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Influence of Post-Tensioning on Performance of Monorail Guideway Girder: A Numerical Analysis

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Abstract: *Modeling the straddle monorail guideway girder numerically is essential for comprehending its structural behavior and optimizing its design. This research employs the Finite Element Method (FEM) to conduct a comprehensive analysis of the monorail girder's performance. The behavior of the girder under various loading circumstances, including as dead loads, live loads, and the effects of tendon configurations, is investigated using FEM. The most critical load scenario for the post-tensioned girder is determined by examining various loading conditions. The analysis is designed to evaluate deflection, and bending moment distribution of the monorail girder. The research emphasizes the significance of post-tensioning as a means of mitigating deflection and enhancing the girder's operational effectiveness. The recognition of the importance of considering the cross-sectional area of the tendon is crucial, as it has the potential to impact the deflection characteristics of the girder. The study also emphasizes the significance of carefully examining the cross-sectional area of the tendon, as it can influence the deflection behavior of the girder. The results of this study also highlight the necessity of taking post-tensioning into account as a potential solution for lowering deflection and improving the performance of monorail girder structures.*

Keywords— Finite Element Method, Posttensioned, Straddle monorail, tendon configurations.

1. INTRODUCTION

This The straddle monorail system is an innovative solution for urban rail transit that has increased popularity in recent years. It is distinguished by its guideway girders and rubber wheels and offers several advantages over conventional public transit rail systems [1], [2]. Its compact nature enables efficient use of urban space and provides an optimal transportation solution without requiring extensive land acquisition or disruptive modifications to existing infrastructure [3]. Additionally, there has been an increase in the use of monorail transit systems in small, medium, and large cities as they have excellent advantages such as greater climbing abilities, less construction time, reduced noise, and low costs. For cities with hills, monorail transit systems have also been implemented and constructed [4]–[6]. The integration of guideway girders and rubber wheels, along with its compact design, cost-effectiveness, minimal disruption to existing infrastructure, and reduced environmental impact, positions the straddle monorail system as an innovative and promising future mode of urban transportation [7], [8].

The straddle monorail system is a type of monorail transportation that uses rubber wheels to facilitate vehicle movement along the guideway girder [1]. The guideway girder, typically made of steel or post-tensioned concrete, provides the necessary support and stability for the monorail system, accommodating vehicle loads and stresses and ensuring structural integrity. The role of the guideway girder in the straddle monorail system emphasizes its important function as a crucial component contributing to the operation and safety of the transportation network [9].

The design and construction of straddle monorail girders must prioritize durability and dependability so that they can withstand the operational demands with minimal maintenance. The use of post-tension concrete girders further facilitates the expeditious and efficient construction of straddle monorail systems. Typically, the span lengths of these girders range from 65 feet to 120 feet [2]. Individual post-tensioned girders are created on the ground and then post-tensioned before being placed above the monorail columns to form a continuous guideway. Various construction methods are used to ensure the monolithic connection between adjacent girders and columns, thereby preserving the structural integrity and continuity of the frames [2]. The use of post-tension concrete girders not only enhances the strength and stability of the straddle monorail guideway system, but also contributes to the overall efficiency of the monorail construction process.

The objective of this study is to investigate the behavior of post-tension concrete guideways through the utilization of the finite element analysis software SAP 2000. It intends to investigate how several factors, such as load locations and

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strand cross section area, affect the bending moment and deflection characteristics of post-tension concrete guideway girders. The examination of these characteristics provides important insights into their impact on the overall structural performance of the monorail guideway girder and ensures its long-term sustainability.

2. NUMERICAL MODEL

2.1 Finite Element Method

The FEM is utilized for modeling the monorail guideway girder numerically. It offers a sophisticated computational technique that enables a more thorough investigation, leading to enhanced design methodologies and optimization strategies. This study achieves the benefits of FEM, such as its ability to model complex geometries and irregular shapes with precision. It also permits the consideration of multiple factors that influence the response of the girder, such as material properties, boundary conditions, and support configurations. This in-depth examination aids in understanding the complicated interactions between various parameters and their effects on the girder's performance.

