ordinary concrete contains Portland cement as the primary binding material. Cement reacts with water to form a paste that binds the aggregates together.
  - Aggregates: The aggregates provide bulk and strength to the concrete. Typically, these include fine aggregates (such as sand) and coarse aggregates (such as gravel).
  - Water: Water is essential for the hydration process, where cement particles react to form a solid matrix.
- Mix Proportions:

- The specific mix proportions vary based on the desired strength and workability. Generally, the water-to-cement ratio is carefully controlled to achieve optimal performance.

Properties:

- Strength:
  - Ordinary concrete exhibits moderate compressive strength. The typical range for compressive strength is between 20 MPa and 60 MPa depending on the mix design.
  - However, it is weak in tension due to its lack of reinforcement.
- Durability:
  - Ordinary concrete can withstand weathering, but its durability depends on factors such as curing, exposure conditions, and quality of materials.
  - It may develop cracks under heavy loads or temperature fluctuations.
- Workability:
  - The workability of ordinary concrete allows it to be easily molded into various shapes during construction.
  - Proper compaction ensures good bonding between aggregates and cement paste.
- Weight:
  - The unit weight of ordinary concrete ranges from approximately 2,400 kg/m^3 to 2,800 kg/m^3.
  - It is considered "normal weight" because of this typical density.

Applications:

- Foundations: Ordinary concrete forms the base for most structures, including residential, commercial, and industrial buildings.
- Slabs and Floors: It is commonly used for floor slabs, pavements, and sidewalks.
- Columns and Beams: Ordinary concrete provides support for vertical and horizontal elements.
- Retaining Walls: It is suitable for retaining walls and other non-structural components.

Limitations:

- Tensile Strength:
  - Ordinary concrete lacks tensile strength, making it prone to cracking under tension.
  - Reinforcement (such as steel bars) is often added to improve tensile behavior.
- Durability in Aggressive Environments:

- In harsh conditions (e.g., exposure to chemicals, seawater, or freeze-thaw cycles), ordinary concrete may deteriorate.
- Specialized concrete mixtures are preferred for such environments.

1.2.2. Reinforced concrete

Reinforced concrete is a composite material consisting of concrete composed of cement, coarse aggregates, fine aggregates, water, and additives, reinforced with embedded steel bars. This combination increases the structural integrity of concrete by providing tensile strength, which concrete inherently lacks. The steel reinforcement, commonly referred to as rebar, helps in withstanding tensile stresses induced by external loads, preventing the concrete from cracking or failing under tension. Reinforced concrete is widely used in construction for various structural elements such as beams, columns, walls, slabs, and foundations due to its versatility, durability, and cost-effectiveness. [1]

Composition:

- Concrete:
  - Concrete serves as the base material, providing compressive strength and durability.
  - It is a mixture of cement, aggregates (such as sand and gravel), and water.
- Reinforcement:
  - The reinforcement compensates for concrete's weakness in tension.
  - Typically, steel bars (rebar) or mesh are embedded within the concrete.
  - These reinforcement elements have higher tensile strength, enhancing the overall performance of the material.

Properties and Advantages:

- Strength:
  - The combination of concrete and reinforcement result in a material that can withstand compressive and tensile forces effectively.
  - Reinforced concrete structures can handle heavy loads, making them suitable for buildings, bridges, and other infrastructures.
- Durability:
  - Properly designed reinforced concrete structures exhibit excellent durability.
  - The alkalinity of concrete protects the steel rebar from corrosion, ensuring long-lasting performance.
- Versatility:
  - Reinforced concrete can be molded into various shapes, allowing architects and engineers to create innovative designs.
  - It can be used in everything from skyscrapers to dams to bridges.

1.2.3. Ultra-High Performance Fiber Reinforced Concrete (UHPFRC)

Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) is an advanced construction material that combines a high-strength cementitious matrix with a dense and uniform distribution of fibers.

Composition:

- Cementitious Matrix:
  - UHPFRC contains a high amount of cement, which acts as the primary binder.
  - Silica fume (SF) is often included to enhance the matrix properties.
  - The low water-to-binder (W/B) ratio (typically between 0.15 and 0.25) ensures minimal porosity and optimal strength.

- Steel Fibers:
  - Short steel fibers are uniformly distributed throughout the UHPFRC.
  - These fibers significantly enhance tensile strength, ductility, and crack resistance.
  - The volume fraction of fibers exceeds 2% by volume, contributing to the material's exceptional performance.

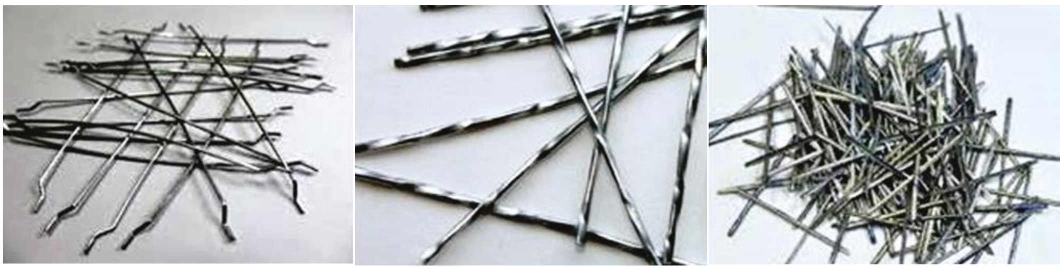

Figure 1. 1 Steel fibres – Hooked end, twisted and straight [2]

- Fine Aggregates:
  - Crushed quartz or other ultra-fine aggregates are used to create a dense matrix.
  - The particle size distribution is carefully controlled to improve packing efficiency.

- Admixtures:
  - Superplasticizers (SP) are essential additives that reduce water content while maintaining workability.
  - Other admixtures may be included to enhance specific properties.

Properties:

- Strength:
  - UHPFRC exhibits remarkable compressive strength, often exceeding 150 MPa (28-day strength).
  - Its tensile strength reaches up to 6 MPa, far superior to normal concrete.

- Durability:

  - UHPFRC offers exceptional durability due to its low porosity and dense microstructure.
  - It withstands aggressive environments, chemical exposure, and freeze-thaw cycles.

Applications:

- UHPFRC is ideal for high-strength, durable bridge components.
- Piers used in marine structures for enhanced resistance to wave action.
- Its toughness makes it suitable for protective structures against blast action.
- UHPFRC allows for slender and lightweight precast components.
- Provides long-lasting performance in tunnels and subway systems.

Figure 1. 2 Constructed ultra-high-performance fiber reinforced concrete girder [3]

Challenges and Opportunities:

- Cost:

  - UHPFRC production involves specialized materials and precise mix design, leading to higher initial costs.
  - However, its long-term benefits justify the investment.

- Design Standards:
  - Comprehensive design standards specific to UHPFRC are still evolving.
  - Researchers and practitioners continue to refine guidelines for optimal performance.
- Complex Mix Design:
  - Achieving the right balance of ingredients requires expertise.
  - Uniformly mixing the steel fibers to achieve a homogenous mixture is critical operation.
  - Proper casting, curing, and handling is critical for consistent results.

1.2.4. Advantages of UHPFRC over ordinary concrete

- Significant Cost Saving due to lighter and thin sections
- Span up to 100m, thus reduce foundation cost significantly cheaper & better solution against steel structures
- Attains early strength which can help reuse of staging and shuttering faster in comparison to normal concrete
- Extremely Durable due to ultra-denseness of concrete
- Easier Handling & Transport (Lower Tonnage Crane Required)
- Doesn’t shrink and minimal creep
- Shortened Construction Period. (more than 20%)

1.3. Notion of prestressing

Concrete exhibits strength when compressed but when subjected to tension it becomes weak. However, the employment of prestressing ensures its ability to withstand tensile & compressive stresses under range of external loading conditions. Prestressed concrete involves intentionally inducing internal stresses within the concrete structure without any external loads. These internal stresses are strategically placed to counteract the stresses arising from external loads during service conditions. By doing so, prestressed concrete significantly improves its behavior and load-carrying capacity.

This technique improves the structure's strength, longevity, and quality while also being very cost-effective. Prestressing is a technique of mitigating tensile stress in portions of reinforced concrete members by introducing compressive stresses, typically by the use of steel wires or strands, until the tensile stress becomes lower than the tensile strength of concrete preventing any concrete cracks as a result. Thus, one may classify concrete as an elastic material. Because prestretched concrete can withstand the effects of continuous loading without suffering major damage, it possesses a high degree of elasticity. Prestressed concrete is recommended for dynamically loaded structures because it has a better fatigue strength than other known building materials and because prestressed steel has a modest stress fluctuation.

To understand prestressing, let's consider an analogy with an old-era barrel used to transport liquids and food grains. The barrel is tightly wrapped by metal bands, creating hoop compression around it. When this barrel is filled with any liquid, it exerts hoop tension on its entire surface. The hoop compression from the metal bands helps in counteracting the hoop tension exerted by the liquid within. This arrangement is akin to prestressing. Similarly, in concrete structures, internal compressive stresses are induced using tensioned steel bars (tendons) before the structure experiences any external loads. There have been numerous significant advancements in PSC over last 2 decades, mainly due to following reasons:

- High strength concrete and steel wires are readily available.
- Development of sophisticated construction procedures.
- Improved efficiency in designing structural concrete mixes.
- Innovative post tensioning technologies.
- Yield strength of steel bars has evolved and increased from around 415 MPa to 600 MPa over last three decades.
- Concrete quality has improved in performance and strength throughout time. High performance and high strength concretes are now available, with design strengths up to M150.
- Prestressing steel is available in 7-wire strand with a tensile strength of 1860 MPa. In the near future, 7-wire strands will have 2160 MPa strength.
- Galvanized strands are highly durable.
- PSC bridges can now stretch 250m-300m, which was previously impossible
- Rising useage of external prestressing in bridges.

These internal stresses counteract external forces, enhancing the concrete's performance. The concept can be summarized as follows:

- Application of Initial Force:
  - Prestressing involves applying an initial force to the concrete structure.
  - This force is intentionally induced to prepare the concrete for the stresses it will encounter during its lifetime.
- Counteracting External Loads:
  - The induced internal stresses counteract the tensile stresses that would otherwise develop under external loads.
  - By doing so, prestressed concrete becomes capable of withstanding greater loads and resisting deformation more effectively than traditional concrete.

Requirement of Prestressing Concrete:

- Weakness in Tension:
  - Concrete being strong in compression exhibits weakness in tension.
  - Tensile stresses in concrete leads to early flexural cracks, particularly in flexural members like beams and slabs.
- Minimizing Flexural Cracks:
  - To overcome this weakness, prestressing intentionally induces compressive stress in the concrete.
  - The pre-compression helps in increasing the bending capacity, shear strength, and torsional strength of the flexural members.
  - As a result, flexural cracks in members are significantly reduced.

Advantages of Prestressed Concrete:

- Improved Structural Efficiency:
  - Prestressed concrete allows for longer spans and thinner sections, reducing the overall material usage.
  - It enhances the structural efficiency of bridges, buildings, and other infrastructure.
- Increased Durability:
  - The pre-compression minimizes cracking and improves the concrete's resistance to environmental factors.
- Reduced Maintenance:
  - Structures built with prestressed concrete require less maintenance over their lifespan.

Disadvantages of Prestressed Concrete:

- Higher Construction Costs:
  - The specialized design, materials, and installation increase initial costs.
  - However, long-term benefits often justify the investment.
- Risk of Corrosion:
  - Tendons may be susceptible to corrosion over time, affecting the prestressing force.

1.3.1. Methods of prestressing:

Compressive stresses in concrete are induced either by doing pre-tensioning or post-tensioning the steel reinforcement.

I. Pre-tensioning:

Concrete, though exhibits strength in compression, exhibits weakness when subjected to tension. For addressing this, it needs support in resisting tension caused by external forces from applied loading which results in cracks and ultimately causes failure. During service, bending tensile stresses can be countered by introduction of prestressing. In pre-tensioning, tendons or cables, are pulled (put into tension) through the concrete formwork prior to pouring of concrete. Once the concrete has hardened and attains desirable strength, the tendons are released. Tendons tend to get shorten and transfer the stored strain energy to the concrete through the bond action acting between concrete and tendons. Compressive stresses are thus introduced into the concrete.

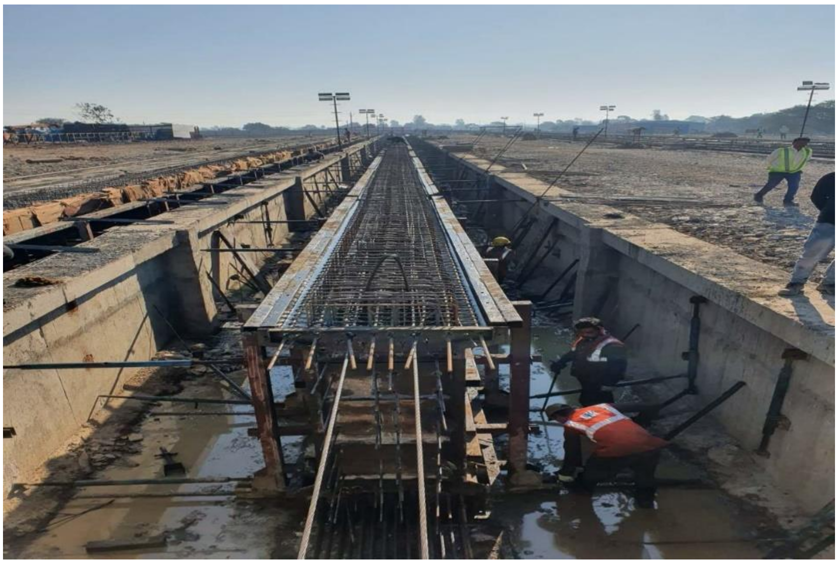

Figure 1. 3 Construction of I Girder by Pretensioning

Fig 1.3 & 1.4 shows casting bed, reinforcement cage and casting of pretensioned I Girder and Fig 1.5 & 1.6 shows multi pull jacks and anchor block wall from where prestressing will be done to stress the tendons.

Figure 1. 4 Preparation of reinforcement cage for pretensioned I girder

Figure 1. 5 Multi pull jacks and anchor block wall for pretensioned I girder

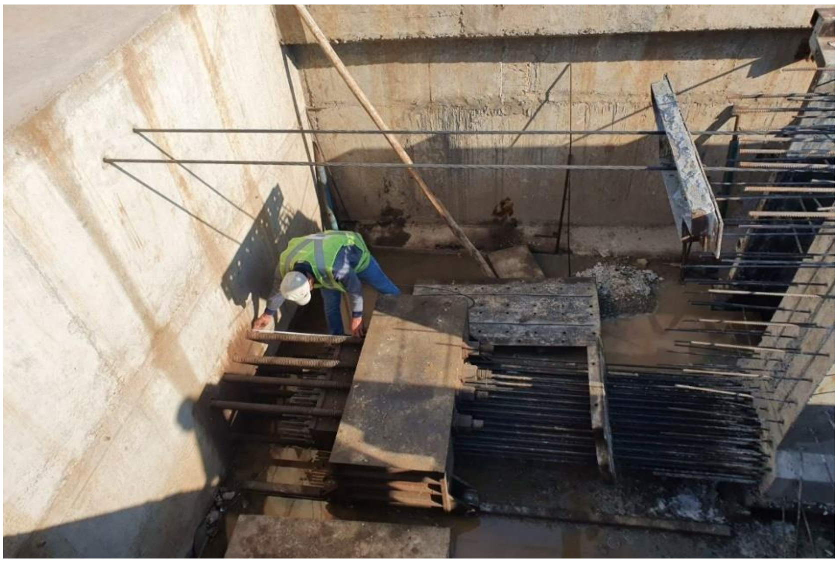

Figure 1. 6 Anchor Block Wall for pretensioned Girder

Stages involved in Pre-Tensioning Method:

- Stage 1: Reinforcement and tendons are aligned in the structural mould.
- Stage 2: Tendons are pulled to about 78% of their ultimate tensile strength (UTS).
- Stage 3: Concrete is then poured into the structural moulds and is cured for attaining the required initial strength.
- Stage 4: The jacking force is then released & the tendons are fixed by themselves into the concrete once the curing of concrete is done.

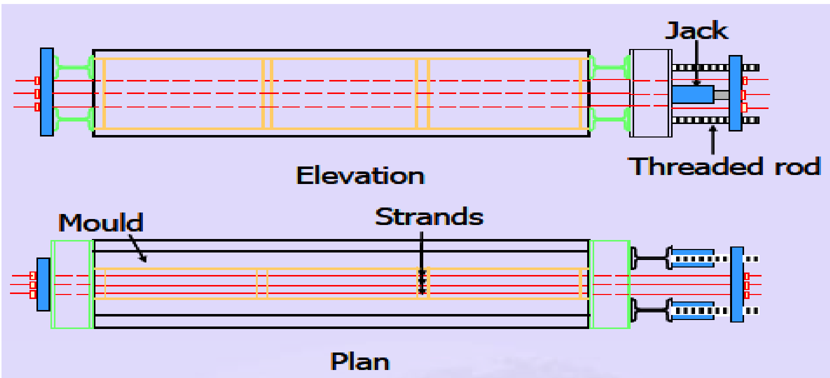

Figure 1. 7 Cable profile of I girder prior to casting of concrete [4]

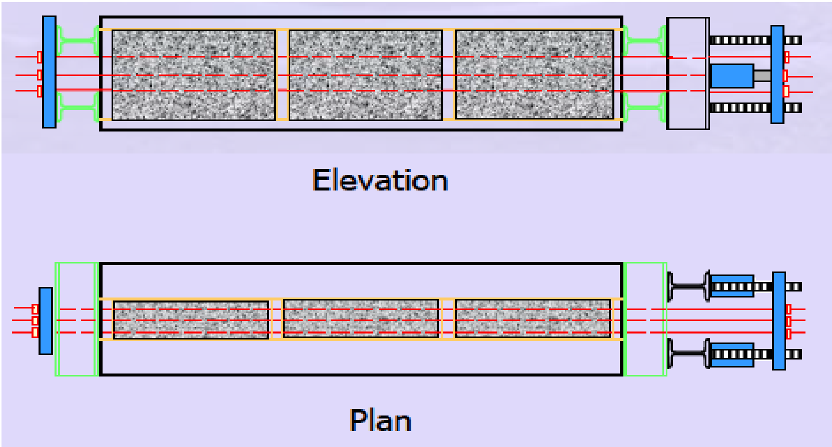

Figure 1. 8 Cable profile of I girder post casting of concrete [4]

II. Post-Tensioning:

In post-tensioning, concrete is initially cast around ducts that house the reinforcing tendon. Once the concrete has reached the desired strength, the tendons are threaded through the ducts and stressed (tensioned).

This is accomplished by jacking the tendons at one or both ends with hydraulic jacks. The second end, or both ends, are then anchored, and the jacks are removed. The tendons tend to shorten, delivering the stored energy in them to concrete as compressive force via the bearing action, causing compression in concrete.

The ducts are then filled with cement grout to protect the tendons from corrosion and facilitate the transfer of prestressing forces into the concrete. Post-tensioning can also be accomplished by attaching external tendons to the concrete section in a suitable location to impart compressive force. This post-tensioning method provides access to the tendons for examination and maintenance.

Figure 1. 9 Preparation of reinforcement cage for post-tensioned I girder

Figure 1. 10 Constructed post-tensioned I girder

Stages involved in Post-Tensioning Method:

- Stage 1 - In the structural mould, reinforcement and cable ducts are suitably placed as per the desired cable profile.
- Stage 2 – Concrete is then poured into the structural mould and is cured to attain the required initial strength.
- Stage 3 - Tendons are threaded into the ducts and stressed to approximately 78% of their ultimate tensile strength (UTS).
- Stage 4 - Jacking force acting on the tendons is then removed by placing wedges into the anchorages. To protect the tendons from corrosion, cement grout is pumped into the ducts.

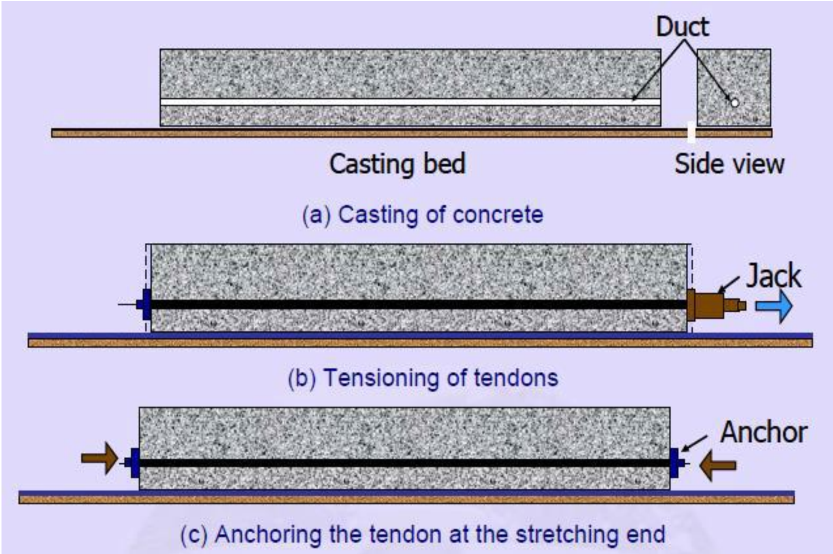

Figure 1. 11 Stages involved in post-tensioning [4]

Fig 1.11 illustrates the various stages involved in post-tensioning technique, starting with casting of concrete and progressing through the stressing of tendons to the wedges being locked into the end anchorages.

1.3.2. Prestress Losses

Prestress losses are categorised into following types:

1. Immediate losses
2. Time-dependent losses

The immediate losses occur once the tendons are prestressed, and prestress is just transferred to the member. The time-dependent losses occur over the service life of prestressed member.

