

## **TALL STRUCTURES DEFORMATION MONITORING USING RTK-GPS (CASE STUDY: MENARA SARAWAK ENTERPRISE, JOHORE)**

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### **Abstract**

*The need for deformation surveys of large engineering structures (bridges, dams, tall structures, etc) often arises from concerns associated with environmental protection, property damage and public safety. For example, since there are many high buildings than in the past, it is therefore very important to monitor the buildings to ensure they are still under stable behaviour. The stability condition of high buildings can be achieved only through proper monitoring and deformation analysis. Conceptually, in order to sustain the engineering structures in safe condition, some deformation monitoring systems should be set up so that we can assess structural changes that may occur over the time. The geodetic sensors systems such as accelerometers, inclinometers, strain gauges, close-range-photogrammetry, precise levellings and total stations are familiar tools/methods to many professionals (e.g. engineers, surveyors) involved with structural monitoring. Recently, the Global Positioning System (GPS) has emerged as sensor for many deformation applications. The use of GPS for deformation studies has evolved rapidly especially Real Time Kinematic (RTK). This technique has been considered as a cost-effective tool to monitor safety and performance of engineering structures, including high buildings and to obtain high productivity in terms of accuracy and reliability. This paper highlights the concept and methodology of the RTK-GPS and its potential application for high building monitoring surveys. The experiments have been carried out on a high building, Menara Sarawak, Johore Malaysia. Some preliminary results is presented and discussed.*

**Keyword:** RTK-GPS, Deformation monitoring, high building

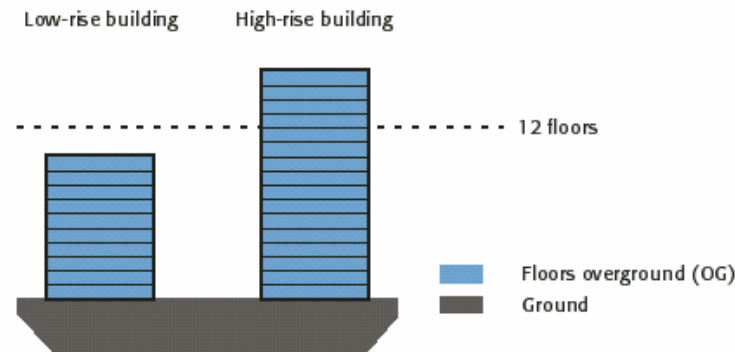
## **1.0 INTRODUCTION**

Deformation refers to the changes a deformable body undergoes in its shapes, dimension and position. Deformation survey can be used for obtaining the information about stability of some object likes natural or man-made objects. The man-made objects such as large engineering structures are subject to deformation due to various factors: changes of ground water level, tidal phenomena, tectonic phenomena, land movements, or any other natural disasters. The large engineering structures may include dams, long span bridges, high rise buildings, reservoirs, sport domes, planetariums, Olympic stadium etc. Therefore it is important to measure this movement for the purpose of safety assessment as well as preventing any disaster in the future.

A high-rise building is defined as a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels. To be considered a high-rise building an edifice must be based on solid ground, and fabricated along its full height through deliberate processes (as opposed to naturally-occurring formations) – see Figure 1. A high-rise building is distinguished from other tall man-made structures by the following guidelines (Emporis, 2004):

- i. It must be divided into multiple levels of at least 2 meters height;
- ii. If it has fewer than 12 such internal levels, then the highest undivided portion must not exceed 50% of the total height;

- iii. Indistinct divisions of levels such as stairways shall not be considered floors for purposes of eligibility in this definition.



**Figure 1: General Definition of High-rise Building (Emporis, 2004)**

Nowadays, there are much more large and tall engineering structures (high rise buildings) than the past. These structures are being designed to be much more flexible and to resist extensive damage from changes in temperature, severe wind gusts and earthquakes. Structural engineers require precise, reliable instruments to resolve their concerns about angular movements, displacements and structural vibrations. Hence, some actions can be taken before the disasters strike. It can save lives, avert large financial liabilities and avoid severe environmental damage.

