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Bridge Approach Slabs

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ABSTRACT

Approach slabs are reinforced concrete slabs used to provide a smooth transition between the bridge deck and the adjacent paved roadway. Their function is to eliminate or minimize the effects of any differential settlement between the bridge abutment and the approach roadway fill. A two-dimensional nonlinear finite element parametric study was conducted to investigate the effects of several parameters on the behavior of bridge approach slabs. The parameters used have been identified from both a literature review and a survey of state transportation departments. The parameters are the length and thickness of the approach slab; type of connection between the approach slab and the abutment; and height and density of the embankment. The paper presents the results of the parametric study that relate the effects of these parameters on the stresses and settlements developed in the approach slabs. It also provides recommendations for minimum length and thickness of bridge approach slabs based on same results.

Keywords: Bridge abutments, bridge deck, concrete slabs, differential settlements, embankments, finite element method, structural design.

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INTRODUCTION

Settlement of the paved roadway at the roadway/bridge interface often leads to abrupt grade differences between the bridge deck and the roadway pavement. This condition leads to the formation of a bump at the end of the bridge, which is a very complex problem due to many factors including compaction, drainage, embankment height, traffic level, temperature cycles, and downdrag on the abutment (Briaud et al., 2004). Approach slabs provide a smooth transition between the bridge deck and the roadway pavement by keeping the effects of this differential settlement within tolerable limits. Consequently, approach slab design is critical; defective bridge approach slabs can create uncomfortable riding conditions, cause traffic delays and accidents, and require frequent and costly maintenance.

The purpose of this research is to identify the most critical parameters that affect the behavior of bridge approach slabs and recommend appropriate slab dimensions and type of connection between the slab and the abutment.

Problems associated with bridge approaches

Bridge abutments are supported on stable foundations. As a result, they rarely settle. On the other hand, roadway pavements are supported on embankments, which are prone to settlement. This is particularly true for embankments constructed on compressible cohesive soils (Dupont and Allen, 2002; Wahls, 1990). Embankment foundation settlement is the primary cause of bridge approach settlement and leads to differential settlement between the bridge deck and the adjacent paved roadway. White et al. (2005) argues that embankment foundation settlement is caused by a number of factors that includes (1) seasonal temperature changes causing horizontal movements of abutments; (2) loss of backfill material by erosion; (3) poor construction practices; for example, poor joint and drainage system construction, and poor compaction of backfill material; (4) settlement of the foundation soils; and (5) high traffic loads.

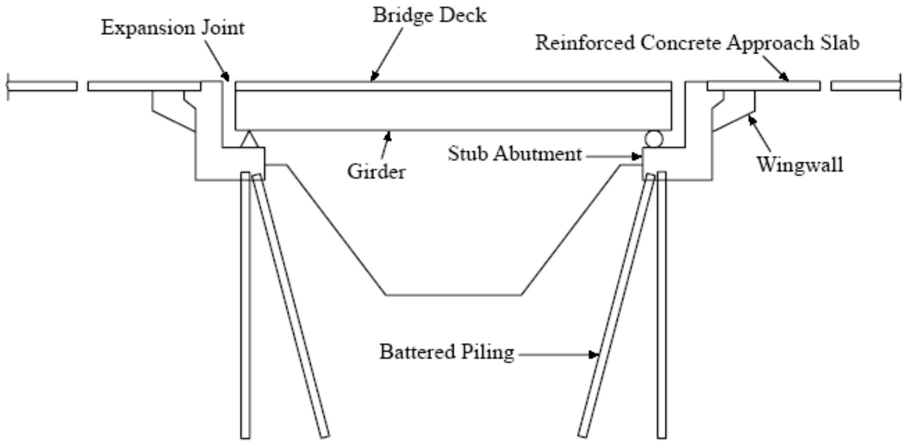

Figure 1. Typical components of a bridge (Greimann et al., 1987).

Several methods are used to stabilize embankment foundation materials: (1) use of surcharge fills; (2) waiting periods; (3) wick drains; (4) lightweight embankment materials; and (5) removal and replacement of unsatisfactory fill (Chini et al., 1993). The fact was confirmed by the responses to our survey of state transportation departments, which indicated the use of surcharge fills and waiting periods as the most commonly-used methods when the approach embankment is founded on compressible foundation. In addition, twenty-nine states use special provisions in the design and construction of approach embankments; the provisions pertain to compaction, use of clay plugs, and use of select materials.

Approach slabs are used either alone or in combination with other measures to help reduce the differential settlement between the bridge deck and the highway pavement. In fact, forty-three states or 93 percent of the respondents list the use of approach slabs as the most common solution for reducing loads on embankment foundations and minimize problems at bridge approaches. The fact confirmed the findings of an earlier survey (Hoppe, 1999), which indicated that 95 percent of the states use approach slabs to minimize differential settlement effects and provide a smooth transition from the roadway pavement to the bridge deck. Geotextiles are used by ten states as a means to reduce settlement of the embankment fill; however, only one state indicated that the method is successful. The use of approach slabs also eliminates pressure on the abutment wall from expansion of approach pavement, which has been known to cause severe abutment and pier damage (Arsoy et al., 1999; Xanthakos, 1995; Burke, 1987).

The survey responses indicate that the settlement of the bridge approach fill is the most serious problem associated with bridge approaches. In fact, thirty-five states reported problems with settlement of embankment fill. The fact is confirmed from literature review that also indicated lateral movement of embankment (Khodair and Nassif, 2005) and poor design of structural components (Amde et al., 1989) as the other two most common problems associated with bridge approaches.

