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Comparative Study of Single and Double Stage Post-tensioning of I-Girder for Various Spans in Metro Projects-A Review

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***Abstract*— As Indian Metro Cities are growing with population serge the new transport systems like Metro are required in High priority. For Metro construction the I girders and U girders components designing, and construction should be fast and reliable is need in now days. This project analyzed various span Post tensioned I-Girders by using STAAD software. This report explains the general sectional properties material strength loading condition and analysis of I-Girders for Single stage & Double stage comparison.**

***Keywords*— metro; I Girder; post-tensioning;**

I. INTRODUCTION

This template, The Metro Bridges, iconic architectural marvels intertwined with the heartbeat of urban landscapes, serve as lifelines connecting bustling city sectors with seamless efficiency. At first glance, they are colossal structures of steel and concrete, but upon closer inspection, their design unveils a narrative of innovation and engineering prowess.

In both bridges and metro systems, girders are indispensable components, providing the structural backbone necessary for safe and efficient transportation infrastructure.

In the realm of bridge construction, post-tensioning plays a pivotal role in enhancing the structural performance and longevity of various bridge components. Single-stage and double-stage post-tensioning are two primary techniques employed in this process, each with its own unique characteristics and applications.

The superstructure of a large part of the viaduct comprises of simply supported spans with precast pre tensioned U-girder. However, at obligatory locations of span, and where it is not feasible to provide U girder, pre tensioned / post tensioned I girder or box girder will be provided. Normally the super structure will accommodate the two tracks situated at 5.03m c/c.

The concept of pre-stressed concrete appeared in 1888 when P.H. Jackson was granted the first patent in the United States for prestressed concrete design. According to Freyssinet, it was in 1903 that he first had the idea of consolidating concrete by prestressing.

A. History of Bridges and Pre-stressed Concrete

Industrial Revolution (18th-19th Century):

The industrial revolution spurred advancements in iron and steel production, leading to the widespread adoption of metal beams in construction.

Early Steel Bridges (Late 19th Century):

The introduction of steel as a construction material revolutionized bridge engineering, enabling the construction of longer, stronger, and more durable bridges.

I-girders became a popular choice for bridge construction due to their high strength-to-weight ratio, allowing engineers to design bridges with longer spans and reduced dead load.

Development of Rolled Steel Sections (Late 19th Century):

The invention of the Bessemer process and subsequent advancements in steel manufacturing led to the mass production of rolled steel sections, including I-beams

Expansion of Railway Networks (Late 19th-Early 20th Century):

The rapid expansion of railway networks during the late 19th and early 20th centuries drove demand for robust bridge structures capable of supporting heavy locomotives and freight traffic.

I-girders played a significant role in the construction of railway bridges, offering an economical and efficient solution for spanning over railway tracks and waterways.

Advancements in Bridge Design and Construction (20th Century):

Throughout the 20th century, engineers continued to refine the design and construction of I-girder bridges, incorporating innovations such as welded connections, high-strength steels, and improved fabrication techniques.

Modern Applications and Innovations (21st Century):

In the 21st century, I-girder bridges remain a prevalent choice for infrastructure projects worldwide, thanks to their cost-effectiveness, ease of fabrication, and structural efficiency.

B. Pre-stressed Concrete

Pre-stressed concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from external loads are counteracted to desired degree. In reinforced concrete structures, the prestressing is mostly done by tensioning the the steel reinforcement.

Advantages and Disadvatages of Pre-stressed Concrete.

As compared to RCC, steel prestressed concrete gives technical advantage. Prestressed concrete members possess improved resistance to shearing forces, because of compressive prestress, which reduces the principal tensile stress. In Long span members we can use curved cables to reduce shear forces.

Advantages of pre-stressed concrete

- Low maintenance cost is enough.
- It is economical for long-span structure.
- It takes less time for construction.
- Even in shallow foundations prestressed concrete can be used for longer spans.
- The prestressed concrete provides the smooth and pleasant crack free surface.
- As compared to RCC, prestressed concrete gives better resistance to shear failure.
- In Prestressed concrete structures the sustainability will be increase against sudden impact.
- Prestressed concrete can reduce the depth of foundation.
- As compared to RCC, prestressed concrete is more durable.
- Prestressed concrete is widely used in the construction of bridges, railway sleepers, and dams.
- In prestressed concrete Dead load of the structure is less than as compared to RCC.

