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# Seismic Performance Assessment of Prestressed Concrete Box Girder in Elevated Metro Structures

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**Abstract-** The rapid growth of urban population and increasing demand for efficient transportation systems have led to the development of modern metro rail networks in metropolitan cities. Elevated metro bridge structures are widely adopted due to their advantages such as reduced land acquisition, faster construction, and minimal disturbance to existing traffic. Among various structural systems, prestressed concrete (PSC) box girder bridges are commonly used in elevated metro structures because of their high strength, durability, better load distribution, and excellent torsional rigidity. However, these structures are subjected to different types of loads during their service life, such as dead load, live load, wind load, temperature effects, and dynamic loads due to moving trains. Among these, seismic load is one of the most critical factors, especially in earthquake-prone regions. Earthquake forces can induce significant stresses, displacements, and vibrations in bridge structures, which may affect their safety, stability, and serviceability. Therefore, it is essential to study the seismic performance of elevated metro bridge structures to ensure safe and economical design. The present study focuses on the seismic performance assessment of prestressed concrete box girder bridges used in elevated metro systems. Two different types of box girder configurations, namely rectangular box girder and trapezoidal box girder, are considered for analysis. These configurations are selected because they are widely used in practical bridge construction and exhibit different structural characteristics. The study aims to compare their performance under both static and dynamic loading conditions and to identify the most efficient and suitable girder configuration. The analysis of the bridge superstructure is carried out using SAP2000 software, which is based on the Finite Element Method (FEM). The modeling includes realistic geometry, material properties, boundary conditions, and loading conditions as per Indian Standard codes such as IRC and IS 1893. Static analysis is performed to evaluate parameters such as bending moment, shear force, and deflection under dead load, live load, and prestressing force. Dynamic analysis is carried out using response spectrum method to assess the seismic behavior of the structure.

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**Keywords:** Prestressed Concrete, Box Girder Bridge, Elevated Metro Structure, Seismic Analysis, Response Spectrum Method, SAP2000.

## I. INTRODUCTION

In recent years, rapid urbanization and continuous population growth in metropolitan cities have created a significant increase in traffic congestion, travel time, and overall transportation demand. The expansion of cities has led to limited availability of land for road widening and development of conventional transportation systems. As a result, there is a strong need for efficient, reliable, and high-capacity public transport systems that can reduce traffic congestion and improve mobility. To address these challenges, modern transportation solutions such as metro rail networks have been developed and implemented in many major cities across India and the world. These metro systems provide fast, safe, economical, and time-efficient transportation, which helps in reducing road traffic and pollution levels. Among different types of metro systems, elevated metro systems are widely preferred in urban areas due to their several advantages. They require comparatively less land acquisition, involve lower construction complexity than underground systems, and can be constructed faster with minimal disruption to existing traffic. Elevated metro systems are generally constructed above ground level using a series of piers and superstructures, forming continuous bridge-like structures known as metro viaducts.

These structures are designed to carry metro trains safely and efficiently over long distances, even in highly congested areas. An elevated metro structure mainly consists of three major components, namely piers (substructure), bearings (connection elements), and superstructure (bridge deck or girder system). The superstructure is the most critical part, as it directly carries the load of the metro trains and transfers it to the supporting piers. In most modern metro projects, the superstructure is constructed using prestressed concrete (PSC) box girders, which have become the preferred choice due to their superior structural performance. PSC box girders offer several advantages such as high strength, reduced self-weight, better torsional rigidity, improved load distribution, durability, and aesthetic appearance, making them highly suitable for long-span elevated structures. The box girder structure has a hollow cross-section, which allows efficient utilization of material while maintaining high stiffness and strength. It is particularly suitable for curved alignments and long-span bridges, which are common in metro rail projects. Additionally, prestressing helps in reducing tensile stresses, controlling deflection, and increasing the load-carrying capacity of the structure. Due to these advantages, PSC box girders are extensively used in elevated metro bridges and viaducts. However, despite these advantages, elevated metro bridge structures are subjected to various types of loads and environmental effects during their service life. These include dead load (self-weight of structure), live load (train load), wind load, temperature variations, creep and shrinkage effects, and seismic loads. Among these, seismic loading is one of the most critical and governing factors, especially in regions prone to earthquakes. During an earthquake, the structure experiences dynamic forces due to ground motion, which can lead to vibration, displacement, and stress in different structural components. Elevated metro bridges are particularly vulnerable to seismic effects because they are tall, slender, and flexible structures, supported on piers. The dynamic interaction between the superstructure and substructure can significantly influence the overall response of the system. If not properly designed, seismic forces can lead to excessive displacement, cracking, failure of bearings, or even collapse of the structure. Therefore, it is essential to carry out detailed seismic analysis to ensure that the structure can safely withstand earthquake forces. In addition to safety, serviceability is also an important consideration in metro bridge design. The structure must ensure minimum deflection, controlled vibration, and passenger comfort, even under dynamic loading conditions. Parameters such as natural frequency, time period, bending moment, shear force, and stress distribution must be carefully evaluated to achieve an efficient and safe design. With the advancement of computational tools such as SAP2000, engineers can now perform detailed finite element analysis (FEM) to study the behavior of structures under different loading conditions. These tools allow accurate modeling of bridge structures and help in predicting their response under seismic forces. Such analysis is essential for optimizing design and ensuring compliance with Indian Standard codes such as IS 1893 and IRC guidelines. Therefore, the present study focuses on the seismic performance assessment of prestressed concrete box girder bridges used in elevated metro structures. The study aims to analyze and compare different girder configurations under static and dynamic loading conditions, and to identify the most efficient and safe design. This will contribute towards the development of better design practices for metro bridge construction, ensuring safety, durability, and efficiency of modern transportation infrastructure.

