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Executive Summary Report

Forces in Wingwalls from Thermal Expansion of Skewed Semi-Integral Bridges

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Project Background

Bridges that utilize expansion joints have an overall higher maintenance cost due to leakage at the expansion joint leading to deterioration of the joint, as well as structural components beneath the joint including the superstructure and substructure. Jointless bridges, such as semi-integral and integral bridges, have become more popular in recent years because of their simplicity in the construction and the elimination of expansion joints. Jointless bridges also improve riding quality, promote lower impact loads, reduce snowplow damage to decks and approach slabs, as well as improve the seismic resistance of the bridge.

Semi-integral bridges are popular in Ohio and have the deck, girders, approach slab, and diaphragm acting together as a single unit. Flexible bearing surfaces such as elastomeric pads are used in place of the bonded construction joints used for integral abutment bridges. Prior research has shown that skewed semi-integral bridges tend to expand and rotate as the ambient air temperature increases through the season. As a result of the bridge movement, forces are generated and transferred to the wingwalls of the bridge. ODOT does not currently have a procedure to determine the forces generated in the wingwalls from the thermal expansion and rotation of skewed semi-integral bridges.

ODOT does not currently have a procedure to determine the forces generated in the wingwalls from the thermal expansion and rotation of skewed semi-integral bridges. In a former study, it was determined that these thermal forces can be significant. However, this study examined a bridge with a minor skew and wingwalls that were parallel to the diaphragm of the bridge. In addition, the instrumentation used to measure the forces was localized in a relatively small area of the wingwall and may not have provided a representation of the forces existing over the height of the wingwall. Larger skews and longer spans may produce even larger forces. The effects of the stiffness of the backfill behind the diaphragm and the approach slab on the magnitude of the forces transferred to the wingwalls is also not fully understood

Wingwalls that are parallel to the diaphragm of the bridge are subjected to an axial force from the thermal movement. ODOT is now utilizing more wingwalls that are turned back and run perpendicular or nearly perpendicular to the diaphragm. Wingwalls that are turned back would be subjected to bending from the thermal bridge movement in addition to the axial force. Stresses from the combined bending and axial forces could be critical in the design of the wingwall.

Study Objectives

The main focus of this research project was to utilize the results of field assessments, as well as a computer analysis, in order to achieve the following:

- Evaluate condition of wingwalls and wall abutments for the bridges instrumented
- Asses the cause of the observed distress in the walls
- Monitor the movement of the bridges due to temperature changes
- Begin to develop guidelines to assist in achieving improved design of skewed semi-integral bridges
- Improve the understanding of the soil-structure interaction between superstructure, substructure, and embankment soil due to changes in temperature

To investigate these objectives, the two skewed semi-integral bridges located in the northern and central Ohio were instrumented and analyzed in this project. In addition a parametric study was performed to assess other parameters affecting the bridge's behavior.

Description of Work

Part of the research in this project involved monitoring bridge in two different geographical locations in Ohio. One bridge was located in northeastern Ohio near the city of Defiance. The other bridge location was in central Ohio near the city of Newark.

The bridge near Defiance (DEF-24-0981) was on US-24 over the Tiffin River. Though two similar bridges exist at this location, only the westbound bridge was instrumented and studied. Construction began on the bridge in May 2006. The bridge is a four-span 440-foot composite structure with outside spans of 120 feet and inside spans of 100 feet. It has a skew of 45 degrees and features six 72-inch Modified AASHTO Type IV prestressed concrete I-beams with reinforced concrete deck. The bridge's substructure includes semi-integral abutments and drilled shaft foundations. The wingwalls run parallel to the bridge. The wingwall at the acute corner of the rear abutment for the westbound bridge was instrumented. This wingwall was 18 in. thick, over 18 feet in length, and more than 8 feet high. Seismic pedestals exist at the piers but no guide bearings existed at the abutments. Bridge construction was completed and the two westbound lanes opened to the public in August 2007. Figure 1 shows the bridge.

Figure 1: DEF-24-0981

The bridges in Muskingum County consisted of two nearly identical bridges for east and west bound State Route 16 near Newark, Ohio. The bridges pass over Raiders Road and were opened to traffic in 1998. Both of these bridges were instrumented well after their completion. The east and west bound single span bridges have lengths of 140ft and 139ft, respectively. They are both semi-integral bridges with a skew angle of 45^{o}. The steel plate girders spaced 10ft apart and support a reinforced concrete deck. The outside girders have a bearing retainer assembly at the bearing pads to r esist transverse movement of the girders. The bearing pads are supported by 19ft high full width abutment walls at each end of the bridge. The wall abutments are supported on a 3ft deep by 14.5ft wide concrete strip footing without any deep foundation. After the bridge was open to traffic, signs of distress were observed as cracks at the abutment/wingwall interface of the west wall of the west bound bridge (Figure 2) as well as the east wall of the east bound bridge.

