Stress Analysis of Three-Span Prestressed Concrete Bridge According to Modified Span Length Subjected to Thai Truck Load

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Abstract.

In the limited construction area, it is an alternative method that has the least impact on the existing bridge structures. The construction of the columns to support the bridge at an alternate position caused the modification in span lengths was chosen to study in this research. This method must be also achieved with the least impact of traffic. The three-span prestressed concrete bridge was simulated and analyzed by the finite element method. The models were subjected to the vehicles according to the standard loadings of Thai truck loads. The moving loads were applied to the bridge models which have the existing spans and varied spans caused by the construction of replaced columns. The variations in bridge lengths were ranged from 5% to 25% with an interval of 5% and caused the shortening of the first span and lengthening of the middle span. The bridge lengths were varied from 26.25 to 43.75 meters respectively. The stress analyses were carried out to determine the stresses induced in concrete, tendons, and rebars and then compared to their allowable strength. The conclusions were made for the span lengths which could affect the serviceability of the bridge.

Keywords.-

1. INTRODUCTION

Transportation is continuously developing to support economic growth and increasing population. The design and modification of the existing structures to be constructed in limited areas are sometimes unavoidable. These infrastructures, including elevated structures and underground structures, and then have the role important for the near future.

In the limited construction area, this study is an alternative method to construct the infrastructure with the least impact on the existing structures. The three-span prestressed concrete bridge was chosen and simulated in this study. The sky train route has been planned and affects the structural modification to the existing bridge caused the modification to replace the position of existing columns of the bridge in the route area. To replace the substitute supports, the variation of the bridge length will be shortened and lengthened in the adjacent spans. The method of design will be a benefit for the construction cost as well as the least effect of traffic.

However, the modification in span lengths play an important role in the stresses distorted in the existent bridge and affect the serviceability of the bridge as well. The structural analyses must be carried out to compare the stresses after the structural modification to their allowable stresses for the materials used to ensure its serviceability. The modified span length after the modified structure must not affect the capacity to carry truck loads or vehicles according to the design specifications. The methods and results of this study can be used as a guideline for the remodel of the bridge structure for the existing bridge structures in the limited construction areas.

2. BACKGROUND

2.1. Standard Loadings for Thai Truck

According to the standard loadings of the Department of Highway's regulations [1], the design specification is not specified for the axle loads and distance between wheels. Therefore, the truck load applied in this study is referred to from relevant research [5]-[7]. The compiled data is based on the trucks' manufacturers that are used in Thailand to determine the distance between the axles of different types of trucks. The vehicle that may cause damage to the highway is chosen in this study. The axle loads and positions of the front and rear wheels are shown in figure 1.

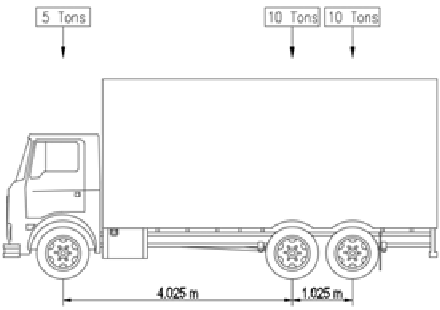

Figure 1 Thai Truck Loading.

2.2. The Bridge Span Length

Recently, the design and construction of major bridges in Thailand have been developed rapidly. In order to compare and select the most suitable form for the bridge design, we shall consider various forms of the bridges and their span lengths. These forms of bridges are shown in Table 1. Since the three-span prestressed concrete bridge has been chosen in this study, the Cast-in-Place Posttensioned Box-Girder Conventional with the span length of 35 meters will be introduced in the analyses.

Table 1 Bridges and span lengths

Bridge Type	Span Length(m)
Precast Pretensioned I-Beam Conventional	0 - 45
Cast-in-Place Posttensioned Box-Girder Conventional	30 - 90
Precast Balance Cantilever Segmental Constant Depth	30 - 90
Precast Balance Cantilever Segmental Variable Depth	60 - 180
Cast-in-Place Cantilever Segmental	60 - 300
Cable-Stay with Balanced Cantilever Segmental	240 - 450

3. METHODS

3.1. Allowable Stress (Serviceability Limit State)

Prestressed concrete must be ensured so that the stress does not exceed the safe strength. The allowable stress limit for concrete according to the United States Standard (AASHTO) [4] must not exceed these values.

$$\text{Compressive Stress: } f_c = 0.45 f_c^{'}$$

$$\text{Tensile Stress: } f_c = +1.60(f_c^{'})^{1/2}$$

where f_c is the compressive stress in prestressed concrete.

