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Research paper

Static responses analysis of prestressing tension force effects on vertical deflection and shear force of simply-supported and continuous prestressed concrete bridges

Ali Fadhil Naser *

Building and Construction Engineering Technical Department, Al-Furat Al-Awsat Technical University/ Al-Mussaib Technical College, Babylon, Iraq
**Corresponding author E-mail:ali_hu73@yahoo.com*

Abstract

The purpose of this study is to investigate and evaluate the effect of prestressing tension force on the static responses such as vertical deflection and vertical shear force of prestressed concrete bridges. Simply-supported I-girder bridge model and continuous box girder concrete bridge model are selected. Each model is used 12 levels of prestressing tension force ranged from 500kN to 6000kN. Finite element analysis method is used in static analysis. The results of static analysis shows that simply-supported bridge model appears the maximum value of upward deflection (18mm) due to prestressing force stage and maximum value of downward deflection (-15mm) due to service loads stage. Therefore, the prestressing tension force has significant effect to reduce the downward deflection due to service loads. This model also appears direct proportion between prestressing tension force and vertical shear force for prestressing force analysis and service loads stages. For continuous box girder bridge model, the prestressing tension force has no important effect on the upward vertical deflection due to prestressing load stage and it appears just downward vertical deflection. Therefore, this types of model needs to increase the prestressing force tension of steel tendons to reduce the downward deflection and to increases upward deflection. Continuous box girder bridge model gives opposite proportion between prestressing tension force and vertical shear force in positive and negative area within prestressing force analysis stage. Under service load stage, the positive and negative vertical shear force is decreased when the prestressing tension force increased.

Keywords:*Bridge; Deflection; Prestressing Force; Shear; Static Responses.*

1. Introduction

Bridges are an important part of the transportation engineering system and they are structures that have total length more than 6m. They provide a connection over urban congestion, waterways, valleys. The volumes and traffic loads carried by using transportation system are limited the capacity of bridges structures. Therefore, it becomes necessary to complete a balance between future traffic loads and volumes and the cost of a heavier and wider bridge structure. [1], [2]

Prestressing means determinedly carrying a self-equilibrated state of stress in structure before it is applied service loads. It is important to improve structural performance of structure such as stability, bearing capacity, stiffness, and limitation of cracks (decrease of tensile stresses). Prestressing can be used in rehabilitation, strengthening of structures by providing confining loads. [3]

Prestressing tension force is one of the most significant factors in prestressed concrete bridges and it can be determined the load carrying capacity ofbridges structures. But the losses of Prestressing force may be caused the failure of bridges structures which it makes prestressing force identification (PFI) critical index to evaluate the bridges safety. The prestressing force can be introduced by using steel strands, steel tendons, and steel wires. Therefore, steel strands are the most important member of the prestressing concrete structure. [4], [5]

Prestressing concrete system can be defined as concrete that internal stress is presented to stabilize the stresses resulting from external loads to a preferred degree. The prestressing system is used to control crack development in concrete, reduce vertical displacement and reduce concrete tensile stress. According to the result of elastic shortening, creep and shrinking of concrete, steel relaxation and frictional loss between steel tendons and concrete, prestressed concrete may be leaded to lose the prestressing force which in turn would lead to disastrous failures of the prestressing concrete bridge. [4], [6]

During the 20th century, prestressing concrete bridges have become a favorite kind in the bridge building internationally, because of many reasons such as economy and savings in life-cycle costs. It is necessary to develop an effective method to evaluate the existing prestress forcein bridges constructed by using prestressing system, not only to ensure the structural and operational safety, but also to warn of unexpected damages.[4], [7].

2. Past related studies

Most past studies investigated the effect of prestressing tension force on the dynamic responses of prestressed concrete beams, and they did not study the relation with static responses such as vertical deflection and shear. This paragraph will be described thepast related studies.

S. Bae1,2013 studied the influence of prestressing force and bending moment on the radial stress in control structures. By using theoretical equations and FE analyses, radial stresses calculated and compared. Different loading conditions are examined to study their effects. [8]

Noble, D. et al 2014 inspected the effect of prestressing tension force amount andeccentricity on natural vibration frequencies of prestressed concrete structures. Their paper defines and analyses the test of impact hammer directed prestressed concrete beam at different levels of prestressing tension force. The purpose of the research is to investigate how the natural vibration frequencies of prestressed concrete structures change withprestressing tension forcevalues. According to the experimental modal analysis, it can be noted that from there is no change in the natural bending frequency for a straight profiled prestressing strands, and that the calculation of natural vibration frequency is independent of prestressing tension force value over the given range of prestressing force value. [9]

