Shift in the natural frequencies of the deck of Bangabandhu Jamuna bridge due to CFRP strengthening

A.F.M.S. Amin, M.M. Islam, N. Fuad, M.S.I. Choudhury, A. Hasnat & K.M. Amanat
Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

ABSTRACT: Well defined and prominent cracks appeared predominantly in the longitudinal direction on the deck of Bangabandhu Jamuna Bridge in 2006 after only eight years of service. These cracks appeared mainly at three locations – middle of the box section and inside-outside edges of the deck-web joint of south cantilever - throughout the length of the bridge length. Traffic and environmental loading beyond the as-built design provisions were attributed for such distresses. During 2012-2013, the deck underwent strengthening at top surface with CFRP plates. In the adopted composite laminate system, epoxy based mortar grout was poured atop CFRP for thermal insulation and SMA wearing course was laid atop mortar grout. Such strengthening of deck surface altered the stiffness characteristics of deck, hence deformation properties of the presetresses box. To measure the alteration in stiffness quantities, vibration measurements were taken under ambient condition (no traffic), rail induced and/or traffic induced excitations using tri-axial velocity sensors at selected critical locations of deck before and at different stages of composite strengthening. The progressive transformation of dynamic properties was recorded. To obtain progressive changes of stiffness values, an FFT procedure was applied on measured trace velocity record to estimate corresponding natural frequencies. Natural frequency enhancements, hence the changes in stiffnesses were attributed to strengthening works. Presented measurement procedures and preliminary estimates are vital for monitoring the performance of strengthening work over the time and also to detect any future occurrence of laminate interface separation/ possible CFRP debonding.

1 INTRODUCTION

The 4.8 kilometer long Bangabandhu Bridge over the Jamuna river provides strategic east-west surface connectivity for Bangladesh. The fixed link is also a component of the proposed Asian Highway and Trans-Asian Railway network. The forty eight post-tensioned 100 meter prestressed box girder spans of the continuous span bridge with eight expansion joints and 18.5 meter road-rail carriageway was the first application of segmental precast prestressed concrete bridge construction in Bangladesh. Four lanes of the bridge are dedicated for vehicular traffic and a dual gauge rail track located at the north side of the bridge facilitates the movement of broad gauge and meter gauge trains. The multipurpose bridge has monopoles at pier head units to transport electricity to the other bank of the Jamuna. A 760mm diameter high pressure gas pipe line transports gas from eastern part of the country to the west. The 7 modules of the continuous spans are connected through modular type expansion joints. The longitudinal and transverse prestressing for PC box was designed not to allow any tension. The bridge was opened to traffic in 1998 (Hyundai 1997). Since its opening, traffic moved on the bare concrete deck with a recommendation to place asphalt pavement after five years of service (RPT-NEDECO-BCL 1998). However, this was not in place until 2011, when the measurements during the work reported in this paper were undertaken. This allowed the deck to remain exposed to heat and cold. Since the opening, the bridge did have a few cracks on the deck. Those cracks progressed gradually in terms of number and width. Amanat *et al.* (2010) reports the sectional deficiencies for the as-built condition for the traffic and the environmental load for which the bridge was getting exposed to. During 2012-2013, the Bangladesh Bridge Authority decided to install stone mastic asphalt pavement, thermal insulation and carbon fiber plates as strengthening measures to protect the bridge from harsh environmental loadings and also to enhance the structural performance. Water proofing membranes were applied to protect the epoxy based CRFP plate system and thermal insulation coatings. Thus a system of lamina was installed through a very large scale strengthening work of its kind in the world. However, special emphasis were given to prevent debonding and separation of lamina. Furthermore, all nonfunctional road side expansion joints and buffers were replaced with new ones. Thus the box girder of the bridge underwent a structural transformation in terms of change in stiffness, water insulation and thermal insulation properties. It is of utmost importance for the maintenance engineers to monitor the temporal evolution of stiffness, thermal insulation and water proofing insulation properties of the deck over the time span and document the observations in its maintenance records.

