Bridge components to satisfy the demanding requirements of modern bridges

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Summary

As bridge spans increase, and bridge behaviour becomes less standard as engineers develop new ways to design and build their structures, the design and manufacture of the critical mechanical parts of a bridge (in particular its bearings and expansion joints) must adapt to satisfy the structure's needs. This is especially true in the case of extreme events such as earthquakes and other exceptionally demanding conditions. There also results a demand for supplemental components or systems to support the innovative solutions developed for challenging circumstances, such as dampers to control sudden movements of a bridge deck, and automated monitoring systems which can provide real-time information on the structure's condition. Such supplemental components may be of particular interest, for example, in a seismic zone or where similar uncertainties exist.

This paper considers the role of such bridge components, with reference to major structures on which they have been installed.

Keywords: bridges; seismic; bearings; expansion joints; dampers; structural health monitoring.

1. Introduction

Bridge engineering has made great advances in the past several decades, with bridges now spanning greater distances and carrying more traffic with greater safety, and thanks to innovative designs can achieve this using less material than ever before. However this constant drive to improve and innovate in the bridge sector results in ongoing challenges for the suppliers of key bridge components such as bearings and expansion joints. These mechanical parts of a bridge typically facilitate movements of the bridge deck, while transferring forces from the deck to the abutments or providing a driving surface at the ends of the deck for traffic, and are therefore less robust and more subject to wear and damage than the mass concrete or steel main structure. Therefore the suppliers of such components, and other parts such as hydraulic dampers which can control extreme movements and monitoring systems which can help oversee the condition and performance of an exceptional structure, must be equally innovative, developing their products to support the ongoing advancements in the broader bridge construction industry.

2. Expansion joints

2.1 Increasing demands on expansion joints

Bridges generally move in a steady and predictable manner under influences such as temperature, traffic loads and wind. However large bridges, today sometimes with longitudinal movements exceeding 2,000mm, often have quite complex movement characteristics and sometimes present exceptional demands for the expansion joints which facilitate the large movements while providing a driving surface for traffic at the ends of the bridge deck. The effects of normal daily and seasonal temperature variations, wind, traffic and other live loads, and micro-movements due to solar radiation (arising from temperature changes every time the sun is blocked by a cloud) can result in a modern slender bridge moving several hundred kilometres during the lifetime of an expansion joint.

At the same time, traffic continues to increase, presenting another challenge. Assuming a bridge carries just 6,000 vehicles a day on each traffic lane, the total design traffic volume per lane during an expansion joint's working life of 40 years will be likely to exceed 200 million axle loads. This enormous figure indicates why fatigue is a major issue when designing durable expansion joints.

The combination of such greatly increasing movements and loads on the expansion joints of modern bridges requires suppliers to continue to improve the performance of their products and develop new ways of satisfying the sometimes exceptional demands, for example as presented below for the cases of two very important expansion joint types, modular and finger joints.

2.2 Modular expansion joints

Modern modular expansion joints are often best suited to satisfy the movement demands of today's exceptional bridges, in particular due to their ability to facilitate very large longitudinal movements of the bridge deck, and their great flexibility while achieving this, allowing also transverse and vertical movements of the deck as well as rotations about any axis.

However even modular joints face a number of particular challenges in the case of bridges whose expansion joints are subjected to extreme movements (either movement capacities or accumulative movements) and/or extreme loading (resulting from exceptionally large traffic volumes etc). A number of special features which can help overcome these particular challenges are outlined below, as well as examples illustrating the recent implementation of such solutions on major structures.

2.2.1 Special sliding materials

The sliding material normally used to facilitate the sliding of the moving parts of an expansion joint could not withstand the extreme movements of some expansion joints, and a suitable alternative must be specified. A material which meets modern demands is for instance *Robo®Slide*, as shown in Figure 1. This is a high grade sliding material with excellent abrasion resistance and very low friction characteristics. Tests carried out on this material showed that above a sliding distance of 2.5km, the friction level is approximately 5 times lower than that of PTFE for this application. The material has also been shown to be twenty times more durable and 2.5 times stronger in compression.