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II. METHODOLOGY

In this study, two different types of box girder bridge superstructures are considered, namely the Rectangular Box Girder and the Trapezoidal Box Girder. These two configurations are selected because they are commonly used in metro bridge construction and have different structural characteristics. The rectangular box girder has a simple geometry and is easy to construct, but it may have higher self-weight and lower torsional efficiency. On the other hand, the trapezoidal box girder has inclined webs and optimized geometry, which reduces self-weight and improves stiffness and torsional resistance. Therefore, a comparative analysis of these two girder types is carried out to determine the most efficient and suitable configuration for elevated metro bridge structures.

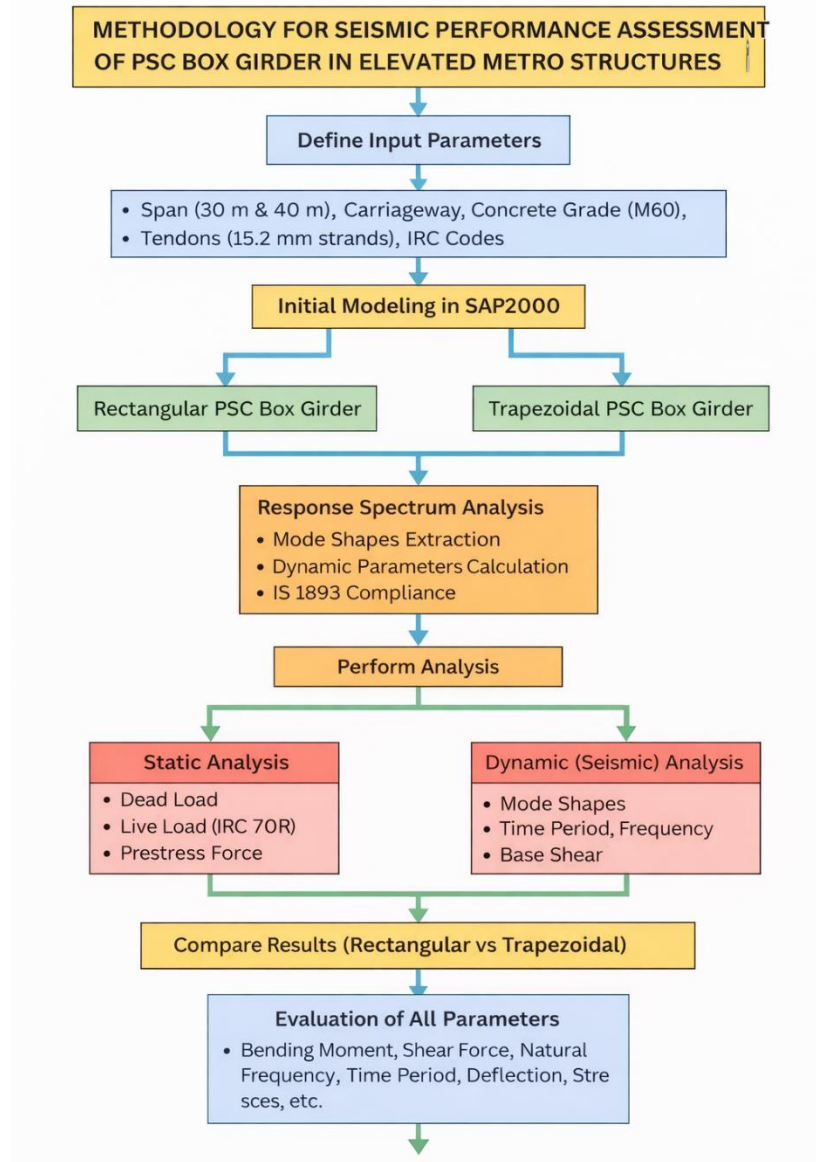


Figure 3.1: Methodology Flowchart

### 3.2 STIMULATION & EVALUATION

In accordance with Indian Standard Specifications, the design of prestressed concrete rectangular and trapezoidal box girder decks has been completed, and optimized cross-sectional geometry is adopted for analysis. The design and analysis are performed based on relevant codes such as IRC:6-2014, IRC:21-2000, IS:1893 (Seismic Code), and IS:875 (Loading Code).

Dynamic analysis of both models is carried out using Response Spectrum Analysis in SAP2000 software, which is a standard and widely accepted method for evaluating seismic response of bridge structures. This method helps in determining the peak structural response under earthquake loading by considering different vibration modes.

