The modular expansion joints of the Sheikh Jaber Causeway in Kuwait

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Abstract

When completed in 2018, the Main Link of the Sheikh Jaber Al-Ahmad Al-Sabah Causeway in Kuwait will be one of the longest sea bridges in the world, with a length of 36 km. The project to supply many of the expansion joints required presented significant challenges, including ensuring durability, designing with extra-low height, and supplying – with ex-works lengths of up to 25.4 m – within the limited time period allowed by the bridge construction contract.

Keywords: Expansion joints; modular; design; supply; bridge; causeway.

1 Introduction

The Sheikh Jaber Al-Ahmad Al-Sabah Causeway (Figure 1) is currently being constructed in Kuwait by a Hyundai – Combined Group joint venture, with each company having primary responsibility for part of the project, and in particular for its Main Link (Contract RA/140), which extends 36 kilometres across Kuwait Bay from Kuwait City. This link includes a cable-stayed main bridge of longer spans and greater height above the water than the rest of the causeway, featuring an elegant curved pylon. When completed in 2018, it will be one of the longest sea bridges in the world.

Figure 1. Artist’s impression of the Sheikh Jaber Al-Ahmad Al-Sabah Causeway’s main link, with length of 36 km, being constructed in Kuwait

A bridge of such extraordinary length requires an enormous number of expansion joints, the selection, design and supply of which are described below.

2 Overview of expansion joints required

The part of the structure for which Combined Group has primary responsibility requires expansion joints at 58 bridge axes, with a total length of over a kilometre. The required longitudinal movement capacities of these joints are summarised in Table 1.

Table 1. Overview of expansion joints required

Movement capacity	Number of joints
401 mm – 480 mm	29
321 mm – 400 mm	6
241 mm – 320 mm	16
161 mm – 240 mm	5
81 mm – 160 mm	2

In specifying and selecting the expansion joints required to satisfy these movement requirements, the contractor took great care in selecting the optimal solution to meet its needs. Having first determined that expansion joints of the non-rigid modular type would be best suited to satisfy the range of movement capacities required, as summarised in Table 1, as well as any transverse or vertical movements and any rotations, it was then necessary to pick a specific modular joint type as supplied by a particular manufacturer. Considering especially the significance of this bay crossing and the demanding gulf/marine environment, it was particularly important to ensure that the expansion joint solution would provide good service with minimal disruption to traffic for maintenance and replacement reasons throughout the bridge's long service life. It was also necessary to select a modular joint type that could be designed with a particularly low height to suit the superstructure's design.

Having considered all such requirements and other factors, the Tensa-Modular expansion joint was selected for use at all bridge axes. This type of joint, and the extensive laboratory testing to which it has been subjected in accordance with the applicable AASHTO specification [1], is described below.

3 The Tensa-Modular joint

The Tensa-Modular joint (Figure 2) selected for use can facilitate very large longitudinal movements, and offers great flexibility, being also able to accommodate transverse and vertical movements, and rotations about all axes. Modular joints divide the structure's total movement requirement among individual, smaller gaps. The gaps are separated by centerbeams, which create the driving surface and which are supported at regular intervals by support bars underneath. The gaps are made watertight by rubber seals between each pair of adjacent surface beams. Tensa-Modular is a modular joint of the single support bar type (with every support bar supporting all centerbeams), with pre-stressed, free-sliding, bolted stirrup connections between centerbeams and support bars (see Figures 3 and 4). Rubber control springs, positioned in sets below the centerbeams as shown in Figure 4, coordinate the movements of the centerbeams. This elastic system avoids constraint forces and reduces the effects of loading on the joint, extending its service life.

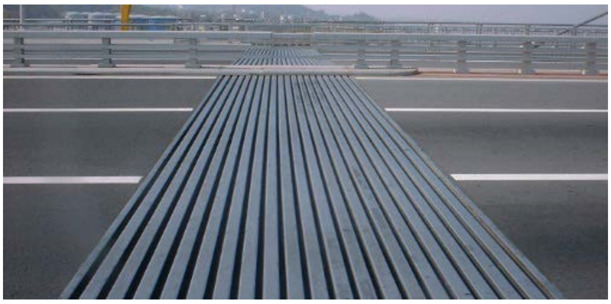

Figure 2. A modular expansion joint, viewed from above, showing the centerbeams and edgebeams that form its driving surface

