INSTRUMENTATION AND MONITORING OF IN-SITU PRECAST CONCRETE APPROACH SLAB SYSTEM WITH NOVEL JOINT DETAIL

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ABSTRACT

The use of full depth precast panels in bridge construction as opposed to cast-in-place approaches is favorable for both time savings and quality control during construction. However, this approach has seen limited implementation due to serviceability (in terms of cracking and settlement) and durability concerns associated with the joints between adjacent panels. In this field study, an improved longitudinal joint detail consisting of interlocking looped reinforcement bars was used to construct precast approach slab systems for a replacement bridge located in Union County, South Carolina. A monitoring program was implemented to assess the performance of the approach slabs during and after construction to aid in further implementation of this system as an alternative to current construction methods. The approach slabs were instrumented with strain and displacement gages and measurements were collected periodically for a period of 18 months. A series of load tests were also performed on the approach slab system. Results of long-term monitoring and load tests indicate the approach slabs are functioning adequately.

Keywords: Accelerated Construction, Assessment and Monitoring, Connections

INTRODUCTION

The use of precast prestressed concrete pavements have been advancing rapidly in the past decade due to a combination of cost and time effectiveness[1]. Precast approach slab systems can be used to replace the current practice of using cast-in-place approach slabs as they offer speed of construction, do not require closure of the bridge for extended period of time waiting for the concrete to reach its specified strength. In addition, the higher quality of the plant-controlled concrete makes the use of these systems cost competitive when life-cycle and maintenance costs are considered. However, the main issue with precast approach slab systems is the serviceability (in terms of cracking and settlement) and durability of the connection between adjacent panels. Previous implementation efforts of precast approach slabs systems included post-tensioning of adjacent panels on-site; such as the Iowa Highway 60[1,2].

This paper provides an overview of the on-site instrumentation, long-term monitoring, and load testing of precast concrete approach slab systems that uses longitudinal connection detail to connect the adjacent slabs. The performance of the precast concrete approach slabs utilized on a replacement bridge over Big Brown Creek on River Road (S-86) in Union County, South Carolina is summarized. The bridge has three continuous spans of Type IV girders, length of 255 feet, skew angle of 38 degrees, and integral end bents.

The approach slabs were fitted with a longitudinal shear key detail consisting of looped interlocking reinforcement bars. The South Carolina Department of Transportation (SCDOT) is considering the use of this structural system in future bridge construction. This research program summarizes the performance of the precast concrete approach slab systems in terms of serviceability (in terms of cracking and settlement). Emphasis is placed on potential changes in long-term behavior of the approach slab systems.

Strain and displacement gages were installed inside the precast approach slabs and on the bridge approach. Concrete cylinders were sampled from each batch of concrete used during the casting of the approach slabs as well as the shear key closures adjoining each slab. The structural behavior of the precast approach slabs was monitored while in service for a period of 18 months after bridge construction was complete. Concrete cylinders were tested for compressive strength and modulus of elasticity. Details regarding the type and location of sensors used for monitoring as well as tasks performed by personnel from the University of South Carolina (U.SC) are summarized.

PRECAST APPROACH SLAB SYSTEM

The bridge consists of two approaches at either side of Big Brown Creek. The south side approach is referred to as the 'Bent One' approach and the north side approach is referred to as the 'Bent Four' approach. Each approach is comprised of four separate precast concrete slabs which are joined with a female to female shear key closure joint. The general layout and labeling scheme of the precast slab system on the Bent One approach is shown in Figure 1. Each approach has two 'exterior' slabs labeled 'A' and 'D' and two 'interior' slabs labeled 'B' and ‘C’. The approach slabs are 12 inches thick and consist of both longitudinal and transverse reinforcing bars located at the top and bottom of the slabs. Interior slabs are identical in size and reinforcing layout and are larger than the exterior slabs. They are situated directly beneath the two traffic lanes with the center shear key joint located directly in the middle of the roadway. The ‘exterior’ slabs are situated at the edges of the roadway. These slabs make up the shoulder of the roadway and also support the bridge parapet walls which were formed after the approach slabs were set in place. The layout of the Bent Four approach is similar to the Bent One approach but the individual slabs are not labeled as no sensors were placed within the precast concrete slabs on the Bent Four approach.

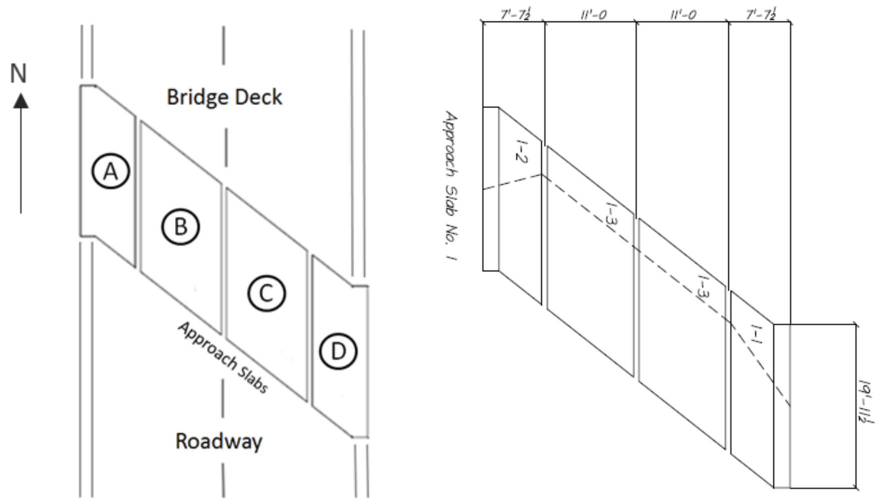

Fig. 1 Layout of precast approach slab system

The approach slabs rest on a macadam (crushed stone) sub-base material and provide a transition from the paved roadway to the deck of the bridge superstructure. The sub-base was roller compacted (relative compaction of 100%) to a depth of six inches. Beneath the sub-base a #789 stone (pea-size gravel) was used for back-filling around the wing walls up to the grade of the roadway. A corrugated pipe drain was provided at the base of the wing wall to allow for proper drainage. A 10 mil polyethylene moisture barrier was placed on top of the sub-base just prior to setting of the approach slabs.

