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Identification of dynamic parameters of the Jamuna Multipurpose Bridge in ambient transverse vibration

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Abstract

Jamuna Multipurpose Bridge, located in a seismically active region, is the most important bridge in Bangladesh. The bridge has been instrumented with sensors to monitor its behaviour. The present paper analyses ambient vibration of the pier-deck system in transverse direction and compares the recorded vibration with an SDOF model in frequency domain. The frequency spectrum of the response of the pier-deck system in ambient vibration suggests that the actual behaviour of the system is more like a Two Degree of Freedom system. An analytical model of the TDOF system is then developed in the paper and the predominant frequency of the ambient vibration of the deck is explained.

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1. Introduction

The 4.8 km long Jamuna Multipurpose Bridge over the mighty Jamuna river has established the long cherished road link between the East and West of Bangladesh. The bridge site location map is shown in Fig.1. The bridge is located in a seismically active region and has been designed to resist dynamic forces due to earthquakes with peak ground acceleration as high as 0.2g [1]. JMB is the first bridge in the country where seismic pintles have been used. The pintles act as an isolation device for protection against earthquakes [2]. The bridge has also been instrumented with accelerometers [3]. The present study is aimed at identifying the dynamic parameters of the bridge in transverse vibration from the recorded data. A number of schemes for identification of the dynamic parameters of bridges have been developed in recent years [4,5]. The schemes are intended for particular applications depending on the type of bridge, nature

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of excitation or kind of isolation devices. In the present study dynamic parameters of the Jamuna Bridge in transvers vibration have been identified for ambient vibration. Since the study deals with low amplitude ambient vibration the effect of isolation devices is negligible. However the dynamic parameters obtained from the study are helpful in studying the behaviour of the bridge when isolation devices come into effect.

2. Bridge description

The bridge is slightly curved in plan. The main bridge is about 4.8 km long, prestressed concrete box-girder type, and consists of 47 nearly equal spans of 99.375 m. plus two smaller end spans of 64.6875 m. The main bridge is supported by twenty-one 3-pile piers and twenty-nine 2-pile piers. There are 128 m long road approach viaducts at both ends of the main bridge. There are six hinges (expansion joints) that separate the main bridge structure into seven modules (two end modules, four 7-span module and a 6-span module in the middle). For seismic protection of the Jamuna bridge, seismic protection devices consisting of steel pin dissipating elements and shock transmitter units have been placed in between the girders and the piers. Salient features of the bridge are shown in Table 1.