Fig. 1: High grade sliding material, e.g. Robo®Slide

2.2.2 Asymmetrical control system

The symmetrical control systems generally used in modular expansion joints to regulate the widths of the gaps between the joint's lamella beams do not suffice when the movement capacity becomes very large, due to the friction and other forces which arise as the joint opens and closes. To overcome this problem, and ensure that the movement of the joint will be evenly distributed among the joint's individual gaps, an alternative, asymmetrical control system has been developed. This incorporates a staggered layout of the control springs, with the number of springs being increased at one end of the joint to counteract the build-up of friction forces. Figure 2 shows the underside of a joint with such a system.

Fig. 2: Asymmetrical control system

2.2.3 Highly durable control springs

The control springs which regulate the gap width between a joint's lamella beams are subjected to additional loading when installed in an expansion joint that must facilitate extreme movements, and must be adapted to suit. For instance, the rubber mixture of Mageba's control springs has been optimised to improve overall performance and durability by a factor of 2.5, as verified by testing at an independent institute (Figure 3).

Fig. 3: Testing of Mageba's 4th generation control springs at -20°C

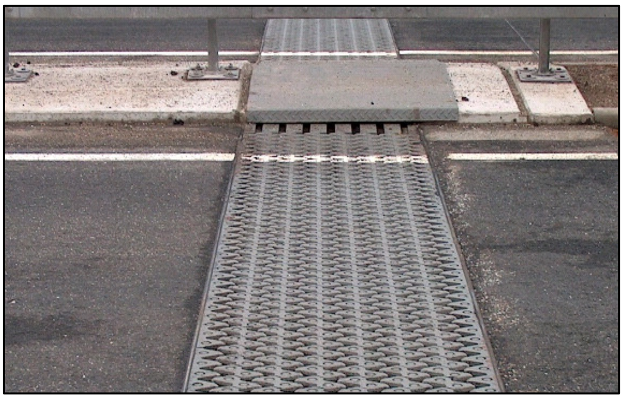

Fig. 4: Noise-reducing "sinus plates" on a modular joint

2.2.4 Noise reduction

Noise generated by traffic crossing a modular expansion joint can be significant, especially in the case of large joints on busy bridges with high traffic speeds. Suitable surfacing to reduce the noise generated becomes a requirement in many cases, for instance on elevated highways in populated areas.

A solution which incorporates the fixing of profiled steel plates (so-called "sinus plates" due to their shape) is shown in Figure 4. These plates eliminate straight edges perpendicular to the direction of travel, and ensure that vehicles travelling over the joint continuously grip the surface, greatly reducing the noise generated by traffic on the joint.

Noise measurements carried out on different structures by an independent body have shown that modular expansion joints with sinus plates are significantly less noisy (up to 70% less noise generated by traffic) than other types of expansion joint. [1]

2.2.5 Anti-skid protection

Fig. 5: Lamella surfaced with anti-skid coating

As the span of a modular expansion joint increases, so too does the distance a vehicle will have to travel in crossing the joint with reduced ability to brake, especially in wet weather conditions. Large expansion joints therefore require some form of surface treatment to improve tyre grip. A proven anti-skid surface, for example, is *Robo®Grip*, as shown in Figure 5. This is a five-layer laminate coating that is applied cold in liquid resin form. It was originally developed for aircraft carrier ships of the British Royal Navy, where high friction and durability under extreme conditions is required. This special surface treatment results in a friction coefficient μ of up to 0.9 and guarantees at least $\mu = 0.5$ over its full service life, even under the most adverse traffic and weather conditions. It is also resistant to pollution and ultra-violet radiation.