The friction losses occur due to the friction acting at the interface of tendon and concrete, anchorage slip and elastic shortening in the member are basically categorised as the immediate losses and the losses resulting due to creep and shrinkage of concrete and relaxation of steel are termed as the time dependent losses. [5]

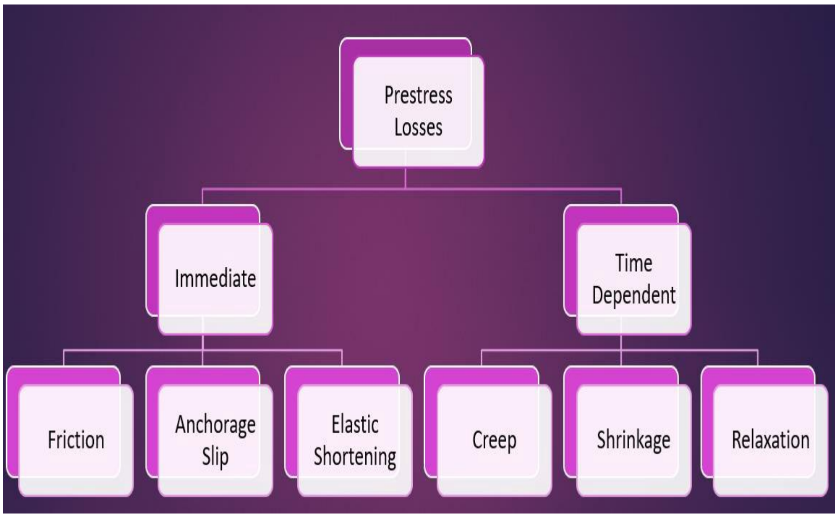

Figure 1. 12 Types of prestress losses

1.3.3. Advantages of prestressing in concrete

- Prestressed concrete members are much lighter as compared to RCC members.
- In PSC, member remains uncracked under the applied service loads.
- Reduced corrosion of reinforcing steel leads to increased durability.
- PSC member takes full advantage of the concrete and steel strength.
- Shallower section depth raises the span-to-depth ratio.
- Uncracked section has higher stiffness and shear resistance.
- Prestressing allows for longer spans, making it a more sustainable and cost-effective solution.
- Faster construction, improved control over quality and cheaper maintenance expenses.
- Suitable for repetitive construction.
- Slender sections enhance aesthetic appeal.

1.3.4. Limitations of prestressing

- High tensile strength materials are expensive.
- Mandatory need of control over quality and strict inspection.
- Expenses of auxiliary equipment involved is quite high.
- Prestressing requires highly skilled manpower and technology. Thus, it is not used as largely as reinforced concrete.

1.4. Significance of the study

Post-tensioned I-girder superstructures are gaining popularity due to their structural efficiency, improved stability, cost-effectiveness, ease of construction, and faster erection times.

Ultra-high-performance fiber reinforced concrete boasts exceptional mechanical properties, including high compressive and tensile strength, and enhanced durability. Its remarkable strength-to-weight ratio allows for the design of lighter and more slender structural elements in bridge construction, enabling longer spans and reduced material consumption. This not only enhances the aesthetic appeal of bridges but also minimizes their environmental impact.

However, despite its numerous advantages, the widespread adoption of UHPFRC in bridge construction is still evolving, mainly due to factors such as cost, material availability, and the standardization of design guidelines.

Therefore, it is imperative to evaluate the feasibility of using ultra-high-performance fiber-reinforced concrete instead of ordinary concrete in bridge superstructures, especially concerning economic considerations.

1.5. Objective of the study

The objective of this research is to conduct a comparative efficacy study between post-tensioned I-girders fabricated from ultra-high-performance fiber-reinforced concrete and ordinary concrete. The primary objectives of this research are as follows:

- To analyse the post tensioned I girder type superstructure for a standard flyover with total carriageway of 16.0 meters across a range of span lengths, including 25m, 30m, 35m, 40m, and 45m adhering to the standard loading specifications outlined in IRC:6-2017 for road bridges.
- To develop the design of post-tensioned I girders in accordance with the specifications provided in IRC:112-2020, and to incorporate NF P18-710 and NF P18-470 (French standards) selectively if Indian codes pertaining to ultra-high-performance fiber-reinforced concrete are not applicable.
- To conduct cost analysis comparing post tensioned I girders constructed from ordinary concrete and ultra-high performance fibre reinforced concrete across various spans considering the following factors-
    - Manufacturing of concrete
    - erection
    - prestressing cable
    - un-tensioned reinforcement
    - vertical shear reinforcement

- interface shear reinforcement

1.6. Outline of the thesis

This M. Tech dissertation comprises five chapters, each delving into a specific aspect of the research topic.

Chapter 1: Introduction

The inaugural chapter of this M. Tech dissertation presents an overview of plain concrete, reinforced concrete, ultra-high-performance fiber-reinforced concrete, and prestressing, elucidating their significance in the realm of construction. It delineates the research objectives and underscores the necessity for a comprehensive efficacy assessment comparing post-tensioned I-girders constructed from ultra-high-performance fiber-reinforced concrete with those made from ordinary concrete.

Chapter 2: Literature Review

The succeeding chapter of the thesis conducts an in-depth examination of prior studies concerning the application of UHPFRC in infrastructure industry, their design, the effectiveness of post-tensioned I-girders in bridges, and the various codes for loading specifications and design for prestressed road bridges.

Chapter 3: Methodology

This chapter focuses on the methodology used to design post-tensioned I girders made from ordinary concrete and UHPFRC, including the calculation of concrete and reinforcement quantities. Ultimately, it compares the economic aspects of the two types of girders.

Chapter 4: Results and Analysis

This chapter presents the results in a structured format, facilitating straightforward assessment of the outcomes for post-tensioned I girders constructed from ordinary concrete and UHPFRC across spans ranging from 25.0m to 45.0m. This allows for a distinct comparison between the two types of girders based on span length.

Chapter 5: Conclusion, Future Scope and Social Impact

The final chapter of the thesis provides an in-depth exploration of the research findings, offering conclusions drawn from the analysis. Additionally, it offers recommendations for future scope of research within the field. Moreover, the chapter delves into the practical implications of the thesis work, aiming to benefit the society.

CHAPTER 2
LITERATURE REVIEW

2.1. General

A literature review is a crucial part of any research project, as it provides a comprehensive overview of the existing knowledge on a particular topic. The purpose of this literature review is to identify current advances in the field of ultra-high-performance fiber-reinforced concrete (UHPFRC) and its application in bridge engineering, as well as to highlight the research gaps this study aims to address.

To achieve this goal, a thorough review of the literature has been conducted, covering a wide range of topics related to post-tensioned girders and UHPFRC. The review also examines the codal provisions stated in IRC:6-2017 and IRC:112-2020 regarding standard loading specifications and the design of post-tensioned concrete girders for bridges, respectively. Additionally, it includes guidelines from NF P18-470 and NF P18-710 (French standards) on the material properties and design of UHPFRC members, areas where Indian codes are currently silent.

Despite its numerous advantages, the widespread adoption of UHPFRC in bridge construction is still evolving, mainly due to factors such as cost, material availability, and the standardization of design guidelines.

The aim of this thesis is to evaluate the feasibility of using UHPFRC over ordinary concrete in bridge superstructures, particularly with regard to economic considerations.

This literature review chapter provides a detailed overview of existing research on ordinary concrete, UHPFRC, and their applications in bridge superstructures. The literature is systematically reviewed, and the methodologies and findings of each study are evaluated. This allows for the identification of any gaps or inconsistencies in the existing research and provides a deeper understanding of the factors that influence the feasibility of using different types of concrete in the construction of post-tensioned girder superstructures

2.2. Provisions from code

IRC:6-2017 also known as the Indian Roads Congress Standard Specification and Code of Practice for Road Bridges [6] outlines the various standards and guidelines for loads and load combinations applicable for the road bridges in India.

IRC:112-2020 refers to Indian Roads Congress Code of Practice for Concrete Road Bridges [7] delineates the design criteria for reinforced concrete and prestressed concrete applicable for road bridges in India as per the Limit State Method (LSM).

NF P18-470 2016 is a French Standard that specifies the requirements for ultra-high-performance fiber reinforced concrete mixtures used in structural elements such as bridges, roads, and buildings. It outlines the composition, properties, and testing methods for UHPFRC as well as its material constituents to ensure their quality and durability in construction projects.

NF P18-710 2016 is a French Standard that specifies the design rules for reinforced and prestressed structures specific to UHPFRC. It is a national complement to Eurocode 2 “Design of concrete structures” [8] and gives requirements in terms of resistance, serviceability, durability and fire resistance for concrete structures.

2.3. Research studies

S. Abdal et. al. (2023) have investigated Ultra-high-performance concrete (UHPC) as a form of cementitious composite that has been the most innovative product in concrete technology over the last three decades [9]. Ultra-high-performance concrete has been widely used in various construction designs due to its exceptional mechanical properties and durability. Research on its behavior has significantly increased in recent decades. The authors found that despite its high costs limiting the use of ultra-high-performance concrete in bridge engineering, little is known about its application in various bridge engineering elements. The goal of their study was to review the applications of state-of-the-art UHPFRC in bridge engineering as deeper understanding of UHPFRC will contribute to increase its market share in both national and global infrastructure sectors.

Luca Markus and Paul Gauvreau (2020) presented the findings of a study on the efficiency of post-tensioned bridges, marking the first step in providing designers with a simple and sensible basis for evaluating bridge design approaches. The approach begins by outlining the key properties of simply supported multiple-T bridge systems. Designs were created within a specific parameter range and computer-evaluated against applicable safety and serviceability requirements. This resulted in the identification of a selection of valid examples with the lowest reference depth (defined as the cross-sectional area to deck width ratio). Reference depth was chosen as the primary metric of efficiency since it measures the volume of concrete regardless of span or breadth. According to the study, cross sections with three webs reduce reference depth. For each span length, the efficient span-to-depth ratio values were well-defined and constrained. The authors discovered that decreasing reference depth does not need a considerable amount of prestressing steel [10]. The authors' findings were well compared to current industrial standards, with the created efficient cases beating the majority of the examples obtained in terms of reference depth, concrete volume, and prestressing amount. Their examples were significantly less thin than industry standards, having a lower span-to-depth ratio.

Buttingol et. al. (2017) have conducted a study of current advances in understanding UHPFRC characteristics and design processes. UHPFRC, a revolutionary material, has unique qualities such as high ductility, low permeability, remarkable compressive strength, and increased toughness when compared to traditional concrete. Understanding both its material and mechanical qualities is critical for properly using its excellent structural potential. However, present design codes are not appropriate for this new material and must be reviewed before applying to UHPFRC. The first section of the study discusses material features such as hydration, permeability, the role of fibers, mix design, fiber-matrix bond qualities, workability, mixing procedures, and curing. The second section discusses the material's mechanical properties and design recommendations, focusing on factors such as size effect, compressive and flexural strength, tensile stress-strain relationship, shear and punching shear capacity, creep and shrinkage, fracture energy, and steel bar anchorage and adherence. It also discusses the tensile mechanical characterisation utilizing inverse analysis based on bending test results. The third section investigates the material's behaviour at high temperatures, encompassing physical-chemical transformations of the concrete, the spalling effect, and transitory creep [2].

Doo-Yeol Yoo and Young-Soo Yoon (2016) explored the structural behaviors of ultra-high-performance fiber-reinforced concrete (UHPFRC) elements under varying loading circumstances to prevent repetitive research and improve practical applications. his study thoroughly examined the behavior of several UHPFRC structures under a variety of loads, including flexure, shear, torsion, and high-rate loads (such as collisions and blasts). Furthermore, the bond performance of UHPFRC and reinforcements, which is critical for the structural performance of reinforced concrete structures, was examined [11]. They concluded that incorporating 2% steel fibers into UHPFRC beams reinforced with steel bars improved post-cracking stiffness and ultimate load capacity. However, it lowered beam ductility because to the good binding strength with steel bars and the potential for crack localization. Incorporating 2.5% steel fibers resulted in a shear strength that was roughly 250% higher than that of non-fiber beams. Shear strength rose further with more fiber content and a lower shear span-to-depth ratio. Because to the outstanding fiber bridging at fracture surfaces, UHPFRC beams failed less abruptly than standard concrete.

Rim Nayal et. al. (2010) identified the repair of the existing bridges as one of the most critical needs in maintenance of the transportation infrastructure. They discovered that over 2,000 bridges in Kansas alone will require repair over the next decade. The majority of these bridges have 30-meter or shorter spans and shallow profiles. The inverted-T bridge system has recently grown in popularity due to its lower weight and higher span-to-depth ratio than prestressed I-girder bridges. However, using the inverted-T method to replace existing cast-in-place bridges presents complications. The authors' goal was to use post-tensioning as a promising solution to these difficulties. This method boosted the span-to-depth ratio while decreasing the likelihood of transverse cracks in the cast-in-place deck, which are a primary source of reinforcement corrosion. The authors observed that girder concrete strength has a significant impact on increasing span to depth ratio. Increasing girder concrete strength from 41.37 to 55.16 MPa, for example, raises maximum span by 15%, whereas increasing strength from 55.16 to 68.95 MPa increases maximum span by 11%. They discovered that for durability difficulties, post tensioning should be applied as soon as feasible after casting the deck to control crack growth in the diaphragm. [12].

2.4. Research gap

- Numerous research has been done on the design and applications of UHPFRC in infrastructure industry, but still there is lack of comparative studies on the use of UHPFRC over ordinary concrete with regard to economic feasibility.
- At this juncture, IRC Codes do not offer any design parameters or methodologies for UHPFRC. Since French design standards and material specifications are utilized, it is imperative that the design aligns with the specific environmental factors, climate conditions and materials.
- Although the use of ultra-high-performance concrete (UHPC) in bridge engineering is constrained by its high costs, there is limited understanding regarding its application in different bridge components. Consequently, a thorough examination of the economic viability, constraints, and construction feasibility of current UHPC development trends is imperative to assess its current status and potential outlook.

CHAPTER 3
METHODOLOGY

3.1. General

This chapter pertains to design of post-tensioned prestressed I girder for 25m, 30m, 35m, 40m and 45m straight span (c/c exp. Joint) made of ordinary concrete and UHPFRC for deck width of 16.0m. For analysis, ordinary RCC deck slab has been considered with thickness of 220mm in all spans.

M50 grade concrete is adopted for ordinary concrete post tensioned I girders for 25m, 30m, 35m, 40m spans and M55 grade concrete is adopted for 45m span. M155 grade concrete is used for post tensioned I girders made of UHPFRC for all spans. Fe500 grade steel is used for both type of girders for shear and untensioned reinforcement. Prestressing cables having 7 ply uncoated high tensile strength strands of 15.2mm diameter are used for all girders

The tendon profile is considered as straight at mid portion and linearly varying at ends in UHPFRC girders. Whereas in ordinary concrete girders cable profile is considered as straight in mid portion and linearly varying at ends with both regions connected with a parabolic profile. All the tendons are stressed from both ends in both type of girders.

For analysis and prestress calculation, grillage analysis of the superstructure has been carried out in MIDAS Civil 2023. For design, bending moment and shear force is considered at following sections-

a) Centre line of bearing
b) Start of tapering section
c) End of tapering section
d) L/4
e) Centre line of intermediate diaphragm
f) L/2

Design of governing girder among outer and inner girder is presented here. The requirement of shear reinforcement, interface shear reinforcement and untensioned reinforcement is calculated manually in accordance with the IRC:112-2020. Once the optimal girder depth, prestress cable, vertical shear reinforcement, interface shear reinforcement, and untensioned reinforcement are computed, their quantities are determined, and a comparison is conducted between post-tensioned I girders constructed with ordinary concrete and those made with ultra-high performance fiber reinforced concrete.

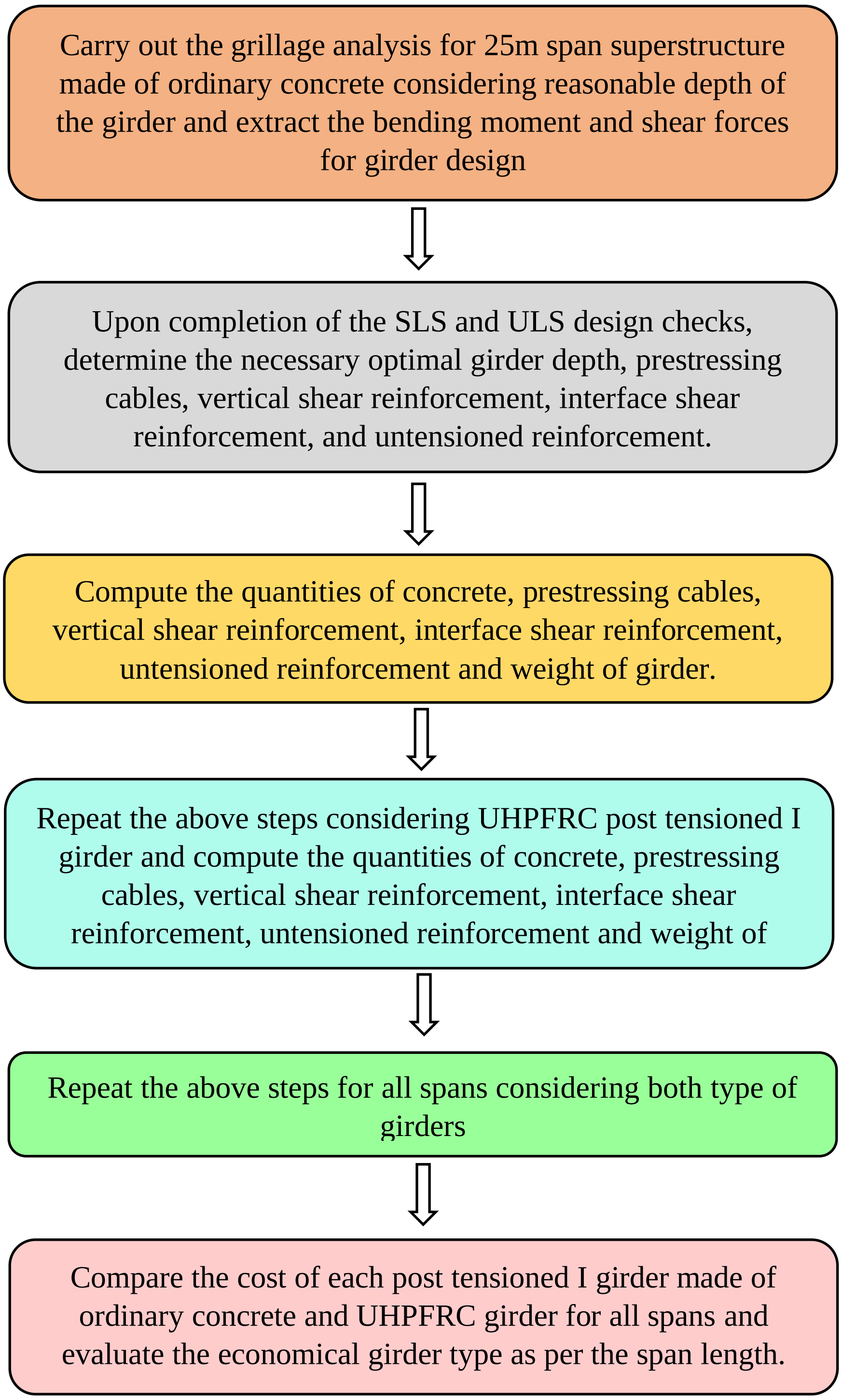

Figure 3. 1 Flowchart depicting methodology and workflow

3.2. Material properties

3.2.1. Concrete

- Grade of ordinary concrete for 25m, 30m, 35m and 40m spans: M50

  Following are the properties of ordinary M50 grade concrete-

  - Unit weight (γc): 25kN/m^3
  - Characteristic cube strength (f_{ck}): 50 MPa
  - Mean tensile strength (f_{ctm}): 3.50 MPa
  - Modulus of elasticity (E_{cm}): 35000 MPa
  - Poisson's ratio (μ_c): 0.2
  - Coefficient of thermal expansion (α_c): 1.2 x 10^{-5} /ºC

- Grade of ordinary concrete for 45m span – M55

  Following are the properties of ordinary M55 grade concrete:

  - Unit weight (γc): 25kN/m^3
  - Characteristic cube strength (f_{ck}): 55 MPa
  - Mean tensile strength (f_{ctm}): 3.70 MPa
  - Modulus of elasticity (E_{cm}): 36000 MPa
  - Poisson's ratio (μ_c): 0.2
  - Coefficient of thermal expansion (α_c): 1.2 x 10^{-5} /ºC

- Grade of ultra-high performance fiber reinforced concrete (UHPFRC) – M155

  Following are the properties of M155 grade ultra-high performance fiber reinforced concrete (UHPFRC):

  - Unit weight (γc): 25kN/m^3
  - Characteristic cube strength (f_{ck}): 155 MPa
  - Mean tensile strength (f_{ctm}): 6.00 MPa
  - Elastic Modulus (E_{cm}): 50000 MPa
  - Poisson's ratio (μ_c): 0.2
  - Coefficient of thermal expansion (α_c): 1.2 x 10^{-5} /ºC
  - Heat Treatment class: TT1+2

3.2.2. Reinforcing steel

- Grade of reinforcing steel: Fe500D

  Following are the properties of Fe500D grade reinforcing steel:

  - Unit weight (γ_s) = 78.5 kN/m^3
  - Yield strength (f_y) = 500 MPa
  - Poisson's ratio (μ_s) = 0.3
  - Modulus of elasticity (E_s) = 200000 MPa
  - Coefficient of thermal expansion (α_s): 1.2 x 10^{-5} /ºC

3.2.3. Prestressing steel

- All prestressing cables are having 7 ply uncoated high tensile strength strands of 15.2mm diameter

Following are the properties of prestressing steel:

  - Nominal area of each strand: 140 mm^2.
  - Unit weight (γ_{ps}): 78.5 kN/m3
  - Poisson's ratio (μ_{ps}): 0.3
  - Modulus of elasticity (E_{ps}) = 195000 MPa
  - Ultimate Tensile strength (f_{ups}): 1860 MPa
  - Breaking load of each strand: 260.4kN
  - Maximum jacking force: 0.783 x Ultimate tensile strength
  - Slip at jacking end: 6mm
  - Coefficient of friction (μ): 0.17
  - Wobble coefficient (k): 0.002/m
  - Coefficient of thermal expansion (α_s): 1.2 x 10^{-5} /°C

3.3. Modelling

The superstructure is modelled as a grillage in MIDAS Civil 2023 as per the guidelines stated in chapter 4 of "Bridge Deck Behaviour" by E.C. Hambly with longitudinal members representing the PSC I girders and transverse members representing the deck slab. The longitudinal members are spaced according to the centre-to-centre spacing of the girders, and the transverse members are positioned to optimize the aspect ratio of the grillage for improved accuracy [13] [14]. The properties of the longitudinal girders are assigned to the longitudinal members, while the deck slab properties are assigned to the transverse members.