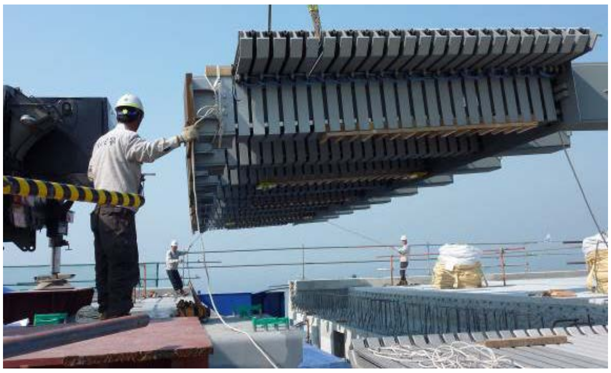

Figure 3. Installation of a Tensa-Modular joint in a concrete bridge deck, showing the support bars beneath the surface that span the bridge gap

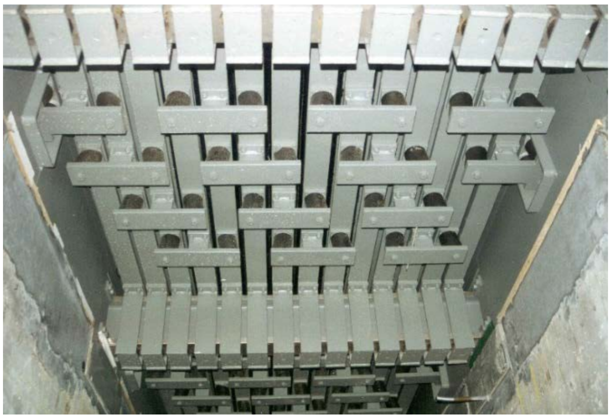

Figure 4. An installed Tensa-Modular joint, viewed from below, showing the "stirrup" connection of each centerbeam to each support bar, and the pairs of control springs which distribute deck movements among the individual gaps

Since the bridge is being constructed with separate superstructures for eastbound and westbound road traffic, two expansion joints are being installed at each axis, one per carriageway. The lengths of the individual expansion joints range between 13.3 m and 25.4 m. Design and manufacture of the expansion joints, to incorporate a specified seismic performance, is primarily in accordance with AASHTO LRFD Bridge Construction Specifications. These AASHTO specifications include, in particular, specifications for very demanding prequalification testing that should be carried out, prior to use, on specimens of an essentially similar design to verify long-term performance and durability. The importance of verifying long-term performance and durability is discussed in Section 3.1 below, and the AASHTO testing which is very useful in achieving this is described in Section 3.2.

3.1 The importance of verifying long-term performance and durability of a bridge's expansion joints before use

The long-term ability of key bridge components such as expansion joints to perform properly is the subject of increasing attention among bridge engineers, in part due to poor performance in the past. With today's greater focus on life-cycle costs, including not only direct costs but also bridge user costs (traffic disruption etc.) and environmental costs, it is clear that there is much to be gained from paying attention to long-term performance when selecting key components for a project.

Consideration of the costs of a bridge's expansion joints, during the complete life-cycle of the bridge, shows that the cost of procuring a suitable, high-quality joint and installing and maintaining it properly, will be repaid many times by minimizing the need for costly repair and replacement works [2]. A properly selected and designed joint may provide good service for 40 years or more, while a cheaper alternative, selected primarily with a view to minimizing short-term construction costs, is likely to require replacement much earlier. Maintenance and repair effort during the shorter service life of a low-quality joint are also likely to be higher, not only for the joint itself but also for the parts of the bridge beneath that it fails to protect. And the cost of maintenance and replacement works, considering direct costs to the owner and the indirect costs of disruption to traffic etc., are likely to amount to many times the cost of the original joint. Indeed, the initial supply and installation costs of a bridge's joints have been stated by some authorities to be "insignificant" in the context of total life-cycle costs [2].

3.2 Laboratory testing

Laboratory testing can play a very helpful role in ensuring that the expansion joints to be used on a structure can be expected to provide good long-term performance. The AASHTO LRFD Bridge Construction Specifications stipulated for use in the supply of the Sheikh Jaber Causeway's expansion joints contain, in Appendix A19, specifications for various prequalification tests, including the Opening Movement and Vibration test, the Seal Push-Out test, and extensive fatigue testing. Having been successfully subjected to all of this testing, as described below, use of the Tensa-Modular expansion joint could provide great confidence to the engineers who are responsible for the bridge's long-term performance.