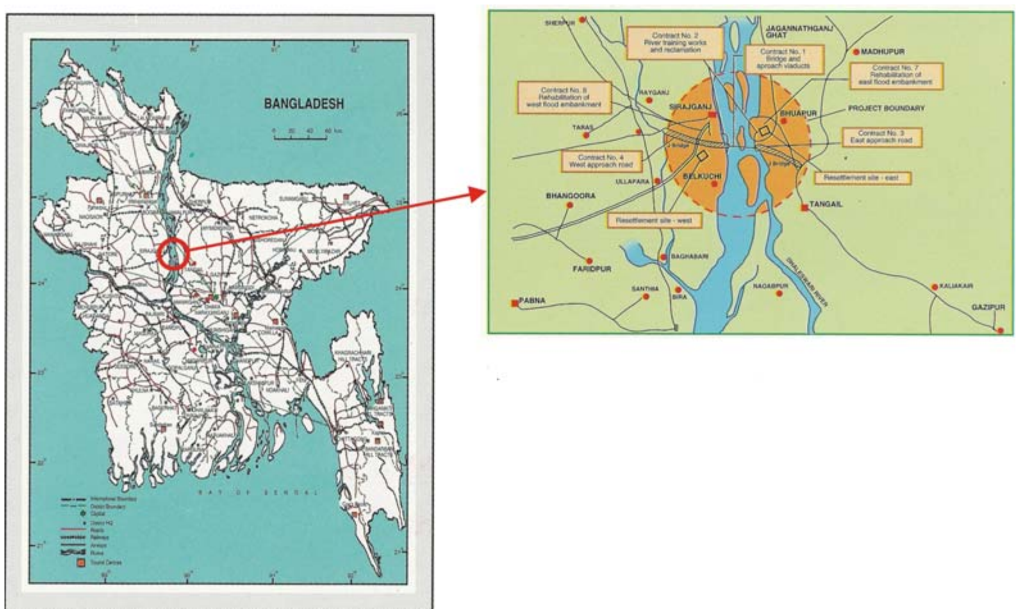


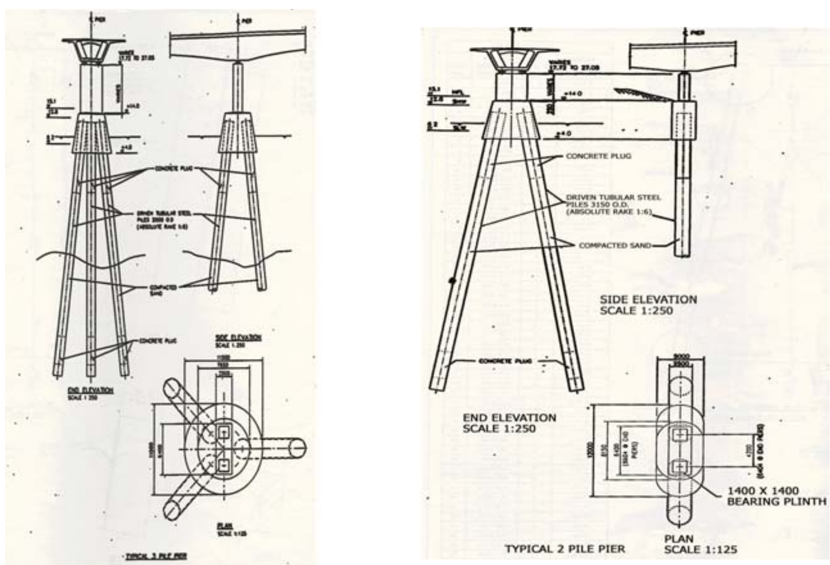
Fig. 1. Location of the Jamuna Multipurpose bridge

2.1 Pile configuration

The substructure of each module consists of three 3-pile piers and three or four 2-pile piers for the six and seven span modules respectively. The foundations consist of driven tubular steel piles, filled with concrete. Pile diameters are 3.15m for the 2-pile piers and 2.50m for the 3-pile piers, and toe levels vary from -70.Om PWD (Public Works Datum) to -82.0m PWD, with a head level of +11m PWD. The thickness of the steel tube varies along the length of the pile. Pile caps are of precast reinforced concrete shell with in-situ reinforced concrete infill construction. They have a base level of +11.0 m PWD, and so the piles are embedded some 7m within the caps. The pile caps carry pier stems which in turn support the bearings. Figure 2 shows the general arrangement of piles.

Table 1. Salient features of the bridge

Length of bridge	4.8 km
Length of viaduct of each side	128.0 m
Width of bridge	18.5 m
Number of spans	47+2
Length of each span	99.375 m
Length of end span	64.6875 m
Number of lanes	4
Number of rail-lines	1
3 Pile Pier (2500 mm OD)	21
2 Pile Pier (3150 mm OD)	29
Number of Total Piers	50
Number of Total Piles	121
Tubular steel Pile Thickness	40mm to 60mm
Average Length of Pile	83.0 m (72 m below river bed level)
Box girder segment length	4.0 m
Absolute rake of Pile (Batter Pile)	1 : 6
Pier Stem height	2.72m to 12.04m



(a) (b)

Fig. 2. General arrangement of piles (a) Three pile pier (b) Two pile pier

2.2 Pier stem

The height of pier stem varies from 2.72m to 13.05m and is constructed of reinforced concrete. Figures 3 and 4 show the cross-section and elevation of the pier stem respectively. The hollow section of pier stem is filled with concrete up to 3m of ifs height. The cross-sectional properties of hollow and solid sections are given in Table 2.

