Optimization of oblique Angle Design of Abutments and piers, and piers Shape of Continuous Prestressed Concrete Box Girder Bridges: Static Analysis part 1

Ali Fadhil Naser

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Abstract- Skewed bridges are normally used to cross roadways, waterways, or railways that are not perpendicular to the bridge structure at the intersection. It is required when it is often not possible to arrange that a bridge spans square to the feature that it crosses, particularly where it is important to maintain a relatively straight alignment of a roadway above or below the bridge. The pier shape has important effect on the structural performance of the bridge structure according to the location conditions. The main aims of this study are to select the optimal design of piers shape and skew angles in the prestressed box girder bridge, to study the effects of pier shape and skew angles on the static structural responses. There are 120 bridge model are used in this study. FEM of SAP2000 Ver. 14.0.2 is used in the analysis. The results of structural analysis show that the pier shape and skew angle has significant effects on the static responses of the bridge structure. For vertical displacement, the optimal models are skew angle of bridge structure is range from 36 degree to 54 degree and the solid rectangular pier (skew abutments and skew piers). The models of two square piers (skew abutments and without skew piers) and 48 skew angle is the optimal models for bending moment. For tensile stress, the model of skew angle 48 degree and the model of solid rectangular pier (skew abutments and skew piers) is the optimal model. It can be concluded that the skewed models gives good results than straight model.

Index Terms— bridge, box girder, bending moment, vertical displacement.

I. INTRODUCTION

A bridge structure can be defined as a structure consists of supports erected over dejection or an obstruction, such as highway, railway, water, and having a track or passageway for carrying traffic or other moving loads. [1, 2, 3]

Skewed bridges are normally used to cross roadways, waterways, or railways that are not perpendicular to the bridge structure at the intersection. This type of bridges is characterized by their skew angle. The angle between a line normal to the centerline of the bridge and the centerline of the support (abutment or pier) is known as skew angle. Namely there are no calculation methods or guidelines given in the specifications to cover or estimate the effect of skew. So for decades, skewed bridges were analyzed and designed in the same way as straight ones regardless of the skew angle. [4].

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Dr.Ali Fadhil Naser, Ministry of Higher Education & Scientific Research / Foundation of Technical Education /Al-Mussaib Technical College/Iraq.

Skew bridge is required when it is often not possible to arrange that a bridge spans square to the feature that it crosses, particularly where it is important to maintain a relatively straight alignment of a roadway above or below the bridge. This increases the spans but more significantly usually results in the end and intermediate supports being at an angle to the longitudinal axis of the bridge, rather than square to it. Skew support arrangements give rise to torsion effects that must be taken into account in design. [5]

There are many researchers studied the skewed bridges. Theoretical and experimental analysis was used in the evaluation of the effects of skew angles on the structural performance of this type of bridges. NCHRP (2002) investigated the skew correction factors for live load shear and the development of design guidelines for the variation of the skew correction factors along the exterior beam length and across the end bearing lines of simple span and two-span continuous beam and slab bridges. This study was performed through finite element analysis of 41 bridge models, including 25 simple span beam-slab models, 3 simple span concrete T-beam models, 4 simple span spread concrete box girder models and 9 two-span continuous beam-slab models. They investigated the influence of skew angle, beam stiffness, span length, intermediate cross frames, beam spacing, slab thickness and bridge aspect ratio on the skew correction factor variation. [6]

X.H. He. et. Al (2012) summarized the analysis and testing results of a research project that encompassed 1:8 scale model of a three-span continuous prestressed concrete (PC) box girder bridge having a 45degree skew. The scale-model structure replicates an actual bridge being constructed for a high speed railway between Beijing and Shanghai. Their study includes static and dynamic testing analysis. Along with summarizing the design and construction details and the experimental procedure, the displacements and stresses, natural frequencies, mode shapes and damping ratios are presented and compared with the responses that obtained from FE analyses of the tested structures. The influence of skew on the bridge's static and dynamic behavior is also investigated. They found that when the skew angles increase, the vertical bending moments and deformations decrease. However, the torsion stresses and deformations increase as well as differential reaction levels. They recommended that the skew angles above 45degree were not suitable for skewed bridges on the high speed railway. The increasing of skew angle was observed to increase the first modal frequency for box girder bridges, but no obvious trend for the higher modes was observed. From these results it can be noted that the skew increases the apparent stiffness relative to mass. [7]

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S. I. Ibrahim (2011) studied the effects of skew angle in the reinforced concrete T-beam bridge deck has single span with two traffic lanes. He used the FEA analysis in the theoretical model. His study included using different span lengths such as 12, 16, 20 and 24m and skew angles are 0°, 15°, 30° and 45°. The FEA results and comparison of skewed bridge with straight bridge indicate that the maximum live load bending moments and deflections were decreased in T- beams for skewed bridges, while the maximum values of shear, torsion and supports reactions were increased in some T-beams for skewed bridges for all considered span lengths (12, 16, 20 and 24m). [8]

A. Dhar et al (2013) presented the behavioral aspects of a skew bridge model. They compared the result of analysis with the straight model by using a 3D bridge model in Finite Element Analysis software–ABAQUS. In their study, a simply supported reinforced concrete bridge structure was adopted. The results of the bridge model in ABAQUS showed that with the increasing in the skew angle, the support shear and mid-span moments of obtuse longitudinal girders increase, while these parameters decrease in the corresponding acute longitudinal girders. Most importantly, the increasing of skew angle rapidly will cause increasing in the torsion moment in the obtuse angled girder. Such changes in the moment are generally not considered while designing a straight bridge. Generally, with increasing skew angle, the slab showed asymmetric bending with increasing deflection at obtuse corner and decreasing deflection at the acute corner. [9]