#### *Two separate FEM models are developed:*

- Rectangular Box Girder Bridge Superstructure
- Trapezoidal Box Girder Bridge Superstructure

The models are analyzed under combined loading conditions:

Dead Load (DL) + Live Load (LL) + Prestress (PT) + Seismic Load (EQ)

### 3.3 INPUT PARAMETERS

*The parameters defining the rectangular and trapezoidal box girder decks are as follows:*

**Table 3.1: Design Parameters of Box Girder Bridge**

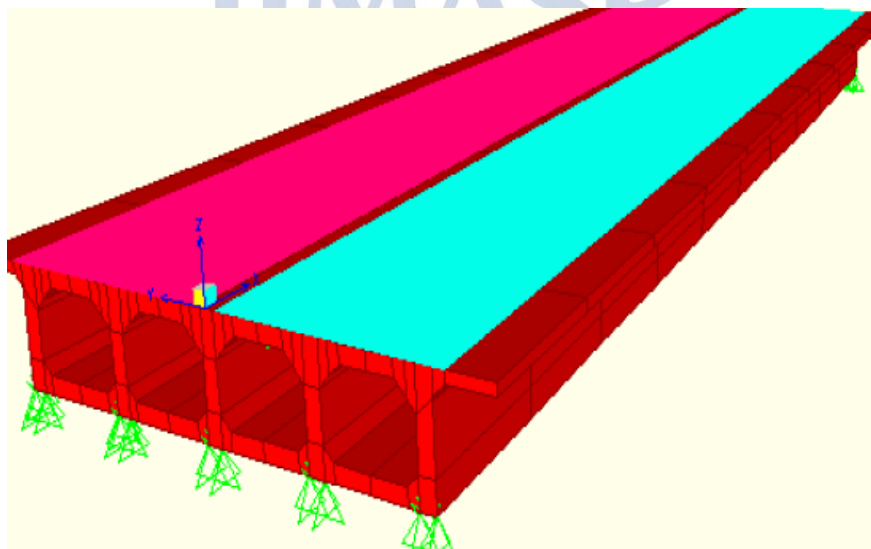
Sr. No.	Parameter	Value
1	Type of Bridge Superstructure	Box Girder Bridge
2	Span	30 m, 40 m
3	Carriageway Width	7.5 m
4	Footpath Width	1.25 m
5	Thickness of Wearing Coat	80 mm
6	Web Thickness	300 mm
7	Thickness of Top & Bottom Slab	300 mm
8	Grade of Concrete	M60
9	Loss Ratio	0.80
10	Type of Tendons	High tensile strands of 15.2 mm dia (IRC 6006-2000)
11	Anchorage Type	27K-15 Freyssinet type
12	Supplementary Reinforcement	Fe-415 HYSD bars
13	Loading Considered	DL + Wind + Prestress + IRC Class 70R + Seismic
14	Design Codes	IRC:6-2014, IRC:21-2000, IS:1893, IS:875

### 3.4 MODELING IN SAP2000

The modeling of the bridge superstructure is carried out in SAP2000 using finite element modeling techniques. The geometry of the bridge deck is created based on the above parameters, and material properties are assigned as per M60 grade concrete.