The current paper addresses monitoring the serviceability performance of the superstructure of the Bangabandhu Bridge by deploying sensors at strategic locations. While visual observation provides a first hand impression on the health status of a bridge, deployment of sensors at the locations strategically important from structural engineering viewpoint provides ample opportunity for the maintenance engineers not only to quantify the vital structural parameters of the bridge but also to compare all these parameters over a regular interval of the maintenance history.

2 FIELD VIBRATION MEASUREMENT

The idea behind conducting the investigation by field vibration measurement was based on the fact that natural frequency of the deck system is directly related to its stiffness. Stiffness further depends on the modulus of elasticity, moment of inertia and length. Therefore, there lies an opportunity to compare the natural frequencies of the bare un-strengthened deck with that measured after repair and strengthening. This shall enable one to assess the relative change in the stiffness in as-built post-strengthening condition and compare the values with the theoretical design considerations as well. All these steps shall lead towards assessing the structural integrity of the lamina system over the service history. Furthermore, the change in deck stiffness due to strengthening may infer the evolution of the behavior of the whole box girder.

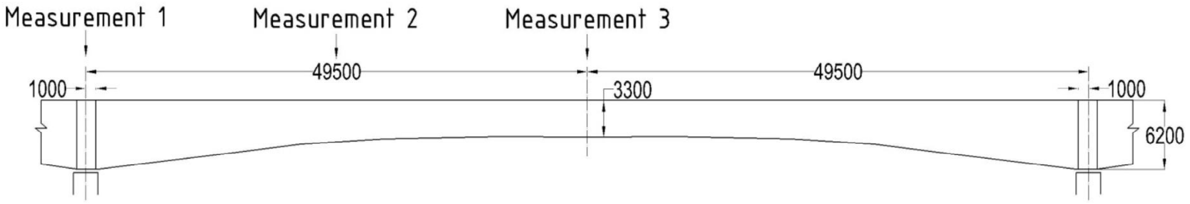


Figure 1. Vibration measurement locations along a typical 100 m span

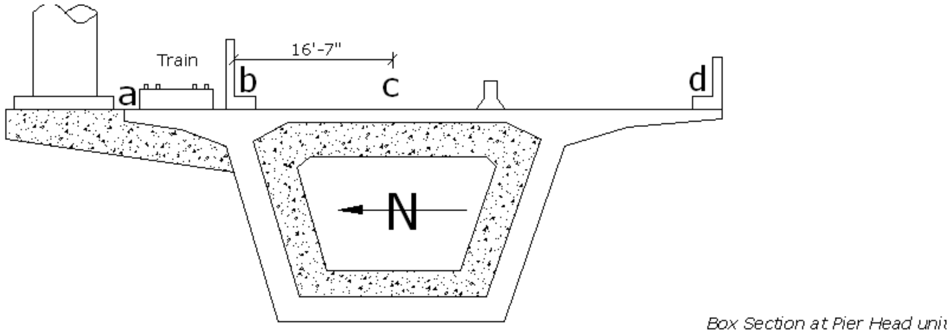


Figure 2. Vibration measurement locations along a typical transverse span over the Pier Head Unit (Measurement 1, Figure 1)

Based on the above ideas and considering the longitudinal crack layouts observed in the bridge, the stiffness of the deck system was thoroughly investigated in the transverse direction at three locations of a typical span (Figure 1). At each measurement locations, four vibration sensors (Vibra+) were installed at namely, ‘a’, ‘b’, ‘c’ and ‘d’ locations (Figures 2 and 3) to take velocity measurements due to vibration along three axes (Figure 3). Figure 4 illustrates the sensor and the data collection arrangement. Sensors located at a-c locations were logged in a single computer at synchronized mode. Since the bridge was partially in operation, true synchronized data could not be included from the ‘d’ sensor (Figure 3).