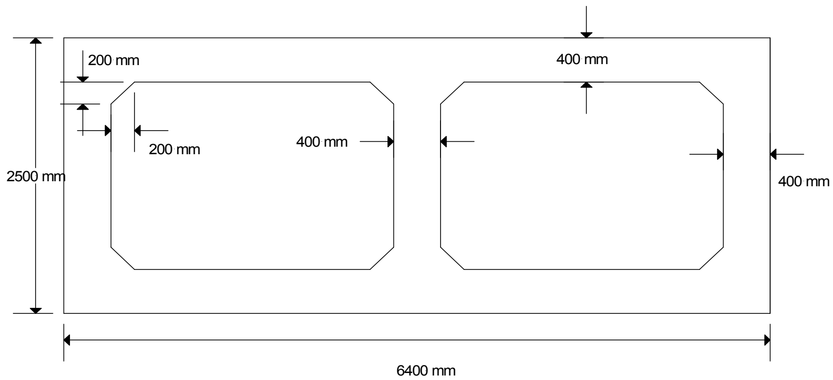


Fig. 3. Cross- section of pier stem

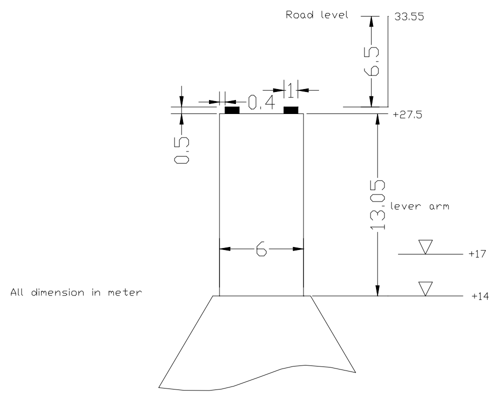


Fig. 4. Elevation of pier stem

Table 2. Cross sectional properties of pier stem

Section Type	Area, m^2	Moment of Inertia (longitudinal), m^4	Moment of Inertia (Transverse), m^4
Hollow	6.84	5.85	38.42
Solid	15.0	7.81	45.0

2.3 Deck configuration

The deck is of prestressed post-tensioned concrete segmental construction, with a varying depth single box section (Fig. 5). Spans cantilevering out from the piers are joined by an in-situ closure at mid-span. The width of the box-section is the same for all sections which is 18.5m but the depth varies from 6.5m at the pier top to 3.25m at midspan. Accordingly, area and moment of inertia both in longitudinal and transverse direction vary along the span.

3. Seismicity of bridge site

Professor Bolt in his report [6] on Seismicity Studies for Jamuna Bridge, Bangladesh, mentioned that the adopted site of the bridge (24.42^{o}N, 89.75^{o}E) could experience shaking from both great and moderate-sized distant earthquakes and from moderate near-site earthquakes during the lifetime (considered as 100 years) of the bridge structure. According to Bolt [5], only one seismic source needs to be considered in postulating strong ground shaking at the Jamuna Bridge site: Zone D at a distance of 25 to 50 km. The design peak ground acceleration is 0.2g. Bolt [6] mentioned that his work had been hampered by the lack of recordings from seismographic stations in the region. He recommended that several strong motion accelerometers should be installed near the bridge structure so that any local shaking can be measured accurately.

4. Instrumentation plan

It was planned to instrument one of the seven modules of the bridge and also to install a few sensors at the abutment. The seven-span module next to the west-end module (designated as Module 1 in the bridge design) was chosen because of its proximity to the most likely source of a major earthquake. The bridge is designed for a peak ground acceleration of 0.2g due to a 7.0 magnitude earthquake in the Bogra fault zone, which is about 25 to 40 kms from the west end of the bridge. Besides, six free field stations, three on each side of the Jamuna River, were to be setup to measure the ground motions. The stations are 70 to 90 km apart from one another forming an equilateral triangle as closely as possible on both sides of the bridge.