The bridge side edge of each approach slab is seated on a ledger formed into the cast-in-place bridge deck. A photograph of the ledger is shown in Figure 2. Vertical dowel bars are embedded into the cast-in-place ledger and each approach slab has corresponding vertical sleeves embedded near the bridge side edge of the slab. These sleeves are located such that full alignment with the dowels is achieved. Alignment of reinforcing dowels is shown in Figure 2 for the placement of an interior slab on the bridge approach. Dowel sleeves were filled with grout after the approach slabs were set in place.

Fig. 2 Interior approach slab being set with vertical dowel alignment

The precast concrete approach slabs utilized a connection joint detail consisting of interlocking looped (U-bar) reinforcement oriented transversely, relative to the joint, along with a female-to-female shear key as well as two longitudinal reinforcing bars. The purpose of the shear keys is to provide resistance to moving traffic loads by facilitating the transfer of shear forces between adjacent slabs. Shear keys allow the system of discrete panels to react monolithically (as a single piece of reinforced concrete) under applied loadings. The U-bars are spliced with the transverse reinforcement within the precast panel and are 0.625 inches in diameter (No. 5). The two longitudinal reinforcing bars are 0.75 inches in diameter (No. 6), located in the middle of the joint, threaded through the inside of the loop bars, and are tied in at the top and bottom. The loop bars have an even spacing where each panel is out of phase with the adjacent panel by a half space. Photographs showing the interlocking of reinforcement between adjacent slabs and longitudinal reinforcement are shown in Figure 3. The connection joint is intended to transfer and distribute shear and moment between adjacent panels, thereby enhancing strength of the approach slab system while exhibiting satisfactory crack resistance. After the precast concrete approach slabs were set in place, longitudinal bars were tied to the top and bottom loop bars and the shear keys were filled with concrete.

Fig. 3 Interlocking of loop bars after slab placement and (left); shear key connection joint with longitudinal reinforcing bars (right)

After the bridge parapets were placed each approach was covered with asphalt pavement. The asphalt surfacing is 2.5 inches thick and extends up to the cast-in-place bridge deck. Figure 4 shows the bridge after construction was completed.

Fig. 4 Replacement bridge over Big Brown Creek

INSTRUMENTATION

Sensors were placed during fabrication of the precast approach slab segments, just after placement of the approach slabs and prior to casting of the shear keys, and after construction of the parapets. Vibrating Wire Strain Gages (VWSGs), Vibrating Wire Displacement Gages (VWDGs), and Electrical Resistance Strain Gages (ERSGs) were utilized to record strains and displacements due to service level loading conditions as well as long term behavior due to thermal and other effects.

The approach slabs were monitored with the following sensors: six Model 4200 Geokon Vibrating Wire Strain Gages (VWSG), four Model 4420 Geokon Vibrating Wire Displacement Gages (VWDG), and twelve Vishay Micro-Measurements Electrical Resistance Strain Gages (ERSG).

The Bent One approach was instrumented with one VWDG mounted on each parapet and parallel to the direction of traffic, twelve ERSGs, and six VWSGs. A plan view of the Bent One approach instrumentation is shown in Figure 5 and a cross-section view is shown in Figure 6. An expanded schematic of the details shown in the figures can be found in Ziehl et al. 2015[3].

The Electrical Resistance Strain Gages (ERSGs) were welded onto No. 4 sister bars and placed into the precast slabs during casting. These reinforcing bars, each instrumented with two gages, were constructed with sufficient length such that the bar was fully developed at both ends. In the exterior slabs a single bar was located closest to the existing reinforcement nearest to the closure pour connecting the interior slabs. Each interior slab was instrumented with sister bars at either side of the slab. In each of the four slabs sister bars were placed parallel to the direction of traffic at a distance of approximately four feet from the bridge side edge of the approach slab. Sister bars were placed and tied in plane with the bottom mat reinforcing bars.

A single Vibrating Wire Strain Gage (VWSG) was placed in each closure pour perpendicular to the direction of traffic flow to measure concrete strain in this direction. Additional VWSGs were located within the precast slabs at the locations shown in Figure 5 and Figure 6. These gages were situated parallel to the direction of traffic flow at a distance of approximately four feet from the bridge side edge of the approach slab. VWSGs were placed and tied in plane with the bottom mat reinforcing bars.

Both Bent One and Bent Four were instrumented with two Vibrating Wire Displacement Gages (VWDGs) placed on the parapets. The gages on Bent Four were placed in the same manner and location as those placed on the Bent One approach and are shown in Figure 5 (plan view) and Figure 6 (cross-section). All sensor wires were routed to and stored in enclosure boxes.

