Sliding finger joints of the Audubon Bridge, Louisiana, USA

T. Spuler, G. Moor & C. O'Suilleabhain
Mageba SA, Bulach, Switzerland

ABSTRACT: Sliding finger expansion joints with very large movement capacity, believed to be the largest of their type in the world, have recently been installed on the John James Audubon Bridge in Louisiana, which on completion in late 2011 will be the longest cable-stayed bridge in the Western Hemisphere. This paper describes the selection of expansion joint type and the various challenges faced in delivering these joints, including their design, manufacture and installation.

1 INTRODUCTION

The John James Audubon Bridge, currently under construction in Louisiana and with an expected completion date in late 2011, will span the Mississippi River near Baton Rouge, providing an important transportation link where previously only a ferry service existed. The landmark bridge requires expansion joints at either end of the main span deck that will facilitate very large longitudinal movements of up to 1,240mm (in excess of 48 inches). The large movement requirements of the joints presented a particular challenge in their design and fabrication, as described below.

Figure 1. Audubon Bridge – artist's impression.

2 BRIDGE DESIGN AND EXPANSION JOINT MOVEMENTS TO BE FACILITATED

The bridge has a main span of 1583 feet (482 m), extending from Axis 3E to Axis 3W, at which locations large expansion joints are required. A smaller expansion joint is required at a discontinuity in the deck of the west approach structure, at Axis 7W. The main structure has a primarily steel deck with a width of approximately 72 feet (22 m) and is supported by a total of 136 cable stays along its length, with bridge bearings at each end of the main span. Shear keys located between these bearings prevent transverse movement of the ends of the bridge deck, and therefore of the expansion joints. The movement requirements of the expansion joints are presented in Figure 2.

Bridge axis	**Longitudinal movement** (inches)	**Longitudinal movement** (mm)	**Transverse movement** (mm)	**Rotation** (rad)
3E	+/- 24.3 inches	+/- 618 mm	+/- 5 mm	+/- 0.007 rad
3W	+/- 13.9 inches	+/- 353 mm	+/- 5 mm	+/- 0.010 rad
7W	+/- 6.1 inches	+/- 155 mm	+/- 5 mm	+/- 0.010 rad

Figure 2. Movement requirements of expansion joints.

3 SELECTION OF EXPANSION JOINT TYPE

The bridge owner expressed a preference for finger type joints, with a view to minimizing maintenance costs throughout the life of the joints. Finger joints contain fewer moving parts than other types of joint, and cantilever finger joints in particular have no moving parts, contributing to reduced potential for maintenance needs.

At Axis 7W, where the movement requirements are relatively small, a simple cantilever finger joint could be used, as the movement is within the normal range of such a joint. This type of joint, as shown in Figures 3 and 4, has no moving parts, and is therefore an ideal candidate where low maintenance effort is a key consideration.

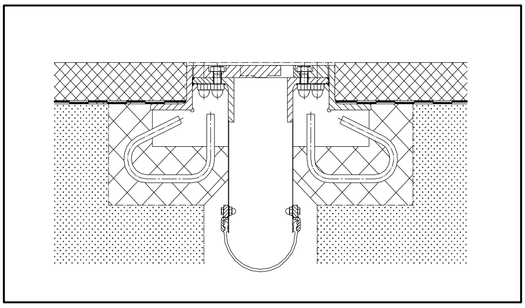

Figure 3. Cantilever finger joint – cross-section.

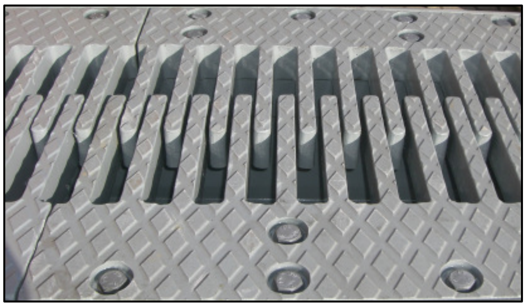

Figure 4. Cantilever finger joint – top view.

At Axis 3E and Axis 3W, where cantilever finger joints could not practically be proposed, sliding finger joints were chosen. Contrary to the cantilever finger joint, the finger plates of the sliding finger joint receive sliding support at the tip of each finger.