Nobel, D. et al 2014 studied the effect of prestressing tension force magnitude on the dynamic responses of un-cracked prestressed concrete beam. They described the results of dynamic tests on damaged post-tensioned concrete beams. The natural vibration frequency of the cracked beams were calculated by using experimental modal analysis. During Analysis, the relationship between prestressing tension force and natural frequency for both the cracked and un-cracked beam sections was determined. The results showed that the marked difference in vibration behaviour was observed for the cracked beams between the non-fully prestressed and the fully prestressed case. [10]

R. Frans, and Y. Arfiadi, 2016 optimized the cross section and prestressing tension force of prestressed concrete beam by using fast multi-group optimization method of simply-supported beam. The purpose of their paper is to minimize the weight and the total cost of the prestressed concrete beam. The results of analysis found that the weight and total cost are 155.9 kN and 16.340.000, respectively. They concluded that the optimization method appeared good performance in the case of calculating the optimum cross section and prestressing force. Although the lower and upper bounds are different. [11]

J. Li, 2016 studied the relationship between the natural vibration frequency of continuous steel beam and the prestressing force by using experiments and numerical simulation. He excitedthe continuous beam model under different prestressing force values by using the hammering method, and the acquired vibration signal was divided and analysed dependent on Fast Fourier Transformation (FFT) and Hilbert-Huang Transform (HHT), respectively. He compared betweenthe two analytical methods. According to results of analysis, he found that the relationship between the vibration frequency of the beam and the prestressing force value cannot be explained better based on the conventional mechanic's theory. While, the relationship between the vibration frequency of the beam and the prestressing force can be obtained better through the instantaneous frequency of the beam and other indicators that was calculated dependent on HHT method. The natural vibration frequency of the beam was increased along with the rising prestressing force.[12]

S. Ajinkya and V. Khurd, 2017 studied the effect of prestressing force, eccentricity, cable profile andon the responses of the post-tensioned concrete beam. They Developed 3D-FE modelling and it was suitable for identifying the effect of different design features on the response of posttensioned concrete beam They concluded that prestressing force, eccentricity, cable profile should be considered in the design process of the posttensioned concrete beam. [13]

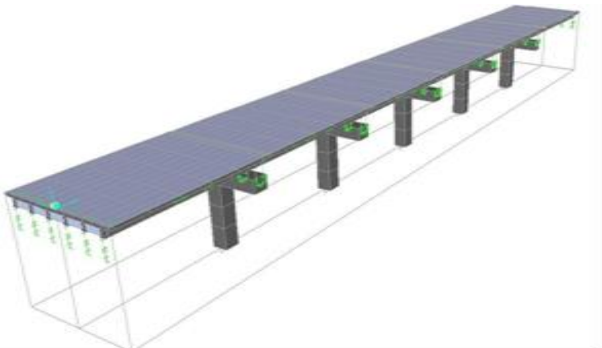
H. Sungnam, 2017 evaluated the effects of prestressing methods and prestressing force levels on the friction losses of prestressed tendons. He used two full-scale prestressed concrete girders for the friction loss experiment. The prestressing force level was different from 13% to 45% of the ultimate tensile strength of the prestressing tendon. The results of experiment indicated that the actual friction loss measured at low prestressing force levels was increased to 4.3 times higher than the theoretical friction loss. The variance between the measured and theoretical friction losses gradually decreased when the prestressing force level increased. On average, the ratio of the prestressing force at the jacking end to the prestressing force measured at mid-span was 85.4% with jacking at both ends, and 81.1% with jacking at one end. [14]

B. Tang, et al 2018 noted that the effect of prestressing force on the dynamic factors of pretension and posttensioned steel beams is a widely discussed topic. They found that the natural bending frequencies of prestressed steel beams tend to be decreased as the value of the prestressing force was increased. They concluded that the natural vibration frequency was increased with the eccentricity and cross-sectional area of the prestressed tendon. Indicating that the eccentricity has a much larger effect on natural frequencies than the cross-sectional area. The prestressing force has no influence on the oven-order frequencies but decreases the odd-order frequency. The prestressing effect is much weaker than the effects caused by the eccentricity and cross-sectional area of the tendon with the increasing order number. [15].

