



# Effect of Span Length on Structural Performance of Prestressed Concrete Girder Bridges Using Finite Element Analysis

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**Abstract:** Prestressed concrete girder bridges are extensively used in transportation infrastructure due to their high structural efficiency, durability, and ability to accommodate varying span requirements. Among the critical design parameters, span length significantly influences bridge behaviour, serviceability, material consumption, and economic feasibility. The present study investigates the effect of span length on the structural performance of prestressed concrete girder bridges using analytical and finite element modelling approaches. Continuous prestressed concrete girder bridge models with span lengths varying from 20 m to 80 m were developed and analyzed under standardized dead load, live load, impact load, and seismic loading conditions. The study evaluated important structural parameters including deflection, bending moment, shear force, stress distribution, and natural frequency. Finite element analysis was performed to simulate bridge behaviour and compare performance under different span configurations. The results indicated that increasing span length significantly increased deflection, bending moments, and vibration sensitivity while reducing structural stiffness and natural frequency. Longer spans required greater prestressing force, larger girder depth, and higher material consumption to maintain structural safety and serviceability requirements. Conversely, shorter spans exhibited lower deformation and improved stiffness but required additional

supports and foundations. Comparative analysis demonstrated that medium-span bridge configurations provided better structural efficiency and economic feasibility compared with very short and very long spans. The study further confirmed the effectiveness of finite element analysis in predicting the structural response of prestressed concrete girder bridges under varying span conditions. The findings of this research may assist bridge engineers and infrastructure planners in selecting optimum span configurations for safe, durable, and cost-effective bridge design.

**Keywords:** Prestressed Concrete Girder Bridge, Span Length, Finite Element Analysis, Structural Performance, Deflection Analysis



## 1. Introduction

Prestressed concrete girder bridges have become one of the most widely adopted structural systems in modern transportation infrastructure because of their high structural efficiency, durability, serviceability performance, and economic feasibility. The rapid expansion of highway networks, urban transportation systems, railway corridors, and expressway infrastructure has significantly increased the demand for bridge systems capable of carrying heavy vehicular loads while maintaining long-term structural stability and safety. Among various bridge forms, prestressed concrete girder bridges are extensively preferred for short-, medium-, and long-span applications due to their superior load-carrying capacity, reduced maintenance requirements, improved crack resistance, and enhanced durability under varying environmental and loading conditions (Chen & Duan, 2014). The integration of prestressing technology into bridge engineering has revolutionized concrete bridge design by enabling concrete members to resist tensile stresses more effectively and achieve longer spans with reduced structural depth and self-weight.

The concept of prestressing was introduced to overcome the inherent weakness of conventional concrete in tension. In ordinary reinforced concrete structures, tensile stresses caused by external loading often lead to cracking and excessive deflection, thereby reducing durability and service life. Prestressing technology introduces compressive stresses into concrete members before the application of service loads, effectively counteracting tensile stresses developed during bridge operation. This mechanism significantly improves flexural performance, crack resistance, and stiffness characteristics of bridge girders. As a result, prestressed concrete bridges are capable of supporting higher loads over larger spans while maintaining satisfactory serviceability and structural safety (Lin & Burns, 2019). The development of prestressed concrete technology by Eugène Freyssinet during the early twentieth century marked a major advancement in structural engineering and laid the foundation for modern prestressed bridge systems (Freyssinet, 1956).

In bridge engineering, span length is considered one of the most influential design parameters affecting structural configuration, load distribution, dynamic response, material consumption, and overall economic feasibility. Span length generally refers to the horizontal distance between two consecutive supports such as piers or abutments. The selection of an appropriate span length is a critical aspect of bridge design because it directly influences bending moments, shear forces, deflection behaviour, stress distribution, vibration characteristics, and foundation requirements. As span length increases, bridge girders experience larger flexural and shear demands, leading to increased deformation, higher prestressing force requirements, and greater material consumption (Nawy, 2020). Conversely, shorter spans generally exhibit higher stiffness and lower deflection but require additional intermediate supports and substructure elements, thereby increasing foundation complexity and construction cost.