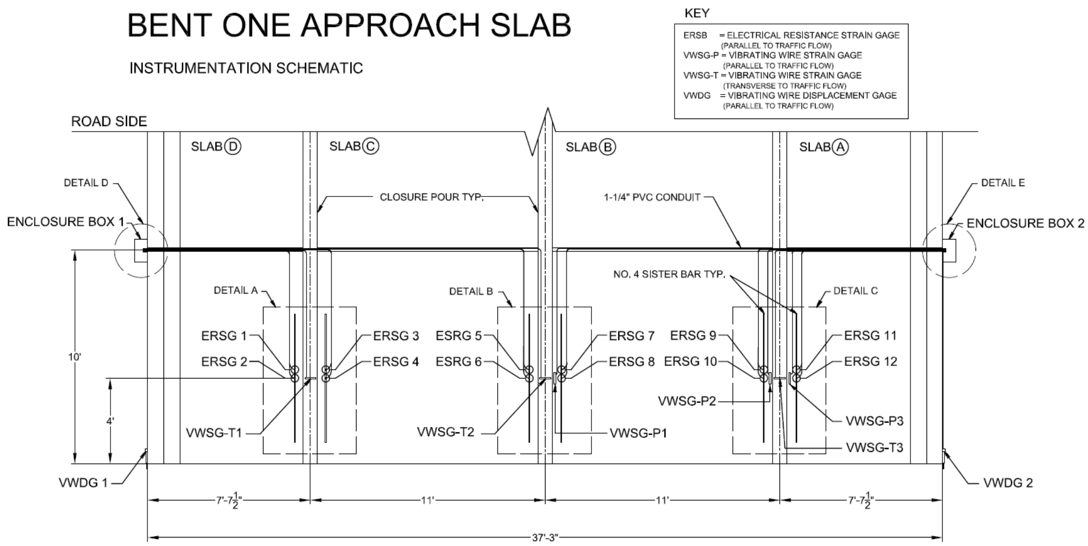

Fig. 5 Bent One approach slab schematic - plan view

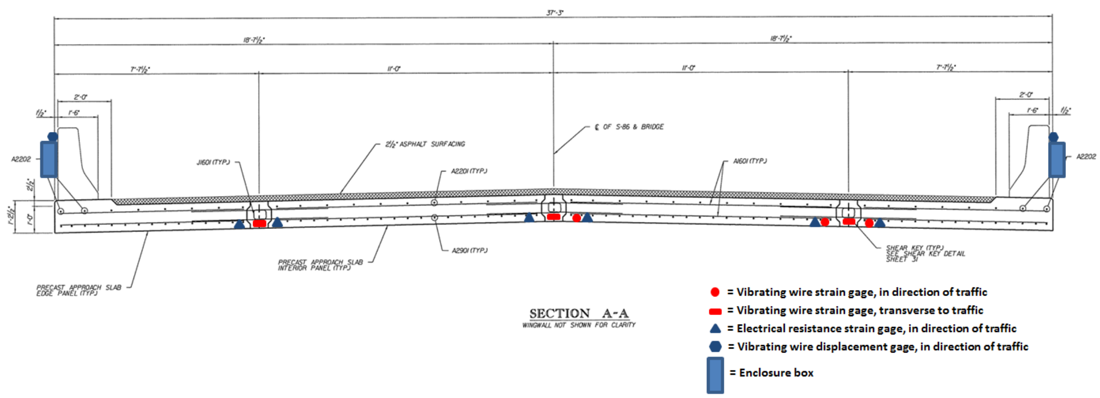

Fig. 6 Bent One approach slab schematic - cross-section

DATA ACQUISITION

Data was acquired continuously during dynamic loading tests and discretely for long term measurements and static loading tests. In addition to data gathered through the instrumentation detailed in this report visual observations were recorded during each site visit. Visual observations include monitoring of cracking as well as other signs of distress. Visual observations are described in the results section of this report.

Data acquisition systems included Vishay Micro-Measurements P3 strain indicators, a Vishay System 7000 data acquisition system, and a Geokon GK-404 vibrating wire readout system. The GK-404 and P3 systems were used for discrete measurements. The GK-404 was used to acquire data from VWSGs and VWDGs and the P3 was used to acquire data from the ERSGs. The P3 strain indicator has a one μ-strain resolution with +/- 0.1% accuracy.

The System 7000 and Strain Smart software were used to acquire data continuously from the ERSGs during dynamic loading. The 7000 System has accuracy of +/- 0.05% of full scale. Because the dynamic loads were applied over a brief period of time the higher data acquisition frequency of the System 7000 was needed for this loading scenario. A data acquisition frequency of 10 Hertz was used during the dynamic load testing.

LONG-TERM READINGS

Initial readings were taken before and just after casting of the concrete approach slabs, just after bridge completion, and intermittently as shown in Table 1 thereafter. The data set includes initial readings and significant events during the slab setting process such as transportation of the approach slabs and filling of the shear key closures.

DYNAMIC AND STATIC LOADING TESTS

Strain measurements were recorded periodically during dynamic and static loading of the Bent One approach slabs. Continuous readings were recorded for dynamic loading events using the Vishay Micro-Measurements System 7000 and Vishay Micro-Measurements Strain Smart software. Discrete measurements were recorded for the static loading events using the Geokon GK-404 portable readout system.

Table 1 Data acquisition schedule

Sensor	Description						
VWSG	Prior to casting	After casting	After placement	3 months*	6 months*	13 months*	18 months*
VWDG	N/A	N/A	After placement	3 months*	6 months*	13 months*	18 months*
ERSG	Prior to casting	After casting	After placement	3 months*	6 months*	13 months*	18 months*

**After completion of bridge*

EXPERIMENTAL PROGRAM

MATERIAL TESTING

Concrete cylinders were sampled from each batch of concrete used in casting the approach slabs and the shear key closures. These cylinders were used to determine compressive strength and modulus of elasticity of the concrete. A total of 15 cylinders were collected for each batch of concrete to provide three specimens for testing compressive strength at 7, 14, 28, and 56 days and 3 specimens for modulus of elasticity testing at 56 days. The approach slab system required several separate batches of concrete: Batch 1 for the casting of approach slab 'B', Batch 2 for the casting of approach slab 'C', Batch 3 for casting of approach slabs 'A' and 'D', and Batch 4 for the shear key closures. Slump tests were also performed on each batch of concrete. Figure 7 shows concrete compression testing in progress and the modulus of elasticity test setup.

Fig. 7 Compressive strength testing (left); modulus of elasticity testing (right)

Concrete compressive strength testing was performed in general conformance with ASTM C39 / C39M- 12a[4]; modulus of elasticity testing was performed in general conformance with ASTM C469/C469M[5]; and sampling of concrete and slump testing were performed in general conformance with ASTM C31- 12[6] and ASTM C143- 12[7].