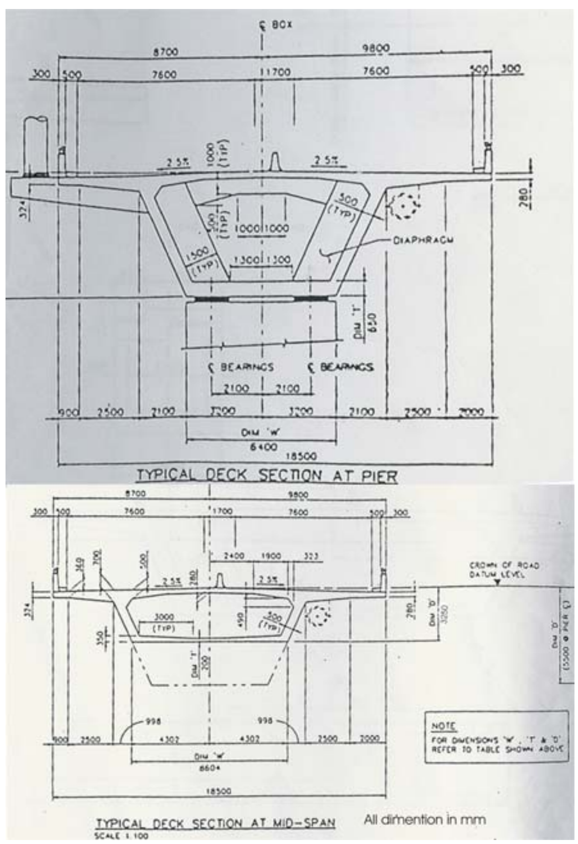


Fig. 5. Typical deck cross sections

In addition, one borehole sensor was to be placed at the West End of the bridge. There was also provision for a portable free field station to be placed at any suitable location, which could be moved if necessary.

Two triaxial, one biaxial and five uniaxial accelerometer (Model Episensor) sensors and three displacement sensors were installed on Module 1 of the bridge structure. There are thus sixteen channels of data. These data are fed to three digital K2 data recorders labelled Jamuna, Meghna and Surma. Each K2 recorder can support up to six channels of data. It was decided to place the three recorders and the communication enclosure close to one another within the box girder deck (Fig.6) near Pier P10.

All the sensors were placed in their designated positions and each of them connected to one particular channel of a recorder. These were connected to one communication enclosure for data transfer to the Data control centre server through the 2.4 GHz wireless radio and antenna hoisted on a lamp post of the bridge (Fig.7). The system was set at UTC time through a GPS.

