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Facilitating innovative bridge design – the bearings and expansion joints of the Golden Ears Bridge

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ABSTRACT: The Golden Ears Bridge was opened to traffic in 2009 and features an unconventional hybrid cable-stayed design which allows the bridge deck, rather unusually, to rise and fall under the influence of traffic alone. The design of the bridge presented particular challenges for the mechanical parts of the bridge, most notably its bearings and expansion joints which had to be designed to facilitate very large movements and rotations, seismic conditions, and changes between downward and uplift force conditions many times every day. The clever designs and careful detailing of these components of this special structure played an important role in complementing the innovative design of the bridge, a fine example of how such structures can still be designed to optimise, economise and impress.

1 INTRODUCTION

Construction of the Golden Ears Bridge near Vancouver, British Columbia was completed in June 2009, creating a new transportation link across the Fraser River. The bridge features an unusual hybrid cable-stayed design, which places exceptional movement requirements on the mechanical parts of the bridge, in particular its bearings and expansion joints. The location of the bridge in a seismically active area also resulted in requirements relating to the performance of these vital bridge parts during and in the aftermath of seismic events. This combination of factors presented significant challenges for the design and fabrication of the bridge's expansion joints and bearings, which are described below.

2 THE GOLDEN EARS BRIDGE

This fine five-span bridge creates a vital new link between the densely populated areas on each side of the Fraser River and will strongly support economic development in this part of British Columbia. The new crossing has three main spans of 242m which together with end spans of 121m result in a total length of 968m, excluding approach structures. Several key factors influencing its design included: its location in an area of moderate to high seismicity; ground conditions of deep soft liquefiable river deposits; a ground profile which would make one of the four towers significantly shorter (and therefore stiffer) than the others; and proximity to an airport which would limit the permissible height of the structure. The result of the challenging design is an unusual hybrid cable-stayed structure, with behaviour between that of a true cable-stayed bridge and an extradosed bridge, featuring a composite steel-concrete deck and relatively flat harped cable stays with low profile (Bergman et al, 2007). The deck is integral with the towers, thus receiving vertical support from the towers at these locations, and the cables, which are at a relatively low angle to the deck, act to prestress the deck as well as support the central area of each span. The low profile design thus achieved minimises its effects on local air traffic.

3 THE BEARINGS OF THE BRIDGE

3.1 *Exceptional movement and loading requirements*

The bearings of a typical bridge support the bridge deck from below, facilitating limited movements and rotations of the deck as required. The design of the Golden Ears Bridge, however, resulted in the following very demanding combination of requirements for each bearing:

- Longitudinal movement of 3,100mm
- transverse movement of 50mm
- rotation of 0.039 radians
- downward bearing capacity of 4,600 KN
- uplift capacity of 3,920 KN
- and all of this with frequent changes between downward and uplift force conditions, many times a day.

Large as the longitudinal and transverse movements and rotations are, and even considering the significant uplift force, a relatively standard bearing type with appropriate detailing and special materials could have been designed to fulfil these requirements. However the final requirement, for the bearing to be designed to withstand frequent changes between downward and upward vertical force, was defining in this challenge. A solution based on a spherical bearing type, which was initially investigated, would have satisfied all movement requirements very well, but the materials used at the sliding interfaces would have suffered from the hammering which would result each time the vertical force on the bearing changed from downward to upward. It became clear that a bearing design which would allow large sliding movements, but in which the sliding interfaces were in a constant state of pre-compression to prevent such hammering, was required.

3.2 *General approach to design of the bearings*

A standard bearing type fulfilling these requirements was not known to the bearing supplier, so a special design had to be developed. The final design features a long part which is bolted to the bridge deck and a shorter part which is anchored to the concrete pier below. These parts interact by virtue of their overlapping horizontal plates, which are separated by large, sliding elastomeric bearings. The construction of the bearings is shown in Figures 2 to 4. The elastomeric bearings, which provide the required pre-compression of the sliding interfaces, have vertical steel pins through their cores to limit deflection which would reduce the bearing capacity of the unit.