$f_c^{'}$ is the compressive strength of concrete for use in design.

f_1 is the tensile stress in prestressed concrete.

The allowable stress limit for prestressing tendons at service limit state after losses according to the United States Standard (AASHTO) [4] must not exceed these values.

$$\text{Tensile Stress: } f_{pe} = 0.80 f_{py}$$

where f_{pe} is the effective stress in the prestressing tendon after losses.

f_{py} is the yield strength of prestressing tendon.

The nominal shear resistance for post-tensioned segmental box girder bridges according to the United States Standard (AASHTO) [4] The nominal shear resistance is given by the lesser of the two values and must not exceed these values.

$$V_n = V_c + V_s \tag{3.1}$$

In which $V_c = 0.166K(f_c^{'} b_v d_v)^{1/2}$

$$V_s = \frac{A_v f_y d_v}{s}$$

$$V_n = f_c^{'} b_v d_v \tag{3.2}$$

where A_v is the area of a transverse reinforcement within distance

b_v is the width of web adjusted for the presence of ducts.

d_v is the effective shear depth.

f_y is the minimum yield strength of compression reinforcement.

K is the stress variable used in calculating torsional cracking moment.

s is the spacing of reinforcing bar.

V_n is the nominal shear resistance of the section considered.

V_c is the nominal shear resistance provided by the concrete.

V_s is the nominal shear resistance provided by the shear reinforcement.

3.2. Materials and Method

The three-span prestressed concrete bridge with the span lengths of 35.00+35.00+35.00 meters was chosen for the existing structure. The depth of the box girder is 2.40 meters. The top flange of the box girder is 8.50 meters wide. The variations in bridge lengths due to the modification of replaced columns were ranged from 5% to 25% with an interval of 5% and caused the shortening of the first span and lengthening of the middle span. The shortening and lengthening of span lengths were varied from 26.25 to 43.75 meters respectively. Six models of existing and modified span of bridge were analysed and the stress results were then compared. For quantitative comparisons, the maximum stress induced in materials was determined. Bridge standard moving loads according to AASHTO LRFD Bridge Specifications for Highway Bridges for each span length were separately applied to the bridge. The analytical existing models for plan view and elevation view are shown in figure 2. The cross-section and dimensions of the box girder are shown in figure 3. The modified span lengths for each model are also shown in Table 2

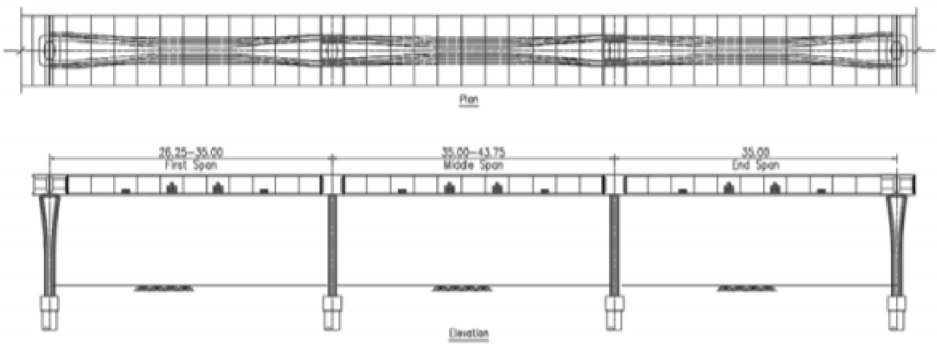

Figure 2 Existing span length of prestressed concrete bridge.

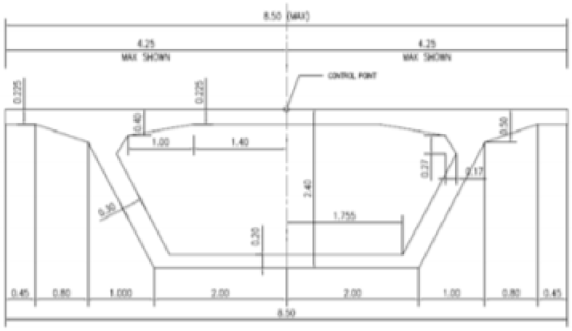

Figure 3 Cross section of prestressed concrete bridge.

