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SEISMIC INSTRUMENTATION SYSTEM FOR JAMUNA BRIDGE

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SUMMARY

The 4.8 km Jamuna bridge, located close to a potential fault zone capable of producing a major earthquake, has special earthquake protection devices. A digital seismic instrumentation system has been recently installed to monitor the dynamic response of the bridge and the performance of its earthquake protection system during earthquakes. Seventeen accelerometer sensors and three displacement sensors have been placed on the bridge structure. Accelerometers have also been installed at six free-field sites including a borehole in the northeast and central north region of Bangladesh to obtain earthquake data for future seismic hazard assessment studies. This paper presents the various components of this seismic instrumentation system.

INTRODUCTION

Bangladesh is a riverine country having three major rivers namely the Padma (the Ganges river is renamed), the Meghna and the Jamuna (new course of the Brahmaputra river). The Jamuna river is the mightiest among the three and ranks as the fifth largest river in the world in terms of volumetric discharge. It is a fairly young and untamed braided river. The Government of Bangladesh (GoB) formed the Jamuna Multipurpose Bridge Authority (JMBA) in 1985 to implement the construction of a multipurpose bridge over the Jamuna river. On the basis of satellite imagery and earlier bathymetric surveys, the site for a bridge was selected near Bhuapur-Sirajganj where the river flows in a relatively narrow belt and mostly in one channel. Fig.1 shows a map of Bangladesh along with the main rivers and the bridge location. Through expensive river training works, the bridge project narrowed the river at the bridge site to a width of 4.8 km from a flood width of about 14 km. The Jamuna Bridge (named Bangabandhu bridge), completed in 1998 with a project cost of around one billion US dollars, is the only road and railway link across the Jamuna river, connecting the central north region (which includes the capital Dhaka) of Bangladesh with the north-eastern region (Rajshahi Division). This multipurpose bridge also carries a 230 KV electric power line, a gas pipeline and telecommunication cables across the river. It is generating multifaceted benefits for the people, promoting better inter-regional trade and economic and social development. It is located on the strategic Asian Highway and the Trans-Asian Railway which, when fully developed, will provide an uninterrupted international road and railway link

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between South-East Asia to Europe. This bridge, therefore, assumes a great national and international importance and its proper functioning is vital to the national economy.