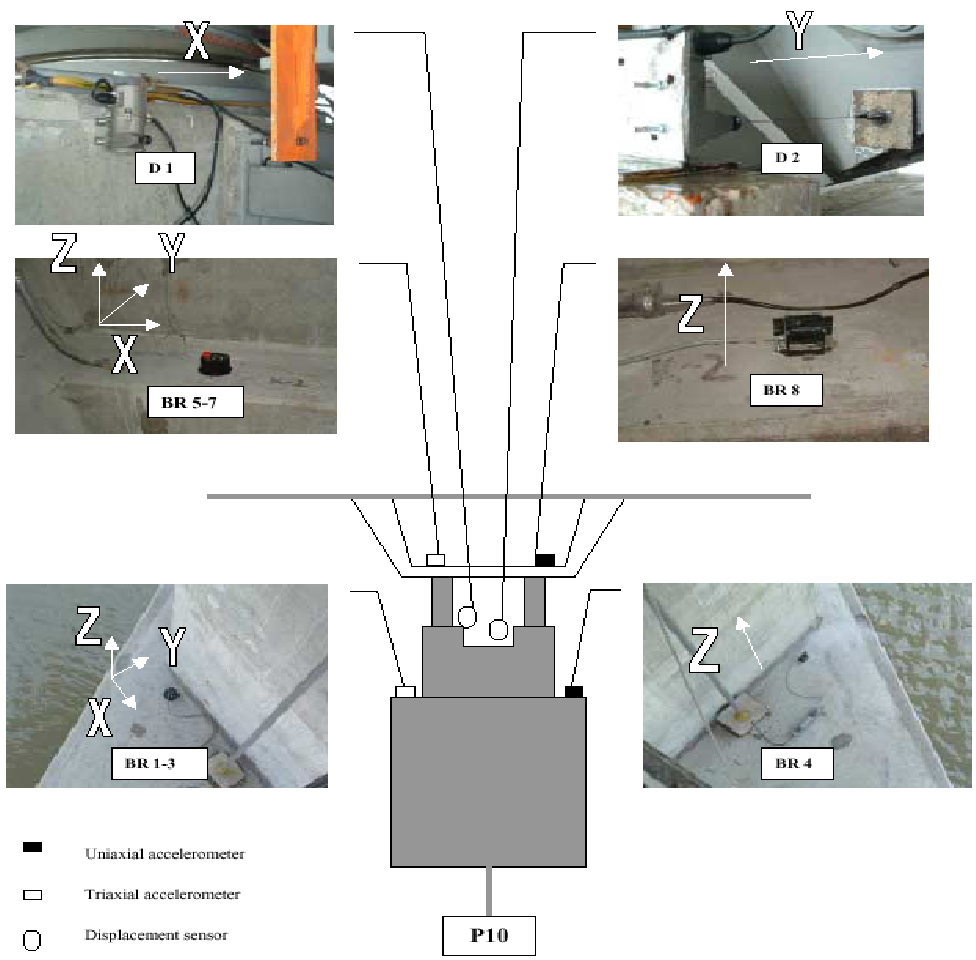


Fig. 6. Location of various accelerometer and displacement sensors at pile and pier.

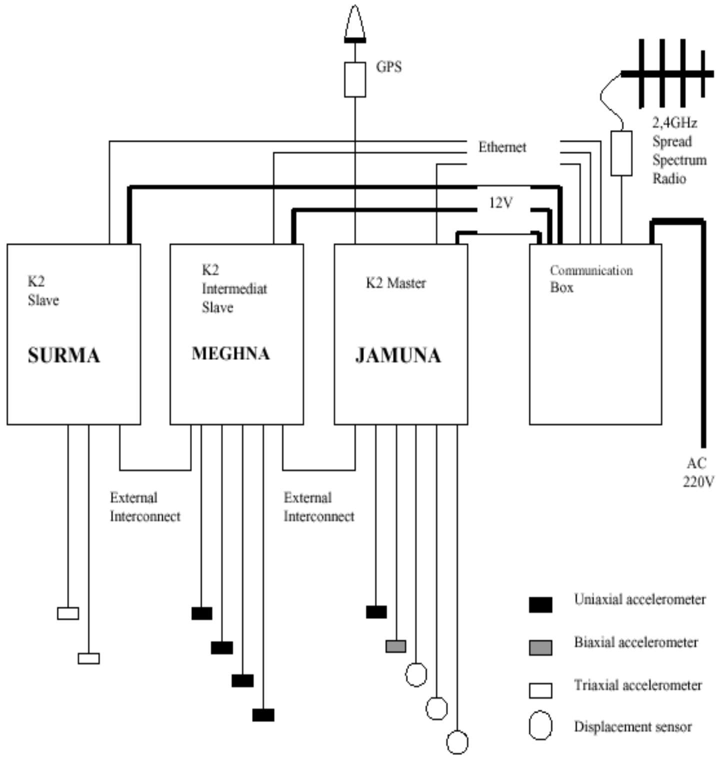


Fig. 7. Connectivity among the sensors

5. Ambient vibration of the pier-deck system

Ambient vibration of the bridge is being constantly monitored with the installed sensors. Vibration of the bridge during train and road traffic movement is also being consciously recorded. A typical example of transverse vibration of pile-cap at BR1-X and corresponding vibration in the box-girder cum deck at BR5-X is shown in Figures 8 and 9. The Fourier spectrums of these noise data of ambient vibration are shown in Figures 10 and 11. From Fig. 10 the predominant frequency of the input motion can be found approximately 1.58 Hz. In addition to this frequency, the major contribution in the deck vibration comes from the frequency level 1.37Hz and a secondary contribution from 1.1 Hz, as can be seen from Fig. 11.

