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Structural Health Monitoring of Large-Scale Bridges: A Synopsis of the Padma Bridge

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ABSTRACT

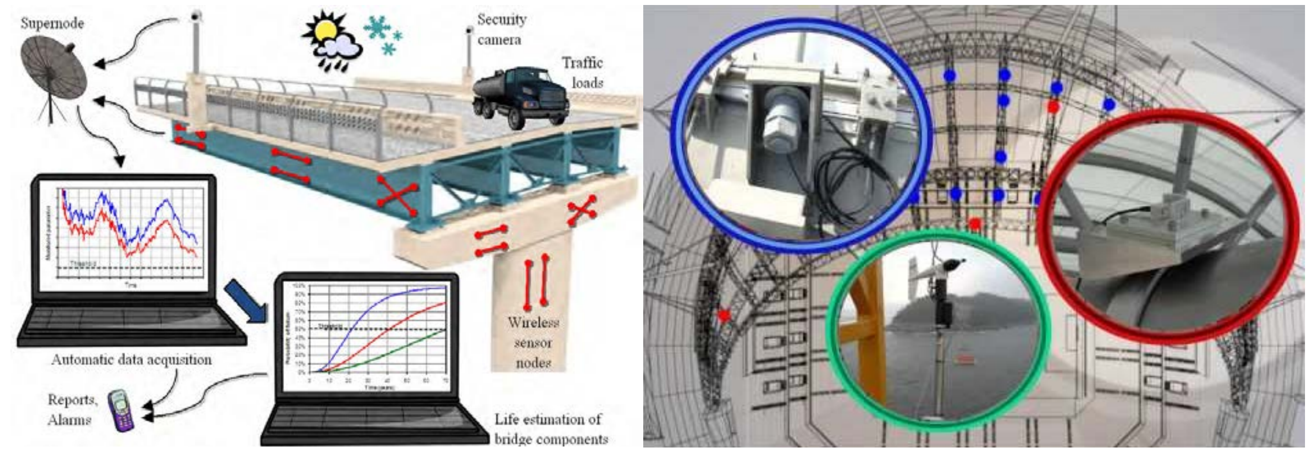
In the recent decade, the concept of "structural health monitoring," or SHM, has gained prominence due to its promise of reflecting the condition of structures and facilitating the monitoring of their behavior. Bangladesh is a country with a long coastline, thus it is unfortunate that the SHM system has not been more widely deployed on the country's many highway bridges across rivers. Saving money on manpower, remote monitoring allows for accurate, up-to-date assessments of a bridge's structural soundness. Recent developments in sensor, communication, and storage technologies have made a worldwide SHM system for infrastructures possible. The primary goal of this investigation is to assess the performance of the structural health monitoring system on the Padma Multipurpose Bridge. Recent developments in SHM's integration with ITS show the usefulness of ITS devices (such as traffic cameras and traffic detectors) in analyzing bridge responses to multimodal traffic with varying loads or during critical events that cause excessive vibration beyond the normal limit, which can be of great assistance in tackling the Padma bridge's serviceability challenge. Integrating information from an ITS device with SHM may increase the reliability and precision of the SHM system. As a consequence of this integration, the SHM system would be less likely to misdiagnose damages (i.e., vibrations caused by big cars on a bridge may be perceived by a SHM sensor as a structural health concern of the bridge), resulting in decreased maintenance costs. This investigative study provided a summary of the SHM systems now in place for major bridges in Bangladesh, such as the spectacular Padma Bridge, and discussed their use and appropriateness in the near and far future.

1. INTRODUCTION

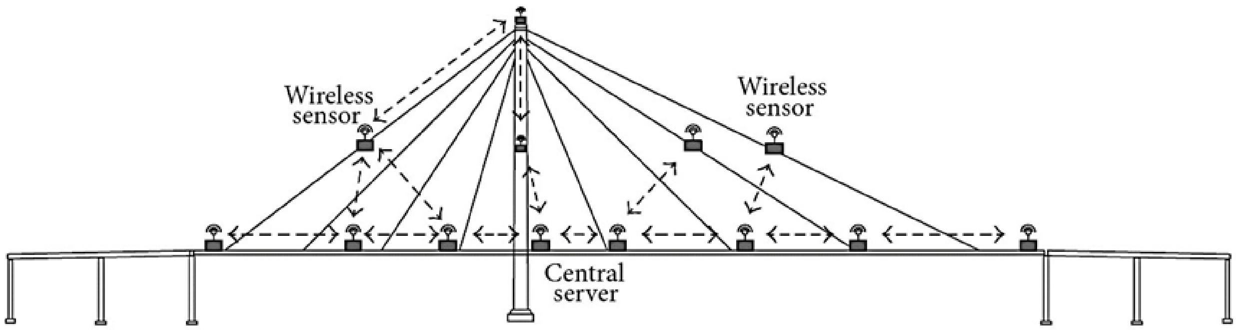
Bridge designs have a tendency to become more flexible throughout time, and their shape and function are becoming more complex. Therefore, ensuring the safety of these bridge structures is a crucial concern. Although safety monitoring is costly, it is impossible to guarantee a bridge's safety based solely on inspections and upkeep. Thus, the use of structural health monitoring (SHM) techniques has become crucial for ensuring the safety of bridge structures, particularly those with a long span. Due to the high expenses of bridge repairs and high-rise building rehabilitation, it is essential to continuously check structural health. SHM has the ability to extend the design lives of structures, ensure public safety, and significantly lower the cost of restoration. While failure or a loss of functionality in the structure can be avoided, damage, or the decline of system performance, cannot be prevented but can only be reversed. Therefore, SHM approaches are important topics for research in the field of engineering and academia [1]. Other than performance, safety, dependability, and serviceability are essential components of any engineering structure [2]. In consideration of these, it is crucial to use technology to monitor the engineering structures through evaluation and assessment [3-5]. In recent years, structural health monitoring (SHM) research has received increased attention from academic institutions, governmental organizations, and businesses in a variety of industries, including civil, marine, mechanical, military, aerospace, power generation, and offshore oil and gas. Engineering constructions function differently depending on their age, kind of material, service condition, and arrangement. Around the world, SHM technology is used in a variety of applications. For instance, in largespan bridges, such as the Hakucho Bridge in Japan [6], the Bill Emerson Memorial Bridge in the United States [7], the Jindo Bridge in South Korea [8], the Tsing Ma Bridge and the Ting Kau Bridge in Hong Kong [9], and the Sutong Bridge and the Jiangyin Changjiang River Bridge in China, SHM techniques have been developed extensively. These systems ensure the safe operation of the bridge, and numerous techniques are used to extend the life of bridges [10-13].