The sliding finger joint is an asymmetric construction consisting of complementary “male” and “female” parts. The female part consists of a steel plate with fingers bolted on top, which is fixed at one side of the expansion gap. The male part is an opposing plate with protruding fingers which is fixed at the other side of the gap. As the bridge deck expands and contracts, the fingers of the male part slide longitudinally between the fingers of the female part, always maintaining contact with (and receiving support from) the base plate of the female part below. Sliding finger joints can therefore facilitate relatively large expansion and contraction movements.

The male finger plates of a sliding finger joint are pre-tensioned downwards to ensure that their fingers remain in permanent contact with the opposing sliding surface below. Thus rotation of the joint, for example due to settlement of an abutment, can be facilitated, and the fingers of the joint will not protrude above the carriageway surface, or spring up, even under heavy over-rolling traffic. Furthermore, sliding finger joints can be used if the bridge has a longitudinal slope and the sliding bearings supporting the bridge deck are installed horizontally, as the resulting vertical movement of one section of deck relative to the other as the joint opens and closes can be accommodated by the joint's flexibility.

Since the fingers that span the expansion gap act statically as simply supported beams (without any cantilever effect), relatively simple anchoring of the joint is possible. The flexible and shock-absorbing effect of the pre-tensioning also reduces the impact of loading and therefore protects the bridge structure underneath from fatigue-related problems. Finally, the design also enhances driver comfort and reduces noise to a minimum.

Two types of sliding finger joint, which differ primarily in the way the pre-tensioning downwards of the finger plates is achieved, were considered. One type, the steel/elastomer bonded variety, utilises the elasticity of the elastomeric block from which the fingers protrude to ensure a downward tendency in the fingers. This type is shown in Figures 5 and 6.

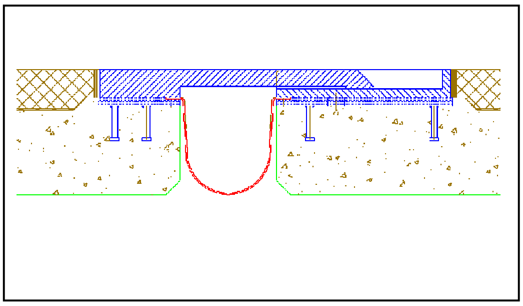

Figure 5. Sliding finger joint (steel/elastomer bonded system) - Cross-section.

Figure 6. Sliding finger joint (steel/elastomer bonded system) – As installed.

The second type, using primarily steel parts, achieves the pre-tensioning downwards of the finger plates by means of steel springs below the plates. This type is shown in Figures 7 and 8.

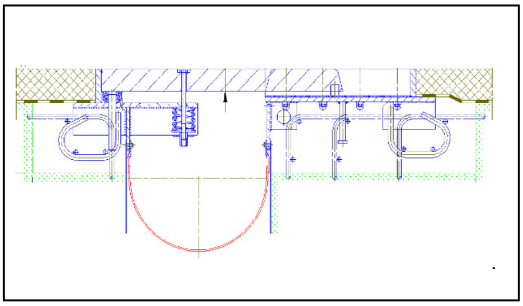

Figure 7. Sliding finger joint (steel system) – Cross-section.

Figure 8. Sliding finger joint (steel system) – As installed.

For the very large movement requirements of the finger joints on this bridge, the steel variety was selected. A static proof by calculation of the performance of the joint over its design lifetime can be more readily produced, and durability is maximized by the almost exclusive use of steel in this type of joint. Although the elastomeric bonded type has its own advantages, including easy replacement of finger plates should the need arise (Spuler et al, 2010), the arguments in favour of the steel version were deciding.

4 DESIGN OF THE JOINTS

Verification of the design of the joints in accordance with the AASHTO LRFD Bridge Design Specifications (AASHTO, 2007) was carried out, as defined by the bridge designer.

4.1 *Preliminary considerations*

During the preliminary design stage it was estimated that the largest complete expansion joints, including drainage and cover plates, would weigh approximately 24 tonnes, presenting considerable difficulties and risks during handling, transportation and installation. It was also considered that a design that would enable transportation in a 40-foot container, to reduce the risk of damage during transport, would be highly desirable. A design which would allow part of the joint to be replaced in the future if necessary without replacing the entire joint (for example, leaving the drainage channel beneath undisturbed) would also be preferable.

Bearing these considerations in mind, it was decided to design the sliding finger joints with separate drainage channels, to be assembled without welding on site.