Disadvantages of Pre-stressed concrete

- It is economical for large-span structures only.
- Prestressed concrete requires more space.
- Highly skilled manpower and supervision required.
- Transportation of pre-stressed concrete is a little difficult.
- Higher grades of concrete and steel are needed to get good strength.
- Specialized equipment such as jacks, anchorage required for prestressing in concrete

II. METHODS OF PRE-STRESSING

Pre-tensioning

In pretensioned members, the tendons are tense before casting of the concrete. One end of the reinforcement is secured to an abutment while the other end of the reinforcement is pulled by using a jack and this end is then fixed to another abutment. The concrete is then poured. After the concrete has cured and hardened the ends of the reinforcement are released from the abutment. By bond action the reinforcement which tends to come its original length can compress the concrete surrounding. The prestress is thus transmitted to concrete entirely by the action of bond between reinforcement and surrounding concrete.

Post-tensioning

A post-tensioned member is one in which the reinforcement is tensioned after the concrete has fully hardened. When concrete has hardened and developed its strength. The tendon is passed through the duct. One end is provided with an anchor and is fixed to the one end of the member. Now the other end of the tendon is pulled by a jack that is butting against the end of the member. The jack at that time pulls the tendon and compresses the concrete. After the tendon is subjected to the desired stresses the end of the tendon is also properly anchored to the concrete

Pre-tensioning and Post Tensioning of Concrete: A Comparative Look

Pre-tensioning and post tensioning of concrete, In comparison of two it becomes clear that each has its own set of advantages.

Efficiency in Material Use

- Pre-tensioning often requires less concrete and steel due to high initial compression. This can result in cost-effective structures.
- Post-tensioning structures could be thinner, more flexible structures and can be also lead to economic structures.

Structural Benefits

- Pretensioned concrete components are strong and have capacity to take higher loads.
- Post-tensioned concrete having greater flexibility, could allow design creativity, like in projects which having unique architectural requirements.

Single-stage and double-stage post-tensioning.

In the realm of bridge construction, post-tensioning plays a pivotal role in enhancing the structural performance and longevity of various bridge components. Single-stage and double-stage post-tensioning are two primary techniques employed in this process, each with its own unique characteristics and applications.

Single-Stage Post-Tensioning:

Single-stage post-tensioning involves the simultaneous tensioning of all the tendons in a bridge structure once the concrete has reached a sufficient level of strength. This method typically employs specialized equipment to apply the required tension to the tendons, which are then anchored at the ends of the bridge span. The tendons are typically installed before the concrete is poured, and once the concrete has cured to the desired strength, they are tensioned to impart compressive forces on the concrete, enhancing its load-carrying capacity.

Double-Stage Post-Tensioning:

Double-stage post-tensioning, on the other hand, involves tensioning the tendons in two separate stages. In the first stage, the tendons are partially tensioned shortly after the

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concrete is poured and has achieved a specified strength. This initial tensioning helps to mitigate early-age shrinkage and creep effects in the concrete. Then, in the second stage, typically after the concrete has further cured and gained additional strength, the tendons are fully tensioned to their design load.

This method offers several advantages, including reduced concrete cracking and improved long-term performance due to the staged application of forces. It is often employed in bridges with longer spans or complex geometries where controlling early-age concrete behavior is critical.

III. I GIRDER IN METRO VIADUCT

Fig-: 4 Mumbai Metro Line 1

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Metro rail transportation is mostly built in urban areas, and known as mass rapid transit (MRT), heavy rail, or metro, is a type of high-capacity public transport. It’s a totally rail-based mass transit system, which could be elevated, or underground. According to one study metro rail can have a very high capacity of 40,000 – 80,000 passengers per hour per direction.