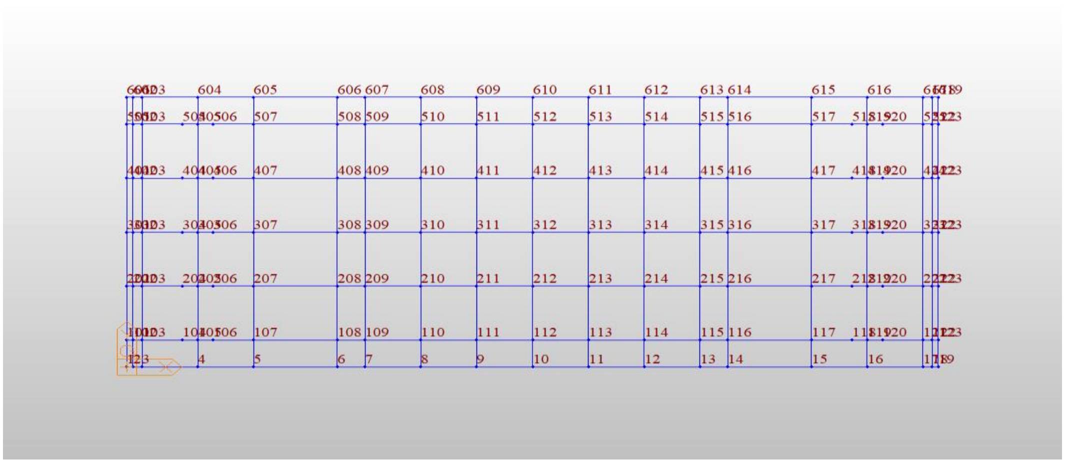

Figure 3. 2 Node numbers of grillage model in MIDAS Civil

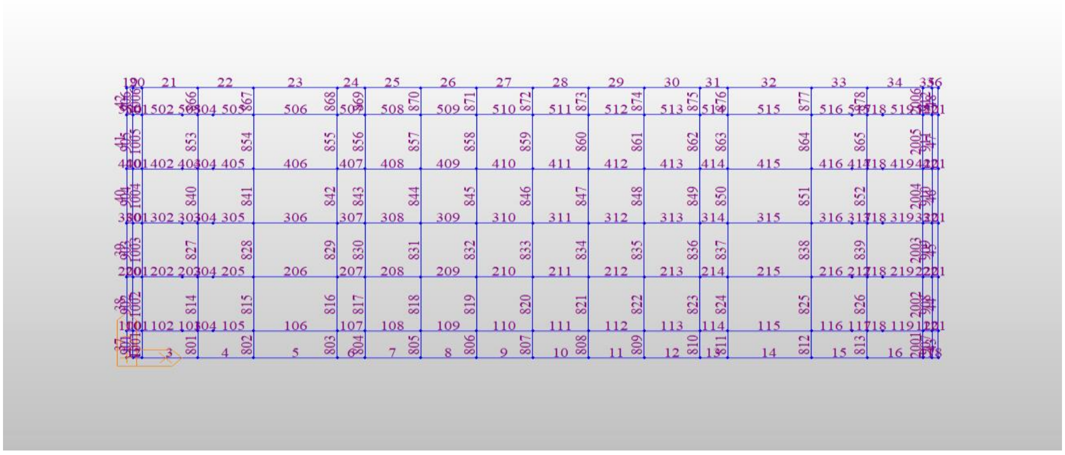

Figure 3. 3 Element numbers of grillage model in MIDAS Civil

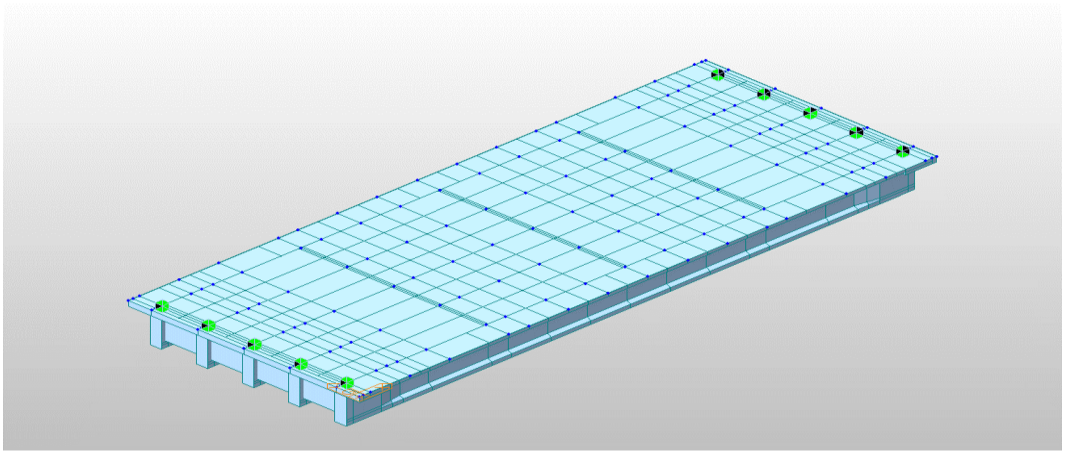

Figure 3. 4 3D rendered view of grillage model in MIDAS Civil

3.3.1. Loading

a) Dead Load

Dead load of the girders has been assigned to the model with the inbuilt self-weight command of the MIDAS Civil software.

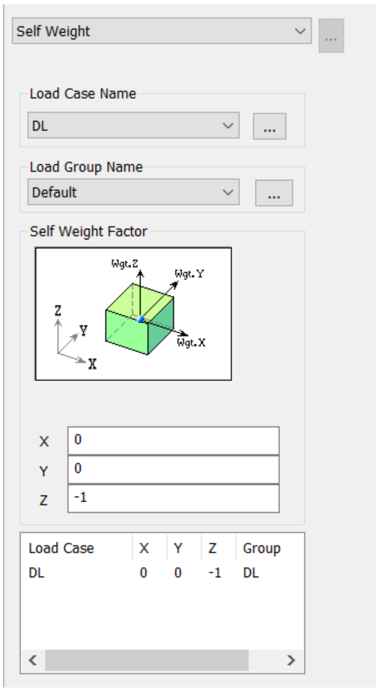

Figure 3. 5 Self weight command in MIDAS Civil

Load of deck slab is assigned as line load over each longitudinal member contributory to the effective width for each girder considering the density of green concrete as $26 kN/m^3$.

Thickness of deck = 220 mm

Effective width for Outer Girder = 3.2 m

Effective width for Inner Girder = 3.2 m

UDL applied on outer girder = 0.220 m x 3.2 m x 26 kN/m^3 = 18.3 kN/m

UDL applied on inner girder = 0.220 m x 3.2 m x 26 kN/m^3 = 18.3 kN/m

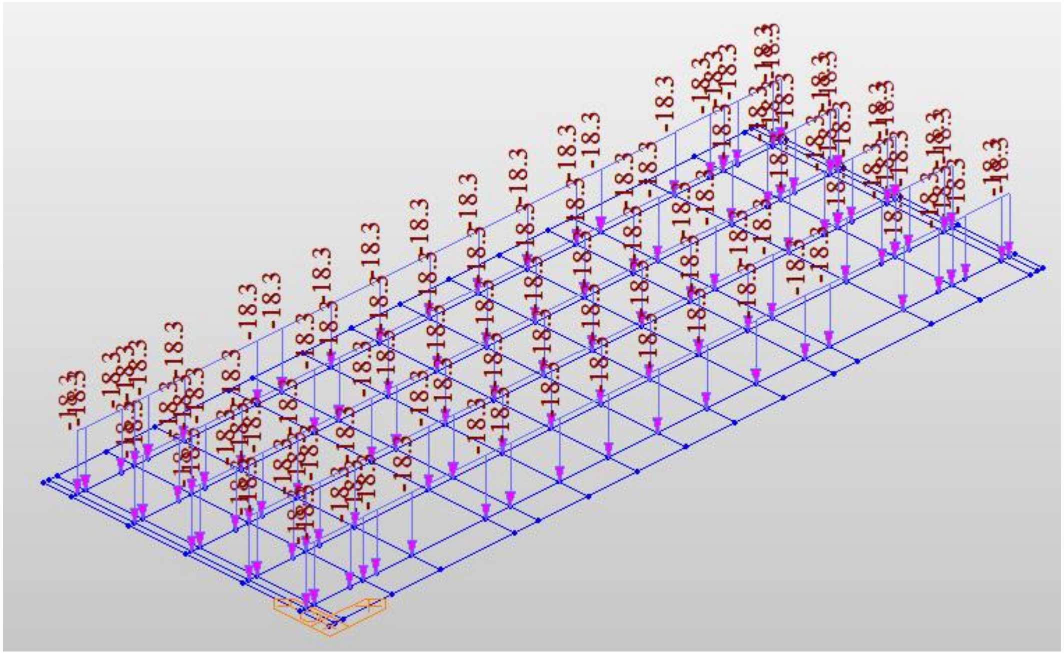

Figure 3. 6 Deck slab load applied in grillage model in MIDAS Civil

b) Crash barrier

Load of crash barriers is assigned as a line load over the edge longitudinal members of intensity 12.5 kN/m corresponding to the standard section of crash barrier as per IRC:5-2015.

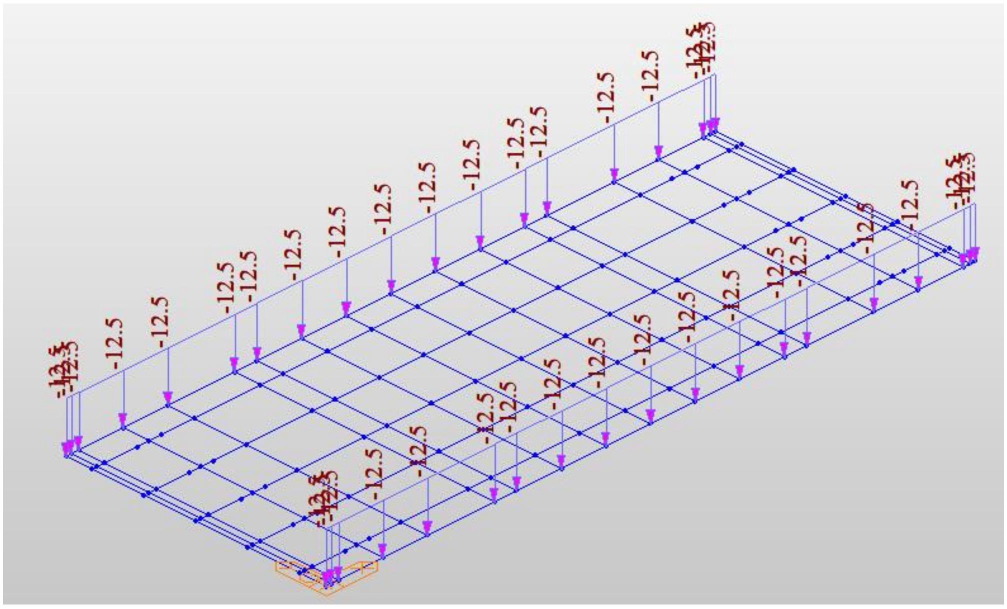

Figure 3. 7 Crash barrier load applied in grillage model in MIDAS Civil

c) Wearing coat

Load of wearing coat is assigned as a line load over each longitudinal member contributory to the effective width for each girder considering the thickness of wearing coat as 65mm with the density of 22kN/m^3.

Wearing coat thickness = 65 mm

Unit weight of wearing coat = 22 kN/m3

Girder spacing = 3.2 m

Girder cantilever = 1.6m

Crash barrier thickness = 0.5 m

UDL on inner girder = 0.065 m x 22 kN/m3 x 3.2 m = 4.576 kN/m

UDL on outer girder = 0.065 m x 22 kN/m3 x (3.2m-0.5m) = 3.861 kN/m

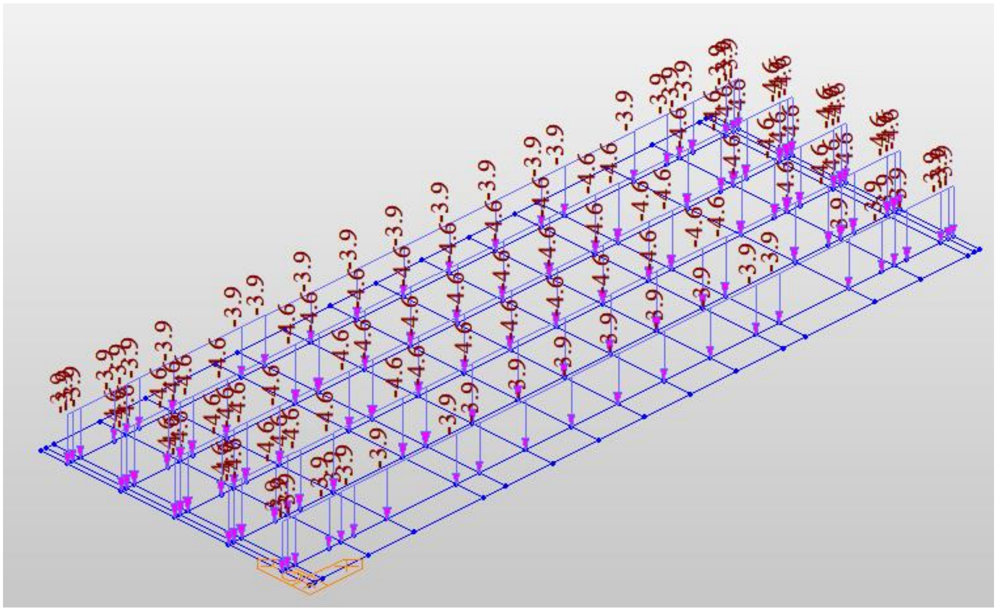

Figure 3. 8 Wearing coat load applied in grillage model in MIDAS Civil

d) Differential temperature

Differential temperature varying over the depth of the girder is assigned to the longitudinal members in accordance with the IRC:6-2017 for both rise and fall case.

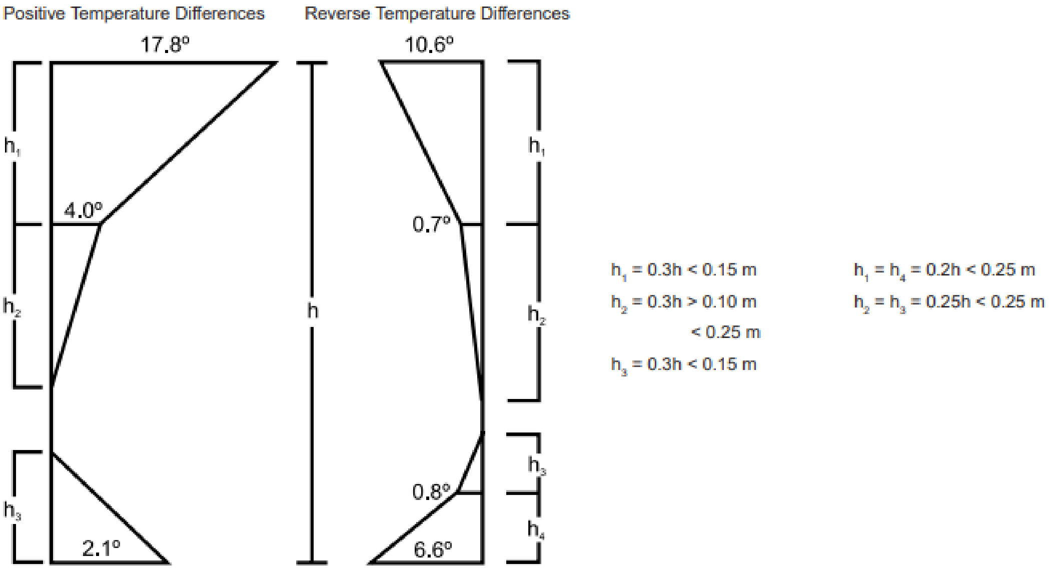

Figure 3. 9 Differential temperature load as per IRC:6-2017

e) Prestressing force

It is proposed to use 15.2mm diameter strands with Ultimate Tensile Strength (UTS) of 1860Mpa. Prestress force is applied in MIDAS Civil considering maximum jacking force as 78.3% of UTS as stated in IRC:112-2020. All losses in prestress are calculated in MIDAS Civil software in accordance with chapter 7.9 of IRC:112-2020.

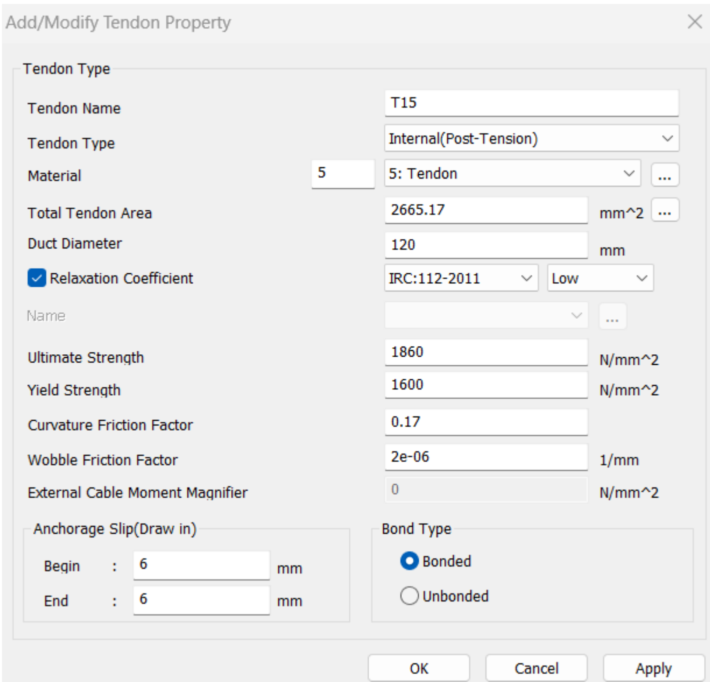

Figure 3. 10 Tendon properties defined in MIDAS Civil

f) Live load

Live load is applied in MIDAS Civil with trains of Class A, Class 70R wheeled & Special Vehicle as per IRC: 6-2017.

