Research Article

The Impact of Asphalt Wearing Surface Thickness on Response of Two-Span Continuous Cast-in-Place Prestressed Concrete Box Girder Highway Bridge

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Abstract

This paper presents the finite element analysis (FEA) results of a two-span continuous cast-in-place prestressed concrete box girder highway bridge with various asphalt wearing surface thicknesses. The benefits of the FEA can be extremely valued when visualizing the substantial cost and time savings, the potential of signifying any attractive response at any location in the system and at any load value and, and the capability to modify any constraint of interest. Based on the analysis results, asphalt wearing surface thicknesses considerably enhances the ultimate positive and negative moments, ultimate deflection, and ultimate positive and negative stress. The stress due to truck load were below the allowable tensile and compressive strength of deck as well as the asphalt wearing surface had a strong impact on the positive stress, moderate impact on the ultimate moment and corresponding deflection, and small impact on negative stress.

Keywords: Asphalt Wearing Surface, Thickness, Two-Span Continuous, Cast-In-Place, Prestressed Concrete, Box Girder, Highway Bridge.

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1. Introduction

The using of continuous cast-in-place concrete box girder highway bridges has increased in recent times. In construction of this type bridges having variable or constant section height, the cantilever technique can apply if the number of spans in more than two. Box girder section consists of single or more box girder based on Highway Bridge wide. Recently, many attractive research topics have arisen such as to be taken in to consideration prestressed concrete highway bridge in the analysis. Normally, bridges are analyzed by assuming that they are instantaneously built in a time. In this analysis, real material properties should be taken into account [1-6].

In this paper, the finite element analysis (FEA) using commercial software was used to simulate the response of two-span continuous cast-in-place (CIP) prestressed concrete box girder Highway Bridge with various asphalt wearing surface thicknesses (t_{ws} = 0, 1, 2, 3, 4, and 5 in.). Actual steel reinforcing details and geometry of cast-in-place prestressed concrete box girder Highway Bridge as well as various asphalt wearing surface thicknesses were considered in the FEA. The ultimate moment capacity and corresponding deflection, and stress response profile were obtained.

Table 1. FEA of Six two – span continuous CIP prestressed concrete box.

Thickness of asphalt (t_{ws}), in.	Ultimate deflection, in.	Ultimate positive moment, kips.ft	Ultimate negative moment, kips.ft	Ultimate positive stress, ksi	Ultimate negative stress, ksi
0	1.69	31300	47200	1.62	3.21
1	1.82	33900	49100	1.80	3.33
2	1.96	36100	52500	2.04	3.58
3	2.10	38600	58200	2.37	3.82
4	2.24	39800	60500	2.50	4.00
5	2.38	40800	62700	2.58	4.10

2. Finite Element Analysis

Table 1 shows the FEA of six two-span continuous CIP prestressed concrete box girder Highway Bridge with various t_{ws} of 0, 1, 2, 3, 4, and 5 in. The ultimate compressive strength of 4.0 ksi, uniaxial tensile strength of 0.4 ksi, and initial young's modulus (E_c) of 115 ksi MPa are needed to define the concrete failure surface. Therefore, Figure 1 shows the William and Warnke [7] which was used to defined the concrete criterion with Poisson's ratio of 0.2.

The assumed steel reinforcement stress strain behavior is elastic-perfectly plastic material which is identical in compression and tension as shown in Fig. 1. The steel yield stress and Poisson's ratio are 60 ksi and 0.3. The steel plate is assumed as linear elastic material with Poisson's ratio of 0.3 and elastic modulus of 29000 ksi. Perfect bonding between the concrete and steel reinforcement was assumed. A two-span continuous cast-in-place prestressed concrete box girder highway bridge has two equal spans of length 157 ft. with a column bent as shown in Figure 2. The superstructure is 34 ft. wide. The elevation of the bridge is shown in Figure 2.