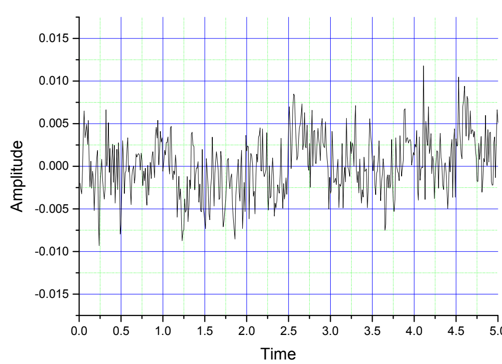


Fig. 8. Amplitude VS Time (without traffic BR_1X)

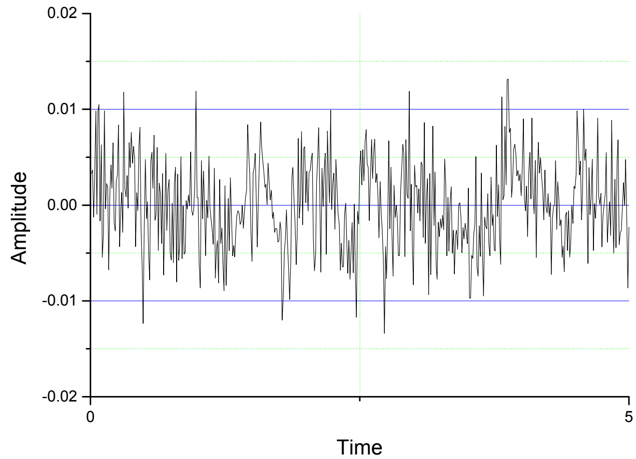


Fig. 9. Amplitude VS Time (without traffic BR_5X)

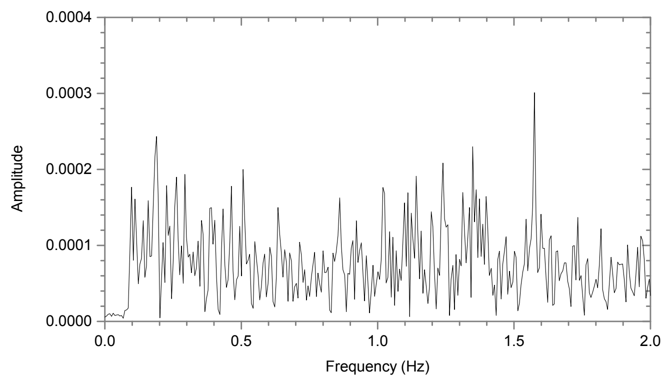


Fig. 10. FFT of BR_1X (without traffic)

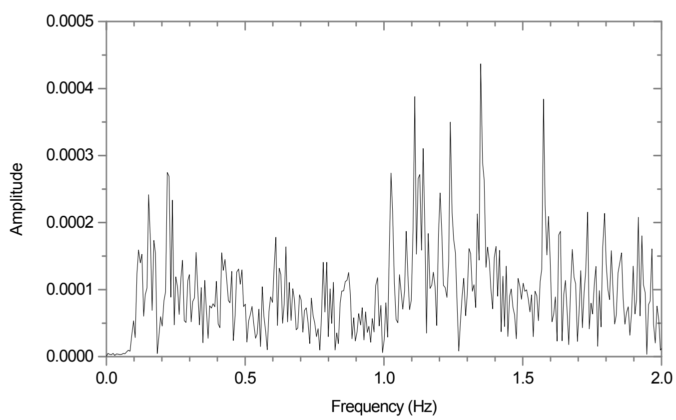


Fig. 11. FFT of BR_5X (without traffic)

