Design and Detailing of Bridge Approach Slabs: Cast-in-Place and Precast Concrete Options

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Abstract. Approach slab is a structural concrete slab that spans from the back wall of the abutment (i.e. end of the bridge floor) to the beginning of the paving section. The purpose of the approach slab is to carry the dead and live loads over the backfill behind the abutments to avoid differential settlement that causes bumps at the bridge ends. Cast-in-place (CIP) concrete approach slab is the current practice in most of the states in US with various spans, reinforcement, thicknesses, and concrete covers. However, it has been reported that most approach slabs experience cracking and settlement, which result in premature deterioration and shorter service life. The replacement of deteriorated approach slabs causes costly and long traffic closure and detouring. Precast concrete (PC) approach slabs is a promising solution that could provide longer service life and accelerated construction/replacement. This paper presents a literature on current approach slab practices and innovative precast concrete solutions. Also, an analytical investigation is conducted using finite elements to evaluate the performance of the current approach slab practices in the state of Nebraska. Several parameters are considered in this investigation, such as volume changes due to shrinkage and temperature changes as well as skew angle and bridge width. Analysis results indicate that volume changes cause high tensile stresses along abutment line, which results in longitudinal cracks. Also, high skew angles result in stress concentrations at the slab corners and the increase in slab width increases the stresses in transverse direction.

1 Introduction

Approach slabs are usually supported by the back wall of the abutment at one end and a grade beam or sleeper slab at the other end. Soil backfill supports the approach slab in between the two ends across the bridge width. Figure 1 shows the plan view of a typical approach slab system. Despite the simplicity of approach slab structural system and its design as a one-way cast-in-place (CIP) reinforced concrete slab, it has been reported that most approach slabs experience cracking at early ages, which results in premature deterioration and shorter service life. The purpose of the paper is to present the different practices of approach slab design and detailing according to several US Departments of Transportation (DOTs). Special attention will be given to the current practice of Nebraska Department of Transportation (NDOT) and its recent implementation of precast concrete (PC) approach slabs as alternative to CIP concrete approach

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slabs to minimize deterioration and construction duration. A finite element analysis was also conducted to evaluate the behavior of approach slabs under dead load, live load, and volume changes. Other parameters were considered in this investigation including skew angle and bridge width.

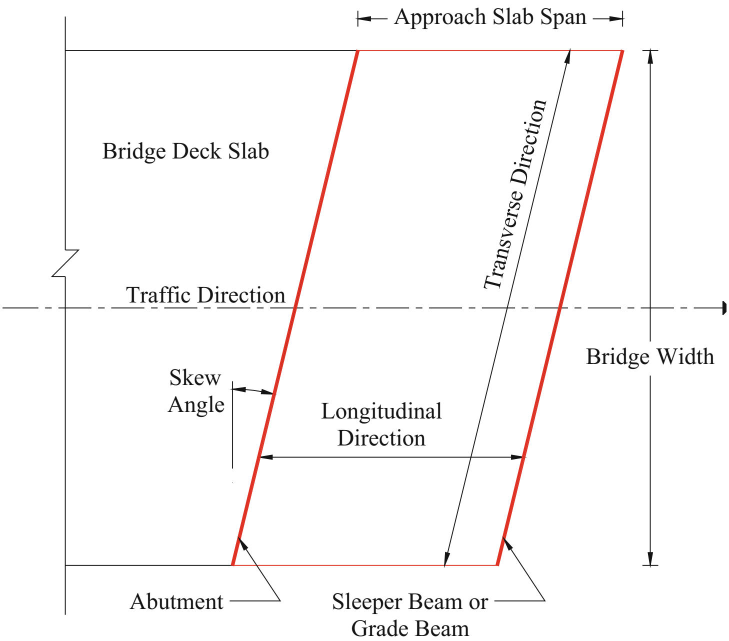


Fig. 1. Typical approach slab system

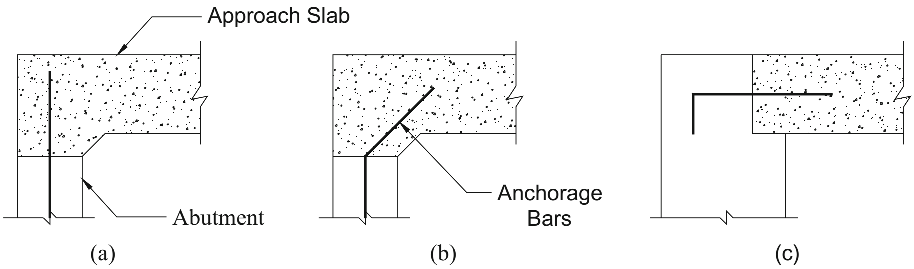


Fig. 2. Different anchorage bar layouts at joint between approach slab and abutment; (a) vertical, (b) bent, and (c) horizontal.