2.2.6 Earthquake protection features

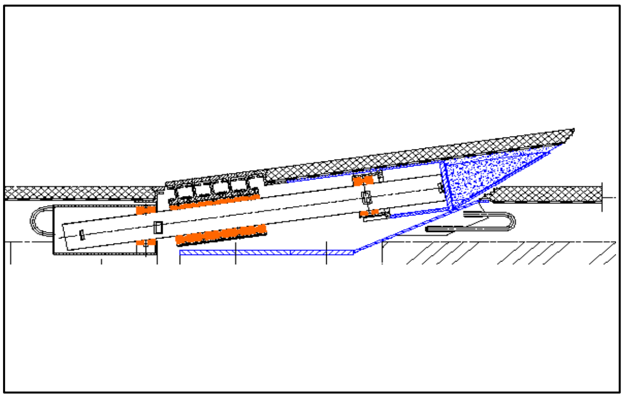

Fig. 6: Fuse®Box system for seismic events

Depending on their location, bridges can also be affected by earthquakes, which can result in the destruction of the bridge's expansion joints and possibly severe damage to the bridge structure itself. Serious damage to a large bridge can have very serious consequences for an area which has recently been devastated by an earthquake, as its function as a lifeline to the area takes on great importance in such circumstances – in facilitating the evacuation of the affected population and access to the area by emergency services. A feature, known as *Fuse®Box*, which allows the connection of an expansion joint to the main structure to break in a controlled manner in the event of an earthquake, is shown in Figure 6. This system permits the expansion gap to close during an earthquake without being destroyed, and to settle afterwards in such a way as will allow emergency vehicles to travel across the joint. Such a system therefore facilitates essential activities such as emergency services, evacuation and reconstruction in the aftermath of an earthquake – activities which are all the more vital in an urbanised area where effective disaster relief is all the more critical.

2.2.7 Implementation: Modular expansion joints of the Golden Ears Bridge, Canada

Fig. 7: The Golden Ears Bridge during construction

The Golden Ears Bridge (Figure 7) near Vancouver in Canada, which opened to traffic in Summer 2009, has been fitted with modular joints with up to 17 gaps, which allow movements of up to 1360mm. These joints can absorb the movements of a limited scale earthquake as well as normal service movement, but are equipped with *Fuse®Box* protection to protect the joint and the main structure from serious damage in the case of a larger earthquake. The expansion joints also feature *Robo®Slide* special sliding material, advanced highly durable control springs and asymmetrical control systems, combining many of the above referenced features [2].

2.2.8 Implementation: Modular expansion joints of the Incheon Grand Bridge, South Korea

Fig. 8: The Incheon Grand Bridge, South Korea

At 12.3km long and with a main cable-stayed span of 800m, the new Incheon Grand Bridge (Figure 8), currently under construction to serve Seoul's new Incheon International Airport, will be one of the five longest of its type in the world. The modular expansion joints of the bridge's main span, each with 24 gaps and allowing longitudinal movements of up to 1,920mm, were delivered and installed in 2009. These are special constructions in their own right, and feature *Robo®Slide* high grade sliding material, an asymmetrical control system, advanced highly durable control springs and *Robo®Grip* anti-skid surfacing. The joints are also equipped with a *Robo®Control* structural health monitoring system (see below) [3]

2.3 Finger expansion joints

Finger type expansion joints offer an attractive alternative to other types of joint, especially due to their relative simplicity and lower number of moving parts, and low noise emissions from the passage of traffic across the continuous surface. However, apart from longitudinal movement, they are relatively limited in the movements (in any other direction) and rotations (about any axis) they can accommodate. In the past, finger type joints have generally been used only to accommodate longitudinal movements of significantly less than one metre, where other movements and rotations are very limited. However, similar to the case of modular expansion joints, these joints can be designed and fabricated by competent suppliers to exceed the accepted range of capabilites of the past, helping to fulfil the needs of bridge builders for extraordinary key components.

2.3.1 Implementation: Sliding finger joints of the John James Audubon Bridge, Louisiana

The John James Audubon Bridge, currently under construction over the Mississippi River, will be the longest cable-stayed bridge in North America. The bridge requires expansion joints that will allow exceptionally large movements for the prefered sliding finger type of joint. The largest joints (shown in Figure 9) will facilitate longitudinal movement of up to 1,240mm, believed to be unprecedented for a sliding finger joint. These movement requirements presented a particular challenge for design and fabrication, but the successful completion and delivery of the joints to site early in 2010 showed that even movements in excess of one metre can now be facilitated by sliding finger expansion joints [4].

Fig. 9: A sliding finger joint for the Audubon Bridge USA (with transportation frame on top)

3. Bearings

3.1 The requirement for special bridge bearings

Bearings also play a vital role in any large bridge, taking on the role of transferring weight and other forces from the bridge deck to its abutments, while generally also enabling the bridge deck to move as may be required by the bridge design. The needs of the great majority of bridges can be fulfilled by a widely available range of relatively standard bearing types, although it must be recognised that the performance of any bearing, and in particular its durability and long-term performance, depends greatly on its careful selection, design, detailing and manufacture using high quality materials. Use of specially developed materials, such as the high grade sliding material *Robo®Slide*, by experienced manufacturers can help ensure that a bridge's bearings will continue to perform well for many years after inferior bearings have already failed.