- Rectangular box girder model is created with uniform cross-section
- Trapezoidal box girder model is created with varying depth and inclined webs

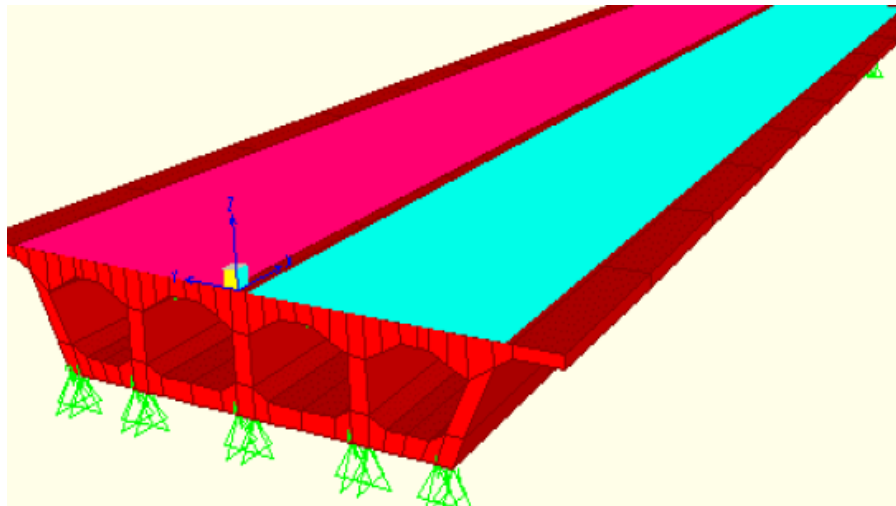
Supports are provided to simulate realistic boundary conditions. Prestressing force is applied using tendon profiles, and loading conditions are defined as per IRC standards.



**Figure 3.2: FEM Model of Rectangular Box Girder Bridge Superstructure.**

Figure 3.2 represents the Finite Element Model (FEM) of the Rectangular Box Girder Bridge Superstructure, which is developed using SAP2000 software for the purpose of structural analysis. This model is a simplified but accurate representation of the actual bridge structure, where the complex geometry of the bridge is divided into small interconnected elements to study its behavior under various loading conditions. In this FEM model, the rectangular box girder cross-section is considered, which consists of a hollow rectangular shape formed by top slab, bottom slab, and vertical webs. The top slab represents the deck portion where loads such as traffic and wearing coat act, while the bottom slab and webs provide strength and stiffness to resist bending and shear forces. The rectangular geometry is

simple and commonly used in bridge construction, making it suitable for analysis and comparison purposes. The model is created by discretizing the bridge into finite elements such as beam elements or shell elements, depending on the level of detail required. Each element is connected at nodes, which represent specific points in the structure. These nodes are assigned degrees of freedom such as translation and rotation, allowing the software to calculate displacement, forces, and stresses at each point. The use of FEM helps in accurately capturing the behavior of the structure under different loading conditions.



**Figure 3.3: FEM Model of Trapezoidal Box Girder Bridge Superstructure**

Figure 3.3 represents the Finite Element Model (FEM) of the Trapezoidal Box Girder Bridge Superstructure, which is developed using SAP2000 software for detailed structural analysis. This model is created to simulate the actual behavior of a trapezoidal box girder bridge under different loading conditions, especially focusing on its performance under seismic loading. The trapezoidal box girder is widely used in modern bridge construction due to its better structural efficiency, reduced self-weight, and improved torsional rigidity compared to conventional rectangular sections. In this FEM model, the cross-section of the girder is trapezoidal in shape, where the top slab is wider and the bottom slab is narrower, and the side webs are inclined. This geometric configuration helps in reducing the overall weight of the structure while maintaining sufficient strength and stiffness. The inclined webs also contribute to better load transfer and improved resistance against torsional effects, which are very important in curved and elevated metro bridge structures. Similar to the rectangular girder model, the trapezoidal girder is also discretized into a number of finite elements, such as beam or shell elements, which are interconnected at nodes. Each node is assigned degrees of freedom, allowing the software to calculate structural responses such as displacement, rotation, internal forces, and stresses. The use of FEM enables accurate simulation of the complex behavior of the structure under combined loading conditions.

