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Monitoring of Offshore Platform Subsidence Using Permanent GPS Stations

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Abstract: Offshore platforms undergo subsidence, especially due to production activities. The monitoring of such subsidence requires specialised technique (i.e. GPS) as the platforms are situated at sea (i.e. hundreds of kms from mainland). Unfortunately standard GPS processing procedure is unable to achieve the required accuracy (several cm) over long baselines. The research focuses on the development of processing strategy (i.e. estimation and subsidence analysis) for monitoring of offshore platform subsidence using three permanent GPS stations of the Malaysia Active GPS system (MASS). The estimation of each epoch employs Bernese GPS software, followed by subsidence analysis using in-house software. Preliminary results are also shown.

Keywords. Offshore platforms, GPS, Bernese GPS Software, Subsidence Detection

1 Introduction

Oil and gas remain the energy source in Malaysia, where each of them contributes almost 33% and 41% of total energy generation. Two major petroleum explorers in South China Sea are PETRONAS and SHELL and these petroleum companies have involved in erecting offshore platforms for petroleum and gas production in Malaysian waters. Most of these offshore platforms are located 120 – 250 km from shore and they require very high precision, reliable and highly available positioning tool for the monitoring of subsidence at these offshore platforms. These platforms experience subsidence due to the withdrawal of gas from beneath the seabed which causes the seabed to experience compaction. Determination of subsidence of offshore platforms can be carried out by using either geotechnical, structural or geodetic method. In this study, the geodetic method was used and it involves the reference network of Global Positioning System (GPS) observation.

2 Global Positioning System (GPS)

Due to the constantly growing technological progress in all fields of engineering, the increasing demand for higher accuracy, efficiency, and sophistication of the deformation measurements, geodetic engineers have continuously search for better monitoring techniques and have to refine their methods of deformation analysis. The advert of space techniques such as GPS has opened a new dimension in data acquisition which involves offshore structures such as gas and oil platforms which are situated hundreds of kilometers offshore. A suitable technique of data acquisition has to be identified in order high accuracy observation can be obtained and its results can be used for deformation analysis.

The establishment of a network of control points on offshore platforms as well as on land requires a measuring tool that able to give us a very high precision and a reliable data that are necessary for deformation or subsidence monitoring. A number of control stations between datum points (i.e. control points on land) and object points (i.e. control points on offshore platforms) need to be established for measurement of baseline vectors (ΔX, ΔY, ΔZ). In order to detect and measure the vertical displacement or subsidence of offshore platforms, GPS is considered as the best tool to determine relative position between control stations because GPS allows us to achieve a desirable precision (i.e. $\pm$0.1ppm) that is necessary for subsidence monitoring (Ashkenazi & Ffoulkes-Jones (1990), Leick (1995), Krijnen & Hues (1995)).

3 Malaysia Permanent GPS Stations

The Malaysia Active GPS System (MASS) or Zero Order Network is a network of GPS permanent stations established by the Department of Surveying and Mapping Malaysia throughout the whole country of Malaysia. These station automatically record and archive data from available GPS satellites for accurate position determination 24 hours a day. MASS provides code range and carrier phase data in support of post processing applications. The acquired GPS data is available for distribution to the public by the Geodesy Section, Geodetic Survey Division, Department of Survey and Mapping Malaysia (DSMM).

The main objectives of the establishment of these MASS permanent stations are to analysis the accuracy of the existing geodetic network and to provide GPS data to all users in Malaysia for carrying their works for the development of the country. Another important objective is to provide supports for researchers for a wide range of applications (e.g. geodesy, surveying, mapping, engineering, scientific, and geodynamic studies) in Malaysia. One recent research work is on crustal movement due to the impact of earthquake that created killer waves or tsunami in this part of Southeast Asia region.

3.1 MASS Sites

There are eighteen mass sites that have been established at selected sites as shown in Fig. 1. Eight of these MASS sites are located in Peninsular Malaysia while the rest are established in Sabah, Sarawak and one in the Federal Territory of Labuan. The GPS receiver installed at MASS stations are TRIMBLE 4000SSE and 4000SSI dual frequency receivers whilst the GPS antenna used are TRIMBLE Compact L1/L2 with ground plane and TRIMBLE Choke Ring with radome (Fig. 2). These antennas are permanently mounted on pillars at appropriate locations, which provide an uninterrupted view of the surrounding sky and are inaccessible to unauthorised persons. Each permanent GPS station also consists of TRIMBLE Universal Reference Station (URS) software operating on the Windows NT system platform. All these stations are tied to local geodetic survey networks to a high degree of accuracy.

Fig. 1 Location of MASS stations in Peninsular Malaysia and Sabah and Sarawak.

The network of the MASS stations is remotely operated and managed from the Geodetic Data Processing Centre, Geodesy Section, DSMM, Kuala Lumpur. Each MASS station records in TRIMBLE proprietary formats and converts to RINEX with the Coarse Acquisition (C/A) code, P/Y code, L1/L2 carrier phases observable. The data format for all MASS stations is supplied in one-hour blocks with either in RINEX format or DAT format files.

