Monitoring Bridge Deformations during Static Loading Tests Using GPS

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Key words: Bridge, Static Loading Test, Deformation, GPS, OTF

SUMMARY

The static loading test of a bridge is a fundamental check of the actual behavior of a bridge under extreme loading conditions. By measuring bridge deformations and comparing it to expected theoretical values resulting from design, bridge safety can be assessed. In this paper, GPS is presented as a viable tool to monitor bridge deformation in Egypt. GPS was used for deformation measurement and the results were compared to those of precise leveling. Based on the results, it was feasible to continuously monitor selected points along the bridge and to overcome problems relating to leveling benchmarks.

Two GPS Trimble receivers were used to monitor deformations of Maadia Bridge during static loading tests. The bridge lies along the Northern International Coastal Road, between Rasheed and Abu-Quier. The GPS receivers were set up to record signals every 3-sec. and the On The Fly (OTF) technique was used to process the GPS observations. The results were then post-processed using two different techniques; filtering and improved mean value, in order to filter out noise and undesirable frequencies. The final GPS results were found to be consistent with those obtained from precise leveling.

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1. INTRODUCTION

During the 1980's, deformation monitoring of engineering structures worldwide started using GPS for deformation measurements techniques alongside conventional measurement techniques, as high accuracy GPS derived three-dimensional positioning became possible (Erol et al, 2004). For Egypt, scientific literature includes examples of early uses of GPS in deformation monitoring in Egypt. Baraka (1990) presented an investigation covering the design, implementation and analyses of a GPS regional deformation monitoring network within the Aswan area in Southern Egypt, and its potentials to extend to monitor the Aswan High Dam. A second example was the study and establishment of a regional GPS deformation monitoring network, with connections to the International GPS Geodynamics Service network (IGS), along the Western shore of the Gulf of Suez (Baraka, 1996).

Geodetic measurements are made to targets (usually small retro prisms) mounted on the structure, or to GPS antennas. The prisms are arranged to be visible from the location of a surveying instrument and to be able to indicate movement in the region of interest. The prism array's layout is developed based on expected direction and range of motion. Locations of the GPS antennas are determined by considering the expected movements of the structure and the special requirements for precise positioning using GPS. The requirements include clear visibility to the sky; power and data links for the GPS receiver; and absence of structures that reflect incoming GPS signals resulting in a condition known as multipath. GPS measurements may be reduced to positional data in real time. This is valuable when immediate knowledge of a structure's behavior is required. Alternatively, GPS data can be collected over a period of time and post-processed for detailed analysis. While GPS can carry a higher cost per point monitored than total stations, the advantages of GPS make it the preferred technology in many applications (Stenmark, 2002).

Static loading tests of bridges are regularly conducted in Egypt to monitor deformations of the new constructed bridges under extreme loading conditions. The results of such tests are compared to their corresponding design values. The deformation of the bridges was used to measure by using mechanical dial gauges (deflectometers) fixed between the bridge beams and a metal or wooden frame. They are used to measure the amount of deflections when it is possible to place this instrument over a shuttering under the body of the structure with ease of access. However, this is not the case for a bridge crosses over a body of water, e.g. canals or rivers as well as cases where bridge rises with its middle spans tens of meters above the ground. Such cases constitute situations that result into expensive set up procedures for deflectometers with shuttering and significant obstacles in the accessibility to deflectometers in their locations under such bridge. In this case, other means of deflection measurements should be sought. It is found that this method has deficiencies such as (Abdel-Gawad, 1994):

- The change of temperature and humidity may cause expansion or shrinkage in the metal or wooden frame which affect the reading of the mechanical dial gauge.
- Any settlement in the ground below the frame may affect the mechanical dial gauge reading.
- Any deformation in the frame due to observer weight may affect the dial gauge reading.