In this study, the dimensions of the guideway girder were carefully designed to replicate the actual conditions of the monorail guideway that was used during construction. The guideway girder consisted of 25 meters in length. The geometry and cross-sectional profile of the guideway girder, as well as the precise locations of the column supports, were carefully determined based on design considerations, and previous study. Fig.1. provides an illustration of the guideway girder's geometry and cross-section.

Fig.1. *A post-tensioned guideway girder's length and cross section.*

2.2 Material Properties

The properties of both concrete and steel reinforcement investigated in this study are summarized in Table 1. Recognizing these properties is essential for gaining insights into the performance of the concrete utilized in the monorail guideway girder. Among these properties, the modulus of elasticity is crucial in determining the rigidity and resistance to deformation under applied loads [10]. In contrast, Poisson's ratio describes the lateral contraction of a material subjected to axial stress. The unit weight parameter provides information regarding the density of the concrete, which contributes to calculations involving structural dead loads. In addition, the cracking strength value helps assess the resistance to fissure propagation and durability of the concrete. Table 1 also includes important parameters for the steel reinforcement, such as the yield strength and modulus of elasticity.

The post-tensioning procedure employed six tendons for girder to enhance structural integrity and load-carrying capacity, as shown in Fig.2 . The mechanical properties of the strands used in the system are presented in Table 1. The study considered various options for tendons profiles. **Error! Reference source not found.** provides a visual representation of the profiles of the post-tension tendon employed in the current investigation, illustrating the key characteristics and dimensions of these crucial elements in the guideway girder system.

Fig.2. *A graphical illustration of the tendons profile employed in the guideway girder.*

Table 1: Modeling parameters of concrete, steel reinforcement, and the strands [2].

Material	**Material Properties**	
	Parameter	***Value***
Concrete	Specified compressive strength	$f_c' = 70\ MPa$
	Modulus of Elasticity	$E_c = 36300\ MPa$
	Cracking strength	$f_{cr} = 3.35\ MPa$
Reinforcement	Yield strength	$f_y = 400\ MPa$
	Modulus of Elasticity	$E_s = 200000\ MPa$
Prestressing steel	Size	$15\ (A_{stand} = 140mm^2)$
	Specified tensile strength	$f_{bu} = 1860\ MPa$
	Yield strength	$f_{py} = 0.90 f_{pu} = 1674\ MPa$
	Modulus of Elasticity	$E_p = 200000\ MPa$

2.3 Loading Setup

In the numerical modeling process, various loading conditions were thoroughly examined to accurately identify the most critical load situation for the post-tensioned girder. Since the monorail's load is dynamic in nature, resulting from the movement of the monorail along the guideway girder,

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determining the worst load situation is essential when assessing the performance of the guideway girder under operational conditions load. In accordance with the study conducted by Sirisonthi et al. (2021), which involved a comprehensive load test on a precast post-tensioned continuous girder for a straddle monorail, both service and ultimate loading conditions were investigated to determine the load-deformation behavior of the girder [2]. Fig.3. and Table 2 provide a visual representation of the design load patterns and dimensions of the straddle monorail loads, including axle loads and the distances between axles, enabling a detailed analysis of the applied loads in the numerical model.

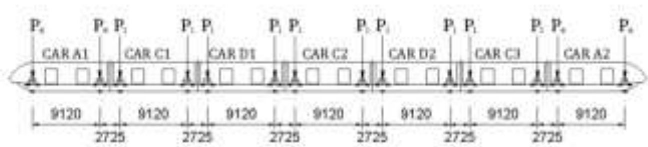

Fig.3. *Details and location of axle load according to Sirisonthi et al. (2021),* [2].

Table 2: Monorail axle loads [2].

Load Conditions	***Axle Load Pe & Pi (KN)***	
	Axle load Pe (kN)	***Axle load Pi (kN)***
Seated +8 Passengers/m^2	130.2	131.9

3. Results and Disscussion

3.1 Severe Load Condition

To identify the most severe load scenario, an assumption was made that the load will move from the left support to the right at regular two-meter intervals, as illustrated in Fig.4. Following that, a numerical simulation was performed to determine the maximum magnitude of the load which causes the maximum bending moment in the guideway girder. The bending moment analysis of the simulated monorail load revealed an overall pattern in which the bending moment reduced as the concentrated loads of the monorail moved away from the left support. This observation is illustrated in Fig., which demonstrates that the maximum moment occurred when the load was derived from the left support and progressively decreased as the load was transferred to the right support. By establishing the severe load condition through this analysis, the study enables us to precisely evaluate the structural response of the monorail girder under demanding operational conditions. In the following section, the severe load condition is used to evaluate the bending moment and deflection after the application of post-tensioning force.