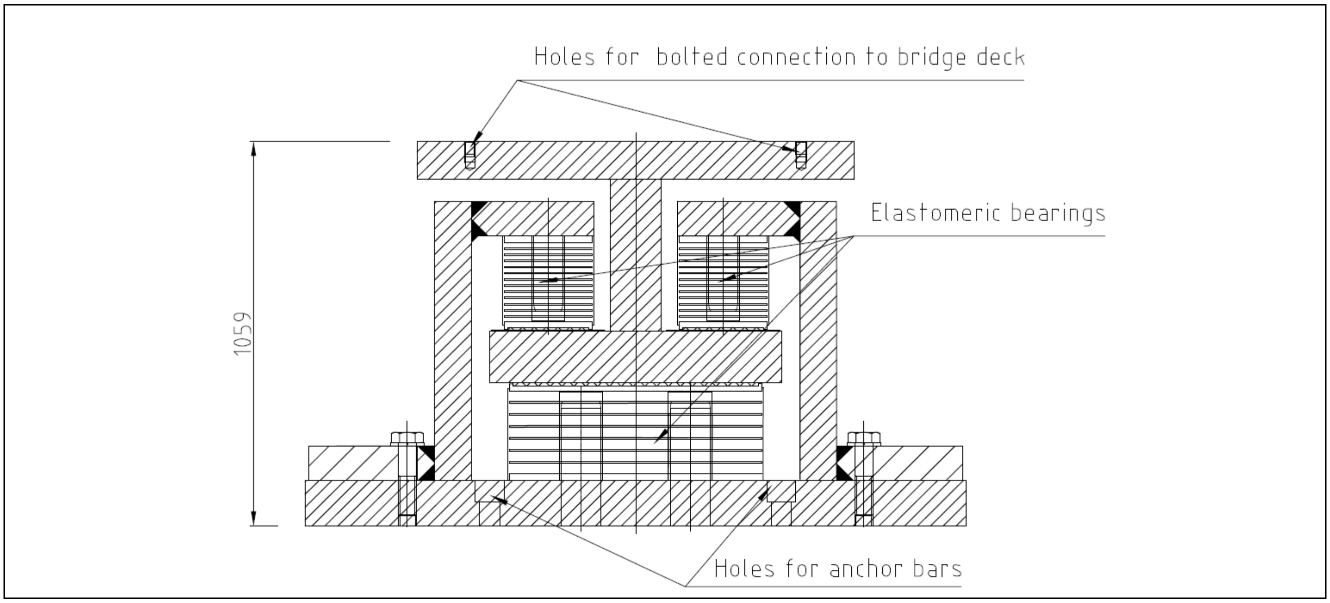

Figure 1. Cross section (transverse) through bearing.

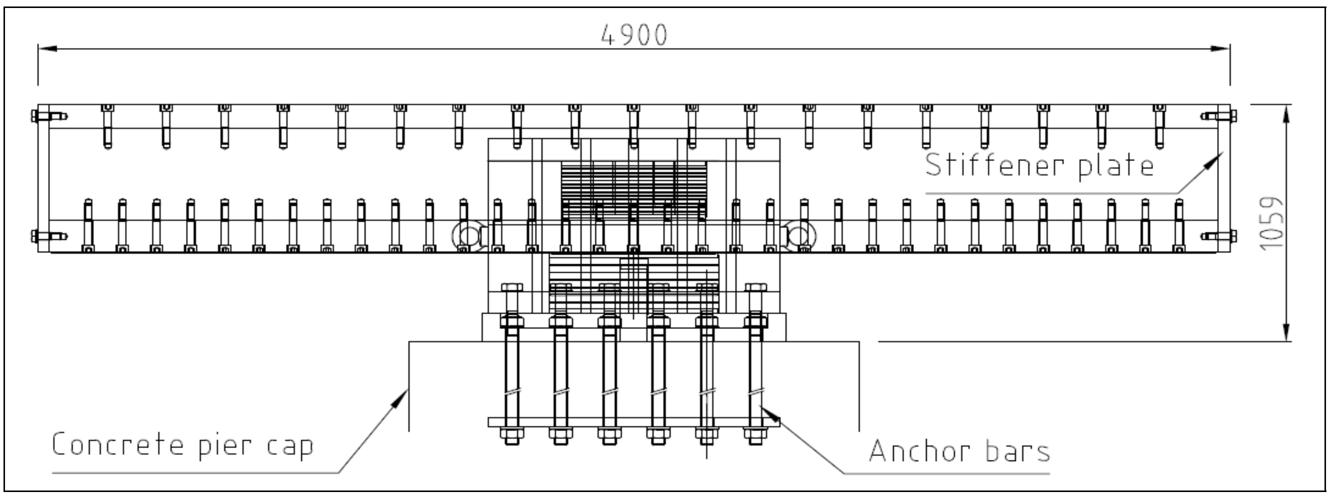

Figure 2. Cross section (longitudinal) through bearing.

