FREE VIBRATION DIFFERENCES BETWEEN TRAFFIC AND NO TRAFFIC CONDITION ON SUSPENSION BRIDGE

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ABSTRACT:

The paper presents free vibration characteristics of Fatih Sultan Mehmet suspension bridge by means of Ambient Vibration Test with traffic and no traffic conditions. In order to characterize free vibration differences between traffic and no traffic condition temporal and spectral analyses of recorded motions are also utilized and the effects of traffic conditions are presented. Significant amplitude differences in the natural frequencies and displacements between AVS with traffic and AVS with no traffic indicates the importance and impact of traffic load conditions on the bridge

KEYWORDS: Suspension bridge, spectral analysis, traffic, vibration

1.INTRODUCTION

Dynamic parameters of a suspension bridge can be determined by means of Ambient Vibration Test (AVS). There is no artificial excitation in AVS and bridge's motion is caused by traffic, wind and other environmental (ambient) factors.

Several applications related to ambient vibration survey have been reported in literatures. Mclamore and his friends did a related study for Ambient Vibration of two suspension Bridges", in 1971 (1). Abdel-Ghaffar and his staff searched ambient vibrations of Golden Gate Bridge in 1984 (2,3). "Ambient Vibration testing on the Humber Suspension Bridge" was performed by Browjohn et.al in 1986 (4). In addition, some ambient vibration survey studies were performed for the suspension bridges in Turkey. Erdik and his staff performed an ambient vibration study in 1989 for Boğaziçi Suspension Bridge (5).

Limited number ambient vibration tests related to Fatih Sultan Mehmet Bridge have been reported. The first study "Ambient Vibration Survey of the Fatih Sultan Mehmet (Second Bosphorus) Suspension Bridge" was performed by J. M. W. Brownjohn; A. A. Dumanoğlu; R. T. Severn,1992 (6). Ambient accelerations due to dynamic excitation by wind and traffic were measured on the deck, towers, cables and hangers of the bridge. From these measurements, natural frequencies, mode shapes and damping ratios for vertical, lateral, torsional and associated modes in the deck and tower up to a maximum of 2 Hz were obtained. The objective of the test was to validate the mathematical modeling used in seismic analyses of the bridge. The agreement between the experimental and theoretical modes was acceptable for vertical modes bellow 1 Hz, and for torsional modes, but it was difficult to identify the lateral modes due to low levels of response (7,8).

The second investigation was performed by N.M. Apaydın at the scope of PhD study (9). The study was done using seismometers and Global Positioning System (GPS) units. Dynamic characteristics of the Fatih Sultan Mehmet Bridge were explained and a comparative study was presented from analytical investigations, the ambient vibration survey and GPS records. It should be noted that in the last few years, GPS technology has been used in numerous studies related to civil engineering structures, especially to long period structures (10).

In this study, standard Fourier transform method is used to determine free vibration properties. MATLAB (commercial integrating technical computing program) is used for signal processing and data analysis (11).

A variety of methods have been developed for define natural frequencies from ambient vibration data. The term “ambient” covers any all sources uncontrollable input, such as wind and traffic. Input type can affect natural frequencies and modes shapes of long span bridges.

The study elaborated in this paper discusses the effects of moving traffic on the bridge. This kind of study constitute a novel approach in suspension bridges and very important to determine behavior and performance of these long-span structures (12). Dynamic effects caused by moving vehicles on the bridge have been done and the results of these computations are being discussed in here.

The natural frequencies of vibration of Fatih Sultan Mehmet Bridge were accurately determined by measuring traffic-excited vibrations in 3 directions with accelometers mounted at various locations on the bridge

2.PROPERTIES OF THE SUSPENSION BRIDGE

Fatih Sultan Mehmet Bridge is a modern type suspension bridge and links two parts of Turkey and joins together the European and Asian parts of Istanbul. The seismicity of Istanbul and the location of the bridge increase the importance of the evaluation of the dynamic performance of the bridge. Daily traffic of the bridge is approximately 200.000 vehicles.