2. SIGNIFICANCE OF STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) is the formulation and application of methodologies and procedures that are helpful for the continual monitoring and upkeep of the structure's functional value. The primary goal of SHM is to warn the system in the early phases of damage start and prevent further failure propagation with the use of ongoing structurally integrated sensor monitoring. The development of SHM aids in damage detection and strategy analysis, which further aids in extending the useful life of engineering structures or components by preventing failure [14]. Any nation or state grows and prospers only if they carefully maintain and keep an eye on the key structures such as bridges, roads, railways, skyscrapers etc. In addition to averting financial losses, maintaining and monitoring the structures will promote public safety and health. It is obvious that if major structures are not adequately maintained and the recommended maintenance rules are not followed, this would have disastrous effects.



(a) Structural Health Monitoring equipment for a typical bridge segment



(b) WSNs-based bridge health monitoring system [17]

Figure 1: Structural Health and WSNs-based bridge health monitoring

These mishaps result in a great loss of life and hurt both the national and global economies. Enhancing public safety is one of SHM's key advantages. Sensors are used in advanced SHM techniques to gather data, which is then properly analyzed (Figure 1a). The government makes sure everyone is secure by requiring local governments to monitor all important buildings. Structures begin to age and have numerous cracks and weak places. The SHM procedure can be used to find flaws and cracks in older buildings. The management can either fix the problems or isolate the building for everyone's safety once the flaws are identified [15, 16]. The use of SHM by engineers enables them to identify early signs of poor structural health and related risk. Floods, which are brought on by broken dams, pipelines, and dykes, can be avoided with the aid of early detection [3]. Regular structural health monitoring aids in the early detection and correction of cracks and failures. This increases their lifespan as well as their effectiveness.

Advanced SHM techniques including the optical method, transient thermo graphic method, and eddy current method make it simple to detect even the smallest failure. Even the slightest cracks may be repaired with ease. This delays the spread of cracks that could eventually result in structural failure [18]. Implementing SHM not only increases the life of the structures and ensures public safety, but it also lowers both the short- and long-term costs related to structures. In particular, the business sector supports effective SHM as a way to boost total earnings. The maintenance schedules for the entire structure can be extended with the prompt detection and repair of minor faults. Fixing problems early on helps structures prevent significant damage and reduces costs associated with demolishing and rebuilding the entire structure [19].

3. REGIONAL STUDIES ON BRIDGE CONSTRUCTION WORLD-WIDE

In the past, SHM systems have included wired data collecting devices that may periodically collect structure data. These systems use various sensing device types, specific damage diagnostic and prognosis techniques, and structural conduct measurements to evaluate structural safety conditions. However, because expensive communication connections must be constructed and maintained on a regular basis, wired structural monitoring systems are not generally used due to their high cost. Low-cost wireless structure monitoring systems are now conceivable because of recent advancements in WSN and MEMS technologies (Figure 1b). In comparison to conventional wired SHM systems, the collaborative nature of WSNs for SHM application has a number of advantages, including self-organization, quick deployment, flexibility, and built-in processing power. In this light, WSNs are crucial in developing a highly adaptable and affordable SHM system that can act appropriately and quickly in response to real-time events.

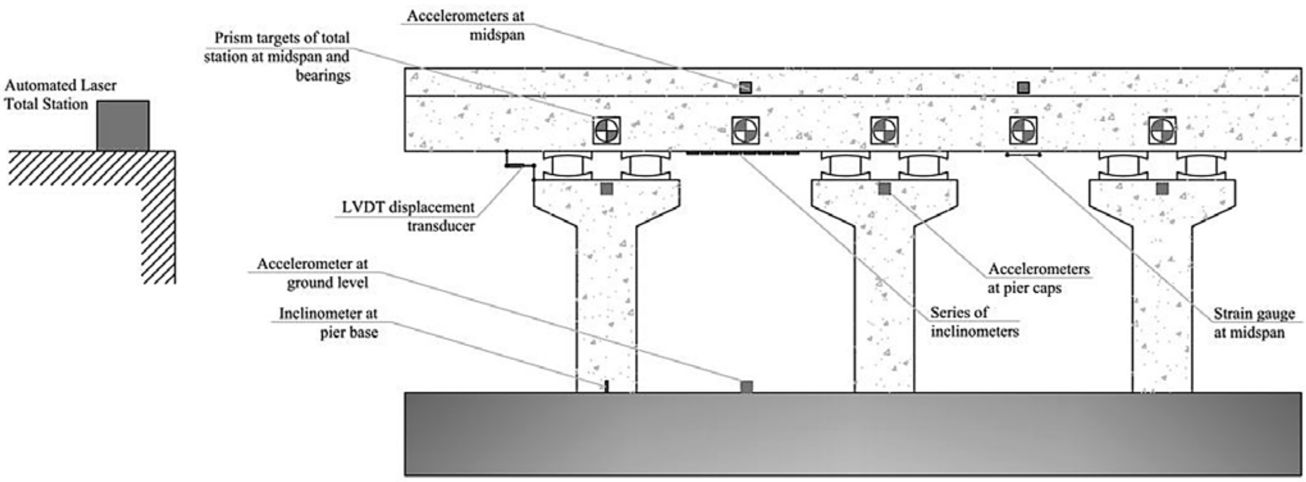


Figure 2: Placement of sensors on the bridge deck and piers [20]

Over 135 bridges in the United States are said to have partially or completely fallen between 1989 and 2000. Due to the scour of a bridge masonry pier, the Entre-os-Rios Bridge in Portugal fell in 2001, killing 59 persons. The significance of SHM systems for bridges is readily apparent.

Pre-stressed concrete box Girder Bridge known as St. Marx Bridge is situated in Vienna. In order to identify severe vehicle loads that could result in structural damage, a structural health monitoring system and a video control system were installed in 1998. There are currently four accelerometers and one temperature sensor installed. The Meriden Bridge has undergone extensive bridge health monitoring thanks to the installation of WSSNs and a wired system. A wired monitoring system with 38 different types of sensors was installed along with five Imote2 sensors [17, 21] (Figure 2). The first bridge with an extensive, self-contained wireless monitoring system is South Korea's second Jindo Bridge. A total of 71 WSS nodes with 427 sensing channels were installed on the girder, pylons, and cables. The nodes are made up of a sensor board, a battery, and the Imote2 (which has an integrated power management circuit, radio, and CPU on board) [22, 23]. Full-scale bridge health monitoring of the Meriden Bridge was carried out by deploying WSSNs and a connected system. A wired monitoring system with five Imote2 sensors and 38 sensors of various types was installed.