2 Current Practice of Bridge Approach Slabs in US

The current practice of CIP concrete approach slabs in US vary among State DOTs with respect to the following parameters: slab length, slab thickness, concrete cover, and top and bottom longitudinal and transverse reinforcement. Thiagarajan *et al.* (2010) performed a comprehensive review of approach slab practices in US states DOTs to develop approach slab design and detailing recommendations and perform cost analysis. Below is a summary of ranges of the different design parameters:

1. Span length ranges from 10 ft. to 33 ft.
2. Slab thickness ranges from 8 in. to 17 in.
3. Concrete cover ranges from 1 in. to 4 in.
4. Bottom longitudinal reinforcement ranges from #5 @ 8 in. to #10 @ 6.5 in.
5. Top longitudinal reinforcement ranges from #4 @ 18 in. to #7 @ 12 in.
6. Bottom transverse reinforcement range from #4 @ 24 in. to #6 @ 6 in.
7. Top transverse reinforcement ranges from #4 @ 18 in. to #6 @ 12 in.

Table 1 summarizes the current approach slab detailing for five different U.S. states that represent different geographic and climatic regions: California Department of Transportation (Caltrans); Washington State Department of Transportation (WsDOT); Missouri Department of Transportation (MoDOT); Iowa Department of Transportation (Iowa DOT); and Colorado Department of Transportation (CDOT).

Table 1. Different approach slab designs

State DOT		Caltrans (Type N)	WSDOT	MoDOT	Iowa DOT	CDOT
Span (ft.)		30	25 (at short edge)	20	20 (centerline)	20
Slab thickness (in.)		14	13	12	12	12
Main longitudinal reinforcement	Top	#5 @18″	#6@5″	#5@12″	#6@12″	#4 @18”
	Bottom	#10 @6″	#8@5″	#6 @5″	#8 @12″	#6 @6″
Concrete cover (in.)	Top	2	2.5	2	2.5	3
	Bottom	2	2	2	2.5	3
Transverse reinforcement	Top	#5@18″	#5 @18″	#5 @12″	#5 @12″	#5 @12″
	Bottom	#5 @6″	#5@9″			
Abutment joint type (Fig. 2)		Vertical #5@9″	45° bent #5@12″	Horizontal #5 @12″	Vertical Stainless-Steel Dowel	Horizontal #5 @12″
Other edge joint type		Horizontal #6 dowel @12″ to paving	Horizontal 1.5 in. diameter dowel bar @ 18 in. to paving	Resting on sleeper slab		

Chee (2018) conducted a survey covering 23 US DOTs, including NDOT, located in middle to east coast of US to collect data about the performance of existing approach slabs. The survey covered the primary issues with approach slab, cracking direction and location, and methods to minimize approach slab cracking. Most of the surveyed DOTs stated that settlement and concrete cracking are the top two problems with approach slabs. Transverse and longitudinal cracks are the common crack patterns in most states while few states reported diagonal cracking in addition. The methods recommended to minimize approach slab cracking include increasing thickness and/or reinforcement; limiting slab dimensions by adding joints; treating approach slabs similar to decks with respect to curing; and using sleeper slab with piles as shown in Fig. 3.

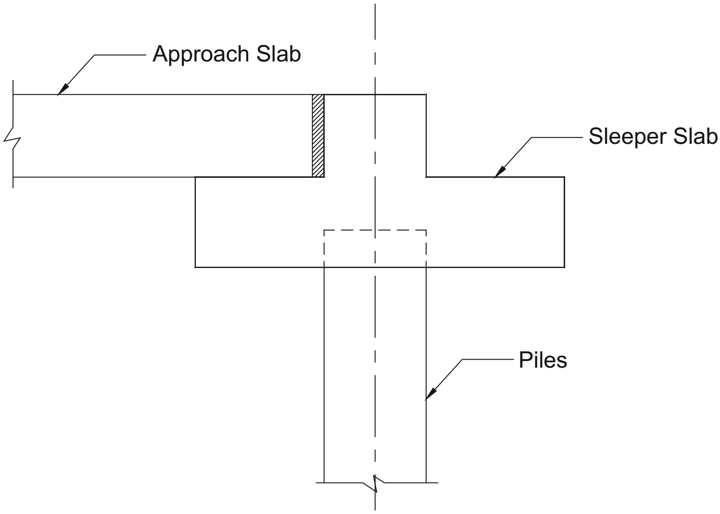


Fig. 3. Sleeper slab with piles.