Based on the design practice, the width of 12 in. for girders with the exterior girder flaring to 18 in. at the anchorage end and a thickness of 7 in. at the edge and 12 in. at the face of the exterior girder for the overhang were selected. The deck and soffit thicknesses depend on the clear distance between adjacent girders. 7.875 in. and 5.875 in. are chosen for the deck and soffit thicknesses respectively. The length of this flare is usually taken as one-tenth of the span length 15.7 ft. A typical section for this bridge is shown in Figure 3.
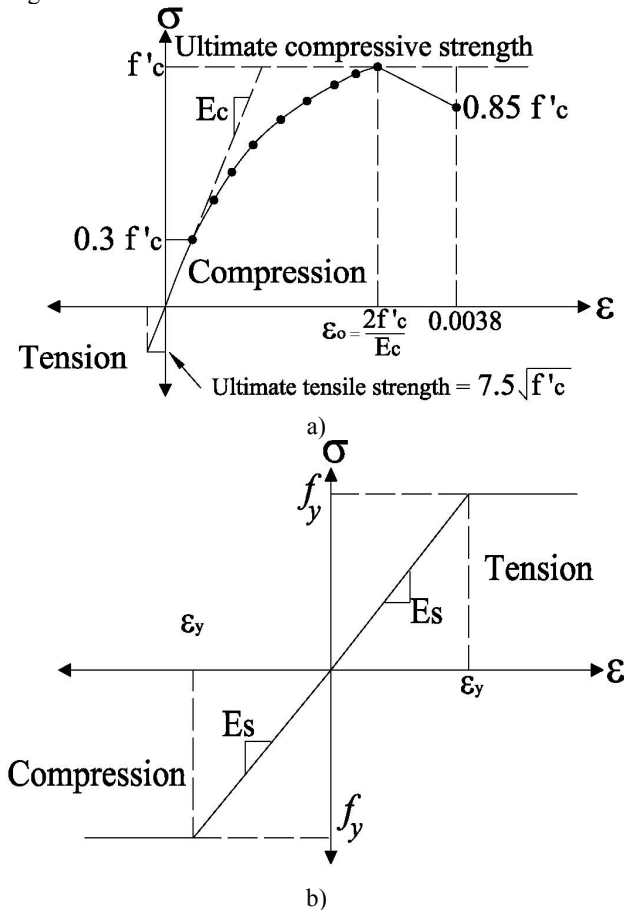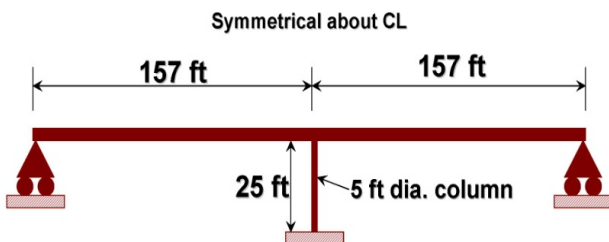

Fig. 1 Concrete (a) and steel (b) stress-strain curve

Concrete:
    Initial concrete $f'_{ci} = 3,500$ psi , $E_{ci} = 3,372$ ksi
    Final concrete $f'_c = 4,000$ psi , $E_c = 3,600$ ksi
Prestressing steel:
    $f_{pu} = 270$ ksi low relaxation strand
    $E_p = 28,500$ ksi
    Prestressing stress at jacking $f_{pj} = 0.8 f_{pu} = 216$ ksi
**Reinforcement steel:**
    $f_y = 60$ ksi , $E_s = 29,000$ ksi
    Prestressing stress at jacking $f_{pj} = 0.8 f_{pu} = 216$ ksi
Prestressing: Anchorage set thickness = 0.375 in.

Fig. 2 Continuous CIP prestressed concrete box Girder Bridge and selected materials

The thickness of soffit slab is flared to 12 in. to lower the gravity center of the superstructure at the face of a bent cap in a CIP posttensioned box girder with parabolic cable path as shown in Figure 4. The position of the jack at the end section and maximum dead load moments mainly controled the cable path. Maximum eccentricities should take place at maximum points of dead load moment and almost no eccentricity should be nearby at the jacked end section. For this study, the maximum dead load moments occur at the bent cap, close to 0.4L for Span 1 and 0.6L for Span 2.
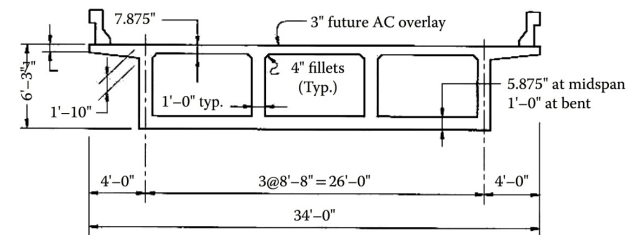
Properties	Midspan	Bent (face of support)
Cross section area – A ft.²	57.25	68.98
Moment of initial I ft.⁴	325.45	403.56
Center of gravity – y_b ft.	3.57	3.09