3.2.1 Testing of long-term opening/closing movements and resistance to traffic-induced vibrations

The Opening Movement and Vibration (OMV) test in accordance with NCHRP Report 467 [3] (Figure 5) is carried out on a full-scale specimen of the modular joint type which is to be prequalified. It simulates, on the one hand, the opening (and closing) movements that can be expected to occur during a 75-year lifetime due to daily thermal cycles (i.e. one opening and closing cycle per day) – and thus features 27,400 cycles. At the same time, the test simulates the vibrations caused by traffic, with a 33 kN force applied to a centerbeam at high frequency for the entire duration of the opening movement testing. Inspection of the tested expansion joint after completion of the test allows the ability of the expansion joint to withstand these principal impacts to be evaluated.

Figure 5. Opening Movement and Vibration (OMV) Test per NCHRP Report 467

3.2.2 Testing of long-term seal strength and watertightness

Following completion of the OMV test, the Seal Push-out (SPO) test (Figure 6) is carried out. This test assesses the strength of the connection of the elastomeric seals to the centerbeams which support them, and thus indirectly tests the ability of the joint to remain watertight. Since the SPO test is carried out on the same joint which has already been subjected to the rigors of an OMV test, it simulates the weakened condition with respect to movements that a seal may exhibit after many years of service, making it a more demanding and a more realistic test of performance and durability.

Figure 6. Seal Push-Out (SPO) test in accordance with NCHRP Report 467

3.2.3 Fatigue testing

Fatigue testing of modular expansion joints is also specified in AASHTO's LRFD Bridge Construction Specifications, Appendix A19, with the testing based on NCHRP Report 402 [4]. This presents a practical test procedure for the determination of the fatigue resistance of critical details in the joint's construction. The onerous testing required simulates the fatigue-inducing movements and stresses of a service life on a full-scale section of a joint which contains all critical members and connections. It involves the subjecting of expansion joint specimens to an enormous number of load cycles, and its complexity increases with the complexity of the joint itself. For a highly developed and particularly flexible type of modular joint such as Tensa-Modular, fatigue testing can be especially demanding.

Testing was carried out at America's leading institute in this field, the ATLSS Engineering Research Center of Lehigh University, Pennsylvania (Figure 7), as described by Moor et al [5]. After extensive discussions with ATLSS, considering the specifications of various American states, it was concluded that testing should consist of six million load cycles for each specimen – twice the figure of three million which might otherwise be considered based on the relevant S-N curve (which plots stress [S] against number of cycles to failure [N]). The number of cycles was doubled in this way in order for the statistical probability of a value falling above the S-N curve, and thus within the "infinite life regime (where failure will not occur after any number of cycles), to increase from 50% to 95% - a much higher degree of certainty. In relation to the fatigue testing of modular expansion joints, this factor of two is specified, for example, by Washington State Department of Transportation, one of America's leading authorities in this field.

In accordance with AASHTO requirements, at least ten S-N data points are required to confirm that values consistently fall above the appropriate S-N curve. In the case of the Tensa-Modular joint, the test specimens were tested under constant amplitude fatigue loading at a nominal stress range of 110 MPa (16 ksi), corresponding to the constant amplitude fatigue threshold (CAFT) for AASHTO Category B (much better than the Category D specified by the standard in the absence of such testing). The testing was completed successfully, with the fatigue resistance of all details verified by testing of ten specimens, each subjected to six million load cycles without any fatigue cracking.

Figure 7. Fatigue testing – one test specimen

4 Design and detailing of the joints for the causeway structure

Having selected the above-mentioned specific type of modular joint for use in the bridge construction, the responsible engineers on the bridge's design and construction team then had to ensure that the joints of that type, as designed and detailed for delivery to the construction site, would precisely meet this particular structure's needs. As noted above, the joints were required to be designed primarily in accordance with AASHTO LRFD Bridge Construction Specifications. Apart from ensuring that the designed joints would be able to accommodate all structure movements and rotations, and satisfy all other requirements including those relating to strength and durability, specific attention was paid to the following issues.

4.1 Design of joints with extra-low height

A particular challenge was posed by the very limited depth of the block-outs of the structure, which required the height of the modular joint to be significantly less than it would otherwise be – not an easy task given the build-up of a typical joint, as shown in Fig. 3 and Fig. 4. The height of the joint is essentially defined by the height of the center beams which form the driving surface; the height of the support bars beneath, which provide support to the center beams; and the stirrup frame which connects the two, allowing the center beam to slide along the support bar.

A cross section through a standard support bar, at its connection to a center beam above, is shown in Fig. 8 (left). As can be seen, the support bar is a structurally efficient I-profile beam, which maximises the bending moment capacity for a given amount of steel. Given the limited height available in the block-outs for this particular project, the decision was made to substantially redesign this detail, incorporating a full-section rectangular steel support bar as shown in Fig. 8 (right). This enabled the height of the joints to be reduced enough to fit into the blockouts, resolving a major difficulty.

