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A Parametric Study of the Development of Transverse Deck Cracking

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Abstract

Bridges and especially bridge decks experience problems of transverse cracking and deterioration. The causes of early age cracking are mainly due to plastic shrinkage, temperature effects, autogenous shrinkage, and drying shrinkage. Many parameters can affect the development of such cracks. The cracks can be influenced by material characteristics, formwork, climate conditions, geometry, load patterns, amount of deflection, and time dependent factors. It is important to resolve the issue of transverse deck cracking otherwise several bridge decks may experience loss of stiffness and the possibility loss of function which may affect the safety of bridges. This paper examines the effect of a wide range of parameters on the development of cracking. The parameters include, the number of spans, the span length, girder spacing, deck thickness, concrete compressive strength, dead load, hydration, temperature, shrinkage, and creep. The importance of each parameter is identified and then evaluated. Also, the AASHTO Standard Specification limits live-load deflections to L/800 for ordinary bridges and L/1000 for bridges in urban areas that are subject to pedestrian use. One of the main objectives of the study is also to ensure that the current deflection limit is adequate. It is determined that the deflection limit is an important parameter to affect cracking. The current deflection limit needs to be revisited and modified. A set of recommendations to limit the transverse deck cracks in bridge decks is also presented.

Keywords: transverse crack, deck, shrinkage, deflection limit, creep, overlay.

1 Introduction

Several studies have addressed transverse cracking of bridge decks [1,2,3,4,5,6,7,8,9]. General provisions to control cracking due to shrinkage and temperature are provided by American Concrete Institute (ACI). ACI 224 [10] provides recommendations to control cracking of concrete structures. Many studies also highlighted the importance of selection of proper mix-design to limit cracking of bridge decks [8,11,12,4,6]. Transverse cracks in bridge decks are developed during the hardened concrete phase at early ages before service loads are applied. They are full-depth cracks and are typically spaced at 3 to 10 feet apart. They are the most frequently observed cracks in concrete bridge decks. There are a number of problems associated with transverse cracking of bridge decks. Transverse cracks can reduce the service life of structures and increase maintenance costs. Associated structural problems include accelerated corrosion of reinforcing steel, deterioration of deck concrete, and possible damage to underlying components. Transverse deck cracking can also be detrimental to the overall bridge aesthetic. Transverse deck cracking also increase carbonation and chloride penetration leading to accelerated corrosion and deterioration.

Altoubat and Lange [13] stated that restrained concrete fractures at a lower stress level than the static tensile strength by about 20%. It was suggested that periodic wetting may lessen the issue of early age cracking. Darwin, et al. [14] conducted a wide survey on issue of bridge deck cracking. It was observed that cracks tend to develop at early age while they continue to increase with time. Also, bridge decks with silica fume experienced less cracks due to the fact that less evaporation was produced before the wet curing started. A number of recommendations were developed to reduce cracking based on study developed by Eppers, et al. [6]. It was recommended to place concrete of bridge decks only when ambient air temperature is between 40 to 45˚F (4 to 7˚C) and 85 to 90˚F (29 to 32˚C) and also to avoid placing concrete in certain days, at which there is a change of temperature greater than 50˚F (10˚C). It was also concluded that continuity of prestressed bridges results in more cracking. Girder restraint may lead to more likelihood of cracking hence its effect can be reduced by increasing spacing between girders. It was also observed that deck with small thickness of 6.25 in. (159 mm) experienced more cracking. Frosch, et al. [8] conducted field and laboratory investigation to examine factors to affect transverse and longitudinal deck cracking. Frosch, et al. [15] concluded that the thermal effect is attributed to the drop of temperature that may be experienced, if a cold weather was experienced directly after a significant increase of temperature achieved during hydration process. Also, analyses of that study determined that shrinkage solely may not be capable of initiating cracks while combination of shrinkage and cooling, after hydration, may lead to initiation of cracks. Issa [11] identified numbers of factors affecting cracking of bridge decks while it was mentioned that these factors are interacting. Factors include high evaporation rate leading to high shrinkage, use of concrete with high slump, and sequence of concrete pouring. Saadeghvaziri and Hadid [12] examined a number of structural design factors that may affect transverse deck cracking. It was recommended to specify an upperbound for concrete compressive strength since actual concrete compressive strength is usually higher than the specified strength. It was stated that actual boundary conditions shall be in consistency with what were used in design while time dependent loads need to be included in design as well. It was also concluded that employing larger spacing between girders, deck with larger thicknesses, or flexible girders may reduce deck cracking. Oh, et al. [16] studied the effect of temperature and relative humidity on deck cracking. Hydration increases temperature of deck at early ages while solar radiation also affects the temperature of the deck. Change in relative humidity is greater at exposed depth of deck than at inner unexposed surface. Therefore, deck cracking may occur near the deck surface due to relative humidity. The investigation provides approaches to evaluate the effect of temperature and relative humidity in early age concrete decks. Shing et al. [9] derived a number of recommendations to limit transverse deck cracking. Recommendations include using flexible girders, reducing longitudinal restraints, using concrete girders for their coefficients of thermal expansions, and pondering a minimum deck thickness of 8.5 in. (216 mm).