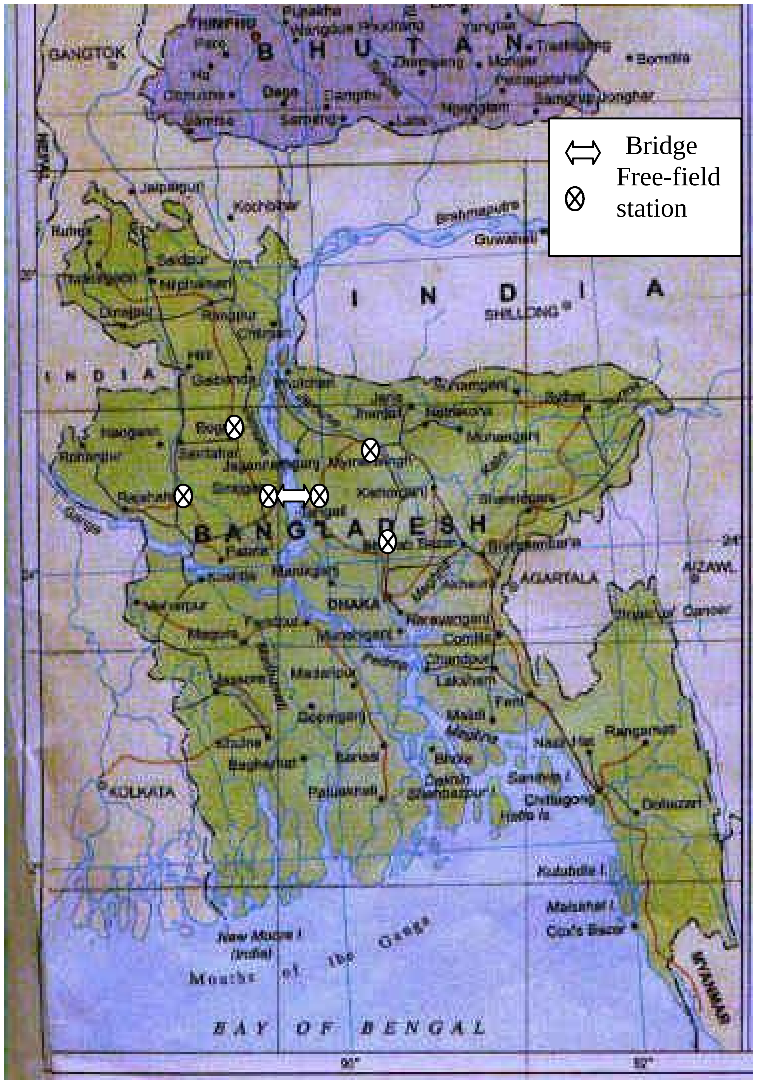


Fig. 1: Map of Bangladesh Showing Location of Jamuna Bridge and Free-Field Stations

The main bridge is prestressed concrete box-girder type consisting of 47 nearly equal spans of 99.375 m plus two smaller end spans of 64.6875 m. There are 128 m long road approach viaducts at both ends of the main bridge. Six expansion joints separate the bridge structure into seven modules (two end modules, four 7-span modules and a 6-span module in the middle). Fig.2 shows the plan layout of the bridge modules. The bridge running approximately in the east-west direction is slightly curved in plan. To withstand predicted river scour and possible earthquake, the bridge is supported on 80 to 85 metres long and 2.5 m and 3.15 m diameter tubular steel piles. Each bridge module consists of three 3-pile piers and the remaining 2-pile piers. The piles were driven by special 240 ton hydraulic hammer at a batter of 1:6 and later filled with concrete. Average embedment of piles is about 72 m below the river bed level. The piers are numbered P1 to P48 eastward. The piles are embedded about 7 m within the reinforced concrete pile cap. The pile caps support the pier stems, varying in height from 2.72 to 12.05 m, which in turn supports the deck.