V. Khatri et al (2012) analyzed the skew bridges by using different computational methods. A bridge deck consists of beams and slab was defined and it modeled by using grillage and finite element method. The effect of grid spacing on different skew angles on same-span of reinforced concrete bridges using the finite-element method and grillage analogy method was compared. The maximum reactions force, deflection, bending and torsion moments was calculated and compared for both analysis methods. The total of nine different grid sizes (4 divisions to 12 divisions) have been studied on skew angles 30°, 45° and 60° to determine the most appropriate and efficient grid size. The results of finite element method (FEM) and Grillage method showed that the results are always not similar for every grid size. The bending moment calculated by using FEM overestimates the results obtained by grillage analysis for larger grid sizes. The torsion moment behavior showed reverse of bending moment and difference between reaction values of grid sizes between two methods decreases as skew angle increases. [10]

F. B. Diab et al (2011) investigated the effect of skew angle on the wheel load distribution in steel girder highway bridges. The finite element method was used to investigate the effect of various parameters such as the span length, girder spacing, and skew angle, on simply supported, one-span, two-lane, three-lane and four-lane steel girder bridges. A total of 270 bridge cases were analyzed and subjected to AASHTO HS20 design trucks positioned on each bridge to produce maximum bending in the interior steel girders. A combination of five typical span lengths, three girder spacing, and six skew angles were used in evaluating bending moments in skewed steel girder bridges. The finite element results showed the reduction in bending moment for all skewed bridges up to 30 degrees can be neglected and such bridges can be designed as straight bridges. These results are consistent with the AASHTOS standard specifications and the LRFD procedure by not specifying any reduction factor for bridges with skew angles up to 30 degrees. For highly skewed bridges and span length less than 80 ft (24 m), the finite element results showed a reduction in moment ranging between 10% and 20% for skew angles up to 40 degrees, and between 20% and 35% for skew angle up to 50 degrees. For practical application, a conservative reduction in girder bending moment of 15% was suggested for skew angles between 30 and 40 degrees and another conservative reduction in girder bending moment of 25% for bridges with skew angles between 40 and 50 degrees. [11]

C. C. Fu et al (2012) presented twenty-eight FEA models in their study. The transverse post-tensioning orientation and locations can greatly decrease stresses caused by vehicular loads. Transversely post-tensioning should be done parallel to the supports (i.e., parallel to the skew), especially when near the abutments of a skewed adjacent precast-concrete slab bridge. The transverse post-tensioning that is parallel to the skew instead of normal to the beams decreases the transverse stresses present at the slab-deck interface. They concluded that all bridges should be built with as small a skew as was practical, but there was significant increase in transverse stress in bridges with skew angles that exceed 30 degree. [12]

K. M. Kassahun (2010) studied the skew slab-girder bridges and he used five different numerical models have been created and compared using SCIA engineer and ATENA 3D finite element model. The effect of the angle of skewness on the internal force distribution was investigated using two finite element models. Four skew angles of 0o, 30o, 45o, and 60° were considered for each finite element model. The results showed that the maximum value of live load bending moments in girders of skew bridges were generally smaller than those in right bridges of the same span and deck width. On the contrary, the torsion moment in the obtuse corner of the bridge and the transverse moments in the deck increase with skew angel. [13]

The objectives of this study are to select the optimal design of piers shape and skew angles in the prestressed box girder bridge, to study the effects of pier shape and skew angles on the static structural responses. .

II. DEFINE OF BRIDGE MODEL

The bridge model type is a continuous prestressed concrete box girder bridge. It consists of three spans. The firsts, second, and thirds span has length is equal to 30, 40, 30 respectively. The width of box girder is equal to 8.5m and it has two lanes for forward traffic. There are 120 bridge models are used in this analysis according to types of models and skew angles of abutments and piers. SAP2000 VER. 14.2 is used to analyze the bridge models. Figure (1) shows the straight bridge model and Table (1) lists the model types and skew angles.

III. MATERIALS PROPERTIES OF MODELS

a. Concrete density=26kN/m3, Poisson ratio (μ) =0.2, concrete grade 40.
b. Live load: vehicle type is HSn-44L-1, according to ASHTTO Standard.

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c. Load combinations: the load combinations consist of two combinations. The first combinations is COMB I= dead load + prestressed load. The second combination is COMB II= COMB I + live load (traffic load) + temperature load.
d. Prestressed tendons properties: the prestressing tendons made of 1×7 wires 15.24-1860-II-GB/T5224-1995. Tendon area is equal to 1656mm2. The standard strength and controlled tension force of steel strands is equal to 1395MPa and 2310kN, respectively..

IV. STATIC ANALYSIS RESULTS

The static analysis responses of 120 models includes vertical displacement, positive bending moment, negative bending moment, positive shear force, negative shear force, tensile stress, and compressive stress.

A. Vertical Displacement

In general, vertical displacement is the shifting of body in a vertical direction, resulting in a permanent change in elevation. Two types of vertical displacement are uplift, an increase in elevation, and subsidence, a decrease in elevation. [14]. For bridge engineering, the vertical displacement are the most relevant parameters to be monitored in both the short and long term of bridge life. [15]

Figure 2 shows the results of static analysis of vertical displacement for 120 models. According to the piers type, the maximum value of deflection is equal to (76mm) within bridge model of two square piers (skew abutments and skew piers) and the minimum value is equal to (32mm) within solid rectangular pier (skew abutments and skew piers). Therefore the optimal model that gives the minimum value of vertical displacement which is solid rectangular pier (skew abutments and skew piers). For skew angle effect, the maximum value of vertical displacement is equal to 76mm at skew angle 66 degree within model of two square piers (skew abutments and skew piers), and the minimum value of vertical displacement is equal to 32mm at 54 degree within model of solid rectangular pier (skew abutments and skew piers). Therefore, the optimal skew angle for this type of bridge is range from 36degree to 54degree because of these degrees gives the minimum values of vertical displacement. It can be concluded that most skewed bridge models appears lower values of vertical displacement than straight bridges models.