5.1 SDOF model

In order to understand the dynamics of the system, at first, a Single Degree of Freedom system of the pier and deck is studied. For the SDOF system, a 100m segment of deck is considered on a single pier and the planer curvature of the bridge is ignored. Although, the depth of the deck varies parabolically along the length, for simplicity, here a linear variation is assumed (Fig. 12). Instead of the complicated cross-section of the original deck a simplified cross-section is assumed for calculation (Fig. 13). The mass of the deck of a 100m segment is found to be $1.095x10^5$ slug. Assuming a linear shape function of the pier, the total lumped mass of the SDOF system can be thought of deck mass plus one-third of the pier mass, which amounts to $2.304x10^5$ slug.

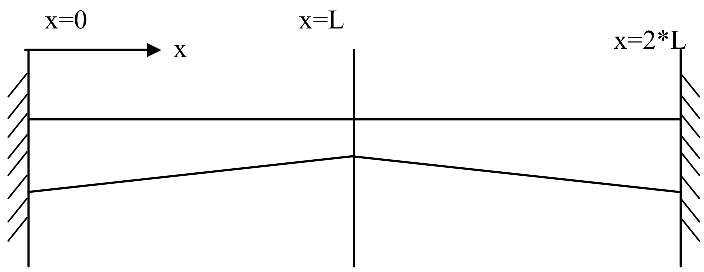


Fig. 12. Simplified deck profile

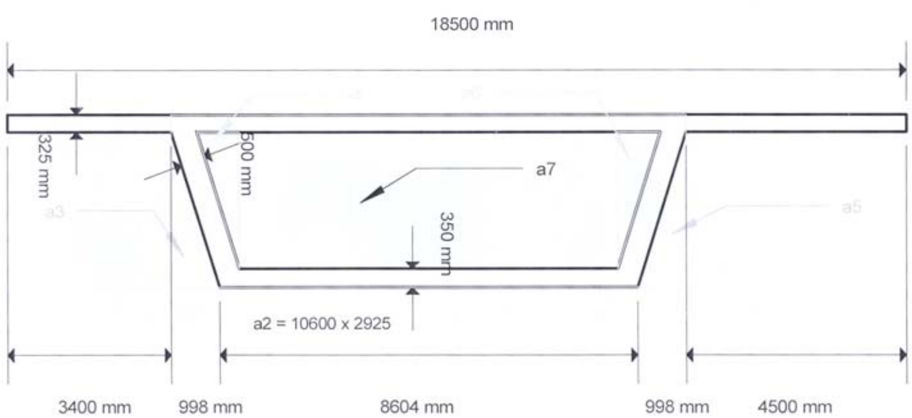


Fig. 13. Simplified deck cross-section at mid-span

The stiffness of the pier is calculated $1.055*10^7$ lb/in assuming the pier to act like a cantilever. Contribution of the deck stiffness is taken into account assuming that the 100m segment of the deck is fixed on both ends. The total stiffness of the system becomes $1.67x10^7$ lb/in. Hence the natural frequency of the SDOF model is 1.08 Hz which is very close to the secondary peak of the Fourier spectrum of the deck vibration (Fig. 11).

5.2 TDOF model

Although the SDOF model explains the secondary frequency of 1.1Hz, it fails to reflect the predominant frequency of 1.37Hz. From Fig. 11, three distinct peaks can be observed. One of which, 1.58 Hz, is the contribution of the forcing frequency of the ambient input vibration as seen in Fig. 10. The two peaks suggest that the pier-deck system can be better simulated with a Two Degree of Freedom system (as shown in Fig. 14). The governing equations of motion of the system are as follows.