The bridge, commissioned in 1988, has a main span of 1090 m. The bridge deck is hollow box composed of orthotropic, stiffened panels, having aerodynamic cross-section. The deck has a 33,80m x 3,00m box section and two cantilever side-walks of 2.80m at each side. Total width of the deck is 39.40m. The deck is supported from main cables with the hangers. The cable clamps were erected along the main cables with 17,92 m intervals. The diameter of the main cables on the main span is 0,77m and of the backstays 0,80m. Four steel towers of 107.1 m height support the deck (Fig.1)

(a) (b)

Figure 1: General Arrangement of Fatih Sultan Mehmet Suspension Bridge

3.MEASUREMENTS

Fig.3 shows the locations of sensors to measure the vibrations of the Fatih Sultan Mehmet Bridge.

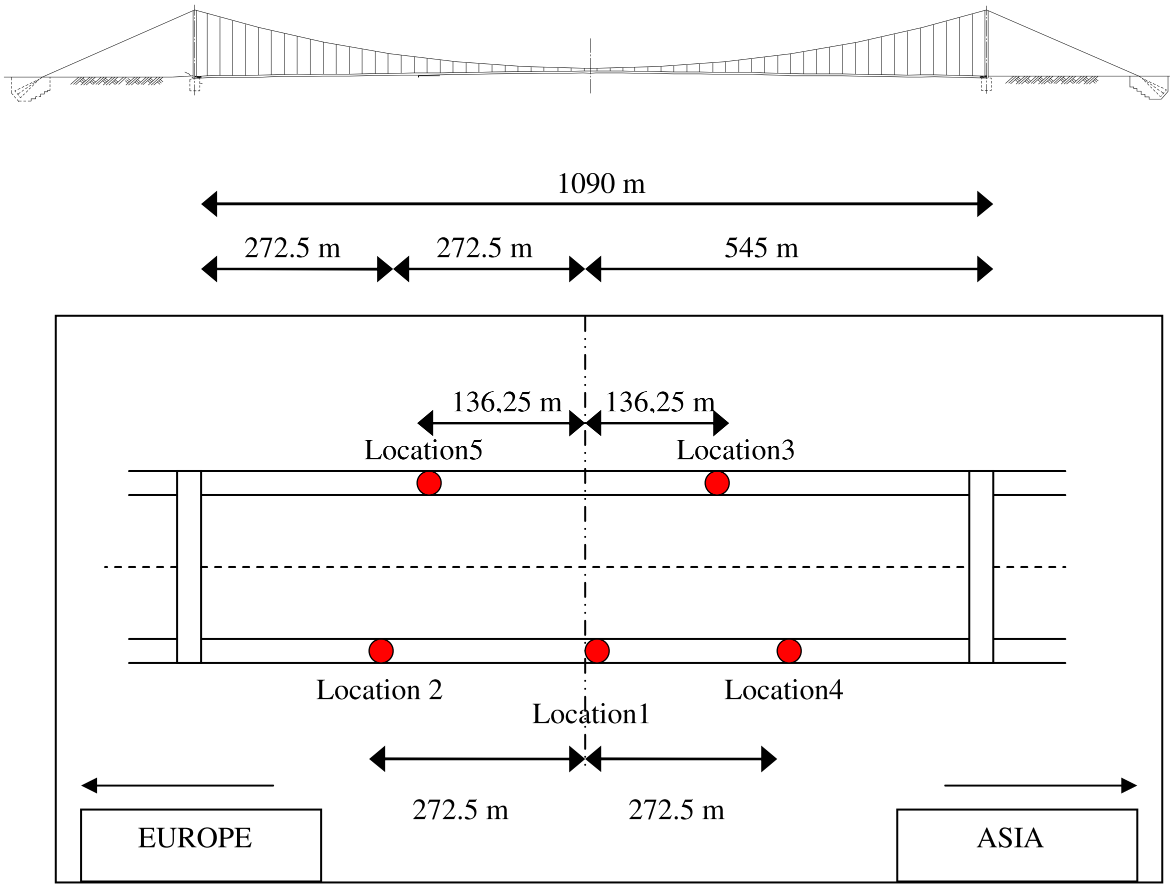

Figure 3: Set-up of Ambient Vibration Survey of Fatih Sultan Mehmet bridge

Full-scale measurements of ambient vibrations were made on the Fatih Sultan Mehmet Bridge in order to determine free vibration of the bridge and to compare the vibrations by spectral ratio and transfer function due to moving traffic for vertical, lateral, longitudinal directions. In order to investigate traffic effects on natural frequencies of the bridge, it is required to obtain data from full traffic condition and no traffic condition. For this reason two measurements are conducted at two different time using portable equipments.