Fig. 3 Typical section of box girder
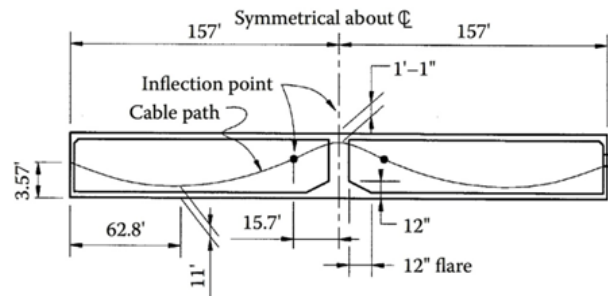

Fig. 4 Cable path

3. Results and Discussion

3.1. The effect of asphalt thickness on the ultimate deflection

Figure 5 shows the impact of asphalt thickness on the ultimate deflection of simulated bridge in which the ultimate of each model was normalized with respect to model without asphalt wearing surface (t_{ws} of 0 in.). Inspection of Figure 5 reveals that the ultimate deflection enhancement percentage is 8%, 16%, 24%, 33%, and 41% for asphalt thickness of 1, 2, 3, 4, and 5, respectively, which is almost equal to 8 times

the asphalt thickness. Therefore, the increase in the ultimate deflection is directly related to an increase in the asphalt thickness with almost with a liner relationship. This enhancement can classify as moderate impact as compared with other investigated parameters.
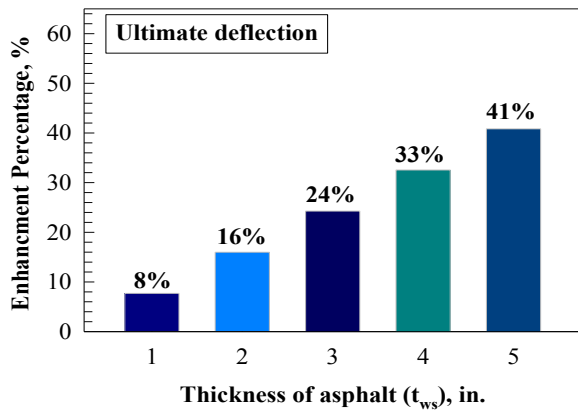

Fig. 5 Ultimate deflection enhancement percentage

3.2. The effect of asphalt thickness on the ultimate moment

The impact of asphalt thickness on the ultimate moment of simulated bridge is shown in Figure 6 in which the ultimate of each model was normalized with respect to model without asphalt wearing surface (t_{ws} of 0 in.). Inspection of Figure 6 reveals that the ultimate positive moment enhancement percentage for asphalt thickness of 1, 2, and 3 in. is the same as the enhancement of deflection. But the ultimate positive moment enhancement percentage for asphalt thickness of 4 and 5 in. is the less than the enhancement of deflection.
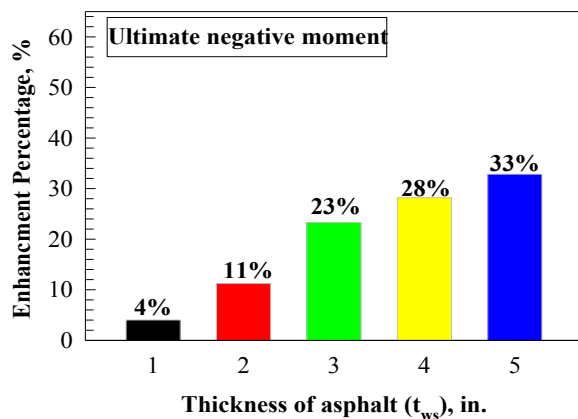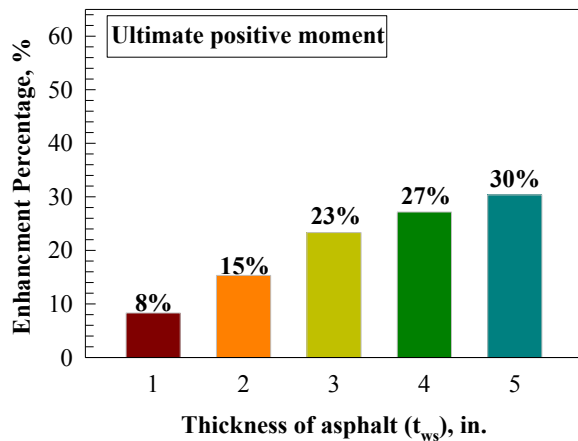