3 Nebraska Department of Transportation (NDOT) Practice

A 14 in. approach slab is specified by NDOT to be simply supported by the abutment and the grade beam as shown in Fig. 4 (BOPP 2016). The grade beam is a reinforced concrete beam parallel to the abutment, supported by piles to minimize settlement, and extended to cover sidewalk. The minimum span length of approach slab is 20 ft. measured at the centerline of roadway from the end of bridge floor to centerline of grade beam. The main longitudinal reinforcement is #8 @ 5 in. and #5 @ 12 in. for bottom and top reinforcement, respectively. The transverse reinforcement is #5 @ 12 in. and #5 @ 8 in. for top and bottom reinforcement, respectively. The main longitudinal reinforcement cover is 2.5 in. and 3 in. for top and bottom reinforcement, respectively. The approach slab is anchored to the abutment using #6 bar bent at 45 deg. inside the approach slab with adequate development length and spaced at 12 in.

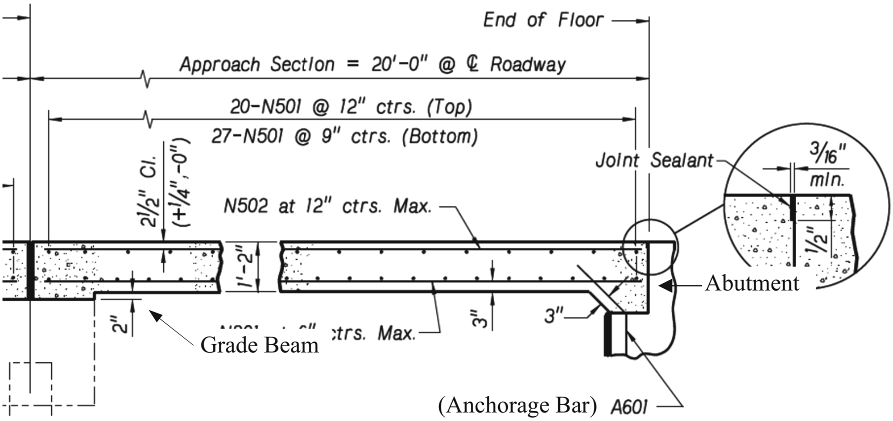


Fig. 4. Current NDOT bridge approach slab (BOPP 2016)

Figure 5 shows the approach slab cracking patterns in two bridges in Nebraska. The figure shows several longitudinal cracks extending from the abutment and grade beam ends towards the middle of approach slab.

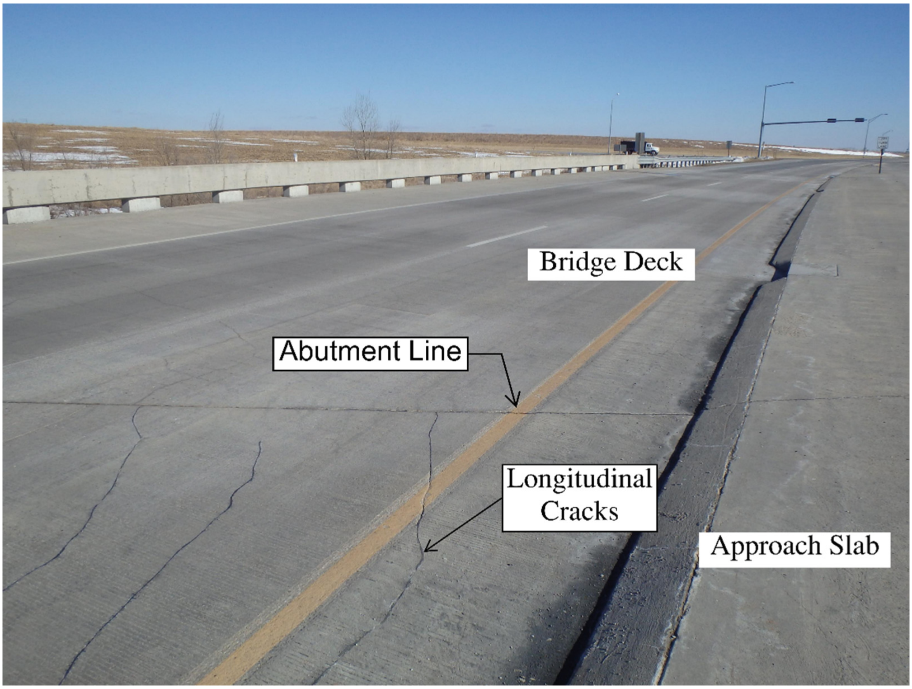


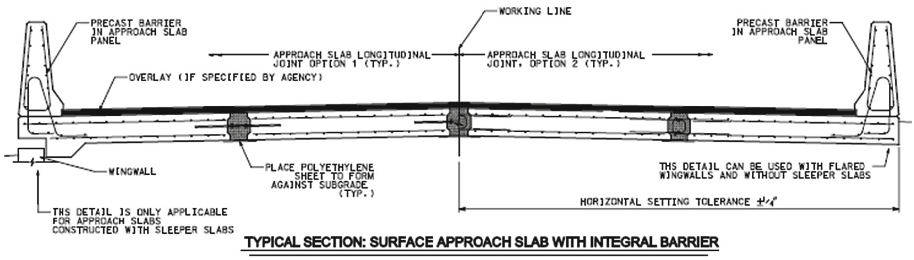
Fig. 5. Example of approach slab cracking in Nebraska