The structural behaviour of prestressed concrete girder bridges under varying span configurations has attracted considerable attention from researchers and bridge engineers over recent decades. Increasing transportation demand and higher traffic intensity have necessitated the construction of longer-span bridge systems capable of carrying heavier vehicular loads with improved structural reliability and durability. However, increasing span length also introduces several engineering challenges associated with structural stability, serviceability performance, vibration sensitivity, and construction economy. Longer-span bridges are more susceptible to excessive deflection, fatigue stresses, dynamic amplification, and vibration-induced discomfort under moving traffic loads. In addition, increased span length often requires deeper girders, larger prestressing tendons, and more sophisticated construction techniques to maintain acceptable structural performance (Podolny & Muller, 2018).

The advancement of finite element analysis (FEA) and computational modelling techniques has significantly improved the capability of engineers to analyze and predict bridge behaviour under varying loading and environmental conditions. Traditional analytical methods based on classical beam theory and simplified assumptions were often inadequate for accurately evaluating complex three-dimensional bridge behaviour, especially in long-span and continuous bridge systems. Modern finite element modelling approaches enable detailed simulation of stress distribution, deformation patterns, vibration characteristics, and load transfer



mechanisms with improved precision and reliability (Nilson, Darwin, & Dolan, 2018). These numerical tools allow bridge engineers to optimize girder geometry, tendon arrangement, material utilization, and span configuration for achieving enhanced structural efficiency and economic performance.

Prestressed concrete girder bridges are commonly categorized into I-girder bridges, T-girder bridges, and box girder bridges depending on their structural configuration and span requirements. I-girder bridges are widely used for short- and medium-span applications because of their simple geometry, ease of fabrication, and efficient flexural resistance. Box girder bridges are generally preferred for medium- and long-span bridges due to their superior torsional rigidity, aerodynamic stability, and ability to resist eccentric loading conditions. T-girder bridges, on the other hand, are often adopted for moderate span applications where economical construction and simplified structural configuration are required (Raju, 2017). The selection of an appropriate girder system depends largely on span length, traffic demand, loading conditions, site constraints, and economic considerations.

Several researchers have investigated the influence of span length on the structural performance of prestressed concrete bridge systems. Earlier studies reported that increasing span length significantly increases bending moments, shear forces, and deflection response while reducing structural stiffness and natural frequency. Lin and Burns (2019) observed that prestressed concrete girders exhibited improved crack resistance and serviceability performance compared with conventional reinforced concrete girders; however, longer spans required greater prestressing force and increased girder depth to maintain structural stability. Similarly, Chen and Duan (2014) reported that span length had a direct impact on bridge economy because longer spans increased material consumption and construction complexity. Podolny and Muller (2018) further emphasized that long-span bridge systems required careful dynamic analysis to prevent excessive vibration and fatigue-related deterioration under moving vehicular loads.

The serviceability performance of prestressed concrete girder bridges is another important aspect strongly influenced by span length. Serviceability generally includes deflection control, vibration response, crack resistance, and long-term deformation characteristics under working load conditions. Excessive deflection and vibration can reduce riding comfort, affect structural durability, and increase maintenance requirements over the operational life of the bridge. Prestressing technology helps minimize tensile stresses and control deflection; however, the effectiveness of prestressing systems decreases with increasing span length beyond practical design limits (Nawy, 2020). Therefore, understanding the relationship between span length and serviceability performance is essential for ensuring safe and durable bridge structures.

Dynamic behaviour and vibration response have become increasingly important considerations in modern bridge engineering due to the increasing speed and magnitude of vehicular traffic. Longer-span bridges generally exhibit lower natural frequency and higher flexibility, making them more susceptible to vibration amplification under moving loads, wind forces, and seismic excitation. Dynamic effects can lead to fatigue stresses, discomfort to bridge users, and long-term structural deterioration if not properly controlled. Researchers have demonstrated that prestressing improves bridge stiffness and dynamic stability; however, span length remains one of the governing parameters influencing vibration characteristics and modal behaviour (Nilson et al., 2018). Consequently, dynamic analysis using finite element modelling has become an essential component of bridge performance evaluation.