Figure 2: West Wall Cracks

Two types of instrumentation were utilized for DEF-24-0981. Vibrating wire (VW) strain gages were used to measure both strain and temperature inside the wingwall. A total of eight VW strain gages were embedded in the wingwall perpendicular to the face. The eight VW strain gages were placed in two columns of four gages. One column of gages was installed as close as possible toward the bridge and other column of gages was closer to the approach slab. The installation of VW strain gages was completed in November 2006, and the concrete for the wingwall was poured the following week. In addition to the VW strain gages, digimatic indicator targets were installed on each side of the expansion joint material between the wingwall and diaphragm in the hardened concrete.

The wingwall/diaphragm interface joints of the outside acute corners of both of the MUS-16-0261bridges were instrumented with Digimatic indicator metal targets. The wall abutments near the instrumented wingwall/diaphragm interfaces were also instrumented to monitor their tilt due to either differential settlement and/or thermal effects. Thermal couples were installed to measure internal temperatures.

An analytical study was also performed on the instrumented bridges to model their behavior. A parametric study was then performed to investigate bridges with different skews and spans.

Research Findings & Conclusions

As expected, the average stress in the wingwall increased as the temperature increased for the DEF-24-0981 bridge. The magnitude of the stress however was not consistently associated with a specific temperature. Over time the stress distribution changed shape with the larger stress existing approximately halfway up the wall. The stresses near the bridge were in general lower than the stresses further toward the approach slab, supporting rotation of the bridge. The majority of average stress measurements did not exceed 150 psi (Figure 3). The data from measuring the joint opening between the wingwall and diaphragm showed all of the movements are complex and are affected by the temperatures that vary in magnitude, duration, history, and location on the bridge.

The MUS-16-0261 bridge was constructed well before instrumentation was installed and hence behavior can only be discussed from the time of instrumentation. The largest total movement of the joint over the sampling period occurred on the east bound bridge and was over 0.3". Tilt of the abutment walls and the wingwalls were found to very minimal. The bearing retainer, shown in the plan details, had a 0.25" clearance between the retainer and the plate at the bottom of the girder. If the capacity of the retainer was exceeded, it would have likely been the result of a bearing failure of the concrete at the bolt and concrete interface. Figure 4 provides an external view of the location of the bearing retainer which has been patched. The spalling of the concrete could be due to bearing failure of the concrete, especially considering the small amount of cover from the skew effect. Corrosion of the anchor bolts is also likely occurring by evidence of the staining below the retainer location on the abutment wall. Another issue is related to the bending of the wingwall caused by the force from the diaphragm is the limited reinforcement in the wingwall and the minimum embedment shown in plans.

The results of the field data collected from both bridges and the analytical study show the behavior of the diaphragm to be very complex due to the numerous factors influencing the system.

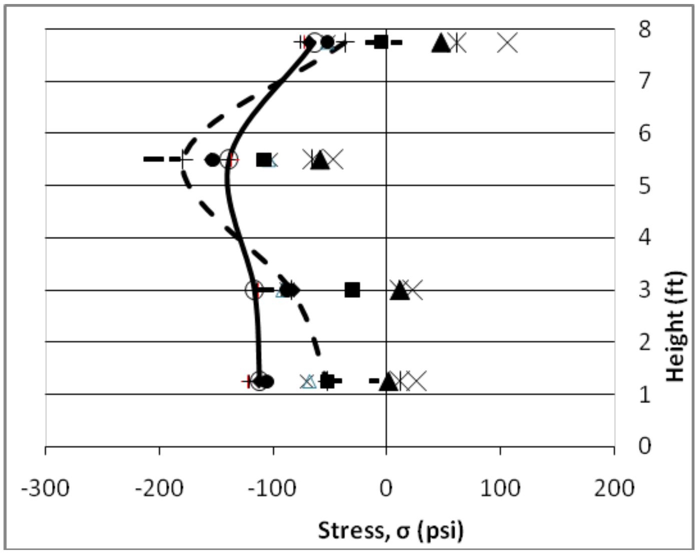

Figure 3: Average Wingwall Stress (DEF-24-0981)

Figure 4: Bearing Retainer (MUS-16-0261)

Implementation Recommendations

Based on the results of the following recommendations are made:

- For the design of the wingwalls turned to run nearly parallel with the longitudinal axis of skewed semi-integral bridges should include a 100 psi loading at the wingwall/diaphragm interface from the thermal expansion of the bridge.
- Though analytical evaluations show that longer spans and higher skews than allowed by ODOT's BDM could be used, additional considerations for larger movements and stresses generated at the wingwall/diaphragm interface would need to be considered in designs.
- Bearing retainers in diaphragms, if used, should assure adequate cover to avoid spalling of concrete. This is especially true of bridges with very high skews.
- Internal temperatures in the wingwall of the bridge can vary from ambient temperatures, making it difficult to estimate the affects of the thermal expansion of the bridge.
- The behavior of the wingwall/diaphragm interface is complex due to the combination of longitudinal sliding, movement in the direction of the skew into the wingwall, and rotation. All of these movements are also affected by the temperatures that vary in magnitude, duration, history, and location on the bridge.