B. Positive and Negative Bending Moment

Bending moment is mostly used to find bending stress and it can be defined as the internal torque holding a beam together (stopping the left and right halves from rotating - if it was to break in half). There are two types of bending moments according to the effect of external load and types of girders (simply supports spans or continuous spans). Positive bending moment appears where the load is pushing down and reactions at the end push upwards. On the other side negative bending moment bows upwards- called hogging. [16]. Tensile and compressive stresses increase proportionally with bending moment, but are also dependent on the second moment of area of the cross-section of the structural element. Failure in bending will occur when the bending moment is sufficient to induce tensile stresses greater than the yield stress of the material throughout the entire cross-section. [17]. The results of bending moment can be shown in figure (3). The model of one circle pier (skew abutments and skew piers) gives the maximum value of positive bending moment which is equal to 25960kN.m and the model of two circle piers (skew abutments and skew piers gives the minimum of positive moment which is equal to 13250kN.m. According to effect of skew angle, the angle 66 degree and 48degree gives the maximum and minimum value of positive bending moment (25960kN.m and 13250kN.m) respectively. Therefore, the model of two circle piers (skew abutments and skew piers with 48 skew angle is the optimal model for positive bending moment. For negative bending moment, figure (4) shows the results of negative bending moment and it can be noted that the model of one circle pier (skew abutments and skew piers) gives the higher value of negative moment within skew angle is 54 degree which is equal to 34849kN.m and the model of two square piers (skew abutments and without skew piers) gives the lower value of negative moment which is equal to 15842kN.m within skew angle is 48 degree. Therefore, the models of two square piers (skew abutments and without skew piers) and 48 skew angle is the optimal models for this type of bridge. It can be concluded that most skewed bridge models appears higher values of bending moment than straight bridges models.

C. Positive and Negative Shear Force

Shear force is unaligned forces pushing one part of a body in one direction, and another part the body in the opposite direction. When the forces are aligned into each other, they are called compression forces. [18]. The results of positive and negative shear forces can be shown in figure (5) and figure (6). From these figure it can be noted that the maximum and minimum values of positive shear force is equal to 8693kN and 6778kN respectively within model of two square pier (skew abutment and skew piers), but according to skew angle effect, 24 degree and 42 degree give the minimum and maximum value of positive shear force respectively. For negative shear force, model of two square pier (skew abutment and skew piers) appear the higher and lower values which are to 7812kN and 4685kN respectively within skew angles 0degree and 66 degree.

D. Tensile Stress

The results of tensile stress analysis are shown in figure (7). The model of circle pier (skew abutments and skew piers) appears higher value of tensile stress which is equal to 9.12MPa within skew angle 66 degree and this value is more than the values in the standards. Therefore, the cracks will appear in this model. The lower value of tensile stress appears in the model of solid rectangular pier (skew abutments and skew piers) which is equal to 2.04MPa within skew angle 48 degree. Therefore, according to piers shape and skew angle effects, the model of skew angle 48 degree and the model of solid rectangular pier (skew abutments and skew piers) is the optimal model in the design of this type of bridge structure. The tensile stresses must be lower than the allowable values in standard to avoid the cracks in the bridge structure.

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Table (1) The types and numbers of bridge models

Model type	Skew angle	Number of models
Solid rectangular pier (skew abutment and without skew pier)	0 to 66	12
Solid rectangular pier (skew abutment and skew pier)	0 to 66	12
One circle pier (skew abutment without skew pier	0 to 66	12
One circle pier (skew abutment and skew pier)	0 to 66	12
Two circle piers (skew abutment without skew pier)	0 to 66	12
Two circle piers (skew abutment and skew pier)	0 to 66	12
One square pier (skew abutment and without skew pier)	0 to 66	12
One square pier (skew abutment and skew pier)	0 to 66	12
Two square pier (skew abutment and without skew pier)	0 to 66	12
Two square pier (skew abutment and skew pier)	0 to 66	12
Total numbers of models	**120**	

E. Compressive Stress

Figure (8) shows the values of compressive stress. From this figure it can be noted that the higher value of compressive stress is equal to 23.4MPa within two square pier (skew abutment and skew piers) and 48 degree models. The lower value of compressive stress is equal to 11.36MPa within models of one square pier (skew abutments and skew piers) and 66 degree. According to the optimal design, the compressive stress must be increased to allowable value that is used in standards.

V. CONCLUSION

The main conclusions of this study are:

1. This study presented the effects of pier shape and skew angles on the static structural responses of prestressed concrete box girder bridge. 12 skew angles models and 10 piers shape models are used in this analysis. Therefore, the total numbers of models are 120 models.
2. SAP2000 ver. 14.2 software was used in the static analysis of the bridge structure. The bridge model type is a continuous prestressed concrete box girder bridge. It consists of three spans. The firsts, second, and thirds span has length is equal to 30, 40, 30 respectively. The width of box girder is equal to 8.5m and it has two lanes for forward traffic.
3. The static structural responses included vertical displacement, bending moment, shear force, tensile stress, and compressive stress.
4. The results of static analysis show that the pier shape structure and skew angle of abutments and piers have significant effects on the static structural responses. For vertical displacement, the optimal models are skew angle of bridge structure is range from 36 degree to 54 degree and the solid rectangular pier (skew abutments and skew piers) because of these models gives the minimum values of vertical displacement. It can be concluded that most skewed bridge models appears lower values of vertical displacement than straight bridges models.
5. According to effect of skew angle, the angle 66 degree and 48 degree gives the maximum and minimum value of positive bending moment (25960kN.m and 13250kN.m) respectively. Therefore, the model of two circle piers (skew abutments and skew piers with 48 skew angle is the optimal model for positive bending moment. For negative bending moment, the model of one circle pier (skew abutments and skew piers) gives the higher value of negative bending moment within skew angle is 54 degree which is equal to 34849kN.m and the model of two square piers (skew abutments and without skew piers) gives the lower value of negative moment which is equal to 15842kN.m within skew angle is 48 degree. Therefore, the models of two square piers (skew abutments and without skew piers) and 48 skew angle is the optimal models for this type of bridge. It can be concluded that most skewed bridge models appears higher values of bending moment than straight bridges models.
6. The maximum and minimum values of positive shear force is equal to 8693kN and 6778kN respectively within model of two square pier (skew abutment and skew piers), but according to skew angle effect, 24 degree and 42 degree give the minimum and maximum value of positive shear force respectively. For negative shear force, model of two square piers (skew abutment and skew piers) appear the higher and lower values which are to 7812kN and 4685kN respectively within skew angles 0degree and 66 degree.
7. The results of tensile stress show that the model of circle pier (skew abutments and skew piers) appears higher value of tensile stress which is equal to 9.12MPa within skew angle 66 degree and this value is more than the values in the standards. Therefore, the cracks will appear in this model. The lower value of tensile stress appears in the model of solid rectangular pier (skew abutments and skew piers) which is equal to 2.04MPa within skew angle 48 degree. According to piers shape and skew angle effects, the model of skew angle 48 degree and the model of solid rectangular pier (skew abutments and skew piers) is the optimal model in the design of this type of bridge structure.
8. The higher value of compressive stress is equal to 23.4MPa within two square pier (skew abutment and skew piers) and 48 degree models. The lower value of compressive stress is equal to 11.36MPa within models of one square pier (skew abutments and skew piers) and 66 degree.

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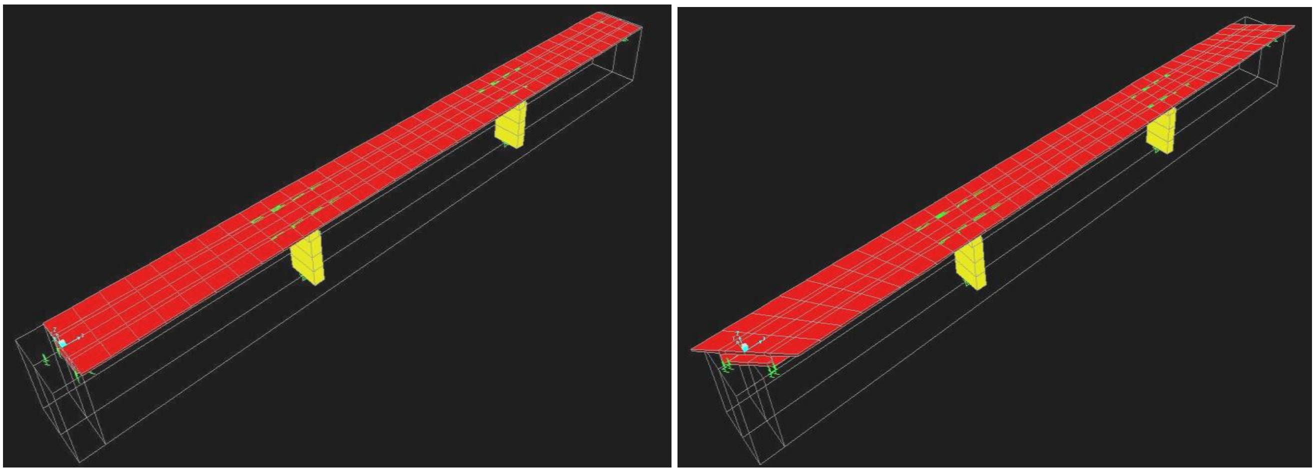
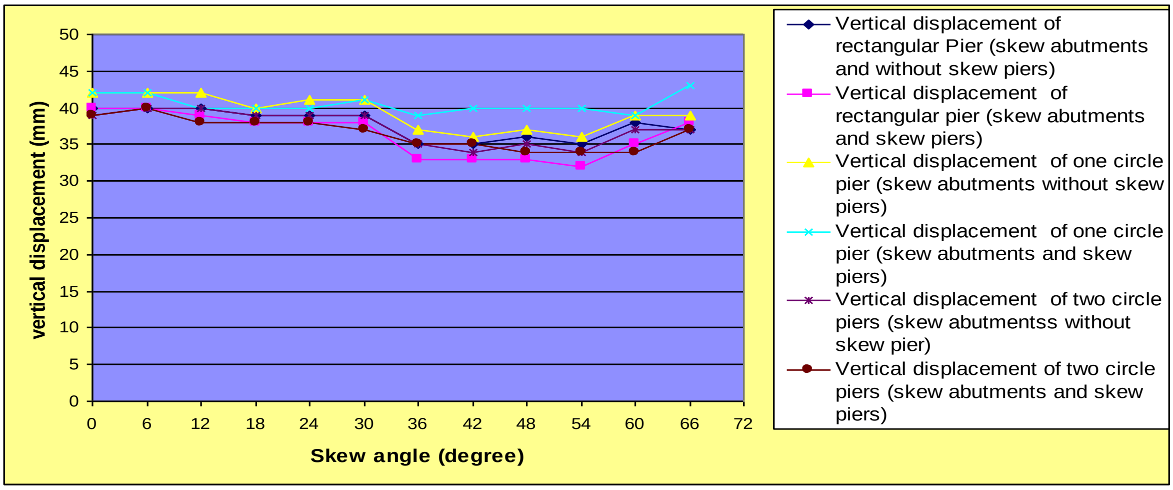


(a) (b)