Economic feasibility is also significantly affected by span length in prestressed concrete bridge systems. Longer spans generally require larger girder sections, increased prestressing tendons, and greater quantities of concrete and reinforcement steel, thereby increasing construction cost. However, longer spans reduce the number of intermediate piers and foundations, which may improve hydraulic clearance and reduce substructure cost. Conversely, shorter spans exhibit lower superstructure cost but require additional supports and foundation systems. Therefore, optimum span selection involves balancing structural safety, serviceability performance, construction feasibility, and lifecycle economy (Chen & Duan, 2014). Modern bridge design practices increasingly emphasize performance-based optimization approaches to identify economical and structurally efficient span configurations.



Despite extensive research in prestressed concrete bridge engineering, comparatively limited studies have comprehensively evaluated the combined influence of span length on structural behaviour, serviceability performance, dynamic response, and economic efficiency using integrated finite element analysis approaches. Many earlier investigations focused primarily on isolated structural parameters such as flexural behaviour or load-carrying capacity without simultaneously considering vibration characteristics and material utilization. Therefore, further analytical investigation is necessary to develop a comprehensive understanding of span-related bridge behaviour and identify suitable span configurations for safe, durable, and cost-effective bridge construction.

The present study therefore focuses on investigating the effect of span length on the structural performance of prestressed concrete girder bridges using finite element analysis. Continuous prestressed concrete girder bridge models with span lengths varying from 20 m to 80 m were developed and analyzed under standardized dead load, live load, impact load, and seismic loading conditions. Important structural parameters including deflection, bending moment, shear force, stress distribution, and natural frequency were evaluated to assess bridge behaviour under varying span configurations. The study also examines structural efficiency and economic implications associated with span variation. The findings of this research may assist bridge engineers, structural designers, and infrastructure planners in selecting optimum span configurations for modern prestressed concrete bridge systems.

## 2. Research Methodology

### 2.1 Introduction

The present study adopted a quantitative analytical methodology to investigate the effect of span length on the structural performance of prestressed concrete girder bridges using finite element analysis (FEA). Prestressed concrete bridge systems involve complex interaction between girders, deck slabs, prestressing tendons, supports, and externally applied loads. Conventional analytical methods based on simplified beam theory are often insufficient for accurately predicting the three-dimensional behaviour and dynamic response of bridge systems, particularly for long-span structures. Therefore, finite element modelling was employed in the present study to simulate bridge behaviour with greater precision and reliability (Chen & Duan, 2014).

The methodology focused on developing continuous prestressed concrete girder bridge models with span lengths varying from 20 m to 80 m under standardized loading and boundary conditions. The bridge models were analyzed under dead load, live load, impact load, and seismic load conditions to evaluate important structural parameters including deflection, bending moment, shear force, stress distribution, and natural frequency. The finite element analysis procedure enabled detailed evaluation of structural response under varying span configurations and provided a basis for comparative assessment of bridge performance.

### 2.2 Research Design

The present investigation followed a quantitative analytical research design based on finite element analysis techniques. Continuous prestressed concrete girder bridge models were developed and analyzed using STAAD.Pro software. The study adopted a comparative approach in which multiple bridge models with different span lengths were analyzed under identical material properties, loading conditions, and support configurations.

The selected span lengths represented short-span, medium-span, and long-span bridge systems commonly used in transportation infrastructure projects. Equal span arrangements were considered in all models to ensure uniformity in structural comparison and simplify analytical evaluation. The adopted research design enabled systematic assessment of the influence of span length on structural efficiency, serviceability behaviour, and economic feasibility of prestressed concrete girder bridges (Lin & Burns, 2019).