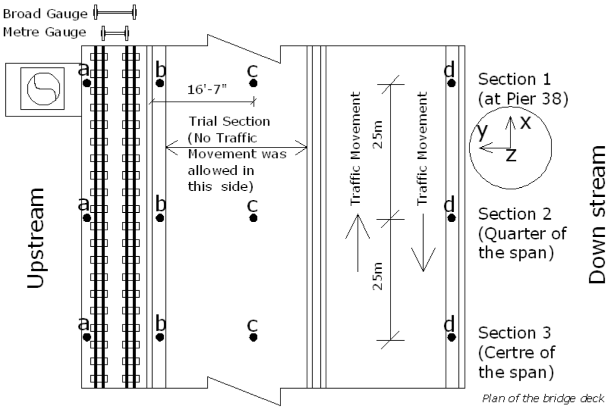


Figure 3. Vibration measurement locations along typical transverse spans at Measurement Locations 1, 2 and 3 (from top to bottom), see also Figure 1.

(a)

(b)

Figure 4. Field campaign for vibration measurement (a) Sensors installed on the deck before placing the stone mastic asphalt. (b) Data collection arrangement

3 FIRST IMPRESSIONS FROM MEASUREMENTS

After the opening of the bridge in 1998, the train movement over the bridge was occasional. However, gradually it increased, first with the introduction of meter gauge trains and then broad gauge strains were also introduced to cross the bridge. Thus, the progressive development of cracks in the bridge was first assumed to be due to broad gauge train movement and repetitive vibrations occurring from such trains to initiate the cracks. However, it was only for the first, the work presented in this paper, the synchronized vibration measurements using velocity sensors were taken over the bridge at deck level not only for the ambient condition but also during the passage of meter gauge (1000 mm track gauge) and broad gauge (1435 mm track gauge) trains. Normal traffic flows were present in the downstream side (Figure 3) while taking the measurements.

Figure 5 presents the comparison for x, y and z axes measurements. A trace data clearly shows significantly larger vibration in all measurement locations and all axes for the meter gauge trains. The broad gauge trains, although have larger static wheel loads, induces smaller vibration amplitudes due to greater stability achieved from wider axels.

4 RESULTS AND DISCUSSION

A preliminary evaluation of the fundamental natural frequencies at each of the locations for Z-direction is compared in Figure 6 by analyzing the measurements taken before (bare and cracked concrete) and after strengthening conditions. The measurements taken due to excitation from ambient vibration are compared with those due to broad gauge and meter gauge trains. At present, a train takes about 20 to 30 min to cross a bridge.