Fig. 1 The bridge models: (a) Straight model, (b) Skewed model



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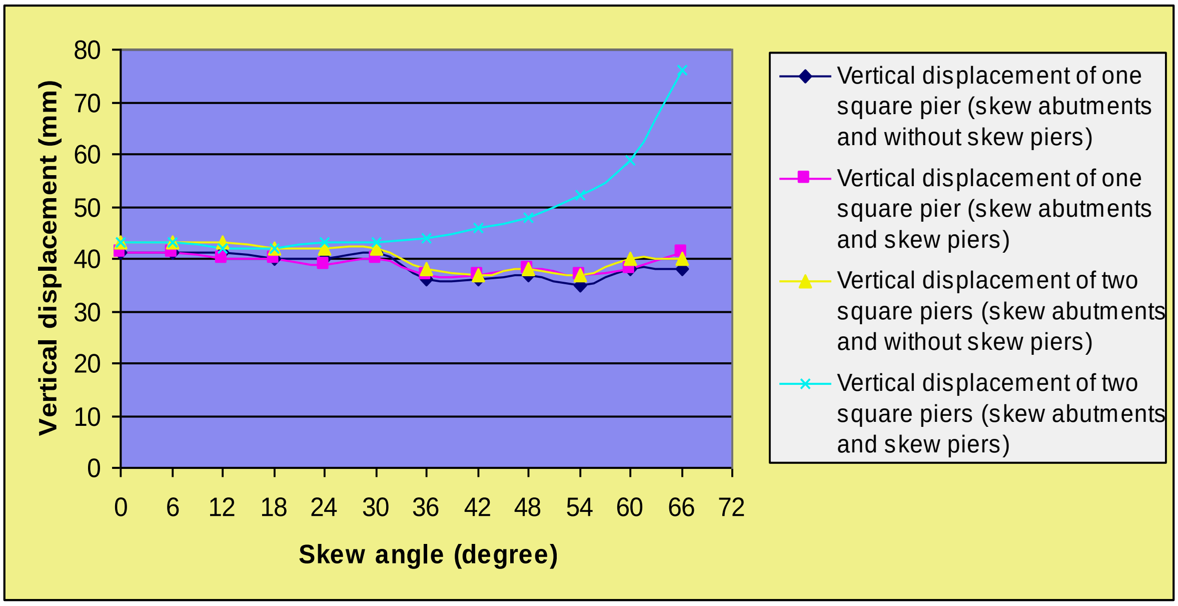

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Fig.2 The vertical displacement of 120 bridge models

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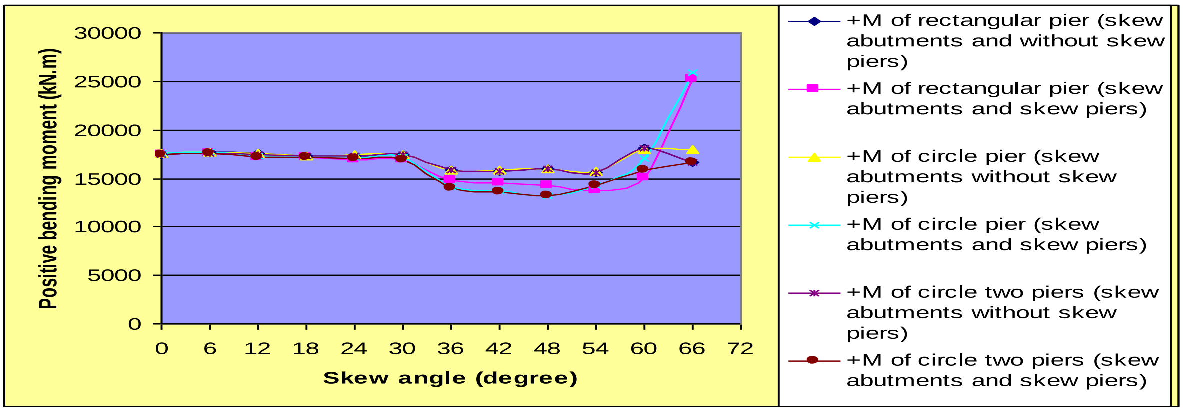

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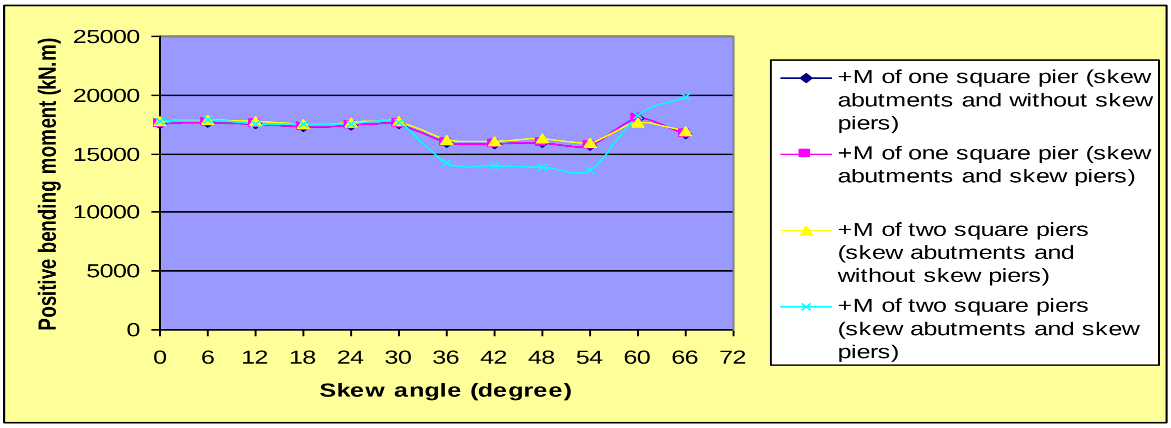
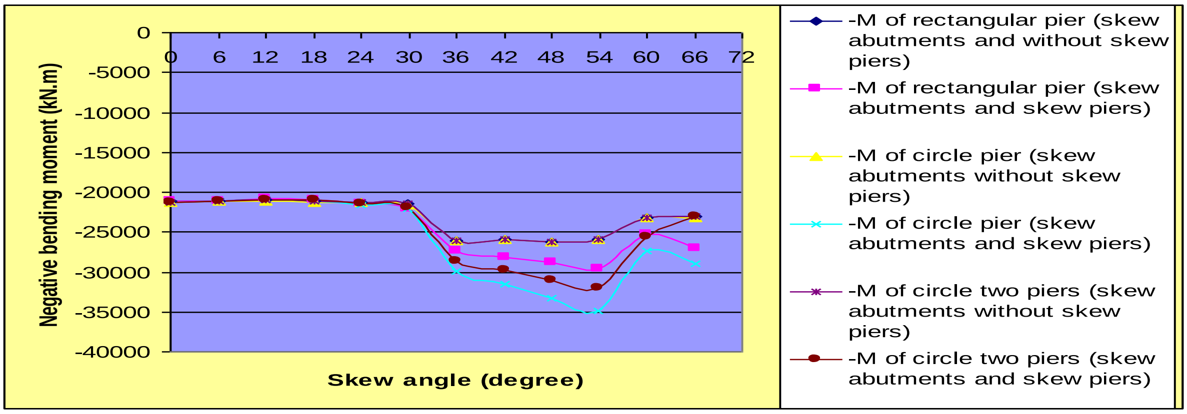