The overall analytical framework adopted in the study is illustrated in Figure 2, which presents the finite element analysis procedure followed for bridge modelling and structural evaluation.



### 2.3 Bridge Configurations

The selection of appropriate bridge configurations is an important aspect in the structural analysis of prestressed concrete bridge systems because bridge geometry significantly affects load distribution, stiffness, dynamic response, and overall structural efficiency. In the present study, seven continuous prestressed concrete girder bridge models were selected with span lengths ranging from 20 m to 80 m.

Prestressed concrete I-girder systems were adopted for short- and medium-span bridges because of their high flexural efficiency, ease of fabrication, and economical design characteristics. For larger span lengths, prestressed concrete box girder systems were selected due to their superior torsional rigidity, improved vibration resistance, and enhanced stability under long-span conditions (Podolny & Muller, 2018).

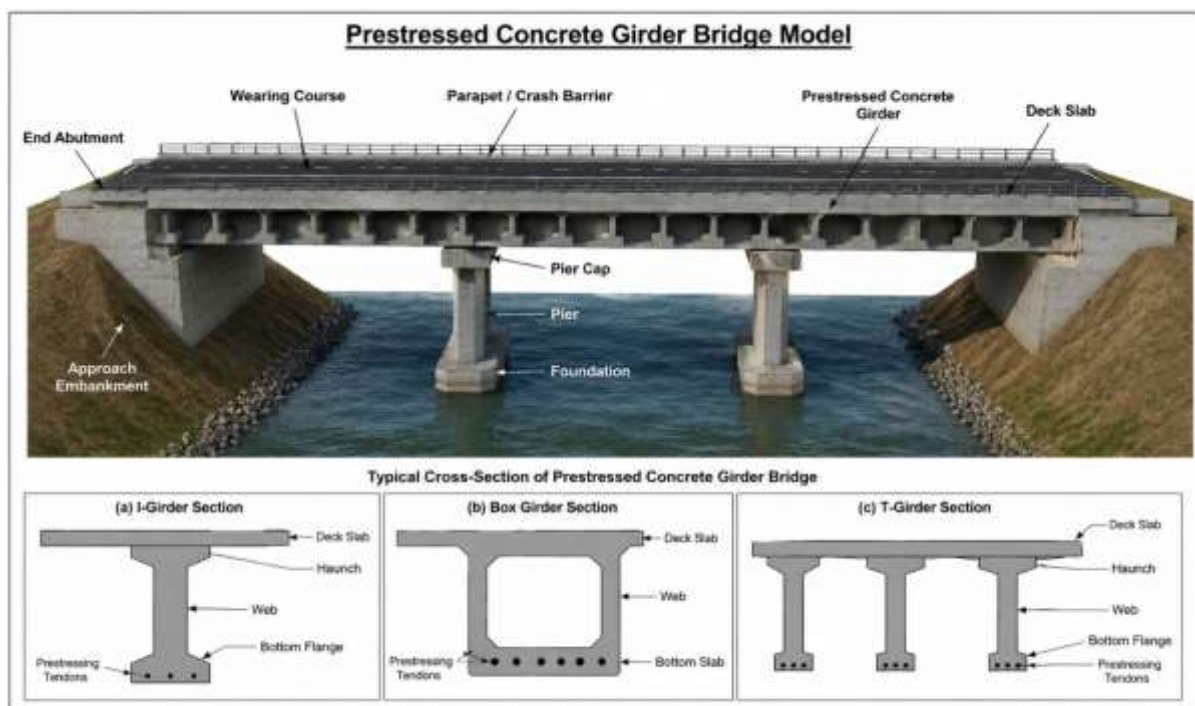
The selected bridge configurations are presented in Table 1.

**Table 1. Span Length Configurations Considered**

Model	Span Length (m)	Bridge Type
B1	20	PSC I-Girder
B2	30	PSC I-Girder
B3	40	PSC I-Girder
B4	50	PSC I-Girder
B5	60	PSC Box Girder
B6	70	PSC Box Girder
B7	80	PSC Box Girder

The selected bridge models enabled comprehensive assessment of structural behaviour under varying span conditions. Short-span bridges were expected to exhibit higher stiffness and lower deformation, whereas long-span bridge systems were anticipated to experience increased bending moments, deflection, and vibration sensitivity.