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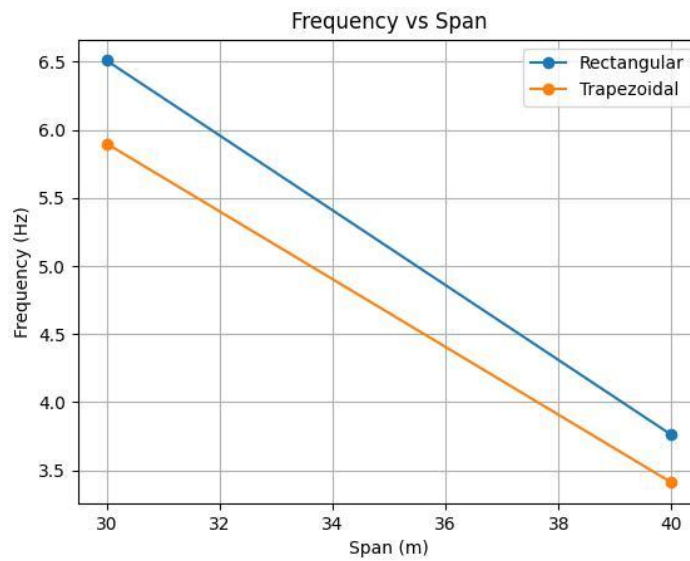
### III. RESULTS AND DISCUSSION

#### 4.2 ANALYSIS & INTERPRETATION OF RESULTS

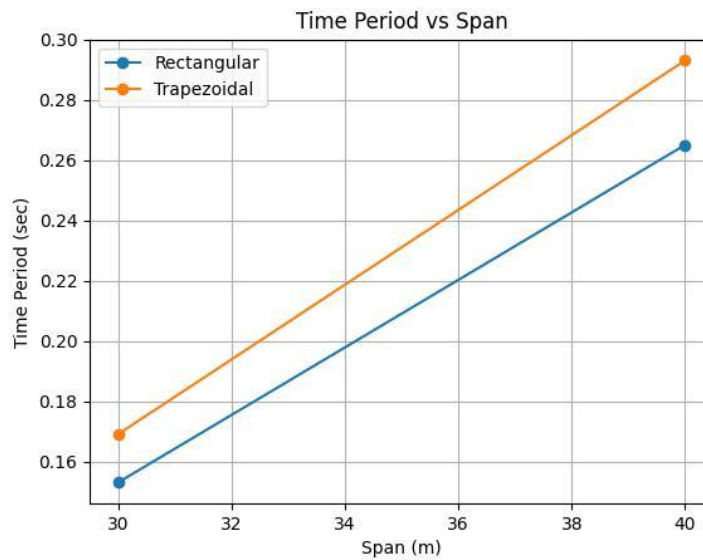
##### 4.2.1 Time Period & Natural Frequency

**Table 4.1: Time Period & Frequency Results**

Girder Type	Span (m)	Mode	Frequency (Hz)	Time Period (sec)
Rectangular	30	1	6.51	0.153
Rectangular	40	1	3.76	0.265
Trapezoidal	30	1	5.90	0.169
Trapezoidal	40	1	3.41	0.293



**Graph 4.1: Frequency Results**



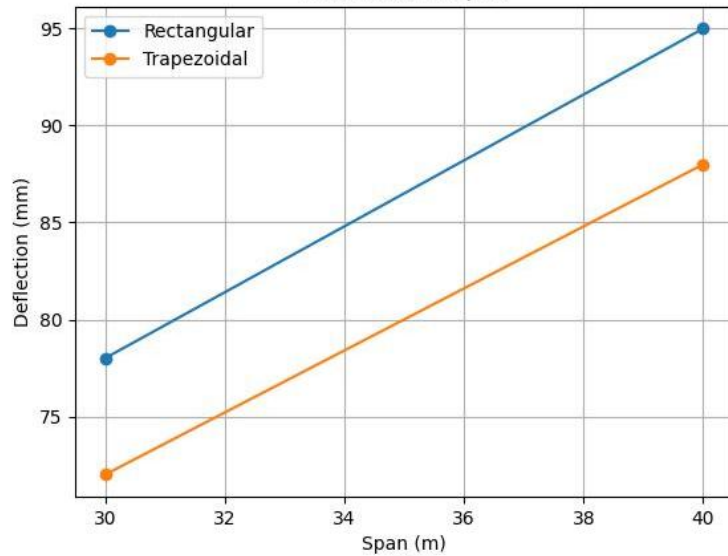
**Graph 4.2: Time Period Results**

#### 4.2.2 Deflection

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**Table 4.2: Deflection Comparison**