A. Geumdang Bridge of South Korea

In Icheon, South Korea, there is a bridge called Geumdang that has two structural systems: the northern span has a concrete deck supported by four pre-cast concrete I-beam sections, and the southern span has a continuous concrete box girder supported by three concrete piers. In order to monitor the bridge's vertical acceleration, a dense network of wireless sensors was fitted with a high sensitivity PCB Piezotronics 3801 accelerometer (sensitivity is 0.7 V/g).

In Figure 3, a continuous concrete box girder supported by three concrete columns supports the southern span and the concrete I-beam sections.

B. Tamar Bridge

Structure, Cable loads and environment temperatures as well as wind speed and profile were all monitored using the Structural Monitoring System (SMS) installed by

Fugro Structural Monitoring. Engineering data on the performance and state of the bridge before, during and after the strengthening and enlargement has been provided by the SMS (Figure 4). During the strengthening operations, it was specifically employed to track deck profile and cable loads. Among the sensors utilized in the SMS are:

- Fluid pressure-based level sensing system to monitor vertical displacement of the deck;
- Temperature sensors for the main cable, deck steelwork, and air;
- Extensometers and resistance strain gauges to measure loads in supplementary cables.
- Electronic tower top-to-tower distance measurement.

A brief description of the measurement/sensing systems are as follows:

i. Temperature: Platinum Resistance Thermometers (PRTs) on stainless steel shims with adhesive in their positions serve as temperature sensors for steel and cable monitoring. Temperature probes with shielding from radiation make up temperature sensors for air monitoring.
ii. Strain gauges: Resistive strain gauges mounted to main tensioning bolts at deck anchor points are used. Epoxy (protected by foil-backed putty) or micro-welding are two methods of fixing (covered by butyl rubber and neoprene). Around the bolt, gauges are set in pairs 180 degrees apart, with an axial element and an element to measure hoop strain in each pair. The temperature adjustment is provided by the hoop gauges, which are connected to a full Wheatstone Bridge by the four gauges.
iii. Wind detectors: At the top of the Saltash Tower, where wind direction is also monitored, as well as at the deck level of the Saltash Tower and Saltash Approach, wind speed is measured mechanically.
iv. Tower displacement measurements: A Plymouth Tower upper portal-mounted electronic distance measuring device (EDM) measures the distance between two towers. This makes use of a laser that is reflected off a vertical array of tiny prisms on the Saltash Tower upper portal wall; the size of the array permits in-plane movement of the Towers.
v. Level sensing system: A fluid manometer system with fluid-filled pipes runs along the primary span of this level sensing system. Level sensing stations (LSS) with 1/8 span centres monitor heights by taking pressure readings on the fluid head. The system is modelled after a comparable system that Fugro placed on bridges on the Lantau Fixed Crossing. The height measurements are updated every 10 seconds and have a +/5mm accuracy specification [24] (but sampled at 1Hz). Each LSS additionally has a set of fluid temperature sensors.

In order to track the dynamic behaviour of the bridge deck and particular cables, University of Sheffield installed an additional set of sensors in 2006. Four stay cables, P4N, P4S, P1N, and S2S were equipped with two accelerometers, one oriented horizontally and one in the vertical plane of each cable, in order to verify the damper solution's excellent performance (Figure 5 - 7).

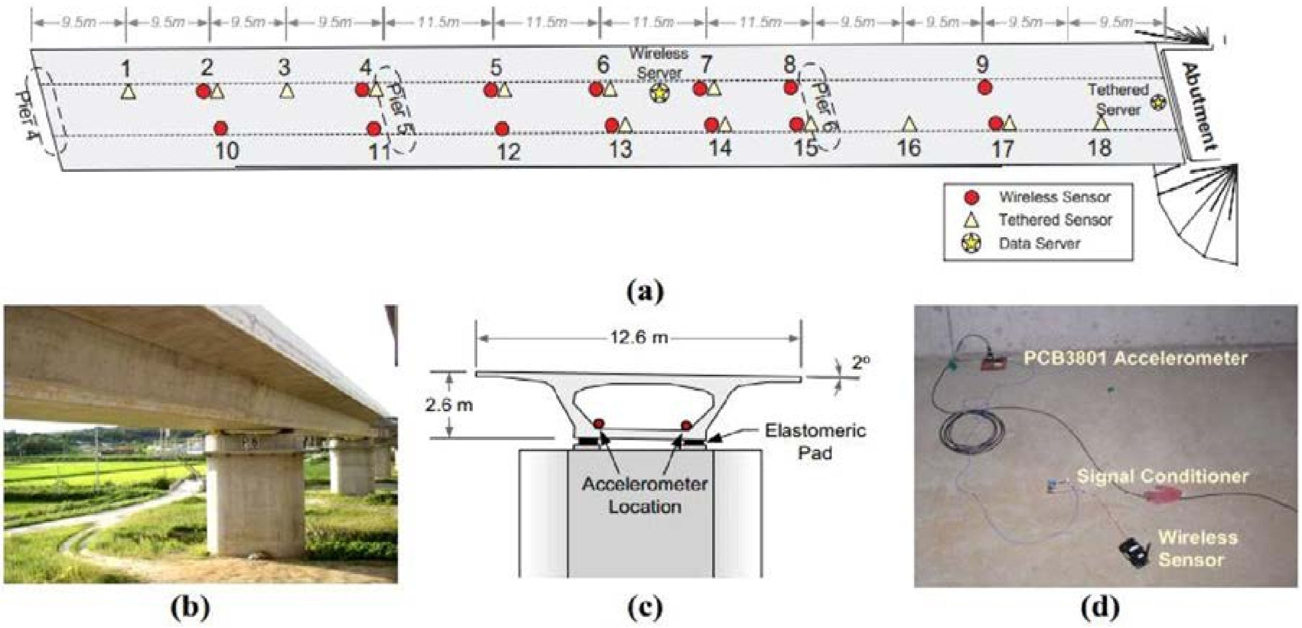


Figure 3: (a) Location of wireless sensors installed along the length of the Geumdang Bridge; (b) External view of the box girder bridge; (c) Cross-section of the box girder showing the location of accelerometer location; (d) Typical wireless sensor-accelerometer installation [21]