The typical prestressed concrete girder bridge model adopted in the study is illustrated in Figure 2, which includes deck slab arrangement, prestressed girders, piers, foundations, and cross-sectional configurations of girder systems.



**Figure 2. Prestressed Concrete Girder Bridge Model**



## 2.4 Material Properties

Material properties significantly influence the stiffness, durability, stress distribution, and load-carrying capacity of prestressed concrete bridge systems. In the present study, standard bridge construction materials commonly adopted in highway infrastructure projects were considered in accordance with Indian Standard specifications.

M50 grade concrete was selected because high-strength concrete provides improved compressive strength, enhanced durability, lower permeability, and better prestress transfer characteristics. Prestressing steel of grade Fe1860 was used due to its high tensile strength and improved fatigue resistance under repeated loading conditions (Nawy, 2020).

The material properties used in the analysis are presented in Table 2.

**Table 2. Material Properties Used in Analysis**

Parameter	Value
Concrete Grade	M50
Elastic Modulus of Concrete	34 GPa
Density of Concrete	25 kN/m <sup>3</sup>
Prestressing Steel Grade	Fe1860
Elastic Modulus of Steel	200 GPa

The elastic modulus values were incorporated in the finite element model to simulate structural stiffness and deformation behaviour accurately. The density of concrete was included to account for self-weight effects in dead load analysis.

## 2.5 Loading Conditions

Prestressed concrete bridge systems are subjected to multiple loading conditions throughout their operational life. Therefore, realistic loading scenarios were incorporated into the finite element analysis to evaluate bridge behaviour under practical service environments.

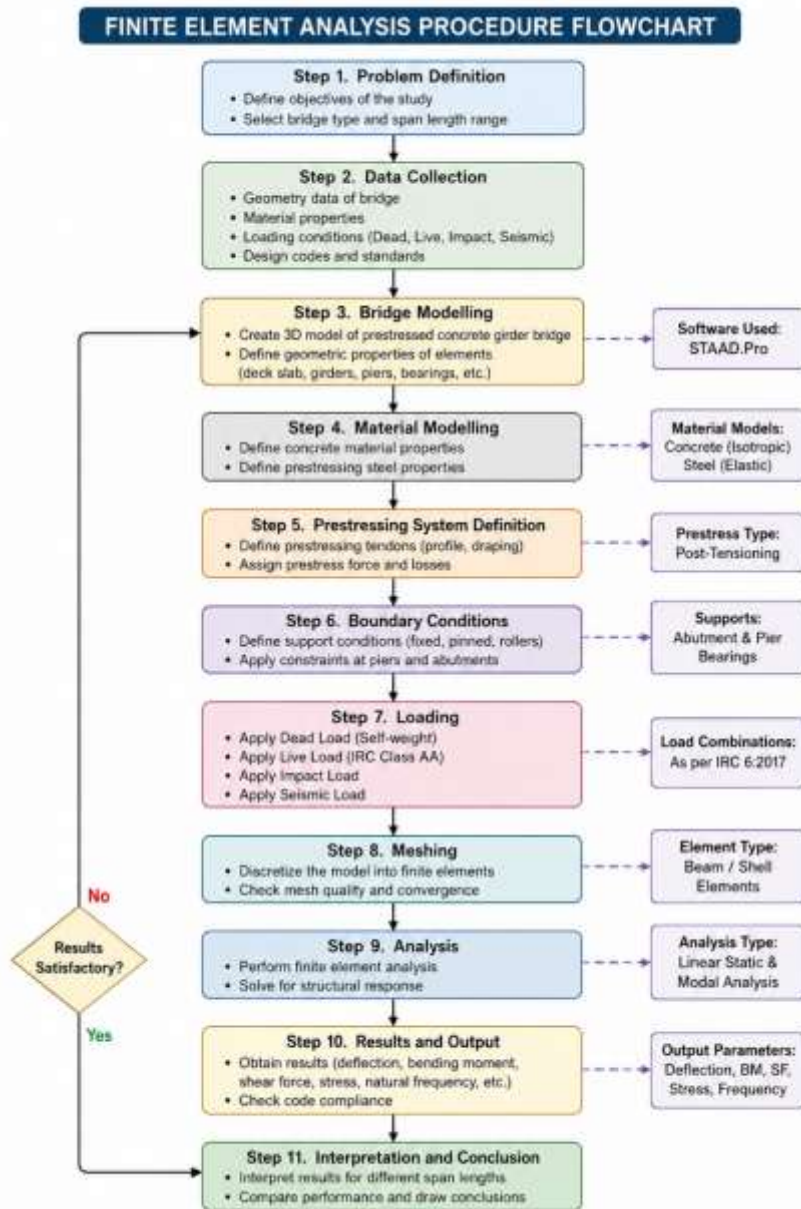
The bridge models were analyzed under the following loading conditions:

- Dead Load (Self-weight)
- IRC Class AA Live Load
- Impact Load
- Seismic Load

Dead load represented the self-weight of bridge components including deck slab, girders, parapets, and wearing course. IRC Class AA live load was applied to simulate heavy vehicular loading conditions commonly experienced in highway bridges. Impact loading was considered to account for dynamic amplification effects generated by moving vehicles. Seismic loading was incorporated to evaluate bridge behaviour under earthquake-induced excitation in accordance with relevant seismic design provisions (IRC, 2017).

Finite element modelling was performed using STAAD.Pro software, which enabled detailed simulation of stress distribution, load transfer mechanisms, deformation behaviour, and dynamic response characteristics.

The adopted finite element modelling procedure is illustrated in Figure 2, which includes bridge modelling, material definition, prestressing system assignment, meshing, loading application, structural analysis, and result interpretation.



**Figure 2. Finite Element Analysis Procedure Flowchart**

## 2.6 Finite Element Modelling

Finite element analysis was performed using STAAD.Pro software because of its capability to accurately represent complex bridge geometry and loading behaviour. The bridge models were discretized into beam and shell elements to simulate deck slab behaviour, girder action, support conditions, and prestressing effects.

Boundary conditions were assigned at piers and abutments to represent realistic bridge support behaviour. Fixed and roller support conditions were incorporated depending on structural requirements. Prestressing tendons were modelled using equivalent prestressing force methods to simulate tendon behaviour and stress transfer within the girders.

Mesh quality and convergence checks were performed to ensure analytical accuracy and stability of the finite element models. The developed bridge models were analyzed under combined loading conditions to obtain structural response parameters including deflection, bending moment, shear force, stress distribution, and natural frequency.



## 2.7 Performance Parameters Considered

The structural performance of prestressed concrete girder bridges was evaluated using the following analytical parameters:

- Maximum Deflection
- Bending Moment
- Shear Force
- Stress Distribution
- Natural Frequency

Deflection behaviour was considered to evaluate serviceability performance and structural stiffness. Bending moment and shear force analysis were performed to examine flexural and shear demand within bridge girders. Stress distribution analysis was conducted to assess the effectiveness of prestressing systems in controlling tensile stresses. Natural frequency analysis was performed to evaluate bridge vibration characteristics and dynamic stability under moving vehicular loads (Nilson et al., 2018).