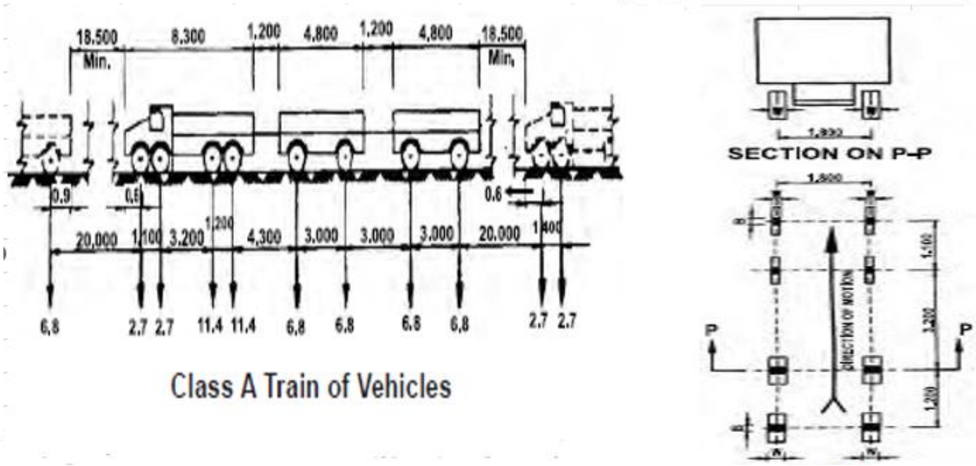

Figure 3. 11 Class A Vehicle as per IRC:6-2017

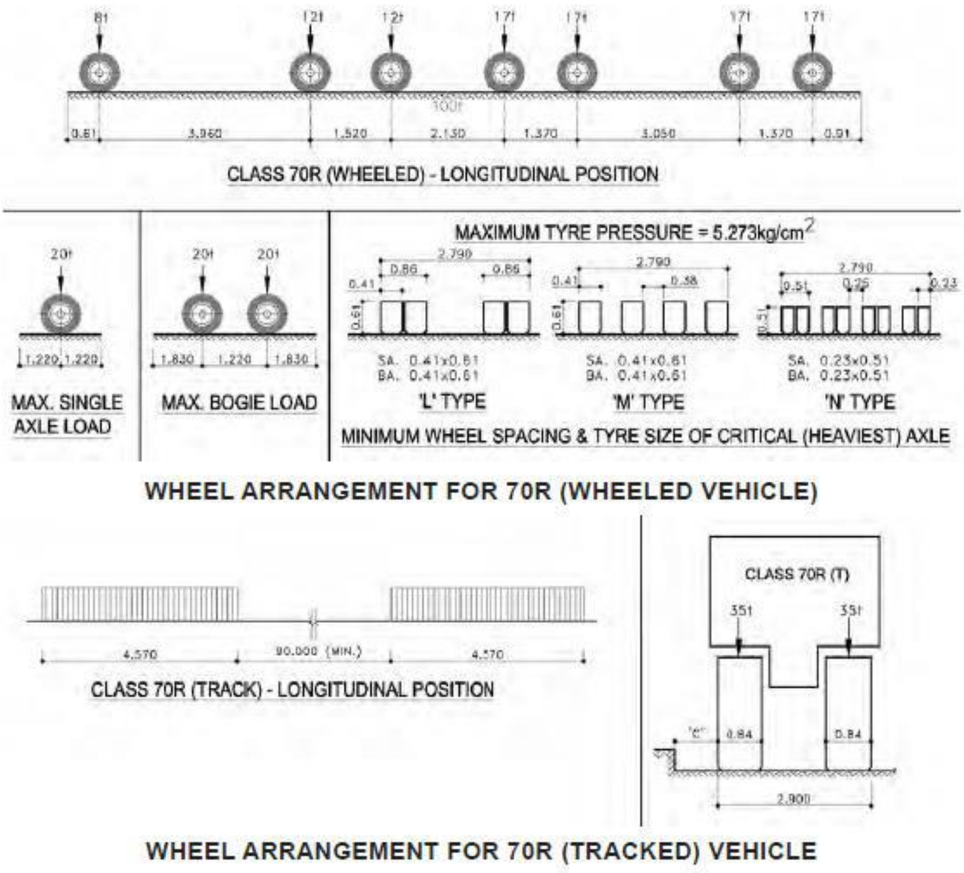

Figure 3. 12 Class 70R Wheeled and Tracked Vehicles as per IRC:6-2017

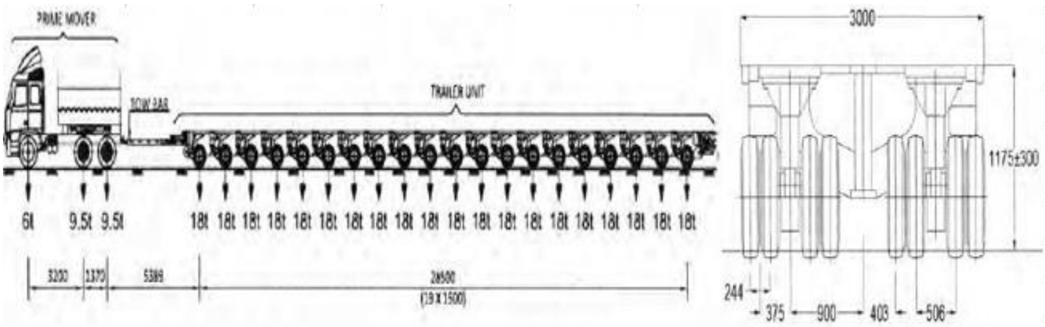

Figure 3. 13 Special vehicle as per IRC:6-2017

Table 3. 1 Live load combinations for different lane width as per IRC:6-2017

Carriageway width	Number of lanes for design	Carriageway width
Less than 5.3m	1	One lane of Class A to occupy 2.3m. The remaining width of carriageway shall be loaded with 500Kg/m^2.
5.3m and above but less than 9.6m	2	One lane of class 70R or two lanes of Class A.
9.6m and above but less than 13.1m	3	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.
13.1m and above but less than 16.6m	4	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.
16.6m and above but less than 20.1m	5	
20.1m and above but less than23.6m	6	

Since, the carriageway width is 16.0 m, so as per the above recommendation One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes or four lanes of Class A will be considered.

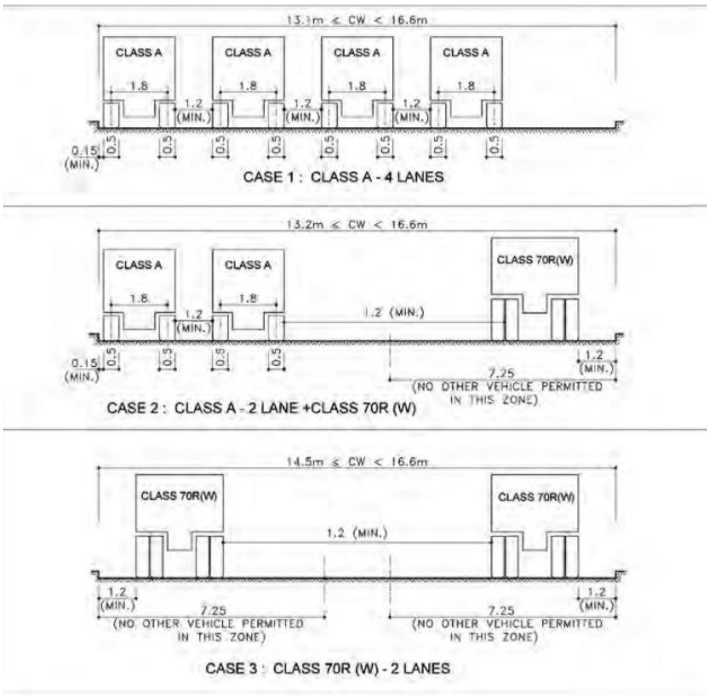

Figure 3. 14 Live load cases for 4 lane carriageway as per IRC:6-2017

3.3.2. Construction Stages

The girders are prestressed at ground in 2 stages before the lifting of the girders. After girders attains the age of 28 days, they shall be lifted/transported & erected over the substructure. The staging for cast-in-situ deck slab shall be erected with support from erected girder itself.

Table 3. 2 Construction stages of superstructure

Construction stage	Girder age (in days)	Deck slab age (in days)
Casting of girder	0	-
Transfer of prestress-Stage 1	5	-
Transfer of prestress-Stage 2	28	-
Casting of deck slab	35	0
Placing of crash barrier and wearing coat	63	28
Open to traffic	91	56
At 100 years	36500	36465

Effects of creep and shrinkage in ordinary concrete girders have been considered as per the defined construction sequence in MIDAS Civil 2023.

UHPFRC girders are subjected to heat treatment class of TT1+2, i.e. it has undergone a heat curing treatment to bring forward the start of setting and to accelerate setting and initial hardening and also undergoes heat treatment at a relatively high temperature (of the order of 90°C) at a degree of humidity greater than 90% for several tens of hours. Thus, as per Cl. 5.5.10.1 of NF P18-470 2016, it is assumed that there will be no shrinkage after the end of the heat treatment. Also, as per Cl. 5.5.11.1 of NF P18-470 2016, creep is non-existent for all the loads applied after heat treatment. [15]

Precast beams are checked under different stages of construction. Stress check is carried out at the extreme fibers of the girders for rare and frequent combinations considering inferior and superior values for prestressing force. For this, appropriate section properties as per the adopted construction sequence are considered with girder properties being considered till the time deck concrete hardens. After 28 days of pouring of deck slab over girders, composite properties are considered.

3.3.3. Load Combinations

Load combinations are considered in MIDAS Civil 2023 in accordance with the Annexure B of IRC:6-2017.

Loads	Rare Combination	Frequent Combination	Quasi-permanent Combination
(1)	(2)	(3)	(4)
1. Permanent Loads:			
1.1 Dead Load, Snow load if present, SIDL except surfacing and back fill weight	1.0	1.0	1.0
1.2 surfacing			
a) Adding to the effect of variable loads	1.2	1.2	1.2
b) Relieving the effect of variable loads	1.0	1.0	1.0
1.3 Earth Pressure	1.0	1.0	1.0
1.4 Prestress and Secondary Effect of prestress		(Refer Note 4)	
1.5 Shrinkage and Creep Effect	1.0	1.0	1.0
2. Settlement Effects			
a) Adding to the permanent loads	1.0	1.0	1.0
b) Opposing the permanent loads	0	0	0
3. Variable Loads:			
3.1 Carriageway load and associated loads (braking, tractive and centrifugal forces) and footway live load			
a) Leading Load	1.0	0.75	-
b) Accompanying Load	0.75	0.2	0
3.2 Thermal Load			
a) Leading Load	1.0	0.60	-
b) Accompanying Load	0.60	0.50	0.5
3.3 Wind Load			
a) Leading Load	1.0	0.60	-
b) Accompanying Load	0.60	0.50	0
3.4 Live Load surcharge as accompanying load	0.80	0	0
4. Hydraulic Loads (Accompanying loads) :			
4.1 Water Current	1.0	1.0	-
4.2 Wave Pressure	1.0	1.0	-
4.3 Buoyancy	0.15	0.15	0.15

Figure 3. 15 Partial safety factors for verification of serviceability limit state as per IRC:6-2017

Also, as per Cl. 7.9.5 (4) of IRC:112-2020, in serviceability limit state, two characteristic values of prestressing force shall be used.

$P_{k.sup} = \gamma_{sup} P_m (t) (x)$

$P_{k.inf} = \gamma_{inf} P_m (t) (x)$

Where, for post-tensioning with bonded tendons γ_{sup} =1.10 and γ_{inf} = 0.9

Loads	Ultimate Limit State		
	Basic Combination	Accidental Combination	Seismic Combination
(1)	(2)	(3)	(4)
1. Permanent Loads:			
1.1 Dead Load, Snow load (if present), SIDL except surfacing			
a) Adding to the effect of variable loads	1.35	1.0	1.35
b) Relieving the effect of variable loads	1.0	1.0	1.0
1.2 Surfacing			
a) Adding to the effect of variable loads	1.75	1.0	1.75
b) Relieving the effect of variable loads	1.0	1.0	1.0
1.3 Prestress and Secondary effect of prestress	(Refer Note 2)		
1.4 Back fill Weight	1.5	1.0	1.0
(a) When causing adverse effect	1.35	1.0	1.0
(b) When causing relieving effect	1.0	1.0	1.0
1.5 Earth Pressure			
a) Adding to the effect of variable loads	1.5	1.0	1.0
b) Relieving the effect of variable loads	1.0	1.0	1.0
2. Variable Loads:			
2.1 Carriageway Live load and associated loads (braking, tractive and centrifugal) and Footway live load			
a) As leading load	1.5	0.75	-
b) As accompanying load	1.15	0.2	0.2
c) Construction live load	1.35	1.0	1.0
2.2 Wind Load during service and construction			
a) As leading load	1.5	-	-
b) As accompanying load	0.9	-	-
2.3 Live Load Surcharge effects (as accompanying load)	1.2	0.2	0.2
2.4 Construction Dead Loads (such as Wt. of launching girder, truss or Cantilever Construction Equipments)	1.35	1.0	1.35
2.5 Thermal Loads			
a) As leading load	1.5	-	-
b) As accompanying load	0.9	0.5	0.5
3. Accidental effects:			
3.1 Vehicle collision (or)	-	1.0	-
3.2 Barge Impact (or)	-	1.0	-
3.3 Impact due to floating bodies	-	1.0	-
4. Seismic Effect			
(a) During Service	-	-	1.5
(b) During Construction	-	-	0.75
5. Hydraulic Loads (Accompanying Load):			
5.1 Water current forces	1.0	1.0	1.0
5.2 Wave Pressure	1.0	1.0	1.0
5.3 Hydrodynamic effect	-	-	1.0
5.4 Buoyancy	0.15	0.15	1.0

Figure 3. 16 Partial safety factors for verification of structural strength as per IRC:6-2017

Name	Active	Type	Description
SLS-R1	Serviceability	Add	LL leading, +ve temp, P/S sup
SLS-R2	Serviceability	Add	LL leading, -ve temp, P/S sup
SLS-R3	Serviceability	Add	LL leading, +ve temp, P/S inf
SLS-R4	Serviceability	Add	LL leading, -ve temp, P/S inf
SLS-R5	Serviceability	Add	+ve temp leading, P/S sup
SLS-R6	Serviceability	Add	-ve temp leading, P/S sup
SLS-R7	Serviceability	Add	+ve temp leading, P/S inf
SLS-R8	Serviceability	Add	-ve temp leading, P/S inf
SLS-R11	Serviceability	Add	LL leading(Wearing_Coat), P/S sup
SLS-R12	Serviceability	Add	LL (Wearing_Coat), P/S sup
SLS-R13	Serviceability	Add	LL leading(Wearing_Coat), P/S inf
SLS-R14	Serviceability	Add	LL (Wearing_Coat), P/S inf
SLS-R1_SV	Serviceability	Add	LL leading, P/S sup
SLS-R2_SV	Serviceability	Add	LL leading, P/S inf
SLS-R3_SV	Serviceability	Add	P/S sup
SLS-R4_SV	Serviceability	Add	P/S inf
SLS_R_ENV	Strength/Stress	Envelope	
SLS-F1	Serviceability	Add	LL leading, +ve temp, P/S sup
SLS-F2	Serviceability	Add	LL leading, -ve temp, P/S sup
SLS-F3	Serviceability	Add	LL leading, +ve temp, P/S inf
SLS-F4	Serviceability	Add	LL leading, -ve temp, P/S inf
SLS-F5	Serviceability	Add	+ve temp leading, P/S sup
SLS-F6	Serviceability	Add	-ve temp leading, P/S sup
SLS-F7	Serviceability	Add	+ve temp leading, P/S inf
SLS-F8	Serviceability	Add	-ve temp leading, P/S inf
SLS-F11	Serviceability	Add	LL leading(Wearing_Coat), P/S sup
SLS-F12	Serviceability	Add	LL (Wearing_Coat), P/S sup
SLS-F13	Serviceability	Add	LL leading(Wearing_Coat), P/S inf
SLS-F14	Serviceability	Add	LL (Wearing_Coat), P/S inf
SLS-F1_SV	Serviceability	Add	LL leading, P/S sup
SLS-F2_SV	Serviceability	Add	LL leading, P/S inf
SLS-F3_SV	Serviceability	Add	P/S sup
SLS-F4_SV	Serviceability	Add	P/S inf
SLS_F_ENV	Strength/Stress	Envelope	
ULS-LL NC	Strength/Stress	Add	LL leading, +ve temp
ULS-LL WC	Strength/Stress	Add	LL leading, +ve temp
ULS-LL-SV	Strength/Stress	Add	LL leading, -ve temp
ULS ENV	Strength/Stress	Envelope	

Figure 3. 17 Load combinations defined for SLS and ULS checks in MIDAS Civil

3.4. Design checks

a) Limit state of serviceability

- Maximum allowable compressive stress in concrete under rare combinations of loads shall be 0.48 f_{ck}, in order to restrict the longitudinal cracks, micro cracks or creep within the acceptable limits. [7]
- Where the compressive stress in concrete under quasi-permanent load combination is below 0.36 $f_{cm}(t_0)$, linear creep may be assumed to act. In case of compressive stress exceeding 0.36 $f_{cm}(t_0)$, non-linear creep shall be considered in analysis. [7]

b) Limit state of fatigue

- The bridge or its components shall not lose its capacity to sustain design loads by virtue of its materials reaching the fatigue limits due to its loading cycle. For carrying out fatigue verification, specialist literature shall be referred. However, fatigue verification is not necessary in case of prestressed concrete structures under the frequent combination of action and prestressing force, only if compressive stresses occur at the extreme concrete fibres, under serviceability limit state. [7]

c) Ultimate limit state

- Ultimate moment capacity for the I girder is calculated in accordance with chapter 8 of IRC:112-2020.
- Ultimate shear capacity for the ordinary concrete I girder is calculated in accordance with chapter 10 of IRC:112-2020. Whereas, ultimate shear capacity of UHPFRC girder is calculated as per Cl. 6.2 of NF P18-710:2016. [16]
- The interface shear capacity for the ordinary concrete I girder is calculated in accordance with chapter 10 of IRC:112-2020 to resist the interface shear arising between the precast girder and cast-in-situ deck slab. Whereas, interface shear capacity of UHPFRC girder is calculated as per Cl. 6.2 of NF P18-710:2016. [16]

d) Provision of minimum reinforcement

- Minimum surface reinforcement is provided in flanges and webs of ordinary concrete girders as per Cl. 16.5 of IRC:112-2020. Whereas, for UHPFRC girders, minimum surface reinforcement is not required as per Cl. 9.2.5 of NF P18-710:2016.
- Minimum reinforcement for crack control is provided in ordinary concrete girders in case there is tension at bottom in rare combination as per Cl. 12.3.3 of IRC:112-2020. Whereas, for UHPFRC girders, minimum reinforcement for crack control is not required as per Cl. 7.3.2 of NF P18-710:2016.

CHAPTER 4
RESULTS

4.1. General

This chapter presents the findings of the analysis and design of superstructure for spans varying from 25m to 45m for both ordinary concrete and UHPFRC. This chapter aims to provide an in-depth analysis and interpretation of the results obtained from the software analysis and design. The ordinary concrete girders were examined for span-to-depth ratios (L/d) ranging from 15 to 18 and UHPFRC girders were examined for span-to-depth ratios (L/d) ranging from 21 to 24 for depth finalisation. Requirement of girder depth, prestress cable, shear reinforcement, interface shear reinforcement and untensioned reinforcement was calculated as per the checks required to be satisfied as stated in the chapter 3.4.

4.2. Schematic Arrangement of Post-Tensioned I Girders made of ordinary concrete

All the 5 spans - 25m, 30m, 35m, 40m and 45m are having deck width of 16.0m. The superstructure comprises of 5 numbers of post-tensioned I girders having centre to centre girder spacing of 3.2m supporting cast in-situ RCC deck slab of 220mm thickness over them. The girders are resting directly over the POT-PTFE bearings.

4.2.1. For 25m span

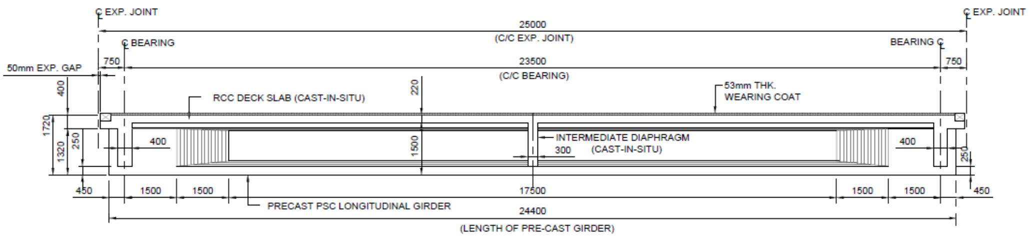

Figure 4. 1 Elevation of 25m span OC post tensioned I girder

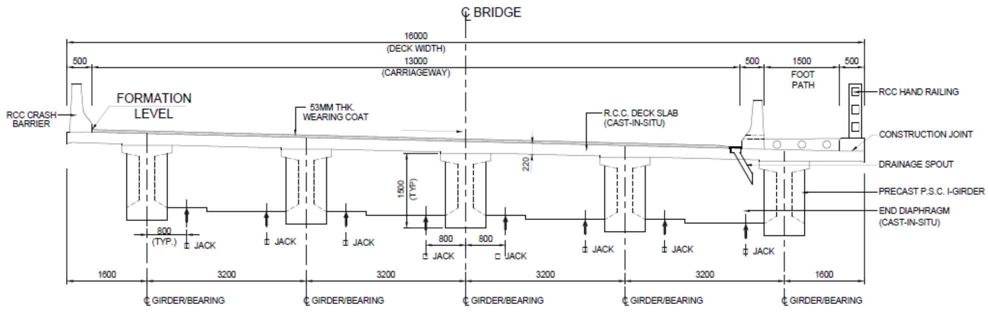

Figure 4. 2 Cross section of 25m span OC post tensioned I girder at support

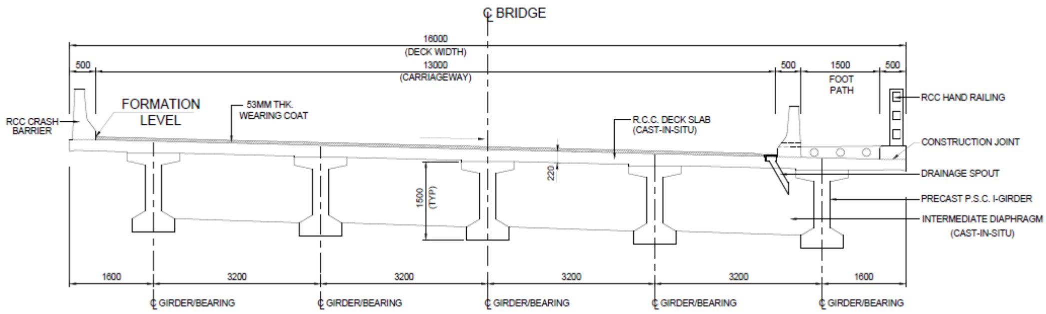

Figure 4. 3 Cross section of 25m span OC post tensioned I girder at mid span

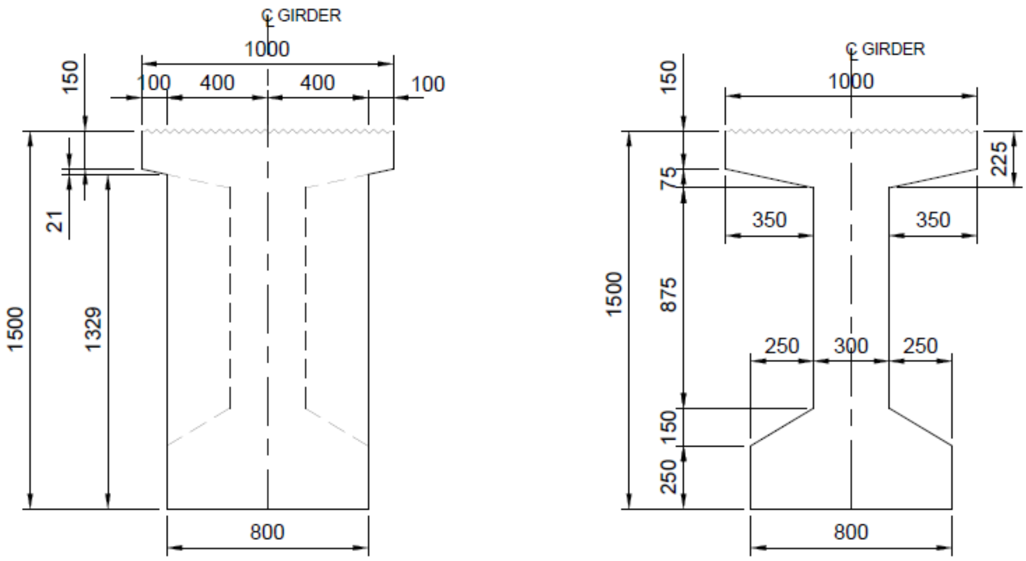

Figure 4. 4 Girder section of 25m span OC post tensioned I girder at support and mid span