For instance, precise leveling can be used instead of deflectometers, where precise leveling proved to be more effective and gives accurate results for deformation (Baraka and Taha, 1992). Deformation monitoring practice using precise leveling in Egypt retains the same level position from start to end during bridge loading. The level is used to observe pre-selected points (points with expected critical deflections) before any loading. The distance between the level and the observed points is not to exceed 25 m. for clear level reading. Such constraints may result in the need to move the level during the loading test and hence may affect the final results. This is usually overcome by observing carefully pre-selected benchmarks, however, in some cases suitable benchmark locations might be prove to be difficult to locate.

Experiments were conducted within this study to investigate the potentials of using GPS to monitor benchmarks and any possible movement during loading tests. This is currently possible due to the maturation of GPS technology, especially the use of carrier phase observables within On The Fly (OTF) techniques. For design and validation of the potential GPS accuracy a test was performed on the premises of the Faculty of Engineering Cairo University, Egypt. The description of the test and results are given next, followed by the results of the experiment using GPS at El-Maadia Bridge.

2. GPS KINEMATIC DEFORMATION MONITORING – VALIDATION TEST

A test was conducted for using GPS in deformation monitoring on the premises of the Faculty of Engineering Cairo University, Egypt. Two GPS Dual frequency receivers, Trimble 4000 were used, where one GPS receiver was used as a reference station while the other was used as a rover station, set up over hydraulic Jack. GPS observation recording interval was set to at 5 sec. To minimize phase center errors, GPS antennas were oriented to north direction for the duration of the test and GPS data was collected for over four hours. The data was then downloaded to computer and GPSurvey version 2.35 was used to process the data. OTF technique was used to resolve the integer ambiguity. During an OTF search, the system conducts a statistical search of all the possible integer ambiguity combinations and ultimately chooses the ones that are statistically the most likely be correct (Roberts et al, 1999). Once fixed, it is possible to position the rover receiver to a precision of few millimeters relative to reference GPS station. The results are given by Fig. 1 where the levels of the rover receiver were plotted against time. Figure 1 showed that levels included variations and drops at the time when the rover receiver was moved down, also that the variation of levels with respect to time were of periodic nature. A first approach to deal with these variations was to apply a mean enhanced value for levels (h_{mi}) at each successive epoch (i) based on all the number (n) of observed levels (h_i) prior to this epoch as given by the following equation (El-Shazly, Abdel-Maguid, 2003):