Fig. 2 Example of one of the MASS station established at JUPEM's building in Kuala Lumpur.

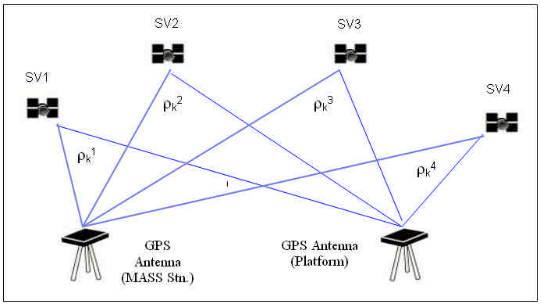
3.2 GPS Data Observation at Offshore Platform

An offshore platform used in this study is located in South China Sea and about 300 km from the offshore of west Peninsular Malaysia. In order to detect subsidence that might occur at this platform, three control stations were established at the platform. The control stations at this offshore platform were observed by using TRIMBLE 4000SSI Geodetic Series GPS receivers for duration of 24 hours at the interval of 15 seconds. The locations of the control stations were located at three corners of the offshore platform. The relative orthometric heights between these control stations are determined by using levelling technique.

4 Technique of GPS Observation

The basic concept in subsidence monitoring for offshore platform is to employ GPS relative positioning of the offshore platform with respect to the stable control stations on shore. The technique used for GPS observation is relative positioning technique (Fig. 3), which involves control stations on shore and three control stations established at the offshore platform. The relative static GPS observations were carried out for 24 hours at 15-second interval to give the required accuracy for such a long baseline. The GPS relative positioning was carried out to determine the coordinates of control points relative to a fixed, known point. The control points are related to fixed point through GPS observations that will give the baseline vectors between points (Caspary (1987), Kuang (1991 & 1996) and Halim & Ranjit (2001)).

Fig. 3 Relative Positioning using GPS technique.



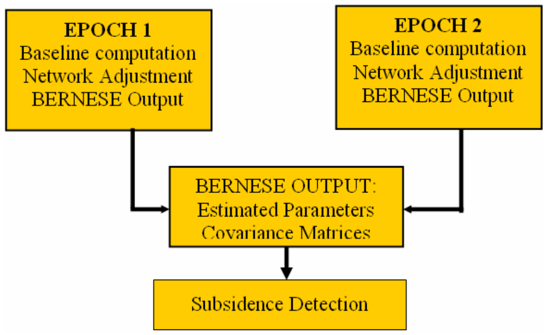
5 Strategy for Detection of Subsidence

The study of subsidence monitoring of offshore platform in Malaysian waters involves the two-epoch analysis (Chen (1983), Caspary (1987); Kuang (1991 & 1996), Halim & Ranjit, (2001)). GPS data from two epochs of observation, which involve GPS data from MASS stations and observed GPS data at control stations established at the offshore platform, are used. The Bernese GPS software is used to process GPS data for all control stations, where baseline computation and network adjustment (or Least Squares Estimation or LSE) are carried out. The outputs from Bernese GPS Software generate the estimated coordinates of all control stations and their covariance matrices for each epoch of observation. This follows with subsidence analysis by using in-house computer program developed for subsidence detection. Fig. 4 illustrates the flowchart of the research methodology.

6 Data Processing

Since the baselines are hundreds of kilometers in length, therefore it requires sophisticated data processing software to achieve high accuracy results. Data of GPS receivers from offshore platform and onshore are processed by using the Bernese GPS Software. This software is suitable for scientific studies in surveying fields that require high precision such as first order GPS network. This software can eliminate certain errors and able to rectify any ambiguity in the processing of baselines of high precision which enable to achieve high accuracy GPS results and analysis (Rothacher & Mervart, 1996). The software is capable of giving baseline solution and network adjustment.

Fig. 4 Flowchart of research methodology.



For the network adjustment, the free network solution is used to define the geodetic coordinates, without fixing or totally constraining particular site coordinates. The computed station coordinates are given in WGS84 coordinates system.

7 Deformation Strategy

The procedure of deformation detection via Iterative Weighted Similarity Transformation (IWST) can be found in Chen et al (1990), Wolf & Ghilani (1997) and Halim & Rusli (1999). The analysis of the vertical displacement of the control station can be carried out after the estimated heights and cofactor matrices of station heights has been obtained from the process of LSE. In the LSE process, the observations of each epoch made on the control stations are adjusted independently and the adjusted heights of each station are computed (Fig. 4). The vertical displacements of a control station is obtained as

$$d_i = H_i^{(2)} - H_i^{(1)} \qquad (1)$$

$H_i^{(2)}$ and $H_i^{(1)}$ is the adjusted height of a same control station obtained from the process of LSE for epoch 1 and epoch 2 respectively; and with the following cofactor

$$Q_d = Q_1 + Q_2 \qquad (2)$$

Q_1 and Q_2 is the cofactor of station heights obtained from the process of LSE for epoch 1 and epoch 2 respectively.

