MONITORING OF BREAKWATER STRUCTURE: GPS VERSUS GEODETIC METHOD

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ABSTRACT

Until recently, we relied exclusively on traditional survey equipments such as EDM/total station/precise levels to determine the horizontal And horizontal movements that occur on large engineering structures such as long span bridges, dams and breakwaters. The GPS technology, however, allows us to measure horizontal and vertical motions much more effectively and conveniently, and it has increased dramatically in the past few years. With satellite information, a GPS receiver can very quickly determine its position to within a matter of meters. On breakwaters, however, an accuracy of a few centimeters is quite important for detecting the build up of stress and pressure caused by sea currents and wave rising toward the ground surface. Typically, we can measure the position of a breakwater benchmarks (monitoring stations) using GPS on a regular basis depending on the activity of the sea current movements especially during the monsoon seasons. GPS offers several advantages compared to breakwater surveys that use typical terrestrial survey instruments, for example, measurements can be made in almost any weather condition and at all time within the required accuracy. This paper therefore highlights the potential use of GPS and conventional geodetic survey methods in breakwater deformation survey. Data collection times were planned to minimize simultaneous logging intervals at redundant stations. The objective was to provide data that would enhance the baseline and network adjustments in the post-processing of the data. In this paper, the first stage campaign of GPS and conventional geodetic survey method for the Kemaman Port Breakwater are presented.

1.0 INTRODUCTION

Various geodetic measurement methods may be employed in monitoring surveys.. These include structural and geotechnical methods, terrestrial survey techniques, and positioning with spaced-based systems. The selection of the most appropriate methods or combination of methods for deformation studies will depend upon cost, the accuracy required and the scale of the survey involved. Conventional survey techniques involve the measurement of angles, directions, spatial distances and height differences using instrumentations and measurement methods adapted from traditional geodetic practice e.g. digital theodolites, precise levels, etc deformation surveys by space-based technique includes Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and the Global Positioning System (GPS). Of these, GPS offers a great advantage interms of productivity and is the most cost-effective.

The Global Positioning System (GPS) is the most important technological innovation in the field of surveying including deformation studies in this century. A constellation of orbiting satellites continuously sends radio signals that can be used with proper receiving equipment and computer processing to determine the relative positions of points on the Earth's surface within a few centimeters or better. This high precision means that slight surface movements of geophysical interest, such as the movements around any engineering structures, can be tracked by repeating measurements at the same survey marks. Similarly, terrestrial survey techniques have been used extensively in the past to record ground movements (horizontal and vertical displacements) around the related structures, including those in Kemaman Port Breakwater platform. However, use of these techniques limits the choice of potential survey marks. These marks, which are usually located near accessible routes, must be visible from other survey marks. In contrast, GPS survey marks can be located almost anywhere, as long as the site has a clear view of the sky. Furthermore, GPS measurements can be made in almost any weather condition. In the case of conventional techniques, determination of horizontal and vertical components requires combination of different sets of conventional observations, such as leveling and distance ranging with the use of laser beams and they are also weather dependent.

To investigate possible deformations or ground movements, the geodetic observations either GPS or terrestrial surveys are repeated at different epochs of time. The measurements of each epoch are adjusted independently and the estimation of deformation is done by calculating coordinate differences between epochs, the first epoch always considered as the zero measurement. The scheduling of measurements, the required accuracy and the identification of the location of control points should take into account the existing geotechnical (or others) designs, that define or anticipate the size, the velocity and the recursiveness of displacement as well as any other associated data . This paper highlights the performance of first stage campaign of GPS and conventional geodetic survey method for the Kemaman Port Breakwater, Trengganu.

2.0 REVIEWS OF GPS AND TERRESTRIAL METHODS IN DEFORMATION STUDIES

Deformation measurements may consist of a combination of observables such as coordinates, coordinate differences, distances, directions, azimuths, etc. Therefore, it needs some special equipments to measure changes in those parameters in relative and/or absolute senses using either geodetic terrestrial (e.g. precise leveling) or satellite-based methods (e.g. GPS, SLR). The GPS technology uses information broadcast by orbiting satellites to accurately monitor changes in the horizontal and vertical position of survey points on natural or/and manmade structures, e.g. landslides, long span bridges, breakwater, tall towers, etc. whereby data on deformation needed to forecast future movements. The radio signals transmitted by GPS satellites include time, ranging data, and information on the predicted position of the satellites in space. Deformation studies on engineering structures often involve a procedure called relative positioning. To carry out this procedure, one receiver is situated at a stable control station and the other is set up at a point where the change in relative position is to be determined. Although a detailed description of how the system works is beyond the scope of this article, the central core of GPS operations is the simultaneous determination of distances between ground station and set of four or more satellites. This is accomplished by distance ranging. The ground-station receiver simultaneously records time-coded ranging signals from the satellites. The ground station also continuously generates a time-tagged replica of the ranging signal sent by the satellites. The time codes are embedded in the signals in such a way that the source-to-receiver transit time can be recovered from the data stream. Multiplication by the speed of light gives the corresponding distances. Details of