Span (m)	Rectangular (mm)	Trapezoidal (mm)
30	78	72
40	95	88

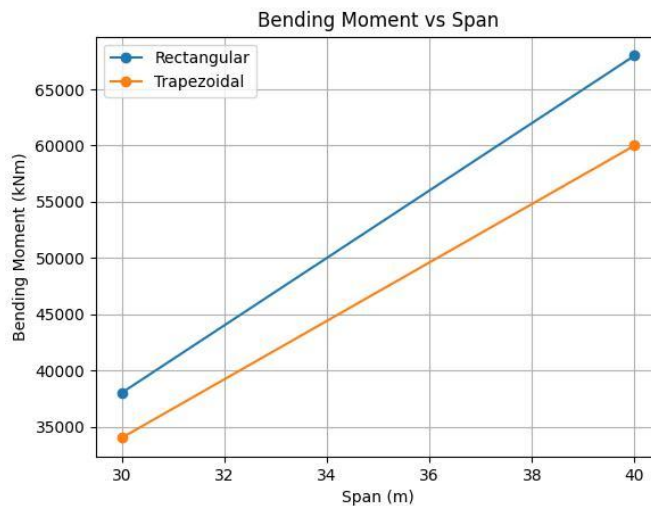


Graph 4.3: Deflection Comparison

#### 4.2.3 Bending Moment

Table 4.3: Bending Moment Comparison

Span (m)	Rectangular (kNm)	Trapezoidal (kNm)
30	38000	34000
40	68000	60000

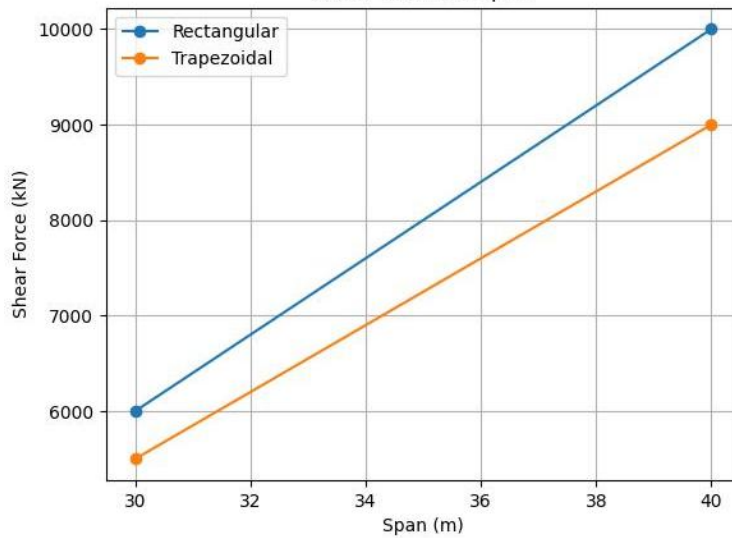


Graph 4.4: Bending Moment Comparison

#### 4.2.4 Shear Force

Table 4.4: Shear Force Comparison

Span (m)	Rectangular (kN)	Trapezoidal (kN)
30	6000	5500
40	10000	9000