Considering equilibrium of mass m_1,

$$m_1\ddot{u}_1 + (k_1 + k_2)u_1 - k_2u_2 + (c_1 + c_2)\dot{u}_1 - c_2\dot{u}_2 = -m_1\ddot{u}_g \tag{1}$$

Considering equilibrium of mass m_2,

$$m_2\ddot{u}_2 - k_2u_1 + k_2u_2 - c_2\dot{u}_1 + c_2\dot{u}_2 = -m_2\ddot{u}_g \tag{2}$$

For undamped condition (c=0), Fourier transformation of Equations (1) and (2) yiled,

$$(k_1 + k_2 - m_1\omega^2)\hat{u}_1 - k_2\hat{u}_2 + m_1\hat{\ddot{u}}_g = 0 \tag{3}$$

$$-k_2\hat{u}_1 + (k_2 - m_2\omega^2)\hat{u}_2 + m_2\hat{\ddot{u}}_g = 0 \tag{4}$$

Thus, from equations (3) and (4)

$$\frac{\hat{u}_1}{-k_2m_2 - m_1k_2 + m_1m_2\omega^2} = \frac{\hat{u}_2}{-m_1k_2 - m_2k_1 - m_2k_2 + m_1m_2\omega^2}$$

$$= \frac{\hat{\ddot{u}}_g}{k_1k_2 - k_1m_2\omega^2 + k_2{}^2 - k_2m_2\omega^2 - k_2m_1\omega^2 + m_1m_2\omega^4 - k_2{}^2}$$

i.e., the transfer functions are $\dfrac{\hat{u}_1}{\hat{\ddot{u}}_g} = \dfrac{\omega^2 - \frac{k_2}{m_1} - \frac{k_2}{m_2}}{\omega^4 - \omega^2\left(\frac{k_1}{m_1} + \frac{k_2}{m_1} + \frac{k_2}{m_2}\right) + \frac{k_1}{m_1}\cdot\frac{k_2}{m_2}}$

and $\dfrac{\hat{u}_2}{\hat{\ddot{u}}_g} = \dfrac{\omega^2 - \left(\frac{k_1}{m_1} + \frac{k_2}{m_2} + \frac{k_2}{m_1}\right)}{\omega^4 - \omega^2\left(\frac{k_1}{m_1} + \frac{k_2}{m_1} + \frac{k_2}{m_2}\right) + \frac{k_1}{m_1}\cdot\frac{k_2}{m_2}}$.

For resonance, $\dfrac{\hat{u}_1}{\hat{\ddot{u}}_g} = \dfrac{\hat{u}_2}{\hat{\ddot{u}}_g} = \propto$. Therefore, the denominator of the transfer functions,

$$\omega^4 - \omega^2\left(\frac{k_1}{m_1} + \frac{k_2}{m_1} + \frac{k_2}{m_2}\right) + \frac{k_1}{m_1}\cdot\frac{k_2}{m_2} = 0 \tag{5}$$

Solving the above equation for ω, the predominant frequencies of a TDOF system can be calculated.

Now for the pier deck stiffness, for the pier stiffness k_1, mass m_1 will be the deck mass and one-third of the pier mass, i.e., 2.23x10^5 slug. For the deck stiffness k_2, mass m_2 will be one-third of the deck mass 7.3x10^4 slug.

The frequency parameters of Eq. (5) are calculated, $\dfrac{k_1}{m_1} = 74.07$, $\dfrac{k_2}{m_2} = 0.27$ and $\dfrac{k_2}{m_1} = 0.09$.

From Eq. (5), $\omega^2 = \begin{Bmatrix} 74.16 \\ 0.27 \end{Bmatrix}$.

Ignoring the long period vibration, $\omega = 8.61$ radian/sec or $f = 1.37$ Hz which coincides with the predominant frequency of the ambient vibration of the deck (Fig. 11).

6. Conclusions

The ambient vibration of the pier-deck system of the Jamuna Bridge was studied in this paper. The bridge is instrumented with accelerometers at different locations. The time-history records from the pile-cap and the deck of a particular pier location were studied in the paper. Two dominant frequencies were observed in the frequency spectrum of the deck vibration. The pier deck system was modeled both as an SDOF system and a TDOF system. The higher of the dominant frequencies corresponds to a predominant frequency of the TDOF system and the lower one corresponds to the SDOF system.

Acknowledgement

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