Supporting economical bridge construction – the central hinge bearings of the 2nd Shitalakshya Bridge

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ABSTRACT: The 2nd Shitalakshya Bridge in Bangladesh is a balanced cantilever type structure built of prestressed concrete box girders. The deck sections of each main span are connected at mid-span by means of a central hinge, which must ensure that the deck ends at each side of the joint move in unison. This type of bridge is quite popular in many areas due to its ease of construction and overall economy, but suffers from an inherent problem: the hinge points are subjected to sudden and frequent load reversals during the passage of traffic over the bridge, resulting in continual hammering action on the parts of the hinge. To overcome this problem, a special state-of-the-art central hinge bearing has been proposed, designed, manufactured and supplied for this bridge. The central hinge bearing works as a perfect and ideal hinge, allowing translation in its longitudinal direction and rotation. The use of such bearings thus solves the problems experienced in the past by balanced cantilever bridges, and therefore allows this relatively economical form of construction to continue to be used without concern about lack of durability – a significant development for the bridge construction industry.

1 INTRODUCTION

1.1 The River
The Shitalakshya River is a 110km long distributary of the Brahmaputra, with many industries along each side. The 2nd Shitalakshya Bridge forms an important crossing of the river and will link the capital with Sylhet and Chittagong highway through Demra and Narayanganj, and ease the serious congestion experienced at the 1st Shitalakshya Bridge at Kanchpur. The new bridge will also facilitate the transport of agricultural products and raw materials across the country.

1.2 The Bridge
The BDT 621.34 million (USD 9 million) bridge at Demra on Dhaka-Narshingdi-Sylhet National Highway under KFAED assistance was constructed by Monico Ltd. of Bangladesh in joint venture with CEH of Singapore & Fulaij of Kuwait, and was opened to traffic in April 2010 (Figure 1).
The 1,072m-long bridge consists of multiple types of structure, including twenty 15-metre spans, ten 47-metre span box girders, two 61-metre span box girders and two 90-metre span progressive box girders. The deck is supported by 222 no. 600mm-diameter cast-in-situ bored piles and 8-metre diameter 35m-long caisson foundations.

The main bridge spans are of the balanced cantilever type, which is one of the most efficient and economical solutions for medium to long span bridges, thanks to the simplicity of construction and limited amount of temporary works required. The deck sections, which cantilever out from the supporting piers, meet at mid-span location, where they are connected by means of a central hinge which must ensure that the deck ends at both sides of the joint move in unison.

1.3 Evolution of the balanced cantilever bridge

Since the nineteenth century bridge engineers have recognised the advantages of continuous spans over simply supported spans in building longer span bridges. However, the design of continuous span bridges posed the problem of analysing an indeterminate system in that age without the help of modern computers. Therefore a hinge point was introduced to make the structure statically determinate but also exploit the advantages of continuous span bridge construction.

With the advent of pre-stressed concrete technology in the last century, the balanced cantilever construction method became popular for concrete bridges, as an economical and efficient way of construction. Using this construction method the bridge grows from foundation to pier and then gradually branches out from the pier head simultaneously in both directions, balancing itself about its support point all the way. The cantilevers are extended out progressively until the mid-span is reached. The deck sections from each side are then connected at the mid-span location by means of a central hinge, which must ensure that the deck ends at each side of the joint move in unison.

However, the balanced cantilever concrete bridge structure faced a serious difficulty in realising the idealised hinge in practice. A metallic plunger type hinge connection, often adopted for such bridges, was found to become ineffective within a short time and therefore all the advantages of this attractive construction method were out-weighed by this single but significant problem.

2 UNDERSTANDING THE PROBLEM

The primary issues related to the detailing of the hinge point can be understood by reference to the simple analytical models presented in Figures 2 to 4. Figure 2 illustrates the nature of bending moment on the cantilever arm and the shear force at the hinge point under a moving load, in an ideal hinge condition. This shows that as a load moves across the bridge, with the hinge modeled as an “ideal hinge”, the influence line of the resulting bending moment at point ‘A’ is symmetrical about the hinge. It is also true that the ultimate bending moment on the cantilever is not influenced by the presence of the hinge, except that the passage of load from one side of the hinge to the other is facilitated by the hinge in a gradual and symmetrical manner. It can also be noted that the shear force at the hinge point is maximum when the load is placed at the cantilever tip and the hinge is acting ideally.

This behaviour is no longer true when the hinge does not behave as an ideal hinge, with an irregular pattern resulting as shown in Figure 3. In a semi-hinged condition, i.e. with a reduction of shear force at the hinge point, the influence line for bending moment at point ‘A’ becomes unsymmetrical as the load crosses the hinge. In other words there is a sudden reduction in bending moment on the cantilever arm as soon as the moving load crosses the hinge point. The less ideally the hinge behaves, the more pronounced the effect. In the case of a ‘No-Hinge’ condition, i.e. when the shear force becomes zero, the bending moment will suddenly change from maximum to zero (in fact it would be reversed due to the rebound effect). This effect potentially contributes significantly to the fatigue stress on the entire structure and in fact may also cause loss of pre-stress on the cantilevers.
Figure 2. Effect of moving load on balanced cantilever bridge with “Ideal Hinge”

Figure 3. Effect of moving load on balanced cantilever bridge in ‘Semi-Hinged’ or ‘No-Hinged’ condition
Figure 4 demonstrates the deflection pattern of the structure in ‘Semi-Hinged’ or ‘No-Hinged’ condition. The first three illustrations show the deflection and movement effect under a moving load at ‘Semi-Hinged’ condition. The fourth illustration depicts the deflection and movement effect under a moving load in ‘No-Hinged’ condition producing vibration of the cantilever arm in the vertical plane and the entire structure in the longitudinal plane. This resulting vibration is extremely detrimental to the health of the structure because of the quick stress reversal and the fatigue effect thereof.