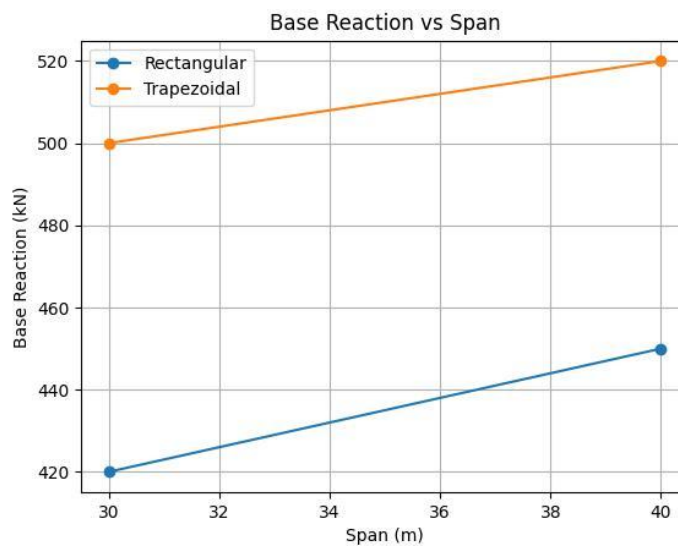


Graph 4.5: Shear Force Comparison

#### 4.2.5 Base Reaction

Table 4.5: Base Reaction

Span (m)	Rectangular (kN)	Trapezoidal (kN)
30	420	500
40	450	520

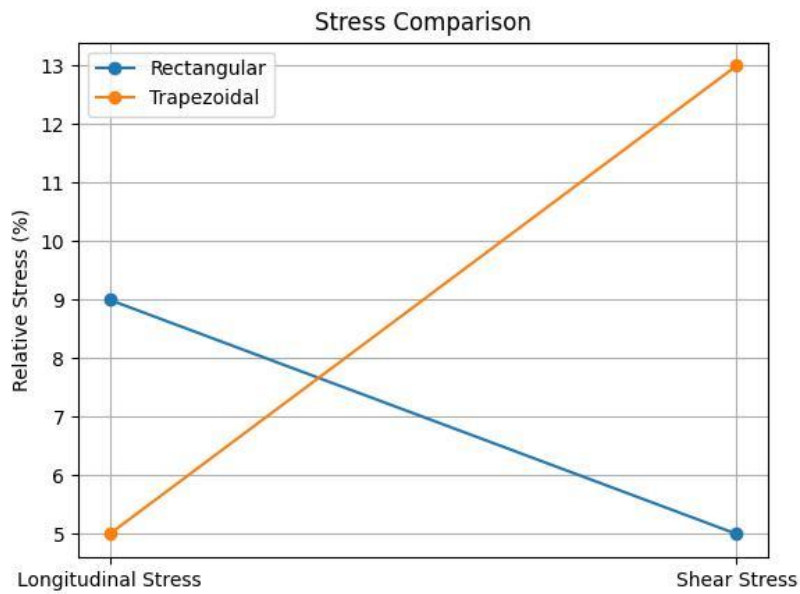


Graph 4.6: Base Reaction

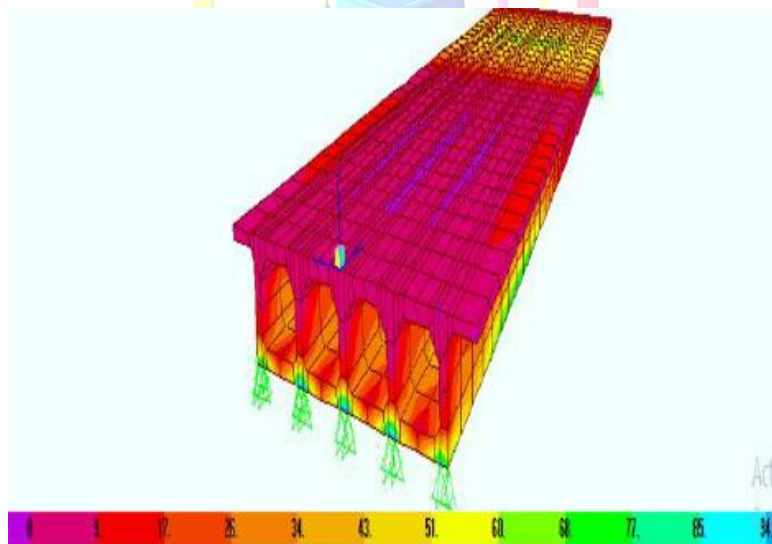
#### 4.2.6 Longitudinal & Shear Stresses

Table 4.6: Stress Comparison

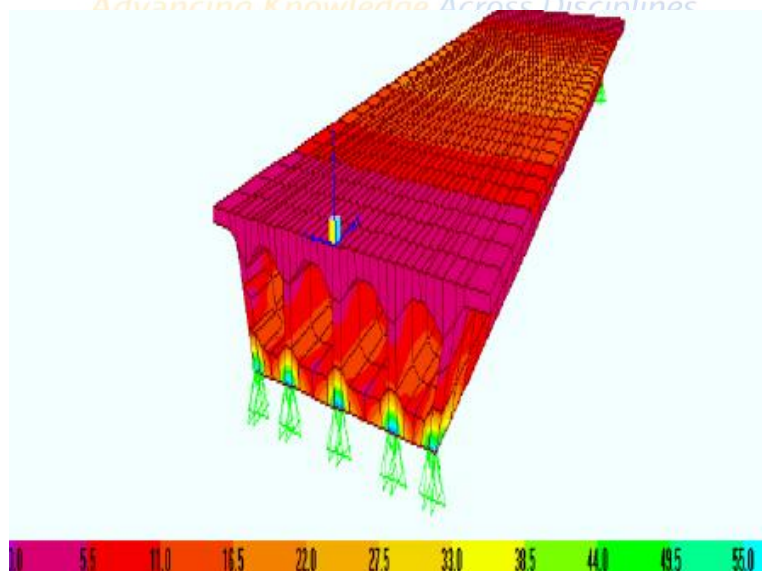
Parameter	Rectangular	Trapezoidal
Longitudinal Stress	Higher (9%)	Lower
Shear Stress	Lower	Higher (13%)