LONG-TERM MONITORING

Discrete readings from VWSGs, VWDGs, and ERSGs were recorded on-site in accordance with the data acquisition schedule. Strain and displacement measurements shown are relative to the initial readings. For VWSGs and ERSGs the initial reading is considered as the reading taken when instruments were tied securely into reinforcing cages just prior to concrete placement. For VWDGs the initial reading was recorded just after the installation of the gages on the outside of the bridge parapets. Vibrating wire based readings have been corrected for effects due to temperature variation and electrical resistance based sensors are corrected for the effect of cable gage length. Photos showing collection of data for VWSGs and ERSGs are shown in Figure 8.

Readings taken for long-term monitoring using ERSGs were variable. Due to space restrictions, data from the ERSGs is reported for dynamic load testing only as described in the following section.

Fig. 8 Strain readings recorded with Vishay P3 strain indicator

LOAD TESTING

Load tests were conducted during the on-site visits. Dynamic and static forces were applied to the precast approach slabs positioned on the Bent One approach using loading trucks of known weight and dimensions made available and operated by the SCDOT. Two load trucks were supplied for each load test. Three load tests were conducted at discrete intervals (6, 13, and 18 months after bridge completion).

The axle weights and dimensions for each load truck are shown in Table 2 and Table 3. Each load truck had a total weight of approximately 45,000 pounds and all trucks had similar dimensions.

Table 2 Weight of loading trucks

6 months after bridge completion		
Truck	Front Axle (pounds)	Rear Axle (pounds)
1	10,340	33,580
2	10,620	34,560
13 months after bridge completion		
1	11,180	36,400
2	11,210	36,470
18 months after bridge completion		
1	10,300	34,000
2	10,900	34,480

Table 3 Loading truck dimensions

Load Truck Wheel/Axle Dimensions (inches)				
Wheel Base: front to 1st rear	Wheel Base: front to 2nd rear	Wheel Track	Tread Width: single front tire	Tread Width: double rear tire
125	178	95	9	23

DYNAMIC LOAD TESTING

Strain measurements from the ERSGs were recorded continuously while the Bent One approach slab system was subjected to dynamic loading. A series of low-velocity and high-velocity passes were made by the load trucks on each approach lane. For the low-velocity passes the driver was instructed to travel over each approach lane separately, in the direction of normal traffic flow, at a speed of approximately 5 mph. The drivers were instructed to keep the trucks in the center of the traffic lane during the pass. High velocity passes were made in a similar manner, but the speed of travel was increased to 45 mph.

ERSGs within approach slabs 'A' and 'B' on the left side of Bent One were monitored while the load truck traveled in the southbound lane over the approach. These measurements are referred to as 'Load Case 2' in the schematic shown in Figure 9. ERSGs within approach slabs 'C' and 'D' on the right side of Bent One were monitored while the load truck traveled in the northbound lane over the approach. These measurements are referred to as 'Load Case 1' in the schematic shown in Figure 9. Each approach was loaded and monitored three times as described above for the low-velocity and high-velocity passes.

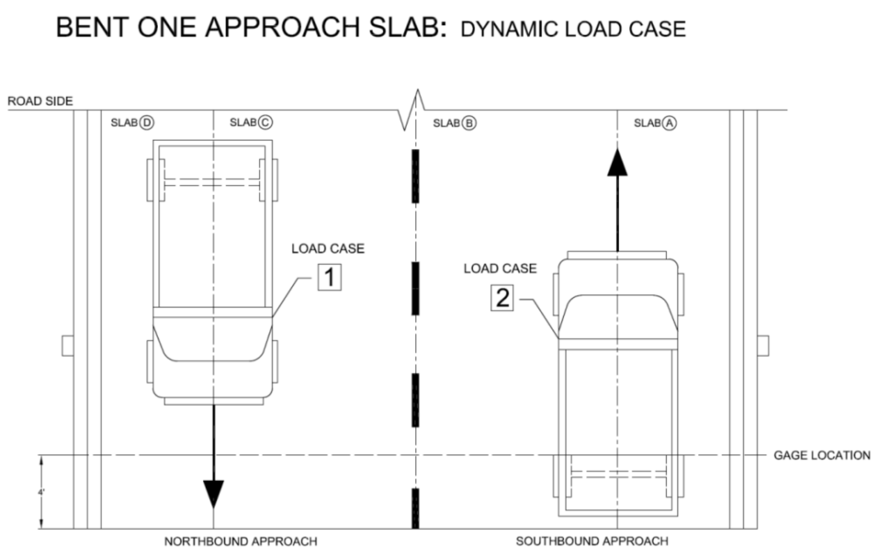

Fig. 9 Dynamic load case schematic

STATIC LOAD TESTING

Strain measurements from the VWSGs were recorded while the Bent One approach slabs were subjected to static loading. Loading trucks were parked with rear axles directly over the strain gage locations for approximately five minutes while measurements were recorded manually from the VWSGs. Each approach was loaded and monitored separately. A schematic showing the position of each truck and labeling of the approach slabs is shown in Figure 10. Measurements from the VWSGs within approach slabs 'A' and 'B' and the shear key closures were collected while the load truck was parked in the south bound lane with the rear axle located directly over the gage locations (a distance of four feet from the bridge side edge of the approach slabs). These measurements are referred to as 'Load Case 4' in the schematic. Measurements from VWSGs within the shear key closures were recorded while the load truck was parked in the north bound lane with the rear axles located directly over the strain gages (a distance of four feet from the bridge side edge of the approach slabs). These measurements are referred to as 'Load Case 3' in the schematic. Each approach was loaded three times with initial readings collected prior to each loading.