The first test was carried out on July 12, 2007 at rush hour and the second was on July 19, 2007 at 5 hour am. To provide no traffic condition, the bridge was temporarily closed to the traffic during the recording period on July 19, 2007. The first test data has been collected at rush hour traffic between 12:00 and 2:00 o'clock pm. The bridge was used by cars, buses and big lorries at that time. The second test was done to collect data under no traffic condition. Coincidently, at that time the bridge was used by small numbers of cars. Before closing the bridge to the traffic at 5 hour am, it was an opportunity to collect data for light traffic. So, on July 19, 2007, two kind of data for light and no traffic conditions were recorded for the investigation.

The ambient vibrations were recorded in horizontal, longitudinal and vertical directions at five different locations for each test. Five Güralp CMG-5T accelerometer sensors with +/- 2 g range and with total of 15 channels were used for the tests and data was recorded at 100 sampling rate. The locations of the sensors were arranged according to determine natural frequencies of the bridge accurately. It was required to set up accelometers synchronously as quick as because bridge was closed during collection of no traffic data. Vertical, longitudinal as well as lateral vibrational motions were recorded for about 10 minutes at all locations.

4.RESULTS

In this study, results were discussed with comparison of the vibrations of the bridge obtained from traffic condition and the vibrations obtained from no traffic condition. In order to characterize effect of traffic, the Fourier Amplitude Spectrum (FAS) method has been used for the analysis (13,14). MATLAB program was used for signal processing and data analysis.

Acceleration data have been divided into several time periods of 180 seconds duration for traffic and no traffic conditions and several combinations have been arranged to obtain all condition of FAS to define differences between traffic and no traffic conditions.

Firstly, accelerations records were de-trended to remove the linear trend from input data before FFT processing. Then, this data has been filtered to remove noise from signal. A band-pass filter with a 0.05 Hz low corner frequency and 10 Hz high corner frequency was used.

From accelerations records, velocities and displacements were calculated for heavy traffic condition, light traffic condition and no traffic condition at longitudinal, transverse and vertical directions for each location. (Figure 4,5)

Fourier amplitude spectrum has been calculated and this spectrum has been smoothed according to optimum smoothing window length before calculating the ratio. The smoothing aims to reduce the effects of noise that is always presented in the records. A smoothing sub-routine (developed by Prof. E. Safak) the uses a triangular running window of given length, nw, was used (15,16,17). To determine the optimum window length, the maximum amplitude of vibrations, and the sum of squared ratios were calculated and plotted.

Next, spectral analysis at different traffic conditions were calculated at different traffic conditions as well as at different locations for Fatih Sultan Mehmet Bridge (Figure 7).
In addition, correlation of spectral analysis at heavy traffic, light traffic and no traffic conditions were examined in between 0-2Hz. (Figure 8).
In this paper, the results obtained from signal processing and data analysis are presented only for location 1. However similar process was applied to data obtained from other locations and all velocities, displacements and FAS were calculated for all locations. Figure 9 shows the correlation of spectral analysis (FAS) of ambient vibration survey data in vertical direction for different traffic conditions at all stations.