$$h_{m_i} = \frac{\sum_{i=1}^{i} h_i}{n} \tag{1}$$

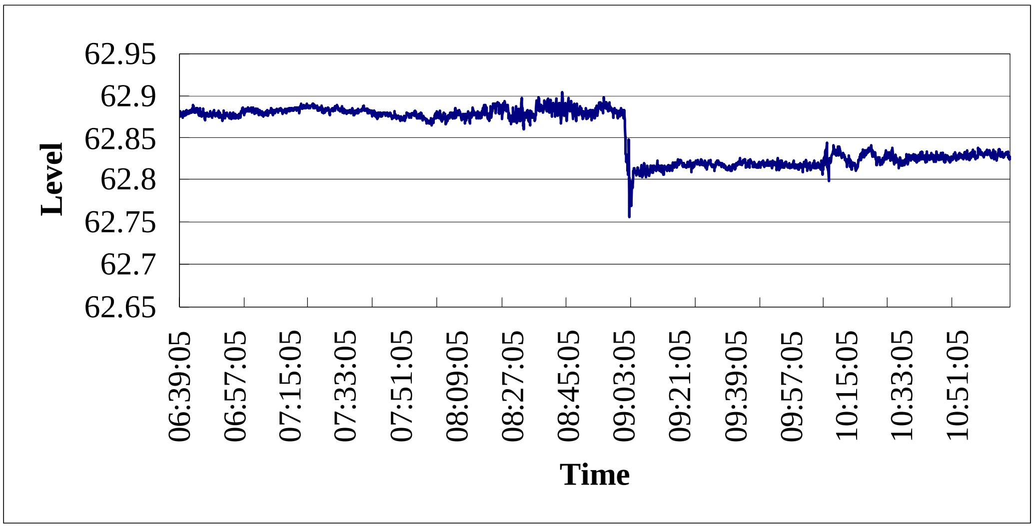

Fig. 1 Test Experiment: Levels From Kinematic Positioning by GPS

By applying the Eqn. 1 to the results of the test, the levels are given by Fig 2. The enhanced levels before imposed movement averaged to be 62.8808 m ± 0.8mm while the values after movement averaged to be 62.8199 ± 0.4 mm. The difference between the above two values is 0.0609 m , and the corresponding value determined by precise leveling is .061 m. The results of the test indicated that the kinematic positioning by GPS provided adequate accuracy after enhancement in the final results.

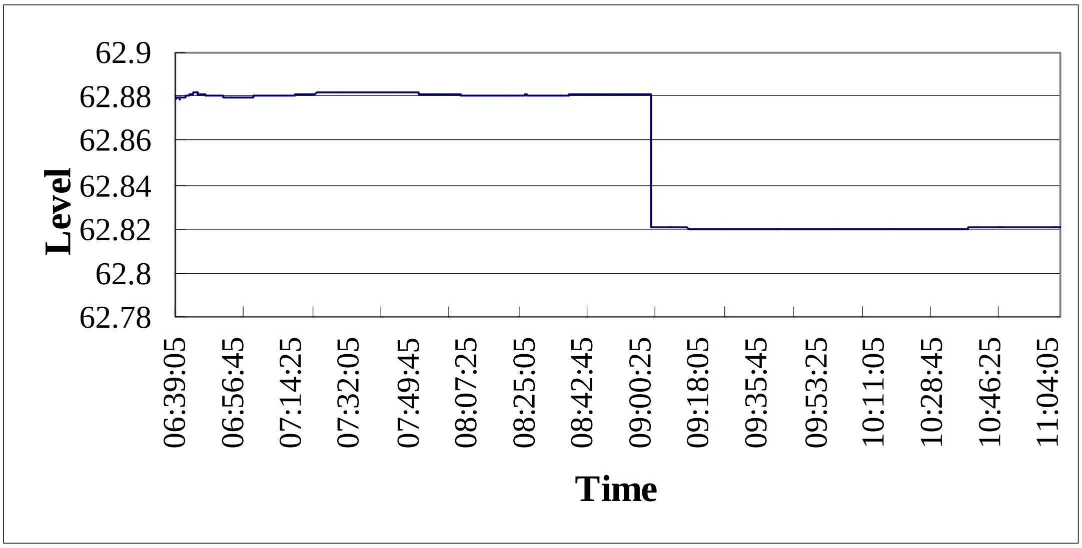

Fig. 2 Test Experiment: Enhanced Levels After Applying Enhanced Average

Another approach in handling the variations of the levels was by transforming the problem to the frequency domain and analyzing the results using spectral analysis techniques to study the variations. By being able to determine the contribution of every existing frequency or wavelength component in the resulting levels, it was possible to determine the resolution of the variations within levels.

The Fast Fourier Transformation (FFT), a widely used spectral analysis concept, was used. The variations were transformed into the frequency domain by FFT after the removal of mean value (Brigham, 1988). Fig. 3 presents the relation between the power of amplitudes and the corresponding frequencies. Upon examining Fig. 3, one notices that the nyquist frequency is equal to 0.5 cycle/5sec or 6 cycles/minute, which is equivalent to half the inverse of the sampling rate 5sec. Also, there is a notable increase in the power after frequency .75 cycle/hour.