GPS observables can be found in Rizos, (1996), Leick, (1995) and Well, et.al (1989).

In conventional geodetic method, the modern surveyor's tool which can be used nowadays in deformation survey, is the total station. This tool includes precise angle and distance measuring instruments in one unit. The total station is used with data collectors, portable field computers which store the data in digital form. The instrument compares the waveform of the light beam going out with that of the returning reflected beam and converts this difference to a slope distance. After surveying a parcel, the surveyor will download coordinates to coordinate geometry software to create a plat of the parcel. The magnitude and direction of the distance change are calculated for each station in the network. The displacements are relative to one or more points that are assumed to be fixed. The calculated displacement vectors are plotted on maps to locate the focus of deformation. The precision of the EDM data is +/- 6 mm, with an additional uncertainty of +/- 1 mm per km of line length.. . The use of total station equipment allow for rapid and automated data collection and high precision in local-scale applications, and can provide an overall representation of geometric status. However, they are can be time consuming and costly when applied to the monitoring of larger networks, are subject to network geometry and station intervisibility constraints. Furthermore, this technique also is limited in accuracy by atmospheric refraction effects which are difficult to model or control.

3.0 DEFORMATION NETWORK

To monitor ground displacements it is imposed to represent the area under investigation by a number of points that are durably monumented. These points are the stations of a geodetic control network. Usually, two categories of stations must be included in the network: the reference stations (reference network) , which are located in geologically stable areas and the control or monitoring stations (relative network) , which are located within the limits of the deformed part of the ground or the construction itself. In this way, the determination of the movement of the control stations is done relatively to the reference ones. Depending on their extent, deformation network may categorized as being of a local, regional, national or global scale. In general the establishment of deformation network involves : (i) network design , (ii) the field campaign, and (iii) network analysis. The network design answers the essential question of where the network points (network configuration) should be measured in order to achieve the required network quality. Network geometry is an important aspect that has to be considered in order to achieve accurate conventional survey results. For this, intervisibility between stations is a major constraint. GPS observations require, from the monument, an unobstructed panoramic view of the horizon. This is not always possible because of vegetation, mountains, buildings etc. Ideally 15 degrees of altitude and above will provide optimal view of satellites, since below this angle the signal accuracy deteriorates because of atmospheric effects. Finally, structural monitoring applications involve relatively short baseline networks, i.e. generally less than 15 kms for GPS and less than 2 kms for terrestrial geodetic method. Compare to the conventional survey, one of the major advantages with using GPS is lower sensitivity of network geometry. Also, with GPS surveys, it is possible to establish a base station a considerable distance from the site without having the concern of tying the local network to a global system.

The control network can be measured by using special techniques, terrestrial or – preferably – satellite (GPS), high accuracy geodetic instrumentation. To investigate possible deformations or ground movements, the geodetic observations are repeated at different epochs of time. The measurements of each epoch are adjusted independently and the estimation of deformation is done by calculating coordinate differences between epochs, the first epoch always considered as the zero measurement. The scheduling of measurements, the required accuracy and the identification of the location of control points should take into account the existing geotechnical (or other) designs, that define or anticipate the size, the velocity and the recursiveness of displacement as well as any other associated data.

4. THE FIELD SURVEY CAMPAIGN

4.1 The GPS Surveys

The monitoring of nine (9) control points was carried out using the latest- state-of-art GPS. These include six (6) monitoring points on the South Breakwater (SBW), i.e. points BW1, BW2, BW3, BW4, BW5 and BW6. These monitoring points have been established by previous consultant surveyors – see Figure: 1. The GPS control network was established using three GPS receivers, Leica System 300. This GPS receiver measures range, range rates and signal phase at the antenna and compute position, velocity and time. The objective of GPS surveys is to determine coordinates of monitoring stations located along the South Breakwater. For this purpose, three (3) GPS control stations located on shore area (stable areas) were established as reference control networks for present and future GPS survey. The stations are GPS01, GPS02 and BWC (see Figure: 2) c . Both GPS01 and GPS02 stations were tied to National GPS Network, i.e. P226 station for duration of more than 1 hour observations. At each control points, GPS observations were carried out for at least 20 minutes for the six monitoring points using all three GPS control stations, i.e. GPS01, GPS02 and BWC . During GPS observations. The Position Dilution of Precision (PDOP) of less than 5 is being maintained. It was believed that geometry yielding a low PDOP would yield the best results.