Elements of Metro viaduct

In metro viaduct construction, the superstructure and substructure elements are essential components that work together to support the elevated tracks and ensure the safety and stability of the entire system. Let's delve into the roles and characteristics of each:

Superstructure:

- It is economical for large-span structures only.
- Tracks and Rails: The superstructure of a metro viaduct consists primarily of the tracks and rails upon which the trains run. These are typically laid on top of the supporting beams or girders.
- Slabs or Decking: A concrete slab or decking system forms the surface on which the tracks are laid. This slab provides a stable base for the tracks and distributes the load of the trains to the supporting beams.
- Ballast or Track Bed: Depending on the design, there may be a layer of ballast or a track bed beneath the tracks. This layer helps to distribute loads, provide drainage, and stabilize the tracks.
- Overhead Catenary System (OCS): In electrified metro systems, the superstructure includes the overhead catenary system, which supplies power to the trains through contact with a pantograph mounted on the train's roof.
- Other Components: Superstructure elements may also include expansion joints, drainage systems, safety barriers, and any necessary signaling and communications equipment.

Substructure:

- Piers or Columns: The substructure of a metro viaduct comprises the piers or columns that support the elevated structure.
- Foundations: Foundations provide the base upon which the piers or columns are constructed.
- Abutments: At the ends of the viaduct, abutments support the transition from the elevated structure to the ground level.
- Retaining Walls: In cases where the viaduct is constructed on uneven terrain or requires support against soil movement, retaining walls may be included as part of the substructure.
- Access Structures: Substructure elements may also include access structures such as staircases, elevators, or ramps that provide access to the elevated tracks for maintenance personnel or passengers.

Both the superstructure and substructure elements of a metro viaduct must be designed and constructed in harmony to ensure the overall stability, safety, and longevity of the infrastructure. Proper coordination between these elements is essential to support the loads imposed by the trains, withstand environmental factors such as wind and seismic forces, and provide a smooth and reliable transit experience for passengers.

I Girder

Spans greater than 28m and radius sharper than, 200 m I-Girder Superstructure/ Steel Span is proposed.

Pic: Kochi Metro I girder

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U Girder
For a Span configuration up to 28m and curvature up to 200m, viaduct shall have Precast Pre-Tensioned U girder system

fig: Mumbai Metro U girder

Mmrdawebsite

IV. LITERATURE REVIEW

The following research paper has been reviewed
Nadavala Mahesh and et al in (2016) studied "A Technique Using Box Girder For Elevated Structures" in this paper, they conducted parametric study of box girder bridges and demonstrated that, Responses parameter longitudinal stresses at the very top and bottom, shear, torsion, moment and deflection are decreases for 3 kinds of box girder bridges As the radius of curvature increases, also it shows very little variation for fundamental frequency of three kinds of box girder bridges because of the constant span length.
The study evaluated the performance of a pier designed using both Pressure Based Design (PBD) Method and Direct Displacement Based Design (DDBD) Technique. Results showed that the pier designed using the PBD Method may not always meet the required performance parameters, while the DDBD Method achieved higher conduct factors than targeted values. The research conducted a parametric study of box girder bridges using finite element analysis. Parameters studied included radius of curvature, span length, span length to radius of curvature ratio, and number of boxes. Findings revealed that as the radius of curvature increases, certain response parameters such as longitudinal stresses, shear, torsion, moment, and deflection decrease for all types of box girder bridges, while the fundamental frequency remains relatively constant.

Vignesh Kini K., Rajeeva S.V. (2017), with the help of CSI ETABS 2016 investigated about the behaviour of composite and RCC girder and their comparison for response spectrum analysis and construction sequence analysis for zone-II in the form of bending moments, displacement and shear force of transfer girder.

Vikas V. Mehetre1, V. T. More (2018) analyzed effect of different positions of shear wall on transfer girder for wind, conventional and stage analysis to study the response and behaviour of 10,15,20,25,30 storey RC building with floating column at exterior position of frame, situated in zone-IV for different cases of each storey i.e. Without shear wall.
In conclusion, the study highlights the importance of considering different positions of shear walls in structures with floating columns and transfer girders, emphasizing the need for comprehensive analyses to ensure structural safety and stability in seismic and wind-prone regions.