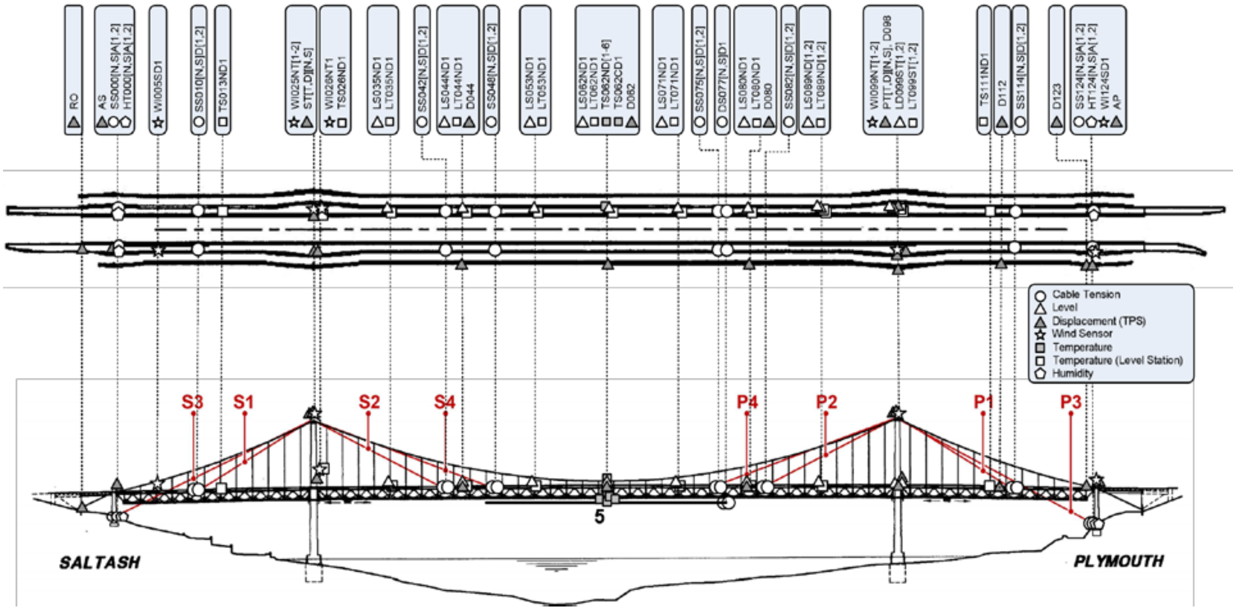


Figure 4: Sensors in Tamar Bridge [25]

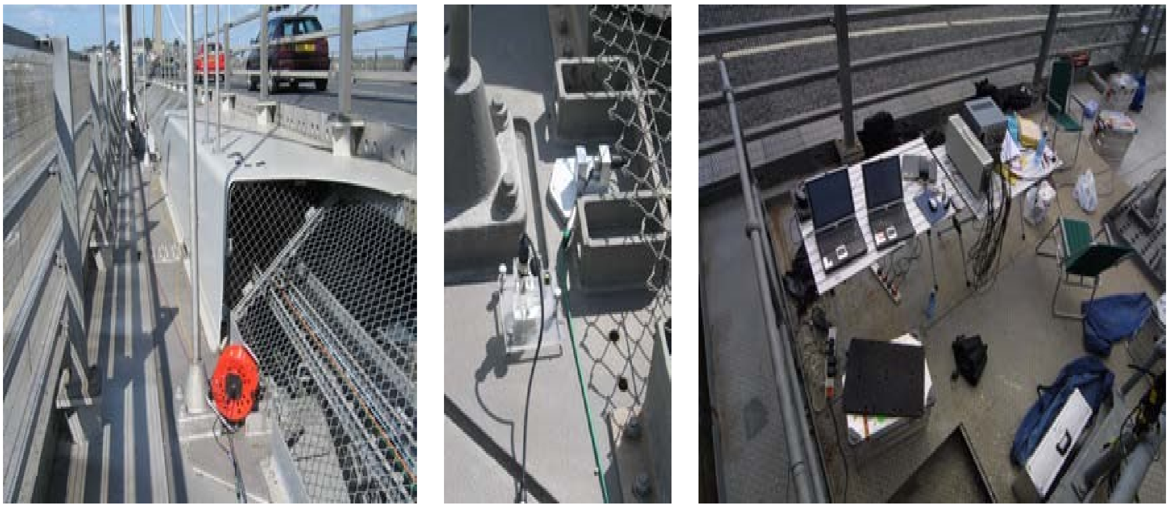


Figure 5: AVT in progress, displaying where the accelerometers are located next to the shear box and the data gathering facility is located close to the tower [25]

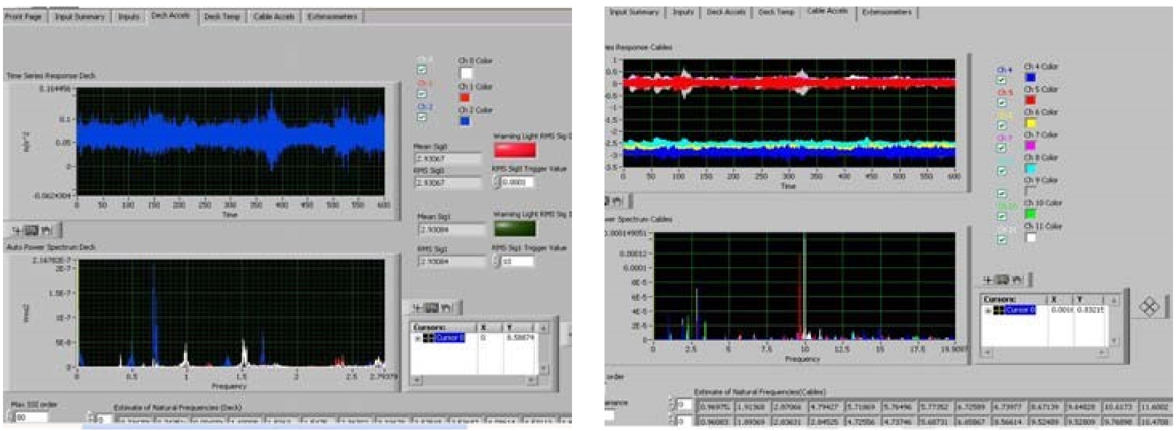


Figure 6: Lab VIEW virtual instrument pages displaying time- and frequency-domain signals from cable and deck accelerometers [25]

Figure 7: Reflector in bridge deck [25]

C. Jinghang Canal Bridge (JCB)

China's Jinghang Canal Bridge is a pre-stressed concrete single-cell box girder bridge with a span length of 150 meters. For long-term monitoring, variables like temperature, reinforcement strain, and deflections are used. Vibrating strain gauges with built-in temperature couplings were incorporated into the bridge to reduce the expense of the long-term monitoring system. Eight cross-sections, including sections Z2 and Z3, A1 to A4, B1 and B2, were employed with the hydrostatic leveling system for long-term deflection monitoring. On the inside surface of the box girder's web, each DT was mounted. The major span support strain increment is determined to be negligible, indicating that concrete shrinkage or creep is negligible there. But the effect has been found to be strong at the middle of the major span. Deflection at mid-span is one of the primary issues with pre-stressed concrete bridges, as evidenced by the discovery that the measured time dependent deflections are greater than the design values [21]. Figure 8 depicts the sensor configuration for the stages of monitoring throughout construction, completion testing, and service.