4.2.2. For 30m span

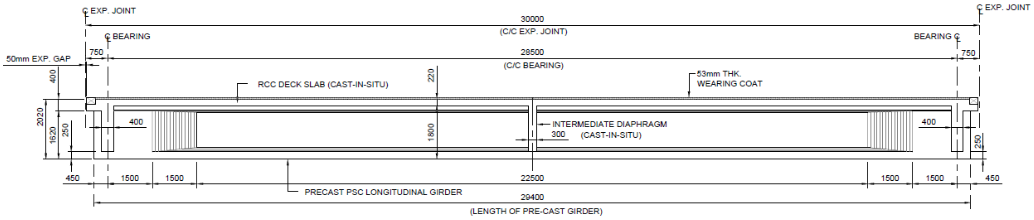

Figure 4. 5 Elevation of 30m span OC post tensioned I girder

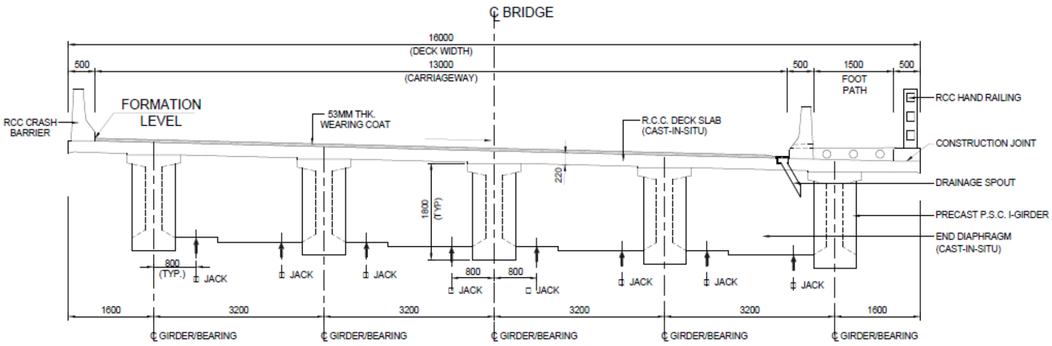

Figure 4. 6 Cross section of 30m span OC post tensioned I girder at support

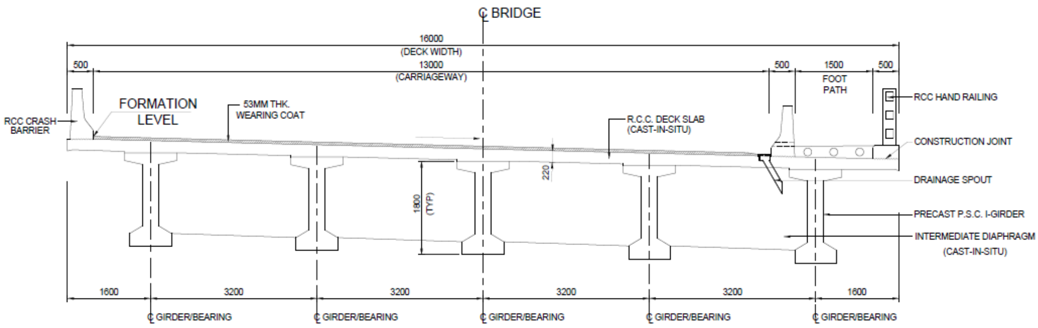

Figure 4. 7 Cross section of 30m span OC post tensioned I girder at mid span

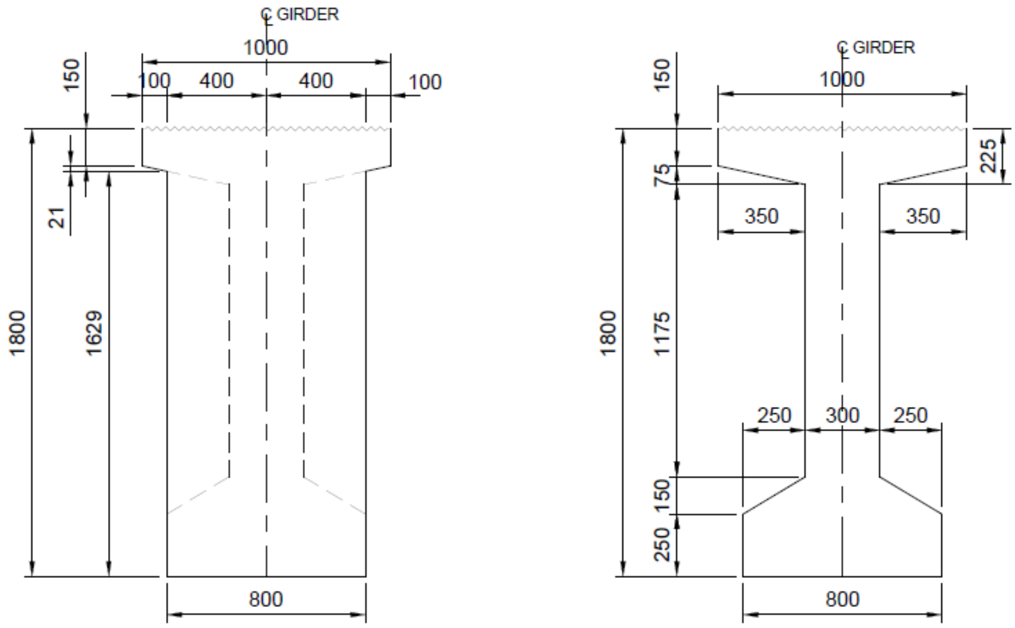

Figure 4. 8 Girder section of 30m span OC post tensioned I girder at support and mid span

4.2.3. For 35m span

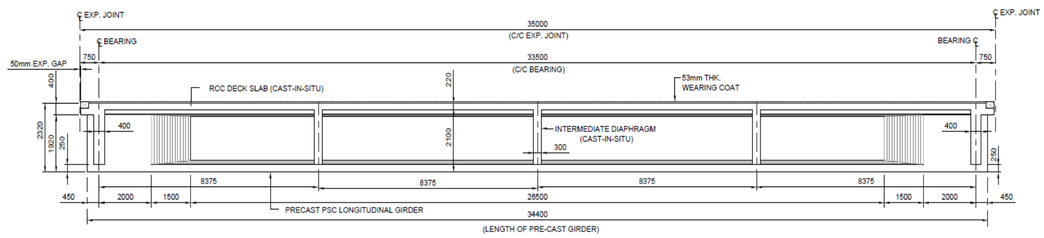

Figure 4. 9 Elevation of 35m span OC post tensioned I girder

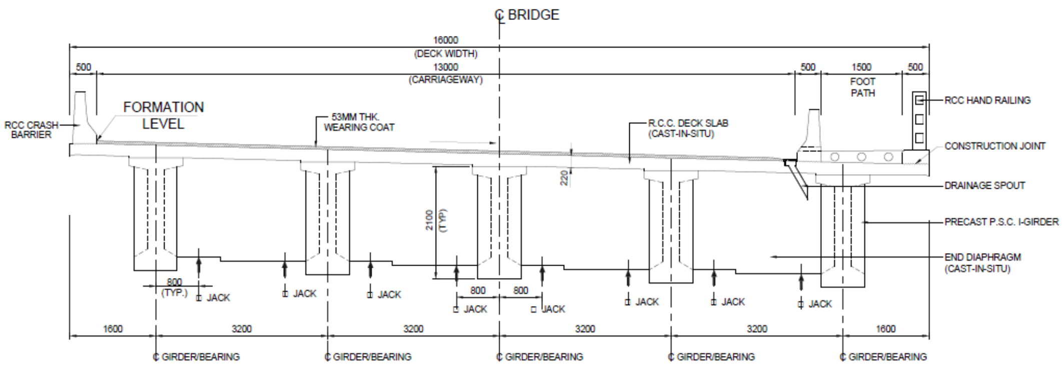

Figure 4. 10 Cross section of 35m span OC post tensioned I girder at support

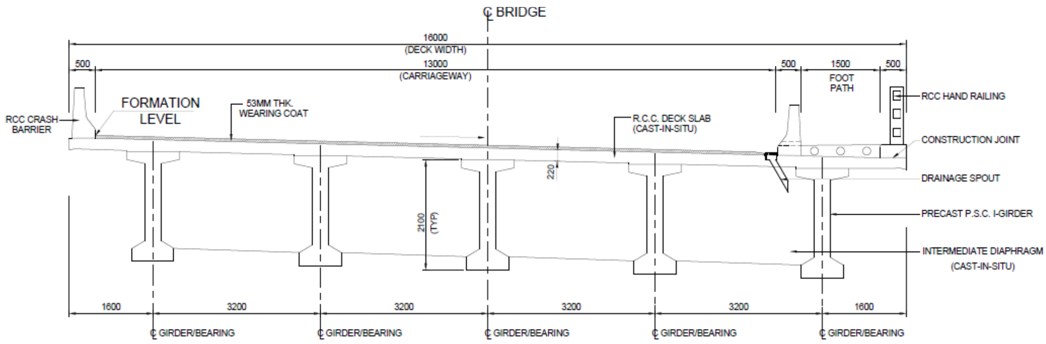

Figure 4. 11 Cross section of 35m span OC post tensioned I girder at mid span

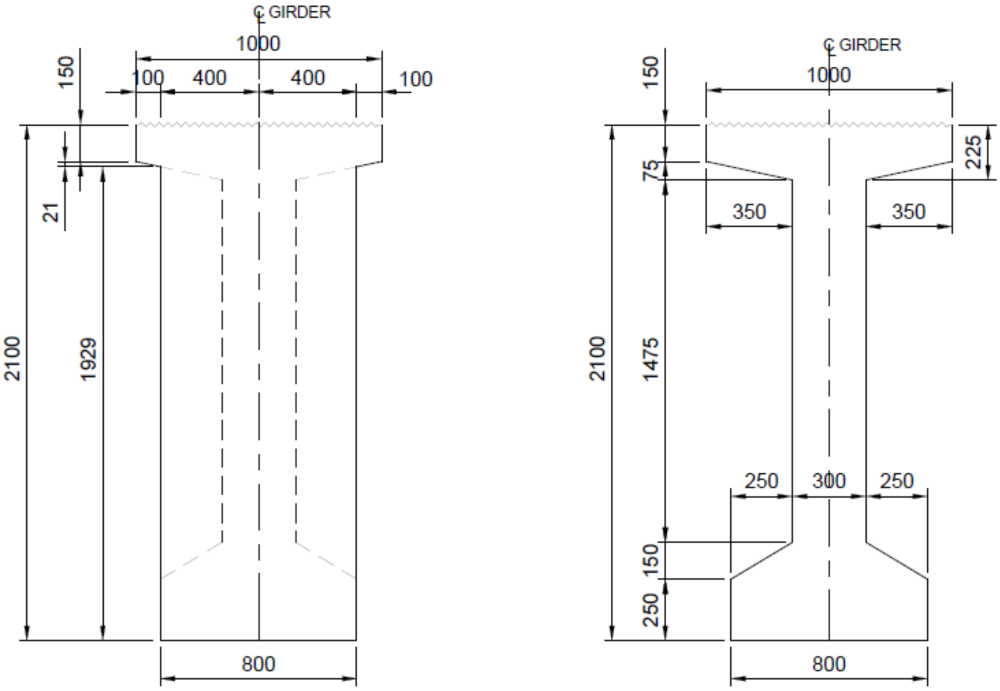

Figure 4. 12 Girder section of 35m span OC post tensioned I girder at support and mid span

4.2.4. For 40 span

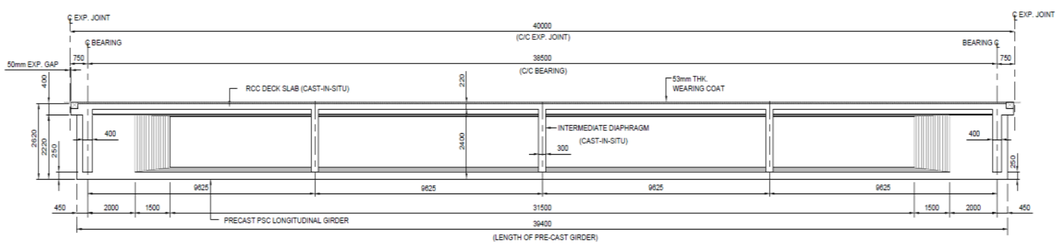

Figure 4. 13 Elevation of 40m span OC post tensioned I girder

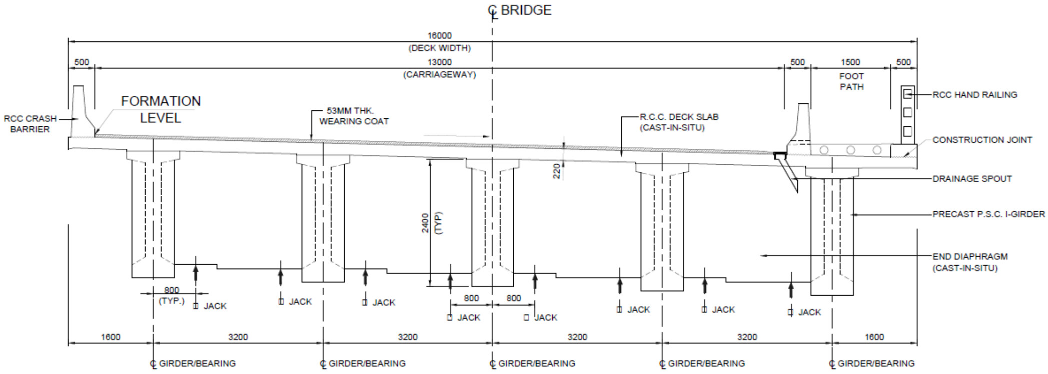

Figure 4. 14 Cross section of 40m span OC post tensioned I girder at support

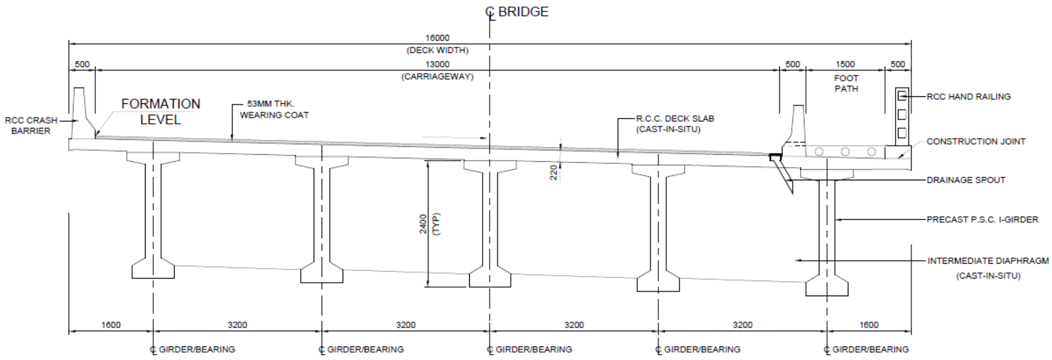

Figure 4. 15 Cross section of 40m span OC post tensioned I girder at mid span

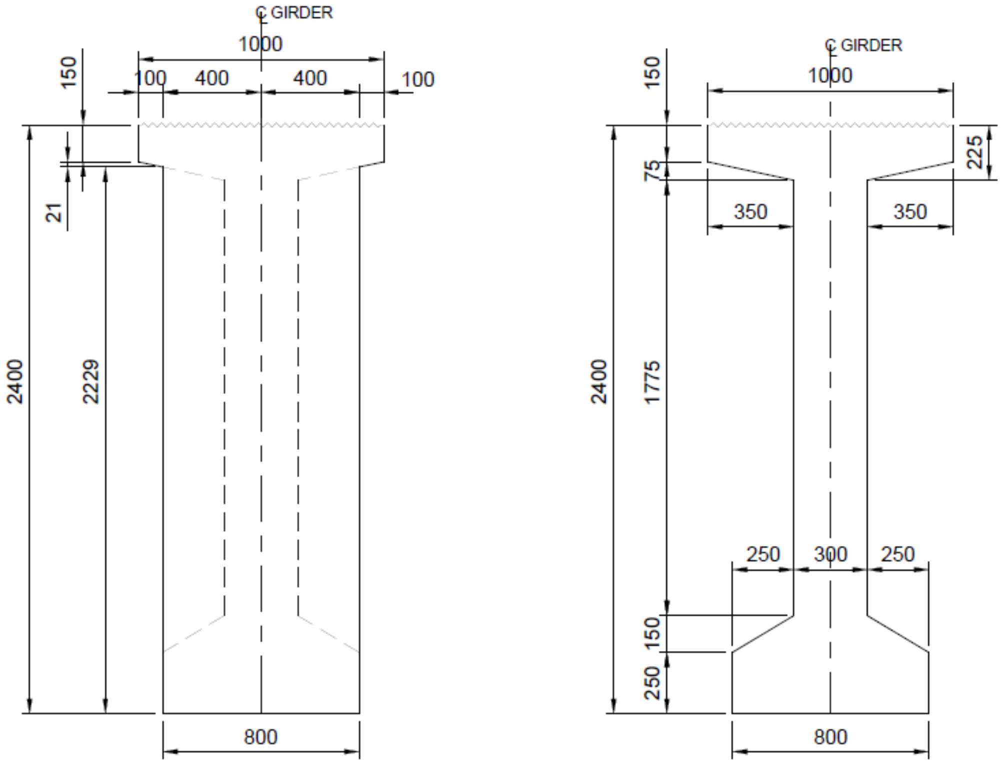

Figure 4. 16 Girder section of 40m span OC post tensioned I girder at support and mid span

4.2.5. For 45m span

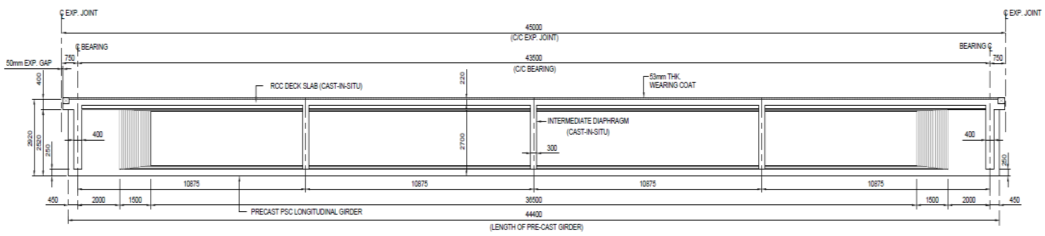

Figure 4. 17 Elevation of 45m span OC post tensioned I girder

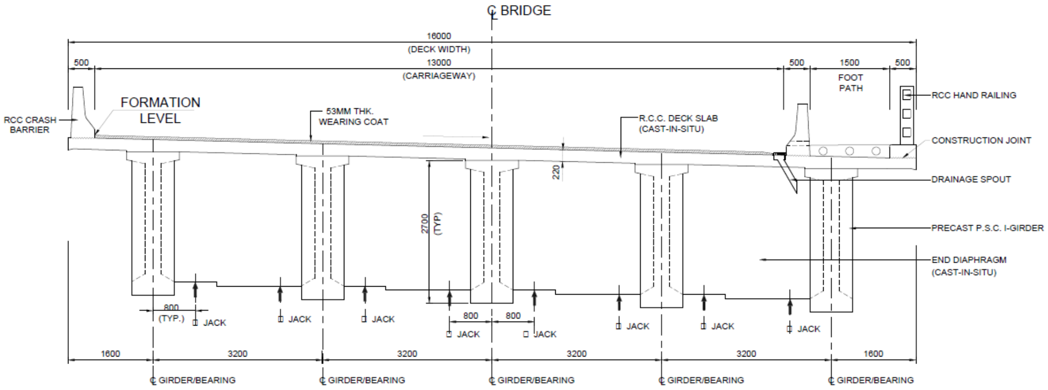

Figure 4. 18 Cross section of 45m span OC post tensioned I girder at support

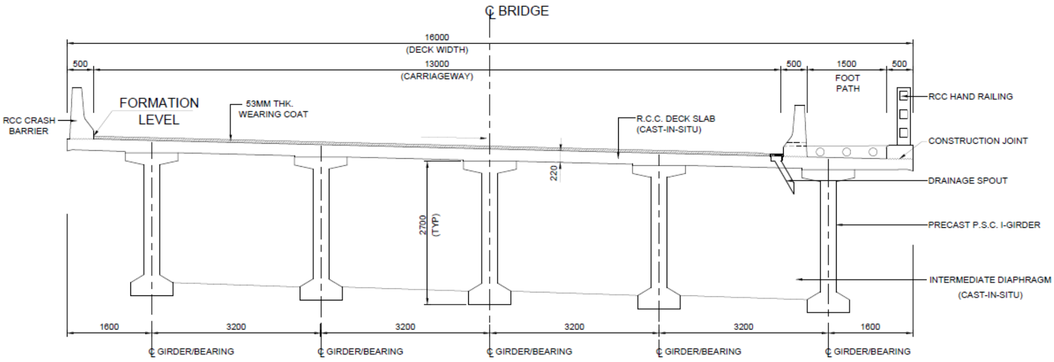

Figure 4. 19 Cross section of 45m span OC post tensioned I girder at mid span

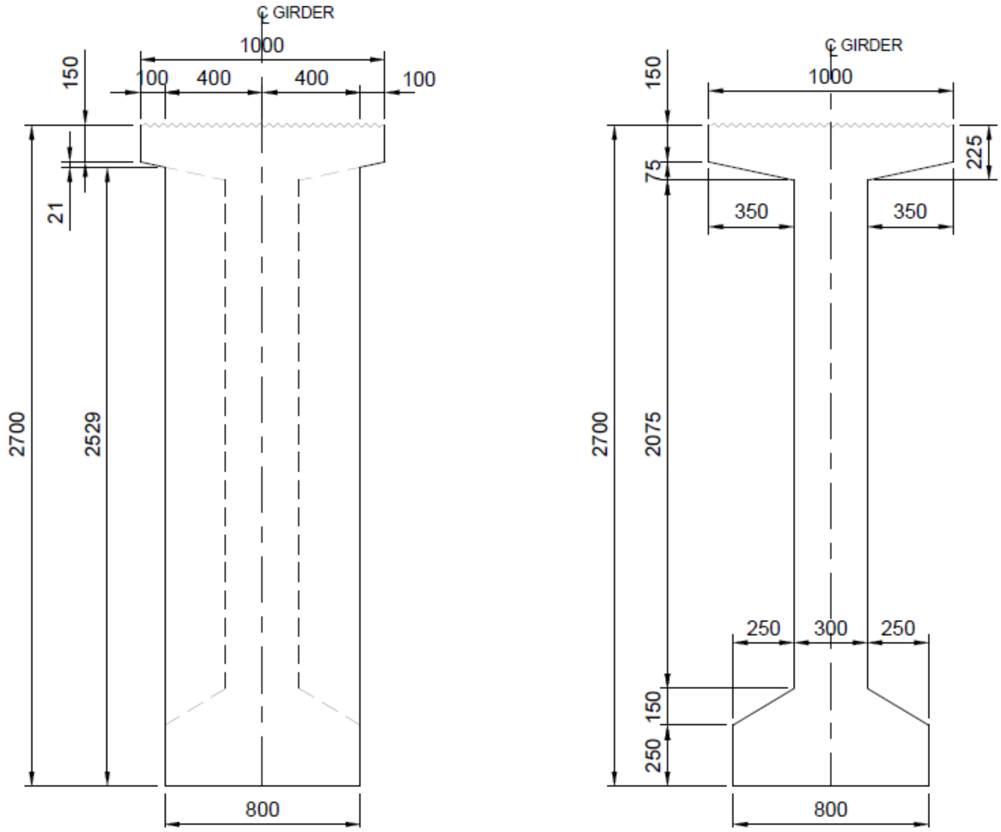

Figure 4. 20 Girder section of 45m span OC post tensioned I girder at support and mid span

4.3. Schematic Arrangement of Post-Tensioned I Girders made of UHPFRC

All the 5 spans - 25m, 30m, 35m, 40m and 45m are having deck width of 16.0m. The superstructure comprises of 5 numbers of post-tensioned I girders having centre to centre girder spacing of 3.2m supporting cast in-situ RCC deck slab of 220mm thickness over them. The girders are resting directly over the POT-PTFE bearings.