Table 2 Modified span length bridge models

Case Study	Span Length(m)		
	First Span	Middle Span	End Span
Existing	35.00	35.00	35.00
Modified 5%	36.50	33.25	35.00
Modified 10%	38.50	31.50	35.00
Modified 15%	40.25	29.75	35.00
Modified 20%	42.00	28.00	35.00
Modified 25%	43.75	26.25	35.00

4. RESULT

From stress analyses, the stresses occurred in prestressed concrete bridge models were analyzed. Thai truck moving loads were applied to each modified span length model. The existing three-span prestressed concrete bridge with the span length of 35.00+35.00+35.00 meters was analyzed to obtain the stresses induced in each material and then compared to the other models by graphical depictions. The modified span lengths were ranged from 26.25 to 43.75 meters and the stress results were carried out. Figure 4 reveals the variations in stress analyses at the top fiber of the box girder cross-section compared to the allowable compressive and tensile strength according to the design standards. In order to compare the stresses occurred in concrete, tendons, and rebars, the allowable stresses regulated by the American Association of State Highway and Transportation Officials (AASHTO) by the Load and Resistance Factor Design (LRFD) method have been referred. The stress results for the bottom fiber of the cross-section are compared in figure 5. The results from stress analyses in concrete box girders indicate that the stresses induced in the existing bridge do not exceed the allowable design strength both in compression and tension. The results of the modified span bridges can be summarized as followings.

From the analytical results in figure 4, it was found that tensile stress of 37.21 kg/cm2 in concrete at top fiber exceeded the allowable Stress for modified 20% span length model (42.00+28.00+35.00), and the value of tensile stress obtained for modified 15% span length model (40.25+29.75+35.00) was 17.85 kg/cm2 and within the limit of allowable stress respectively.

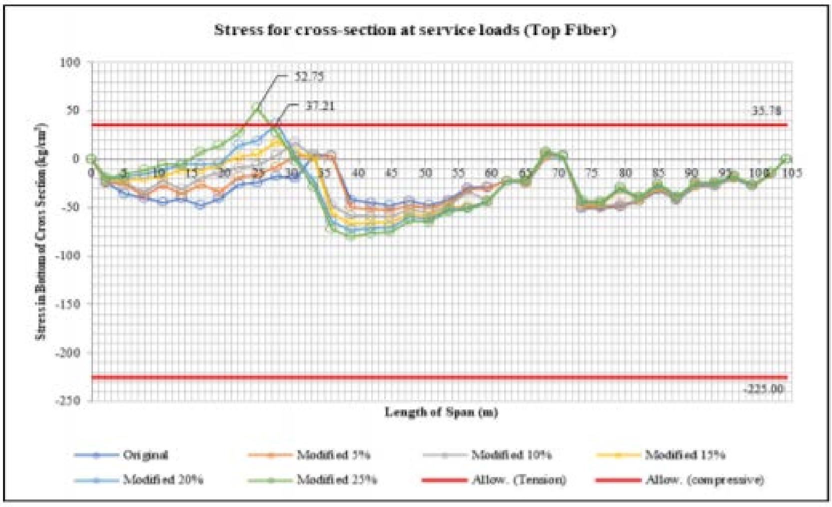

Figure 4 Stress for cross section at top fiber.

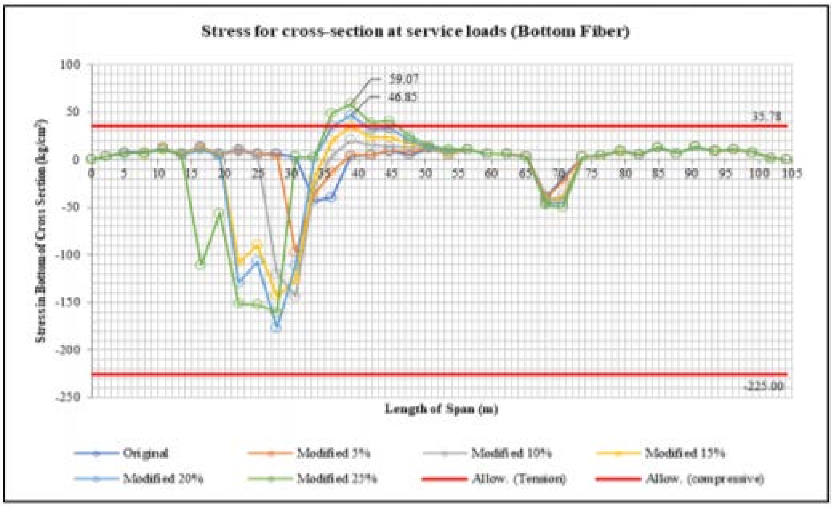

Figure 5 Stress for cross section at bottom fiber.