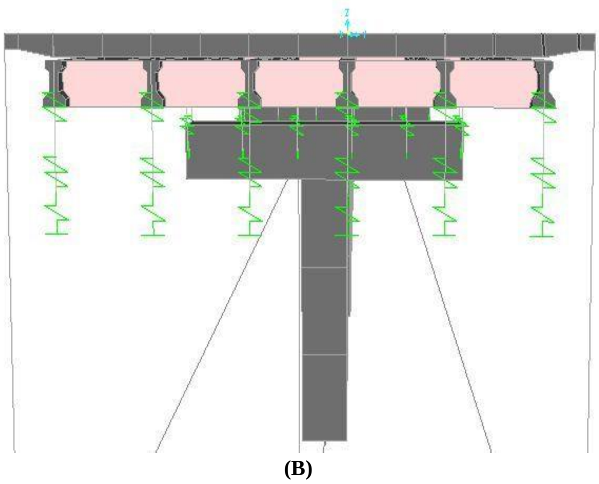
The main objective of this study is to investigate the effect of prestressing tension force on the static responses (vertical deflection and shear force) of prestressed concrete bridges.

3. Explanation of bridges models

According to types of supports and cross-section shape, bridges models can be classified by two types. The first type is simply-supported I girder bridges and the second type is continuous box girder concrete bridge. The two types of bridges models have the same number of spans (6 spans @15m), and same total length (90m) and total width is 11m. The number of loaded lanes is two. Each model is used 12 levels of prestressing tension force ranged from 500kN to 6000kN. Figure 1 shows simply-supported I girder bridge model and Figure 2 continuous box girder concrete bridge model. Table 1 lists the values of prestressing tension force level.



(A)

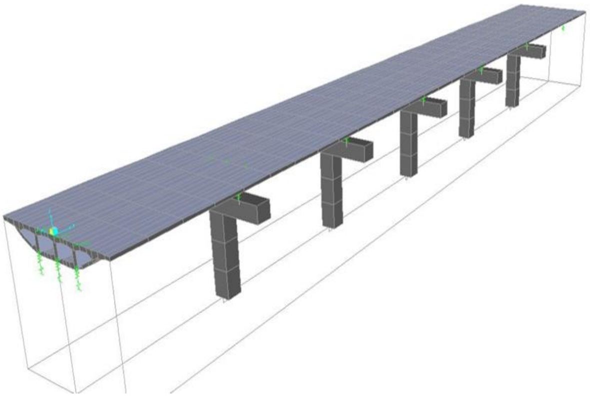


(B)

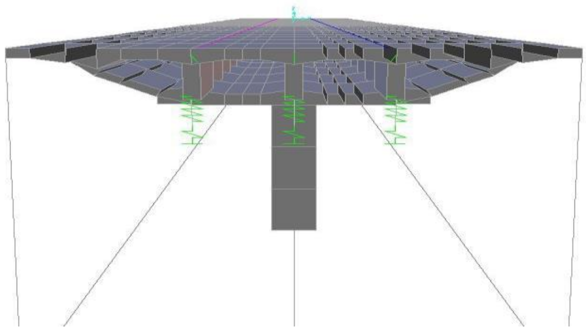
Fig. 1: Simply-Supported I Girder Bridge Model: (A) Longitudinal Section, (B) Transverse Section.

Table 1: Prestressing Tension Force Level of Simply-Supported and Continuous Bridge Models

Model No.	Prestressing tension loads (kN)	
	Simply-supportedbridge model(I-Girder)	Continuous bridge models(box-Girder)
1	500	500
2	1000	1000
3	1500	1500
4	2000	2000
5	2500	2500
6	3000	3000
7	3500	3500
8	4000	4000
9	4500	4500
10	5000	5000
11	5500	5500
12	6000	6000



(A)



(B)

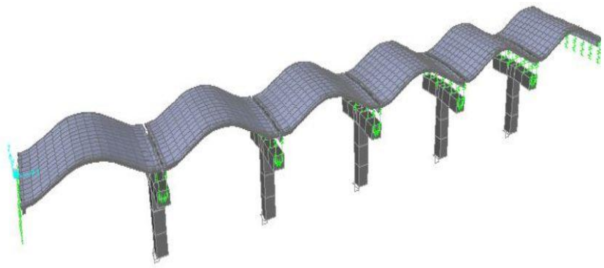
Fig. 2: Continuous Box Girder Concrete Bridge Model: (A) Longitudinal Section, (B) Transverse Section.