To sum up, tensile creep was found to relax the effect of shrinkage at early age of concrete [13,15]. Therefore, it was recommended to use concrete with lower compressive strength since it possesses more creep. Introducing fixity may increase the likelihood of cracking, especially near supports, in bridge decks [12, 9, 14] hence it is important to reduce longitudinal restraint. The use of decks with small thickness may increase potential deck cracking [6,12,9]. Finally, the use of flexible girders may lead to better cracking performance in bridge decks considering that the produced deflection may be substantial [15, 12, 9]. The objective of this study is to perform finite element modeling, analyses, and discussion of Florida department of transportation (FDOT) Steel Girder Bridges in order to limit the development of transverse bridge deck cracking. Many parameters may affect the performance of steel girder bridge such as; load patterns, load magnitudes, deflection limits, bridge span length, bridge continuity, structural system, and others. It is crucial to identify all of parameters that have a major effect on the development of transverse deck cracking. The effect of parameters which are expected to affect the performance and deck cracking of this type of bridges, significantly, should be examined. The study examines the effect of several parameters on the development of transverse cracking in bridge decks including the effect of creep, shrinkage, thermal expansion, strength of concrete, deck thickness, bridge spans, bridge continuity, traffic load and load patterns, and boundary conditions.

2 Modeling and Analyses

An analytical study, which is general enough, is needed to arrive at parameters that affect transverse deck cracking. Therefore, a benchmark bridge (Figure 1) was selected. The RC bridge deck is 7 in. (177.8 mm) thick and supported by seven (7) W 16 x 50 I-girders. The spacing between girders is 6'-4"(1.93 m). The selected bridge was altered to examine different bridge geometries (number of spans, girder spacing, etc.).

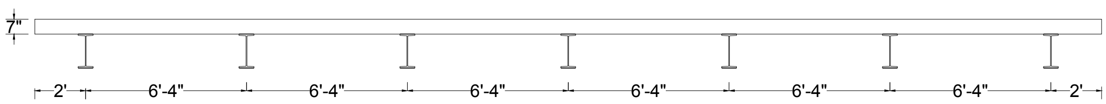


Figure 1. Benchmark Bridge

2.1 Modeling

A 3-D finite element model of the benchmark bridge was developed. The model includes a 3-D finite element model of steel I-girders and RC deck. The steel W shape girders of A992 steel were modeled using shell elements. The shell elements (Figure 2) are four-node quadrilateral elements. The shell elements were used to model top and bottom flanges and the web as well. Compatibility between flanges and web was ensured. Since the objective of the study is to investigate the tendency of bridge decks to develop transverse cracks, the RC bridge deck was modeled more accurately using 8-node solid element (Figure 3). It is important to note that the same distribution and number of elements used to model girder flanges were used to model the parts of deck above flanges to ensure joint connectivity and compatibility. All of what mentioned above was used to model a single span bridge, however, the same type of elements were used to model bridges with different geometry. Figure 4 shows an overview of a typical 3-D finite element model of bridges. It is important to examine the significance of parameters on the development of transverse deck cracking therefore it was necessary to include a large number of parameters in the study. These parameters are expected to affect the behavior and may have a considerable effect therefore the study considers the effect of:

- Number of Spans
- Span Length
- Boundary Conditions
- Deck Thickness
- Bridge Continuity
- Concrete Compressive Strength
- Load Patterns
- Thermal Loads
- Shrinkage
- Creep

To include all of the above parameters, the properties of Benchmark Bridge were altered to produce models to cover all of the listed parameters. The bridge models are donated as Single-Span-N-4000-7-7, Two-Span-N-4000-7-7, Three-Span-N-4000-7-7, Two-Span-D-4000-7-7, Three-Span-N-4000-7-4, Two-Span-N-4000-7-7-(F-F), Two-Span-N-4000-8.5-7, Two-Span-N-4000-10-7, Two-Span-N-5000-7-7, and Two-Span-N-7000-7-7. It is important to note that the generated models are 3-D finite element models (Figure 4). In general, the produced bridge models addressed all of the listed parameters. Compressive strength of concrete, f_c', of 4000, 5000, and 7000 psi (27.6, 34.5, and 48.3MPa), boundary conditions of pin-roller and fixed-fixed (F-F), deck thickness of 7, 8.5, and 10 in. (178, 216, and 254 mm), and number of girders of 7 and 4 are studied. All of remaining four parameters are loads and will be addressed later. The ultimate concrete compressive strength of 4000 psi (27.6 MPa) matches the strength used in the study conducted by Wan et al. [17]. Therefore, the same values of concrete compressive strength at different ages (3, 7, 14, and 28 days) were used. The modulus of elasticity of concrete, E_c, is determined using the ACI 318-08 [18] relationship for normal weight concrete. For this study, the transverse deck cracking is considered to occur once the longitudinal stress produced in bridge decks exceeds the modulus of rupture, f_r.