Fig. 6. Ultimate moment enhancement percentage

On the other hand, the ultimate negative moment enhancement percentage for asphalt thickness of 1 and 2 in. is almost half the positive moment enhancement percentage. But the ultimate negative moment enhancement percentage for asphalt thickness of 3, 4 and 5 in. is the same as the enhancement of positive moment enhancement percentage. These enhancements can categorize as modest impact as compared with enhancement of deflection.
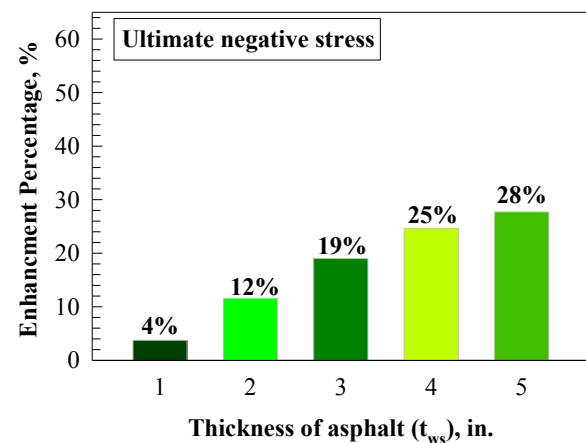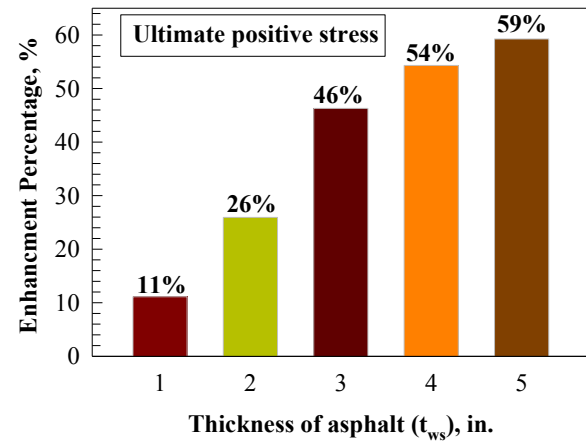