4. Static responses analysis

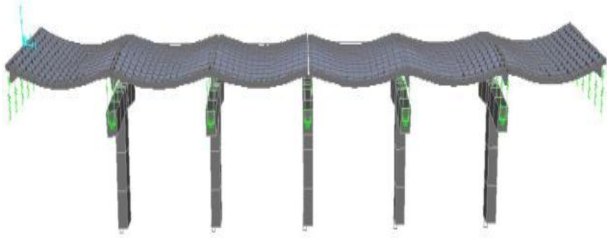
Three-dimension finite element analysis method is usedto study the relationship between prestressing tension force level and vertical deflection and shear. Sap2000 software is adopted to apply the finite element analysis of bridges structure models. Two static responses are selected. These responses are vertical deflection and vertical shear force. There are two types of vertical deflection in prestressed concrete bridge. The first type is resulting by external loads (dead load + traffic load + temperature load + wind load + pedestrian load). The second types is due to prestressing tension force. For design, the prestressing tension force must be resisted the external loads to decrease the vertical deflection, shear force, and tensile stresses. Therefore, the deflection due to prestressing force must be in upward direction.

5. Finite element analysis results

According to load types, finite element analysis results can be divided into two stages. Stages one includes the results of vertical deflection and shear force due to prestressing tension force to inspect the upward deflection due to prestressing tendons force, and the stage two includes the results of service loads (combination loads) to investigate downward vertical deflection andto know the difference value of deflection between prestressing tension force and service load. Figure 3 and Figure 4 shows the sample of vertical deflection due to prestressing tension force and service loads for simply-supported I-girder prestressed concrete bridge model and continuous box girder bridge model respectively.



(A)



(B)

Fig. 3: Vertical Deflection of Simply-Supported I-Girder Prestressed Concrete Bridge Model: (A) Due to Prestressing Tension Force, (B) Due to Service Loads.

(A)

(B)

Fig. 4: Vertical Deflection of Continuous Box Girder Prestressed Concrete Bridge Model: (A) Due to Prestressing Tension Force, (B) Due to Service Loads.

5.1. Vertical deflection results

Figure 5 illustrates the prestressing force and service loads results of vertical deflection analysis (upward and downward) for simply-supported I-girder prestressed concrete bridge model. From this figure it can be shown that the upward vertical deflection values of prestressing force are increased when the prestressing tension force increased and the values are ranged from 0 to 18mm, indicating that the upward vertical deflection is direct proportion with prestressing tension force.According to service loads, the values of downward vertical deflection values are decreased when the prestressing tension force increased. The values range between -15mm and -7mm. Therefore, the prestressing tension force has significant effect to reduce the downward vertical deflection due to service loads, leading to reduce tensile stress and increase compressive stress.

For continuous box girder bridge model, the prestressing tension force has no effect on the upward vertical deflection due to prestressing load, and the values of downward deflection due to service load are ranged from 9mm and 7mm. According to selected prestressing forces level, the box girder model appears just downward vertical deflection. Therefore, this types of model need to increase the prestressing force tension of steel tendons to reduce the downward deflection and to increases upward deflection. Figure 6 shows the vertical deflection values of continuous box girder bridge model.

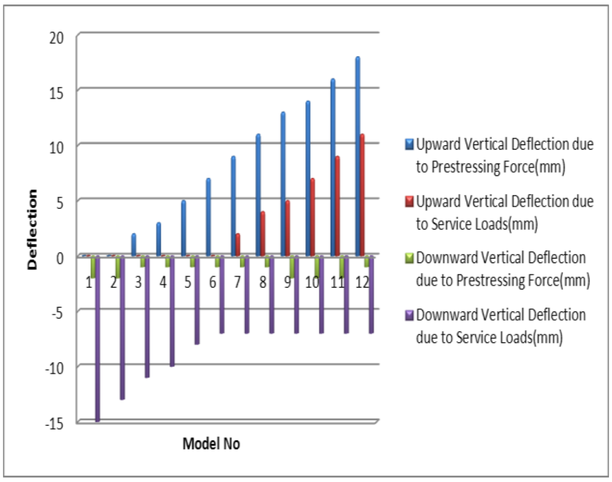


Fig. 5: Vertical Deflection Values of Simply-Supported Bridge Model.

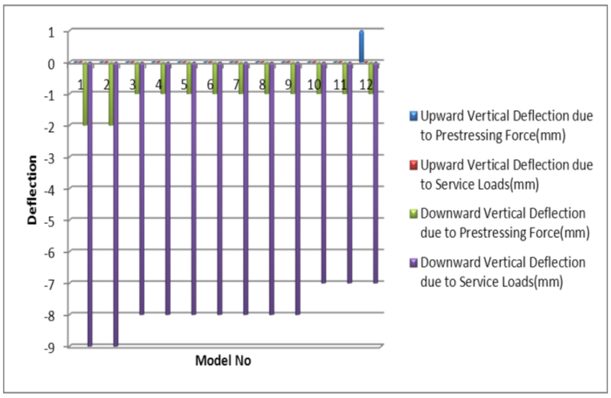


Fig. 6: Vertical Deflection Values of Continuous Box Girder Bridge Model.

