Monitoring and Assessment of Mansoura Railway Steel Bridge using RTK-GPS Technique

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Abstract—**Deformation and movement of bridges are among the problems that widely exist in bridge engineering practice. Therefore, it is very important to monitor and analyze bridges deformation to ensure their safety. This study presents Mansoura-Steel Railway Bridge, Egypt, movement analysis in response to passing trains. This bridge was used for two types of traffics which are trains on the middle and one vehicle lane on each side of the bridge. A Structural Health Monitoring system is designed based on the real time kinematic Global Positioning System (RTK-GPS) to monitor and assess the bridge behavior and movements under the effect of trains' loads. The time and frequency domain GPS observation analysis results are discussed and the results showed that the bridge is safe under affected train loads in time and frequency domain and the bridge should be monitored again under trains and traffic loads to conclude the final recommendation.**

Keywords:RTK-GPS; SHM; Monitoring; Railway Bridge

I. INTRODUCTION

Nowadays, the Global Positioning System (GPS) is used widely to monitor and measure three-dimensional (3D) displacements of large engineering structures. GPS are widely used for the determination of long-term stability and movement of bridges, dams, and other similar projects. GPS as well as some of the classical terrestrial geodetic measuring techniques were employed with the aim of assessing the nature, directions and velocities of deformations of the monitored bridge abutment pier and the adjoining railway track structures [1, 2]. Im et al. [3] and others [4-7] summarized and applied GPS technology applications for structural health monitoring (SHM). For GPS, Surveying accuracy specifications are applied to ensure detection of a given movement under normal operating conditions. Allowable survey error thresholds are related to the maximum expected displacement that would occur between repeated measurement campaigns. For each survey, final positioning accuracies at the 95% probability level should be less than or equal to one-fourth of the predicted displacement value [4-5]. Berber et al. [8] introduced the GPS methodology observations techniques and studied the accuracy of different techniques.

Configuring reactions of engineering structures in a time domain as functions of time are generally inadequate for certain applications and frequency domain analysis has been successfully applied to several large scale structures [9]. Moschas and Stiros [10] concluded that the frequency range 0.4~5.0 Hz covers a wide variety of dynamic motions, and frequency range 0~0.4 Hz corresponds to semi-static displacement, which can be occurred due to slow displacements induced by temperature changes, and the corresponding long-period component of displacements are to smaller or larger degree contaminated by colored noise. In this study, lateral, longitudinal and vertical movements of the main girder of Mansoura railway steel bridge under trains' loads are analyzed using the time series analysis. Trend and periodic of the one Hz GPS time history series were determined by time series analysis. The analyses of the periodic component from time domain to frequency domain are done by the spectrum analysis with the use of Fast Fourier Transform (FFT) low and high frequencies of the bridge.

II. BRIDGE DISCRIPTION AND MONITORING SYSTEM

Mansoura railway steel bridge constructed on 1913 is the oldest bridge in Mansoura City, Egypt. Since that time, this research presents the first study for monitoring the behavior of this bridge. As shown in Fig 1, the bridge comprises of four truss girders and five spans. Each truss span is 70.00 m. This bridge was used for two types of traffics which are trains on the middle (double-track) and one vehicle lane on each side of the bridge. This bridge is used to connect the Egyptian railway lines between the east and west Dommieta Nile river branch. In this study, the real time kinematic (RTK) GPS (one Hz) technique is used to study the movement of Mansoura Railway Bridge under current train loads. For the RTK survey base station is set up over stable ground, as shown in Fig 1, and the radio transmitter is attached. Yeh et al. [11] concluded that the rover station must be located within ~10 km of the reference station to achieve one centimeter level accuracy and it is sunned by Berber and Arsan [12]. In this study, the distance between the base station and rover's positions is 188.0 m.

The data presented in this paper is collected from rover GPS receivers clamped at the top of the mid-span o the first girder (R1) to study the girder movement of the bridge (Fig. 1). The monitoring point is located on the top of the upper girder as shown in Fig. 1. The measuring conditions were favorable for the receiver, which was free of any obstruction at 15º angle view of the horizon and at least 4 satellites were tracked continuously.

Figure 1. Mansoura Railway Bridge and GPS monitoring system

The selected observation point is open sky to decrease the errors due to Multipath. The time observation for the rover point is 40 minutes, approximately, when trains were passing over the bridge. The GPS base and rover receiver recorded at one Hz.