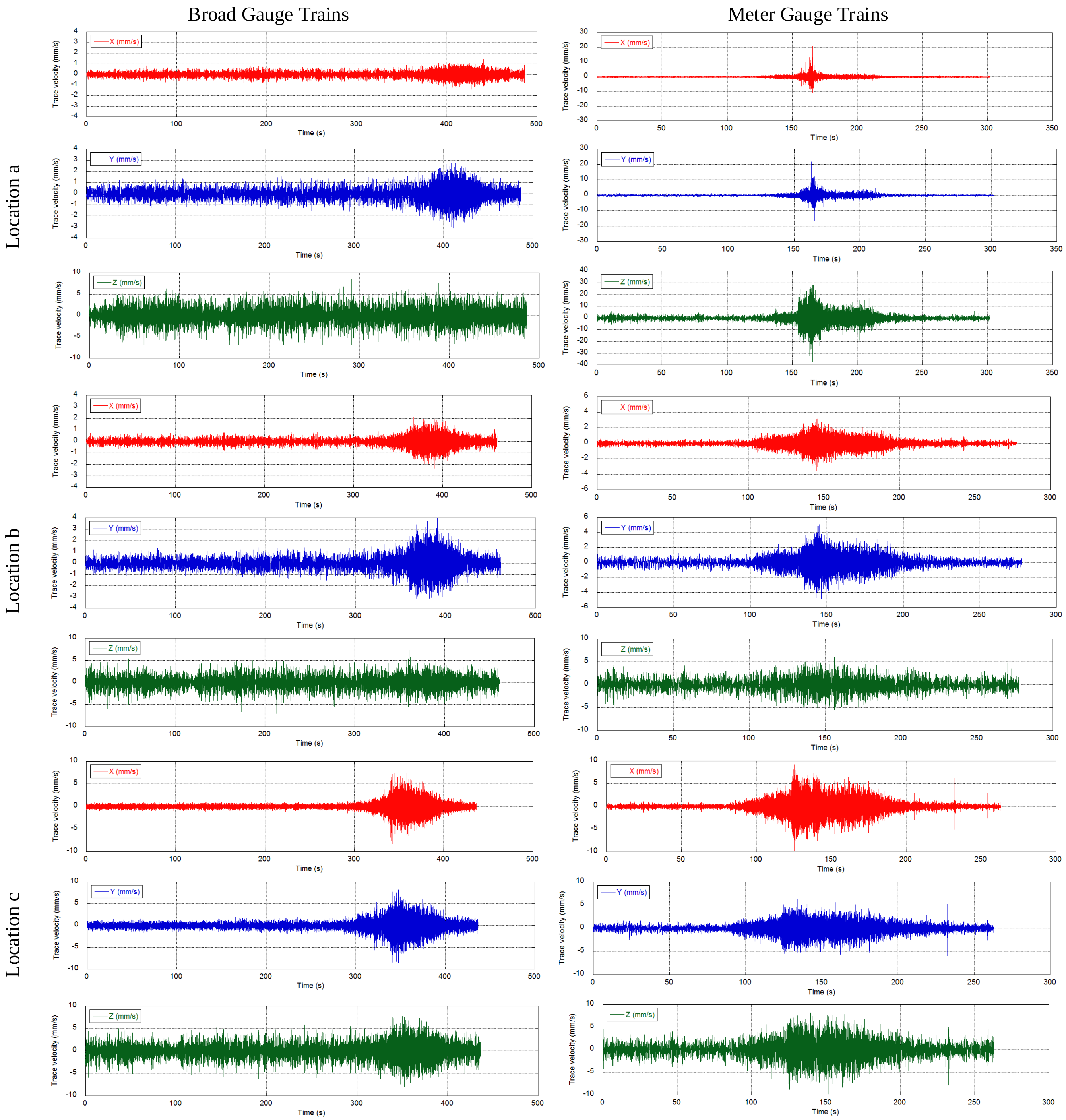
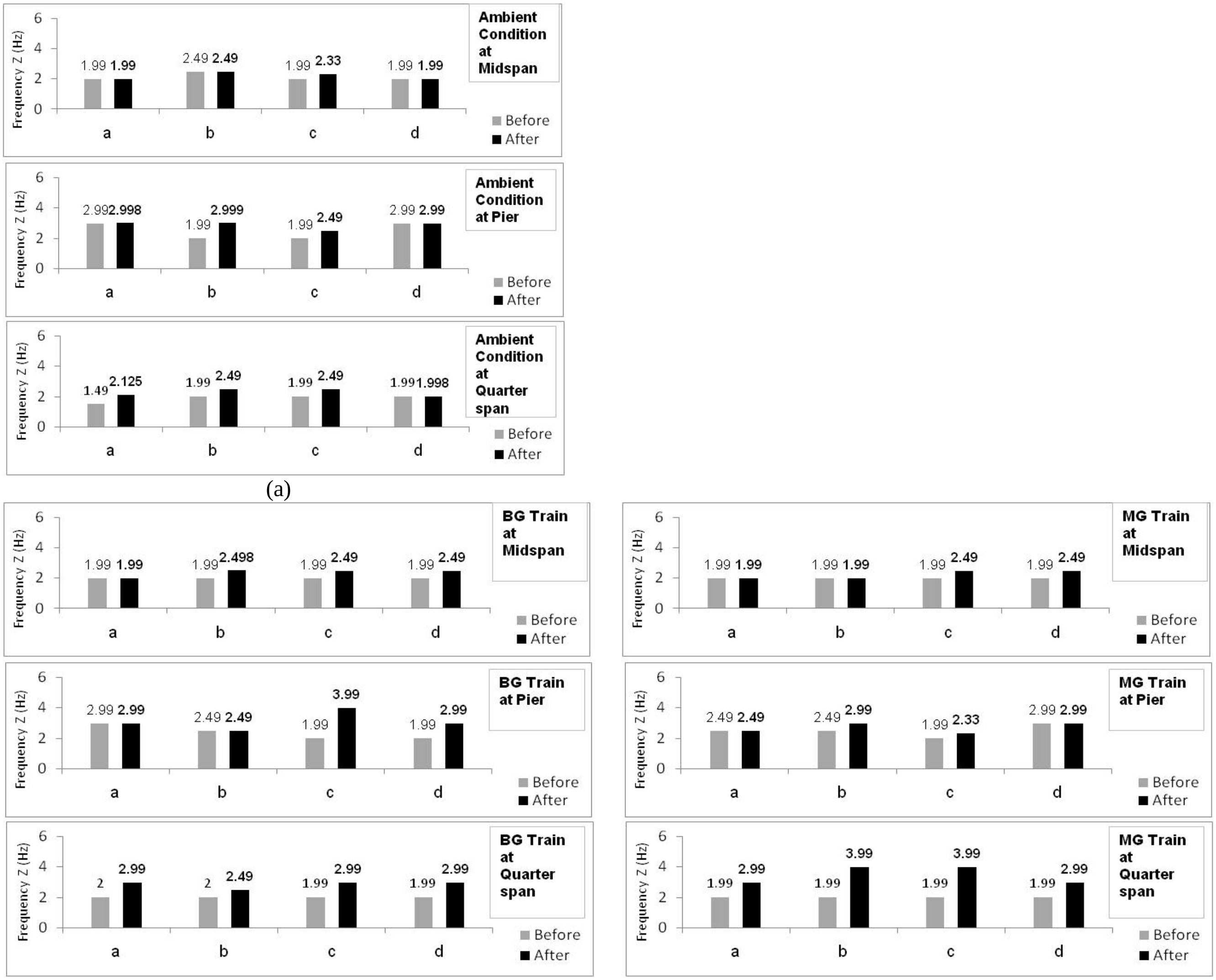


