Seismic isolation of the Jamuna multipurpose bridge

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Abstract

The Jamuna Multipurpose (or Bangabandhu) Bridge consists mainly of a viaduct equal to 4.9 km length. The static arrangement is that of a typical multi-span continuous Gerber girder bridge; each box girder has 6 or 7 spans of 99.750 m. FIP Industriale supplied bearings and seismic devices which were to be designed to satisfy the dual aim of: 1) guaranteeing a «classic» static scheme during normal service operation, providing fixed points for horizontal forces (transversal and longitudinal) and guiding devices to allow longitudinal movements of the deck with respect to the piers; 2) to provide multidirectional dampers able (in the event of an earthquake) to transmit to each pier a horizontal load lower than 4250 kN, limiting at the same time the displacement within ±200 mm. The above targets have been achieved through the design and installation of 118 multidirectional pot bearings (VASOFLOQ type) and 48 steel hysteretic dampers of types MEP and MEPOT. Each damper consists of 42 steel dissipating elements (double tapered spindles) working in parallel, and has yielding force and displacement approximately equal to 3500 kN and 30 mm, respectively. Beyond that limit, the dissipating spindles deform plastically and thus control the horizontal force transmitted to the pier. The damper maximum force at 200 mm displacement has been experimentally verified to be lower than 4250 kN. The difference between types MEP and MEPOT consists in the presence in the latter of two shock-transmission units (OT devices), that are able to accommodate longitudinal displacements due to thermal deformations of the deck, whilst locking during earthquakes. Thus, the MEPOT type is used at the expansion points and the MEP type at the fixed points of the girder. During earthquakes the behaviour of MEP and MEPOT devices are identical.
1 Introduction

The aim of this paper is to discuss the seismic devices supplied by FIP Industriale for the Jamuna Multipurpose Bridge in Bangladesh. As it is well known, seismic isolation can substantially improve seismic performance of different types of structures, and often accrues significant savings in construction costs. In particular, it is an economical way to protect piers and foundations, as well as abutments in some cases, when bridges are located in highly seismic-prone areas such as that of the above mentioned structure. The Jamuna Bridge is located approximately 30 km away from an active fault (Russell [1]). Bridge seismic isolation aims to reduce loads as well as distribute the same throughout sub-structural elements. Also, in the case of the Jamuna bridge, the design engineer's objective in selecting the seismic isolation system was to limit loads on the foundations.

2 Description of the structure

The infrastructure lies 120 km north of the capital Dhaka and comprises a 4.9 km viaduct. In plan view, the viaduct conforms to a 12,000 m constant radius, curved longitudinal axis. The static arrangement is that of a typical multi-span continuous Gerber girder bridge with girders 6 or 7 spans long (99.750 m).

The deck has a box girder structure, achieved by on-site connection of prefabricated precasted reinforced concrete girder elements. It has a 18.5 m wide slab and its height varies from 2.75 to 5.5 m (Russell [1]).

3 Design requirements

The design of the supporting system was conceived considering the behaviour of the structure from a dynamic point of view during the seismic event rather than just the static point of view, at it is usually done.

In terms of design Code reference, the Specification complies with BS 5400; specifically, with Parts 9.1 & 9.2 for the bearings.

As a precise requirement of Specifications and in order to reduce the amount of horizontal load applied at the top of the piers, especially during seismic events with a ground peak acceleration of 0.47 g, FIP was asked to custom design a device capable of keeping horizontal loads generated by the mass of the superstructure within the range indicated in Figure 1, allowing ± 200 mm plastic displacements.

As there are no guided or fixed bearings located in the main piers and the deck rests on free sliding pot bearings of 33000 and 30000 kN vertical load capacity, the design of the seismic devices had to meet the following requirements:

- guarantee a «classic» static scheme under normal service conditions providing fixed points for horizontal forces (transversal and longitudinal) and guiding devices to permit longitudinal deck movements with respect to the piers;
• provide a multi-directional damper system (able to withstand 15 cycles at the design displacement) under seismic conditions;
• provide a lateral stop-block, acting at displacement of 250 mm, designed for 4500 kN capacity;
• all the bearings as well as the seismic devices should be easily replaceable without excessive deck jacking.