D. Kishwaukee River Bridge in Illinois

Since December 2001, an automated bridge monitoring system has been installed on the Kishwaukee River Bridge in Illinois, USA. Because of the structure's long-term stability, crack opening displacements can be directly evaluated using LVDT to determine how the structure will age over time [26] Seven LVDT sensors were put on the Kishwaukee bridge to measure the shear crack opening displacement on the box-girders [27] (Figure 9).

E. Bangabandhu Bridge

The pre-stressed concrete box girder Bangabandhu Bridge is situated in Bangladesh (Figure 10). With a primary span of 100m, the whole length is 4.8 km. The cost to fix surface fractures on the deck in 2014 was roughly 147 million USD. According to reports, these cracks developed as a result of temperature differences between the upper and lower parts [28]. Temperature sensors had been employed to collect data on a regular basis to monitor the temperature variation of the upper and lower parts (Figure 11). The Bangabandhu Bridge is also instrumented with two triaxial, one biaxial, five uniaxial accelerometer sensors and three displacement sensors (Figure 12) [27]. There are sixteen channels of data. The data are fed to three digital data recorders. The recorders are connected to one communication enclosure for data transfer to the server of a Data Control Centre through 2.4 GHz. Wireless radio antenna. One borehole sensor is placed at the west end of the bridge. In addition, six free field stations, three on each side of the Jamuna River, are set up to measure the ground motions. The free field stations are 70 to 90 km apart.

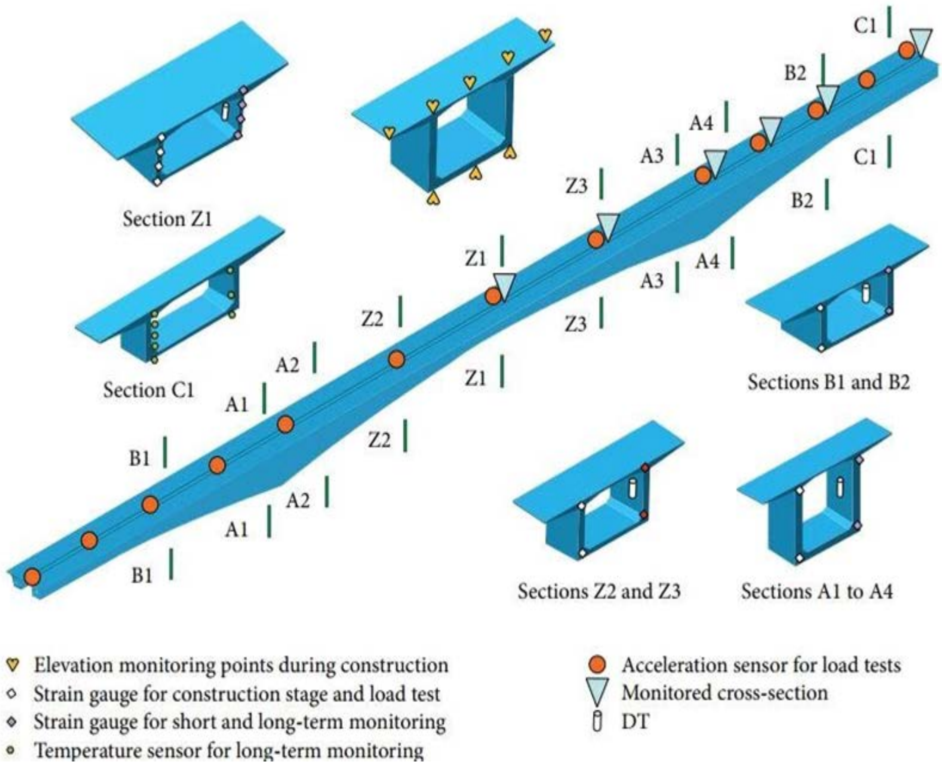
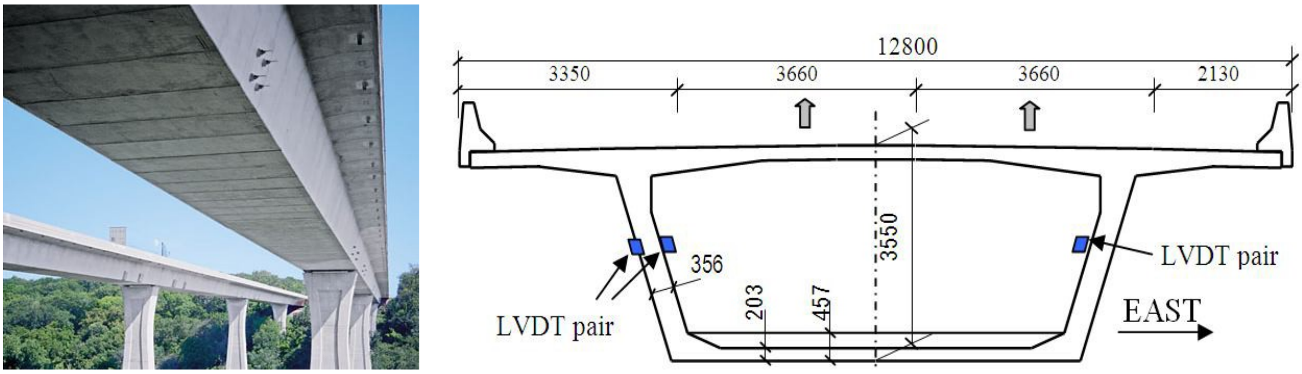


Figure 8: Sensor layout of Jing hang Canal Bridge [21]



(a) (b)

Figure 9: (a) Kishwaukee Bridge, (b) Location of LVDT sensors (unit: mm) [27]

Figure 10: Bangabandhu Jamuna Bridge[21]