In general, there are two types technique in deformation survey, such as geodetic surveys and non-geodetic surveys (geotechnical and structural). Geodetic surveys for example using total stations, precise levels, Global Positioning System (GPS), etc can be based on absolute and relative networks. Detection of deformation via geodetic method mainly consists of two step analysis independent least squares estimation (LSE) of each epochs followed by deformation detection between two epochs. On the other hand, geotechnical and structural methods uses special equipments to measure changes in length (extensometer), inclination (inclinometer), strain (strainmeter) etc.

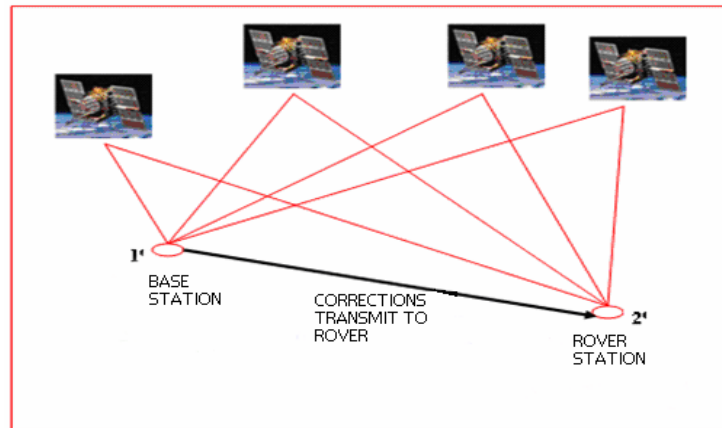
In contrast, the GPS technology can measure directly the position coordinates and nowadays relative displacements can be measured at rates of 10Hz and higher. This provides a great opportunity to monitor, in real time, the displacement or deflection, behavior of engineering structures under different loading conditions, through automated change detection and alarm notification procedures (Ogaja et. al., 2001). One of the most recent real time GPS techniques to date is RTK-GPS. RTK-GPS can achieve the accuracy of  $\pm 2 \text{ cm} + 2 \text{ ppm}$ . A fully automated monitoring system using RTK-GPS technique had been implemented successfully in Dam Diamond Valley Lake, California. This system will provide the information on the displacement of the monitoring points weekly (Duffy et.al, 2001).

## 2.0 CONCEPT AND METHODOLOGY RTK-GPS

Today new GPS surveying methods have been developed with the two liberating characteristics of: (i) static antenna setups no longer having to be insisted upon, and (ii) long observation sessions no longer essential in order to achieve survey level accuracies. These modern GPS surveying techniques includes: (i) Rapid static positioning technique, (ii) Reoccupation technique, (iii) Stop and Go technique, and (iv) Kinematics positioning technique. All of these modern GPS surveying method require the use of specialized hardware and software, as well as new field procedures.

RTK-GPS is one of the important or new techniques in GPS positioning technique. It helps a lot in deformation monitoring. This real time application had been widely used in various survey applications and navigational purposes, regardless on land, at sea or in the air. RTK-GPS . RTK-GPS deformation survey is more to single epoch observation technique.

This deformation survey using GPS technology has higher degree automation. RTK-GPS could achieve accuracy level of  $\pm 2 \text{ cm} + 2 \text{ ppm}$ . In RTK-GPS configuration, a receiver is placed on the reference point with known coordinates as reference station. This reference station will continuously transmit correction message to rover receiver (see Figure 2). Its observation can be done continuously (24 hours) or in a short observation period with its sampling rate as smallest as 0.1s (10Hz).



**Figure 2: RTK-GPS Observation Configuration**

Kinematics parameter is calculated to predict the stability of a structure. RTK-GPS process carrier phase observation at real time to produce coordinates. RTK-GPS differential positioning can be done as long as rover can receive signals from 4 satellites and differential signal from reference station via radio-link (Talbot, 1991). The precise position of rover is obtained after ambiguity is solved. (Talbot, 1991 and Kjell, 1998). The method applied here is On-The-Fly Ambiguity Resolution (OTFAR) in which the true ambiguity is obtained during the observation, topographical data collection (in 3D coordinates for deformation monitoring) can carried out continuously. There are many other ambiguity solving methods and they are applied according type of receivers, for example, Least-Square AMBiguity Decorrelation Adjustment (LAMBDA), Fast Ambiguity Resolution Approach (FARA) and Fast Ambiguity Search Filter (FASF)