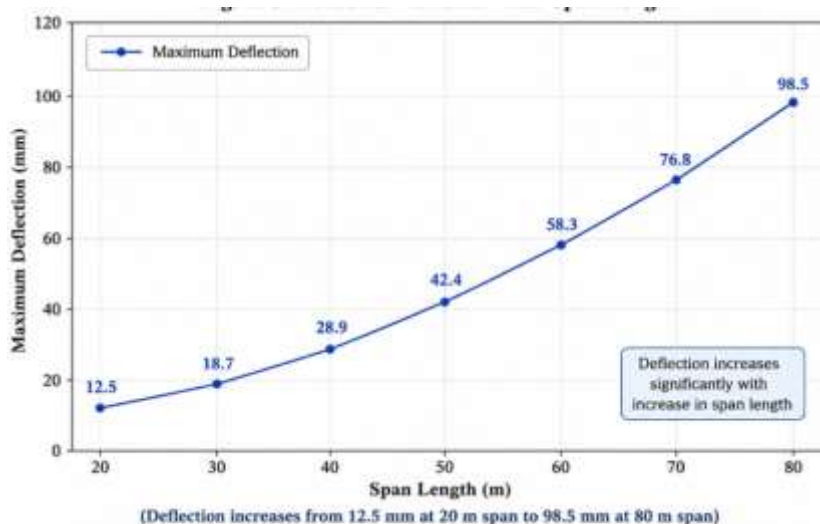
## 3. Results and Discussion

### 3.1 Deflection Analysis

Deflection is one of the most critical serviceability parameters in prestressed concrete girder bridges because excessive vertical deformation can adversely affect structural stability, riding comfort, durability, and long-term operational efficiency of bridge systems. The finite element analysis results presented in Table 3 indicate that maximum vertical deflection increased significantly with increasing span length under combined dead load, live load, impact load, and seismic loading conditions. The 20 m span bridge exhibited a comparatively low maximum deflection of 12.5 mm because of its higher flexural stiffness and reduced bending demand, whereas the 80 m span bridge showed a maximum deflection of 98.5 mm due to increased structural flexibility and reduced stiffness characteristics. The analytical results demonstrate that longer-span bridges experience substantially greater deformation because flexural rigidity decreases progressively with increasing span length. The variation of deflection with span length shown in Figure 3 clearly illustrates the nonlinear increase in deformation as span length increases from short-span to long-span bridge systems. Similar observations were reported by Lin and Burns (2019), who concluded that span length significantly affects bridge stiffness and long-term serviceability behaviour. Chen and Duan (2014) also observed that excessive deflection in long-span bridge systems may lead to serviceability problems, vibration sensitivity, and increased maintenance requirements. Therefore, proper span selection and optimized prestressing arrangements are essential for controlling deflection and maintaining satisfactory structural performance in prestressed concrete girder bridges.

**Table 3. Deflection Results for Different Span Lengths**

Span Length (m)	Maximum Deflection (mm)
20	12.5
30	18.7
40	28.9
50	42.4
60	58.3
70	76.8
80	98.5



**Figure 3. Deflection Variation with Span Length**

### 3.2 Bending Moment Analysis

Bending moment is a fundamental structural parameter governing the flexural behaviour, stress distribution, and load-carrying capacity of prestressed concrete girder bridges. The finite element analysis results presented in Table 4 reveal that maximum bending moment increased substantially with increasing span length. The 20 m span bridge developed a maximum bending moment of 4200 kN-m, whereas the 80 m span bridge exhibited a significantly higher bending moment of 29800 kN-m. This considerable increase in flexural demand is primarily attributed to the increased self-weight effects, larger load transfer length, and reduced stiffness associated with long-span bridge systems. Longer spans experience greater internal stresses under dead and live loading conditions, thereby requiring deeper girder sections, larger prestressing force, and improved reinforcement detailing to maintain structural safety and serviceability. The obtained results indicate that the rate of bending moment increase becomes more significant beyond the medium-span range, suggesting that long-span bridges require considerably higher structural capacity compared with short-span systems. Similar findings were reported by Nawy (2020), who observed that span length strongly influences girder dimensions and prestressing requirements in prestressed concrete bridges. Podolny and Muller (2018) further emphasized that long-span bridge systems require optimized structural geometry and advanced prestressing techniques to control flexural stresses and deformation behaviour. Therefore, bending moment analysis is essential for evaluating structural efficiency and ensuring safe bridge design under varying span configurations.