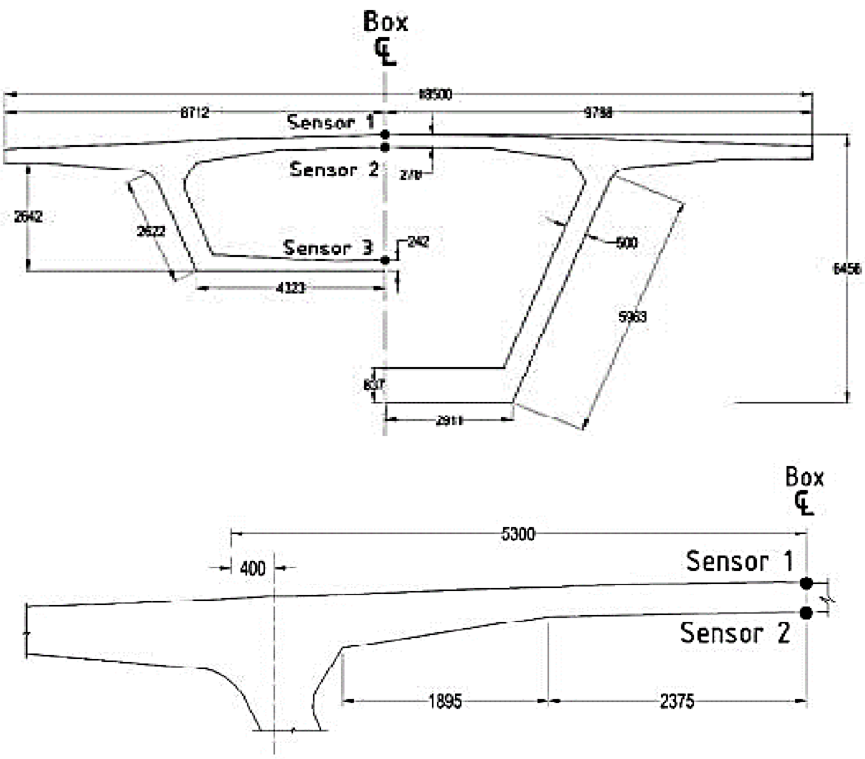


Figure 11: Location of sensors to monitor temperature variation in box girder of Bangabandhu Bridge [28].

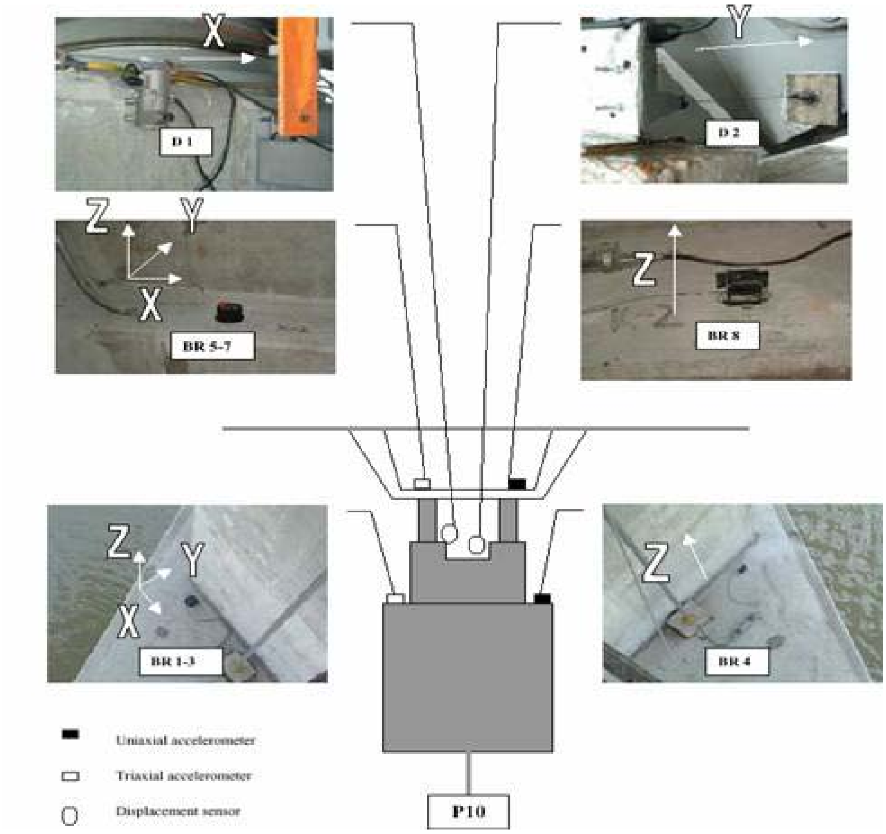


Figure 12: Location of various accelerometer and displacement sensors in Bangabandhu Bridge [28]

Table 1

Sensors used in different notable pre-stressed concrete box girder bridges of the world [21]

Bridge name/ SHM equipment	*Strain*	*Deflection or rotation*	*Support displacement*	*Acceleration or velocity*	*Corrosion*	*Crack*	*Pre-stress loss*	*Traffic camera*	*Temp*	*Weather station*
Ferriby Road Bridge (UK)	Absent	Present	Absent	Absent	Absent	Present	Absent	Absent	Absent	Absent
PI-57 Bridge (France)	Absent	Absent	Absent	Present	Absent	Absent	Absent	Absent	Present	Absent
Leziria Bridge (Portigal)	Present	Present	Present	Absent	Absent	Absent	Absent	Absent	Present	Absent
401 Southbound Bridge (USA)	Present	Present	Present	Absent	Absent	Absent	Present	Absent	Present	Absent
California Pilot Bridge (USA)	Present	Present	Absent	Present	Absent	Absent	Absent	Present	Present	Absent
Utah Pilot Bridge (USA)	Present	Present	Absent	Present	Absent	Absent	Absent	Present	Present	Present
Kishwaukee Bridge (USA)	Present	Absent	Absent	Present	Absent	Present	Absent	Absent	Present	Absent
New 135W Bridge (USA)	Present	Present	Present	Present	Present	Absent	Absent	Absent	Present	Absent
Kamikazue Viaduct (USA)	Absent	Absent	Absent	Absent	Absent	Absent	Present	Absent	Absent	Absent
A curved Bridge (USA)	Absent	Present	Absent	Present	Absent	Absent	Absent	Absent	Present	Absent
West street Onramp Bridge (USA)	Absent	Absent	Absent	Present	Absent	Absent	Absent	Absent	Absent	Absent
North Halawa valley Viaduct (USA)	Absent	Present	Present	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Zhaoqing Xiajiang Bridge (China)	Present	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Present	Absent
Chongqing Shibanpo Bridge (China)	Present	Present	Absent	Absent	Absent	Absent	Absent	Absent	Present	Absent
Xushuigou Bridge (China)	Present	Present	Absent	Absent	Absent	Absent	Absent	Absent	Present	Absent
Jiangin Yangize River Highway Bridge (China)	Present	Present	Absent	Absent	Absent	Present	Absent	Absent	Present	Absent
Anwen Bridge (China)	Absent	Present	Absent	Absent	Absent	Absent	Absent	Absent	Present	Absent

Present (green)
Absent (red)

Bangladesh contains a variety of subsurface soil conditions for bridge foundations since it is a deltaic formation made by the alluvium and sediment deposition carried by the three major rivers, the Ganges/Padma, Brahmaputra/Jamuna, and Meghna, as well as their tributaries and distributaries. The Standard Penetration Tests are the primary field testing for subsurface research in the nation (SPT). At roughly 1.5m intervals, disturbed and undisturbed samples are collected, and those samples are then subjected to the requisite laboratory tests outlined by the designers. Based on the results of the aforementioned tests, the pile bearing capacity—which combines shaft resistance and end bearing of piles-is calculated, and pile settling is evaluated. However, the majority of SPT equipment utilized in the nation is not of the conventional type; the cutters' size, shape, and materials are inadequate to allow for quality sampling and provide representative SPT readings, which in turn is likely to result in an inflated estimate of pile carrying capacity [28, 29].