III. METHODOLOGY AND DATA ANALYSIS

The trend and periodic lateral, longitudinal and vertical movements of the main girder of Mansoura railway steel bridge under effective loads using time series analysis consisted of the following steps:

A. Coordinate transformation and apparent displacement calculation

The data collected were pre-processed using GPS-Trimble software. The output of the GPS software was the time series of the instantaneous Cartesian coordinates of the rover receiver in the WGS84 coordinate system (X, Y, Z). A local bridge coordinate system (x, y, z) was established to be used in the analysis and evaluation of the observed data [13]. The azimuth of the bridge is 21º 52' 23.29'', based on two monitoring point on the bridge girder. Herein, the x-data represents the displacement changes along the longitudinal direction of the bridge, the y-data represents the displacement changes along the transverse direction of the bridge and the z-data represents the relative displacement change a long the altitude direction of the bridge. The similarity transformation was used to extract the time series displacement observations of the x, y and z directions around a relative zero representing the equilibrium level of the monitoring point [10]. Figure 2 shows the three dimensions time series movement for point R1 during the passing of three trains on the bridge in both directions. The observed time when the trains passed on the bridge were from 839 to 869 (T1); 1309 to 1331 (T2) and 1630 to 1649 second (T3), respectively.

B. Filtering the monitoring GPS displacement

From previous studies [10-11, 13], it is known that the time series of GPS displacement calculations is contaminated by noise. For this reason, filters must be used to extract the semi static displacement component of the time series [10, 14]. In this study, the Moving Average (MA) filter with 25 seconds window is used to de-noise the GPS time history observation and extract the semi static displacement of the bridge girder (Fig. 2.a).

The dynamic displacement is computed after subtracting the semi static displacement from the apparent displacement of GPS observations (Fig. 2.b).

C. GPS displacement Frequency identification

The transformation of the time series observations from the time domain to the frequency domain is performed by applying the Fast Fourier Transform (FFT) [9, 15]. In addition, the power spectrums for the low and high frequencies components of the time series were calculated. Figures 3 and 4 show the first mode frequency components every five minutes of the GPS semi static and dynamic displacement calculation in the x, y and z directions to extract the bridge movement mode with time. In addition, the double differentiation procedure is used to convert the GPS measured time series displacement in the x, y and z directions to acceleration time series [13]. Also, the frequencies are computed from the calculated acceleration based on butter band pass filter and compared with previous time and frequency domain calculations, as shown in Fig. 5.

D. Data evaluation

From Fig. 2.a, it can be seen that the periodic of signals is shown clear from 810 to 2100 seconds due to passing of trains at this time period. In addition, the correlation between recorded and filtered data is very high with no displacement information losses. Accordingly, the MA filter is suitable to extract the semi-static displacement from GPS recorded observations [10]. Also, it can be seen that the x- and y-directions movements occur in the same direction and z-direction displacement occurs in the opposite direction at the same time interval of the passing trains. It is noticed that the maximum displacements are 14.0, 20.0 and 63.0 mm and the mean displacements are 1.85e-4, 9.9e-4 and 6.83e-3 mm. The standard deviation displacements are 4.1, 5.5 and 16.5 mm in the x, y and z directions, respectively. The correlations between the three dimensions displacements are 0.82 (x and y), - 0.54 (x and z) and - 0.72 (y and z).

These results indicate that the correlation between x- and y-directions is very high positive correlation; while the correlations between x- and y- directions with z-direction are low and negative correlation duo to passing of trains. Accordingly, it can be concluded that the performance of the GPS observations is very high sensitive with trains passing on the bridge; and the semi-static bridge behavior under train passes is safe. In addition, the correlation between the two directions (x and y) movements and z-direction movement are strongly influenced.