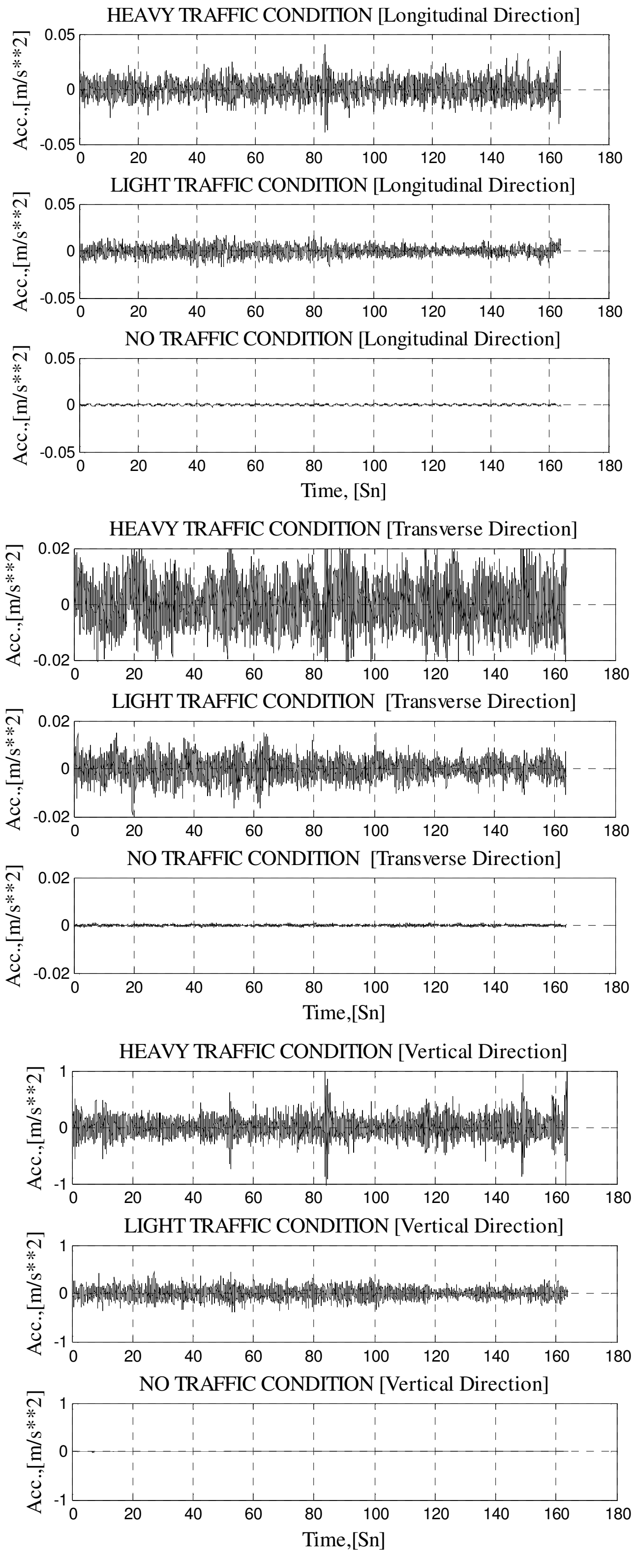

Figure 4: Recorded accelerations for different traffic conditions- Fatih Sultan Mehmet Bridge-location 1