However sometimes bridges are designed with exceptional requirements for how the loading from the bridge deck must be transferred to its support structures, such as in the examples below.

3.1.1 Implementation: Uplift bearings of the Golden Ears Bridge, Canada

The bearings for the main span of the Golden Ears Bridge presented a particular challenge due to the bridge's unusual design which allows the bridge deck at the bearings to lift frequently under the action of traffic alone. Coupled with the need for each bearing to facilitate longitudinal movement of 3,100mm as well as further large movements and rotations, this resulted in an innovative design for the two uplift bearings (see Figure 10) at each end of the main span, each weighing 17 tonnes [2].

Fig. 10: An uplift bearing for the Golden Ears Bridge - during loading for transport

3.1.2 Implementation: Pendulum rocker bearings and wind shoes, Hong Kong and Kazakhstan

Impressive as the bearings of the Golden Ears Bridge are, they are nonetheless bearings in the conventional sense, transferring the forces acting on the bridge deck to its support structures via a compact unit directly below the deck. However more unconventional solutions have also been developed and successfully implemented when required by the innovative design of a special bridge, as illustrated by the pendulum rocker bearings (Figure 11) of the Ting Kau Bridge in Hong Kong. The Irtysh River Bridge in Kazakhstan was also fitted with exceptional pendulum rocker bearings as shown in Figure 12, and with wind shoes to resist transverse wind forces as shown in Figure 13.

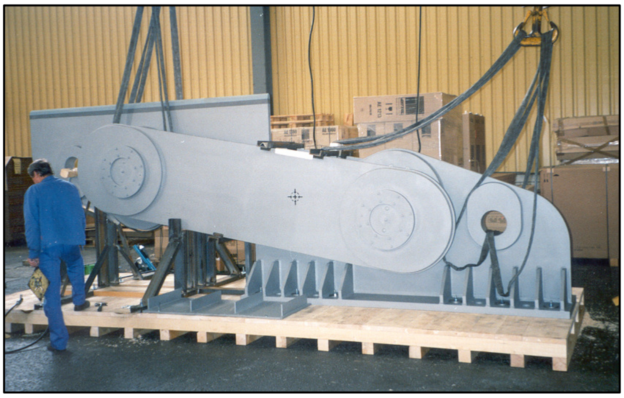

Fig. 11: A pendulum rocker bearing for the Ting Kau Bridge - during assembly

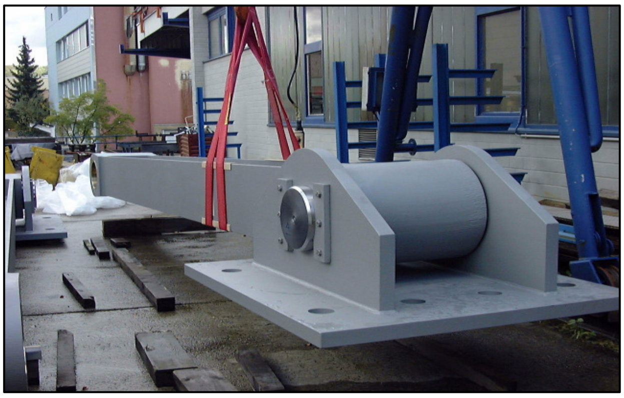

Fig. 12: A pendulum rocker bearing for the Irtysh River Bridge - during assembly

Fig. 13: A wind shoe for the Irtysh River Bridge - during assembly

4. Hydraulic and spring dampers

Hydraulic and spring dampers, typically used to control sudden movements of a bridge deck due to seismic or other non-uniform forces, play an important role in the design and construction of bridges for particularly demanding circumstances or with innovative and slender bridge designs. They come in many shapes and forms, including hydraulic buffers, hydraulic shock transmission units, pre-loaded spring dampers and spring disc dampers. A selection of these are presented in Figures 14 to 16.