(b) Continued

Fig. 3 The values of positive bending moment of 120 bridge models



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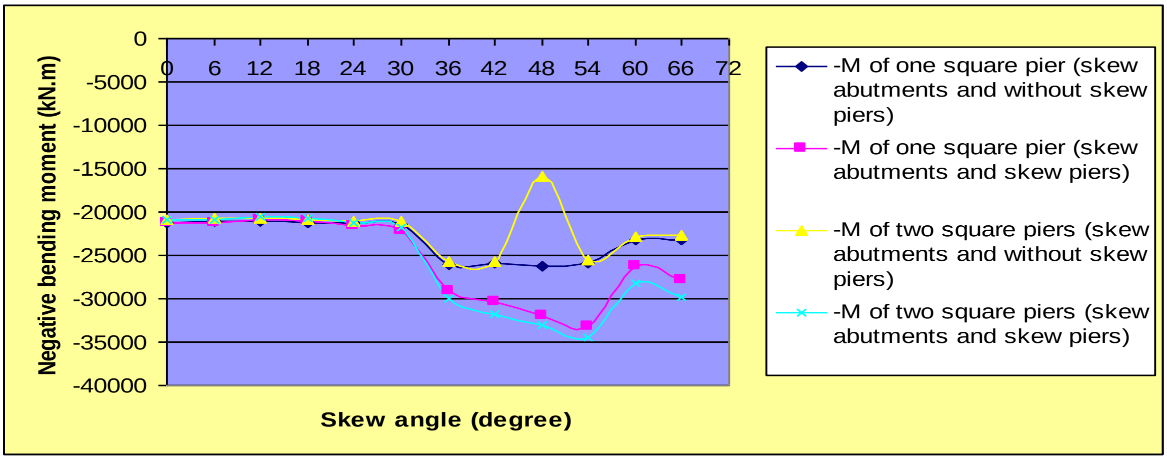

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Fig. 4 The value of negative bending moment of 120 bridge models

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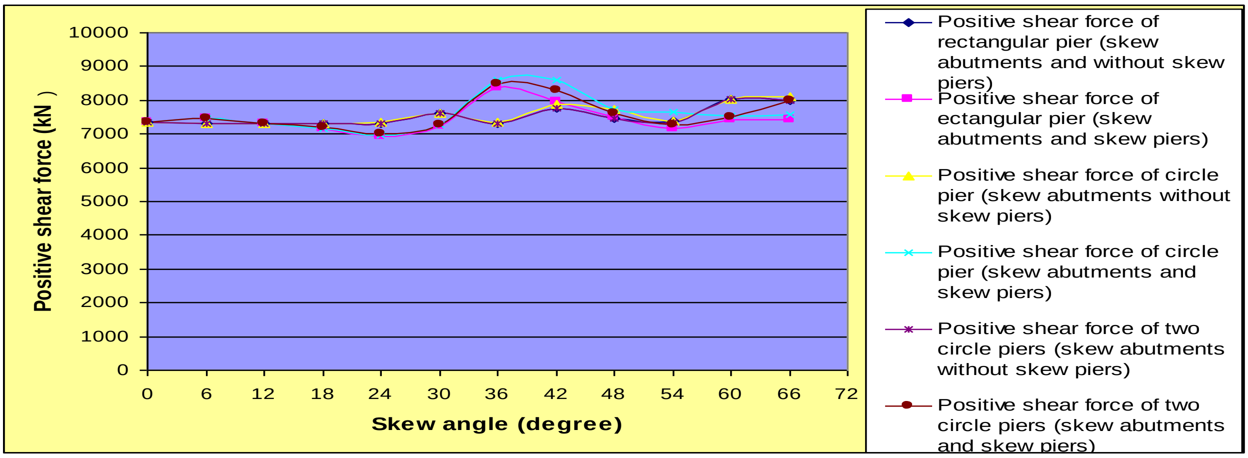