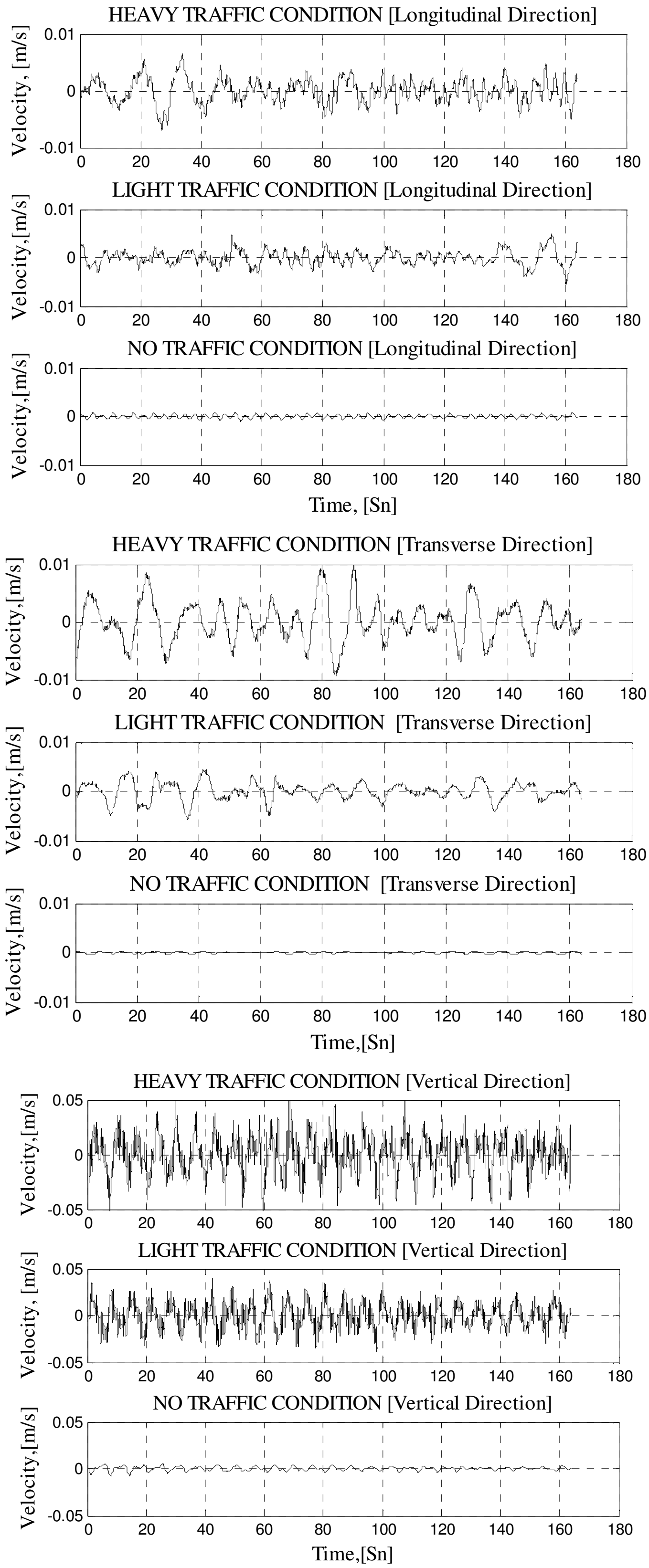

Figure 5: Calculated velocities for different traffic conditions-Fatih Sultan Mehmet Bridge-location 1