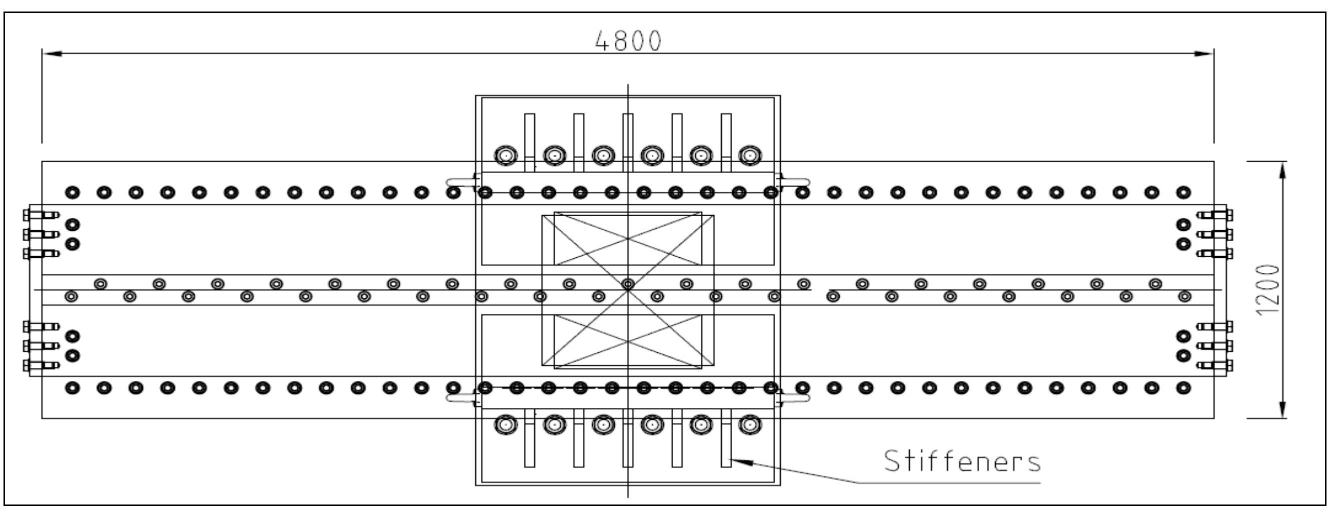

Figure 3. Plan on bearing.

3.3 *Bearing fabrication*

Production of bearings of such dimensions presented many challenges not normally encountered in the manufacture of bridge bearings, requiring special measures to be utilised. To ensure the parallelness of the various bearing parts, which could have been compromised by the very high temperatures which would arise during welding of such large steel plates, possibly causing warping, it was decided to bolt the critical plates together rather than welding. Furthermore, the compressibility of each elastomeric bearing was tested after manufacture to confirm theoretical predictions. Such measures enabled confidence to be gained that these special bearings would perform as required in service.

Due to the scale of the bearings, assembly was carried out on the trucks which would be used to transport them from the factory. Tightening of the bolts to the required torque required six men (see Figures 4 and 5).

Figure 4. Fastening of the bolts of a bearing.

The resulting bearings, each of which weighs 17 tonnes, testify to the fact that suitably qualified engineers can come up with a solution to almost any challenge.

Figure 5. One bearing being securing on a lorry for transport to site.

3.4 *Installation of the bearings*

The installation of the bearings required great precision, particularly due to their very large dimensions. At almost five metres in length, the upper sliding part is exceptionally long for a bridge bearing. The requirement for the sliding surfaces of a sliding bearing to be perfectly parallel becomes more challenging at such dimensions, and also more critical. The sliding surfaces (typically PTFE and stainless steel) of a sliding bearing must be parallel, and movement of one over the other must be in the plane of the interface. This is necessary to ensure even load transfer at all positions of one part relative to the other, and to prevent opening of a gap between the two materials which could result in hammering, and thus damage of the PTFE. Opening of a gap between the surfaces could also result in contamination by dirt and foreign matter which would reduce the bearing's ability to slide smoothly and result in excessive wear of the sliding material. A slight lack of parallelness may not be of great consequence in a bearing with a short sliding plate, but when the sliding plate extends over 1.5m beyond the bearing's lower part, as it does in each bearing supplied for the Golden Ears Bridge, any slight angle between the PTFE and stainless steel surfaces can translate into a significant gap at the end of the sliding plate.