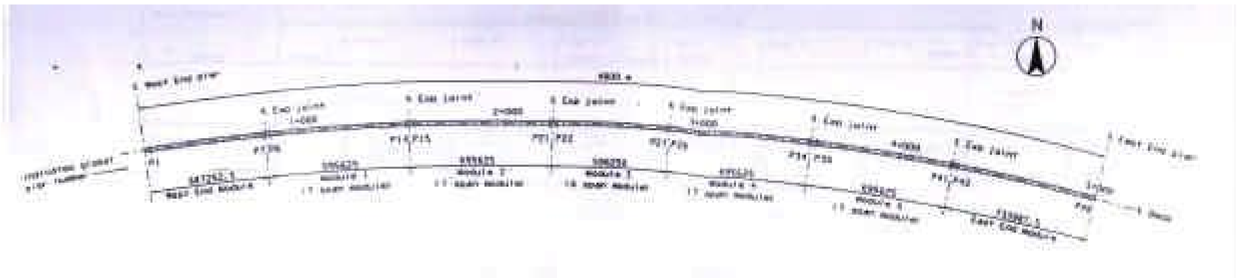


Fig. 2: Plan Showing Different Modules of Jamuna Bridge

Bolt [1] peformed the seismicity study for the Jamuna bridge. Based on his study, special earthquake protection devices consisting of steel pintles have been installed in the bridge superstructure. His work had been seriously hampered by the lack of earthquake recordings in the country. He recommended installation of strong motion instruments. At that time, there was only one analogue seismograph station in the south-eastern port city of Chittagong (installed in 1954) which was far away from the bridge site. Moreover it was not functioning properly. As a result, there were no earthquake recordings for the region. Bolt's recommendations for seismic instrumentation were given due attention during the bridge construction period, and the bridge contractor submitted a proposal for the instrumentation. The current authors presented another proposal for the seismic instrumentation of the bridge and surrounding region with different objectives and layout. The latter's proposal was endorsed by the international panel of experts working for the bridge project after modification to fit a reduced budget. Following the endorsement, the current authors submitted a detailed proposal [2] to JMBA. This proposal was accepted by the relevant government authority and in 2000, JMBA appointed Bangladesh University of Engineering & Technology (BUET) to act as Consultants for implementing the seismic instrumentation project. An international competitive bidding was arranged for the supply and installation of the seismic instruments with GoB funding. Installation of the seismic instrumentation on the bridge and surrounding region was completed in July 2003. The region covered by the free-field instrumentation may be visualized from Fig.1. The salient features of the seismic instrumentation is presented in this paper.

SEISMIC HAZARD

Bangladesh faces a significant risk of earthquake hazard due to its close proximity to the tectonically active Himalayan Range. The rate of regional deformation leading to folding, faulting and uplifting of the nearby mountain regions, in geological terms, is quite high. The collision of the Indian plate, estimated to be moving northward at present at a rate of about 5 cm per year, with the Eurasian plate is the cause of frequent earthquakes in the region. During the last 150 years, five earthquakes of large magnitude (Richter magnitude of 7.0 or higher) with epicentres in India and Bangladesh have affected Bangladesh (Ali [3]). Bolt [1] cited four tectonic blocks (seismic sources) capable of producing major earthquakes. While the Bogra fault system (to the north-west) is near the bridge site, the other fault systems are more than 100 km away. The Assam and Sub-Dauki fault system is to the north/north-east, while the Tripura fault zone is to the east/south-east. Bolt performed an analysis of the 1885 Bengal earthquake (M=7.0) which caused major damages in the Sirajgonj-Bogra region and concluded that the epicentre was possibly in the Bogra fault zone, at a distance of only 25 to 50 km from the bridge site. The different seismic sources along with maximum likely earthquake magnitudes and their distances from the bridge site are listed in Table 1. According to Bolt [1], only one source needs to be considered for postulating strong ground motion for the Jamuna Bridge: Bogra fault zone. He thus developed the design response spectrum for the bridge considering a 7.0 magnitude earthquake at a distance of around 25 to 50 km from the bridge site (24.42°N, 89.75°N). The design peak ground acceleration (PGA) is 0.2g. Seismic steel pintles have been installed between the bridge deck and pier to act as base isolation devices. Using test results on isolator properties presented by FIP [4] and the design response spectrum for the bridge, Ahmad [5] performed nonlinear finite element analysis of a simple bridge model and found that the isolators can provide intended seismic protection to the bridge pier. The correctness of the parameters assumed in the analysis and the bridge model needs to be checked using real vibration data. The 1993 Bangladesh National Building Code (Ali [3], HBRI [6]) divides the country into three seismic zones. The most severe zone is Zone 3, which includes the north and north-eastern parts of Bangladesh. The bridge site is located near the boundary between Zone 2 (Z=0.15) and Zone 3 (Z=0.25), where the zone coefficient Z represents the PGA value for that zone. The bridge design is thus consistent with the seismic zoning map of the country.

Table 1: Maximum Earthquake Magnitude in Different Tectonic Blocks [1]

Tectonic Block	Earthquake Magnitude M	Distance from Bridge Site (km)
Assam fault zone	8.0	120
Tripura fault zone	7.0	180
Sub-Dauki fault zone	7.3	120
Bogra fault zone	7.0	25 – 50