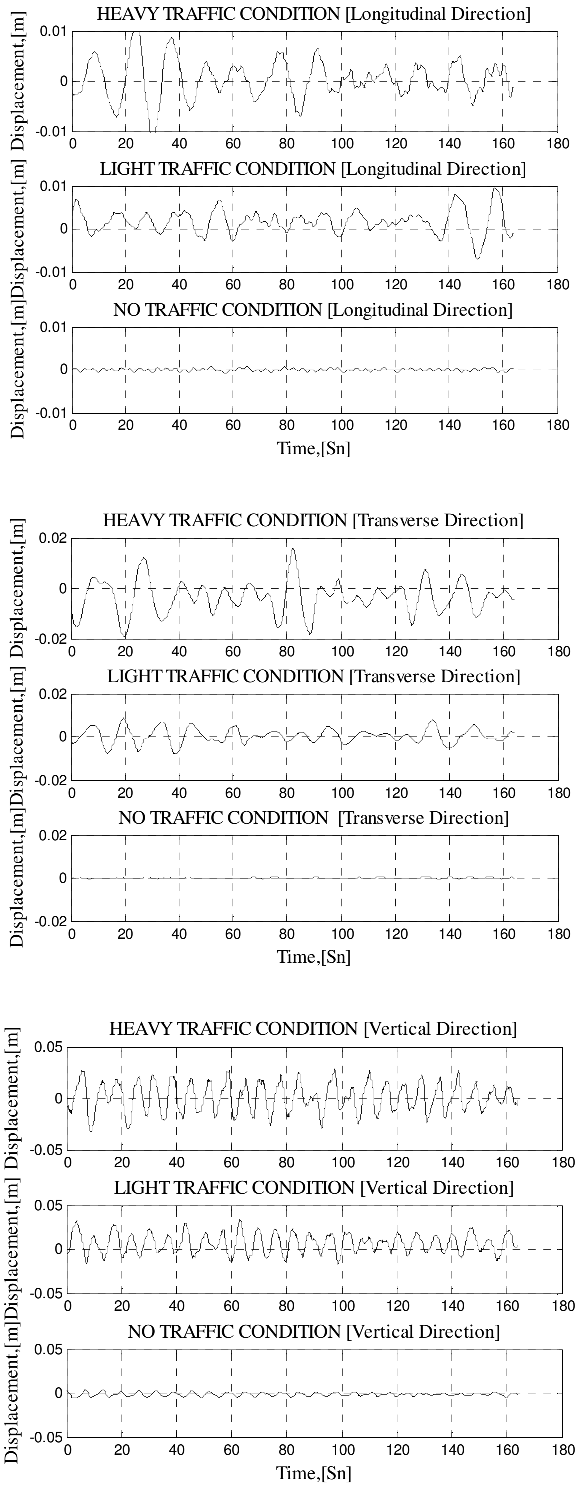

Figure 6: Calculated displacements for different traffic conditions-Fatih Sultan Mehmet Bridge-location 1

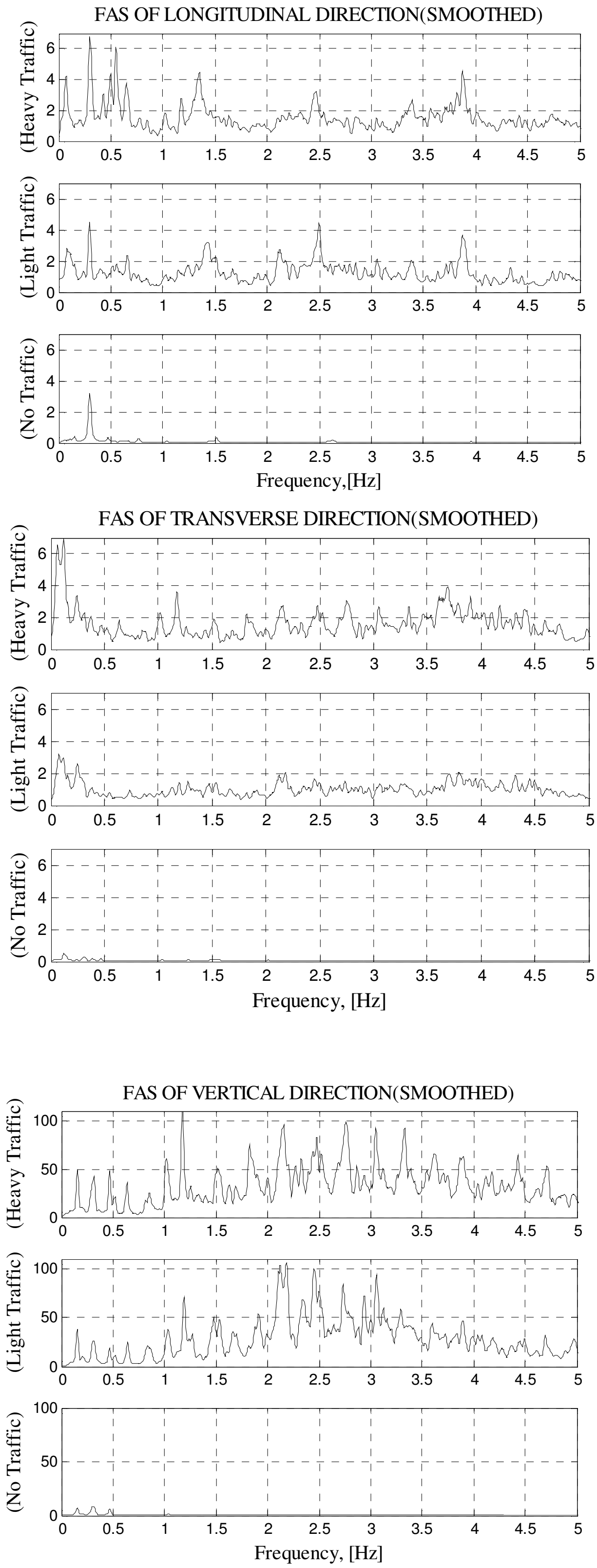

Figure 7: Spectral Analysis-smoothed (FAS) of Ambient Vibration Survey Data at different traffic conditions-Fatih Sultan Mehmet Bridge Deck - location 1