Figure 5. Typical vibration records for broad gauge and meter gauge trains at mid-span locations (Measurement Section 3, Figures 1-3)

Therefore, to exclude the forced vibration situation from train movement, the excitation data after the passage of train was considered for analysis. However, even in such situation, the disturbance from traffic plying over the down stream lanes could not be excluded. However, all ambient vibration data were taken when all traffic over the bridge was closed for a brief period and restricted at least 1 km away from the measurement location (Figure 1) on both sides of the bridge. Within all these limitations, a comparative assessment of pre-repair and post-repair vibration measurements shows a significant increase in deck stiffness, particularly at the mid-span (Location c) and downstream cantilever (Location d). This indicates the cure of crack propagation and substantial strengthening of the deck which was one of the leading objectives of the work undertaken by the Bangladesh Bridge Authority.



(a)

(b) (c)

Figure 6. Fundamental natural frequencies obtained from field vibration measurements. (a) Ambient condition, (b) Excitation due to broad gauge train, (c) Excitation due to meter gauge train

5 CONCLUDING REMARKS

The paper presented a method to assess the post-strengthening stiffness properties of a bridge deck system using vibration sensors. The measurements so obtained are useful not only for immediate assessment of strengthening achievement but also to monitor the time dependent performance of such work. Not to mention, in such an approach, any debonding or lamina separation, if occurs in future, should indicate a reduction in stiffness by displaying lower natural frequency values.

ACKNOWLEDGEMENT

The authors gratefully acknowledge to the Bureau of Research, Testing and Consultancy (BRTC), Bangladesh University of Engineering & Technology (BUET) and the Bangladesh Bridge Authority for their support and cooperation for taking field vibration measurement by conducting free vibration test of box girders of the bridge during different phases of strengthening works.

REFERENCES

Amanat, K. M., Amin, A. F. M. S., Hossain, T. R., Kabir, A., & Rouf, M. A. (2010, August). Cracks in the box girders of Bongobondhu Jamuna Multipurpose Bridge-Identification of causes based on FE analysis. In Proceedings of the IABSE-JSCE Joint Conference on Advances in Bridge Engineering-II (pp. 8-10).

Hyundai 1997. Jamuna Bridge Design Report and As-built Drawings, Bangladesh Bridge Authority.

RPT-NEDECO-BCL 1998. Jamuna Bridge Maintenance Manual, Bangladesh Bridge Authority.