4.2 *Detailing of sliding finger plates*

Sliding finger plates have a simple basic shape and perform a simple function, yet their detailing and fabrication presented one of the key challenges of the project. A very high level of accuracy was required in the fabrication of the finger plates, a tolerance of only +/- 1mm having been determined. Such a high degree of accuracy was deemed appropriate to ensure that no contact would occur between the fingers of the "male" sliding plates and those of the "female" plates between which they would slide, and simply increasing the gap between these opposing fingers was not an option as this would create an unacceptable hazard for motorcyclists driving over the joint, in the area where the gaps between the fingers of one side of the joint are not largely filled by the opposing fingers of the other side.

An anti-skid "diamond" pattern was created on the top surface of the finger plates in the carriageway to increase tire grip which would otherwise be very low on smooth steel, especially in wet conditions. Such a measure was particularly necessary for the larger joints because the amount of time a vehicle's wheels are not in contact with the normal, high-friction driving surface of the bridge increases with the length in the driving direction (and movement capacity) of the joint.

4.3 *Detailing of drainage*

A slope of 8% was specified by the contract documentation. This large gradient results in a depth of 800mm at the lower end of each joint, presenting several challenges. It was important to ensure the strength of the steel plates and their anchorage to the structure, especially when the channel contains dirt and debris and when the joint is wide open (resulting in a large horizontal component to the weight force which is transmitted to the steel plates from the angled membrane). And it was important to ensure the stability of the flexible drainage membrane itself, not only under the weight of collected debris, but also when the empty membrane may be violently pulled upwards by the suction force caused by vehicles passing over the joint. However it was also important to achieve adequate stiffness of the membrane without simply making it thicker, as to do so would increase its weight and therefore the difficulty of its installation or replacement. Furthermore, the connection of the membrane to the steel plates at each side would become a weak point in the design if the membrane was made too thick, as the material, being compressible, would be more likely to slip out of the clamps holding it in position, especially under the weight of debris in the channel.

To address these issues, bends were introduced in the vertical steel plates of the drainage channel to reduce the dimensions of the flexible membrane, and anchoring of the plates to the bridge deck using cast-in-place concrete was detailed (see Figure 17).

Furthermore, the material of the membrane of the drainage channel should be ozone-resistant, to avoid deterioration from the sun's rays which will pass through the fingers of the joint above, and translucent, to enable the condition of the membrane and the amount of debris collected in it to be assessed from below. It was also important to consider the shape of the drainage channel when the expansion joint is fully open and fully closed. When the joint is fully closed there can be no contact between the rigid parts of the drainage channel at either side of the joint, and when the joint is fully open, the flexible membrane of the drainage channel must not be pulled too tight – a minimum sag of approximately 400mm should be maintained.

4.4 *Detailing of cover plates*

Cover plates for cyclists were required at the outer edge of each joint. However, the possibility that vehicular traffic would drive over the cover plates could not be ruled out. Therefore it was important to stress to the contractor the importance of accuracy and workmanship in the placing of the concrete-type deck surface adjacent to the joint in the area of the cover plates, to ensure that the cover plate, which will slide on this surface, has even support and will not become deformed under errant traffic which may at times venture into the cycle lane.

Stainless steel was chosen to avoid corrosion problems, and special durable polyamide strips placed on top of the fingers below the cover plate on the female side of the joint ensure smooth sliding.

5 FABRICATION OF THE JOINTS

Several options for fabrication of the finger plates (the "male" sections which span the gap) were considered. These included cutting by rotary saw, flame-cutting, and welding of fingers onto rectangular base plates. The decision was made to undertake the fabrication of these key finger elements by CNC machining them from 110mm thick steel plates, and mechanical straightening as necessary (Figure 9). In this way the sensitive balance of efforts required and likelihood of success could be optimized. A sliding finger expansion joint of this type and of such dimensions had to the best of the manufacturer's knowledge never been produced before, therefore it could not at that point be concluded that the chosen method would deliver the required results. It was thus decided to fabricate a test piece to validate the selected method (Figure 10). Following unsatisfactory results from the first attempt, a second test piece was fabricated, and this gave sufficient confidence in the technique to proceed to fabrication of the finger plates for the joints.

Figure 9. Mechanical straightening of the fingers of a sliding finger plate.