4 Precast Bridge Approach Slab

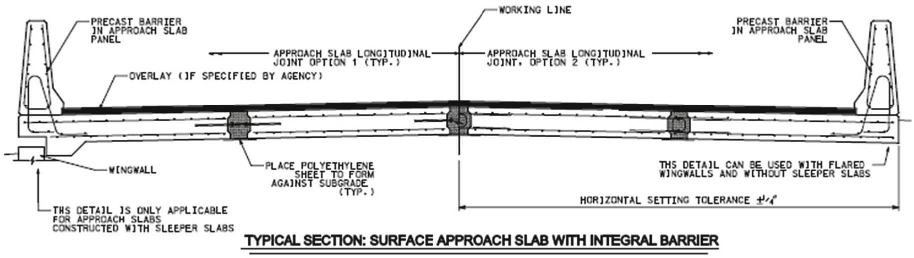
CIP concrete approach slabs face several challenges, such as unexpected weather conditions and low-quality control during placing and curing. These challenges could severely affect the performance of CIP concrete approach slabs and eventually lead to cracking. Precast concrete approach slabs minimizes these challenges as they are fabricated in a controlled environment under high-quality control that ensures reaching the desired properties. Merritt et al. (2007) reported the replacement of the approach slab of a bridge on Highway 60 near Sheldon, Iowa by eight precast concrete panels with dimensions of 20 ft. × 14 ft. × 12 in. The precast slabs were post-tensioned in both direction using 0.6 in. grade 270 7-wire stand @ 24 in. and a flowable grout was used to fill the ducts. The slab placement started from the bridge abutment after fitting #8 stainless steel anchorage bars in sleeves formed in precast panels. Each precast panel had #8@12 in. and #6@24 in. as bottom and top longitudinal reinforcement, respectively, and #5@12 in. for top and bottom transverse reinforcement. A key-shape transverse joints were used to connect the panels using epoxy after aligning the longitudinal post-tension ducks. However, the longitudinal joint was filled with grout. The under-slab was filled by pumped grout. The construction faced some challenges such as aligning panels with skewed bridge floor and post-tension ducts, and panel end damage during post tensioning. Four 12 in. thick precast concrete slabs were used in a replacement bridge over Big Brown Creek on River Road (S-86) in Union County, South Carolina. The bridge was 37.25 ft. wide and had a skew angle of 38°. These panels were tested and long-term monitored by Ziehl et al. (2015). First, the back-fill was replaced by #789 stone and cover by a 6 in. thick roller compacted macadam as a sub-base material and polyethylene moisture barrier. Then, a CIP ledger was cast with vertical dowel bars. The approach slab panels were placed, starting from exterior panel, after filling the anchorage dowels in formed sleeves. A grout was used to fill the dowel sleeves after installing the panels. The longitudinal joints between panels had longitudinal 2#6 bars tied to top and bottom of overlapped #5-U shaped bars and filled with concrete. Separation cracks were noticed at the abutment joint in the 2.5 in. thick asphalt layer placed over approach slab.

In 2012, Precast/Prestressed Concrete Institute (PCI) published guidelines presenting suggested design and details for precast concrete approach slabs. Two typical precast designs were presented simulating two cases: surface approach slab and sub-surface approach slab, as shown in Fig. 6. Also, the guidelines contain different joint configurations for longitudinal and transverse directions. Below are the requirements for using the proposed designs and details:

- Maximum width of 12 ft. for each panel including any projecting reinforcement
- Maximum weight of 100 kips
- Minimum concrete compressive strength 5,000 psi
- Using shrinkage compensating admixture for site cast concrete
- Grout is used for small voids (flowable, same strength of concrete)

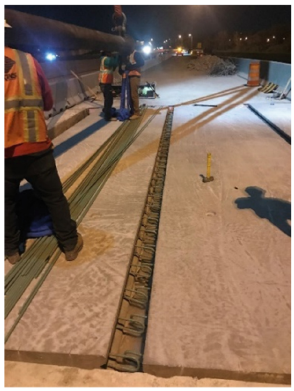


(a)



(b)

Fig. 6. PCI precast approach slab; (a) surface approach slab and (b) sub-surface approach slab (PCI 2012)



(a) **(b)**

Fig. 7. Precast concrete approach slabs in Nebraska; (a) Belden-Laurel Bridge Project and (b) I-680/West Center Bridge Project