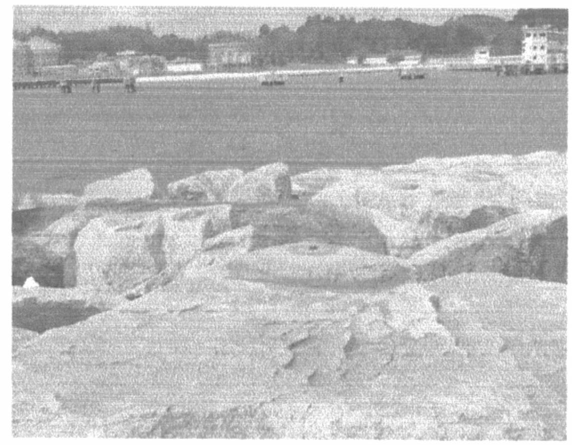

Figure: 1 – One of the Monitoring Station (BW4)

Figure: 2 – One of the Control Station (BWC)

For precise surveys using GPS technique, a base station is occupied for duration of the survey. Also, all adjacent monuments are measured simultaneously whereby at least one common station between each stations is used. This ensures greater realibility in the survey as well as allowing greater ease of blunder detection. GPS data processing was done using SKI Ver. 2.3 software. Output from this commercial GPS software consists of adjusted coordinate differences between two stations for each observating session, along with the associated covariance informationSince, the GPS positioning provides position in geocentric WGS84, the transformation of these coordinates to the local geodetic system is needed. In our case, the GPS data processing and reduction 3d-WGS84 coordinates were done to obtain Cassini-Soldner coordinate via MRT and RSO transformation processes.

4.2 The Geodetic Land Survey

In the geodetic land survey campaign,a total of 6 control points forming the center line of the South Breakwater, i.e. points, BW1, BW2, BW3, BW4, BW5 and BW6 was surveyed using Sokkia Set3F Total stations – see Figure: 3. The Sokkia Set3F is consists of precise angle and distance measuring instruments in one unit. Similar with the other total stations, it is used with data collectors, portable field computers which store the data in digital form.

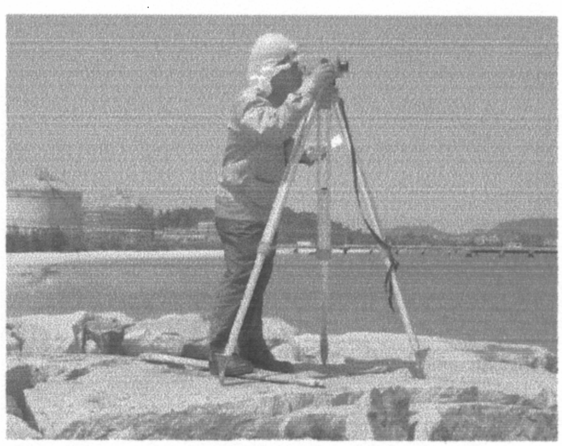

Figure: 3 – Land Survey Observation Using Total Station

The total station instrument provides full basic functionality, allowing low-cost support for deformation survey tasks. Its feature include (i) a high performance coaxial distancer, (ii) endless, clamp-less horizontal and vertical tangent drives , (iii) controllable brightness laser plummet in the standing axis and (iv) flexible, removable data storage (on standard PCMCIA PC cards) . Height for control points were established using precise levelling which have been carried out across from TBM C, located at Tg. Berhala Supply Based.

5.0 RESULTS AND ANALYSIS

Initial observation results (after the adjustment) of the first GPS campaign and Total Station surveys for Kemaman Breakwater is summarized in Table: 1 and Table: 2, respectively .