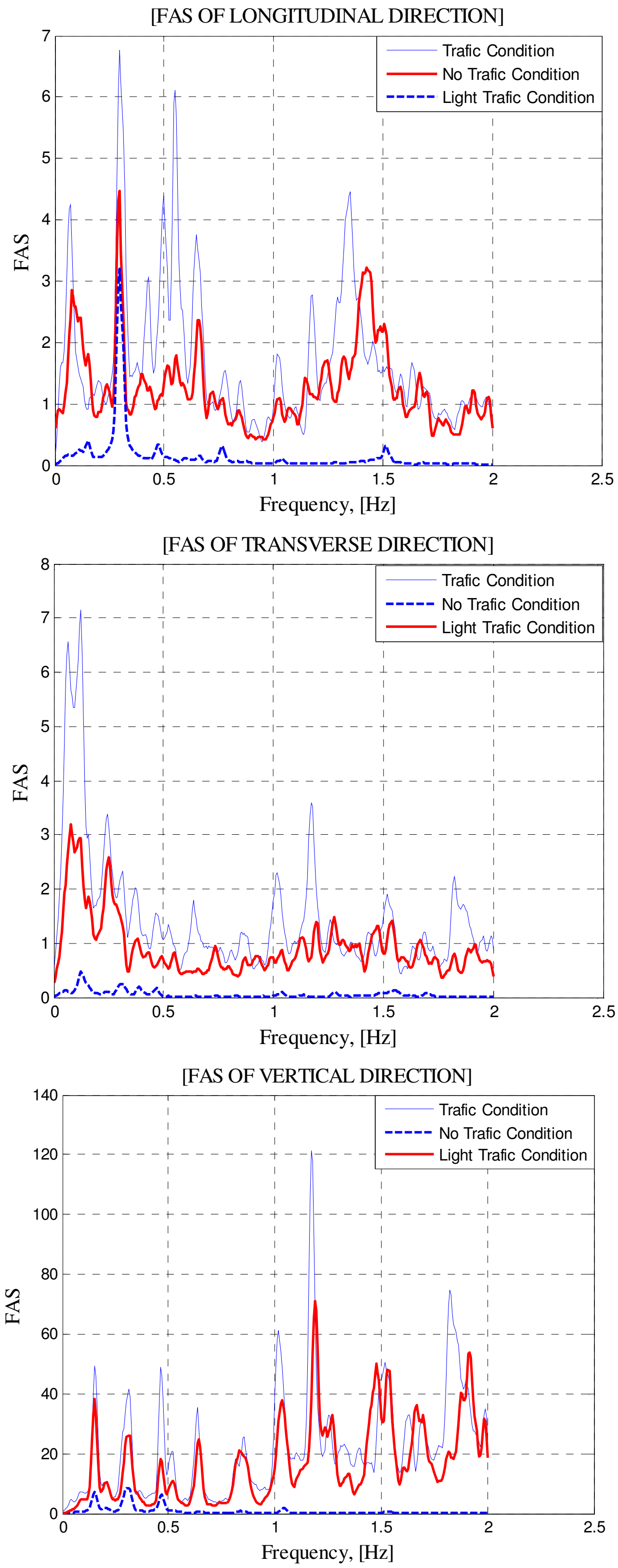

Figure 8: Correlation of Spectral Analysis (FAS) of Ambient Vibration Survey Data at different traffic conditions -Fatih Sultan Mehmet Bridge Deck- location 1