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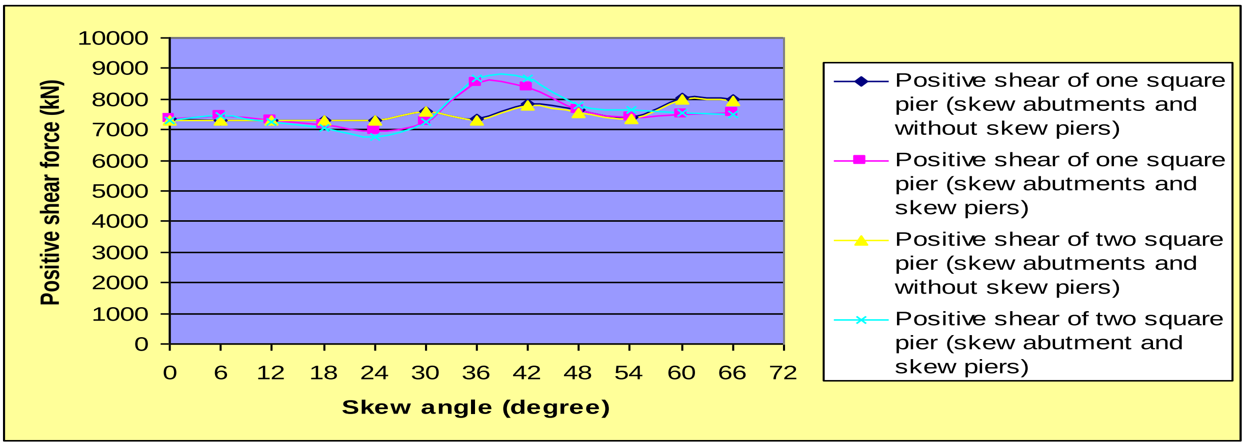

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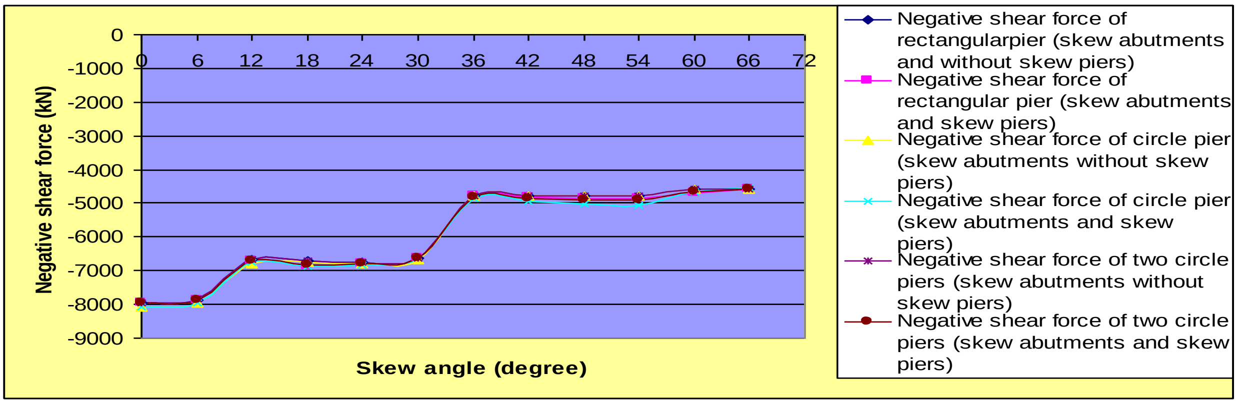
Figure (5) The values of positive shear force of 120 models



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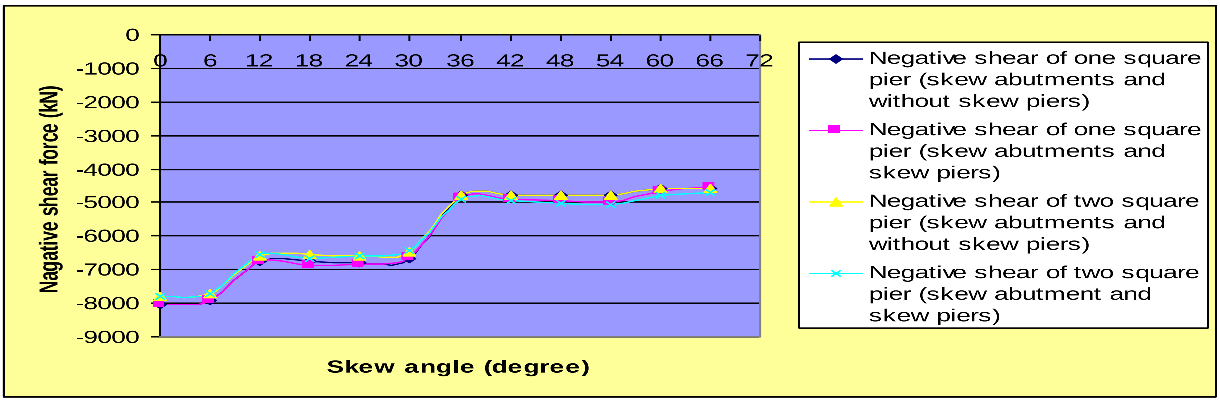

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Fig. 6 The values of negative shear force of 120 models

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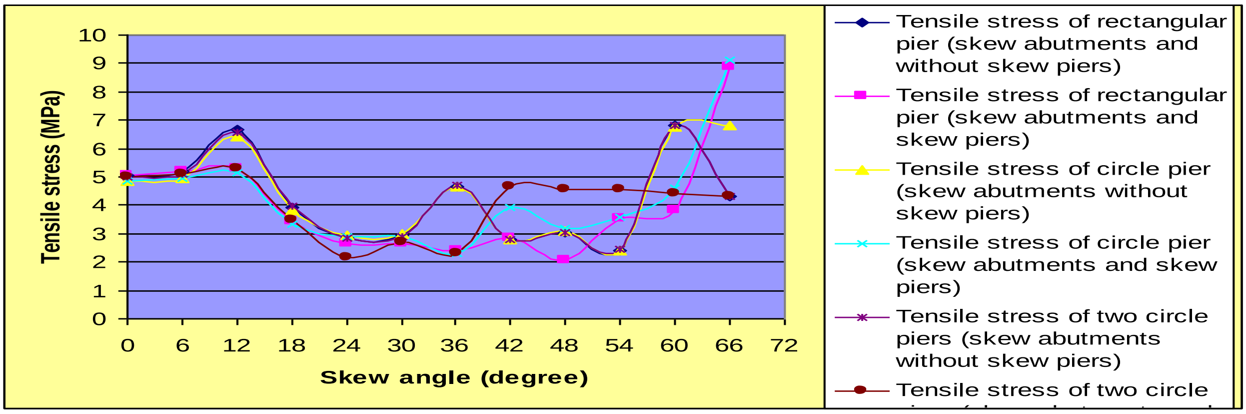