Approach slabs

The information received from the forty-six states that responded to the survey indicates that the use of approach slabs is the most common measure employed to overcome the problem of differential settlement. The approach slab is supported on the abutment at one end and either on a sleeper slab or directly on the fill at the other end (Figure 1). The slab is usually tied to the bridge with dowels. Although most states report satisfactory performance of their approach slabs, a number of states report problems that require maintenance only after a short period of time following construction. In fact, several researchers contest the need for approach slabs. Lock (2002) cites evidence that approach slabs are unnecessary and that regular maintenance of the bridge surface is sufficient to accommodate the soil settlement below the approach roadway. Horvath (2000) notes that if an approach slab is used, the slab will eventually crack in flexure due to the cumulative effects of backfill soil settlement and traffic compaction. Other researchers (Moumena, 1991) suggest elimination of approach slabs from sites with certain geotechnical conditions. This includes sites with very low or no approach embankment and the foundation soils exhibiting an insignificant long-term settlement due to consolidation, secondary compression, and creep.

Approach slab dimensions

The length of the approach slab used by states is often based on experience, finite element simulations, and approximate calculations. In general, the length of an approach slab is compatible with the expected settlement. As a result, longer approach slabs are used in cases involving very soft foundation soils or high embankments or both.

Stewart (1985) suggests using approach slabs 9 m long supported on select backfill material having a maximum plasticity index (PI) of 15, fewer than 40 percent fines, and 95 compaction. Briaud et al. (1997) recommend that approach slabs be designed to span various lengths; typically 4 to 7 m. Thiagarajan et al. (2010) recommend approach slabs having a length of 6 m and thickness 300 mm for new construction. According to Arsoy et al. (1999), “it is often argued that the length of the approach slabs should be made two to three times the height of the abutment.” This argument follows from the rationale that displacing an abutment causes movement of a wedge of the backfill with a height equal to the height of the abutment and a length equal to tan (45+φ/2), which is about twice the height of the abutment; φ is the angle of internal friction of the fill. However, a finite element analysis conducted by Arsoy et al. (1999) indicated that the length of the settlement zone extends to about three and one-half times the height of the abutment.

Surveys conducted by Hoppe (1999) and Thiagarajan et al. (2010) indicate that the majority of states are using 6 m long approach slabs. The shortest reported length is 3 m and the longest 12 m. The reported thickness of the slabs varies from 200 mm for a 4.5 m long approach slab to 425 mm for a 9 m long approach slab. Approach slabs with length of 6 m have a thickness that varies between 225 and 375 mm with 300 mm the average. Flat slabs are reportedly the most common shape for approach slabs; however, other shapes such as tapered, T-beams, and haunches are also used. To provide a smooth transition between the approach slab and the roadway pavement, approach slabs usually rest on a sleeper slab. Approach slabs are usually connected to the abutment by resting the slab on the abutment seat or by attaching it to the abutment with a reinforced steel keeper mechanism.

Longitudinal slope of the approach slab

Ideally, the longitudinal slope of the approach slab should match the longitudinal slope of the bridge. In most cases, however, this is not possible because the slope of the approach slab should also match the slope of the roadway on the other end of the approach slab. Then, there is the issue of rider comfort. As a result, there should be a limit in the difference in slope between the slopes of fixed bridge/approach slab and between approach slab/roadway. According to Briaud et al. (1997), the maximum allowable change in slope should be 1/200 of the approach slab length, based on studies by Wahls (1990) and Stark et al. (1995). This critical settlement gradient was also referred by Long et al. (1998) and is used by several states as a threshold value to initiate maintenance procedures on bridge approach areas. Others (Albajar et al., 2005) establish a threshold value of 40 mm of vertical settlement as the starting point of maintenance procedures (Puppala et al., 2008).

Impacts of superstructure type on the approach slab

Alampalli and Yannotti (1998) note a direct and significant correlation between the condition of the approach slabs and the length of steel superstructure integral bridges; the longer the steel superstructure, the lower the approach slab ratings.

Impacts of approach slab on the bridge

Greimann et al. (2008) investigated the impacts that approach slabs have on integral bridges. They found that tying the approach slab to the bridge induces longitudinal and transverse abutment displacements as well as girder forces; moments and axial forces. Induced abutment displacements range from a maximum positive displacement to a maximum negative displacement while induced girder forces include compressive axial forces and both positive and negative moments. However, the authors make no comparison between the magnitude of induced and existing girder forces and abutment displacements. Furthermore, there are no recommendations for modifications or changes in abutment or girder design as a result of the additional forces induced in the bridge.

Finite element idealization

A nonlinear finite element analysis was conducted to investigate the effects of several parameters on the behavior of bridge approach slabs. The parameters used are approach slab thickness, embankment fill height, embankment fill density, and the type of connection between the approach slab and the abutment. The reinforced concrete approach slab is assumed to behave elastically while the embankment fill’s behavior is modeled using an elastic perfectly plastic stress strain curve with Drucker-Prager yield criteria (Drucker and Prager, 1952), which entails elastic constants, a yield function and a flow rule. This idealization is capable of reflecting the three most important characteristics of the real soil stress-strain curve.

The finite element idealization used to model bridge approaches is shown in Figures 2 and 3. The soil and the approach slab are modeled in ANSYS as quadratic instead of linear plate strain elements with isoparametric formulation to avoid the locking phenomenon of a linear

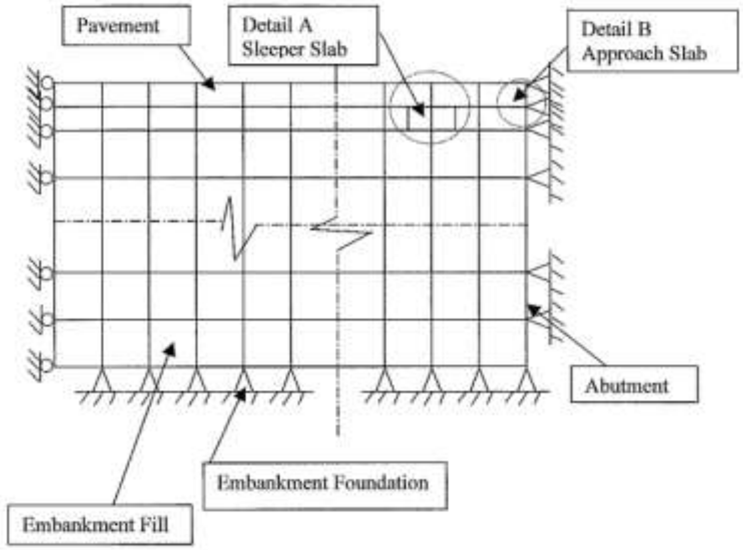

Figure 2. Finite element model of approach to bridge.