James Edmunds and his team (2018)-The research conducted from the Faculty of Engineering and Information Technology at the University of Melbourne delves into an alternative method for rural bridge construction in Australia. Traditional practice involves pouring concrete on-site to connect and distribute loads among beams, but this method poses risks and is often avoided by contractors. As an alternative, the team explores the use of transverse post-tensioning to tie beams together, aiming to assess its effectiveness compared to poured decks.

Emad S. Mushtaha1*, Ranime Nahlé1, Nour Tahmaz1, and Mohammed AlKadry1 (2019) Dept. of Architectural Engineering, College of Engineering, University of Sharjah studied "Designing Guidelines for Metro Stations in Developing Countries: The Case of Dubai". The study underscores the importance of selecting appropriate roof forms for metro stations in hot climate regions like Dubai.

Sandipan Goswami, B. Sc, BE, M. Tech, FIE, C. Eng, PE (M) (2020) "Design of PSC I-Girder Bridge Deck-Girder Superstructure in BS Eurocode II and BD 37/01" This research paper researched on introducing the typical process of designing deck-girder superstructure of pre-stressed concrete bridge, along with the consideration that a design engineer needs to consider each phase of the design process.
Bridge design process is discussed in this paper. After the structural analysis, the bridge is designed in detail. The step-by-step procedure of determining the concrete section dimensions, pre-stressing tendon profile, reinforcing bar layout and material properties are specified in this paper,

Deepak Prasad*1, Jyoti Yadav*2(2022) M.Tech Scholar, Dept. Of Civil Engineering, Sarvepalli Radhakrishnan University, Bhopal, Madhya Pradesh, India. *2Assistant Professor, Dept. Of Civil Engineering, Sarvepalli Radhakrishnan University, in 2022. This project aims to investigate different bridge design alternatives to provide engineers and consultants with accurate and complete information for decision-making. Thorough planning, surveys, and on-site inspections are crucial steps in the bridge design process to ensure safety and avoid financial losses.
The study focuses on the Delhi–Meerut Regional Rapid Transit System (RRTS) project, which aims to enhance connectivity between Delhi, Ghaziabad, and Meerut. Detailed design services are being provided for this project, including civil, architectural, structural, MEP, and property development aspects. While prestressed bridges offer advantages over plate girder bridges under certain conditions, the choice of bridge

type depends on factors such as traffic volume, environmental conditions, and transportation requirements. The study recommends using plate girder bridges for lighter traffic and mild environmental conditions, considering fewer design stipulations. Dynamic analysis using MIDAS software enables informed decision-making and ensures compliance with safety standards.

V. SUMMARIZED FINDINGS OF THE LITERATURE REVIEW

- Metro rails are efficient, fast, reliable, safe, and environmentally friendly.
- Mostly, In Metro viaduct spans greater than 28m and radius sharper than, 200 m I-Girder can be used.
- Post-tensioned simply supported pre-stressed concrete (PC) I-girder bridges are widely used bridge systems for short to medium span (20m to 50m) in Highway bridges.
- Shear, torsion, moment and deflection are increases for 3 kinds of box girder bridges so that as span length towards the radius of curvature ratio increases fundamental frequency decreases for 3 kinds of box girder bridges.
- If the span is more than 25 m, Box Girder is always suitable. And T-Beam Girder is more economical for 25 m span. This type of Bridge lies in the high torsional rigidity available because of the closed box section.
- In terms of stability and economy Box Girder is more suitable as compared to T Girder.
- The design example illustrates that using long-bed, to precast, pretensioned concrete I-girder production for curved bridge construction is highly feasible.
- Even though pre-stressed bridges offer greater advantages over plate girder bridges under the same arbitrary conditions, it has been determined that in situations of lighter traffic, mild environmental conditions, and relatively insignificant transportation, plate girder bridges must be used due to fewer design stipulations and thus must be used.
- Below is the analysis of I-girder Bridge with different support and span.

a. 30-30-30m simply supported span.
b. 30-30-30m continuous span.
c. 35-20-35m continuous span.
d. 25-40-25m continuous span.

The result presented highlights the effect of spacing of the supports on the behaviour of the bridge in terms of deflection and bending.

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