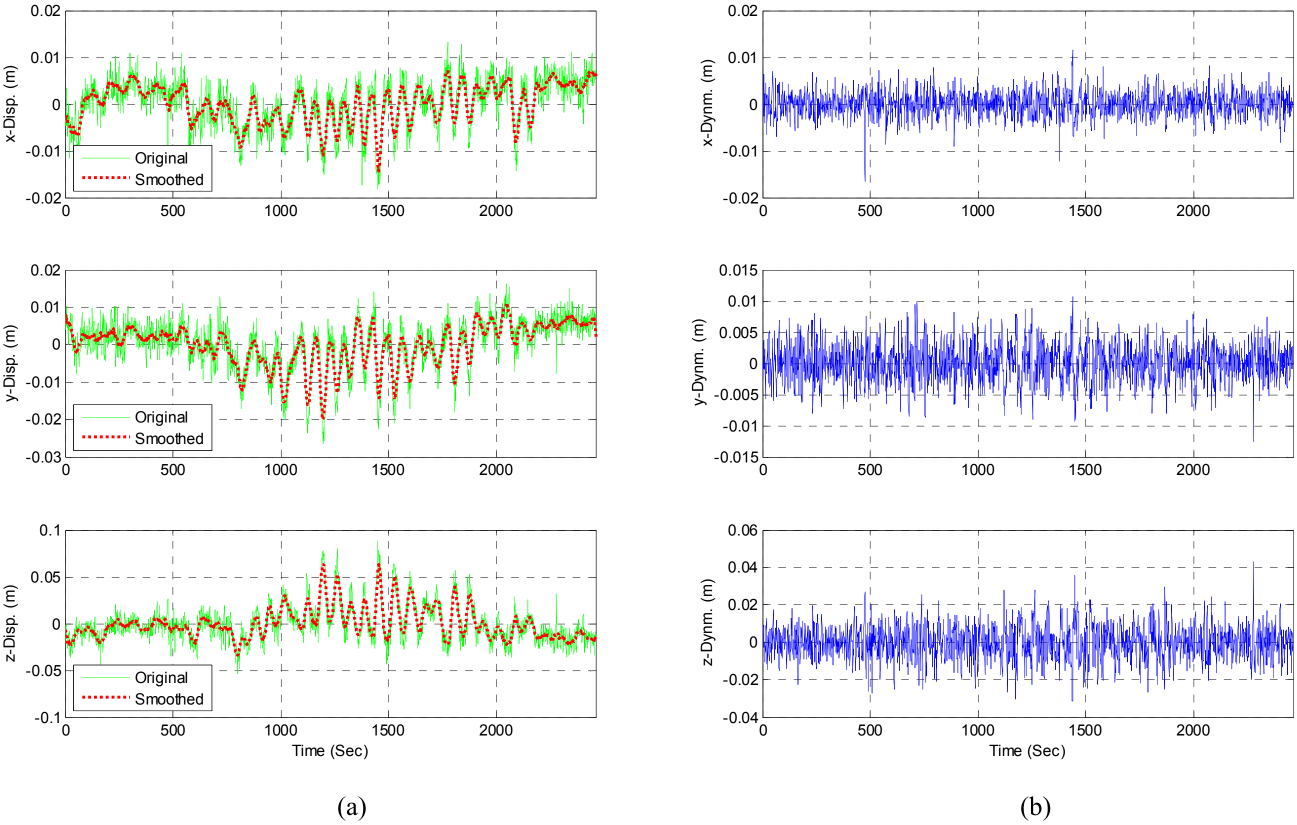


Figure 2. a) Apparent displacement (original) and extracted semi static (smoothed) displacement; b) extracted dynamic displacement from RTK-GPS observations