NDOT had successfully implemented the precast approach slab concept in two projects. The first project is replacing the Belden-Laurel bridge on U.S. 20 over Middle Logan Creek in Cedar County, NE in 2018. The project was the first bridge constructed entirely using prefabricated components, including approach slabs, for accelerated bridge construction in Nebraska. The bridge width was 42 ft. 8 in. Four approach slab panels were used to construct each approach slab of the bridge. Longitudinal joints filled with High Early Strength Concrete (HESC) connected the precast panels and then Ultra-High Performance Concrete (UHPC) were used to fill the transverse joint between panels and bridge deck as shown in Fig. 7. Finally, Flowable fill was pumped underneath the panels to fill the gaps between the panels and backfill. The second project is the replacement of I-680/West Center Road Bridge. The replacement was conducted in two stages, each stage replaced half of the approach slabs using three precast concrete panels and precast concrete rail. Panels were prefabricated by the contractor at his yard and transported and placed overnight road closure. Reinforced longitudinal joints were filled with HESC and vertical dowels bars were used to connect the panels to the abutment using 3 in. diameter dowel holes, while horizontal tie bars were used to connect the panels to the paving section. Figure 8 shows construction joints between precast concrete approach slabs and between approach slab and abutment used in Nebraska.

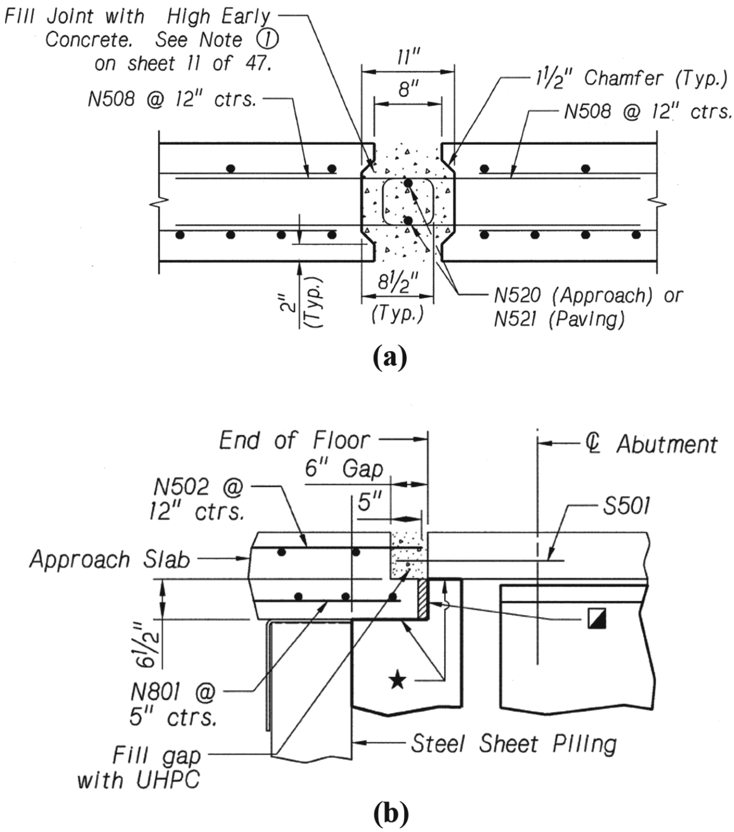


Fig. 8. Construction joints between precast concrete approach slabs in Nebraska; (a) longitudinal joint and (b) transverse joint

5 Analytical Investigation

A parametric study was conducted using Ansys V19 R1 to create a finite element model (FEM) simulating the current practice of approach slab in Nebraska. The properties of an existing bridge in Nebraska were used to create the FEM. The bridge had a skew angle of 14° and the approach slab was 14 in. thick, 43 ft. wide, and 20 ft. span. FEM was used to investigate several parameters including skew angle, volume changes, and approach slab width. The parameters considered in this investigation are shown in Fig. 9. According to BOPP Manual 2016, the required compressive strength for approach slab is 4000 psi., therefore, the cracking stress (modulus of rupture) of normal weight concrete was estimated to be 474 psi according to AASHTO LRFD (2017).