The a posteriori variance factor for both campaigns is estimated from the residuals as:

first campaign:

$$\hat{s}_{01}^2 = \left(\sum_1^n P_i \hat{v}_i^2 \right) / df_1 \qquad (3)$$

second campaign:

$$\hat{s}_{02}^2 = \left(\sum P_i \hat{v}_i^2 \right) / df_2 \qquad (4)$$

with n is the number of observation; df_1 and df_2 is the degree of freedom for the first and second campaign respectively.

The null hypothesis $H_0 : \hat{s}_{0_1}^2 = \hat{s}_{0_2}^2$ with significance level a is tested using

$$[F(a/2; df_2, df_1)]^{-1} < \hat{s}_{01}^2 / \hat{s}_{02}^2 < [F(a/2; df_1, df_2)] \qquad (5)$$

The pooled variance factor $\hat{s}_{0_p}^2$ and its degrees of freedom df_p are computed by using

$$\hat{s}_{o_p}^2 = \frac{\left[df_1 \left(\hat{s}_{01}^2 \right) + df_2 \left(\hat{s}_{02}^2 \right) \right]}{df_p} \qquad (6)$$

where;

$$df_p = df_1 + df_2$$

According to Chen *et al.* (1990), in the vertical network, the datum parameter is a translation quantity t_z in a vertical direction. To satisfy the condition $\left\{ \sum_i |w_i - t_z| \right\}$ is minimum, the weight matrix W_r is selected by arranging all the w_i in a sequence of their increasing algebraic values, and the middle value is the value t_z. The station or pair of stations in the middle place has a weight 1 and the rest zero.

The new vector of displacements d_r and its cofactor matrix Q_{dr} for the control stations from Eq. 1 and the cofactor of its station heights are transformed into a common datum by using the equation below:

$$\tilde{d}_r = \left[I - H_r (H_r^T W_r H_r)^{-1} H_r^T W_r \right] d_r = S_r d_r \qquad (7)$$

and

$$Q_{dr} = S_r Q_{dr} S_r^T \qquad (8)$$

The displacement of each station is then tested at 95% confidence level to determine the stability of the control stations (i.e. whether the control stations have moved or remain stable).

8 Initial Study

The study of subsidence detection for offshore platform in Malaysian waters involves three control stations on shore and three GPS stations on the offshore platform. The result from the Bernese GPS Software gives the ellipsoidal heights of all the six control stations. Computer software for subsidence detection was used for the two epochs analysis. This software requires information on the difference in height of the six control stations and its standard deviation of observation. In the process for detecting subsidence of control points, one of the onshore control stations was held fixed and the displacement of each station is then tested at 95% confidence level to determine that any of the control station has experienced any subsidence. The output of this software will identify if any of the six control stations in the network are stable or have moved.

Table 1 below shows the heights in meters of the six control stations for epoch 1 and 2. Station 1, 2 and 3 are control stations located onshore while station 4, 5 and 6 are control stations established on the offshore platform.

Table 1. The heights (in meters) of the six control stations established at the offshore platform at two difference epochs.

Stn	Epoch 1	Epoch 2
1	3.896	3.896
2	2.387	2.387
3	7.782	7.782
4	49.949	49.913
5	49.827	49.796
6	50.467	50.445

Table 2. Result from the subsidence monitoring program which indicates the stability of the six control stations.

Stn	*dz*	Stat. Value vs Conf. Level	Status
1	-0.011	23931962.492 > 4.654	Moved
2	0.025	171986793.921 > 4.654	Moved
3	-0.011	23931962.604 > 4.654	Moved
4	-0.011	95727850.480 > 4.654	Moved
5	0.020	110071548.204 > 4.654	Moved
6	0.011	95727850.480 > 4.654	Moved

Table 2 shows the displacement (*dz*) of each station in the network and statistical analysis carried out at 95% confidence level. The results obtained from the output of the Bernese GPS software indicate that subsidence experienced by the offshore platform at cm level can be detected. Results from the above tables indicate the offshore platform experienced a significant movement in vertical displacement.

9 Conclusions

From this study, the use of the Bernese GPS software is considered suitable for processing long baselines. This software is able to produce high accuracy results, which are considered important and vital in subsidence monitoring survey. The differences in height between the three control stations on the platform derived from levelling and GPS observations are similar in magnitude and orientation of the tilts and thus indicate the practicality of using GPS technique in subsidence monitoring especially for such a long baselines.

The existence of MASS stations throughout the peninsular of Malaysia, Sabah and Sarawak gives better option in carrying out subsidence monitoring of offshore platforms in Malaysian waters. The permanent MASS stations that operate at 24 hours a day and all year round enable surveyors and geodesists to achieve high accuracy results in point positioning that are required for subsidence monitoring.

The software developed for the purpose of subsidence monitoring used in this study indicates that the three control points established at the offshore platforms have experienced subsidence or vertical displacement.

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