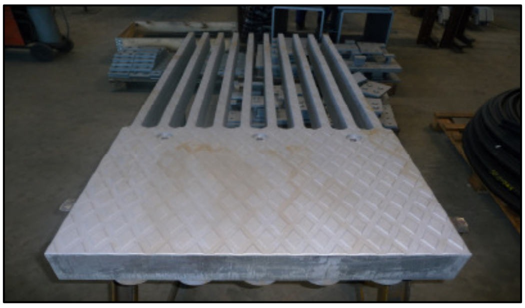

Figure 10. One of two test pieces created to confirm fabrication method for sliding finger plates.

Following fabrication of all parts of each expansion joint, including its finger plates, substructure, drainage and cover plates for cyclists, a trial assembly of each joint was carried out, prior to application of corrosion protection (Figure 11). After it had been confirmed that all parts fitted together as planned, and that no further welding, cutting, drilling or straightening would be required, the joints were disassembled once again and corrosion protection was applied to the individual parts. Following the subsequent final assembly, specially designed transportation and installation frames were connected to the joints to ensure safe lifting, carriage, and adjustment and installation on site (Figure 12). To ensure maximum protection from the elements during the journey to site and while stored awaiting installation, the joints were transported in 40-foot containers.

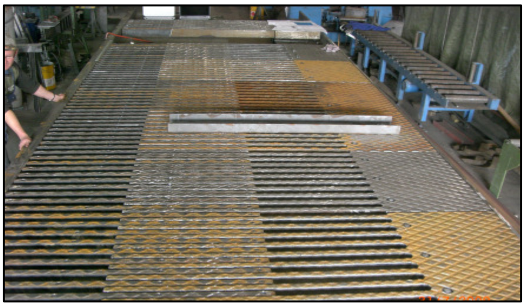

Figure 11. Pre-assembly of a joint, prior to application of corrosion protection.

Figure 12. A sliding finger joint in the factory, with transportation frame (yellow).

6 INSTALLATION OF THE JOINTS

Prior to lifting each expansion joint into its block-out, some preparatory work was required. First, the pre-setting of the joint was adjusted, to ensure that the degree of opening of the joint matched the bridge gap width at the time of installation (Figures 13 and 14). As the temperature of a bridge varies, its deck contracts or expands, causing the gaps at the ends of each section of deck (at the expansion joint locations) to open or close. It is important that the expansion joint is installed with an appropriate pre-setting, which will ensure that the joint's future capacity to open and close corresponds with the future opening and closing movements of the bridge gap. This was especially significant for the largest joints, which had been delivered fully closed to allow them to be transported in a 40-foot container.

Figure 13. Lengthening of beams of installation frame using supplied extension pieces.

Figure 14. Opening of joint (adjustment of pre-setting).

Following the adjustment of pre-setting of the joints (Figure 15), they were placed on a support frame to enable the drainage channel (consisting of large steel plates and a flexible membrane) to be connected to its underside (Figure 16).

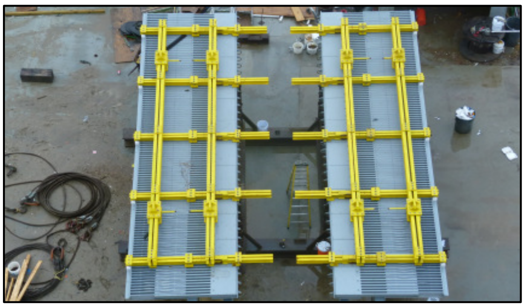

Figure 15. View of two joints from above after adjustment of pre-setting on site.

Figure 16. Connection of drainage channels to joints after placing on a support frame.

The next steps in the installation process are illustrated in Figures 17 to 21. After ensuring that adequate space would exist to allow the designed concrete mix to be placed and properly compacted, threaded rods with nuts to allow precise adjustment of height were drilled into the base of the block-outs, and additional reinforcement was placed. Each expansion joint was then lifted into its block-out, and rested on the threaded bars, and level adjusted to match the adjacent deck surface. The joint, and the vertical steel plates of its drainage channel, were then secured to the deck reinforcement bars, and shuttering was placed to close the gap to the drainage channel at the bottom surface of the deck. The transportation frame was then removed, and concrete was poured, taking care to ensure proper compaction in all areas.

