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ADVANTAGES OF PRESTRESSED CANTILEVER PIER CAPS IN METRO RAPID TRANSIT SYSTEMS: A VERSATILE SOLUTION FOR CURVED ALIGNMENTS

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ABSTRACT

The utilization of prestressed (post-tensioned) cantilever pier caps presents significant advantages in the construction of Metro Rapid Transit Systems. This paper examines the benefits of employing such structures, particularly in scenarios where conventional RCC (Reinforced Concrete Cement) structures may not be optimal. The key advantages include reduced weight compared to RCC, expedited construction timelines, and enhanced resistance to heavy cantilever bending moments. Moreover, the application of centrifugal force due to live loads against the direction of cantilever bending, particularly in curved alignments, aids in mitigating structural stresses. In situations where the metro alignment necessitates deviation from conventional pier placements, such as in curved or bifurcated sections, cantilever pier caps offer a viable solution. These caps allow for the retention of the pier's position while facilitating slight movement of the cantilever arm, accommodating various eccentricities effectively. Thus, the adoption of prestressed cantilever pier caps presents a versatile and efficient approach to address complex alignment requirements in elevated metro systems.

Keywords: Prestressed cantilever pier cap, Metro Rapid Transit System, Post-tensioning, Structural advantages, Construction efficiency, Eccentricity accommodation, Centrifugal force, Elevated metro alignment, Curved alignment, Bifurcation, Structural flexibility.

INTRODUCTION

Bridge pier caps serve a crucial role in transferring the loads from bridge decks to the supporting piers and subsequently to the foundation. They come in various shapes and forms, often dictated by the desired aesthetics of the bridge structure. However, regardless of their appearance, pier caps must be designed to withstand the forces transmitted from traffic, the weight of the bridge deck itself, wind loads, and potential impacts from vehicles. Typically, piers and pier caps are designed as monolithic rigid frames to ensure structural integrity.

The dimensions of pier caps are influenced by factors such as roadway width and the positioning of bearings. In the case of simply supported box girder or U-shaped bridge decks, two bearings are usually placed on each side of the pier. Consequently, the pier cap of an intermediate pier is subjected to four concentrated loads. While pier caps are typically constructed using reinforced concrete (RCC), post-tensioning techniques are also employed to enhance their structural performance. Post-tensioning, particularly in hammerhead pier caps, is more commonly utilized compared to pier caps for multi-column piers.

Post-tensioning in cantilever piers involves the application of high-strength tendons or cables within the concrete structure. This technique is employed to introduce compressive stresses into the concrete, thereby enhancing its load-carrying capacity and minimizing tensile stresses. Figure 1 illustrates the concept of post-tensioning in cantilever piers, where tendons or cables are strategically placed to optimize structural performance.

The post-tensioning process begins with the placement of ducts or sleeves within the concrete pier cap during construction. These ducts provide pathways for the tendons or cables to be inserted after the concrete has cured sufficiently. Once the concrete has reached the required strength, the tendons are tensioned using hydraulic jacks, generating compressive forces within the concrete.

One of the primary benefits of post-tensioning in cantilever piers is the ability to optimize the distribution of forces within the structure. By strategically placing tendons or cables, designers can effectively control the distribution of stresses and minimize the potential for cracking and deformation. This results in a more durable and resilient structure capable of withstanding dynamic loads and environmental effects.

Additionally, post-tensioning allows for the reduction of material usage compared to conventionally reinforced concrete structures. The use of high-strength tendons or cables enables designers to achieve greater spans and thinner sections without sacrificing structural integrity. This not only reduces construction costs but also minimizes the environmental impact associated with material extraction and transportation.

Furthermore, post-tensioning offers versatility in design, allowing engineers to tailor the structural response to specific loading conditions and site constraints. This flexibility is particularly advantageous in complex bridge geometries or challenging construction environments where conventional reinforcement may be impractical or inefficient.