INSTRUMENTATION PLAN

Objectives

The seismic instrumentation is intended to: (i) record the free-field motion in the north-west and central north region of the country and (ii) measure the structural response of the bridge during an earthquake. Such measurements are now considered essential by the engineering profession for large critical structures in earthquake prone regions. Moreover it will be a valuable source for seismological and earthquake engineering research in the country. The objectives of ground motion recording is to obtain valuable data on the occurrence of seismic events in the region, develop attenuation relationships and determine local site effects (if any). This is expected to lead to an improved seismic hazard estimation for the region, since seismic hazard estimations for the country have so far been based on attenuation relationships developed for other countries. The free-field data will also be required in defining the input motion to the bridge structure. The instrumentation on the bridge structure is intended to measure the important components of the global response of various structural elements. Important dynamic characteristics of the bridge and its substructure will be identified. Validity of bridge design assumptions and parameters will be verified. It may be possible to identify limitations of current seismic codes and suggest improvements. The vibration data will permit developing reliable and simple numerical models for dynamic analysis of this bridge and similar other bridges. Effectiveness of the seismic protection system of the bridge will also be ascertained. The other important role would be to provide data that would be useful for rapid assessment of the bridge damage in the event of a potentially damaging earthquake.

Components

Due to budgetary constraints, only one bridge module is instrumented. The 7-span bridge module (containing piers P8 to P14) next to the west end module and the west abutment are instrumented due to their proximity to the Bogra fault zone. In addition, ground motion is measured at free-field stations covering a large area on both sides of the Jamuna river. The total instrumentation consists of accelerometer sensors, displacement sensors, data acquisition systems, data transmission systems, computers and other accessories. The instrumentation plan is based on previous seismic instrumentation work (Huang [7], Malhotra [8], Trnkoczy [9]). The instrumentation consists of commercial off-the shelf models having a proven track record in the field. The different types of instruments are listed below:

Accelerometer Sensors:

There are 37 force balance accelerometer sensors, out of which 13 are on the bridge structure [BR1 to BR13] and 3 on the west abutment [AB1 to AB3]. 18 sensors [FF1 to FF18] are used to determine the free-field motion at six stations. There are 9 triaxial (three-component) accelerometers, 1 biaxial (two component) accelerometer and 5 uniaxial (one component) accelerometers. These have a full-scale range of ±2g. Additionally one borehole triaxial accelerometer (BH1 to BH3) was planned at a depth of 70 m.

Displacement Sensors

There are 3 digital displacement (single component) sensors (D1 to D3) on the bridge to measure relative displacement between two moving parts of the bridge structure.

Data Acquisition System

The data acquisition system collects and records data from the sensors. For the bridge instrumentation, it consists of multi-channel digital recorders with GPS time option and at least 18 bits of resolution. They can send continuous stream of data for transmission to the Data Control Centre. Also they can record events on to their PCMCIA (removable storage) device, as soon as a specified system trigger threshold is exceeded. Each event is time-stamped using a GPS receiver. Each free-field triaxial accelerometer unit contain digital recorders with GPS timing, these recorders can acquire and record data on PCMCIA cards with 18 bits of resolution. These units get their power supply from solar panels charging their batteries.

Data Control Centre (at Bridge Site) Computers

The Data Control Centre continuously collects the data transmitted by the Data Acquisition Systems. This centre, located in a building at the east end of the bridge, contains a personal brand computer server of latest configurations. The computer uses Windows operating system and a network management system software that can continuously receive and display transmitted digital data from the data acquisition systems. Also it records data on to its hard disk whenever the centralized data acquisition system triggers. The computer also contains software for performing instrument corrections, data filtering, ground motion integrations, Fourier and response spectra calculations, interactive graphics and printing, remote control of data acquisition system etc. In addition to this computer server, a laptop computer is required for directly communicating, configuring settings and collecting data from the free-field stations and K2 recorders.

Data Analysis Centre (at BUET) Computer

BUET will be operating the instrumentation and analyzing the seismic data for a period of five years. The Data Analysis Centre is located in the Civil Engineering Building, BUET. The Data Analysis System consists of another personal computer server for analysis work, with similar configurations as the Data Control Centre computer server. It can also communicate with the Data Control Centre computer.