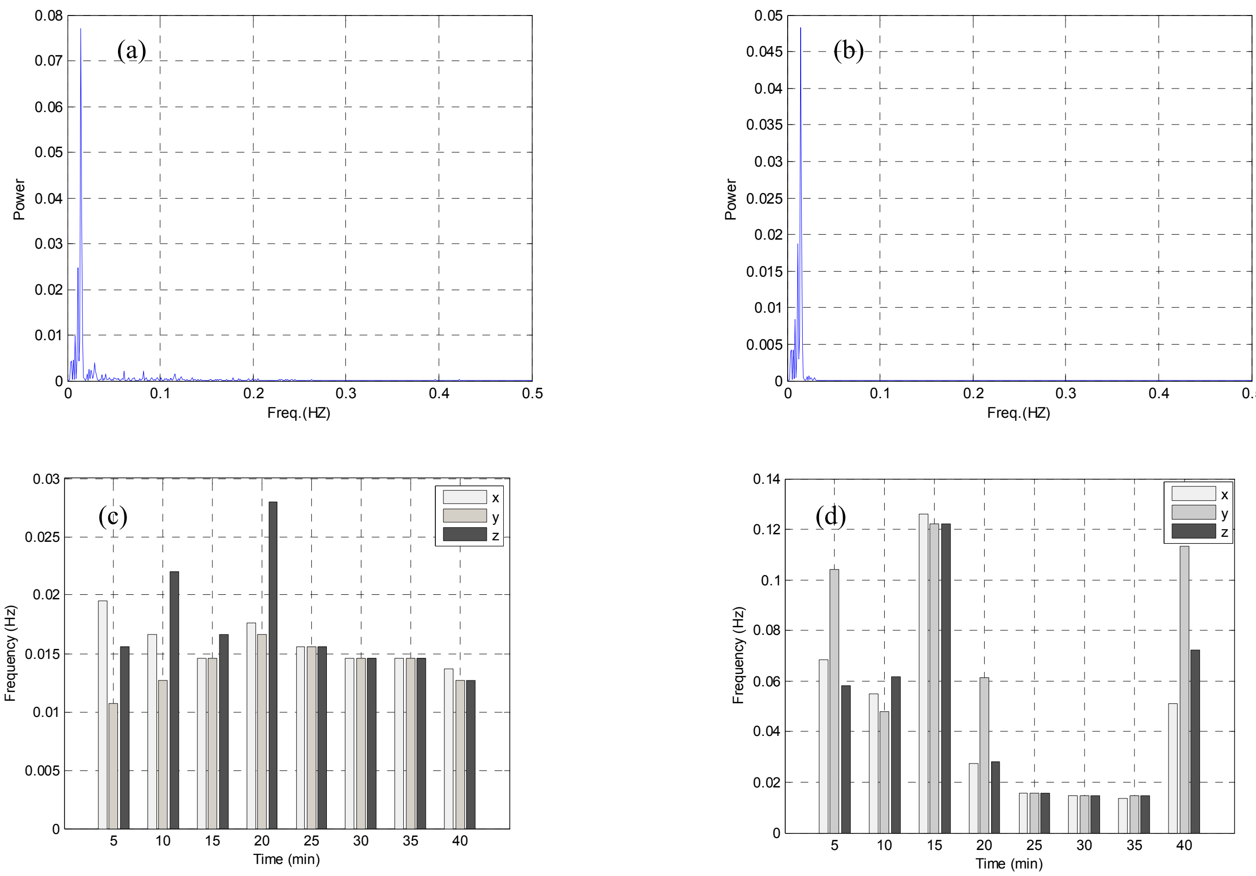


Figure 3. a) z-apparent frequency; b) z-semi static frequency; c) time frequency semi static displacement; d) time frequency dynamic displacement

From Fig. 2.b, it is shown that the dynamic displacement contains a remnant noise [10]. The extracted dynamic displacement can be used to examine the quality of the filter used and guide to understand the behavior of structures under affecting loads. Also, the dynamic displacements ranges are 28.0, 23.3 and 74.5 mm and the standard deviations are 2.5, 3.0 and 8.8 mm in the x, y and z directions, respectively. This result indicates that the maximum dynamic displacement is occurred in the z-direction and y then x directions. In addition, as per the observed conditions, it is concluded that the dominant noise for the dynamic displacement is vibration noise. As per examining Figs. 3.a, b and 4.c, the apparent calculated frequency based on high pass filter contains the two frequency semi-static (Fig. 3.b) and dynamic (Fig. 4.c). In addition, the high power spectrum is apparent; semi static and dynamic for the z-direction are equal. Thus means that the vibration noise affects the GPS dominant frequency calculations in static, semi-static and dynamic displacements. For this reason, the frequency calculations are divided into semi-static and dynamic based MA filter and dynamic signals, respectively (Figs. 3.c and 3.d).

Based on the recorded data, the trains passed on the bridge at the 15th, 25th and 30th minutes. From Figs. 3.c and d, it can be seen that the bridge first mode signal groups are equally for three direction movements in semi-static and dynamic movement components. But the dominant frequencies shapes are mostly not equal. It means that the dominant frequency at load cases are occurred due to the train's passes otherwise occurred due to ambient environmental and observation noise. In addition, the frequency is higher at the 15th minute than other announced frequency; this is due to the train passing time is near the observation point. Otherwise, at the 25th and 30th minutes is via versa with other announced frequency. Also, it can be seen that the correlation between the frequency domains in the three dimensions is high during the monitoring time, approximately. The results, also, show the significant dominant high and low frequency of the apparent displacement in x, y and z directions are close to 0.015 and 0.004 Hz, respectively. The z-direction power spectrum in low and high frequencies are higher than x and y directions. It means that the high and low frequencies reflected the expected movements of the bridge [9]. The frequency modes of the structure can be extracted from dynamic displacement, as shown in Fig. 4.