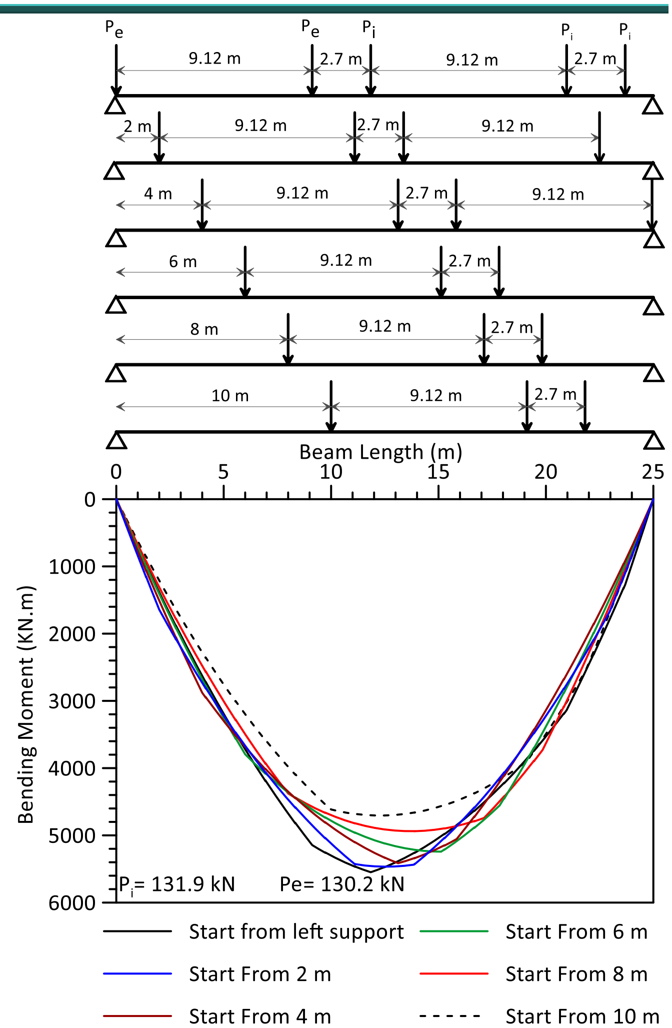

Fig.4. *load scenario and corresponding bending moment in the guideway girder.*

3.2 Bending Moment

The results shown in Fig.5. provide light on the relationship between the bending moment and the length of the monorail guideway girder under the severe load scenario specified in the previous section. This study evaluated three distinct combination loads: Comb 1 (LL + DL), Comb 2 (1.2 LL + 1.6 DL), and Comb 3 (1.2 LL + 1.6 DL + tendons). The highest bending moment is found at Comb 2 (1.2 LL + 1.6 DL), which is in line with expectations.

The study also shows how post-tensioning significantly affects the bending moment experienced by the concrete girder supporting the monorail guideway. The bending moment is significantly decreased by using post-tensioning procedures, with the maximum bending moment falling from 5500 kNm to less than 3600 kNm. The findings highlight the practical benefits of incorporating post-tensioning techniques into the design and construction of monorail guideways, as it optimizes the structural response. Furthermore, the reduction in bending moment achieved through post-tensioning has various advantages, including more efficient resource utilization and higher load-carrying capacity of the monorail girder.