4.3.1. For 25m span

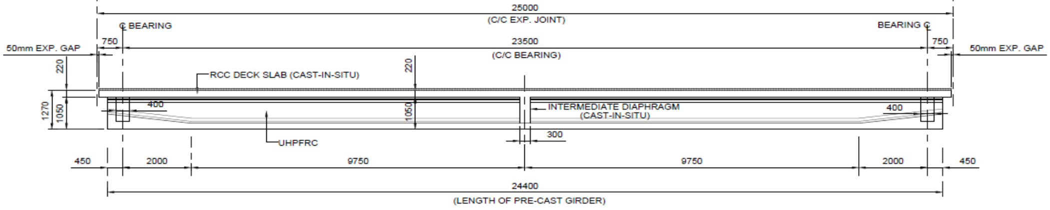

Figure 4. 21 Elevation of 25m span UHPFRC post tensioned I girder

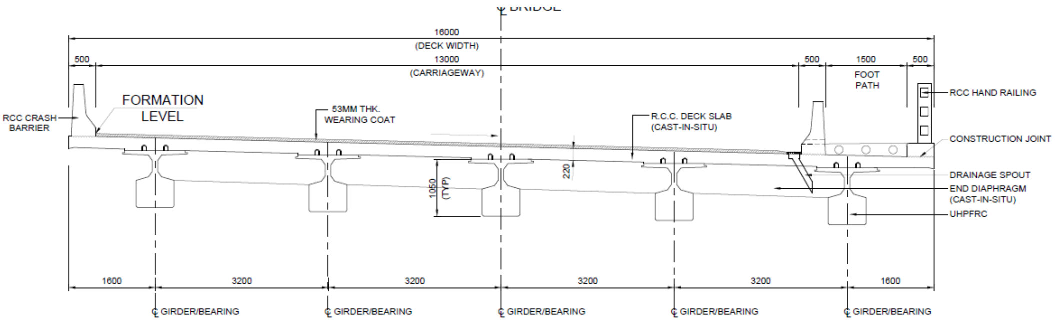

Figure 4. 22 Cross section of 25m span UHPFRC post tensioned I girder at support

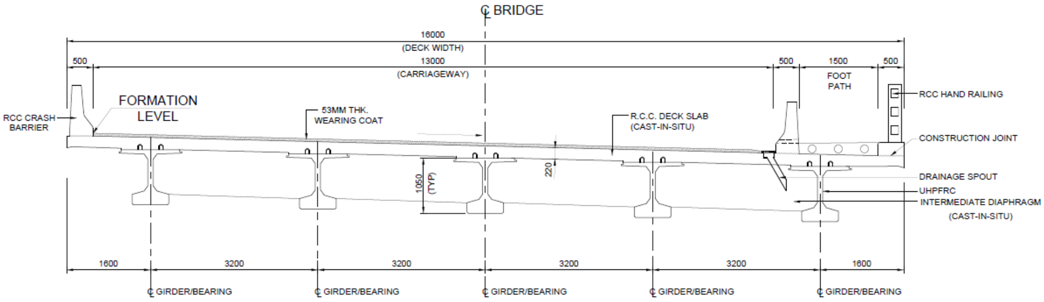

Figure 4. 23 Cross section of 25m span UHPFRC post tensioned I girder at mid span

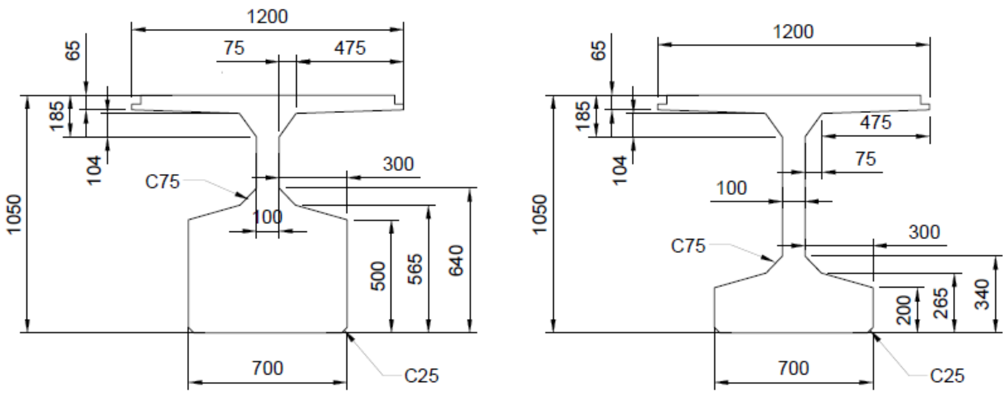

Figure 4. 24 Girder section of 25m span UHPFRC post tensioned I girder at support and mid span

4.3.2. For 30m span

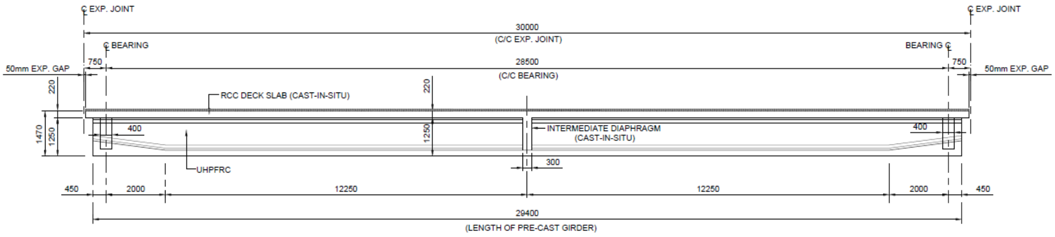

Figure 4. 25 Elevation of 30m span UHPFRC post tensioned I girder

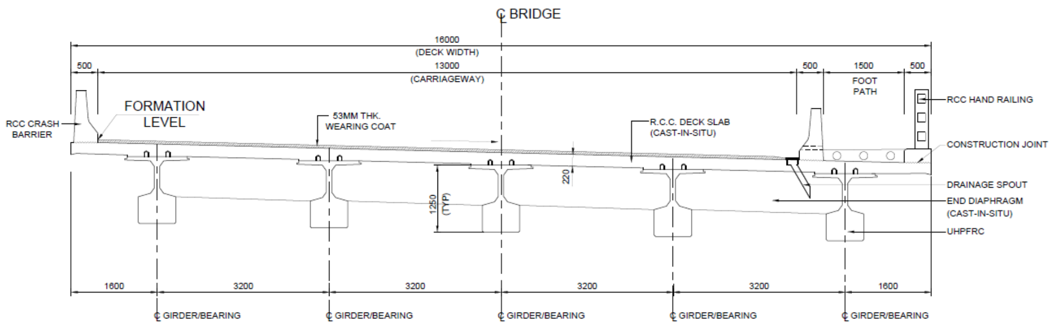

Figure 4. 26 Cross section of 30m span UHPFRC post tensioned I girder at support

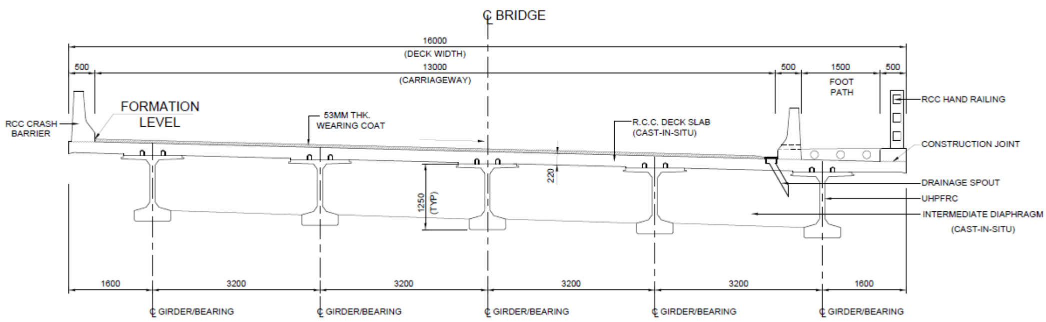

Figure 4. 27 Cross section of 30m span UHPFRC post tensioned I girder at mid span

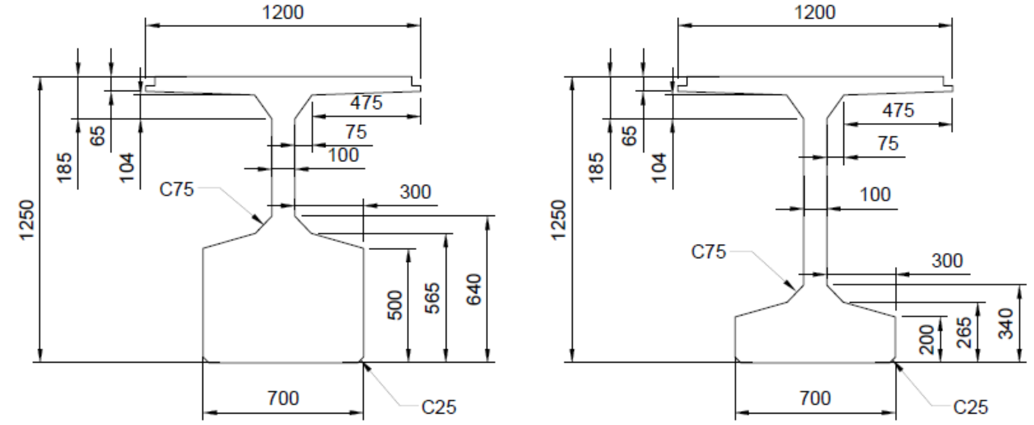

Figure 4. 28 Girder section of 30m span UHPFRC post tensioned I girder at support and mid span

4.3.3. For 35m span

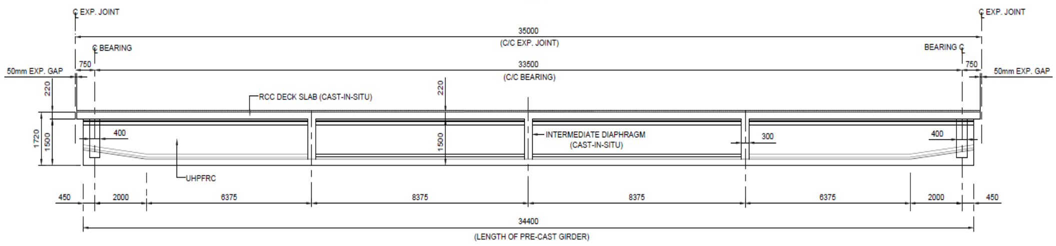

Figure 4. 29 Elevation of 35m span UHPFRC post tensioned I girder

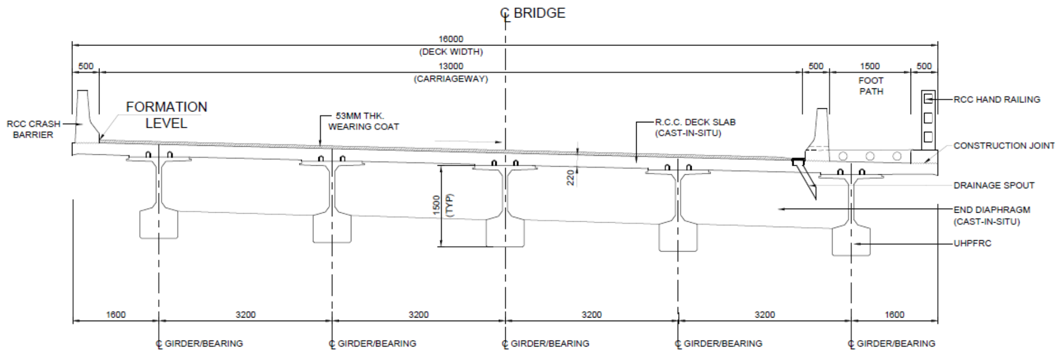

Figure 4. 30 Cross section of 35m span UHPFRC post tensioned I girder at support

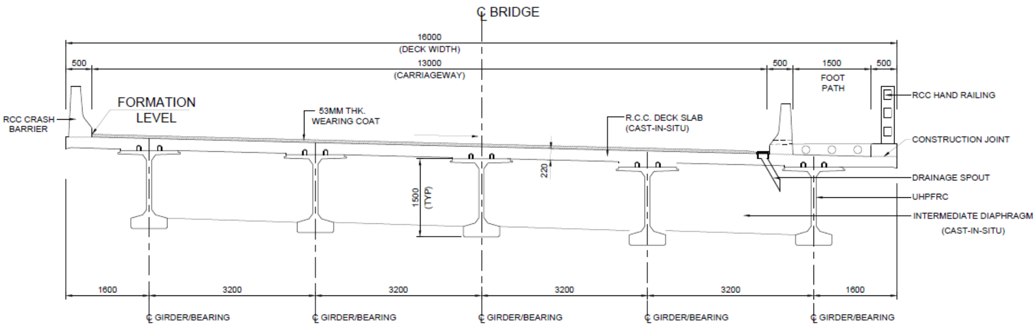

Figure 4. 31 Cross section of 35m span UHPFRC post tensioned I girder at mid span

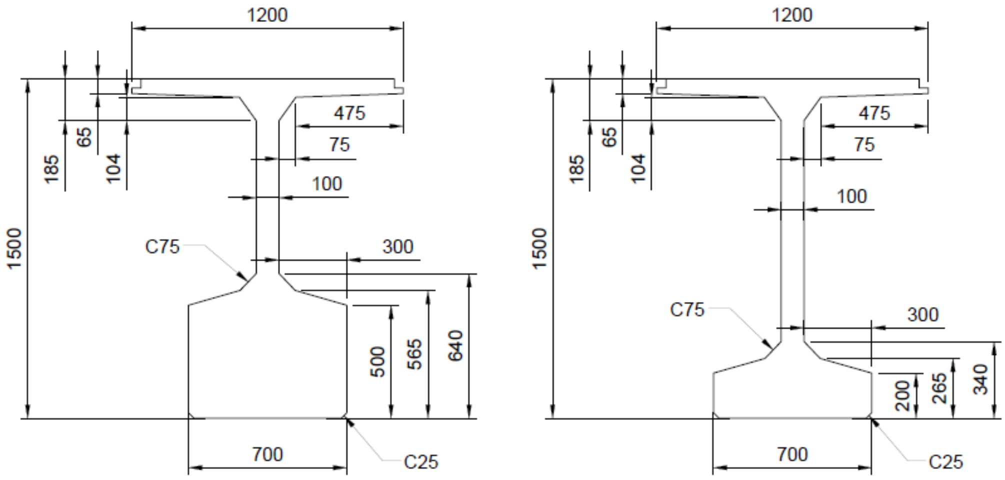

Figure 4. 32 Girder section of 35m span UHPFRC post tensioned I girder at support and mid span

4.3.4. For 40 span

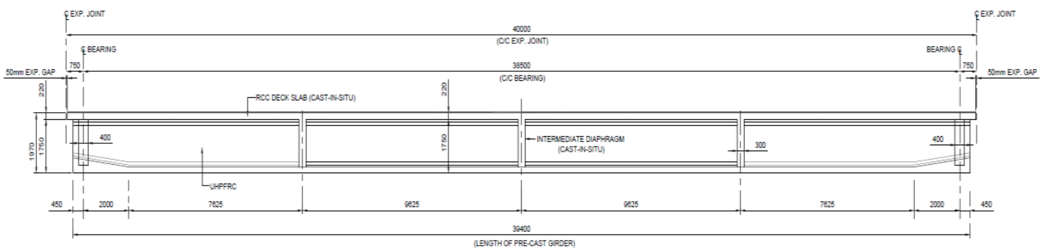

Figure 4. 33 Elevation of 40m span UHPFRC post tensioned I girder

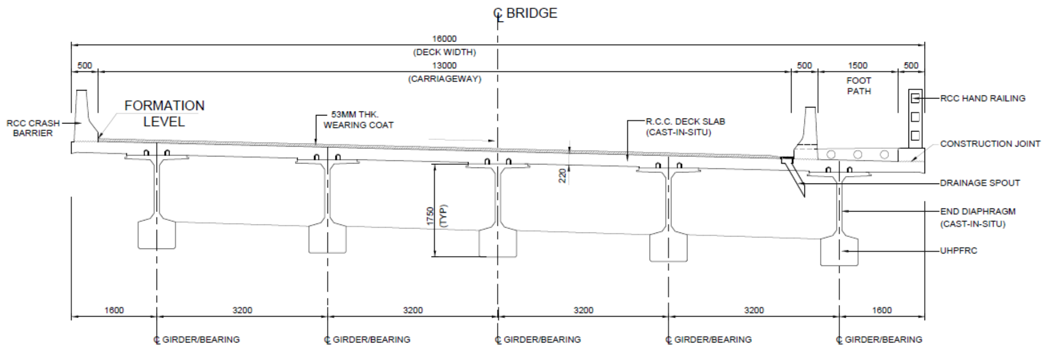

Figure 4. 34 Cross section of 40m span UHPFRC post tensioned I girder at support

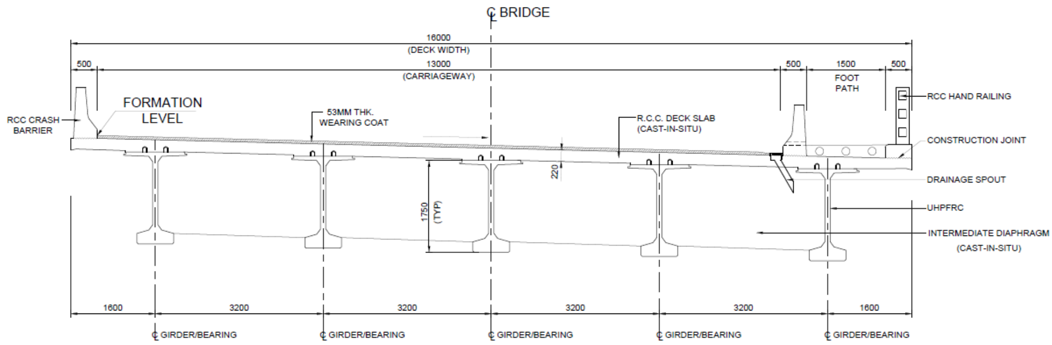

Figure 4. 35 Cross section of 40m span UHPFRC post tensioned I girder at mid span