The first to five frequency modes are 0.015, 0.03, 0.05, 0.10 and 0.125 Hz. Also, it can be seen that the power spectrum in z-direction is higher than other directions. Thus means that the semi-static frequencies are between 0~0.4 Hz and this result cited in Moschas and Stiros [10]. From these results, it can be concluded that the bridge movement under affecting loads in frequency domain is, also, safe.

From Fig. 5, it can be seen that the dynamic displacement calculation reflects the effect of the trains passing on the bridge. The maximum range displacements are 3.0, 4.0 and 12.4 cm in x, y and z-directions, respectively. The dynamic displacement is occurred during the time period from 810 to 2100 seconds. From these results, it can be seen that the dynamic displacement calculated based on band pass filter is better for the dynamic displacement (Fig. 2.b). A double differentiation procedure applied to convert the dynamic GPS displacement calculations to acceleration time series [13]. The FFT is applied to calculate the frequency domain as shown in Fig. 5.c. From this Figure, it can be seen that the high power frequencies in x, y and z-directions are 0.125, 0.165 and 0.178 Hz, respectively. The frequencies modes are shown in between 0.05 to 0.3 Hz. From these results, it can be concluded that the Butter band pass filter can be used to extract the time and frequency domain for GPS dynamic displacement.

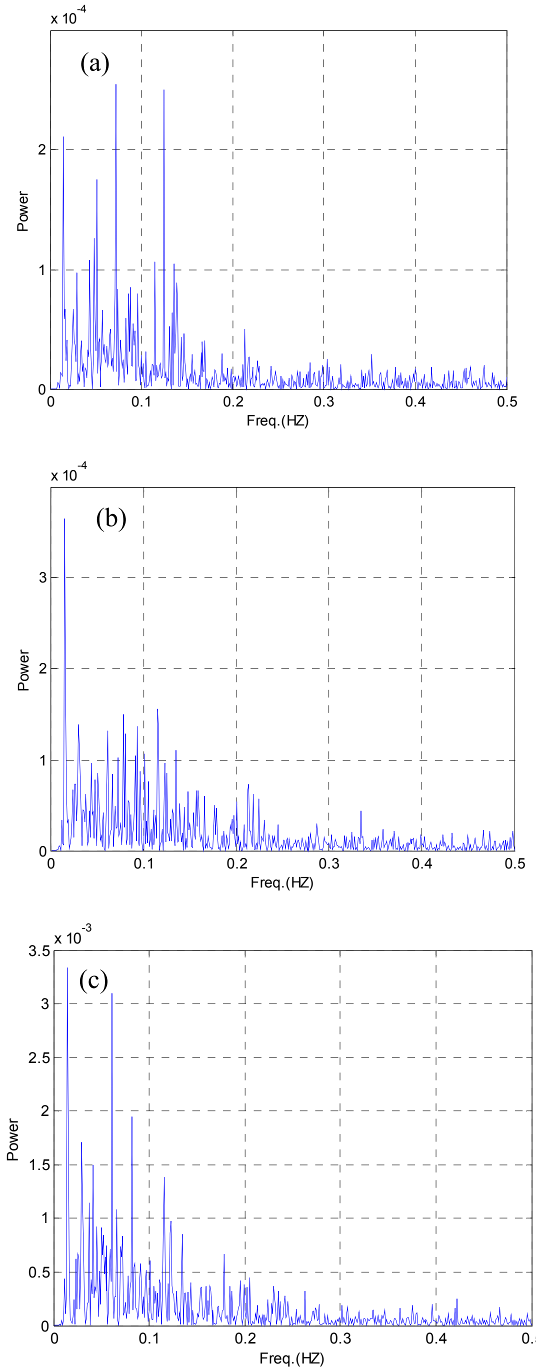
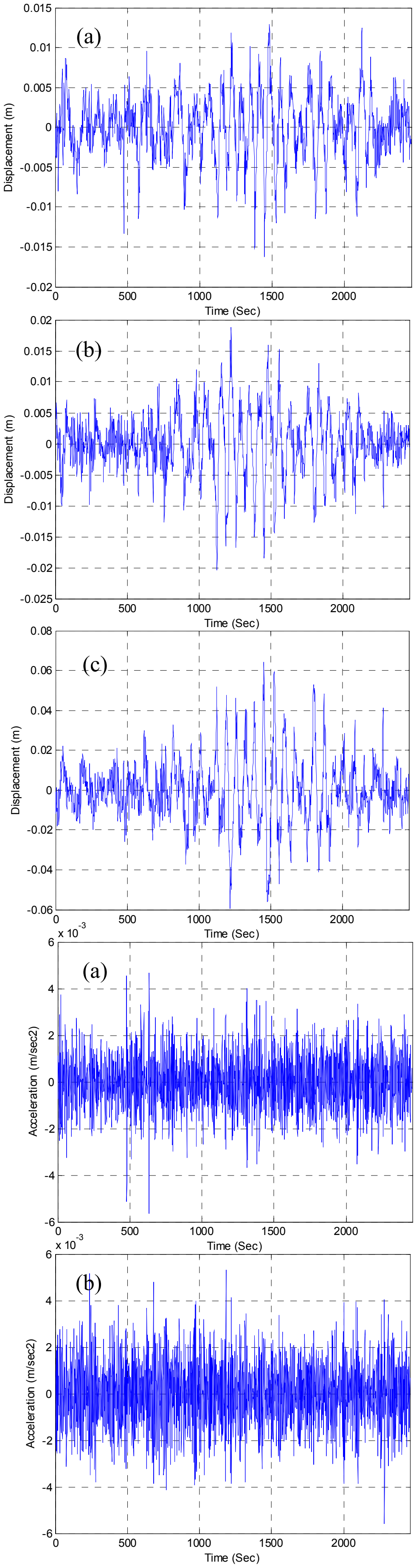