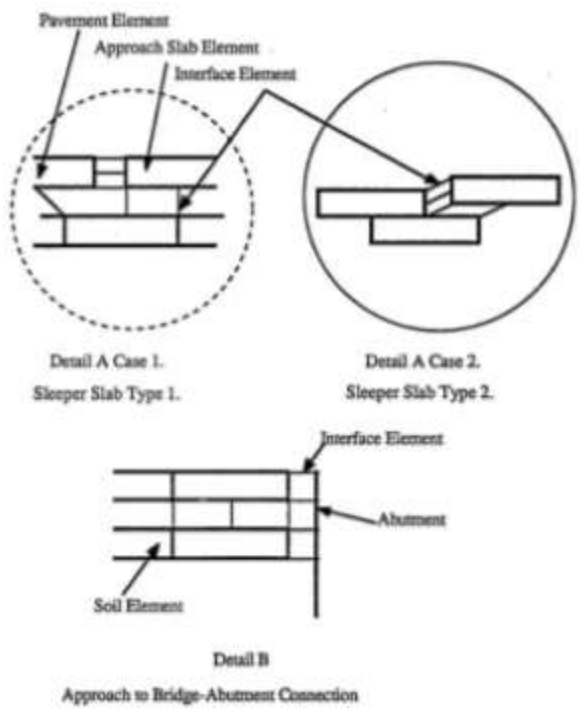

Figure 3. Finite element model details.

element (Chen and Baladi, 1985). Numerical integration was conducted using the third order Gauss quadrature. The embankment foundation layer and the abutment were assumed to be rigid. Interface elements were introduced between the approach slab and the abutment and between the abutment and the embankment fill. Each element consisted of two nodes corresponding to two surfaces with two degrees of freedom at each node (translation in x and y directions). These elements have the capacity to break or maintain physical contact and are able to support both compression in the direction normal to the surfaces and shear in the tangential direction.

To evaluate the finite element predictions, the sections described in Table 1 and illustrated in Figure 4 were

Table 1. Description of finite element analysis sections.

FEM Analysis / Layers	Section 1			Section 2			Section 3		
	Thickness	E	v	Thickness	E	v	Thickness	E	v
Layer 1	79	965	0.40	82	483 -793	0.40	79	1103	0.40
Layer 2	185	30	0.35	142	793	0.40	158	3240	0.35
Layer 3	185	30	0.35	366	655	0.35	158	3723	0.30
Layer 4	996	1034 - 345	0.32	1225	690 - 276	0.36	648	414	0.30
Layer 5	∞	138	0.40	∞	138	0.38	∞	345 - 69	0.25
Layer 1	Asphalt concrete			Asphalt concrete			Asphalt concrete		
Layer 2	Aggregate base			Asphalt concrete base			Emulsion treated aggregate		
Layer 3	Top of subgrade			Subgrade 1			Top of subgrade		
Layer 4	Subgrade 1			Subgrade 2			Subgrade 1		
Layer 6	Subgrade 2			Subgrade 3			Subgrade 2		
Loads	Equivalent distributed load P/L based on HS 20 truck loading								
Units	Thickness (mm) Modulus of Elasticity E (MPa) Poisson's ratio v (no units)								

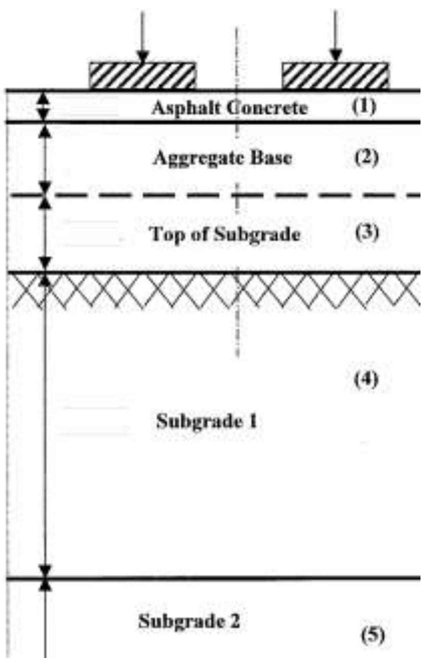

Figure 4. Illustrative section for finite element analysis.

investigated using the proposed finite element model. Displacement measurements of the sections were performed in the field using settlement plates and then compared to the displacements predicted by the finite element model. The two-dimensional finite element model consists of 8-node plane strain elements, which enables variation of thickness without remeshing. An equivalent distributed vehicle equal to P/L was used as a good approximation of truck load (Moumena, 1991) to simulate the truck in this two-dimensional model; P represented the truck wheel load based on HS 20 loading and L the width of the roadway.

Interface element stiffness matrix

The interface element chosen can display one of three characteristics; closed and not sliding, closed and sliding, or open in ANSYS. The equilibrium equations for these cases are as follows:

Case 1: Closed and not sliding

$$\begin{bmatrix} K & 0 & -K & 0 \\ K & 0 & -K & 0 \\ K & 0 & -K & 0 \\ K & 0 & -K & 0 \end{bmatrix} * \begin{bmatrix} U_{s,i} \\ U_{n,i} \\ U_{s,j} \\ U_{n,j} \end{bmatrix} = \begin{bmatrix} F_{si}^{n} \\ F_{ni}^{n} \\ F_{sj}^{n} \\ F_{nj}^{n} \end{bmatrix} + \begin{bmatrix} -KU_0 \\ -K\Delta \\ KU_0 \\ K\Delta \end{bmatrix}$$

Where K = stiffness; Δ = interference; F^n = normal force across gap; and Uo = distance that nodes I and J have slid with respect to each other.