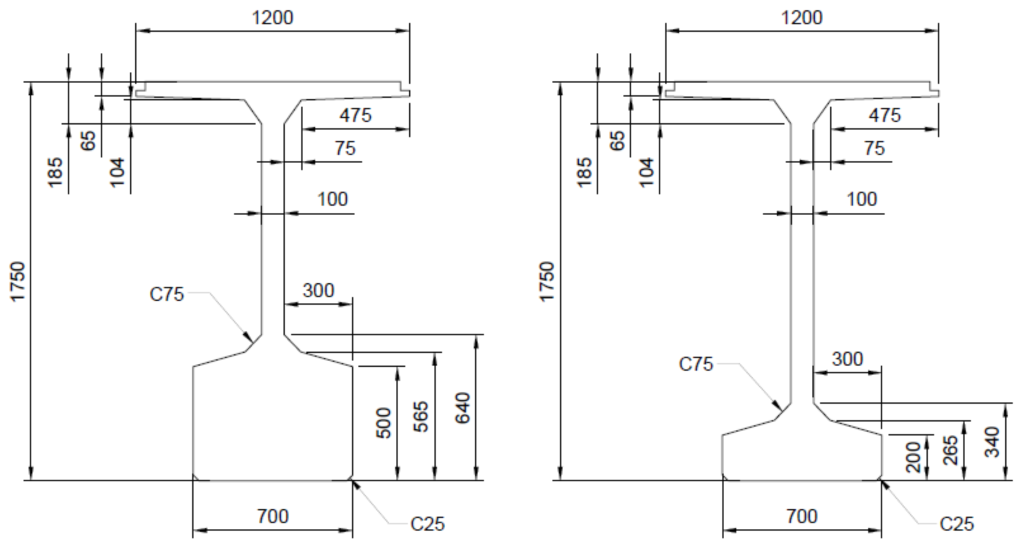

Figure 4. 36 Girder section of 40m span UHPFRC post tensioned I girder at support and mid span

4.3.5. For 45m span

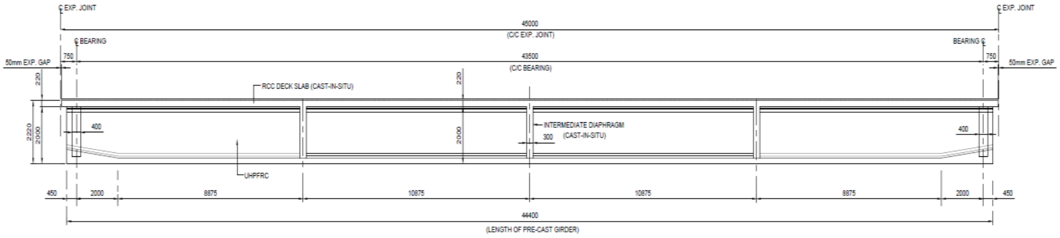

Figure 4. 37 Elevation of 45m span UHPFRC post tensioned I girder

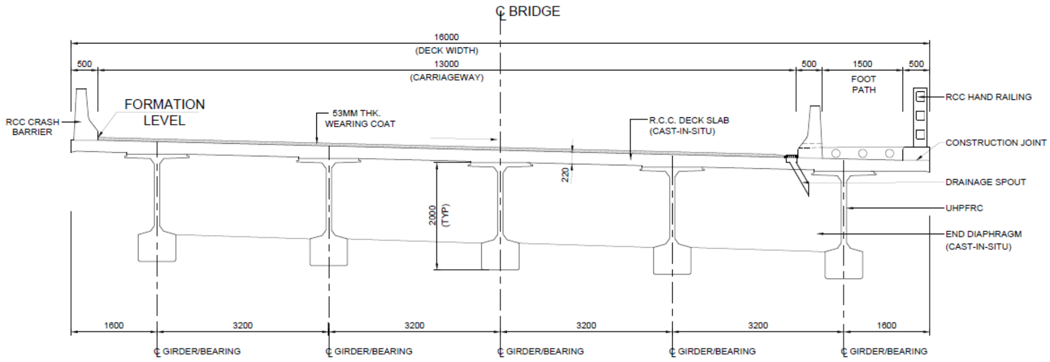

Figure 4. 38 Cross section of 45m span UHPFRC post tensioned I girder at support

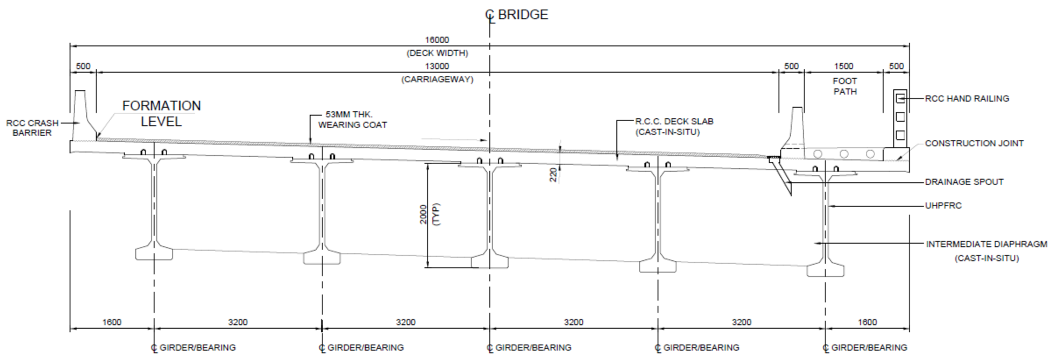

Figure 4. 39 Cross section of 45m span UHPFRC post tensioned I girder at mid span

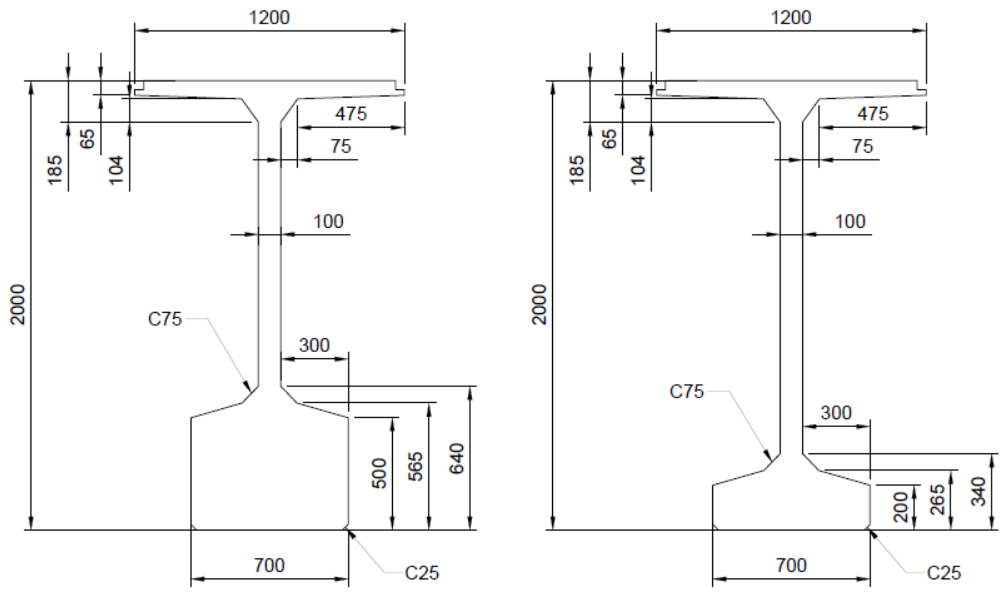

Figure 4. 40 Girder section of 45m span UHPFRC post tensioned I girder at support and mid span

4.4. Summary of bending moment and shear force for post-tensioned I girders for individual loads

The maximum bending moment is considered at mid span and maximum shear force is considered at centre line of bearing among the governing of the inner and outer girders.

4.4.1. For 25m span

Weight of post tensioned I girder made of ordinary concrete – 53 ton

Weight of post tensioned I girder made of UHPFRC – 22 ton

Table 4. 1 Moment and shear force summary for 25.0m span girder

S No.	Loads	Bending Moment (ton-m)		Shear force (ton)	
		Ordinary concrete	UHPFRC	Ordinary concrete	UHPFRC
1	Dead load	134	62	25	11
2	Deck slab	169	169	29	29
3	Crash barrier	55	55	11	11
4	Wearing course	30	30	5	5
5	Governing live load	248	248	41	41
6	ULS combination	908	811	158	139

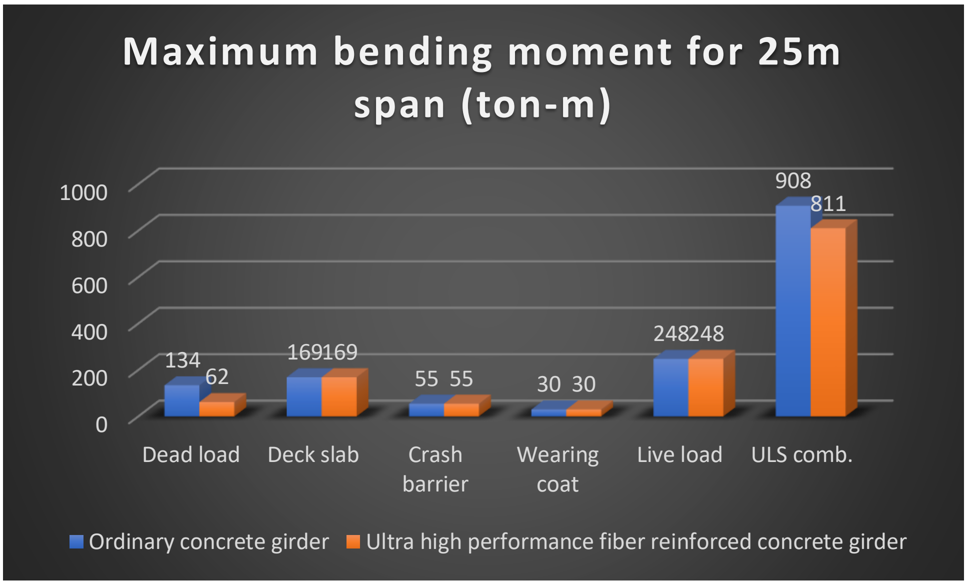

Figure 4. 41 Maximum BM for individual load cases for 25m span

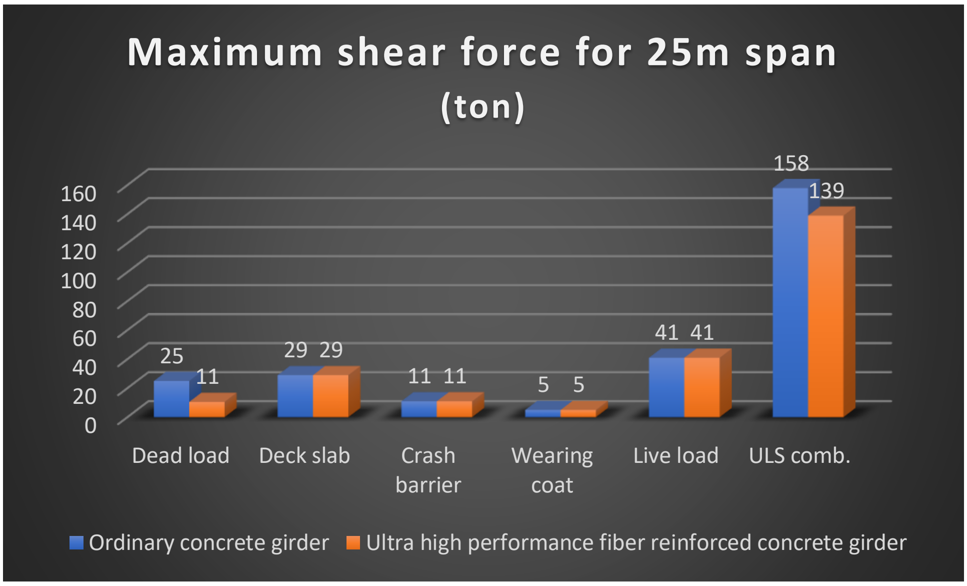

Figure 4. 42 Maximum SF for individual load cases for 25m span

4.4.2. For 30m span

Weight of post tensioned I girder made of ordinary concrete – 71 ton

Weight of post tensioned I girder made of UHPFRC – 28 ton

Table 4. 2 Moment and shear force summary for 30.0m span girder

S No.	Loads	Bending Moment (ton-m)		Shear force (ton)	
		Ordinary concrete	UHPFRC	Ordinary concrete	UHPFRC
1	Dead load	220	96	34	14
2	Deck slab	250	250	35	35
3	Crash barrier	69	69	12	12
4	Wearing course	44	44	6	6
5	Governing live load	327	327	43	43
6	ULS combination	1295	1128	184	157

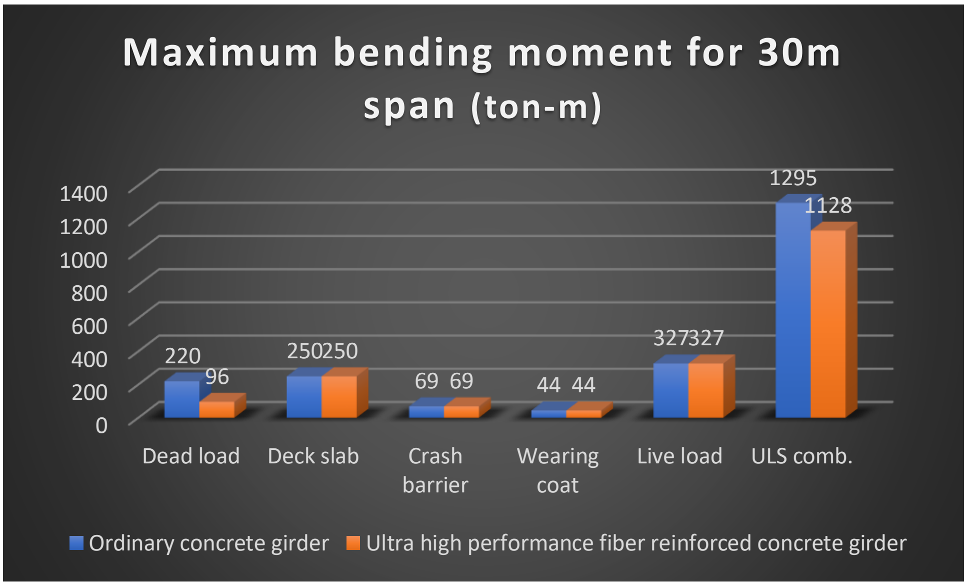

Figure 4. 43 Maximum BM for individual load cases for 30m span

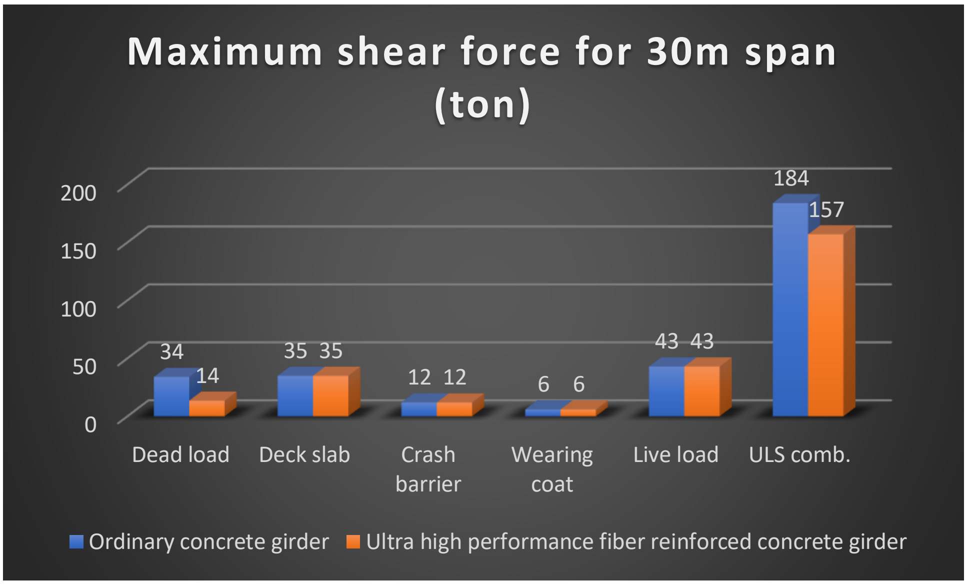

Figure 4. 44 Maximum SF for individual load cases for 30m span

4.4.3. For 35m span

Weight of post tensioned I girder made of ordinary concrete – 94 ton

Weight of post tensioned I girder made of UHPFRC – 36 ton

Table 4. 3 Moment and shear force summary for 35.0m span girder

S No.	Loads	Bending Moment (ton-m)		Shear force (ton)	
		Ordinary concrete	UHPFRC	Ordinary concrete	UHPFRC
1	Dead load	338	146	45	17
2	Deck slab	344	344	41	41
3	Crash barrier	82	82	11	11
4	Wearing course	62	62	7	7
5	Governing live load	389	389	43	43
6	ULS combination	1723	1464	208	170

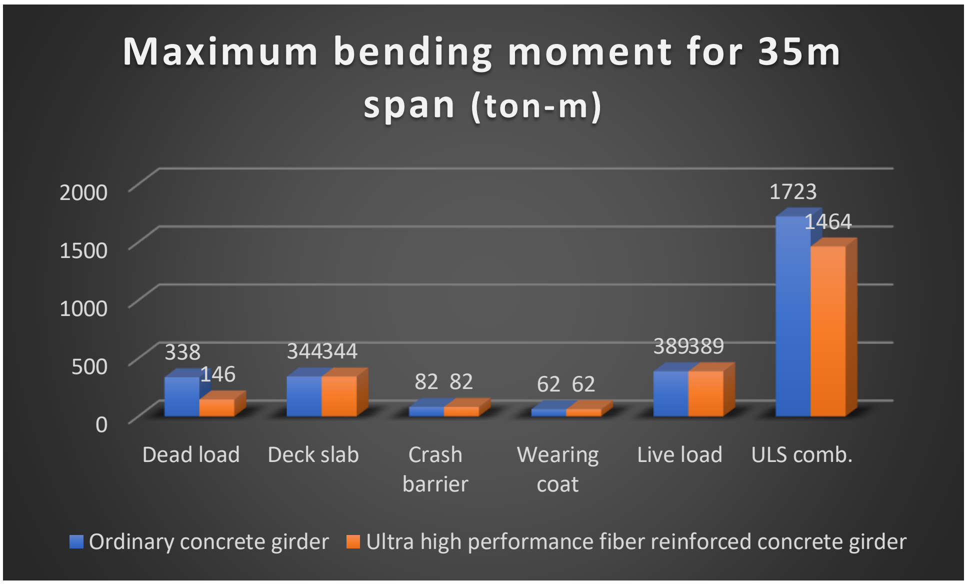

Figure 4. 45 Maximum BM for individual load cases for 35m span

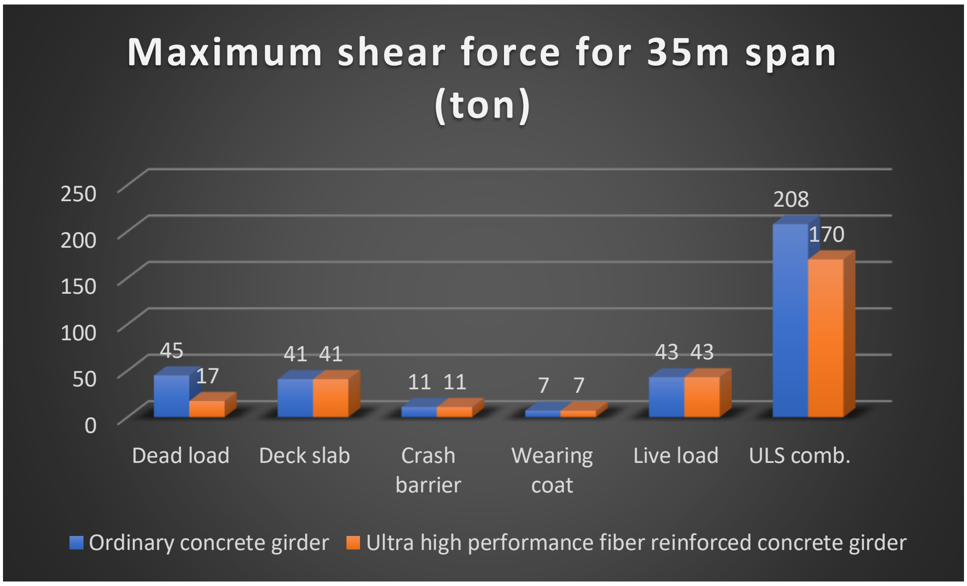

Figure 4. 46 Maximum SF for individual load cases for 35m span

4.4.4. For 40m span

Weight of post tensioned I girder made of ordinary concrete – 117 ton

Weight of post tensioned I girder made of UHPFRC – 44 ton

Table 4. 4 Moment and shear force summary for 40.0m span girder

S No.	Loads	Bending Moment (ton-m)		Shear force (ton)	
		Ordinary concrete	UHPFRC	Ordinary concrete	UHPFRC
1	Dead load	488	204	56	21
2	Deck slab	454	454	48	48
3	Crash barrier	102	102	12	12
4	Wearing course	81	81	8	8
5	Governing live load	467	467	44	44
6	ULS combination	2252	1868	238	191