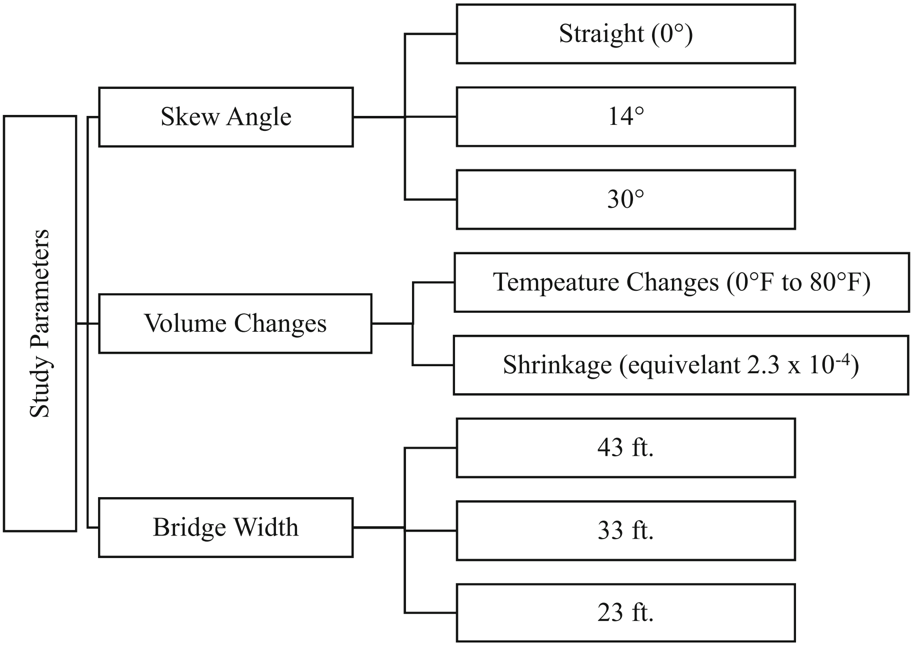


Fig. 9. Parameters considered in the study

The approach slab was simulated using *Solid65* element with an initial dimension as shown in Fig. 10. *Solid65* element allows to simulate slab thickness and rebars, define the cracking and crushing limits, and add the nonlinear material properties. The elements were meshed to a maximum size of 1 ft. to obtain accurate results and parallel to the abutment and slab edge. The joints between approach slab and abutment were simulated as hinge supports every 1 ft. The connection between the approach slab and grade beam was simulated with roller support as there is no anchorage bars and there is no restriction on approach slab horizontal movement. The own weight of the slab was considered in all the cases. The wheel loads were applied as a pressure tire covering 12 in. × 24 in. to fit with the meshing size, which is slightly larger than the 10 in. × 20 in. specified in

AASHTO LRFD (2017). The FEM was solved in material linear behavior to obtain the cracking stresses.

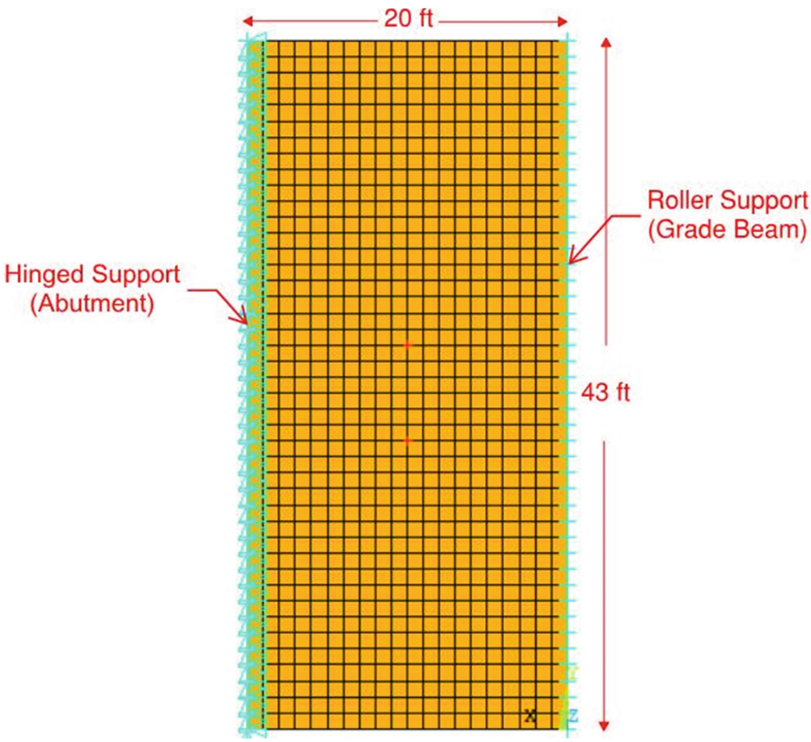


Fig. 10. Finite element model using Ansys V19.

5.1 Skew Angle Effect

Three different bridge skew angles were investigated with placing tandem axle load with impact at 2 ft from the approach slab edge. Figure 11 shows the principle tensile stresses at the top surface of slab due to bridge skew angle. The principle tensile stresses increase at the slab corner with the increase of the skew angle. However, these stresses did not exceed the concrete cracking stress.