$$E_c = 57000\sqrt{f_c'} \quad \text{(US Units)} \tag{1}$$

$$f_r = 7.5\sqrt{f_c'} \quad \text{(US Units)} \tag{2}$$

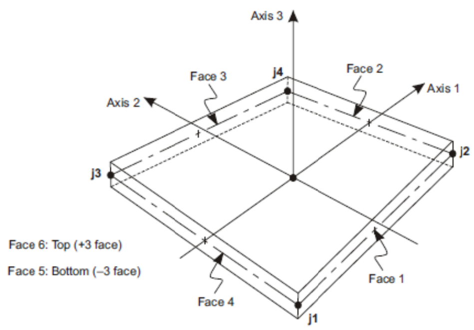


Figure 2. Shell Element

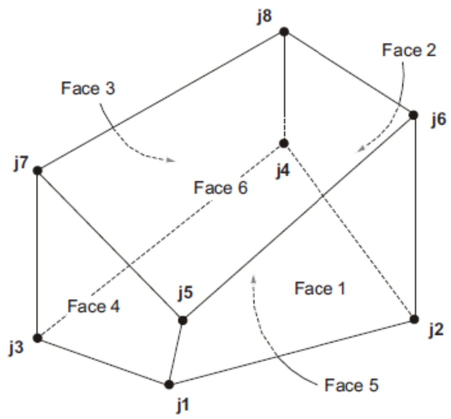


Figure 3. Solid Element

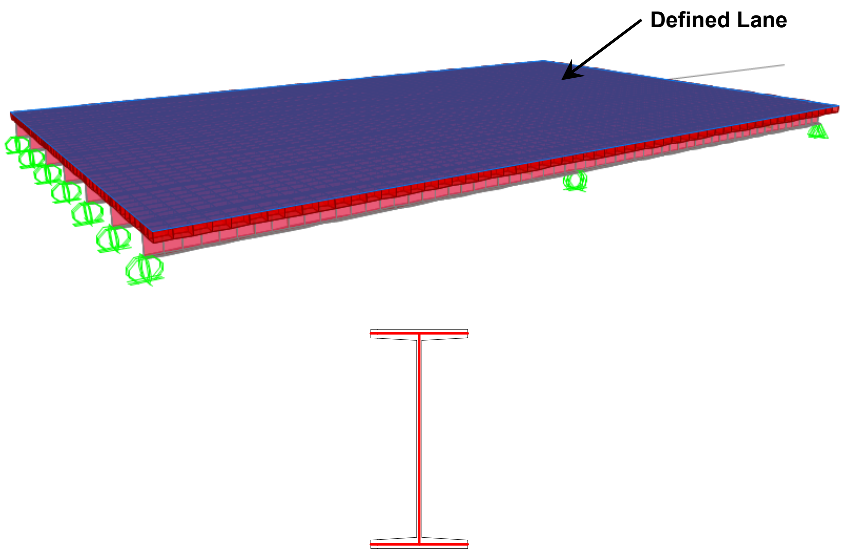


Figure 4. Typical Finite Element Bridge Model

2.2 Bridge Loadings

Several load patterns are included in the study. Load patterns include dead load, increase in temperature due to hydration, temperature, shrinkage, creep, and truck loads. Only bridge deck will be subjected to increase in temperature due to hydrations, which is assumed to be 68˚F (20˚C). The temperature load was taken as increase in temperature of bridge deck and girders by 85˚F (29.4˚C). The effect of shrinkage was considered through applying the strain due to shrinkage on bridge decks. The strain will be assumed to be constant throughout the total depth of the bridge deck. The following equation [12] was used to determine the strain due to shrinkage (ξ_{sh}) at different ages of concrete.

$$\varepsilon_{sh} = -(1.2)k_{vs}k_{hs}k_{f}k_{td}\left(0.78\times10^{-3}\right) \tag{3}$$

Where;

$$k_{vs} = 1.45 - 0.13(V/S) \geq 1.0$$

$$k_{hs} = 2.00 - 0.014H$$

$$k_{f} = \frac{5}{1+f_{ci}}$$

$$k_{td} = \frac{t}{61-4f'_{ci}+t}$$

Where; k_{vs} is a factor to consider the effect of volume-to-surface area ratio of concrete, V is the volume of concrete, S is the surface area of concrete, k_{vs} is a humidity factor, H is % of relative humidity, k_f is a factor to take into account the effect of concrete strength, f'_{ci} is the specified compressive strength of concrete at the time of initial loading (ksi), Tadros and Hadidi (2003) suggests the use of $0.80f'_c$ when this factor is calculated, k_{td} is a time development factor, and t is the maturity of the concrete (in days).

The effect of creep was considered with dead load only. To account for effect of creep, creep coefficient was calculated and was multiplied by the strain due to dead load to obtain the strain due to creep. The creep strain was applied to the bridge deck. The creep coefficient is calculated using the following equations [19].

$$\psi_{(\infty,1)} = 3.5k_{c}k_{f}(1.58 - H/120)t_{i}^{-0.118}\left[(t-t_{i})^{0.6}/\left(10+(t-t_{i})^{0.6}\right)\right] \tag{4}$$

Where;

$$k_{c} = \left[\frac{\left(\dfrac{t}{26e^{0.36(V/S)_{b}}+t}\right)}{\left(\dfrac{t}{45+t}\right)}\right]\left[\frac{1.80+1.77e^{-0.54(V/S)_{b}}}{2.587}\right]$$

$$k_{f} = \frac{1}{\left[0.67+\dfrac{f'_{c}}{9}\right]}$$

Where; k_c is the volume-to-surface area factor, k_f is the concrete compressive strength factor, H is the % of relative humidity, t is the age of concrete at time of interest, t_i is the age of concrete when load is initially applied, e is natural log base (approximately 2.71828), f'_c is the specified compressive strength of concrete (ksi), V is volume of concrete, and S is the surface area of concrete.

The AASHTO LRFD HL-93 loading, which either HS20 truck and lane load of 0.64 kip/ft or tandem load and lane load of 0.64 kip/ft, was used to load the bridge models. The truck loading was applied at 14 days of age of concrete and was called construction load. Also, the truck loading was applied at 28 days of age of concrete while the bridge can be fully loaded at that stage.