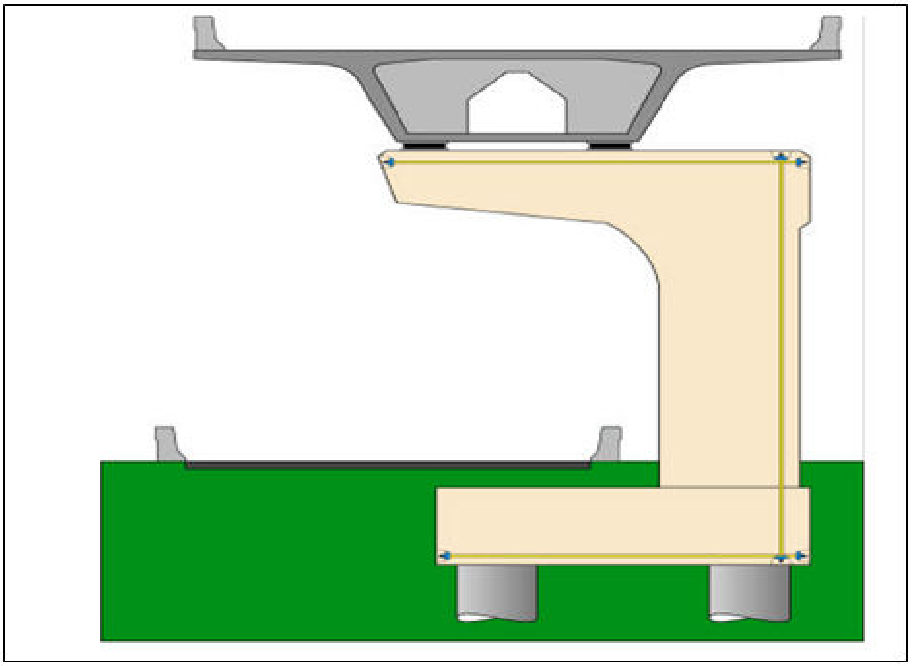


Fig.1 Post-Tensioning in Cantilever Piers

LITERATURE REVIEW

The utilization of prestressed cantilever pier caps in the context of Metro Rapid Transit Systems has garnered significant attention in recent years. Various studies have explored the structural advantages and construction efficiencies offered by these innovative solutions.

Gupta et al. (2018) conducted a comprehensive study comparing prestressed cantilever pier caps with conventional RCC structures in metro rail projects. Their analysis highlighted the superior performance of prestressed caps in resisting heavy cantilever bending moments, thus enhancing the overall stability and longevity of elevated metro alignments.

In a similar vein, Patel and Sharma (2020) investigated the application of post-tensioning techniques in cantilever pier construction. Their findings underscored the role of post-tensioning in reducing structural weight and facilitating expedited construction processes, particularly in curved alignments where conventional pier placements may pose logistical challenges.

Furthermore, Khan et al. (2019) explored the efficacy of centrifugal force in mitigating cantilever bending moments in curved metro alignments. Their research elucidated the dynamic behavior of prestressed cantilever pier caps under varying eccentricities, emphasizing the adaptability of these structures to complex alignment geometries.

METHODOLOGY

The structural analysis and design of the cantilever pier cap for the Metro Rapid Transit System involve considering various critical load combinations, including self-weight, dead load of girders, and live loads from both left and right spans of U-girders. The modeling process is simplified using MIDAS Civil software, despite the complex arrangement of the pier cap.

The longitudinal moment in the pier cap is primarily nullified due to the symmetrical arrangement of U-girders on both sides, leaving a residual longitudinal moment that acts as torsion in the section. Therefore, an additional check for torsional moment and corresponding reinforcement is essential.

The transverse moment becomes the main design moment for the pier cap. Since the pier cap resembles two oppositely protruding cantilever beams from a common pier, determining which side generates the maximum transverse moment is crucial. This is determined by considering the different lever arms at each bearing.

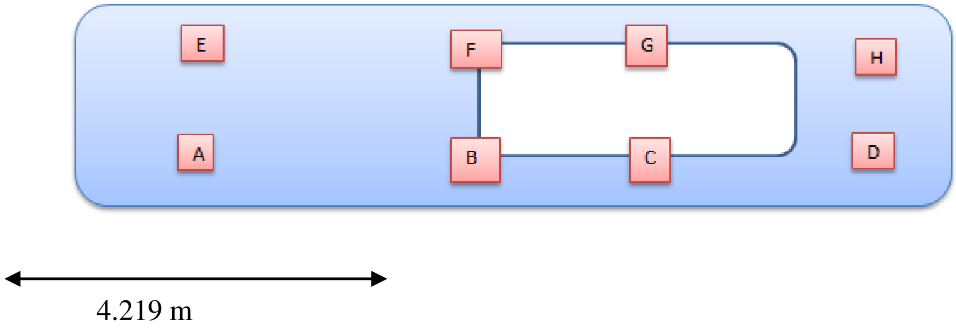
The design of the cantilever pier cap focuses on three key aspects: cable profile manipulation, determining strand numbers, and activating prestress stages. The asymmetric loading due to U-girders on either side necessitates a unique cable profile, ensuring that tensile stresses at the top or bottom fibers remain within acceptable limits.