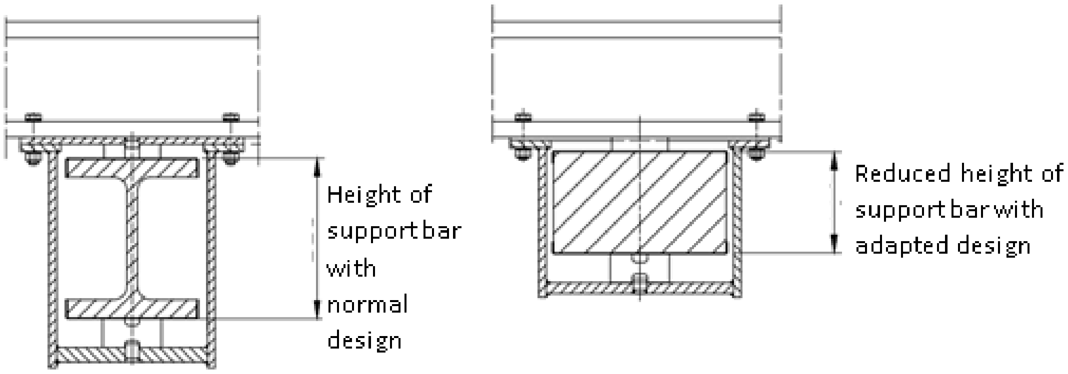

Figure 8. Sections through a standard I-beam support bar (at centerbeam connection), and through a rectangular support bar as specially developed for this project

4.2 Detailing of joints for full-length supply – with ex-works lengths of up to 25.4 m

In addition to taking care during the expansion joint selection process to ensure that the joint selected for use offers the required quality and durability, as described above, bridge designers and planners can also help minimize the life-cycle costs of a bridge’s expansion joints by influencing the joints’ project-specific design. A key way in which they can do this is by minimizing the amount of work affecting the joints that requires to be done on site – or ideally be eliminating the need for any such work entirely. The main potential for such work relates to the connecting together of sections of joint on site, where a joint has been delivered in sections – for example, for construction phasing reasons, for traffic management reasons on an existing structure, or to facilitate transportation of the joint from factory to site. In the case of the Sheikh Jaber Causeway, phasing and traffic management considerations did not apply, but the lengths of the joints, at up to 25.4 m, would make transporting in sections far more convenient.

Connecting together of sections on site involves a significant amount of work, including welding of steel surface beams, insertion of rubber seals in the gaps between the surface beams, and application of corrosion protection to the newly welded areas. Carrying out all this work on a bridge construction site, exposed to inclement weather and construction schedule pressures and perhaps using processes and equipment that vary from their very standardised, highly controlled factory counterparts, can only introduce an element of risk to the quality and durability of the fully installed joint. By specifying that the joints should be fully fabricated to full length in the factory, the bridge’s designers thus ensured that installation-related risks to long-term durability could be minimised.

5 Delivery and installation

At the time of writing, a substantial portion of the expansion joints had been fabricated and delivered to site (Figures 9 to 11) but none had been installed yet. Therefore, the installation process is illustrated here using pictures from the installation of similar expansion joints on other concrete structures (Figures 12 to 14).

Figure 9. Loading of joints with lengths of up to 25m for transport from the factory in Shanghai

Figure 10. Expansion joints as loaded on a truck in Kuwait’s sea port for transport to site

Figure 11. First modular expansion joints as delivered to site

Figure 12. Before lifting a joint into the blockout in a bridge deck, using load-spreading beams as necessary, the blockout must be suitably prepared

Figure 13. Installation beams across the top of the joint enable it to be precisely positioned and height-adjusted using hydraulic jacks under the ends of the beams at each side of the bridge gap

Figure 14. After the expansion joint has been precisely positioned, reinforcement can be placed around it as required in preparation for concreting

6 Conclusions

The supply of the expansion joints described above for the Main Link of the Sheikh Jaber Al-Ahmad Al-Sabah Causeway in Kuwait demonstrates the value placed by Combined Group on maximizing long-term performance and minimizing long-term costs. By properly assessing and confirming the preferred joint type's performance and durability, with consideration of laboratory testing and performance history, a great deal of confidence in the future performance of the joints used could be gained. And by stipulating that the joints should be fully assembled to their full length of up to 25.4 m in the factory, considering the transport challenges that this would present, the risk of installation-related work affecting the long-term performance of the joints could be minimized. The owner of this fine new bridge, and the thousands of users that will depend on it every day, can thus have great confidence that these expansion joints will perform very well for a very long time.

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