5.2 Volume Changes Effect

The effect of volume changes on concrete approach slab was investigated for both concrete shrinkage and uniform temperature change conditions. The concrete shrinkage was calculated according to AASHTO LRFD (2017) Section 5.4.2.3.3 and was determined to be 2.30×10^{-4} at 28 days for the current NDOT curing practices. The temperature changes was determined by AASHTO LRFD (2017) Section 3.12.2.1 procedure A,

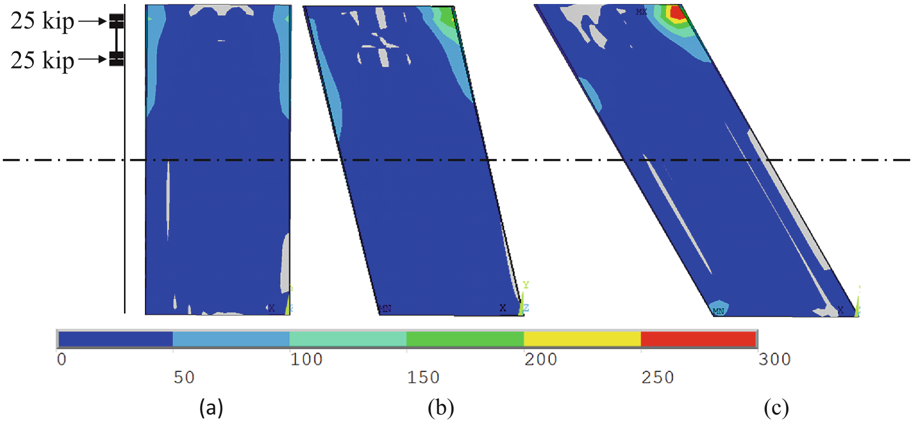


Fig. 11. Effect of skew angle on principle tensile stress at slab top surface (psi); (a) straight (0°), (b) 14°, and (c) 30°

which requires a temperature change from 0 °F to 80 °F. A coefficient of thermal expansion of 6.0×10^{-6} in./in./°F was used for concrete approach slab. Based on the analysis, the uniform temperature change was more critical than concrete shrinkage and, therefore, its effect was investigated for different bridge skew angles. Figure 12 shows the principle tensile stresses at the top surface of slab due to uniform temperature change, which are primarily concentrated along the abutment support line. The obtained tensile stresses are higher than the concrete modulus of rupture and, therefore, results in the observed longitudinal cracking. Figure 13 shows the directions of tension stresses on the top surface of approach slab that explains the cracking phenomena along abutment line.

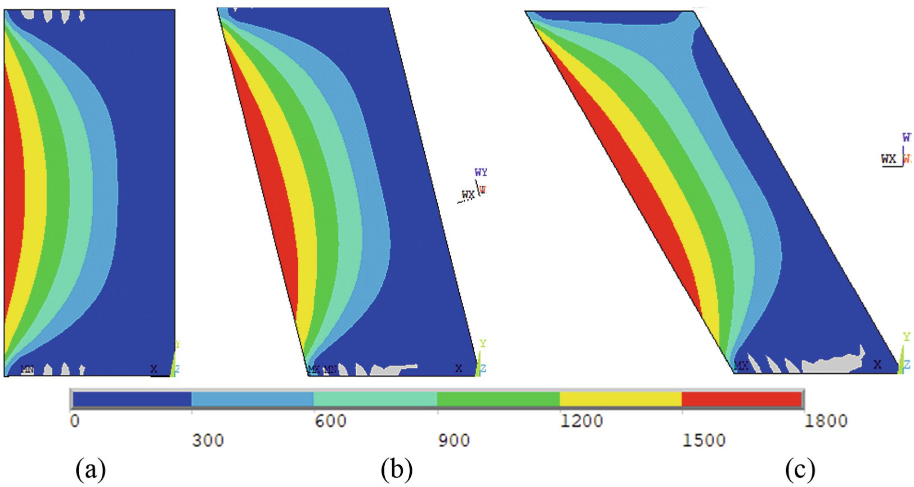


Fig. 12. Effect of concrete shrinkage on principle tensile stress at slab top surface (psi); (a) straight (0°), (b) 14°, and (c) 30°

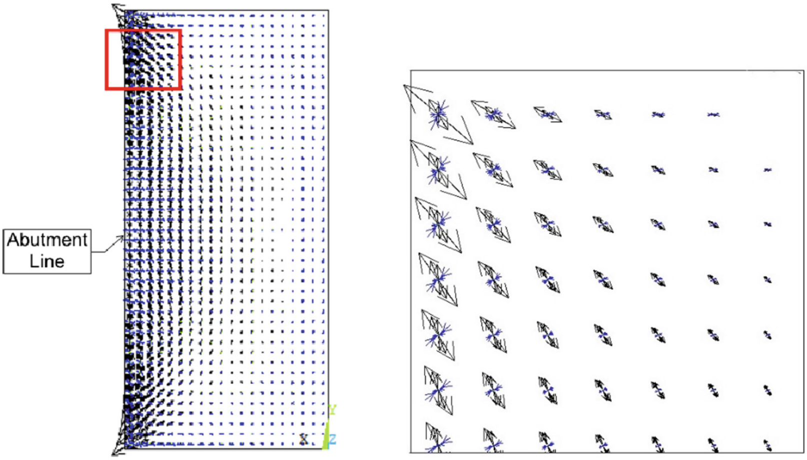


Fig. 13. Directions of tensile stresses at the top surface of approach slab along abutment line