Initially, truck loading was applied as a static load to produce maximum positive moment and maximum negative moment. For maximum positive moment, the truck load was positioned close to mid-span, however, for maximum negative moment, two adjacent spans were loaded with truck load, at the same time, to produce maximum negative moment at the intermediate support. It is important to note that the live load truck loading case followed the dead load case.

In order to accurately investigate the performance of bridge models, more accurate approach was introduced. Lanes for truck loads were defined for all of 3-D bridge models (Figure 4). The truck loads were defined as moving load to take into account all of cases of loading that can produce cracks. Also, impact factor of 33% was applied to accompany the truck loads as per AASHTO-LRFD [20]. Several load combination cases were included in the analyses; moving load was accompanied with dead load for one case, accompanied with hydration, accompanied with temperature, accompanied with shrinkage at 14 days of concrete age and at 28 days of concrete age, and accompanied with dead load and creep.

3 Results and Discussions

As mentioned earlier, truck loading followed dead load and was applied as a static load to produce maximum positive moment and maximum negative moment. Load cases include dead load, hydration, temperature, shrinkage, and creep. When the moving load was introduced, moving load was accompanied with hydration, temperature, shrinkage, and creep. The described load patterns were applied to different 45 bridge models. The development of transverse deck cracking was monitored in light of deflection produced.

3.1 Truck Load Applied as Static Load

The truck load followed the dead load case. Two cases of live load were considered; one case to produce maximum positive moment and other case to produce maximum negative moment. For1-Span Bridge (Single-Span-N-4000-7-7), no cracking occurred and maximum stresses take place under loads. For 2-Span Bridge (Two-Span-N-4000-7-7) and maximum positive moment loading, no cracking occurred and maximum stresses take place under loads. On the other hand, for maximum negative moment loading no cracking occurred and maximum stresses take place under loads and at intermediate support. For 3-Span Bridge (Three-Span-N-4000-7-

7) and maximum negative moment loading, no cracking occurred and maximum stresses take place under loads and at intermediate support. For 3-Span Bridge with spacing between girders larger than the width of the truck (Three-Span-N-4000-7-4), transverse deck cracking occurred for maximum positive moment load case. Also, maximum stresses take place at bottom of the deck. For maximum negative moment load case, transverse cracking occurred as well. Maximum stresses take place at the bottom and at top over intermediate support. For 2-Span Bridge with same width and longer spans (Two-Span-D-4000-7-7), no cracking occurred, however, maximum stress take place at top over intermediate support for maximum negative load case.

It was determined that girders spacing can affect the transverse cracking significantly. Also, aspect ratio did not seem to have a considerable effect on transverse cracking. Number of spans did not show tendency to affect transverse cracking, however, in continuous bridge tendency was demonstrated to produce larger tensile stresses at intermediate support locations. Truck loading did not cause any transverse cracking in most of bridge models studied except those with larger spacing. It can be recommended that spacing between girders can not exceed 10 feet to limit such transverse cracking.

3.2 Effect of Secondary Loads

The secondary loads include hydration, temperature, shrinkage, and creep. As mentioned, hydration effect was considered by applying 68˚F (20˚C) of temperature load to all of decks of bridge models. Temperature effect was considered by applying an increase of temperature of 85˚F (29.4˚C) to bridge deck and girders. Shrinkage effect was considered by applying the proper value of strain due to shrinkage for the deck of each bridge model. Creep was accounted for also by applying a strain to bridge deck.

3.2.1 Hydration

By applying the hydration effect to the decks of bridge models, it was determined that the maximum tensile stress to produce transverse cracking takes place at the top of the bridge decks and at the girders locations. From Figure 5, tensile stress due hydration does not seem to have potential thread to produce transverse cracking for the pin-roller boundary conditions. Therefore, it can be stated that, for bridges with seat-type abutment, hydration will not lead to development of transverse deck cracking. However, when the boundary conditions changed to fixed-integral type abutment, the fixity restrained the deformation of the bridge due to hydration which led to development of transverse cracking. Therefore, the fixed boundary condition shall be avoided. Also, it was observed that the tensile stresses developed in bridge decks increased with the age of the concrete and with the increase of number of spans.