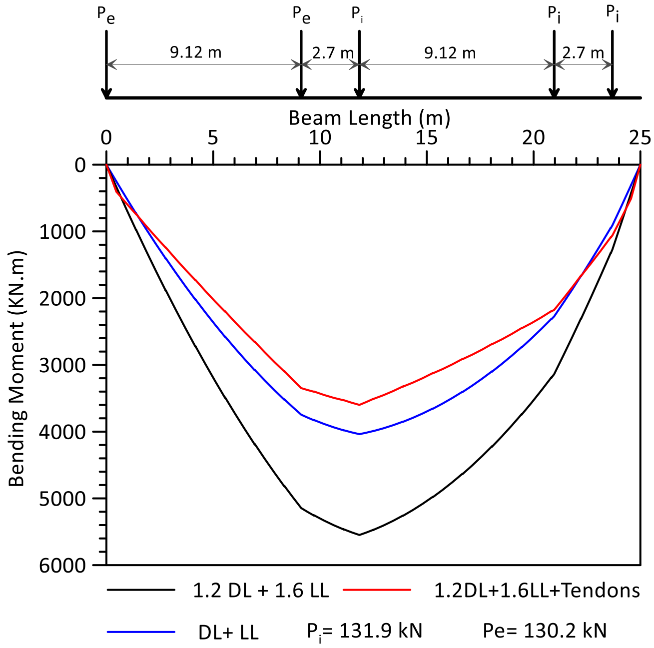

Fig.5. *Bending moment in the guideway girder associated to the severe load scenario.*

3.3 Deflection

An illustration of the relationship between the deflection and the length of the monorail guideway girder is shown in Fig.6., which offers essential details about the structural behavior under severe loads. The analysis performed in this study includes a range of load combinations, with a particular focus paid to load comb 2 (1.2 LL + 1.6 DL) due to its association with the maximum deflection observed. When load comb 2 is applied, the measured maximum deflection reaches 33 mm. The application of post tensioning to the monorail guideway girder structure reduces the maximum deflection by a substantial amount, to less than 18 mm. This result highlights the significant benefits associated with the use of post tensioning, including enhanced structural performance and load-bearing capacities.

The findings of this study emphasize the significance of considering post tensioning as an achievable option for decreasing deflection and enhancing the performance of monorail girder structures. These results have practical implications in the construction of monorail projects, as they highlight the benefits of using post tensioning methods to optimize the overall structural response, improve resource utilization, and promote cost-effective.

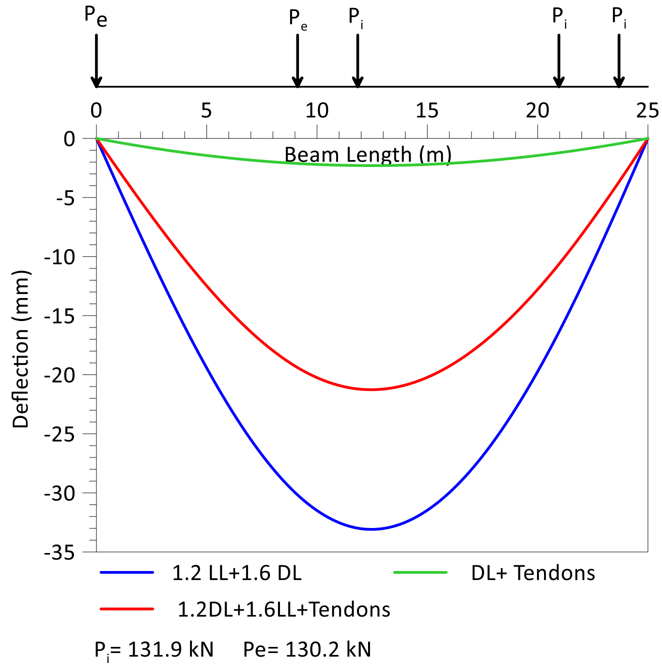

Fig.6. *A relationship between the deflection and the length of the monorail guideway girder corresponding with the severe load scenario.*

Fig.7. shows the interaction between the deflection of the monorail guideway girder and the length of the girder as the cross section of the tendon varies. In the instance of Comb2 (1.2 DL + 1.6 LL + Tendons), as the cross-sectional area of the tendon increases, the deflection of the monorail girder decreases. This demonstrates that a larger cross-sectional area of the tendon contributes to improved structural stiffness, leading to reduced deflection underload. This finding highlights the significance of considering the design and optimization of the tendon cross section to reduce monorail system deflection.