**Table 4. Bending Moment Variation with Span Length**

Span Length (m)	Maximum Bending Moment (kN-m)
20	4200
30	6800
40	9800
50	13600
60	18200
70	23600
80	29800

### 3.3 Dynamic Response Analysis

Dynamic response analysis is an important aspect of modern bridge engineering because bridge structures are continuously subjected to moving vehicular loads, impact effects, wind forces, and seismic excitation during their service life. The natural frequency results presented in Table 5 indicate that dynamic behaviour was significantly influenced by span length variation. The 20 m span bridge exhibited a relatively high natural



frequency of 5.82 Hz because of its greater structural stiffness and reduced flexibility, whereas the 80 m span bridge showed a much lower natural frequency of 1.74 Hz due to increased structural flexibility and reduced rigidity. The reduction in natural frequency with increasing span length indicates that long-span bridge systems are more susceptible to vibration amplification and dynamic instability under moving traffic loads. Lower natural frequencies may increase vibration sensitivity and fatigue-related deterioration, thereby affecting user comfort and long-term structural durability. Similar observations were reported by Nilson et al. (2018), who concluded that increasing span length significantly affects modal behaviour and dynamic performance of prestressed concrete bridge systems. Podolny and Muller (2018) also emphasized that dynamic analysis becomes increasingly important for long-span bridges because vibration response and resonance effects may adversely influence structural safety and operational efficiency. The present results therefore confirm that dynamic response characteristics should be carefully evaluated during bridge design, particularly for long-span prestressed concrete girder systems subjected to heavy traffic and environmental loading conditions.

**Table 5. Natural Frequency Variation**

Span Length (m)	Natural Frequency (Hz)
20	5.82
30	4.71
40	3.88
50	3.12
60	2.64
70	2.18
80	1.74

### 3.4 Structural Efficiency and Economic Performance

Structural efficiency and economic feasibility are among the most important considerations in bridge engineering because optimum bridge design requires balancing structural safety, serviceability performance, material utilization, and construction cost. The analytical results obtained in the present study indicate that medium-span prestressed concrete girder bridges ranging from 40 m to 60 m provided better overall structural efficiency and economic performance compared with very short and very long span bridge systems. Short-span bridges exhibited lower deflection and higher stiffness because of reduced bending demand; however, they required additional piers, abutments, and foundations, thereby increasing substructure complexity and construction expenditure. Conversely, long-span bridges required larger girder dimensions, greater prestressing force, increased reinforcement detailing, and higher material consumption to maintain adequate structural stability and serviceability performance. The finite element analysis further indicated that long-span bridge systems experience greater bending moments, higher deformation, and increased vibration sensitivity, which contribute to higher lifecycle cost and maintenance requirements. Similar findings were reported by Chen and Duan (2014), who observed that bridge economy is strongly influenced by span length because larger spans require advanced construction techniques and greater material utilization. Lin and Burns (2019) also concluded that medium-span prestressed concrete bridge systems generally provide the most balanced combination of structural efficiency, serviceability behaviour, and economic feasibility. Therefore, optimum span selection is essential for achieving safe, durable, and cost-effective prestressed concrete bridge design under modern transportation infrastructure requirements.



#### 4. Conclusion

The present study investigated the effect of span length on the structural performance of prestressed concrete girder bridges using finite element analysis. The following major conclusions were obtained:

1. Increasing span length significantly increased bridge deflection, bending moment, and vibration sensitivity.
2. Structural stiffness and natural frequency decreased with increasing span length.
3. Longer spans required greater prestressing force, deeper girders, and higher material consumption.
4. Short-span bridges exhibited lower deformation but required additional supports and foundations.
5. Medium-span bridges (40–60 m) provided improved structural efficiency and economic feasibility.
6. Finite element analysis proved effective for accurately predicting bridge response under varying span configurations.

The findings of this research may assist bridge engineers in selecting optimum span configurations for safe, durable, and cost-effective bridge design.

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