At 17,000kg each, the lifting in and positioning of these bearings to achieve this parallelness and the correct alignment presented a significant challenge. The bearings were first hung from the bridge deck and connected using pre-drilled holes. The lower connection to the concrete pier cap could then be adjusted utilizing the play in the anchor bars which passed, in oversize sleeves, through the entire depth of the pier cap, before grouting beneath the bearing to ensure even distribution of loads.

Figure 6. Installation of a bridge bearing.

4 THE EXPANSION JOINTS OF THE BRIDGE

4.1 *Demanding requirements*

The expansion joints of a bridge provide a continuous driving surface at each end of the bridge's deck, while facilitating deck movements which might result from temperature variations, wind, creep of concrete, traffic etc. The joints of the Golden Ears Bridge had to be designed to facilitate large deck movements and rotations, and in addition to satisfy specified performance requirements during or in the wake of defined seismic events

– for example, that the bridge should not be seriously damaged and should be possible be re-open to emergency and other traffic without great delay in the immediate aftermath of an earthquake. The delivered solution, modular expansion joints featuring *Fuse-Box* earthquake protection, optimised the cost and space requirements of the joints while satisfying the onerous design demands.

The bridge features expansion joints at a number of locations, including at several positions along each approach bridge as well as at both ends of the main bridge. With its total length of 968m, the main bridge placed the greatest demands for longitudinal movement, as might be expected. The expansion joints at each end of this bridge section were designed for longitudinal movements of up to 1,360mm, and rotations about vertical and transverse axes, during a specified seismic event, of +/- 0.005 radians and +/- 0.030 radians respectively.

For greater movements which might occur in larger, less likely earthquakes, the expansion joints had to be designed to ensure two things:

- The expansion joint itself, and the connecting parts of the bridge, should not be seriously damaged; and
- It should be possible to re-open the bridge to traffic as quickly as possible after the event, to allow the movement of emergency vehicles, the evacuation of affected people, and the provision of relief services such as food, water, housing and reconstruction.

4.3 *Optimal approach using Fuse-Box seismic protection*

The above requirements could be most optimally satisfied by the addition of the *Fuse-Box* system to the standard modular expansion joint which has proven its worth on thousands of bridges worldwide. *Fuse-Box* consists in principle of a triangular steel "nose" at one side of the expansion joint, which rests (with a connection of designed shear capacity) on a steel ramp that is permanently fixed to the main structure. In the event of an earthquake which causes the joint movement capacity to be exceeded, the connection between nose and ramp will fail, allowing the nose (and joint to which it is connected) to move independently of the ramp and main structure to which the ramp is connected. After the earthquake, the joint will remain in place across the bridge gap, and with little or no effort should be capable of permitting the passage of emergency and evacuation traffic. It can also with relatively little effort be reconnected to the bridge to allow normal traffic flow to resume. The principle of the system is illustrated in Figure 7.