Figure 1: Steel hysteretic damper nominal curve requested, indicating range of accepted values.

4 The seismic isolation system

The seismic design requirements were fulfilled by FIP Industriale through the design of multidirectional steel hysteretic dampers comprising double tapered spindles as dissipating elements. These dampers, whose sole aim is to control horizontal forces, are combined with free sliding pot bearings (VASOFLON type) that serve to transmit vertical loads (up to 33000 kN each) and permit horizontal displacements in all directions.

Figure 2 shows the bearing system under both service and seismic conditions of a typical multi-span girder of the Jamuna Multipurpose Bridge. Specifically, the second girder (starting from the east end pier), resting on seven piers. Under service conditions (Figure 2-A), there is a fixed point (pier 38) where a seismic device type MEP is located. On the expansion points, there are seismic devices type MEPOT, capable of accommodating longitudinal deck displacements (due to thermal deformations, creep, and shrinkage), thanks to the presence of Shock-Transmission Units (STUs) coupled in series to steel hysteretic dampers. During an earthquake, all seismic devices behave identically,
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dissipating a great amount of the energy transmitted by the seismic event through the plastic deformation of their steel spindles. In fact, the STUs lock, transmitting the force to the spindles.

Figure 2: Bearing system of a typical girder of the Jamuna Bridge: A) under service conditions; B) under seismic conditions.
Figure 3: Elevation view, along the transverse direction, of the seismic device MEPOT 350/200: 1) spindle dissipating element; 2) Shock Transmission Unit (STU); 3) stop-block element.

Figure 4: Elevation view, along the longitudinal direction, of the seismic device MEPOT 350/200: 1) spindle dissipating element; 2) STU; 3) stop-block element.
Each damper, of both the MEP and MEPOT types, comprises 42 double-taper spindles working in parallel, designed for a yield force approximately 80 kN each and a maximum force of 100 kN each at 200 mm displacement. The spindle (single or double-taper) is one of the dissipating elements typically used by FIP Industriale to achieve steel hysteretic dampers. One of its main advantages is its intrinsic multi-directionality. The STUs in each MEPOT device are two, with a nominal maximum force of 2100 kN each. They comprise double-action hydraulic cylinder-piston systems filled with silicon compound. Figures 3 and 4 show elevation views of a MEPOT seismic device along the bridge transverse and longitudinal directions respectively. As already mentioned, the MEP type is identical save for the absence of STUs.

It is worth mentioning that service loads (i.e., wind, braking actions, etc.) do not stress the dissipating elements owing to the use of "sacrificial restraints", designed to fail at a 500 kN horizontal load. Said sacrificial restraints impede any displacement in the dampers of the fixed type and the transverse movements on those of the expansion type. In the event of a strong earthquake, the sacrificial restraints fail and the dampers are activated.

The seismic devices provided by FIP can also withstand greater displacement than the ± 200 mm design value. The spindles themselves can withstand significantly higher displacements (see § 5). At any rate, under an extremely unlikely earthquake higher than the design-level, a stop-block intervenes with the onset of ± 250 mm transverse displacements.

FIP Industriale also supplied other structural devices for the Jamuna Bridge. These were unidirectional and multi-directional VASOFLON pot bearings with variable vertical load from 8500 to 11500 kN, installed on the West End and East End piers as well as at the Gerber girder connections, as well as special foam rubber bumpers to limit damage to the vertical girder interfaces due to possible hammering.

In conclusion, the FIP Industriale supply for the Jamuna Multipurpose Bridge comprised the following:

- N. 48 VASOFLON Bearings VM 3300 (at the North Side)
- N. 48 VASOFLON Bearings VM 3000 (at the South Side)
- N. 2 VASOFLON Bearings VM 1150
- N. 6 VASOFLON Bearings VM 900
- N. 8 VASOFLON Bearings VU 850
- N. 41 Steel Hysteretic Dampers MEPOT 350/200
- N. 7 Steel Hysteretic Dampers MEP 350/200
- N. 84 Bumpers with a maximum load of 60 tons.