Data Transmission System

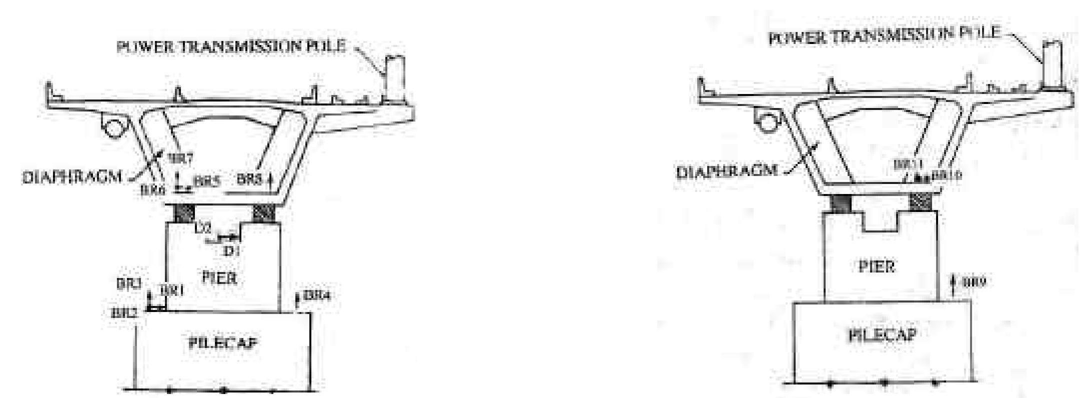
Data transmission from the bridge to the Data Control Centre computer was initially envisaged to be through telephone cables and modem connection. Later after discussions with the supplier, wireless option of data transmission consisting of a wireless IP network and 2.4 GHz. spread spectrum radios, was chosen.

Sensor Locations

The sensors for the bridge structure are placed on the west abutment and on a 7-span module (Module 1 in Fig.2) close to the west end. Fig. 3 shows the different sensor locations on the bridge module. While Figs.3(a,b) are elevation views in the transverse direction at Piers P10 and P9, Fig.3(c) presents plan view of deck around Pier P10. Labelled arrowheads and dots are used to show the directions of measurements. The labellings with D represent relative displacement measurements. The sensor locations have been selected with the following objectives:

Measure tri-axial motions at west abutment
A triaxial sensor (AB1, AB2, AB3) is installed at the West Abutment to measure the abutment acceleration in three directions.

Measure motions on the pilecap
Triaxial accelerometer sensors (BR1,BR2,BR3) are installed on the pile cap top at pier P10 as shown in Fig.3(a). Additional uniaxial (vertical) accelerometer sensor (BR4) is installed on the same pile cap to measure the rocking motion of the pier-pile cap system. Fig. 3(b) shows another uniaxial (vertical) accelerometer sensor (BR9) on the top of the next pilecap at pier P9. Sensors BR4 and BR9 will compare vertical motion of two consecutive pier-pile cap systems. These sensors will be used to obtain the input motion at the base of the bridge pier, above which the isolation system rests.



(a) P10 (b) P9

Fig.3: Location of sensors in bridge module 1 at (a) Pier P10 (b) Pier P9

Measure deck response
One triaxial (BR5, BR6, BR7) and one uniaxial (vertical) accelerometer sensor (BR8) is installed to measure the deck response at the pier P10. These are placed inside the hollow box-girder as shown in Fig.3(a). Sensors BR7 and BR8 will give the rocking motion of the deck at that location. Additionally a biaxial accelerometer sensor (BR10, BR11) will be installed at the next pier P9 to measure the horizontal components (Fig.3b). In order to determine the horizontal deck response in a more detailed manner, two more uniaxial sensors BR12 and BR13 are installed at midspan on both sides of Pier P10 to measure the transverse horizontal motion.