5.2. Vertical shear force results

The results of vertical shear force can be illustrated in Figure 7 and Figure 8. From Figure 7 it can be noted that the simply-supported bridge model appears direct proportion between prestressing tension force and vertical shear force for prestressing force analysis stage in positive and negative sides. For service loads stage, the model appears opposite proportion under prestressing force level from 500kN to 1500kN, and it is appeared direct proportion within from prestressing force level 2000kN to 6000kN.According to Figure 8, continuous box girder bridge model gives opposite proportion between prestressing tension force and vertical shear force in positive and negative area within prestressing force analysis stage. Under service load stage, the positive and negative vertical shear force is decreased when the prestressing tension force increased.

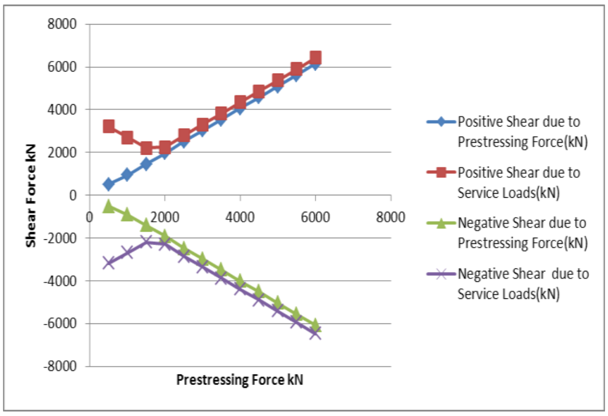


Fig. 7: Vertical Shear Force of Simply-Supported Bridge Model.

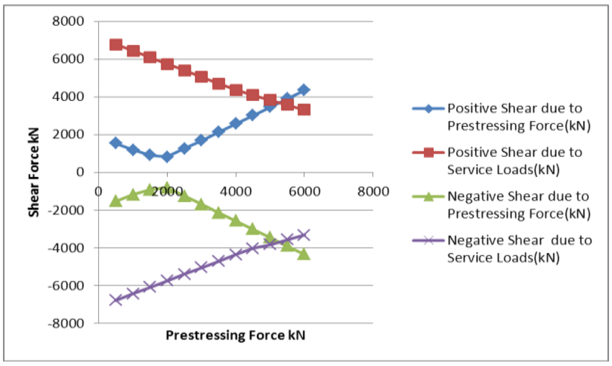


Fig. 8: Vertical Shear Force of Continuous Box Girder Bridge Model.

6. Conclusions

The conclusions of this study are:

1) To Study the effect of prestressing tension force on the static responses (vertical deflection and shear force) of prestressed concrete bridges, two types of bridges models are selected. The first type is simply-supported I girder bridges and the second type is continuous box girder concrete bridge. Each model is used 12 levels of prestressing tension force ranged from 500kN to 6000kN.
2) Three-dimension finite element analysis method is used to study the relationship between prestressing tension force level and vertical deflection and shear. Sap2000 software is adopted to apply the finite element analysis of bridges structure models.
3) For simply-supported bridge model, upward vertical deflection values of prestressing force stage are increased when the prestressing tension force increased indicating that the upward vertical deflection is direct proportion with prestressing tension force. The values of downward vertical deflection values under service loads stage are decreased when the prestressing tension force increased. Therefore, the prestressing tension force has significant effect to reduce the downward vertical deflection due to service loads, leading to reduce tensile stress and increase compressive stress.
4) For continuous box girder bridge model, the prestressing tension force has no important effect on the upward vertical deflection due to prestressing load stage. According to selected prestressing forces level, the box girder model appears just downward vertical deflection. Therefore, this types of model need to increase the prestressing force tension of steel tendons to reduce the downward deflection and to increases upward deflection.
5) The simply-supported bridge model appears direct proportion between prestressing tension force and vertical shear force for prestressing force analysis stage in positive and negative sides. Whereas, the model appears opposite proportion under prestressing force level from 500kN to 1500kN, and it is appeared direct proportion within from

prestressing force level 2000kN to 6000kN within service loads stage. Continuous box girder bridge model gives opposite proportion between prestressing tension force and vertical shear force in positive and negative area within prestressing force analysis stage. Under service load stage, the positive and negative vertical shear force is decreased when the prestressing tension force increased.

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