Figure 4. Dynamic frequency displacement modes in directions a) x; b) y and c) z



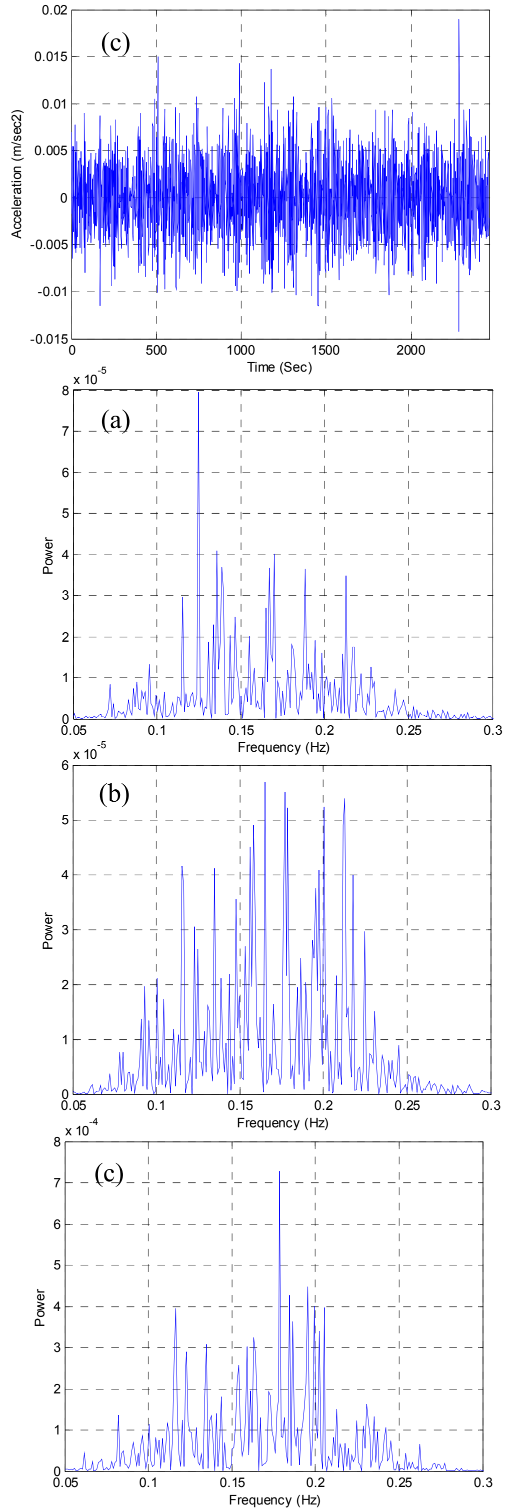


Figure 5. Extracted dynamic displacement; acceleration and frequency calculation for a)X; b)Y and c)Z