Case 2: Closed and sliding

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & K & 0 & -K \\ 0 & 0 & 0 & 0 \\ 0 & -K & 0 & K \end{bmatrix} * \begin{bmatrix} U_{s,i} \\ U_{n,i} \\ U_{s,j} \\ U_{n,j} \end{bmatrix} = \begin{bmatrix} F_{si}^{n} \\ F_{ni}^{n} \\ F_{sj}^{n} \\ F_{nj}^{n} \end{bmatrix} + \begin{bmatrix} -\mu F^{n} \\ -K\Delta \\ -\mu F^{n} \\ -K\Delta \end{bmatrix}$$

Where μ is the coefficient of friction.

Case 3: Open

When there is no contact between I and J the stiffness matrix and the load vector are both null matrices.

Approach slab length

Approach slab lengths up to 12 m were used for this parametric study. This is due to the fact that 90 percent of slabs on federal highways lie within this range (Allen, 1985). In addition, the survey conducted by Hoppe (1999) indicates that the longest approach slab length used by states is 12 m while the survey conducted by Thiagarajan et al. (2010) indicates that the longest approach slab length used by states is 10 m.

SUMMARY OF RESULTS

The following paragraphs summarize the findings of the parametric study. The four parameters discussed in reference to their effect on tensile stresses and settlements developed in approach slabs are the following: (1) approach slab thickness, (2) embankment fill height, (3) embankment fill density, and (4) type of connection between the abutment and the approach slab.

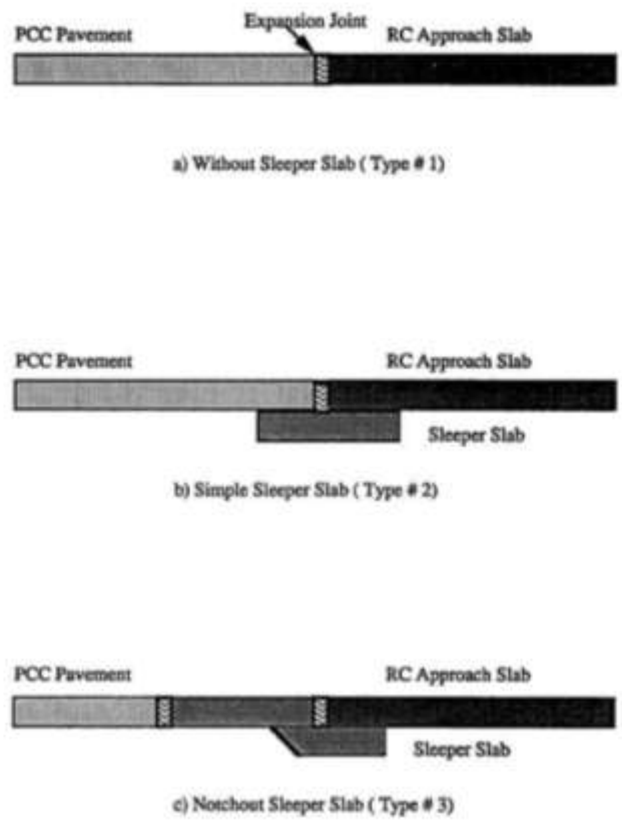

Figure 5. Sleeper slab types.

Approach slab thickness

The finite element analysis model investigated the relationship between the thickness of approach slab and maximum tensile stresses and settlements developed in those slabs. Approach slab length and thickness varied while all other parameters were kept constant. An embankment fill height of 12 m, roller support, loose fill, and sleeper slab type 3 (Figure 5) were used during this investigation. Three approach slab thicknesses were investigated for varying slab length; 150, 300, and 450 mm. The results are illustrated in Figures 6 and 7. The figures indicate that increasing the thickness of the approach slab reduces both the tensile stresses and the settlements in the slab.

Although tensile stresses are higher for longer approach slabs for all three slab thicknesses, the tensile stresses developed in 300 mm and the 450 mm thick slabs are significantly lower than those developed in 150 mm thick slabs. This indicates that the effects of slab thickness on the magnitude of tensile stresses developed in approach slabs are more critical than that the effects of slab length.

Embankment fill height

The effect of embankment fill height on tensile stresses and settlements developed in approach slabs of various lengths was investigated by varying the fill height from 3 to 12 m while the other parameters were kept constant: sleeper slab type 3, loose fill, fixed support, and 300 mm thick approach slab. The results are shown in Figures 8 and 9.

The analysis results indicate that for the same slab length, increasing the embankment fill height increases both the settlements and the tensile stresses in the approach slab.

Embankment fill density

To study the effect of embankment fill density on the performance of approach slabs, fill densities and approach slab length varied while embankment fill height, sleeper slab type, and approach slab thickness were kept constant. An embankment fill height of 3 m, a 300 mm thick approach slab, and a type 3 sleeper slab were used for three different types of embankment fill density; dense, medium, and loose. The approach slab length varied from 3 to 12 m. The results of the analysis are shown in Figures 10 and 11.

The results indicate that increasing the density of the embankment fill results in a reduction in the magnitude of tensile stresses and settlements in the approach slab. The results also indicate that for the same fill density the