5 Testing

Functional tests were carried out at the FIP Industriale laboratory on both spindle dissipating elements and a STU (herein described), as well as on pot bearings and foam rubber bumpers.

A group of four full-scale spindles were tested together (see Figure 5) imposing displacement at a velocity of 100 mm/min. First, 15 complete
hysteretic cycles at the design displacement of ± 200 mm were imposed; then, two of the elements were displaced until one of them failed. Said failure held at a 315 mm displacement. The fifth cycle was selected as reference cycle to compare test results to design requirements. Figure 6 shows the hysteretic loop measured during this cycle on the four elements. The average yield force and displacement were 317.5 kN (corresponding to a force of 3333.75 kN on the complete device consisting of 42 elements) and 27 mm, respectively. During the same cycle, the average maximum force at ± 200 mm was of 397.5 kN (corresponding to 4173.75 kN for the complete device), and thus in compliance with the design limit value. Figure 7 shows the force vs displacement curve measured on a pair of spindles during the 16th cycle, until failure.

Three different types of tests were carried out on the STU at three different temperatures (10, 27 and 40 °C):
1) low velocity test;
2) impact test;
3) dynamic test.

In the first test, the displacement was imposed at a velocity of 0.03 mm/s, i.e. the actual thermal velocity of the bridge, for at least a complete cycle of ± 20 mm. This test aimed to verify that the reaction force opposed by the STU to thermal movements is lower than the specified value (e.g.: 3 % of the nominal load, at ambient temperature). With reference to the nominal load, the measured values were the following: 3.35 % at 10 °C, 2.16 % at 27 °C, and 1.20 % at 40 °C. These differences are due to the changes in the viscosity of the silicon compound with the temperature.

The objective of the impact test was to verify whether the STU is capable of reaching the predicted reaction under an impulsive action (at velocity higher than 20 mm/s). Therefore, a thrust was applied, both in tension and compression, at 26 mm/s. The measured force was 2260 kN, higher than the minimum prescribed value (2100 kN), and the corresponding displacement was about 17 mm (about 7 % of the total device stroke).

The dynamic test consisted of a force-imposed sinusoidal test, with amplitude equal to the design load and frequency as high as possible with available power system, for a certain number of cycles. This test aims to verify that the device response will be almost constant during an earthquake. The actual inputs in the different tests had a maximum load in the range 2000⁻²²60 kN, while the frequency was in range 0.4⁻²⁰.5 Hz. Testing specifications required that the displacement induced by the applied load should not exceed 7 % of the maximum design stroke for the ambient temperature test. The displacements measured range from 4.78 % during the first cycle to 5.76 % during the 20th cycle.

6 Conclusions

The seismic isolation of the Jamuna Multipurpose Bridge represents a successful example of application of seismic devices consisting of multiple
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spindle steel hysteretic dampers and shock transmission units, as well as other structural devices such as free sliding bearings, expansion joints and rubber bumpers. The adoption of the seismic isolation approach permitted endowing the bridge with complete protection against the design earthquake at significant savings in construction costs compared with a traditional approach. Specifically, concerning the foundations. The seismic isolation system was custom designed in such a way as to maintain the classic structural scheme under service conditions and fulfill all design requirements. Furthermore, all the structural devices are easy to install. All such devices were subjected to acceptance tests, and fulfilled the design requirements.

References

Figure 6: Force vs displacement measured on four spindles (5\textsuperscript{th} cycle).

Figure 7: Force vs displacement on two spindles up to failure (16\textsuperscript{th} cycle).
Figure 8: A spindle during a preliminary test (350 mm imposed displacement).

Figure 9: The seismic device MEPOT 350/200 (cf. Figures 3 and 4).