When Comb3 (DL + Tendons) is considered, the results show a different pattern. Increasing the cross-sectional area of the tendon can result in an upward deflection of the monorail girder. It should be noted that this effect is crucial during the application of posttension force prior to erecting the girder and applying live load. This implies that careful attention should be given to this scenario, as it may lead to an undesirable upward deflection, which is indicative of upper tension stress. In such situations, it is essential to monitor and assess the limit of upward deflection in order to maintain structural integrity and prevent potential problems resulting from excessive tensile stress.

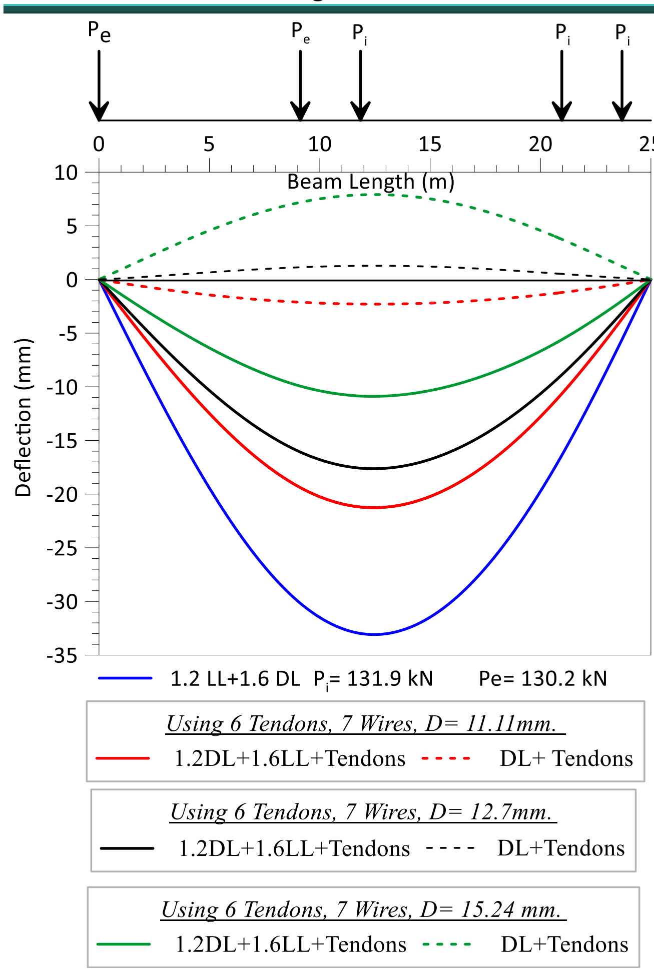

Fig.7. *A relationship between the deflection and the length of the monorail guideway girder corresponding to the variation of the cross section of the tendon.*

4. Conclusion

FEM is an efficient method for examining the structural performance of a straddle monorail guideway girder, allowing engineers and researchers to conduct an exhaustive analysis of its behavior under a variety of loading conditions, enabling design improvement.

A severe load condition was generated using the numerical modeling done in this study in order to appropriately analyze the girder structural performance of the monorail girder under demanding operational conditions. Furthermore, the study revealed that the maximum moment occurred when the load was derived from the left support and gradually decreased as the load was transferred to the right support. Incorporating this knowledge into the design process enables engineers to make informed decisions about materials, cross-sectional shape, and reinforcement, ensuring the structural integrity of the girder and improving overall safety.

The results of this study also highlight the necessity of taking post-tensioning into account as a potential solution for lowering deflection and improving the performance of monorail girder structures. The use of post-tensioning techniques on the monorail guideway girder structure reduced the maximum deflection. Furthermore, the research findings indicate that increasing the cross-sectional area of the tendon resulted in a reduction in the deflection of the monorail girder. These practical implications highlight the benefits of utilizing post-tensioning methods in monorail construction projects, as they optimize the overall structural performance, improve resource utilization, and promote cost-effectiveness.

The study, however, demonstrated a different pattern when the Comb3 (DL + Tendons) combination was considered. In this scenario, increasing the cross-sectional area of the tendon can cause the monorail girder to deflect upwards. This effect is particularly significant during the application of post-tensioning force before erecting the girder and applying the live load. Consequently, it is crucial to exercise careful attention and monitor this condition, as excessive upward deflection indicates the presence of upper tension stress.

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