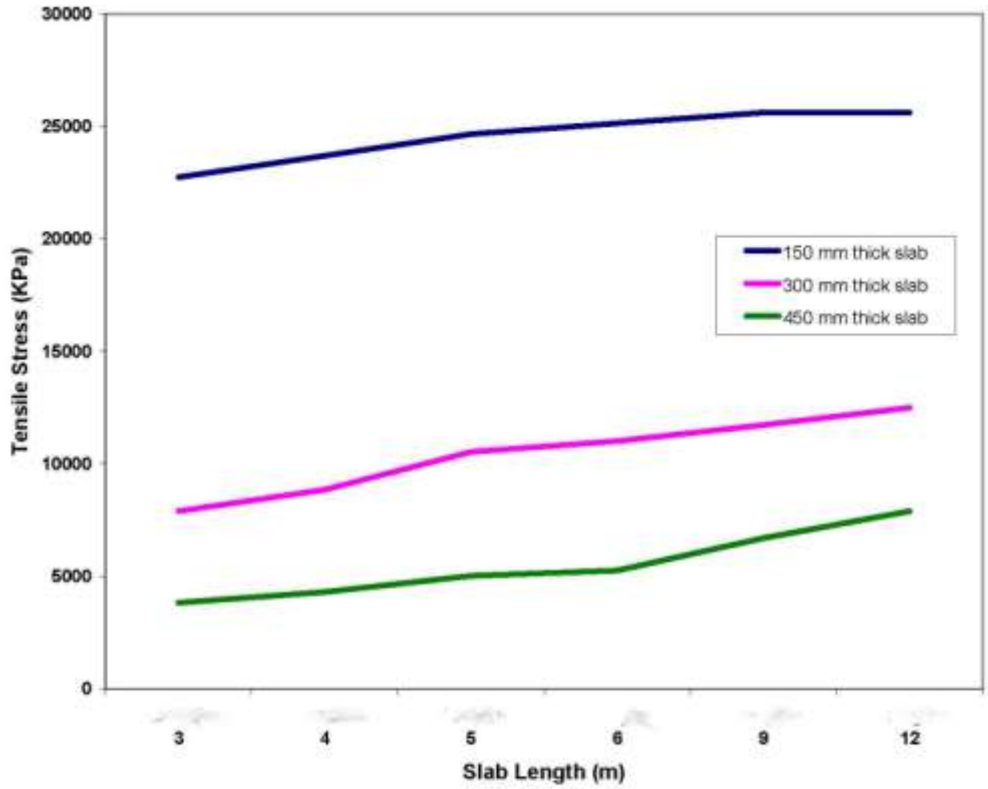

Figure 6. Effect of slab thickness on tensile stresses in approach slabs.

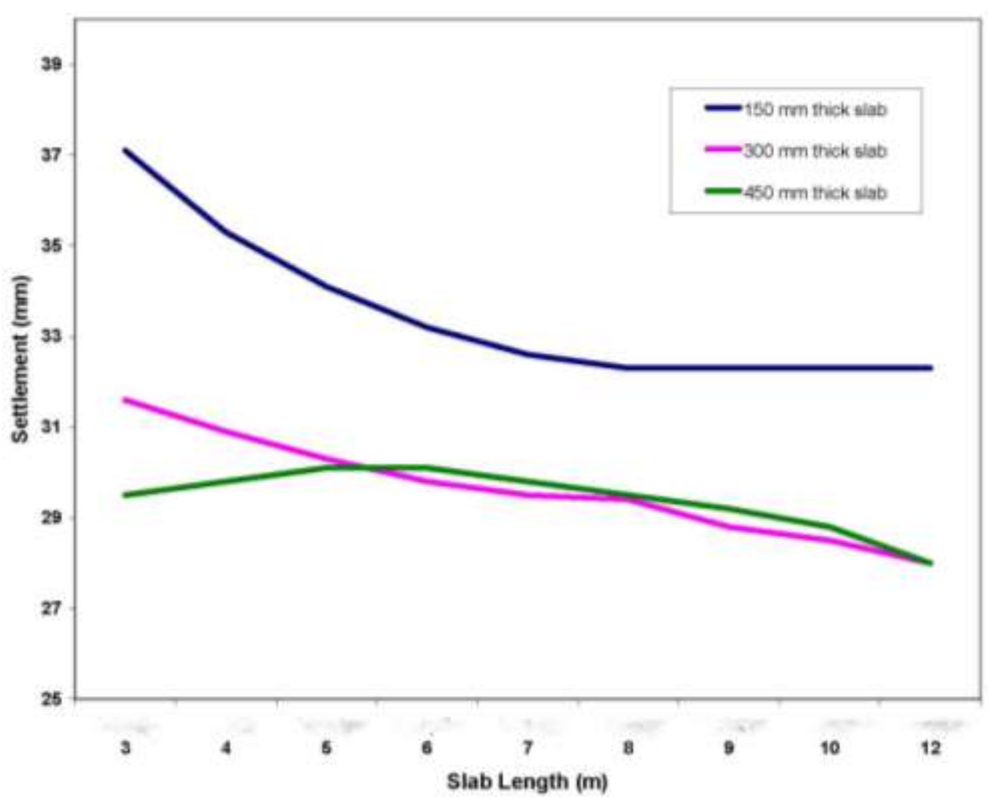

Figure 7. Effect of slab thickness on settlement of approach slabs.