3.2.2 Temperature

By applying the temperature effect to all of the bridge models, it was determined that the maximum tensile stress to produce transverse cracking takes place at the bottom of the bridge decks and at the location of girders. From Figure 6 and Figure 7, tensile stresses developed due to temperature are small and do not resemble a potential cause for transverse deck cracking if seat-type abutments is used. However, when the fixity was introduced (Figure 8), tensile stresses increased significantly and transverse cracking took place. It was observed that stresses slightly increased with the number of spans. Therefore, continuity in bridges can lead to larger likelihood of transverse cracking development. It seems that increase in span length does not affect the stresses due to temperature. The same conclusion can be drawn for the effect of spacing between girders. It seems that the stiffer (thicker) the concrete deck, the lower the tensile stresses is (Figure 6). However, the effect of deck thickness is marginally pronounced. It was also found that the higher the concrete compressive strength, the higher the tensile stresses developed (Figure 7) which could lead to transverse deck cracking. It is recommended to use average concrete compressive strength and to avoid the use of concrete with very high compressive strength, to limit development of such transverse cracks.

3.2.3 Shrinkage

As mentioned earlier, shrinkage was applied as a strain to the decks of bridge models. Tensile stresses developed due to shrinkage (Figure 9) were found to be larger than those developed due to hydration and temperature. It is determined that transverse cracking starts to produce at 7 days. The transverse cracks initiate near the steel girders and deck overhang. It was observed that continuity increased slightly the stress, however, all of bridges developed transverse cracks due to shrinkage at 7, 14, and 28 days. There were not any cracks developed at 3 days. Introducing fixed boundary conditions considerably increased the stresses at especially 7, 14, and 28 days. In addition, the increase of the deck thickness reduces the developed stress which may lead to fewer cracks throughout. When the concrete compressive strength increases the developed stress becomes smaller. This trend is opposite to what presented before. Increase of girder spacing and span length did not seem to have a significant effect on the likelihood of transverse deck cracking. In light of presented observations, it is recommended to avoid fixed boundary conditions and use a thicker bridge decks as well as a moderate concrete compressive strength.

3.2.4 Creep

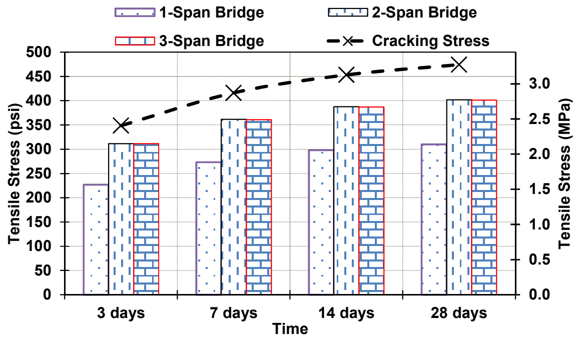
The effect of creep was found to be similar to the effect of shrinkage and it shows similar trend as well. However, stresses due to creep effect were smaller than those produced due to shrinkage.

3.3 Effect of Truck Loads

The truck load was applied as a moving load with an impact factor of 33%. The moving load acts within the limits of the defined bridge lane (Figure 4). When the bridge was loaded at 14 days, the load was called “construction load”, however, when the bridge was loaded at 28 days, the case was called “loaded bridge”. Also, the truck load was applied associated with dead load, hydration, temperature, shrinkage, or creep. The load combinations, between truck load and other secondary loads, were considered at 14 days and 28 days. It is important to note that, when hydration was combined with truck loads, the overall stress decreased. Therefore, this case will not be addressed in the following discussion.