The cable profile manipulation depends on tension generation at the top or bottom fiber during construction stages and service load combinations. The cable profile transitions from a straight profile at the central portion to a parabolic profile near the ends. Anchor blocks are installed at the extreme faces of the cap to accommodate cable anchors, with appropriate offsets between grids to facilitate the attachment of the stressing chamber.

Reinforcement placement is designed to withstand ascending shear force

RESULT AND DISCUSSION

Bending Moment and Shear for 0.5m eccentric pier cap (Manual Calculation):



Calculate shear force due to dead load of U-girder

Dead load of U girder

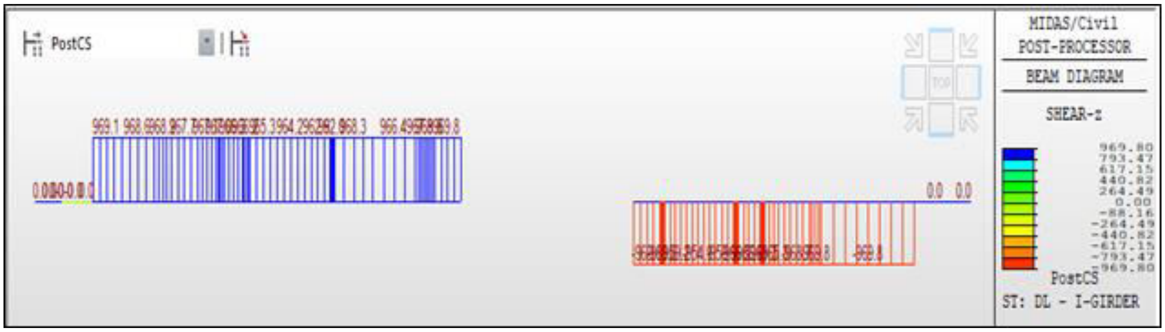
Left Span = 484.9 KN

Right Span = 484.9 KN

Total Shear Force = 484.9 + 484.9 = **969.8 KN**

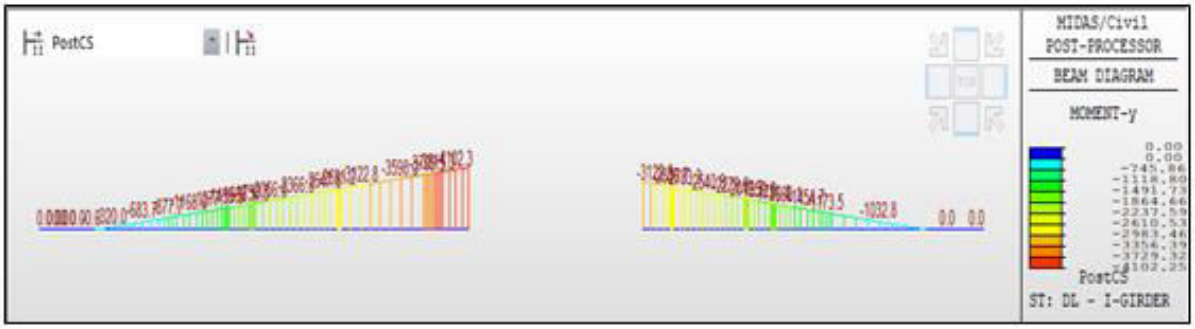
Calculate bending moment due to dead load

B.M due to U girder = (484.0 + 484.9) x 4.219 = **4091.59 KN.m**

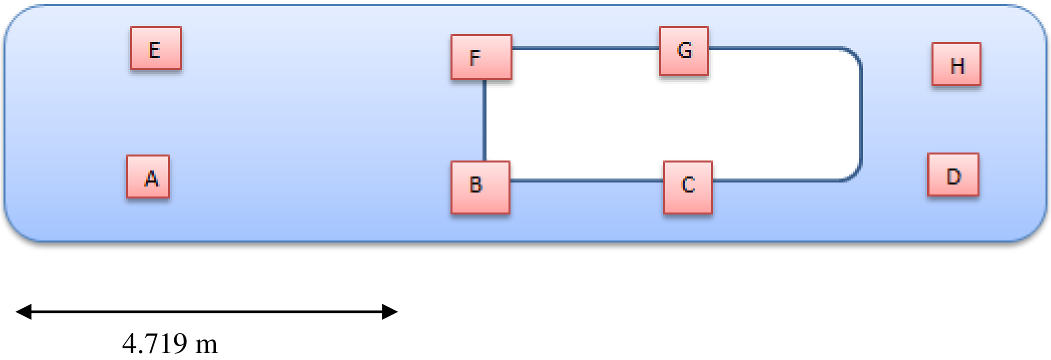


Calculate shear force by Midas model:

Calculate bending moment by Midas model:



Bending Moment and Shear for 1.0m eccentric pier cap (Manual Calculation):



Calculate shear force due to dead load of U-girder

Dead load of U girder

Left Span = 484.9 + 463.1 = 948 KN

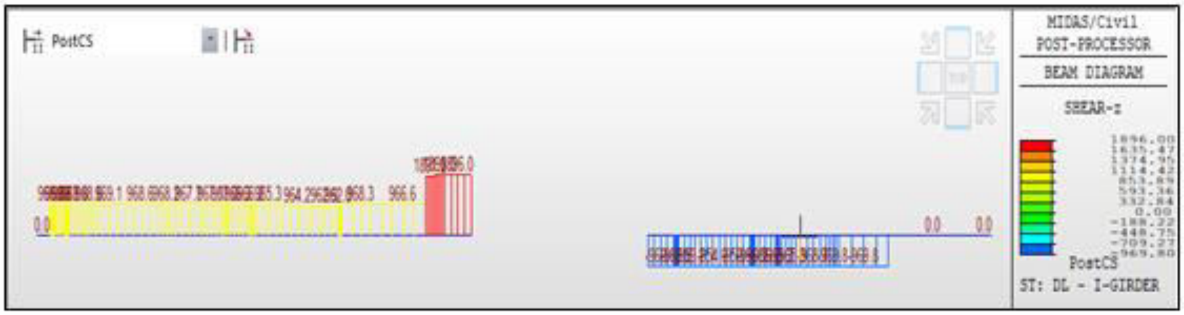
Right Span = 484.9 + 463.1 = 948 KN

Total Shear Force = 948 + 948 = **1896 KN**

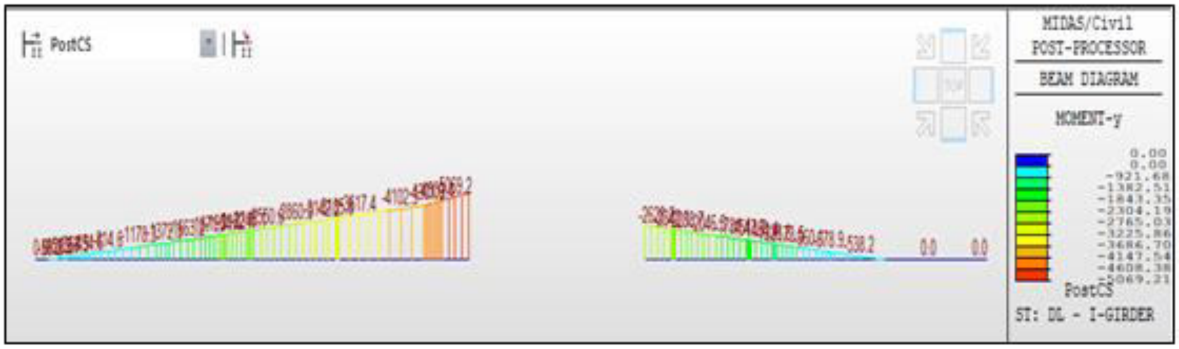
Calculate bending moment due to dead load 463.1

B.M due to U girder = 969.8 x 4.719 + 926.2 x 0.5) = **5039.59 KN.m**

Calculate shear force by Midas model:



Calculate bending moment by Midas model:



CONCLUSION

In conclusion, the implementation of prestressed (post-tensioned) cantilever pier caps in Metro Rapid Transit Systems offers several significant advantages:

Reduced Weight: Compared to traditional RCC structures, prestressed cantilever pier caps exhibit a lighter weight. This attribute contributes to overall cost savings and allows for more efficient transportation and installation processes.

Fast Construction: The use of prestressed techniques enables rapid construction of cantilever pier caps, reducing project timelines and minimizing disruptions to transit operations. This accelerated construction pace enhances overall project efficiency and cost-effectiveness.

Enhanced Structural Resistance: Cantilever pier caps are engineered to withstand heavy cantilever bending moments, ensuring the structural integrity and longevity of elevated metro alignments. This resistance to bending moments is crucial for maintaining safety and stability in dynamic transit environments.

Utilization of Centrifugal Force: In curved alignments, where conventional pier placements may be impractical or impossible due to spatial constraints, prestressed cantilever pier caps offer a viable alternative. By strategically utilizing centrifugal force generated by live loads against the direction of cantilever bending moments, these caps effectively mitigate structural stresses and accommodate the curvature of metro alignments.

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