5.3 Bridge Width Effect

The effect of different bridge width on approach slab performance was studied on 14° skewed bridge case. A 23 ft., 33 ft., and 43 ft. approach slab widths were applied to FEM to obtain the maximum stresses in both directions, longitudinal and transverse, at the bottom surface of approach slab. It was found that applying the tandem axle load at the middle of approach slab gave more representative clarification for the bridge width effect. Figure 14 and 15 show the effect of bridge width on longitudinal and transverse stresses at slab bottom surface. Increasing the approach slab width redistributes the

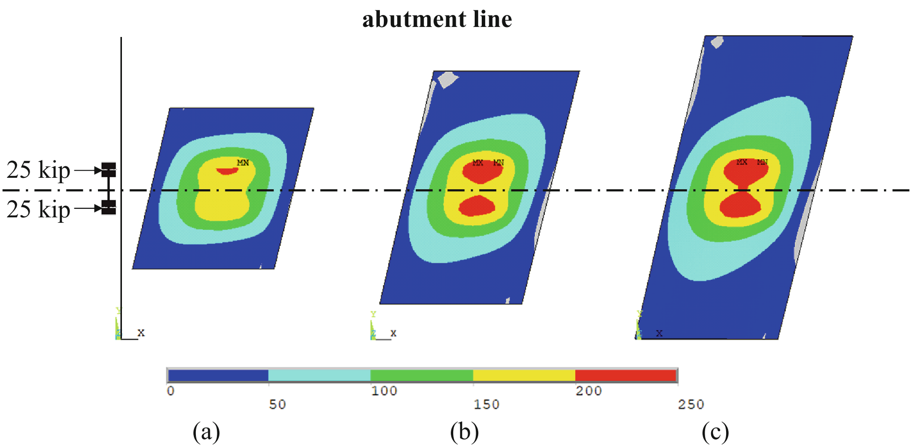


Fig. 14. Effect of bridge width on tensile transverse stresses at slab bottom surface (psi); (a) 23 ft., (b) 33 ft., and (c) 43 ft.

stresses due to wheel load between longitudinal and transverse directions as shown in Fig. 15. This figure shows that the longitudinal stress decrease by 11% and the transverse stress increases by 14.6% when the slab width increases from 23 ft. to 43 ft. So, it can be concluded that the transverse stresses increase with the increase of slab width for the same bridge skew angle which need to be considered in the design.

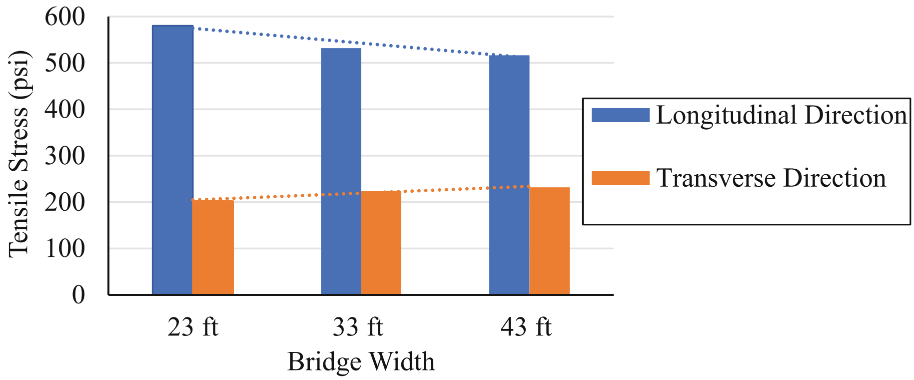


Fig. 15. Effect of bridge width on the tensile stresses' distribution at slab bottom surface for 14° skewed bridge.

6 Conclusions

This paper presents a literature review on the current practices of approach slab in Nebraska and the other DOTs. The causes of approach slab deterioration and its possible solutions were discussed. Also, a parametric study was conduction by finite element modelling. The following conclusions were drawn from this study:

1. The current practices for design and detailing of CIP approach slabs has different parameters with respect to slab length, slab thickness, concrete cover, construction joints and top and bottom longitudinal and transverse reinforcement.
2. Concrete cracking and differential settlement are the two common issues with approach slabs. Using grade beam resting on piles, which is the practice of NDOT, eliminates the settlement problem, however, longitudinal cracking is still a concern.
3. High skew angles result in concentrated tensile stresses at slab top surface at corners under live load.
4. Volume changes due to shrinkage and temperature generates high tensile stresses along abutment line that exceeds the concrete cracking stress. The direction of these stresses explains the cracking phenomena of approach slab along abutment line.
5. The transverse stresses increase with the increase of approach slab width for the same bridge skew angle, which needs to be considered in the design while the longitudinal stresses decrease.

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