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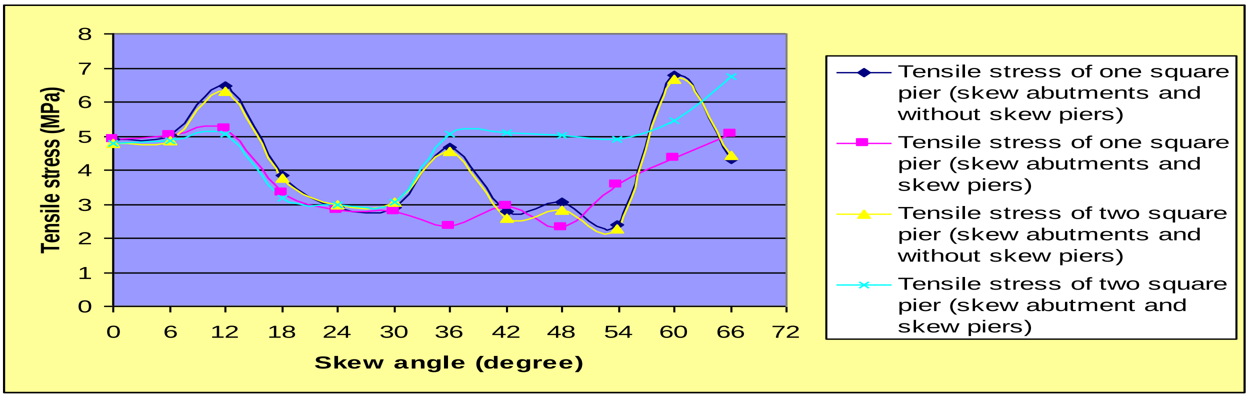

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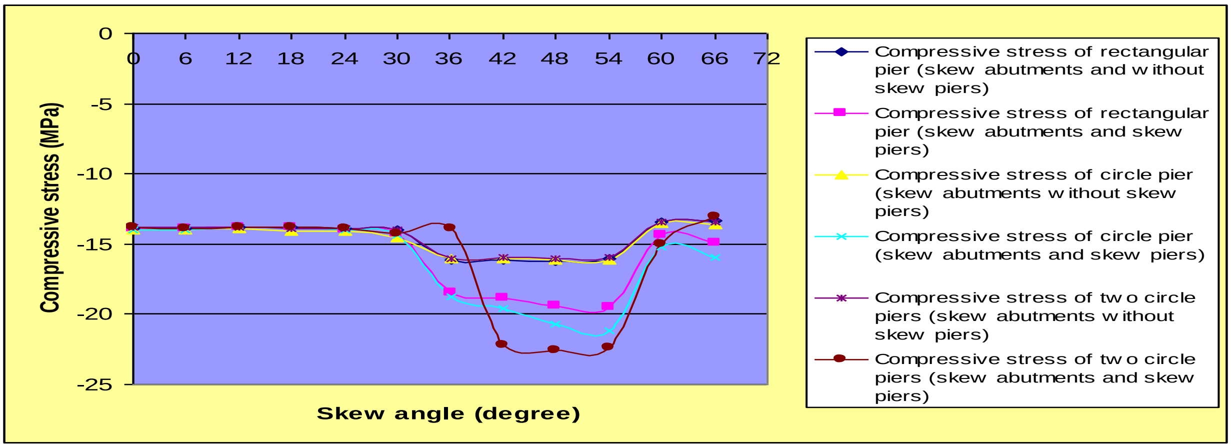
Figure (7) The value of tensile stress of 120 bridge models



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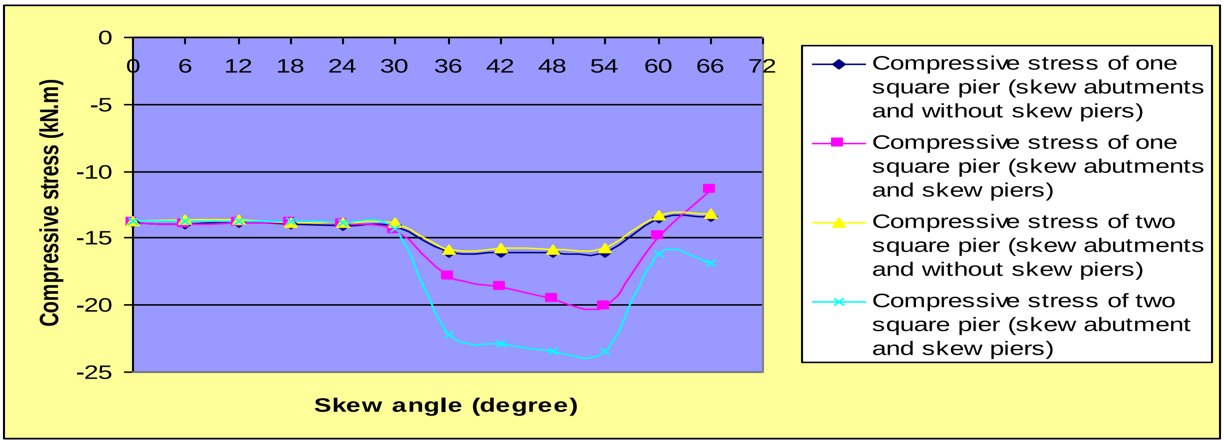

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Figure (8) The value of compressive stress of 120 bridge models

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