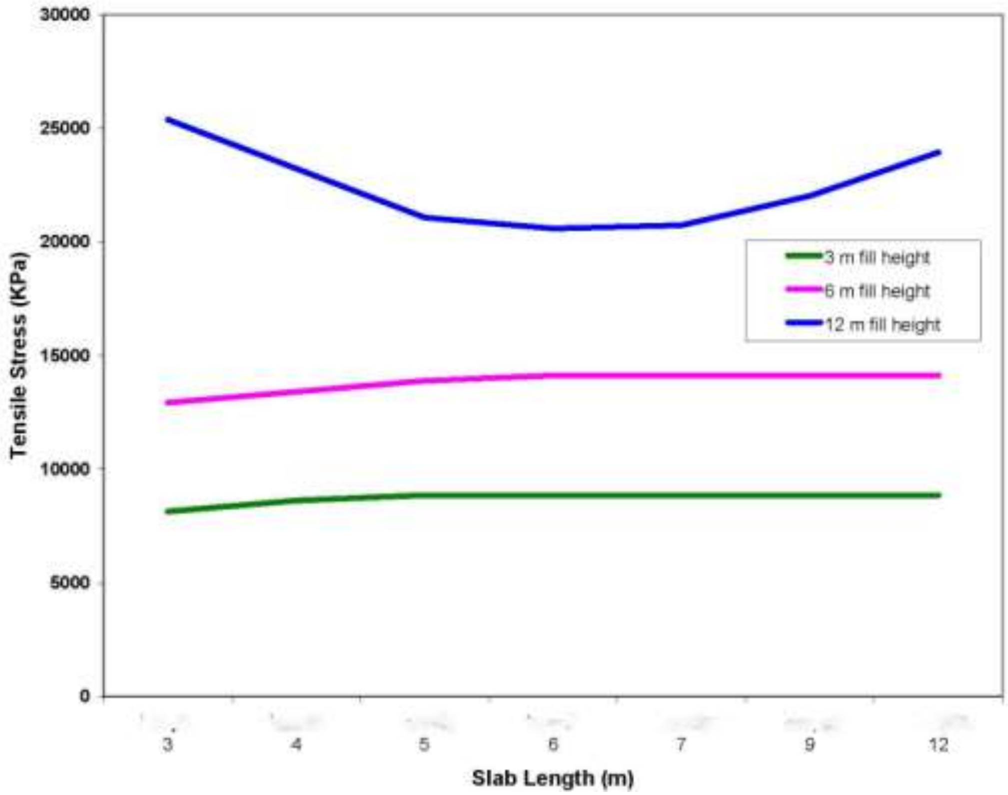

Figure 8. Effect of fill height on tensile stresses in approach slabs.

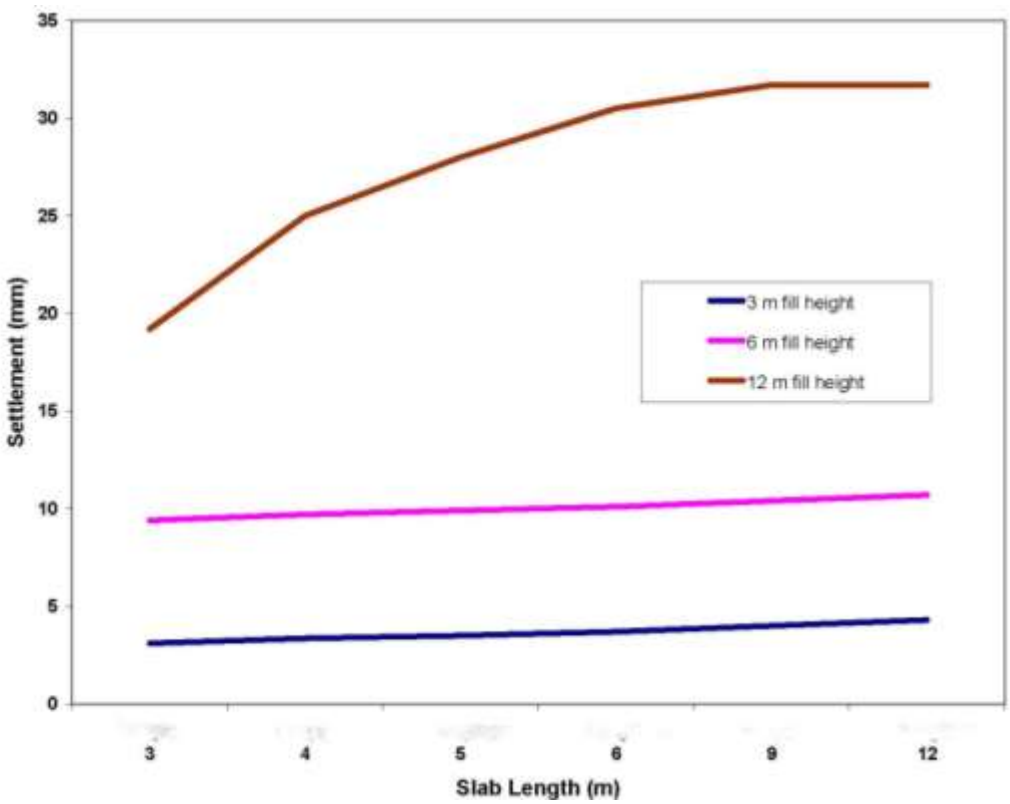

Figure 9. Effect of fill height on settlement of approach slabs.

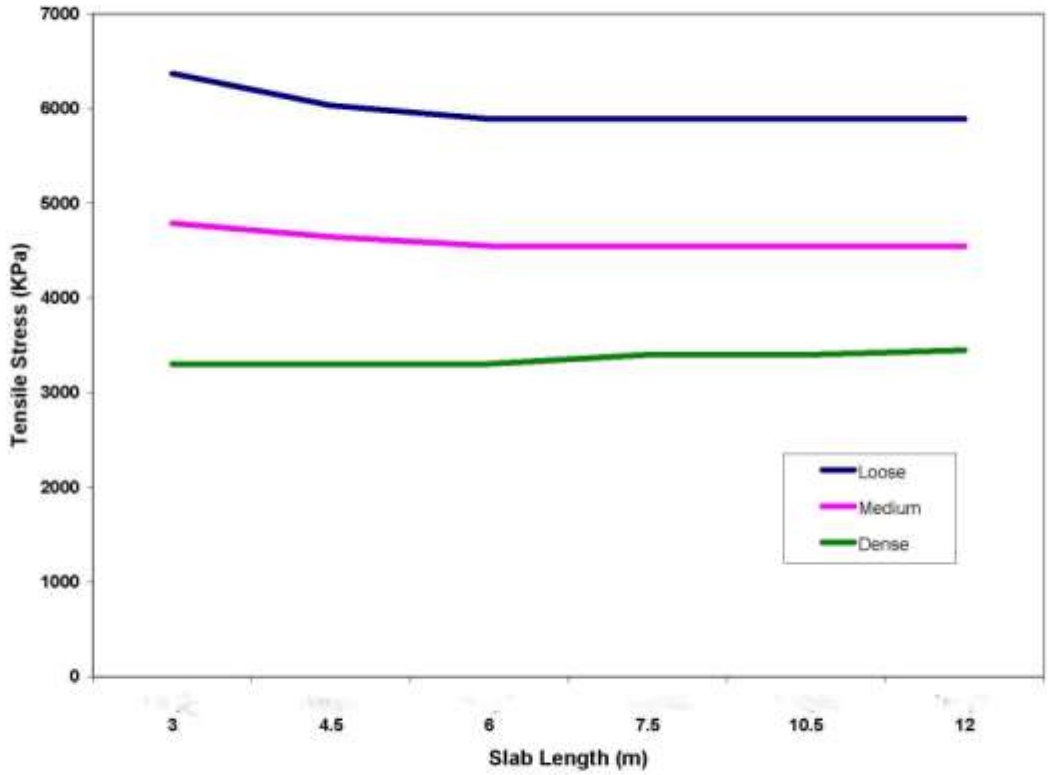

Figure 10. Effect of fill density on tensile stresses in approach slabs.