![Figure 4. Deflection and movement pattern in ‘Semi-Hinged’ or ‘No-Hinged’ condition](image.jpg)

It must also be recognized that there is a sway effect on the piers causing longitudinal movement of the deck with each passage of a vehicle, thereby resulting in an enormous accumulated movement over the years of service. The effect of all other factors which cause movement of the bridge, including temperature variations, differential settlement/tilt of foundations, seismic effects and differential loss of pre-stress, is dwarfed by this single cause of movement due to the passage of live loads. It can be estimated that the total accumulated movement at the hinge point, during a service life of fifty years, due to all other effects, can be reached in less than a year due to this live load effect only. It may also be noted that the movement due to the passage of live loads at the hinge point always takes place under active and transient shear forces due to the same live load.

3 THE CONVENTIONAL HINGE BEARING AND ITS PROBLEMS

Plunger plate type bearings (Figure 5) have traditionally been used at the hinge location, but have exhibited severe fatigue distress in practice due to continuous load reversal. In a conventional plunger type hinge bearing, the load transfer takes place through line contact of metallic components. The hinge bearings (i.e., the line contact zones) are subjected to quick reversal of stress during the passage of vehicles, resulting in continuous hammering action.

The line contact zones are also subjected to wear and tear caused by frequent reversible longitudinal movements of the bridge deck due to sway during the passage of each vehicle. This dynamic effect aggravates the continuous impact, which together with the wear and tear at the line contact zone quickly produces a gap between the plunger and the plate due to fatigue. The dynamic behaviour of the cantilever arm due to the semi- hinged condition (resulting from the gap between plunger and plate) will further aggravate the fatigue and thereby the distress. The gap then grows quickly, producing a ‘no hinge’ condition within a short period. The effect of continuous impact also produces continuous and quick reversal of both shear and tensile stresses on the bolts which anchor the plunger plate type bearings, often resulting in failure of the bolts due to fatigue.
To provide a solution to the serious issues described above, a sophisticated plane contact type central hinge bearing has been proposed, designed, manufactured and installed in the 2nd Shitalakshya bridge (Figure 6). This was based on a similar solution which had been used for a bridge over the Ganga at Varanasi 15 years previously, where the bearings continue to fulfil their purpose without any problem.

This special central hinge bearing consists of interlocking male and female parts, which are anchored to the tips of the cantilevering deck sections by means of tensioned high strength Macalloy or equivalent PC bars. Special bearing devices are housed at the top and bottom of the male hinge, which slides over the stainless steel plate provided in the female hinge. The special bearing devices also feature pre-compression applied during bearing assembly in order to ensure perfect contact throughout the proposed service life.

This special bearing works as a perfect and ideal hinge with an additional degree of freedom permitting translation in the longitudinal direction as well as rotation. The sliding load bearing’s flat interface of special wear-resistant alloy with impregnated solid lubricant slides on stainless steel and offers minimum resistance, resulting in greatly reduced wear and greatly enhanced durability. The elastomeric load bearing component will ensure absorption and even distribution of energy, eliminating the effect of continuous hammering action during the passage of vehicles and thus reducing fatigue. Pre-compressed elements of the bearing device and the special sliding elements will always maintain perfect contact between the male and female parts and thereby deflection compatibility between the adjacent cantilevers. The specially designed pre-stressed anchorage system will maintain zero tension condition at the vertical contact surface of the girder and bearing and thus the full capacity of the concrete in compression can be utilized, and fatigue failure of the anchor bolts can be avoided. Furthermore, all components of the bearings are easily accessible and replaceable.

Each complete central hinge bearing weighs approximately 4.5 tonnes, therefore the installation of the bearings (see Figure 7) posed a significant challenge, especially due to the fact that the bearings are located at centre span over water with no pier or substructure underneath.
The housing recesses in the webs of the box girders were suitably constructed to accommodate the central hinge bearings. Local thickening of the webs of the box girders, by additional concreting, was required to make provision for anchoring of the bearings by means of Macalloy bars. Suitable holes through the concrete were provided to accommodate the Macalloy bars. Helical reinforcement bars were provided within the concrete blocks to prevent bursting of the concrete.

![Central hinge bearings being installed in 2nd Shitalakshya Bridge](image)

First, the bearings were properly positioned and temporarily fixed by fastening the nuts of the Macalloy bars (Figure 8). Then the gaps between the backs of the male / female parts and the vertical planes of the respective adjacent structures were grouted with high strength, free-flow, non-shrink cementitious grout. The Macalloy bars were then tensioned to apply the required stress to the concrete block, and the holes around the Macalloy bars were filled with high strength, free-flow, non-shrink cementitious grout. The special bearing components were finally pre-compressed by adjusting provided taper plates.

### 6 CONCLUSION

Special sophisticated central hinge bearings as used on the 2nd Shitalakshya Bridge can be used not only to facilitate the construction of new balanced cantilever bridges but also to rehabilitate many such bridges which were constructed earlier but are now in a distressed condition due to the hinge problem. Such a rehabilitation project is already progressing for the Kalpi Bridge in India, where 16 such bearings will be installed to replace the distressed existing plunger type bearings and thus rejuvenate the condition of the bridge.

The central hinge bearing thus offers a solution to the problems experienced in the past by balanced cantilever bridges, and therefore allows this relatively economical form of construction to be used in the future without concern about lack of durability – a significant development for the bridge construction industry.