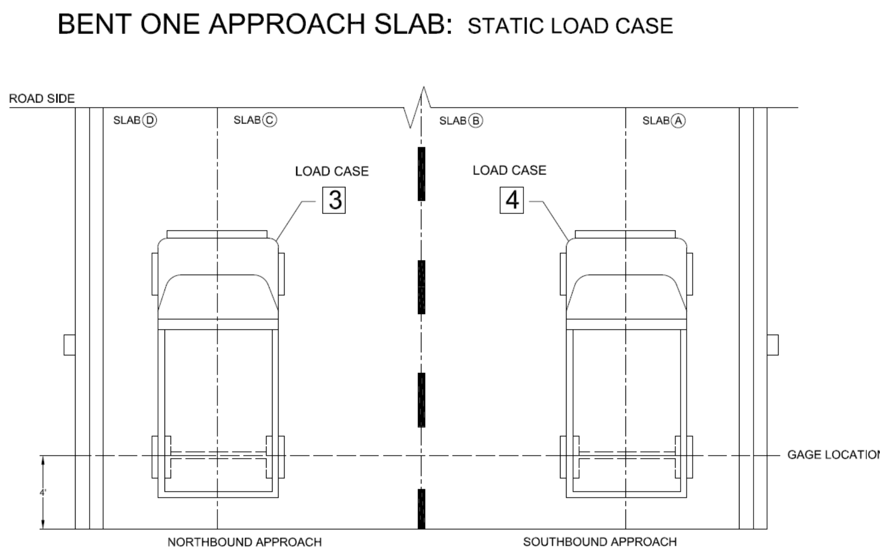

Fig. 10 Static load case schematic

RESULTS

CONCRETE PROPERTIES

Compressive strength test results at 7, 14, 28, and 56 days along with modulus of elasticity (E_c) results for the precast concrete approach slabs are shown in Table 4. Results of individual specimens are provided in Ziehl et al. 2015[3].

The concrete properties were used to determine the cracking strains for concrete under tension or compressive forces. From the ACI 318 building code[8] the tensile rupture stress (f_r) for concrete may be taken as:

$$f_r = 7.5\lambda\sqrt{f_c'} \qquad \text{(ACI 318-14}^{8}\text{)}$$

Where λ, a modification factor for light-weight concrete, is equal to 1.0 for normal weight concrete and f'_c is the 28 day compressive strength of the concrete. This relationship can be used to estimate the tensile rupture stress of the concrete. Using the relationship between stress and strain, given by the modulus of elasticity (E_c), the tensile rupture strains can be estimated for each batch of concrete (Table 4). The tensile rupture strains (ε_r) for the concrete used in the approach slab systems are on the order of 150 µ-strain.

Based on commentary from ACI 318, the compressive strain at ultimate stress (ε_c), where significant cracking begins to occur, is between 1,500 to 2,000 µ-strain. For the purposes of this paper, a value of 2,000 µ-strain will be considered the cracking strain for areas of the approach slab system in compression. The values of compressive cracking strains are also shown in Table 4.

Table 4 Concrete material properties for precast approach slabs system

Approach	B	C	A, D	Closure pour
7-days comp. strength (psi)	7430	7000	6660	4210
14-days comp. strength (psi)	8300	8630	7680	4840
28-days comp. strength (psi)	9660	9050	8390	5200
56-days comp. strength (psi)	10640	10650	9680	5400
56-days modulus (psi)	5.67×10^6	5.73×10^6	5.70×10^6	3.18×10^6
Tensile rupture stress (psi)*	770	770	740	550
Tensile rupture strain (µ-strain)*	136	135	129	170
Maximum comp. strain (µ-strain)*	2000	2000	2000	2000

**calculated value for purposes of comparison*

LONG-TERM MEASUREMENTS

Vibrating Wire Strain Gages

Strain and temperature measurements collected from VWSGs in approach slabs 'A' and 'B' and within the shear key closures were recorded at different points in time occurring during instrumentation and construction of the bridge approach. Plots corresponding to the data are shown in Figure 11 through Figure 13, except for temperatures related to curing which were emitted from the figure. To assess overall performance of the approach slab system the strain readings collected during the first 18 months of service are considered relative to measurements recorded 3 days after casting. At this time (3 days after casting) the concrete was hardened and the approach slabs were fully supported by rigid steel decks in the precast yard. In similar fashion, strain readings collected during the first 18 months of service from

VWSGs located in the shear key closures were compared with strain readings collected immediately after concrete was placed in the closures.

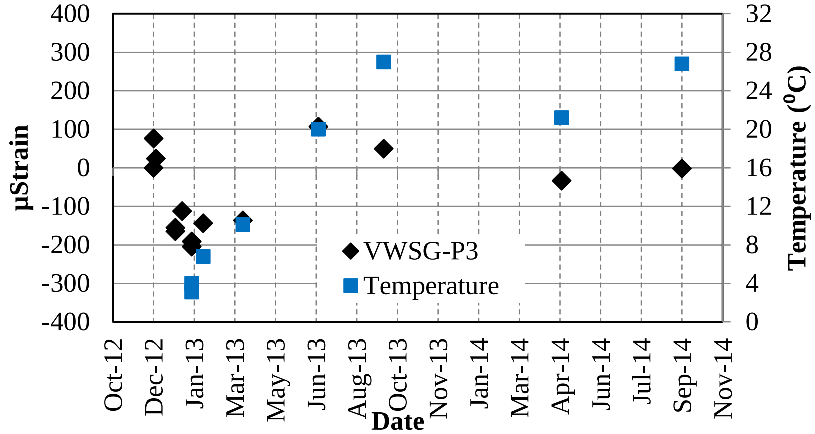

Fig. 11 Vibrating wire strain gage measurements - approach slab 'A'