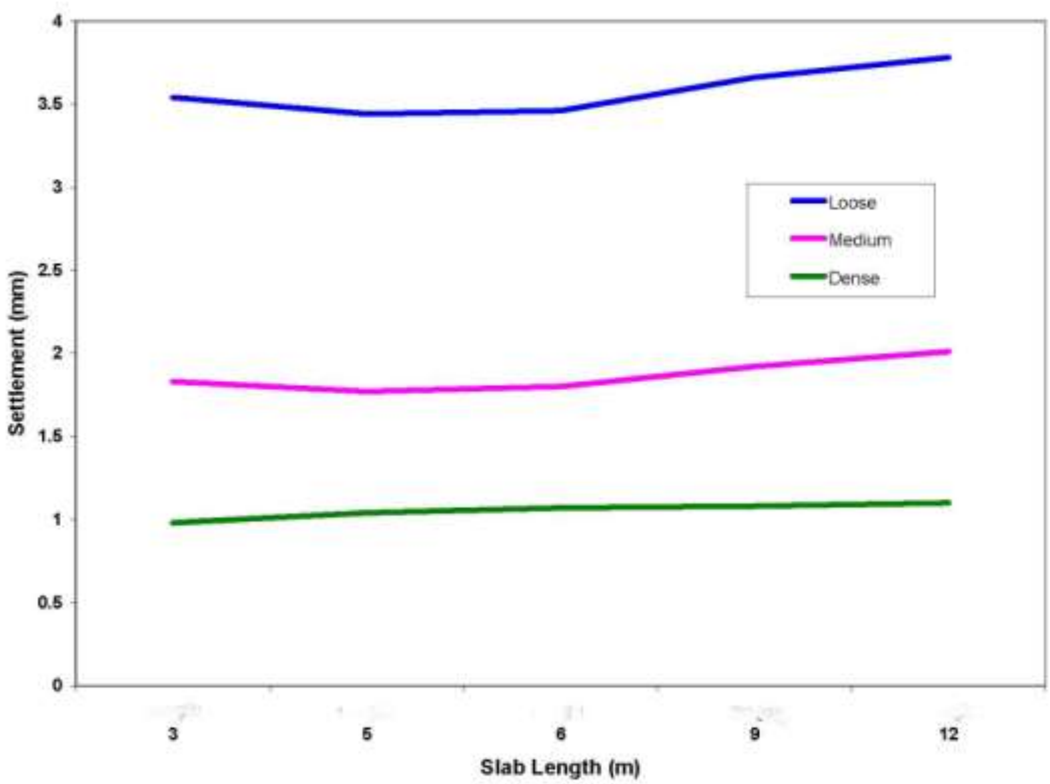

Figure 11. Effect of fill density on settlement of approach slabs.

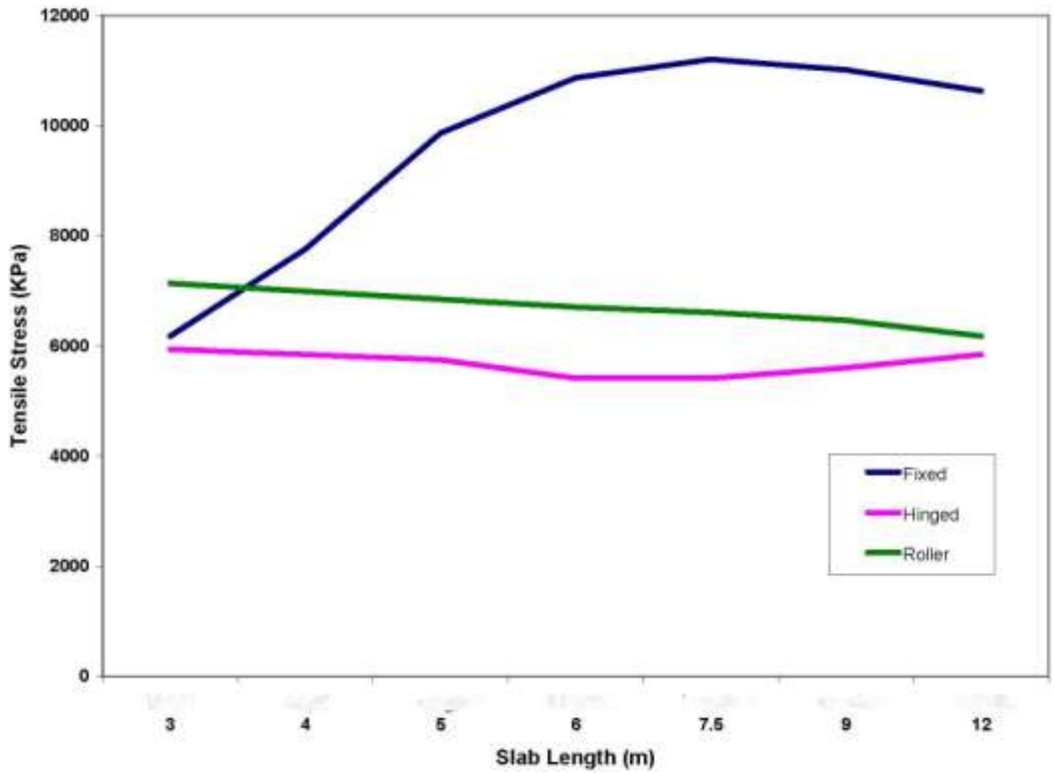

Figure 12. Effect of abutment support type on tensile stresses in approach slabs.

change in slab length has little effect on tensile stresses and settlements.