Measure relative displacement
Displacement sensors are used to measure the relative horizontal displacement between two moving parts of the bridge. Displacement sensors Dl and D2 (Fig.3a) is needed to measure the relative horizontal movements across the isolation system at the selected pier P10. Additional sensor D3 will measure the relative horizontal displacement of adjacent bridge modules across the expansion joint between Module 1 and West End Module. Sensor D1 measures the transverse displacement while D2, D3 measure the longitudinal displacement.

Measure ground motion
In order to record the free-field ground motion, three locations have been selected on each side of the river for housing triaxial accelerometer sensors. On the western side of the bridge, the three stations are located in the towns of Bogra, Natore and the West End (near the west abutment) of bridge. On the eastern side, the three stations are located in the towns of Mymensingh, Gazipur and the East End (near the Data Control Centre building) of bridge. The sensors are installed on concrete pads on firm ground. On each side of the bridge, these stations are approximately 70 to 90 km apart forming a well-conditioned triangle and recordings from these stations may be used to estimate earthquake magnitude and epicenter location. Fig.1 shows the location of these free-field ground stations on the country map. The free field instruments in the four district towns are located within the office complexes of the Local Government Engineering Division (LGED), GoB. In addition, a borehole triaxial accelerometer is planned near the west abutment for measuring ground acceleration at a depth of 70 m so that local site effects can be studied.

INSTALLATION

Kinemetrics, Inc., USA were awarded the contract by JMBA for supplying and installing the seismic instrumentation for Jamuna Bridge (Fig.4) according to the instrumentation plan. The computers were procured from a local vendor through a separate bid process. The following gives a brief description of the instrumentation installed. Episensor model ES-U (uniaxial), ES-T (biaxial/triaxial), ES-DH (borehole) accelerometers and Celesco model PT 8000 displacement sensors have been installed. Fig.5 shows photograph of a triaxial accelerometer on the pile cap at Pier P10.

Fig.4: Jamuna bridge as seen from an observation platform below the deck

Fig.5: Triaxial accelerometer on pile cap

Fig.6 shows a displacement sensor at the expansion joint between Module 1 and West End Module. On the instrumented bridge module, there are three 6-channel K2 recorders with a resolution of 19 bits, collecting data from 13 accelerometer and 3 displacement sensors. To minimize cable lengths and since most of the sensors are located on Pier P10, the three recorders are located near Pier P10 inside the hollow bridge deck. The three units are interconnected so that they all can trigger and record at the same time on to 64 MB PCMCIA memory cards, whenever excessive vibration is detected in the accelerometers selected for system triggering. They get 12V DC power supply from batteries within a communication box which also has a charger to recharge the batteries from AC power outlets inside the bridge deck. Inside the communication box, the K2 recorders are connected by ethernet cabling to a communication device for data transfer through a data transmission system. A fourth 6-channel K2 recorder is located at the west abutment to acquire data from the west abutment and borehole accelerometers. Any sensor can be set to trigger the whole system. In this case the sensors at the pile-cap were set to trigger the system because these will be the ones least affected by the noise from the bridge traffic and ambient vibrations. The trigger value for the bridge sensors was initially set to be 1% of g. The data transmission system which transfers data from the four data acquisition units on the bridge to Data Control Centre consists of a wireless IP network and 2.4 GHz. spread spectrum radios. Two transmitting radio spectrums are placed high on lamp posts of the bridge structure, one at the instrumented bridge module and the other at the west end of the bridge. The receiving radio spectrum is located high on a purposely built tower near the Data Control Centre. The Data Control Centre and the Data Analysis Centre consist of IBM personal computer servers, with Pentium 2.4 GHz processor, double 36 GB SCSI hard-disk having mirror image capability, 1024 MB RAM and 19 inch high resolution monitor. The Data Control Centre computer can continuously display data stream (real time display) of signals transmitted through the spread spectrums (Fig.7). This computer can also be accessed via modem/phone line by dial-up from the Data Analysis Centre at BUET. This has permitted data collection at BUET from Data Control Centre computer without going to the bridge site.