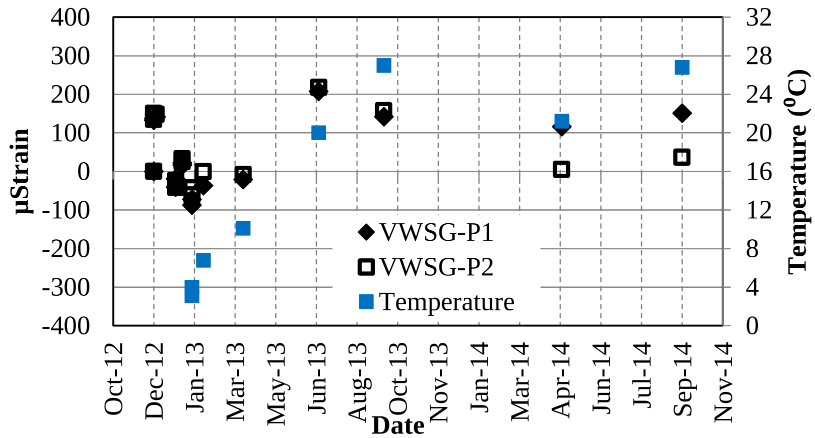

Fig. 12 Vibrating wire strain gage measurements – approach slab B

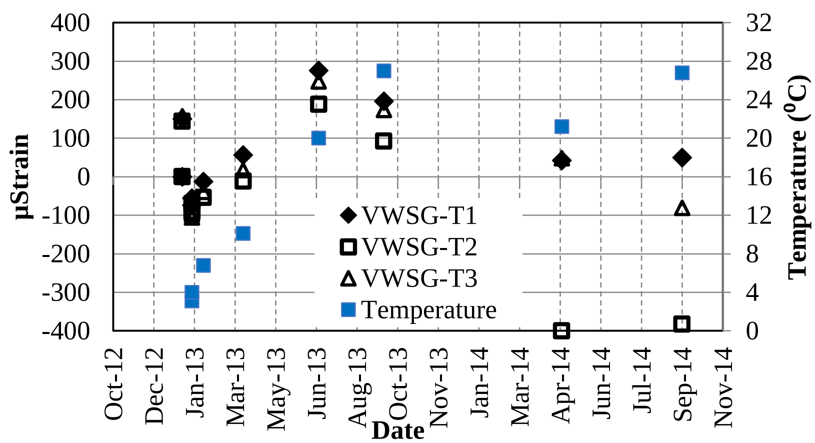

Fig.13 Vibrating wire strain gage measurements – shear key closures

Strain readings collected from VWSGs within the approach slabs are significantly less than the expected tensile rupture strains for the concrete approach slab system. For VWSGs placed within the approach slabs, the maximum measured tensile strain was 83 µ-strain relative to the strain conditions three days after the approach slabs were cast. All three VWSGs within the approach slabs showed tensile strains during the first six months of monitoring. At 18 months, VWSG P3 in slab 'A' and VWSG P2 in slab 'B' showed compressive strains relative to the strain conditions three days after the approach slabs were cast.

Strain readings collected from VWSGs placed within the shear key show that the maximum measured tensile strain was 126 µ-strain relative to the strains occurring immediately after concrete placement. All VWSGs within shear key closures showed compressive strains after 18 months of testing. Overall strains within shear key closures are slightly larger than the strains occurring within the approach slabs but less than the expected rupture strains. It is noted that the changes in long-term strain measurements are related to temperature, shrinkage and creep effects. For example, the strains of VWSG-T1 are low in January which has low temperature as compared to August which has high temperature. Strain measurements collected from VWSGs within both the precast approach slabs and the shear key closures are within tolerable limits for cracking of the concrete.

Vibrating Wire Displacement Gages

Displacement measurements collected from all four VWDGs on Bent One and Bent Four approaches show similar trends with respect to initial readings as shown in Figure 14 and Figure 15. The total displacement of the VWDGs from the initial reading up to 18 months of service ranges from approximately -0.06 to 0.16 in. The largest displacement was observed for VWDG 3, which is located on the Bent Four approach. After 18 months of service VWDGs 2 and 3 exhibited extension relative to the initial reading whereas VWDGs 1 and 4 showed contraction relative to the initial reading. This indicates that the bridge has slightly rotated relative to its initial position.

Relatively small changes can be observed in the displacement readings before and after the cover plate installation. These changes are not thought to be a result of displacement of the bridge approaches and the movements described above take into account the differences between displacement before and after the cover plates were installed. It is difficult to identify with certainty the cause of these small variations. A reasonable conclusion is that during the drilling of holes, which house the anchor bolts by which the cover plates are attached, the displacement gages may have been disturbed by the vibration of the hammer drill. The anchor holes for the cover plates are fairly close to the anchors which attach the displacement gages to the parapet. However, these changes are small, ranging from 0.002 in. to 0.02 in., and are accounted for because they are measured immediately before and immediately after the installation.

The displacements measured from VWDGs on Bent One and Bent Four approaches are relatively small and show trends that are concurrent with one another. Because readings from the VWDGs are small (maximum displacement of 0.16 in.) it is reasonable to conclude that movement or settlement of the approach slabs relative to the cast-in-place bridge deck are also small.