### **3.0 REVIEW ON RTK-GPS IN STRUCTURAL MONITORING**

Structural monitoring serves several purposes. For example, it can provide structural response data allowing for the as-built performance to be checked against design criteria, which will be an increasingly useful exercise given the move towards 'performance based design' of structures. Over a long period monitoring can also provide the opportunity to identify 'anomalies' or 'novelties' that may signal unusual loading conditions or modified structural behavior, which can in the extreme case include damage of failure. A final use is to provide data for calibrating design codes. For the first application, the performance of the building has already been checked against the design and a complete understanding of the way the structure behaves has been obtained (Brownjohn & Pan, 2001). For the second case, procedures are being developed to detect anomalies, but in this case a major value is for the calibration of local design codes.

At present, instead of static deformation monitoring approaches, continuous dynamic deformation monitoring methods have been increasingly used to understand natural events such as landslides and to monitor the stability of manmade structures such as building, bridges and dam (Bock and Bevis, 1999; Leick, 2004). For examples, high precision dynamic RTK-GPS system has been installed to complement existing structural monitoring instrumentation at the Republic Plaza Building, Singapore. The purpose of the GPS system is to provide, to sub centimeter accuracy, and at a rate of up to 10 samples per second, position vectors with respect to a fixed base station, of two antennas installed on the building parapet. The system will be operated in parallel with, and linked to, an existing logging system that records signals from accelerometers and anemometers. The system is intended to be 'open' to future software-based improvements in positional accuracy determination (Ogaja et. al., 2001).

A real time GPS monitoring system with the aid of a Kalman Filter for use in as active tectonic region near Istanbul and its surrounding region has been developed. Istanbul is one of the largest cities in the world and is under possible earthquake threat. In order to set up a powerful control system, a surveying and estimation method was designed and the necessary software, called RT-MODS2 (Real Time Monitoring of Dynamic System 2) was developed. The software reads real time input data from GPS receivers and perform deformation analyses with help of Kalman Filter. Some studies of filtering and deformation analysis were performed in order to detect failures and outliers, and to increase the reliability of the deformation analysis (Ince and Sahin, 2000).

Accelerometers have been used for field measurements of wind-induced responses of buildings. However, wind-induced responses consists of a static component, i.e a mean value and a dynamic fluctuating component. The static component is difficult to measure with accelerometers. The uses of RTK-GPS for measurements of building responses have been proposed. An RTK-GPS (Leica MC1000) has a nominal accuracy of  $\pm 1\text{cm} + 1\text{ppm}$  for horizontal displacements and  $\pm 2\text{cm} + 2\text{ppm}$  for vertical displacements with a sampling rate of 10 Hz. Considering the static component and the first mode predominance for wind-induced responses, GPS is better for wind-induced response measurements. According to the feasibility study of RTK-GPS for measuring wind-induced responses of buildings, responses with amplitudes larger than 2cm and natural frequencies lower than 2Hz can be detected by RTK-GPS (Yoshida et. al., 2004)

A method of analysis using 'Time-Frequency' wavelets has been applied to the fast RTK-GPS results from the experiment to automatically detect 'low' and 'high' frequency components embedded in the noisy time series, frequency changes and their onset times. The algorithm is formulated through the estimation of 'instantaneous' using the wavelet transform and 'change detection' using the cumulative sum (CUSUM) scheme (Mertikas & Rizos, 1997).

#### **4.0 THE EXPERIMENT**

High rise building research is carried out at Menara Sarawak Enterprise which is strategically located on Stulang Laut, Johor Bahru (see Figure 3). The height of the building is almost 120m from ground. The building's structure is consisted of 30 storey tower and 3 basements as car park level. The most of storey tower houses commercial offices, such as Alliance Bank. Each storey is about 3.5 meters in height.



**Figure 3: Menara Sarawak Enterprise**

Two different types of GPS instruments were used to carry out Real Time Kinematics (RTK) GPS observation. Two set of Leica and Trimble instruments were set up at monitoring station and reference station respectively. Therefore, the GPS survey was took one hour with this observation procedure. The stability of high rise building is determined by using modern GPS observation technique, continuous Real Time Kinematics (RTK). The period of the observation is within 1 hour which involved two base ( B1 and B2) and two rover (R1 and R2) – see Figure 4 and 5. The study uses 2 monitoring stations (2 Rovers) which is located on both side of the building's rooftop. It can improve the strength of monitoring network. In other words, if R1 detect the vibration and it can be proven by another rover, R2.