For truck only, it was observed that continuity increased the amount of stress developed. Stress increases with the increase of span length. Increase of girder spacing led to a higher stress to be developed. Fixed boundary condition has a marginal effect on the stress developed. As fixity was introduced, the stress reduces slightly. Increase of deck thickness led to a lower stress to be developed (Figure 10). It was observed that increase of concrete compressive strength led to a higher stress to be developed. However, cracking takes place for all of bridge models. When the truck load was combined with other loads, cracks take place for all of the cases. Stress was maximum when truck load was combined with shrinkage while, at the same time, deflection was maximum. Continuity did not seem to affect the results. Increase of span length led to a larger deflection. Increase of girder spacing did not affect the stress developed in a global sense. Bridge decks with fixed boundary conditions experienced larger stress. The stress reduces as deck thickness increases while deflection follows the same trend. Stress increased with the increase of concrete compressive strength except when truck load was combined with shrinkage.

Using results of analyses, the deflection at which crack shall not take place was calculated and the deflection limit was computed backward as a fraction of span length. The AASHTO Standard Specification limits live-load deflections to L/800 for ordinary bridges and L/1000 for bridges in urban areas that are subject to pedestrian use. In light of results, the current deflection limits provided by AASHTO does not serve the current need to limit such transverse deck cracking. Therefore, there is a need for a new deflection limits to better limit transverse deck cracking. The deflection limit is not expected to make the deck to be transverse crack-free, but it will reduce the number of developed cracks. In turn, this will increase the life time of the deck and will maintain the functionality of the bridge deck.



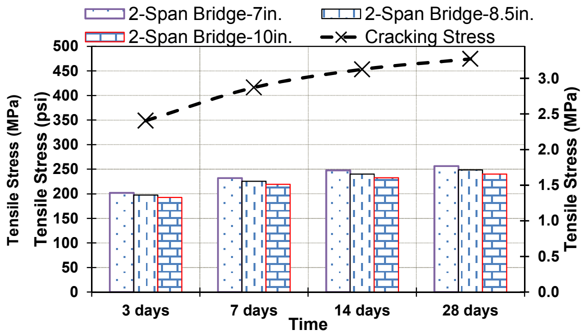
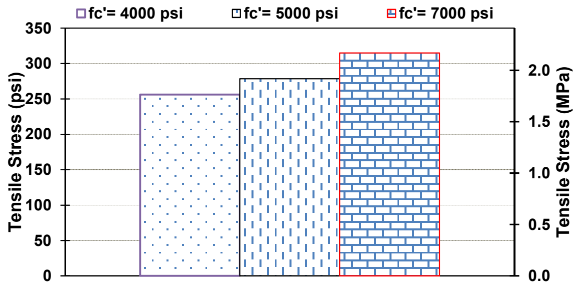


Figure 5. Effect of Hydration (Number of Spans)

Figure 6. Effect of Temperature (Deck Thickness)



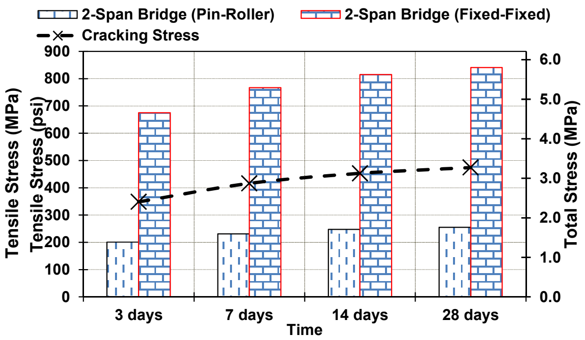
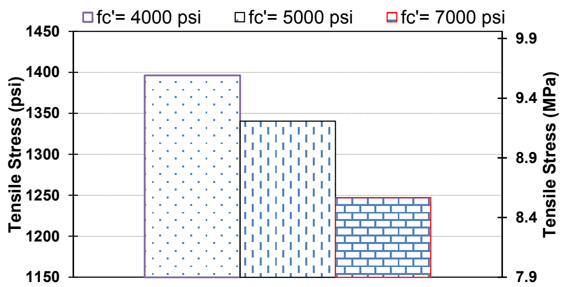


Figure 7. Effect of Temperature (f_c')

Figure 8. Effect of Temperature (Boundary Conditions)