Since the variations reflect the nature of the existing high frequencies within the levels, a low-pass filter would smooth these variations. The low-pass filter used here is applied according to Eren (1980), where the Fourier coefficients were truncated above M, where M was the cut-off frequency. Truncating the frequency domain series above the frequency M corresponds to low-pass filter. After having generated the complex Fourier coefficients, applying the filter only involves the truncation of the coefficients above M (0.75 cycle/hour). Then by an inverse Fourier transform, the time domain representation was generated. The low-pass filtering resulted in frequencies filtered above .75 cycle/hour.. The generated time domain representations are shown in Fig. 4. with the filtered levels (or smoothed levels) wihout noises.

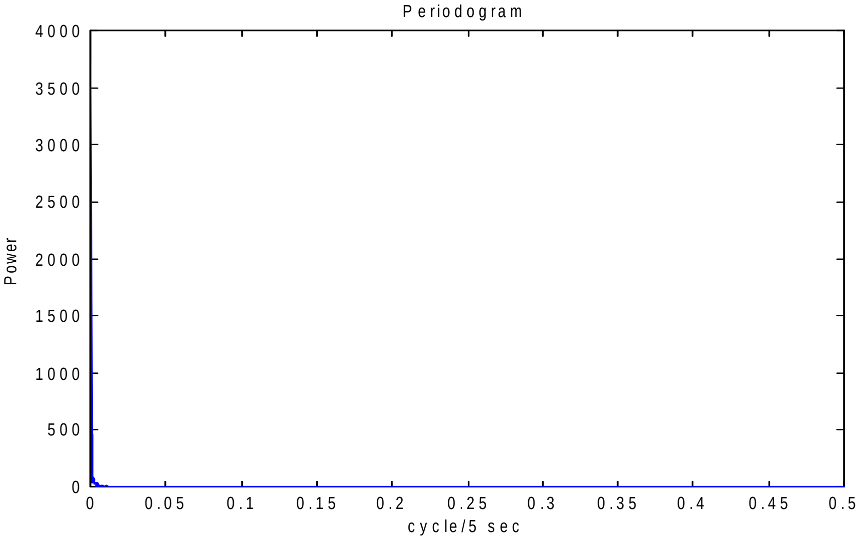

Fig. 3 Test Experiment: Power Presentation Versus Frequency Result From FFT

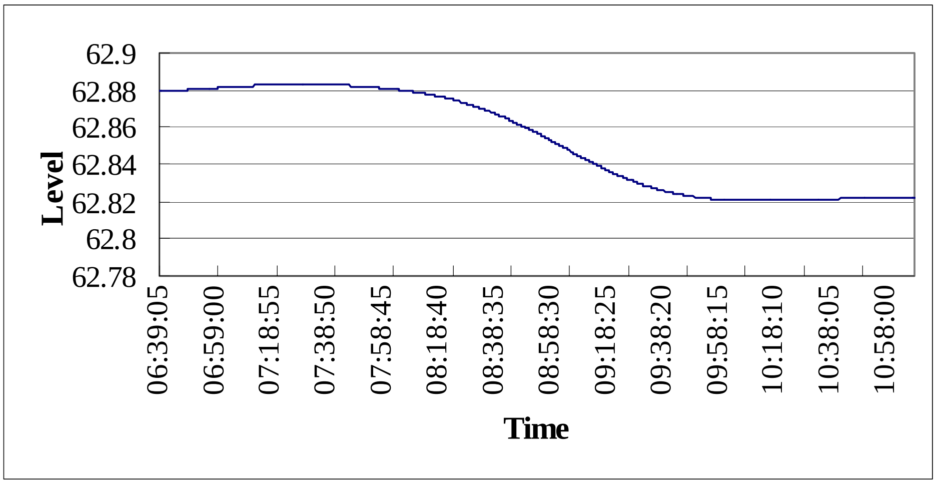

Fig. 4 Test Experiment: Smoothed Levels After Applying Low-pass Filter

3. GPS KINEMATIC DEFORMATION MONITORING –STATIC LOADING TEST

El-Maadia Bridge is one a series of bridges constructed along the Northern International Coastal Road in Egypt. The loading test was performed at the completion of the construction of the bridge. Precise leveling was the fundamental deformation monitoring technique suggested for the test. The loading test period was designed for four hours, monitoring for two hours with load continuously applied for assessing deformation occurrence and two hours after unloading for assessing deformation recovering. A team of the Surveying and Land Information Systems Lab (SLISL) of the Faculty of Engineering at Cairo University selected the location of levels positions and temporary benchmarks within the loading region. The temporary benchmarks were then linked by leveling to a permanent benchmark outside the loading region.