Fig.6: Displacement sensor at expansion joint

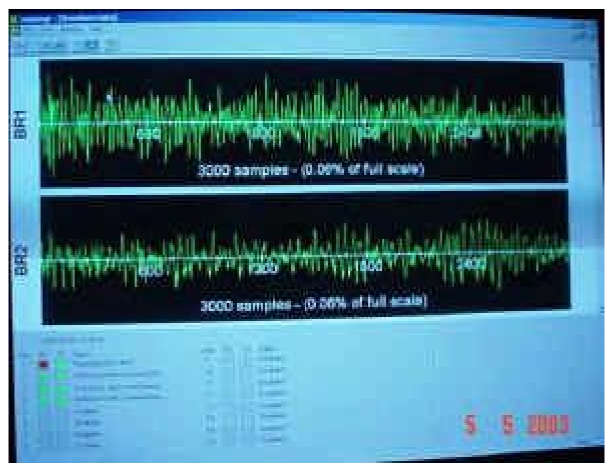


Fig.7: Real time display of data

The free-field strong motion network consists of six Etna strong motion accelerographs with GPS timing at the planned locations. Each unit contains a triaxial accelerometer and when triggered it records data on to a removable 64 MB PCMCIA memory card with a resolution of 18 bits. Recorded events can be off-loaded automatically via modem, manually retrieved by PC or by collecting the PCMCIA memory card. Currently the free-field data is collected by manually downloading the data into a laptop computer. Fig.8 shows a photograph of a free-field unit inside a metallic enclosure for protection. The black box on the concrete pedestal contains the accelerometer and the recording unit. The white box contains a battery and a charger which receives power from a 75 Watt solar panel. There is also provision for AC power supply inside the metallic enclosure. In addition to the six free-field stations, a portable triaxial accelerometer (which will be moved to the epicentral region in case there is a major earthquake) has been installed at the BUET Campus in Dhaka. The trigger value for the six free-field ground accelerometers was set at 0.5% of g. In addition, one more triaxial sensor (Model ES-DH) has been installed in a borehole at West end to measure the ground acceleration at a depth of 58 m. Although originally planned to be at 70 m depth, due to difficulty in boring and maintaining borehole stability, a borehole depth of 58 m was finally accepted. The borehole diameter was 0.25 m, the top 17 m had to be cased to prevent caving. PVC pipes of 0.1m diameter, with glued connections between the pipe segments, were installed down the borehole depth to house the borehole sensor and the connecting cable. The gap between the PVC pipes and the borehole wall was filled with cement grout. The borehole sensor was lowered inside the PVC pipe (Fig.9) to the bottom, the verticality of this pipe is very important. It was found that the error in vertical alignment of the bore hole pipe was only 0.3° (very satisfactory).

Fig.8: Free-field station

Fig.9: Lowering of borehole accelerometer

Various functional tests and noise tests have been conducted to ensure the proper functioning of the different sensors on the bridge and ground. The data obtained are used for noise study and instrument setting adjustments.

CONCLUSIONS

The Bangabandhu bridge over the Jamuna river, connecting the north-western part of Bangladesh with the capital, has been base-isolated to protect it from a major earthquake which may originate in a nearby fault. Due to lack of earthquake measuring equipment in the past, there are no earthquake records for the region. A digital seismic instrumentation project for this critically important bridge and the surrounding region has recently been implemented. The instrumentation consists of accelerometer sensors, displacement sensors, data acquisition systems, data transmission systems, computers and other accessories. A combination of triaxial, biaxial and uniaxial sensors have been employed on a selected module of the bridge structure to measure the various components of bridge vibration. To obtain the ground motion, there are three strong motion accelerometer stations at a distance of 70 to 90 km apart on each side of the bridge. Two data centres have been set up at the bridge site and at BUET for monitoring, processing and analysis of the data. The instrumentation is in operation and it is hoped that with necessary adjustments done with time, the system will yield valuable data to the local researchers to have better ideas on the dynamic performance of the bridge as well as seismic activities of the whole region.

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