Fig. 7. Ultimate stress enhancement percentage

3.3. The effect of asphalt thickness on the stress

Figure 7 shows the impact of asphalt thickness on the ultimate positive and negative stress of simulated bridge in which the ultimate of each model was normalized with respect to model without asphalt wearing surface (t_{ws} of 0 in.). Inspection of Figure 7 reveals that the ultimate positive stress enhancement percentage is 11%, 26%, 46%, 54%, and 59% for asphalt thickness of 1, 2, 3, 4, and 5, respectively, which is almost equal to 2 times deflection enhancement percentage. Therefore, the increase in the ultimate deflection is not directly related to an increase in the asphalt thickness with almost with a nonlinear relationship. This enhancement can classify as strongest impact as compared with other investigated parameters. On the other hand, the ultimate negative stress enhancement percentage is 4%, 12%, 19%, 25%, and 28% for asphalt thickness of 1, 2, 3, 4, and 5, respectively. This enhancement can classify as a tiny impact as compared with other investigated parameters. Typical deflection and stress profile were shown in Figures 8 and 9.
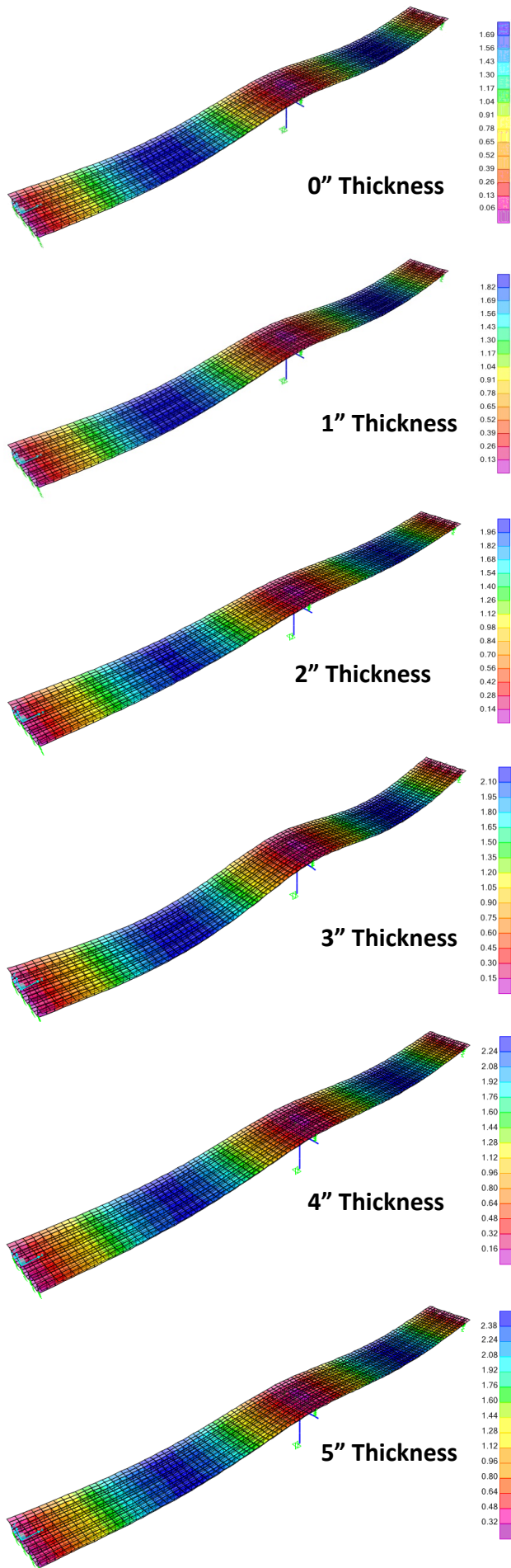
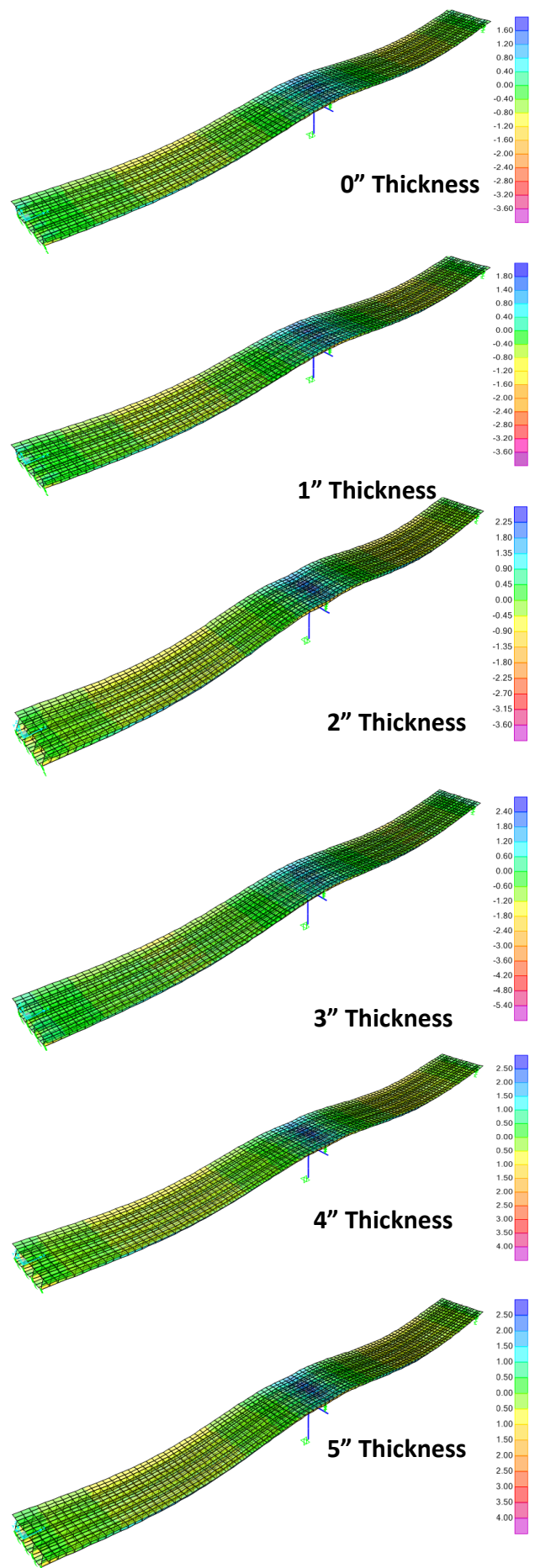**Fig. 8** Deflection profile versus asphalt thickness

Fig. 9 Stress profile versus asphalt thickness

4. Conclusions

Asphalt wearing surface thicknesses is very efficient in improving the ultimate positive and negative moments, ultimate deflection, and ultimate positive and negative stress of a two-span continuous cast-in-place prestressed concrete box girder highway bridge. Increasing asphalt wearing surface thicknesses leads to a strong impact on the positive stress, moderate impact on the ultimate moment and corresponding deflection, and small impact on negative stress. Also, asphalt wearing surface thickness of 4 in. is the optimum thickness and this is based on the ultimate moment capacity and corresponding deflection. Stress and deflection response profile were plotted for two-span continuous cast-in-place prestressed concrete box girder Highway Bridge. This finite element model can be used in additional studies to develop design rules for effect of concrete strength and cable profile as well as prestressing level on the bridge behavior.

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