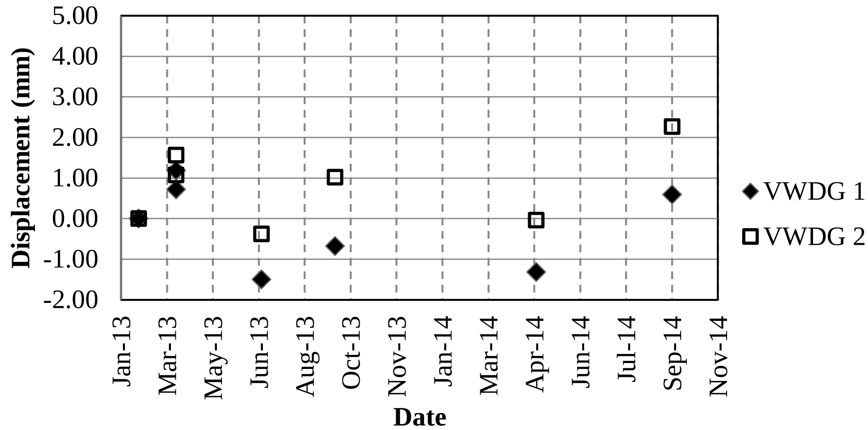

Fig. 14 Vibrating wire displacement gage measurements – Bent One

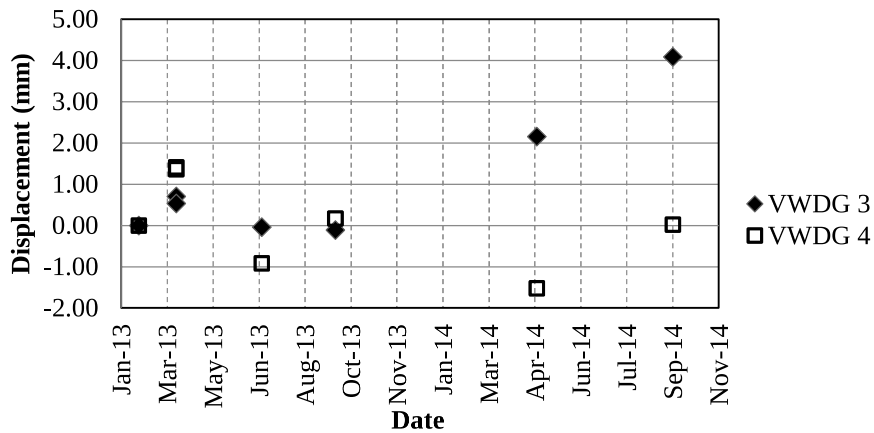

Fig. 15 Vibrating wire displacement gage measurements – Bent Four

LOAD TESTING

Dynamic Loading

Two dynamic load tests were conducted (instead of three dynamic load tests as originally planned) because the wires were vandalized prior to the second scheduled load test. Results from the dynamic load tests on the Bent One approach at six months and 18 months after bridge completion, respectively, were mixed between Load Cases 1 and 2. The Load Case 2 tests for both 5 mph and 45 mph were consistent for each case for both load tests. However, the Load Case 1 tests for both 5 mph and 45 mph were less coherent. Figure 16 shows the results for one dynamic load test, additional plots are provided in Ziehl et al. 2015[3].

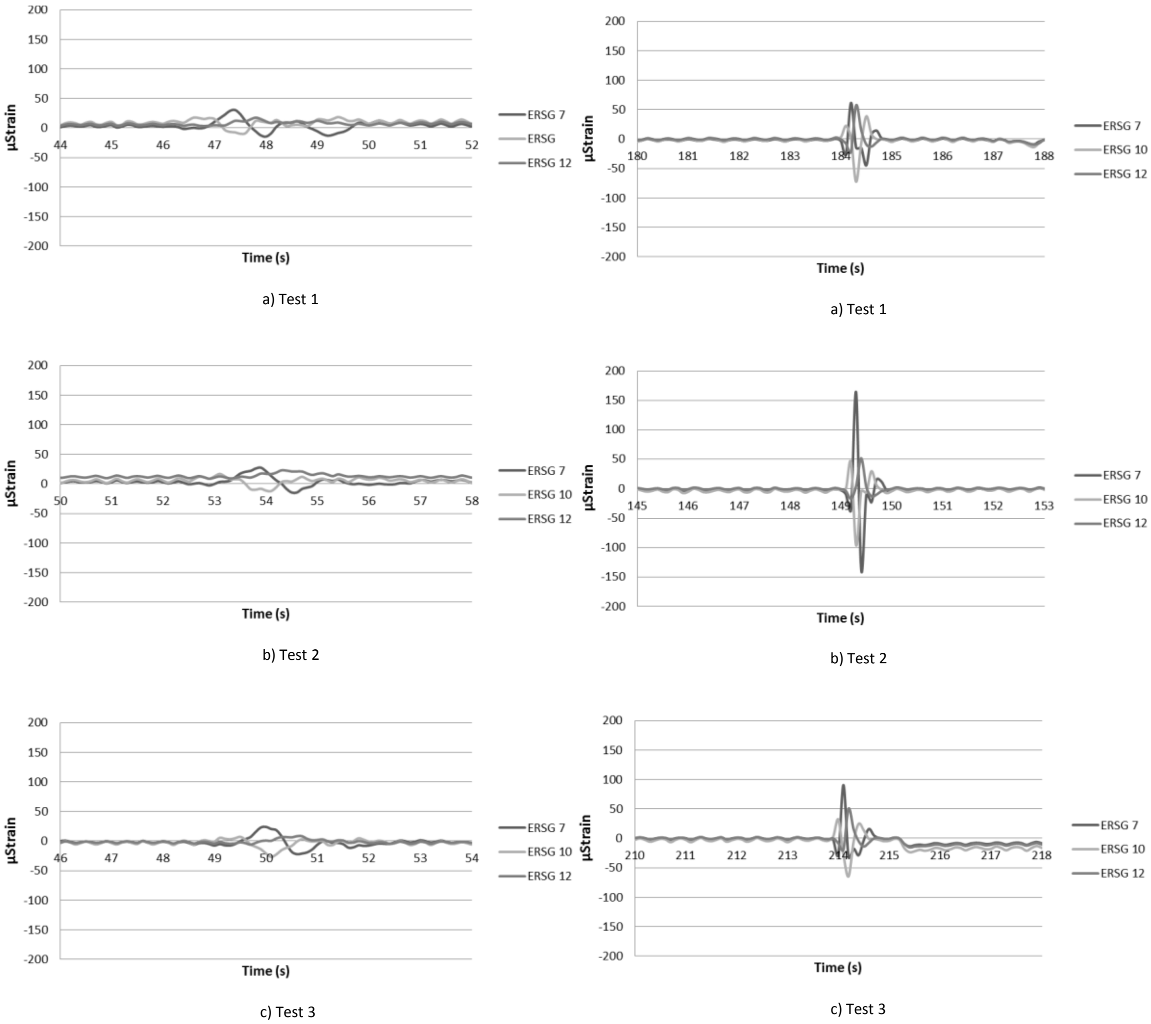

Fig. 16 First load test: Load Case 2, 5 mph pass (left) and 45 mph pass (right)