Fig. 14: A preloaded spring damper

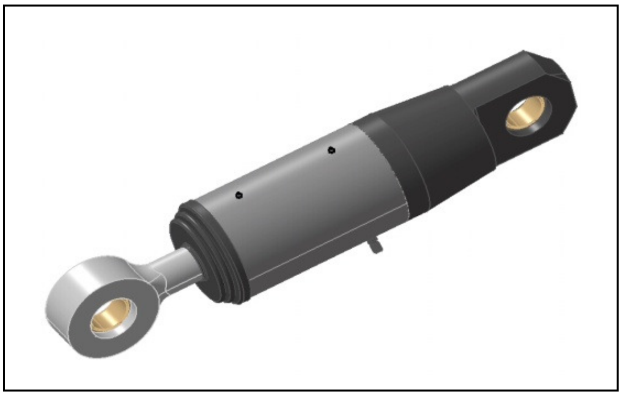

Fig. 15: A hydraulic damper

Fig. 16: A pair of shock transmission units

5. Automated structural health monitoring systems

5.1 The great potential uses of modern structural health monitoring systems

The ongoing drive to build larger, longer and ever more economically results in bridges today being built in ways which are pushing ever further the boundaries of what is believed to be possible or practical. This means that bridges are often built to innovative designs, and using materials and construction methods, which have not been tried and trusted for decades. This can often leave an element of uncertainty about the reliability of a proposed solution, which may result in a perfectly good innovative approach being rejected. A solution to such a situation is offered by modern automated structural health monitoring systems, which can provide detailed, accurate and real-time information on the condition and performance of any structure or any element of the structure, enabling a bridge designer or constructor to have confidence that the structure is performing as intended, and that any unexpected changes in its performance will be immediately recognised, greatly reducing the potential consequences of any residual risks.

Remote monitoring can provide continuous records of almost any variable in a bridge's condition, such as the position or length of any part, or the force acting on that part. Modern automated systems can also be configured to analyse the data gathered, present it in tabular or graphic format, and make it available to an authorised user anywhere in the world via the internet. Automatic notification by e-mail or SMS of the reaching of predefined alarm values of any measured variable can also be provided. Such systems can also be used to provide structural engineering and bridge usage data for any structure – information which may be of particular interest to the owner of a very large bridge. [5]

5.1.1 Implementation: Structural health monitoring of the Incheon Bridge, South Korea

The Incheon Grand Bridge, fitted with exceptionally large modular expansion joints as referenced above, is also equipped with an automated monitoring system focused on its expansion joints. In particular, modular joints of such dimensions are complex steel structures with a large number of moving parts. For safety reasons, their functioning and that of the bridge must be guaranteed at all times, especially for structures of such importance, so it was decided to install an automated system which would provide permanent real-time information, allowing the behaviour of the bridge deck and the expansion joint to be monitored on-line at all times (see Figures 17 and 18). [3]