The AASHTO HS20-44 truck and the lane loads that go along with it are used by the RHD when constructing bridges for Type NH, R, and Z highways and roads. On the basis of IRC: 6-2000, they use an IRC Class A train of vehicles to test the design. The design live loading has been improved to Type HL-93 in AASHTO's 2007 Bridge Specifications. It uses the same design truck as the HS20-44 truck. In addition, a single tandem design with two 110.00 KN axles spaced 1200 mm longitudinally and 1800 mm transversely is employed. Depending on which generates a heavier load, the load combination follows the design truck or design tandem in conjunction with the design lane load. Bridge loadings for Bangladeshi bridges must be standardized to account for all types of traffic, including military vehicles. In Bangladesh, there is currently no independent national design standard or guideline for bridges [28, 29]. The American Association of States Highway and Transportation Officials (AASHTO) Specifications are the most widely used at the moment, with various designers using editions ranging from 1992 to 2007. Additionally, other specialized material is consulted. In some instances, the British Standard (BS) 5400 (1978) has been adhered to. For instance, the Jamuna Design Specification for the Jamuna Multipurpose Bridge was created in accordance with this standard [29]. Specifications from the Indian Roads Congress (IRC) are also frequently consulted. After reviewing the Bangladesh National Building Code 1993 [30] to determine the wind and seismic loading of bridges, the design of the second Kachpur, Meghna, and Gumti bridges mainly adhered to JRA regulations [29].

Table 2

Major river crossings in Bangladesh in order of major span, year of construction, total length, superstructure and foundation type [28]

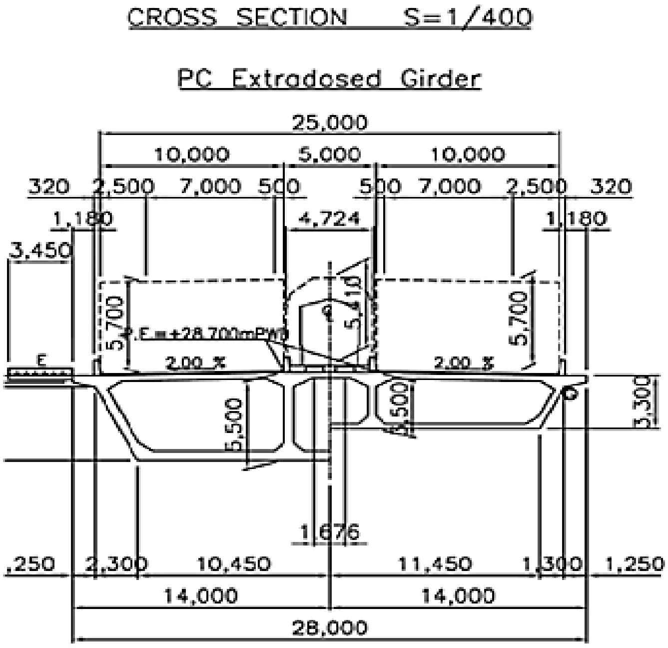
Geological formation/ Canal	Name of bridge	Major Span (m)	Year of completion	Total length (m)	Superstructure for longest span	Foundation
Ganges-Brahmaputra Meghna	Padma Bridge	150	2022	6150	Steel-composite	CFT6
	Lamakazi Bridge	122	1984	226	Steel truss	Bored pile
	Sadipur Bridge	120	2000	163	Steel truss	Bored pile
	Sunamgong Bridge	115	2015	403	Steel truss	Bored pile
	Bhairab Road Bridge	110	2002	1191	PC box girder	Bored pile
	Lalon Shah Bridge	109.5	2004	1640	PC box girder	Bored pile
	Hardinge Bridge	109.5	1915	1640	Steel truss	Caisson
	Moktarpur Bridge	100	2008	1514	PC box girder	Bored pile
	Khan Jahan Ali Bridge	100	2005	1360	PC box girder	Bored pile
	Bangabandhu Jamuna Bridge	100	1998	4800	PC box girder	CFT6
	Bhairab Rail Bridge	91.5	1937	640	Steel truss	Caisson
	Sultana Kamal Bridge	90	2010	1072	PC box girder	Caisson, bored pile
	Gumti Bridge1	87	1994	1410	PC box girder	Bored pile
	Meghna Bridge2	87	1991	930	PC box girder	Bored pile
	Dapdapia Bridge	85	2010	1390	PC box girder	Bored pile
	Keane Bridge	75	1936	387	Steel truss	Steel pile
	Buriganga-I Bridge3	72	1989	847	PC girder	Bored pile
	Kachpur Bridge	72	1977	397	PC I-girder	Caisson
	Gorai Rail Bridge	56	1870	515	Steel truss	Steel pile
	Tora Bridge	54	1972	646	PC girder	Caisson
	Teesta Bridge	50	1901	650	Steel truss	Caisson
	Aminbazar Bridge	46.4	1972	252	PC girder	Caisson
	Jaigir Bridge	46.4	1962	493	RC box girder	Caisson
	Noyarhat Bridge	42	1975	154	PC girder	Caisson
	Baral Bridge, Baghabari	38.1	1978	572	PC I-girder	Caisson

The Padma Bridge (Figure 13), which has a steel truss and composite deck, has the longest 150 m span length, although steel trusses could only reach a 122 m span [26]. The key to lowering the foundation load is achieving the highest stiffness to mass ratio. In this way, the authors understand the challenges of building long span bridges in the Ganges-Brahmaputra-Meghna basin, but they also see how short and medium span bridges (50 m to 200 m) may develop as solutions with higher efficacies. In passing, it is important to remember that even before the Hardinge Railway Bridge was built, there were technologies available to build and erect spans longer than the Hardinge Railway Bridge, such as the 240.9 m single span Lansdowne Bridge Rohri, which was inaugurated in 1887 and spans the Indus River, which is very dissimilar to the Ganges basin. With two main spans of 160 meters each, the 363-meter Jubilee Bridge in Hooghly (22°54'26.10"N, 88°24'16.48"E) is of the cantilever steel truss type. In relation to the Ganges basin, the bridge is situated the furthest west [26, 28].