At the same time, two GPS dual frequency receivers, Trimble 4000 were used to monitor the deformation of temporary benchmarks with respect to the permanent benchmark. The GPS receiver located at the permanent benchmark used as reference station, while the second receiver located temporary benchmark as rover station. The recording interval was set to 3 seconds and receiver antennas were oriented towards the north. The GPS data was collected for 3 hours and 30 minutes, with 20 minutes designated for initial positioning, 1 hour and 30 minutes for loading and the rest of the observing time for unloading period. The data then downloaded to computer and the GPSurvey version 2.35 was used in the processing of the data. The OTF technique was used to resolve the integer ambiguity. The results of the levels are given by Fig. 5.

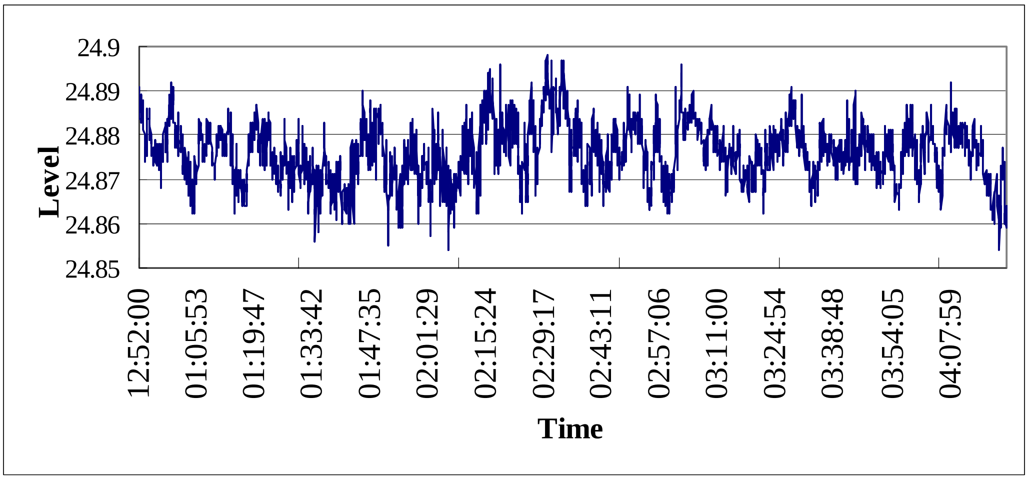

Fig. 5 El-Maadia Bridge: levels from Kinematic positioning by GPS

The figure indicates more noisy data without any clear drops in the levels during loading and unloading. Such noisy data may be attributed to sources such as multipath error resulting from the surrounding structures environment and movements of trucks during maneuvering. The variations of levels were then reduced by taking the mean enhanced value at each successive epoch according to Eq. 1 and results are illustrated in Fig. 6.