For the first load test, Load Case 2, the strain profiles of individual tests for the 5 mph passes are very similar. The largest strains were recorded from ERSG 7, located near the center shear key closure at the middle of the roadway. Very similar strain magnitudes were recorded for both ERSG 10 and 12 which are located next to the shear key closure adjoining approach slabs ‘A’ and ‘B’. Maximum and minimum strain values of 30 and 15 µ-strain were typical for each test. These strains are well below the calculated rupture strains for the precast concrete approach slab systems. The Load Case 2 strain profiles for each of the 45 mph tests are similar but show some variations in magnitude. Once again the largest strains occurred in sensor ERSG 7, located near the center shear key closure at the middle of the roadway. ERSG 10 and 12, located next to the shear key closure adjoining approach slabs ‘A’ and ‘B’, experienced lower strains that were similar to one another. The maximum strain for the series of tests was around 160 µ-strain while the minimum strain (based on the largest strain excursion for each gage) was around 50 µ-strain. During Test 2 the maximum strain recorded on ERSG 7 exceeded the expected rupture strains by approximately 50 µ-strain. However, all the other strain readings for each of the Load Case 2 tests are below the expected rupture strains of the precast concrete approach slabs.

For the third load test, Load Case 2, similar results were achieved for the 5 mph passes with a maximum relative strain recorded at ERSG 7 of 9 µ-strain and a minimum strain of 2 µ-strain. Similar to the first load test, the Load Case 2 strain profiles for each of the 45 mph tests are similar. However, the maximum strain recorded during the third load test is lower than that recorded during the first load test. The largest strain was also recorded at ERSG 7 which is located near the center shear key closure at the middle of the roadway. In general, ERSG 10 and 12 (located next to the shear key closure adjoining approach slabs ‘A’ and ‘B’) experienced lower strains that were similar to one another. All the strains recorded during the third load test, Load Case 1, are well below the calculated rupture strains for the precast concrete approach slab systems.

Static Loading

Results from the first static load test on the Bent One approach at six months after bridge completion were very similar. Additionally, the results from the second and third load tests at 13 months and 18 months after bridge completion were similar to those of the first load test. Both approaches experienced very low strains during static loading. Strain readings for all load tests ranged from -22 to 30 µ-strain. Some gages experienced both tensile and compressive strains during loading and some gages showed either tensile or compressive strains only. VWSG-T2 recorded the largest strains ranging from -22 to 30 µ-strain whereas the other gages experienced very low strains, around 10 µ-strain or less. Trends of increasing strains that may be indicative of damage were not observed. Overall discrete VWSG readings collected during static load tests at six months and 13 months after bridge completion were low with a maximum of 8 µ-strain while at 18 months after bridge completion higher strains were observed with a maximum of 30 µ-strain. All measured strains were less than the calculated rupture strain.

VISUAL OBSERVATIONS

Visual inspections were conducted during each of the on-site visits. No visual signs of distress or damage due to service loads, such as cracking or distortions in the pavement surface or around parapets near the approach slab system, were observed up to 13 months after bridge completion.

During the last load test, cracks at the interface of the approach slabs and the roadway were observed at both Bents (Figure 17). These cracks were most severe on the side of the bridge associated with vibrating wire displacement gages 1 and 4. In the case of VWDG 3 the largest extension was recorded (0.13 in. relative to the reading taken just after bridge construction) in combination with very small contraction at VWDG 4 (0.05 in. relative to the same point in time). This pattern is consistent with the observed cracking assuming that rotation of the approach slab was a contributing factor. In the case of VWDG 1, a relatively small value of contraction was recorded (0.02 in. relative to the same point in time) in combination with 0.03 in. extension at VWDG 2 (relative to the same point in time). This pattern is again consistent with rotation that may lead to cracking, but the relative values are very small. It does not therefore appear that rotation of the approach slabs is the primary cause of the observed cracking. It is possible that differential settlement between the approach slab and the roadway has contributed to the cracking, perhaps in combination with temperature effects related to the roadway asphalt. No cracks were observed at the approach slab/bridge interface indicating that differential settlement between the approach slabs and the bridge is minimal.

Fig.17 Photographs of observed cracks at approach slab/roadway interface
(Upper, approach to Bent Four looking south; lower, approach to Bent One looking north)

SUMMARY AND RECOMMENDATIONS

After 18 months of service, both the Bent One and Bent Four approach slab systems on the replacement bridge over Big Brown Creek in Union County, South Carolina appear to be functioning as intended based on long-term strain and displacement measurements as well as strain readings collected during load testing. No cracking or deformations have been observed around shear key joints connecting adjacent precast slabs or in other areas on the approach. The only cracks observed were at the approach slab/roadway interface as shown in Figure 17. Measured strains within precast panels and within shear key joints are generally below the calculated rupture strains for the approach slab system. Displacement readings collected from vibrating wire displacement gages were small and indicate negligible movement of the approach slabs relative to the cast-in-place bridge deck.

Long-term strain measurements collected throughout the first 18 months of service are generally well below the calculated rupture strains of the concrete approach slab system. Long-term Vibrating Wire Strain Gage (VWSG) readings show consistent trends among different gages placed in the various locations within the approach slab system and the maximum measured strains relative to initial conditions are below the rupture strains. Long-term displacement readings collected during the first 18 months of service from Vibrating Wire Displacement Gages (VWDGs) show similar trends for all gages and overall indicate negligible movement of the approach slabs relative to the cast-in-place bridge deck.

The first, second, and third load tests (static testing was completed during the second load test, however, dynamic load testing was not conducted due to the vandalism of the sensor wires) on the Bent One approach have been completed. Results indicate that the approach slab systems are functioning as intended. In general, strain readings collected from ERSGs during dynamic load testing are below the expected rupture strains of the concrete. Strain measurements collected from VWSGs during static load tests were negligible.

This project allowed for the assessment of the performance and serviceability of precast approach slabs systems as a potential substitute for cast-in-place approach slab systems. The results showed satisfying performance of the precast approach slabs system in terms of cracking and settlement under service loading conditions. Future projects should assess the potential for differential settlement between the approach slabs and the roadway, as motivated by the cracking observed in this region after 18 months of service. The durability of the connection, especially at locations with potential freeze-thaw and corrosion issues, should also be investigated.

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