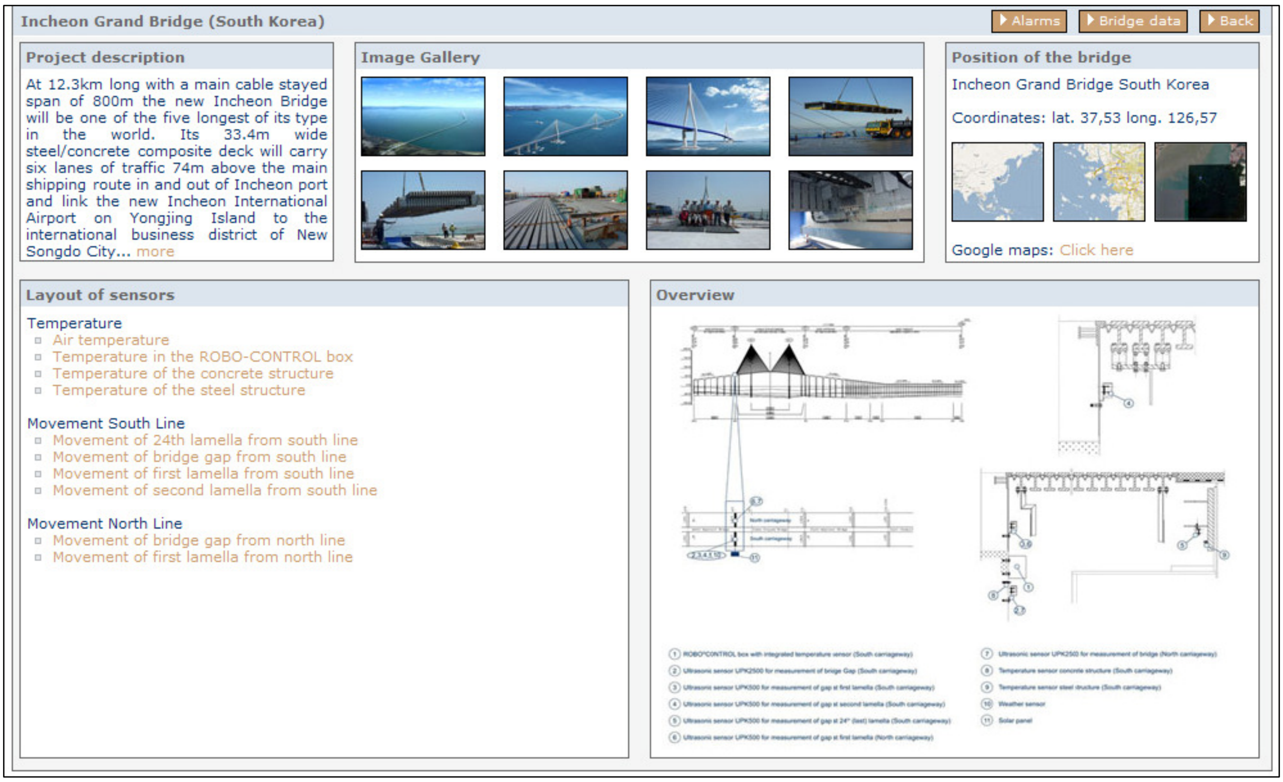

Fig. 17: Web interface of the long-term monitoring system at the Incheon Grand Bridge

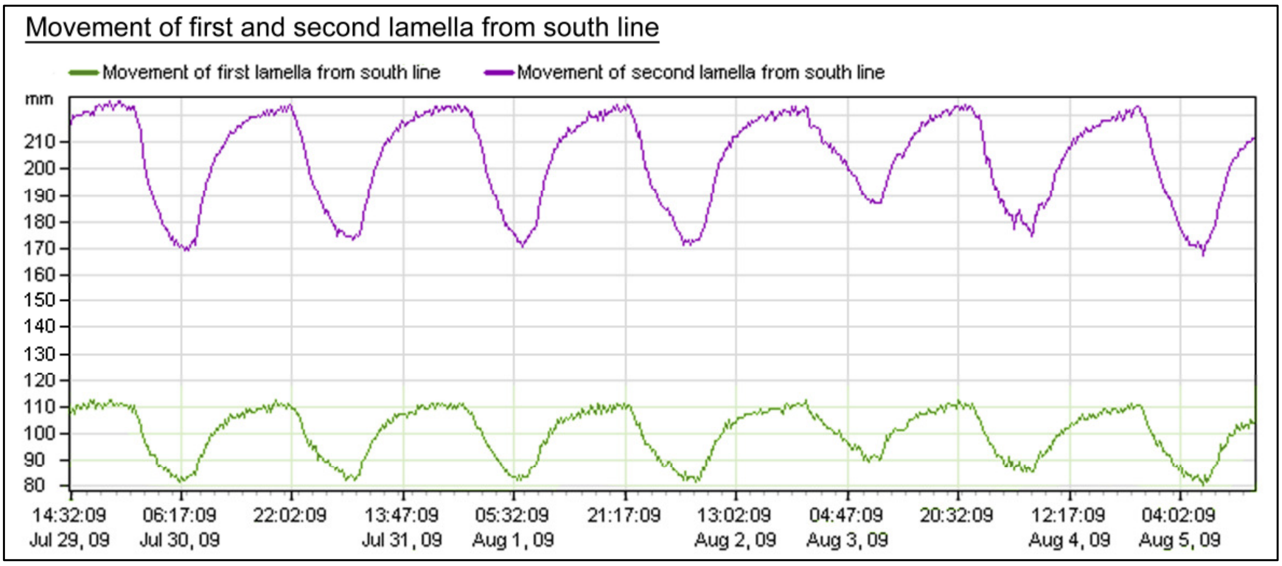

Fig. 18: On-line presentation of detailed measurements in graphic form (7-day period)

6. Conclusions

Exceptional bridge structures, designed and built by a construction industry that continues to push the boundaries of span and performance for such structures while at the same time always striving for greater cost-effectiveness, require exceptional key components to support their design. These components, such as the bridge's mechanical parts (especially its bearings and expansion joints) and supplemental features such as dampers and monitoring systems, must be carefully selected, designed and fabricated to the high standard appropriate to the importance and individuality of the main structure, to adequately support the proper performance of innovative and landmark structures.

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