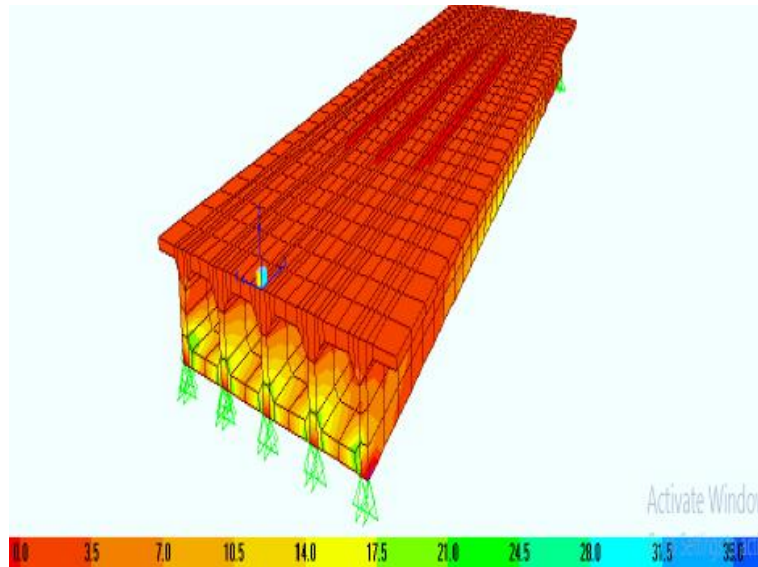
**Graph 4.7: Stress Comparison**



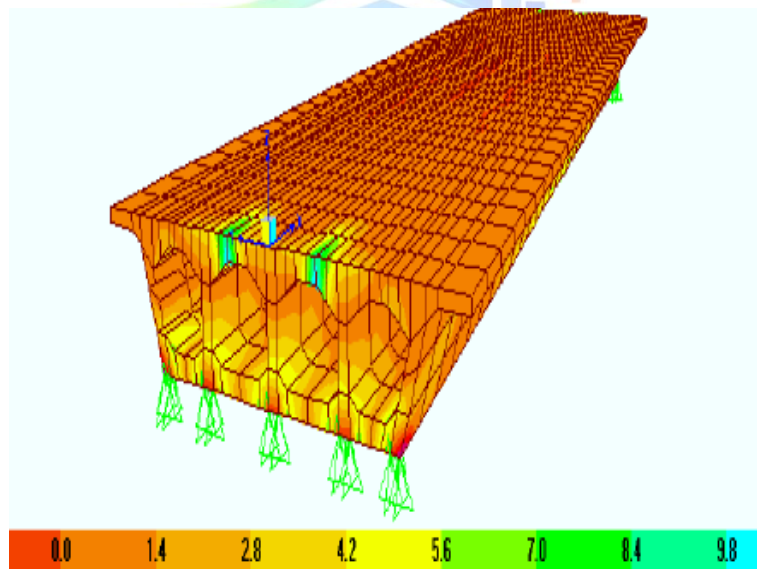
**Figure 4.1: Axial Stresses in Rectangular Box Girder**



**Figure 4.2: Axial Stresses in Trapezoidal Box Girder**



**Figure 4.3: Stresses in Shear: Rectangular Box Girder**



**Figure 4.4: Stresses in Shear: Trapezoidal Box Girder**

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## CONCLUSION

The study evaluates the seismic performance of prestressed concrete (PSC) box girder bridges for elevated metro structures using FEM analysis in SAP2000 under static and dynamic loading. Two configurations, rectangular and trapezoidal box girders, were analyzed and compared. Results show that as span increases, natural frequency decreases and time period increases, making structures more flexible, with 40 m span nearing resonance range. The trapezoidal girder performs better by showing lower deflection, bending moment (about 15–16% less), and shear force (about 10% less) compared to the rectangular girder, indicating improved stiffness, load distribution, and reduced reinforcement requirement. Although trapezoidal girders show slightly higher base reactions, they remain within safe limits. Stress distribution is also more balanced in trapezoidal sections, enhancing durability and structural safety. Overall, the trapezoidal PSC box girder proves to be more efficient, economical, and suitable for elevated metro bridges, especially in seismic regions, due to its optimized geometry, reduced self-weight, and better serviceability performance.

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