IV. CONCLUSIONS AND RECOMMENDATIONS

Mansoura railway steel bridge is constructed on 1913 and this study is the first for monitoring the behavior of the bridge. The system monitoring used is RTK-GPS (one Hz) technique to study the movement of the bridge under train loads. The moving average filter is used to de-noise the apparent GPS displacement observation. The butter band pass filter and Fast Fourier Transform are used to extract the bridge dynamic displacement and frequency modes. The conclusions and recommendations drawn from this study are as follows:

The RTK-GPS one-Hz can provide valuable deformation data of the structure members in time and frequency domain. The Moving Average filter is suitable and simple to extract the static and semi-static displacement of structures based on GPS monitoring observation. Furthermore, the butter band pass filter is a best solution to extract the dynamic and frequency modes of structures.

Mansoura railway steel bridge is safe based on the current passing train loads in time and frequency domains analysis. In the other hand, there is a need to monitor the bridge under trains and traffic loads to conclude the final recommendations.

REFERENCES

[1] S. Otakar and Z. Pavel, "Deformation Measurement of Railway Bridge Abutment Pier"; INGEO 2004 and FIG Regional Central and Eastern European Conference on Engineering Surveying; Bratislava, Slovakia, 2004.

[2] J. Sabova and V. Jakub, "Verification of geodetic points using GPS measurements"; 5th International Scientific Conference - SGEM2005; 2005, pp.615- 620.

[3] S. Im, S. Hurlebaus and Y. Kang, "A Summary Review of GPS Technology for Structural Health Monitoring", J. Struct. Eng., 2011, doi: 10.1061/(ASCE)ST.1943-541X.0000475

[4] A.Knecht and L.Manetti, "Using GPS in structural health monitoring"; SPIE'S 8th annual international symposium on smart structures and materials; Newport Beach (CA), USA, 2011.

[5] CECW-EE, "Engineering and Design: structural deformation surveying"; Manual No. 1110-2-1009; Department of the army, US Army Corps of Engineers, Washington, 2002.

[6] W.R. Gethin, B. Chris and O. Oluropo, "Monitoring the deformation of a motorway viaduct using kinematic GPS"; 4th IAG Symposium on deformation measurement and analysis; LNEC; Lisbon, 2008.

[7] Y. Ting-Hua, L. Hong-Nan and G. Ming, "Experimental assessment of high-rate GPS receivers for deformation monitoring of bridge"; Measurement J.; 2013, , pp.420–432

[8] M. Berber, A. Ustunb and M. Yetkina, "Comparison of accuracy of GPS techniques"; Measurement J.; 2012, , pp.1742–1746

[9] H. Erdogan and E. Gulal, "The application of time series analysis to describe the dynamic movements of suspension bridges", Nonlinear Analysis: Real World Applications, 2009, 10(2), pp. 910–927

[10] F. Moschas and S. Stiros, "Noise characteristics of high-frequency, short-duration GPS records from analysis of identical, collocated instruments", Measurement J., 2013, 46, PP.1488-1506.

[11] T.K. Yeh, B.F. Chao, C.S. Chen, C.H. Chen and Z.Y. Lee, "Performance improvement of network based RTK GPS positioning in Taiwan", Survey Review J., 2012,44,PP.3-8.

[12] M. Berber and N. Arslan, "Network RTK: A case study in Florida", Measurement J., 2013, in press

[13] G.W. Roberts, X. Meng and A.H. Dodson, "Integration a global positioning system and accelerometers to monitor the deflection of bridges", J. of survey engineering, 2004, 130(2), pp.65-72.

[14] F. Moschas and S. Stiros, "Noise characteristics of high-frequency, short-duration GPS records from analysis of identical, collocated instruments." Measurement J., 2013,46, 1488-1506.

[15] M. Kaloop and D. Kim, "GPS-Structural Health Monitoring of a Long Span Bridge using Neural Network Adaptive Filter", Survey review J., 2013, in press.