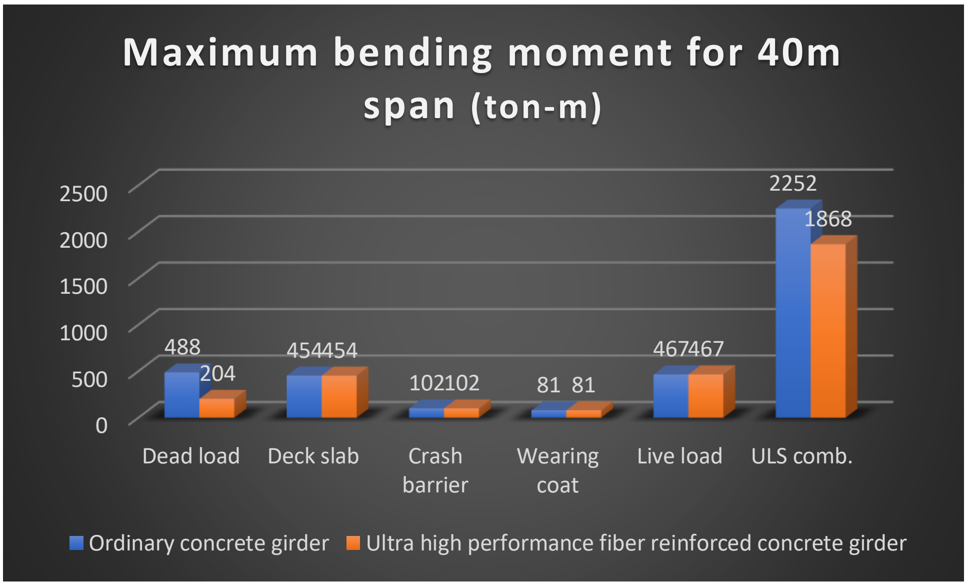

Figure 4. 47 Maximum BM for individual load cases for 40m span

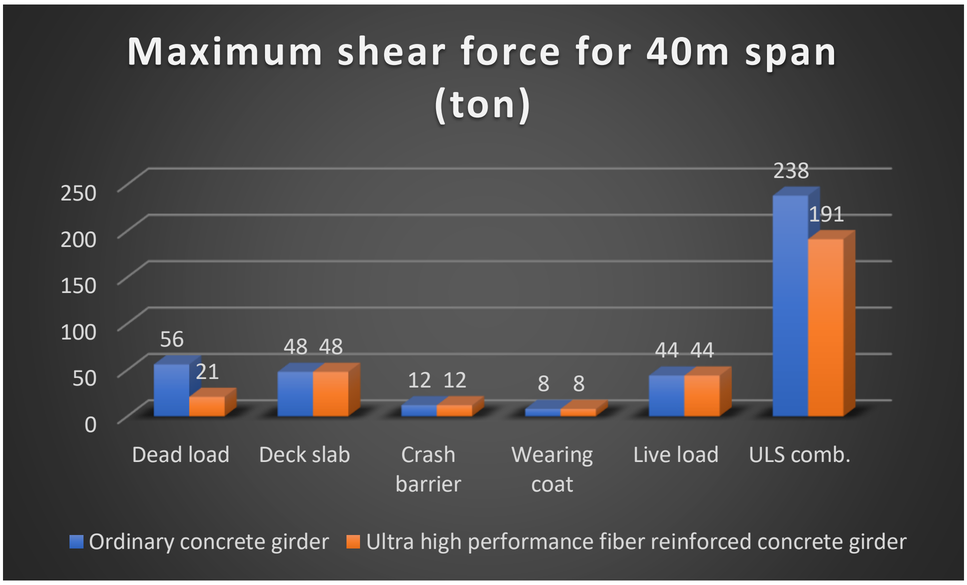

Figure 4. 48 Maximum SF for individual load cases for 40m span

4.4.5. For 45m Span

Weight of post tensioned I girder made of ordinary concrete – 143 ton

Weight of post tensioned I girder made of UHPFRC – 53 ton

Table 4. 5 Moment and shear force summary for 45.0m span girder

S No.	Loads	Bending Moment (ton-m)		Shear force (ton)	
		Ordinary concrete	UHPFRC	Ordinary concrete	UHPFRC
1	Dead load	676	284	69	26
2	Deck slab	580	580	53	53
3	Crash barrier	128	128	13	13
4	Wearing course	104	104	9	9
5	Governing live load	543	543	47	47
6	ULS combination	2865	2336	269	211

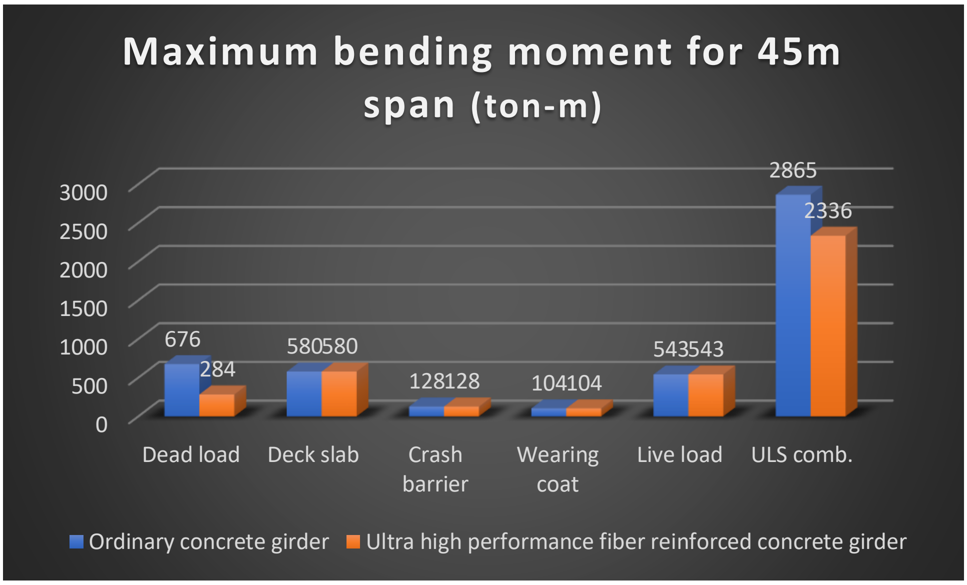

Figure 4. 49 Maximum BM for individual load cases for 45m span

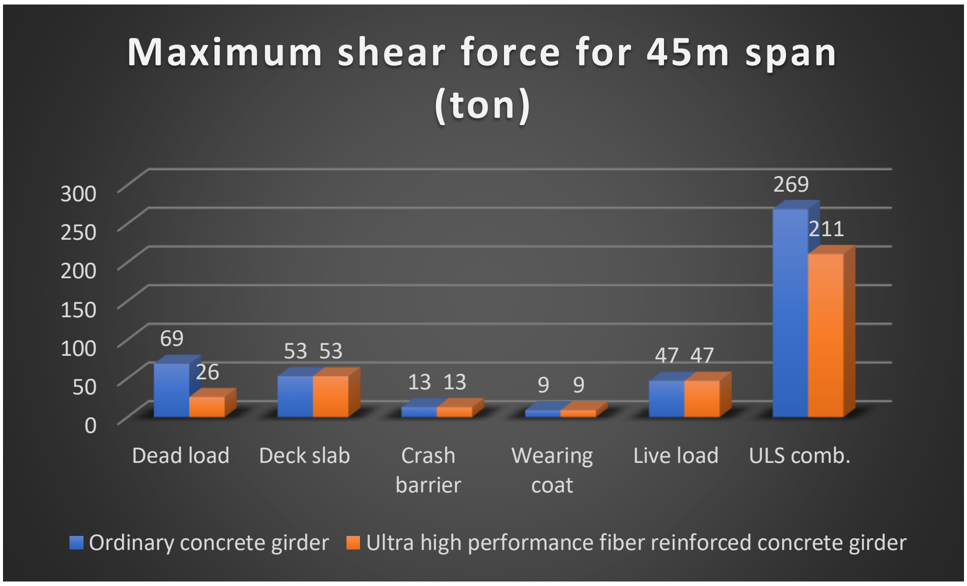

Figure 4. 50 Maximum SF for individual load cases for 45m span

4.5. Quantity & cost comparison

The detailed analysis is done for superstructures comprising of post tensioned I girder made of ordinary concrete and UHPFRC for various spans: 25m, 30m, 35m, 40m and 45m in order to determine their concrete quantity, prestress quantity, shear reinforcement quantity, interface shear reinforcement quantity, untensioned reinforcement quantity and erection quantity. The components common to both type of girders such as deck slab, end diaphragm and intermediate diaphragms are not considered for comparison. Ultimately the cost comparison is done for both type of girders to evaluate the economical girder type for each span length. The rates are considered as per the Delhi Scheule of Rates 2023 [17].

4.5.1. For 25m span

Table 4. 6 Quantity and cost comparison for 25m span girder

S No.	Item	Unit	Ordinary concrete girder			UHPFRC girder		
			Quantity	Rate (₹)	Amount (₹)	Quantity	Rate (₹)	Amount (₹)
1	Concrete	Cum	20.8	14000	291161	8.6	89000	766922
2	Erection	MT	53.0	4600	243800	22.0	4600	101016
3	Prestress cable	MT	1.1	235000	251436	1.1	235000	251436
4	Shear reinforcement (Fe500D)	MT	0.8	90000	74870	0.2	90000	16286
5	Untensioned reinforcement (Fe500D)	MT	0.9	90000	78613	0.0	90000	0
Total cost of each girder			₹ 9,39,881			₹ 11,35,661		

4.5.2. For 30m span

Table 4. 7 Quantity and cost comparison for 30m span girder

S No.	Item	Unit	Ordinary concrete girder			UHPFRC girder		
			Quantity	Rate (₹)	Amount (₹)	Quantity	Rate (₹)	Amount (₹)
1	Concrete	Cum	27.9	14000	391144	11.0	89000	975416
2	Erection	MT	71.2	4600	327520	27.9	4600	128478
3	Prestress cable	MT	1.6	235000	374714	1.5	235000	358769
4	Shear reinforcement (Fe500D)	MT	1.1	90000	100580	0.2	90000	21700
5	Untensioned reinforcement (Fe500D)	MT	1.3	90000	113152	0.0	90000	0
Total cost of each girder			₹ 13,0,111			₹ 14,84,363		

4.5.3. For 35m span

Table 4. 8 Quantity and cost comparison for 35m span girder

S No.	Item	Unit	Ordinary concrete girder			UHPFRC girder		
			Quantity	Rate (₹)	Amount (₹)	Quantity	Rate (₹)	Amount (₹)
1	Concrete	Cum	36.8	14000	515300	14.0	89000	1246423
2	Erection	MT	93.8	4600	431480	35.7	4600	164174
3	Prestress cable	MT	2.2	235000	513069	1.9	235000	457098
4	Shear reinforcement (Fe500D)	MT	1.7	90000	149069	0.3	90000	28990
5	Untensioned reinforcement (Fe500D)	MT	1.8	90000	165632	0.0	90000	0
Total cost of each girder			₹ 17,74,550			₹ 18,96,685		

4.5.4. For 40m span

Table 4. 9 Quantity and cost comparison for 40m span girder

S No.	Item	Unit	Ordinary concrete girder			UHPFRC girder		
			Quantity	Rate (₹)	Amount (₹)	Quantity	Rate (₹)	Amount (₹)
1	Concrete	Cum	46.0	14000	643850	17.3	89000	1536638
2	Erection	MT	117.2	4600	539120	44.0	4600	202400
3	Prestress cable	MT	2.9	235000	683803	2.5	235000	576959
4	Shear reinforcement (Fe500D)	MT	2.7	90000	244203	0.4	90000	37294
5	Untensioned reinforcement (Fe500D)	MT	2.8	90000	252481	0.0	90000	0
Total cost of each girder			₹ 23,63,457			₹ 23,53,291		

4.5.5. For 45m span

Table 4. 10 Quantity and cost comparison for 45m span girder

S No.	Item	Unit	Ordinary concrete girder			UHPFRC girder		
			Quantity	Rate (₹)	Amount (₹)	Quantity	Rate (₹)	Amount (₹)
1	Concrete	Cum	56.0	14000	783387	20.9	89000	1860729
2	Erection	MT	142.6	4600	655960	53.3	4600	245088
3	Prestress cable	MT	3.8	235000	903024	3.1	235000	722419
4	Shear reinforcement (Fe500D)	MT	3.5	90000	312236	0.5	90000	47041
5	Untensioned reinforcement (Fe500D)	MT	3.6	90000	327344	0.0	90000	0
Total cost of each girder			₹ 29,81,951			₹ 28,75,277		

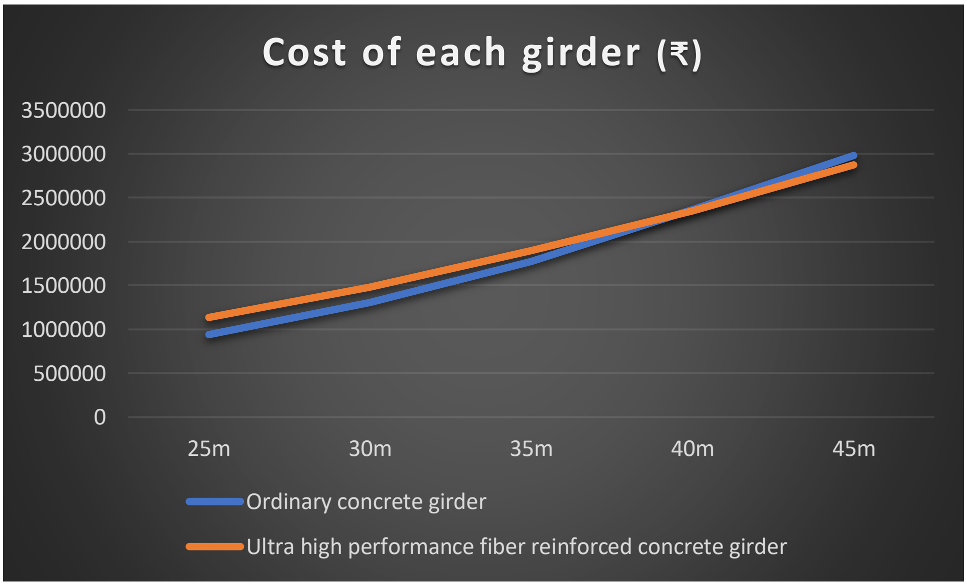

Figure 4. 51 Cost of each girder for different spans for OC girder and UHPFRC girder

CHAPTER 5
CONCLUSION, FUTURE SCOPE & SOCIAL IMPACT

5.1. Summary

The objectives were set after conducting an extensive review of literature concerning the efficiency of post-tensioned I girders, the material properties, and the design of UHPFRC girders. This thorough literature review formed the basis for identifying gaps and constraints in previous studies related to the practical application of UHPFRC girders over conventional concrete girders in bridge engineering.

Chapter 2 of this thesis provides a detailed explanation of the relevant literature, organized into various sections. The inclusion of these literature sources contributes to the overall knowledge base and theoretical framework supporting this research work.

A range of superstructures, spanning from 25m to 45m, underwent analysis and design, considering both ordinary concrete post-tensioned I girders and UHPFRC I girders. Grillage analysis was conducted for all superstructures, and loading was applied following the standard guidelines outlined in IRC:6-2017 for road bridges. Girder design adhered to the specifications outlined in IRC:112-2020. In instances where relevant Indian codes for ultra-high-performance fiber-reinforced concrete were not available, NF P18-710 (French standard) was selectively employed. These aspects are extensively discussed in Chapter 3 of this thesis.

In Chapter 4 of this thesis, a comprehensive presentation of the results derived from software analysis and design of the post-tensioned I girders across all spans is provided. A detailed summary encapsulating the bending moments and shear forces for both types of girders across all spans is outlined. Moreover, a comparison of quantities and costs is presented for post-tensioned I girders constructed from ordinary concrete and UHPFRC across spans ranging from 25m to 45m.

5.2. Conclusion

Various conclusions were drawn from the above studies:

- The optimal span to depth ratio for ordinary concrete post tensioned I girders is approximately 16.
- The optimal span to depth ratio for ultra-high-performance fiber reinforced concrete post tensioned I girders is approximately 22.
- Research findings suggest that ordinary concrete post tensioned I girders are most cost effective for smaller spans ranging up to 40m.
- Conversely, post-tensioned I girders made from ultra-high-performance fiber-reinforced concrete become economically viable for spans exceeding 40.0m. This shift is attributed to various factors, such as reduced girder depth, elimination of untensioned steel requirements, decreased necessity for shear

reinforcement due to the contribution of steel fibers to shear strength, and shallower depths leading to reduced erection costs.

5.3. Future scope

In this research, a comparative analysis has been conducted between post-tensioned I girders fabricated from ordinary concrete and UHPFRC, focusing on identical span lengths. This analysis paves the way for several future considerations:

- Assessing structures with longer spans employing UHPFRC post-tensioned girders, benefitting from their significant compressive and tensile strength. This could potentially lead to fewer substructures compared to structures utilizing ordinary concrete post-tensioned I girders with shorter spans.
- Evaluating superstructures of the same span length based on additional parameters such as cost saving in RE panels and embankments in case of UHPFRC girders owing to their reduced depth.
- Comparing the post tensioned I girders made of ordinary concrete and UHPFRC in terms of sustainability particularly focusing on carbon emissions.

5.4. Social impact

- Research indicates that UHPFRC girders are economical as compared to conventional concrete girders when the span length exceeds 40m. Thus, incorporating the use of UHPFRC shall be contemplated for the highway projects requiring the flyovers, bridges, viaducts etc. of span length in excess of 40m as it can significantly influence the overall project cost.

- Additionally, UHPFRC girders require shallower depths than conventional concrete girders, owing to their significant compressive strength. This implies that the approaches for all structures utilizing UHPFRC will be lowered, potentially leading to cost savings by reducing the overall road profile for a given project.

- This judicious utilization of funds ensures that taxpayer money is wisely allocated for the benefit of society.

- UHPFRC being durable requires less maintenance as compared to conventional concrete. Thus, making it a sustainable option.

- Further, comparison shall be made in terms of CO_2 emissions in both type of girders so as to reduce the overall carbon footprints in a project. Ultimately, this will help in achieving the sustainability goal.

REFERENCES

[1] S Unnikrishna Pillai and Devdas Menon, 2022, Reinforced Concrete Design, Tata Mc Graw Hill Publishing Company Limited.

[2] T.E.T. Buttingol, J.L.A.O. Sousa and T.N. Bittencourt,2017, Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC): a review of material properties and design procedures, IBRACON, Vol. 10, pp. 957-971.

[3] DURA. Technology catalogue, 2023. Kuala Lumour, Malaysia.

[4] Dr. Amlan K Sengupta and Prof. Devdas Menon, 2021, Prestressed Concrete Structures. NPTEL.

[5] N. Krishna Raju, 2007, *Prestressed Concrete*, Tata Mc Graw Hill Publishing Company Limited.

[6] Indian Roads Congress, 2017, IRC:6, Standard Specifications and Code of Practice for Road Bridges, Section II-Loads and Load Combinations.

[7] Indian Roads Congress, 2020, IRC:112, Code of Practice for Concrete Road Bridges.

[8] EN 1992, 2004, Eurocode 2.

[9] S Abdal et.al, 2023, "Application of Ultra-High-Performance Concrete in Bridge Engineering: Current Status, Limitations, Challenges, and Future Prospects", Multidisciplinary Digital Publishing Institute (MDPI), Vol. 13.

[10] Luca Markus and Paul Gauvreau, 2020, Qualitative Measure of Efficiency of Post-Tensioned Concrete Bridges, Journal of Bridge Engineering ASCE, Vol. 25, Issue 7, pp. 1-13.

[11] Doo-Yeol Yoo and Young-Soo Yoon, 2016, A Review on Structural Behavior, Design, and Application of Ultra-High-Performance Fiber-Reinforced Concrete, International Journal of Concrete Structures and Materials, Vol. 10, Issue 2, pp.125–142.

[12] Rim Nayal et. al., 2010, Parametric Study of Posttensioned Inverted-T Bridge System for Improved Durability and Increased Span-to-Depth Ratio, Journal of Bridge Engineering ASCE, Vol. 15, pp. 731-739.

[13] E.C. Hambly, 1991, Bridge Deck Behaviour, CRC Press.

[14] C.S. Surana and R. Agrawal, 2001, Grillage Analogy in Bridge Deck Analysis, Narosa Publishing House.

[15] French Standard, 2016, NF P18-470, Concrete -Ultra-high performance fibre-reinforced concrete- Specifications, performance, production and conformity.

[16] French Standard, 2016, NF P18-470, National addition to Eurocode 2 — Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC).

[17] Director General Central Public Works Department, 2023, Delhi Schedule of Rates (DSR), Vol-1.

PAPER NAME

Ayush Satija_Final Thesis_Plag check.pdf

WORD COUNT **10771 Words**	CHARACTER COUNT **57782 Characters**
PAGE COUNT **65 Pages**	FILE SIZE **3.5MB**
SUBMISSION DATE **May 28, 2024 12:04 PM GMT+5:30**	REPORT DATE **May 28, 2024 12:05 PM GMT+5:30**

10% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

- 8% Internet database
- 3% Publications database
- Crossref database
- Crossref Posted Content database
- 3% Submitted Works database

Excluded from Similarity Report

- Bibliographic material
- Quoted material
- Cited material
- Small Matches (Less then 12 words)

10% Overall Similarity

Top sources found in the following databases:

- 8% Internet database
- 3% Publications database
- Crossref database
- Crossref Posted Content database
- 3% Submitted Works database

TOP SOURCES

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

#	Source	Database	Similarity
1	dspace.dtu.ac.in:8080	Internet	4%
2	researchgate.net	Internet	1%
3	1library.net	Internet	<1%
4	Rim Nayal, Robert J. Peterman, Asad Esmaeily. "Parametric Study of P...	Crossref	<1%
5	pdfcoffee.com	Internet	<1%
6	ia601608.us.archive.org	Internet	<1%
7	pdfcookie.com	Internet	<1%
8	Luca Markus, Paul Gauvreau. "Qualitative Measure of Efficiency of Pos...	Crossref	<1%

9	trid.trb.org Internet	<1%
10	Fiji National University on 2023-05-20 Submitted works	<1%
11	University of Queensland on 2022-09-23 Submitted works	<1%
12	espace.curtin.edu.au Internet	<1%
13	ME MORRIS, RB HANNANT. "SOME ASPECTS OF THE DESIGN AND CO... Crossref	<1%
14	nserc-crsng.gc.ca Internet	<1%
15	Universiti Tenaga Nasional on 2020-10-16 Submitted works	<1%
16	eprints.utm.my Internet	<1%
17	id.scribd.com Internet	<1%
18	umpir.ump.edu.my Internet	<1%