Type of connection between abutment and approach slab

The effect of the type of connection between the abutment and the approach slab on the magnitude of settlement and tensile stresses developed in approach slabs is shown in Figures 12 and 13. Approach slabs were supported on the roadway pavement side on the same type of sleeper slab and on the other side by the abutment using three different types of supports; fixed, roller, and hinged. The thickness of approach slab as well as height and density of embankment fill were kept constant using a 300 mm thick slab, medium density fill, and 6 m high embankment fill.

As shown in Figure 12, the type of connection between the abutment and the approach had a significant effect on the magnitude of tensile stresses developed in the approach slabs only for the case of fixed supports. In fact, most of the increase in the magnitude of tensile stresses occurs as the length of the approach slab increases from 3 to 6 m. In reference to settlements (Figure 13), for all three types of supports increasing the length of the approach slab produces an increase in the magnitude of the settlement in the slab.

EVALUATION AND INTERPRETATION OF FINITE ELEMENT ANALYSIS RESULTS

Tensile stresses

Evaluation of analysis results as illustrated in Figures 6, 8, 10, and 12 indicates a maximum tensile stress of 25,000 KPa for the case of 150 mm thick slabs, 14,000 KPa for the case of 300 mm thick slabs, and 9,000 KPa for the case of 450 mm thick slabs. The magnitude of these tensile stresses is greater than the tensile strength of concrete estimated at 2,833 KPa for concrete with a compressive strength of 21 MPa. Consequently, rebar should be used to add tensile strength to the concrete resulting in a reinforced concrete slab. .

Type of approach slab support at abutment location

The analysis results suggest that either a roller or a hinged support should be used to connect bridge abutments to approach slabs. Fixed supports produce much higher stresses in the approach slabs compared to roller and hinged supports (Figure 12) and should be avoided. In fact, hinged supports may be more practical since they provide resistance to forces, which may pull the slab away from the paving notch and prevent water from dissipating into the embankment fill.

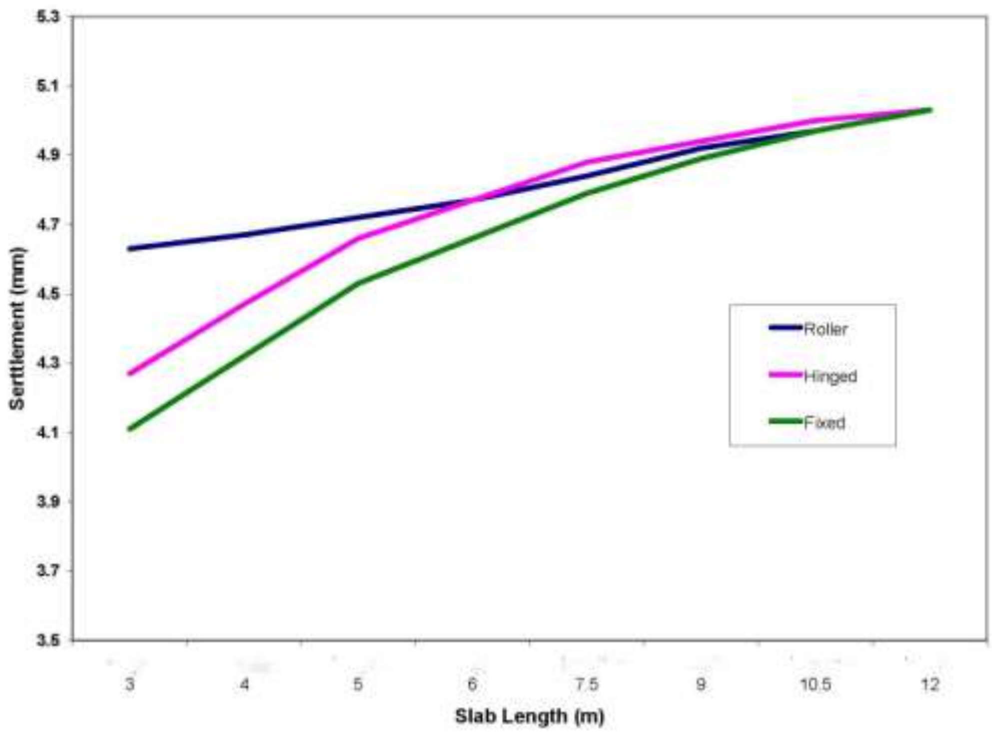

Figure 13. Effect of abutment support type on settlement of approach slabs.

Table 2. Evaluation of slab settlements with Wahl's service criterion.

Slab thickness (mm)	Slab Length (m)	Settlement (mm) (Fig. 7)	Wahl's criterion (mm)	Pass/Fail
	3	37	15	Fail
150	6	33	30	Fail
	12	32	60	Pass
	3	32	15	Fail
300	6	30	30	Pass
	12	28	60	Pass
	3	29	15	Fail
450	6	30	30	Pass
	12	28	60	Pass

Settlements

Evaluation of analysis results as illustrated in Figures 7, 9, 11, and 13 indicates that the most critical settlements occur when the effects of slab thickness are considered (Figure 7). Table 2 compares settlements as illustrated in Figure 7 to Wahl's service criterion of L/200 where L is the length of the approach slab.

Evaluation of the results as illustrated in Table 2 indicates that the approach slab should have a minimum thickness of 300 mm and minimum length of 6 m to satisfy Wahl's service criterion.

Conclusions

Based on the successful performance of approach slabs in many states, the study strongly recommends their use as a means to eliminate or minimize problems associated with bridge approaches. However, approach slabs are not necessary at sites where long-term settlement is insignificant, approach embankment is very low or proper compaction of the backfill is ensured. The results of this study indicate that slab thickness and embankment fill height are more critical than embankment fill density and type of connection between the slab and abutment on tensile stresses and settlements developed in bridge approach slabs. The study recommends use of reinforced concrete approach slabs with a minimum thickness of 300 mm and a minimum length of 6 m. It also recommends the use of roller or hinged supports to connect bridge abutments to approach slabs.

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