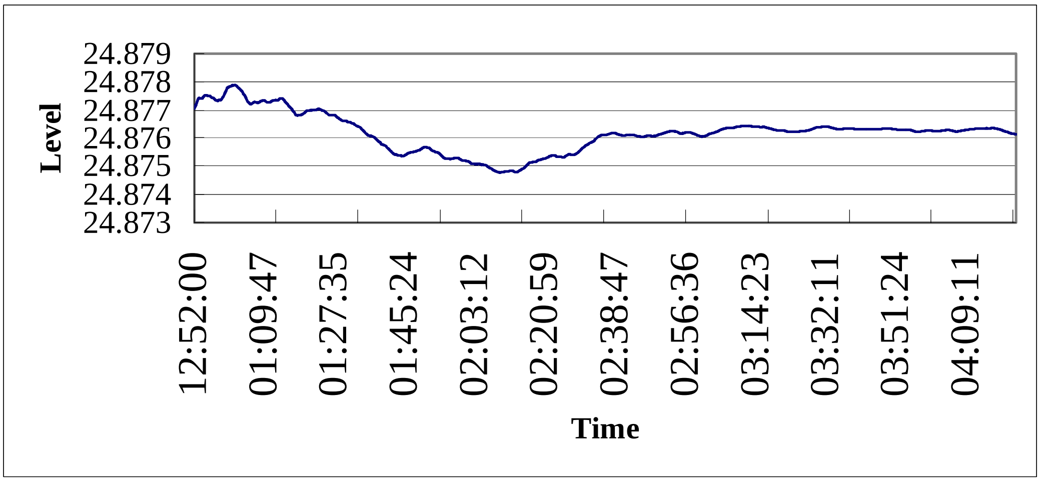

Fig. 6 El-Maadia Bridge: Enhanced Levels After Applying Enhanced Average

The enhanced levels showed irregular variations and from the graph variation are 24.877 m. to 24.8749 m. in loading period and from 24.8749 m. to 24.8763 m. in the unloading period. The difference between the above values is 2.1 mm for loading period and 1.4 mm respectively, the corresponding value as determined by precise leveling are 1.9 mm. and 1.9 mm. The results of the test indicate that the kinematic positioning by GPS would be more consistent upon avoiding multipath effects. Furthermore, GPS deformation monitoring gives complete pattern for the movement of the bridge at specific point.

The variations of the levels, was then transformed to the frequency domain to analyze their characteristics. The variations were transformed into the frequency domain by FFT after the removal of mean values. The results of FFT as power versus frequencies are shown in Fig. 7. Upon investigating the frequency domain results, the nyquist frequency is equal to 0.5 cycle/3sec or 10 cycles/minute. This is equivalent to half the inverse of the sampling rate 3sec. It is also noted that the power indicates low frequencies below .3 cycle/hour. the high frequencies are also found in the results and they are responsible noise in the final results from kinematic positioning.