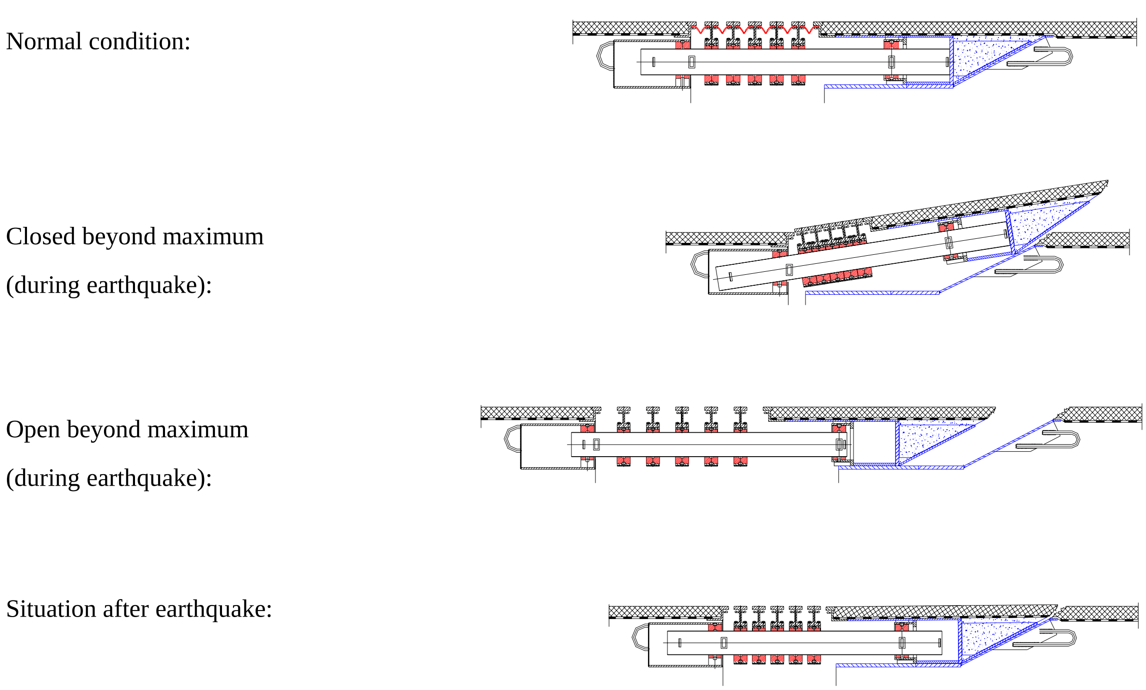

Fig. 7: Principle of the Fuse-Box system

The *Fuse-Box* principle is an elegant solution to the challenges presented, but it is by no means the only option. As an alternative, a standard modular expansion joint without *Fuse-Box* could have been designed to accommodate all seismic movements (including for larger earthquakes). However this would have resulted in a significantly larger expansion joint, with more gaps and larger space requirements in the bridge deck. Such a solution would entail not only higher initial costs, but also higher maintenance costs due to the increased number of wear and tear parts which would then need to be replaced during the lifetime of the expansion joint. The use of Fuse-Box also ensures some protection for the bridge in a seismic event larger than that allowed for in the design of the bridge – no matter how severe an earthquake, the expansion joint will cause less damage to the main structure if it can break free thanks to *Fuse-Box*.

4.4 *Transport and installation*

The transport of the largest joints presented its own challenges, in particular due to the width of each, which greatly exceeded the width of the transporting truck (see Figure 8). This resulted in a need for special measures and permissions for the road transports.

Fig. 8: Expansion joint with Fuse-Box (at left side) ready for transportation

The transportation frames, specially designed to ensure safe lifting of the joints, also enabled the pre-setting of the joints to be adjusted on site. This is necessary to ensure that the width of the joint when connected to the bridge at each side precisely matches the width of the bridge gap at that moment, which varies due to temperature effects and can therefore not be predicted with any certainty.

The installation of one expansion joint, with a total length of 24.5m, is shown in Figure 9, while a view of the underside of a 17-gap modular joint after installation is shown in Figure 10.

Fig. 9: Lifting in of one LR17 expansion joint

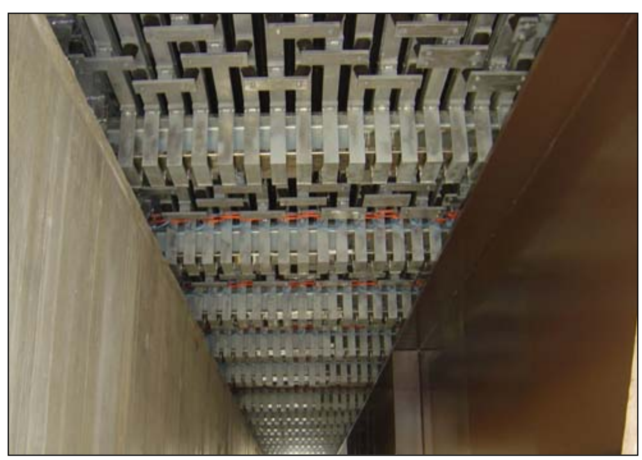

Fig. 10: A large modular expansion joint, viewed from below

5 CONCLUSIONS

The clever designs and careful detailing of the mechanical parts of the Golden Ears Bridge played an important role in complementing the innovative design of this special structure. Had design of the bridge's bearings and expansion joints to satisfy the onerous demands not been possible, the design of the bridge may have had to be adapted in order to fulfil all specified performance criteria, perhaps involving more materials in a relatively standard, less elegant structure. But it is incumbent on the engineering community to push the boundaries of what is possible, or rather, of what is known to be possible, by developing new and better ways of designing and constructing structures such as large bridges. The design and fabrication of the expansion joints and bearings of the Golden Ears Bridge facilitated the innovative design of the bridge, showing that manufacturers of key products right down the supply chain can play an important role in the progression and development of the engineering sector in general.

REFERENCES

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