Table: 1 – The adjusted WGS84 and Corresponding Cassini Coordinates for the Control and Monitoring Stations

Station	**WGS 84**		**Cassini Soldner**	
	Latitude	**Longitude**	**Northing**	**Easting**
GPS01	4 14 40.65110	103 27 27.11390	S 77516.7085	E 62606.9836
GPS02	4 14 28.60207	103 27 33.14592	77886.6746	62793.2835
BWC	4 14 41.52420	103 27 33.22908	77489.7460	62795.5425
BW1	4 14 20.33915	103 27 42.84805	78140.2869	63092.6743
BW2	4 14 20.33961	103 27 49.72826	78140.0793	63304.8470
BW3	4 14 20.32838	103 27 56.11863	78140.2725	63501.9144

BW4	4 14 25.89032	103 28 00.71426	77969.3180	63643.5021
BW5	4 14 35.74554	103 28 00.71005	77666.5967	63643.1382
BW6	4 14 46.22215	103 27 57.14047	77344.8739	63532.8065

Table: 2 – The Cassini Coordinates for Control and Monitoring Stations Using Terrestrial Geodetic Method (Total stations) and Coordinate Differences

Station	**Cassini Total Stations**		**Differences in metres**	
	Northing	**Easting**	**(Total Station - GPS)**	
GPS01	S 77516.777	E 62603.419	0.069	-3.565
GPS02	77886.743	62789.719	0.068	-3.565
BWC	77489.514	62791.975	-0.232	-3.567
BW1	78140.355	63089.110	0.068	-3.564
BW2	78140.148	63301.283	0.069	-3.564
BW3	78140.341	63498.350	0.068	-3.564
BW4	77969.386	63639.938	0.068	-3.564
BW5	77666.665	63639.572	0.068	-3.566
BW6	77344.942	63529.242	0.068	-3.564

The overall results (direct comparison) in Table 1 has shown that the coordinate differences between GPS and Total Station surveys in northing component is about 7 cm except for control station BWC (cf. 23 cm). On the other hand, the coordinate differences for easting component is quite large , i.e. about 3.5 meters. By looking at these initial results, ones may noticed that there is a consistent magnitudes in both northing and easting coordinates between these two survey methods. But, this can be regarded as systematic errors due to some biases/errors in GPS observations and conventional surveys, e.g. the datum defintion adopted for GPS and total station survey, multipath, observational noise, the coordinate transformation processes (coefficients used), Bowditch adjustment, theodolite setting/pointing errors in traverse legs, etc The adjusted Cassini coordinate obtained from our total station survey (noted as UTM02), were also compared with the corresponding coordinates obtained from previous survey which has been carried out by the licensed surveyor in 1999 (noted as BW99). The result is summarized in Table: 3 whereby station BW5 is used as a base (This monitoring station has been adopted by the licensed surveyor as a datum point in their network adjustments !).

Table: Difference in Coordinate for the SBW Between UTM02 and BW99

Stations	**UTM02 – BW99**	
	Northing	**Easting**
BWC	-0.035	-0.052
BW1	-0.038	0.074
BW2	-0.011	0.072
BW3	0.032	0.074

BW4	0.051	0.036
BW5	0.000	0.000
BW6	0.018	-0.083

From Table : 3, it can be seen that the mean value of coordinate differences between these two survey is about 2.83 mm and 20.2 mm for northing and easting, respectively. One of the possible reasons for these coordinate differences might be caused by the field observatioan procedures, the equipment used and network adjustment approach adopted by those survey teams, which are not the same. At the time of this experiment, it is very hard to say that the GPS survey control is more reliable than those obtained from the conventional method, until all the monitoring points be observed in two or more epochs of time. However, as a first step from our experiences, it is seemed to us that one advantage of the GPS technique (compared with conventional method) is the flexibility it allows the user in designing the survey network, line of sight between end points of the survey line is not required, and a very high accuracy can be maintained over lines many kilometers long.

6.0 CONCLUSIONS

In this paper, the GPS technology and geodetic surveying method, i.e. total station surveying presented for the first campaign (phase I) of establishing deformation control network for Kemaman Breakwater structure. Initial observation results of GPS and Total Station presented here are for 2002, which was the first year campaign for this survey. The end objective is to detect the breakwaters movements over the time and to prove that GPS technique could serve as powerful and cost-effective tool for monitoring some types of structural deformation and performance. However, in the case of deformation, movements of breakwater are determined one epoch relative to another. In other words, since only relative movements are of interest, this first GPS campaign has established the first or zero epoch observation for the network. Thus, the second observation of the network using GPS will results in coordinate differences for the monitoring stations which will undoubtedly be more precise than the computed differences used in this comparison. Finally, it is expected that the long term repeated observation of this network using GPS method should resolve the question of the magnitude of the breakwater movements in Kemaman Base Breakwater.

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