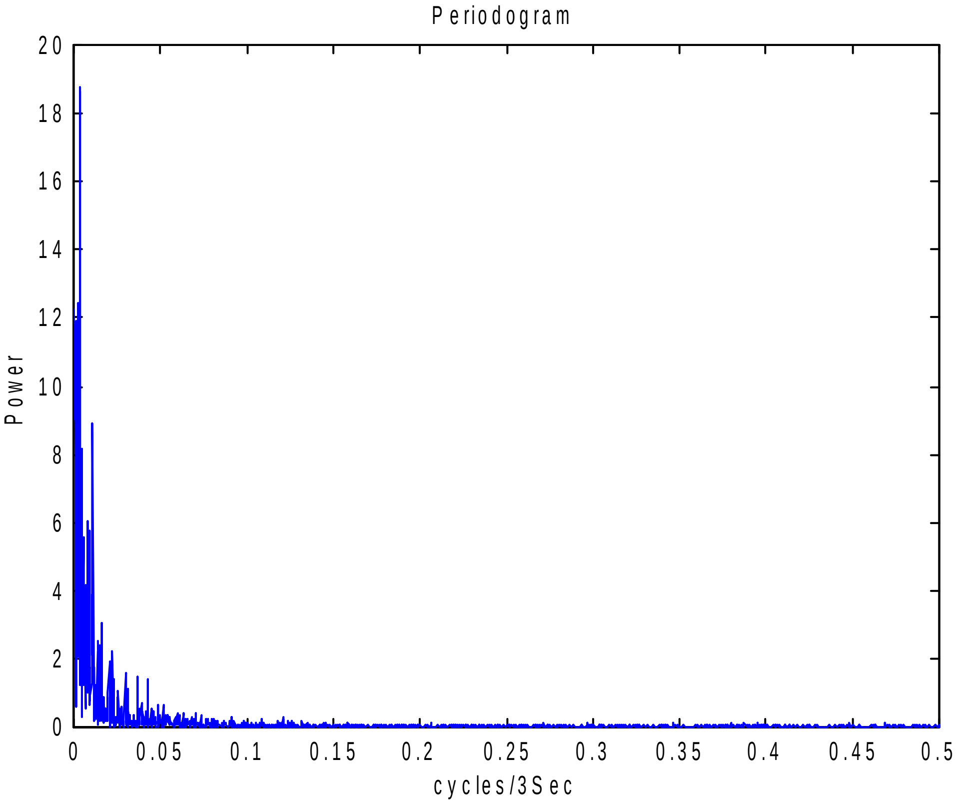

Fig. 7 El-Maadia Bridge: Power Presentation Versus Frequency Result From FFT

Since the variations reflect the existing of high frequencies features of the levels variations which should get smoother when we use a low -pass filter for the differences. By using low-pass filtering as described above we were filtered out any frequencies above .3 cycle/hour. The low-pass filter was applied for the variations. The regenerated time domain representations are shown in Fig. 8. Fig. 8 represents the filtered levels or the smoothed levels wihou noises the same results are may be noticed expect for the zone where the movement occured.

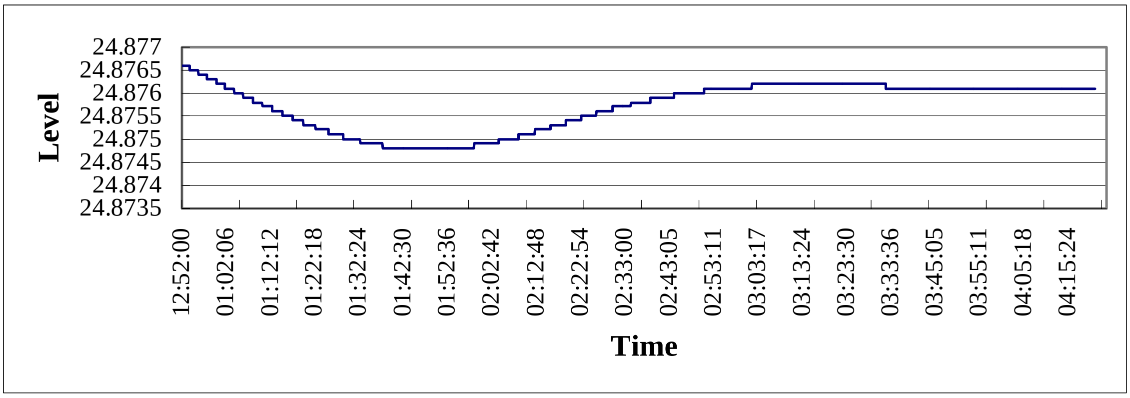

Fig. 8 El-Maadia Bridge: Smoothed Levels After Applying Low-pass Filter

4. CONCLUSIONS

Deformation monitoring constitutes an important stage during and after the construction of large structures. Different techniques are adopted for such monitoring. The GPS has introduced as a valuable technique for the deformation monitoring. The GPS has proven to be effective in define the position in sub-millimeter accuracy. In this paper, the GPS was tested in deformation monitoring and it gave an accuracy reaching fractions of a millimeter. The results from GPS analysis using OTF technique can not be used alone without smoothing the results of levels. The resulting levels show noises which can be reduced using the enhanced means, or using the low pass filter. The smoothed results of GPS levels as compared to the results of precise leveling show that GPS can be used to monitor the bridge deformation during static load tests.

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