For the tensile stress in concrete at bottom fiber in figure 5, it was found that tensile stress of 46.85 kg/cm2 obtained from modified 20% span length model (42.00+28.00+35.00) was more than the allowable and the value of tensile stress obtained for modified 15% span length model (40.25+29.75+35.00) was 34.48 kg/cm2 and within the limit of allowable stress respectively.

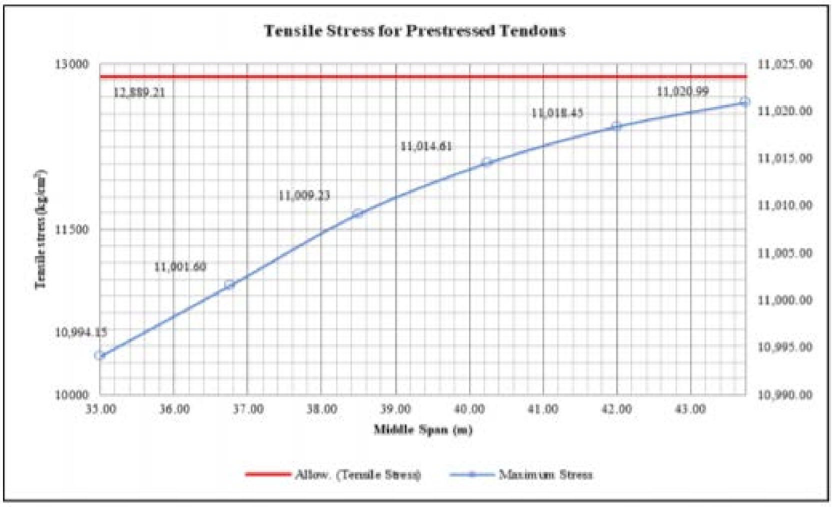

Figure 6 Tensile stress in prestressed tendons.

The maximum tensile stresses in prestressed tendons after losses were also obtained and compared for each model, it was found that the tensile stress in the tendons of

10,020.99 kg/cm2 obtained from modified 25% span length model (43.75+26.25+35.00) was still within allowable limit according to the design specification as shown in figure 6.

Maximum shearing strength at the web of box girder sections were also analyzed and depicted in figure 7. The shearing stresses in concrete and rebar obtained from modified 20% span length model (42.00+28.00+35.00) was calculated to be 518,922.39 kg/cm2 which was more than the allowable stress. However, the value of shear stress obtained for modified 15% span length model (40.25+29.75+35.00) was 482,450.01 kg/cm2 and within the limit of allowable stress respectively.

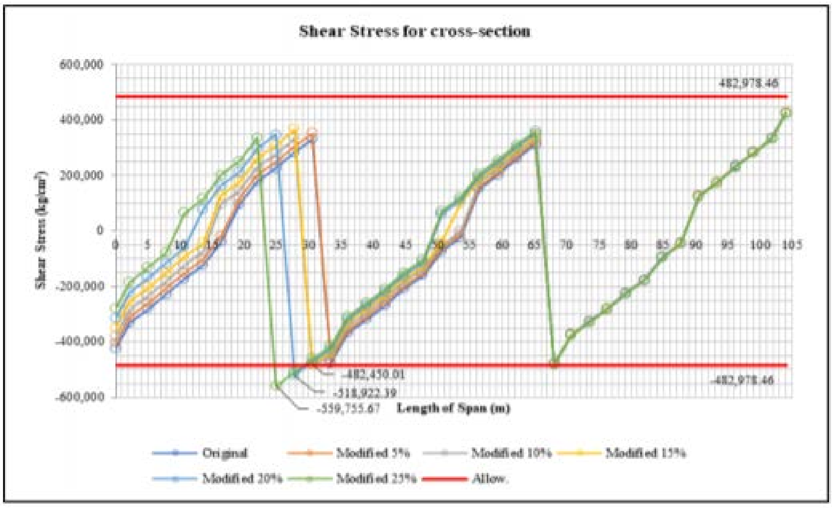

Figure 7 Shear Stress.