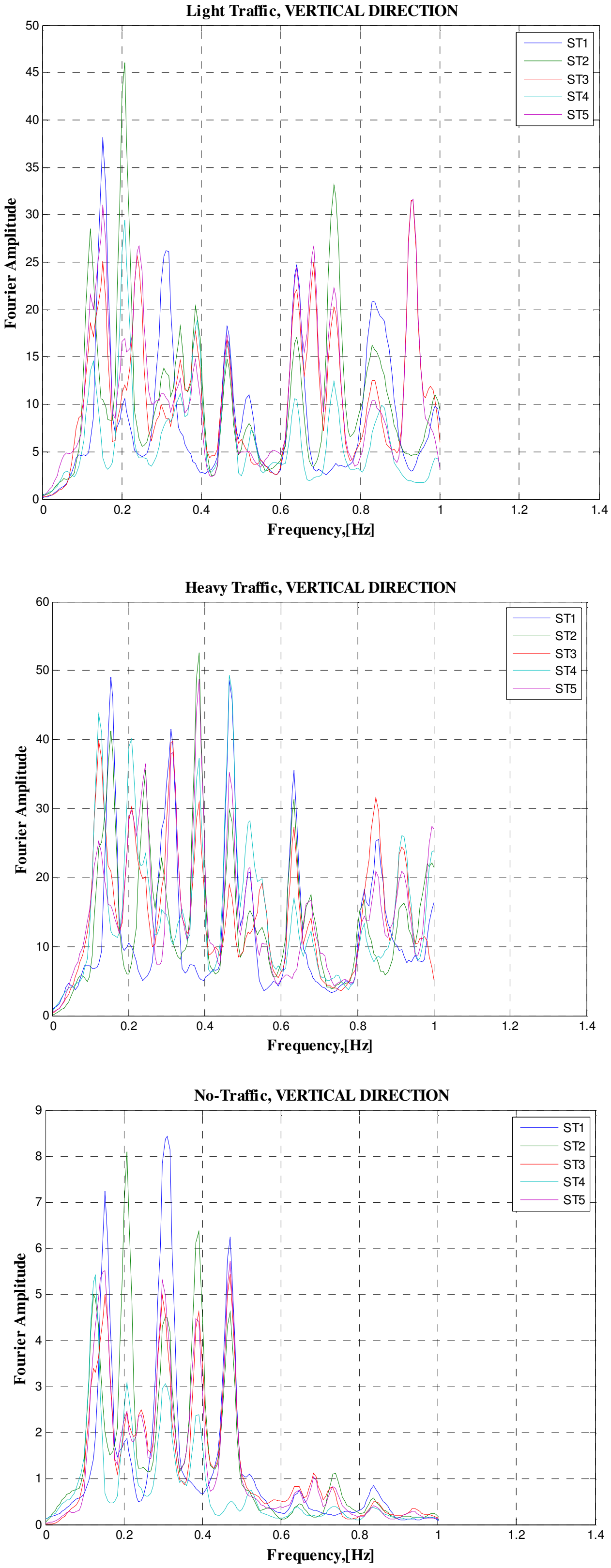

Figure 9: Correlation of spectral analysis (FAS) for different traffic conditions in vertical direction - all locations.

CONCLUSIONS:

Free vibration differences were discussed with comparison of the vibrations of the bridge obtained from heavy traffic condition and the vibrations obtained from light and no traffic conditions. In order to characterize the effect of the traffic and vibration differences between heavy traffic light traffic and no traffic conditions, Fourier Amplitude Spectrums (FAS) were calculated and frequencies and displacements were identified in vertical, lateral, longitudinal directions.

Accelerations records were processed using de-trending to remove the linear trend from input data and filtering to remove noise from signals. Velocities and displacements were calculated for heavy traffic conditions, light traffic conditions and no traffic conditions at longitudinal, transverse and vertical directions for each location. Fourier amplitude spectrum has been smoothed according to optimum smoothing window length.

Acceleration records from different traffic conditions shows that no traffic condition amplification is clearly smaller than other traffic conditions. However, heavy and light traffic conditions acceleration amplifications are very similar. Matching amplification conditions are valid for calculated velocities and displacements. For example, amplifications of velocities and displacements are close to each other for heavy and light traffic conditions especially in longitudinal direction. In addition, displacements are very small in no traffic condition when they compared with light and no traffic conditions. This shows, as it is a long span, any movement causing vibration on the bridge is carried and amplified along the length. So effect of moving traffic whether heavy or light receives the same kind of measurable response from the bridge.

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