**Figure 4: Base 1 (B1) and Rover 1 (R1) Stations**



**Figure 5: Base 2 (B2) and Rover 2 (R2) Stations**

## 5.0 RESULTS AND ANALYSIS

The field measurements had been carried out on Menara Sarawak Enterprise building. Two different types of observed data had been collected in the observation. One of them is RTK-GPS and the other data type is Static-GPS observation data. The developed program, KFilter will perform the structural monitoring analysis based on the continuous RTK-GPS data with helps of Kalman Filtering meanwhile the Static-GPS data was processed using GPS Deformation Analysis Program (Bayrak, 2003) as verification (benchmark) for the structural analysis using developed program.

From the Table 1, both programs show that there is not any deformation displacement detected at the Menara Sarawak Enterprise building. The base stations for Continuous RTK are station 1 and 2 and the monitoring stations (R1 and R2) are 3 and 4. Therefore, the stability of base stations for RTK-GPS (B1 and B2) had been proven using GPS Deformation Analysis Program (Bayrak, 2003). Some report from developed KFilter program for this experiment is shown in Table: 2

**Table 1: Results of Processing From GPS Deformation Analysis Program and KFilter**

**\*\* Mean value for  $\Delta N$ ,  $\Delta E$  and  $\Delta h$  can obtain from KFilter Program by getting the mean for difference values from deformation report.**

**\*\* Units in centimeters, cm.**

Point	$\Delta N$	$\Delta E$	$\Delta h$	Results	Program	Observations
1 2 3 4	-	-	-	Stable (Report in Appendix A)	GPS Deformation Analysis Program	Static
3	-0.3420 (mean)	0.2999 (mean)	0.0713 (mean)	Stable	KFilter	C.RTK (Epoch 1)
4	0.3040 (mean)	0.2240 (mean)	0.1114 (mean)	Stable	KFilter	C.RTK (Epoch 1)
3	0.0118 (mean)	-0.4586 (mean)	-1.2793 (mean)	Stable	KFilter	C.RTK (Epoch 2)
4	0.7824 (mean)	0.7896 (mean)	0.2638 (mean)	Stable	KFilter	C.RTK (Epoch 2)

**Table: 2 – Some Deformation Report for KFilter**

-----Single Point Test ( 14:15:40 )-----			
Difference,cm	t-calculate	t-table	Result
0.395	0.42	1.96	Stable
0.110	0.12	1.96	Stable
-0.130	0.07	1.96	Stable
-----Single Point Test ( 14:15:45 )-----			
Difference,cm	t-calculate	t-table	Result
0.151	0.16	1.96	Stable
0.354	0.38	1.96	Stable
-0.237	0.13	1.96	Stable
-----Single Point Test ( 14:15:50 )-----			
Difference,cm	t-calculate	t-table	Result
0.207	0.22	1.96	Stable
0.166	0.18	1.96	Stable

-0.255	0.14	1.96	Stable
-----Single Point Test ( 14:16:10 )-----			
Difference,cm	t-calculate	t-table	Result
-0.056	0.06	1.96	Stable
0.279	0.30	1.96	Stable
0.029	0.02	1.96	Stable

## 6.0 CONCLUSION

The timely identification of deformation associated with geologic hazards or ground settlement can save lives, avert large financial liabilities and avoid severe environmental damage. Periodic surveys do not provide a real-time warning capability and automated sensors, also unable to provide continuous data; do not yield conclusive information about displacement vectors. However, nowadays relative displacements can be measured at rates of 10Hz or higher. Based on some preliminary results of our first continuous RTK experiment, one is easily provided with dense and extensive time series of phase observations to all GPS satellites in view, on both the L1 and L2 frequency. Real time kinematics monitoring of Sarawak Business Tower may lead to the early detection of changes of the building's response to earthquake and wind load. It is thus an important step towards increasing safety and lifespan of the building.

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