The completion of the installation process primarily consists of installing a cover plate across the joint in the cycle way at the outside end of each joint, bolted to the top of the joint. This can only be done after the wearing course (a latex modified concrete layer) has been placed on the bridge deck, as the free ends of the cover plates will extend over the overlay. The careful and precise placing of the overlay in the area of the cover plates is of particular importance, because the cover plate will slide over this surface as the bridge gap opens and closes.

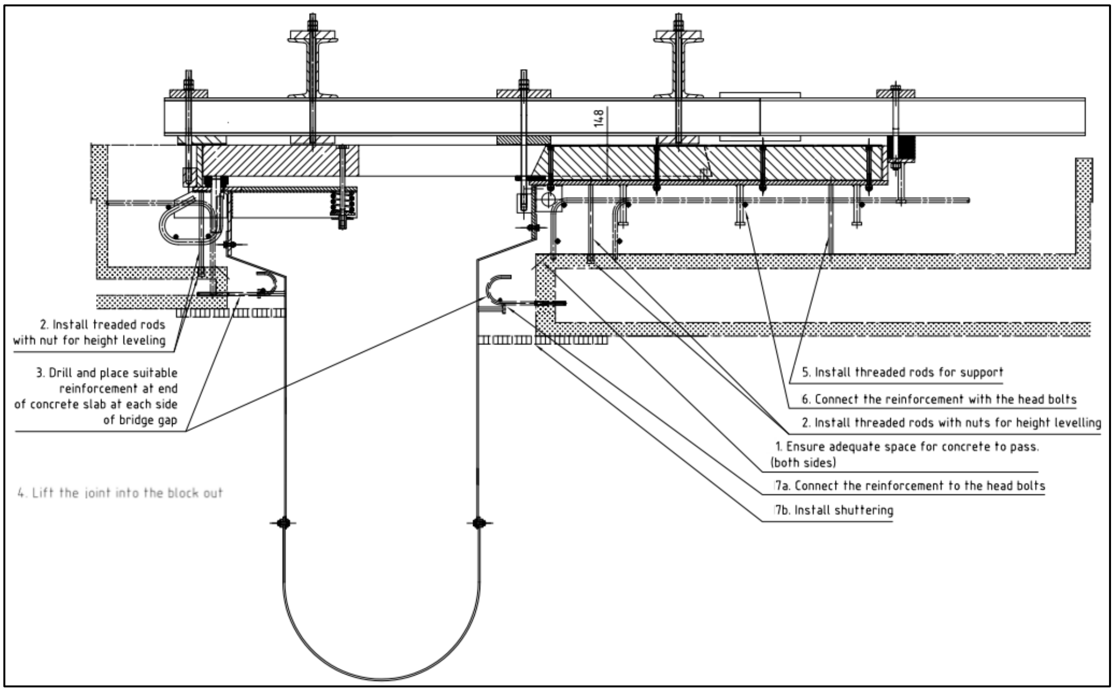

Figure 17. Steps in the installation of each sliding finger joint following connection of drainage channel

Figure 18. Lifting into position of a fully assembled expansion joint at Axis 3E.

Figure 19. View of Axis 3E after positioning of one of its two joints.

Figure 20. Lifting into position of the second expansion joint at Axis 3E.

Figure 21. Axis 3E following positioning of both its expansion joints

7 CONCLUSIONS

Sliding finger expansion joints with exceptional, and probably unprecedented movement for their type (without intermediate support of the finger plates), have now been installed on what will in the coming months open to traffic as the longest cable-stayed bridge in the Western Hemisphere (LTM, 2010). The challenge to design and detail these joints required careful consideration of all factors affecting fabrication, transportation and installation at an early stage; detailed planning; and testing and verification of fabrication methods. Trial assembly prior to application of corrosion protection also served to optimize the quality of the delivered products. Careful planning of final assembly on site, and installation with specially detailed interfacing with the bridge deck were also key elements in the successful delivery of this project.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO) 2007. AASHTO LRFD Bridge Design Specifications, 4th Edition.

Spuler, T. & Moor, G. & O'Suilleabhain, C. 2010. Expansion joint renewal with 'zero' impact on traffic - an optimal solution for urban bridges. *Proc. int. IABSE symp., Venice, 22-24 September 2010.*

Louisiana TIMED Managers (LTM), 2010. Spans connect on longest cable stay bridge in the western hemisphere. *Press release by Louisiana TIMED Managers, December 29, 2010*