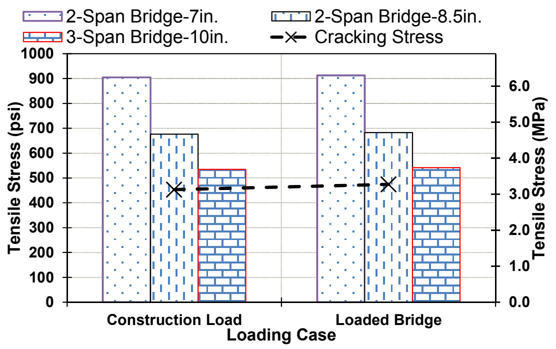


Figure 9. Effect of Shrinkage (f_c')

Figure 10. Longitudinal Tensile Stresses due to Truck Loads (Deck Thickness)

4 Conclusions

This study presents a comprehensive analytical investigation of parameters that may increase the possibility of development of transverse deck cracking since the main focus of the study is to examine the importance of the parameters and to develop set of recommendations. The studied parameters include number of spans, span length, girder spacing, boundary conditions, deck thickness, concrete compressive strength, load patterns, thermal load, shrinkage, and creep. A Large number of bridge models are developed to address all of parameters that are considered to have potential influence on the development of transverse deck cracking. It is important to note that the selection of Benchmark Bridge was intentionally constrained to Florida bridges. It was also ensured that developed models are general enough to cover all parameters of interest.

In the analytical study, the truck load was applied as a static load to produce maximum stresses and as moving load with an impact factor of 33%; the load was applied as a construction load and applied when concrete gained its full strength. Other loads were also considered such as dead load, hydration, temperature, shrinkage, and creep. Also, the other loads were combined with truck loads and applied to bridge decks. The transverse crack was assumed to take place when the tensile stress in the longitudinal direction exceeds the rupture modulus of concrete. Accordingly, the following conclusions are drawn and recommendations are made:

(1) Use of static truck load led to different conclusions than use of moving truck load. It is recommended to apply the truck load as moving load to simulate more accurately the real effect of truck. However, application of both types of loads may lead to a common conclusion. It is concluded that secondary loads such as shrinkage and temperature are important and have considerable influence, which cannot be ignored, on the development of transverse deck cracking.
(2) Under Application of different types of load studied such as; truck, dead, hydration, temperature, shrinkage, or creep, contradicting trends may be obtained for the same examined parameter. Thereby, it is critical to give attention to the significance of type of load to affect the development of transverse deck cracking, through monitoring the amount of stress developed, in order to provide accurate recommendations.
(3) Spacing between girders was found to be an important parameter. When the spacing between girders becomes larger than the width of truck, the stresses developed increased significantly. It may be logical to increase the spacing between girders to provide larger moment of inertia since the part of the deck to work with girders becomes larger. However, the spacing has to be limited. It is recommended to limit the spacing between girders to not to exceed 10 in. (254 mm).
(4) The type of abutment can play an important rule to control the development of cracks. The use of fixed boundary conditions restrains the deformation of bridges which makes the bridge more vulnerable to development of cracks. It is recommended to use seat-type abutment for all of bridges.
(5) The concrete compressive strength has an important contribution. Different conclusions can be drawn based on the type of load applied since opposing trends were observed. However, as mentioned before, the significance of the applied load, in terms of amount of stress developed, is very important. It is recommended to use moderate concrete compressive strength to be used with bridge decks. A concrete with compressive strength of 5000-6000 psi may be employed.

(6) The stiffness of the bridge deck is also imperative and affects the behavior. Increasing the deck thickness lowers the stress produced which, in turn, shrinks the number of developed cracks. Based on limited cases of deck thickness used in the study, it is recommended to use a minimum deck thickness of 10 in. (254 mm).
(7) The deflection limit is found to affect the likelihood of cracking and this limit shall be revised from that given in AASHTO. Such a limit has to be practical and theoretically sound. The new limit may not eliminate cracks, but it shall reduce the number of cracks developed and improve the functionality of the bridge decks.

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