5. DISCUSSION

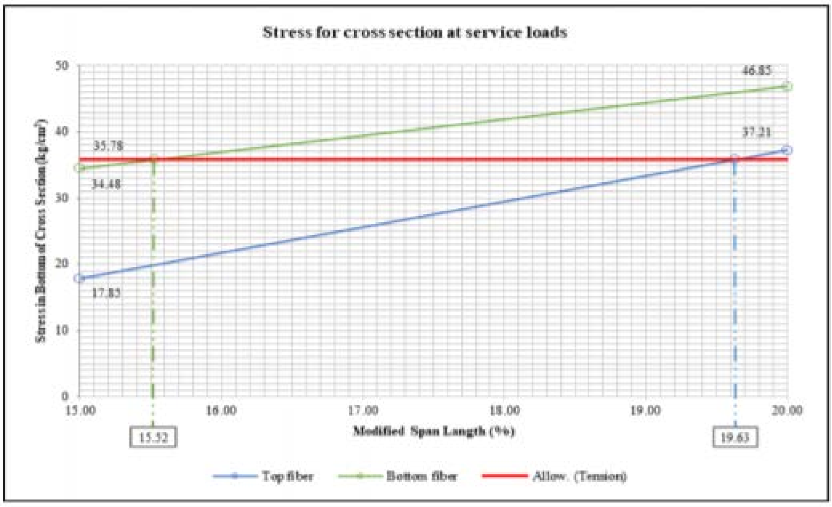

Figure 8 Comparison of tensile stress in concrete box girder.

In this topic, the stresses obtained for each modified span length were plotted and compared to determine the optimum modified span length which this modified span length can still sustain the serviceability of the remodeled bridge. The tensile stresses analyzed in concrete box sections and the shearing stresses obtained from the web of concrete box sections are considered and plotted for each modified span length. From the results in figure 8 compared to the allowable tensile stress of concrete, the modified span length which will not cause the exceeded allowable stress in top fiber in concrete is 41.87+28.13+35.00 meters or 19.63% of the original length. The optimum modified span length obtained from the bottom fiber is 40.43+29.57+35.00 meters or 15.52% of the existing span length, respectively. In this study, the tensile stress induced in bottom fiber is considered to preserve the serviceability of this bridge.

The shear strength obtained from the analyses were also plotted and compared to determine the optimum modified span length which can sustain the serviceability of the bridge. The optimum modified span length that will not cause the exceed of allowable stress is 40.27+29.73+35.00 meters or 15.07% of the existing length as shown in figure 9.

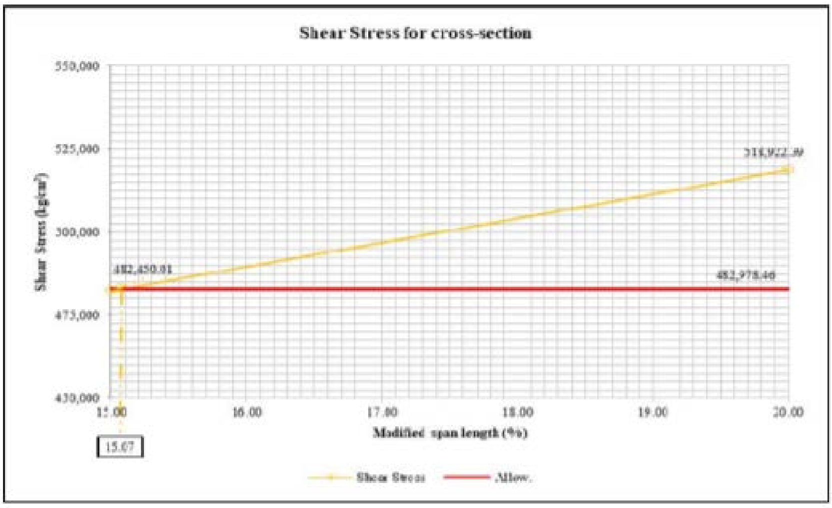

Figure 9 Comparison of shear strength in concrete box girder.

6. CONCLUSION

This objective of this research is to study the behaviour of the stresses induced in a prestressed concrete bridge while the existing bridge length has been modified. The modified span lengths decrease in the first span and the increase in the middle span ranged between 5% to 25%, with the interval change in the length of 5%. These cause the modified span range from 26.25 to 43.75 meters. The finite element models of the bridge were analysed by the moving load of the Thai truck according to standard loading of manufactures with the Midas Civil 2019 program. The stress analyses in concrete box section, tendon, and rebars were carried out and compared. to their allowable stresses [9] according to the design standards of the Highway Association and The American Association of State Highway and Transportation Officials (AASHTO) by the Load and Resistance Factor Design (LRFD) method. It can be concluded that the length of the optimum modified span of the bridge in this case study that will not cause the induced stresses to exceed the design values is 40.27+29.73+35.00 meters or 15.07% of the original length. The shear stress induced in box girder play a major role to preserve the serviceability of this bridge.

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