Figure 13: Padma Bridge

4. STRUCTURAL HEALTH MONITORING OF PADMA BRIDGE

For Bangladeshi bridges, in particular, scouring is a crucial criterion for structural health monitoring in bridges. The government have installed sophisticated computerized sensor-controlled weighing machines on the Mawa and Janjira ends to stop overweight cars from using the Padma Bridge (Figure 14). The main infrastructure operations to set up the weighing machines, according to those who are concerned, have already been finished. The installation of the weighing equipment, which has been inaugurated at the earlier this year, are in full functioning. Furthermore, each freight vehicle will need to cross the bridge after being weighed. For the first time in the nation, a weight scale is being placed that does not need stopping moving traffic to assess weight. Once the car is close enough, the machine's electrical sensors will begin to measure the weight immediately. Electronic sensors will be used to gather the data and transmit it to the main server. Six weight scales will be installed, three on each end of the bridge, by the Seoul-based Korean Expressway. Despite the fact that the bridge is allegedly capable of supporting cars up to 27 tones in weight, it does not yet have a measurement system in place. Since June 25 of this year, the eagerly awaited bridge has been accessible to vehicles. Property Development Limited, which has already finished building two stockyards on both ends of the bridge, is the contractor company for installing the infrastructure, according to the Bangladesh Bridge Authority. Eight guard stations and two driver huts have also been built at the bridge's ends.



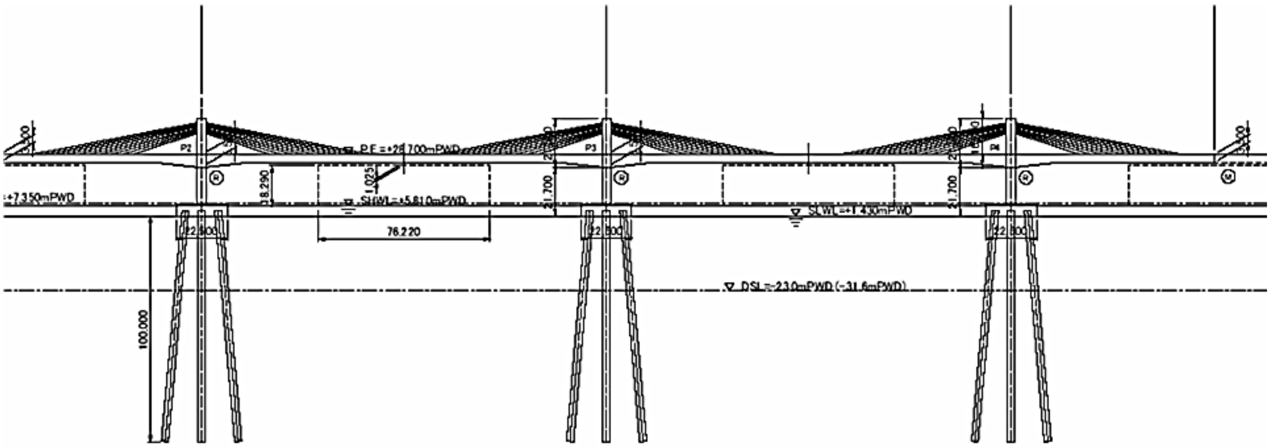


Figure 14: Feasibility Study Preliminary Design for Main Bridge [31, 32]

According to officials, after weighing their loads, cargo trucks that are loaded with goods up to the maximum of 27 tones will be permitted to pass the bridge through the green zone. To get to the stock yards, though, vehicles weighing more than 27 tones must pass through the red zone. The stockyard could accommodate the larger vehicles for a 72-hour parking period. However, additional items could be kept in the stockyard for a week. One of the most unique features of the Padma Bridge is its foundation comprising the deepest driven piles in the world. The pile length is as deep as 127 m. As mentioned earlier scoured depth is a major problem of this river. To investigate the performance of these ultra-long piles vibration measuring instruments may be installed at the pile cap. Some strong motion accelerometers (SMA) can be placed on either side of the river to measure free field motion. Based on the vibration measurements, the effectiveness of the piles may be ascertained. Another interesting feature of the Padma Bridge is use of friction pendulum bearing (Figure 15) to isolate the superstructure from the earthquake ground vibration. Friction pendulum bearings reduce the earthquake induced forces by lengthening the natural period of the isolated structure. They also introduce damping by sliding mechanism. By using friction pendulum bearings, the earthquake induced loads on piles are greatly reduced. However, the actual efficacy of the bearings should be examined through the SHM approach. vibration sensors may be attached at the pier top and girders along the length of the beams. By comparing the motions at different levels of the bridge during a moderate shaking, the performance of the bearings may be understood. Eigenvalue Realization Algorithm (ERA) based system identification approaches may be adopted for SHM of the bridge. Artificial Intelligence (AI) and big data analytics with data over a long period of time may be used for this purpose.

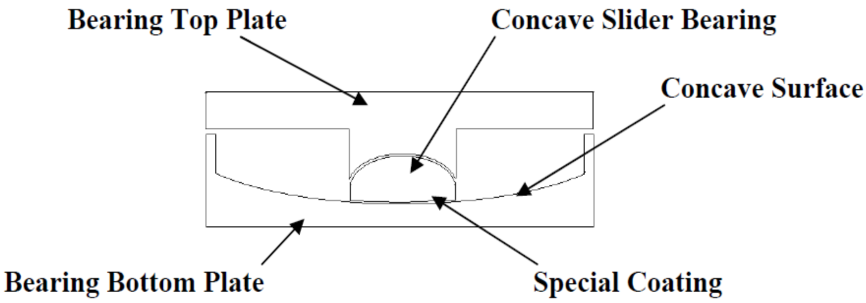


Figure 15: Cross-Section of a friction pendulum bearing [32]

5. CONCLUSIONS

Significance and applications of Structural Health Monitoring (SHM) are discussed in this paper with examples all around the world. The important issues related to the long span bridges particularly in Bangladesh are discussed in length. The SHM approaches adopted for the Padma bridge are described. The unique features of the Padma bridge make the bridge more deserving of constant monitoring of the bridge. Different prospective ways of SHM that can be adopted for the Padma Bridge are briefly mentioned here. The authorities may take all of these ideas into consideration and apply them to ensure that this magnificent bridge continues to function flawlessly for future generations.

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