Chapter 5

The Use of GNSS GPS Technology for Offshore Oil and Gas Platform Subsidence Monitoring

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Additional information is available at the end of the chapter

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Abstract

Due to oil and gas exploitation, offshore oil and gas platform may experience subsidence. Continuing subsidence may deform the platform infrastructures, adding the risk for any failure on the platform objects. The failure means disaster. Therefore the subsidence information is mandatory for risk assessment and safety requirement. Repeatedly or continuous monitoring of accurate positions on the platform by using global navigation satellite system global positioning system (GNSS GPS) technology may reveal the changing of even small positions which are representing subsidence on the platform. This chapter will be deeply discussed on the use of GNSS GPS technology for offshore oil and gas platform subsidence monitoring, especially in Indonesia, the archipelago country where long baseline between reference station in the land and monitoring station at the sea slightly exists. The capability and especially the high performance of this technology on deriving subsidence information along with data sample of long baseline will be highlighted.

Keywords: GNSS GPS, accuracy, oil and gas platform, subsidence, monitoring

1. Introduction

Nearly of today the global navigation satellite system global positioning system (GNSS GPS) technology has been played as remarkable tool for positioning and mapping and with high accuracy can be achieved in the easiest way [1–3]. By observing several satellites and measuring their distance, and with the known of their satellite coordinates and the distance from observation, in this case the coordinate on location at the earth can be calculated. In everywhere and in anytime worldwide when signals from the satellites are received by the receivers, in these cases the position in 3D or even 4D can be determined precisely and even with precision in the order of millimeter. The GNSS (GPS) indeed become a revolution in positioning on the twentieth century.

Repeated or continuous monitoring of accurate positions on the objects (e.g., offshore oil and gas platform) may reveal the changing of positions which are representing deformation (e.g., subsidence). Due to oil and gas exploitation, offshore oil and gas platform may experience subsidence. The rates can vary from 1 to 10 cm per year and even more for certain places. This subsidence information is mandatory for risk assessment and safety requirement. Continuing subsidence may deform the platform infrastructures, adding the risk for any failure on the platform objects.

2. Oil and gas platform subsidence

People commonly use fuel for transportation, electricity, machine, housing, etc. The fuels are produced from oil and gas exploitation. First, we need to explore the existence of oil and gas through exploration using geoscience technique (e.g., geology and geophysics surveys). There are numerous oil and gas reservoirs onshore and offshore all around the world. Platforms are built around offshore reservoirs (**Figure 1**) and also onshore. Once we successfully locate the reservoirs, we do drilling and extract the oil and gas. As the extraction or exploitation continues, the reservoirs may deplete through time due to loss of pore pressure, etc. As consequences, the platform may experience subsidence.

Some platforms have trend of few centimeters per year while others in the order of 10 cm or event more; it depends on how much oil and gas are being exploited, pore pressure decreases, load from rock is there in the surrounding, is level of fluid injection, etc. This subsidence information as mentioned above is mandatory for risk assessment and safety requirement since disaster may occur from that situation.

Figure 2 shows the physical evidence of offshore oil and gas platform subsidence. From the first picture, we can see jacket walkway was missing, while from the second picture, we can see the landing boat is disappearing into the sea. The different elevation levels between decks are about 5–6 m. In this case by seeing the condition of jacket walkway and the landing boat,

Figure 1. Oil and gas platform offshore.

Figure 2. Subsidence evidence on oil and gas platform offshore.

the magnitude of subsidence is already quite large. It may be around 1–3 m. It is true that platform subsidence may reach 1–20 cm per year, especially on old oil and gas platform. The subsidence may continue through years. As mentioned before, continuing subsidence may deform the platform infrastructures, adding the risk for any failure on the platform objects. There are regulations for monitoring oil and gas platform both for onshore and offshore but especially offshore where the risk is higher.

Strategic position around plate boundary has made Indonesia rich of oil and gas resources, probably one of the largest in the world. Three major plates (e.g., Australia, Pacific, and Sunda Block) meet each other in Indonesia and formed many faults and basins area where usually we can found oil and gas resources. Millions of years of burned planktons getting heated by the mantle have turned them into an oil and also gas. Basin in eastern of Sumatera Island, eastern of Kalimantan, and northern of Java Island is rich in oil and gas resources both onshore and offshore. Bird head of Papua also potentially reserves huge amount of oil and gas. According to data released by Indonesia Ministry of Energy and Mineral Resources, the proven oil reservoirs in Indonesia are about 3306.97 MMS TB. Meanwhile the potential reservoirs are about 3994.20 MMS TB.

In spite of these potential resources, the areas of oil and gas in Indonesia especially the offshore area are prone to the risk of subsidence failure on the platform facilities. Along with this risk, the tilting and vibrations on the platform are also the risk. Huge oil and gas company is already realized about this situation, as well as the authorities. There are several regular programs on monitoring subsidence, tilting, and vibration on the platform. Nevertheless continues monitoring seems still beyond the agenda since it is relatively too expensive or people do not realize how important it is.

3. GNSS GPS for monitoring subsidence

The GNSS GPS principle of measurement is by observing of minimum four satellites and measuring their distance. With the known of their satellite coordinates from broadcast or precise ephemeris and the distance from time synchronize of code data or phase calculation, in this case the coordinate on location at the earth can be calculated. This technology can measure accurately an object as small as an ant like depicted in **Figure 3**. From the figure, graph of position repetition within millimeter variation is seen. As mentioned previously the subsidence on the oil and gas platform can be vary for about 1–10 cm per year and even more. So, by using GNSS GPS technology, the accurate information of subsidence on the platform can be achieved confidently.

Once again we mention that the accurate subsidence information of oil and gas platform is mandatory for risk assessment and safety requirement. Monitoring program should be conducted regularly or even continuously. Continuing subsidence may deform the platform infrastructures, adding the risk for any failure on the platform objects. With surrounding full of gases and oil, the failure may cause fatality.

There are several methods on GNSS GPS positioning such as static method/GPS surveys, Real Time Kinematic (RTK), Precise Point Positioning (PPP), etc. each given the different levels of accuracy on the position. For subsidence monitoring, in order to achieve millimeter of accuracy, then the GPS survey method based on phase data should be implemented with stringent measurement and data processing strategies [3, 4]. GPS surveys relay on differential technique using minimum of two receivers and with this data differencing most of biases and error can be reduce significantly. PPP only use one receiver. In this case, the correction of clock and orbit is necessary. These two corrections can be downloaded from IGS community. The RTK is differential positioning in real-time mode with centimeter level of accuracy. In order to fulfill the need for real-time data differential correction, therefore data communication via radio, GPRS, or satellite communication is mandatory.

The principle of subsidence monitoring using repeated static method/GPS survey method is depicted in **Figure 4**. With this method, several points which are placed on the media covering

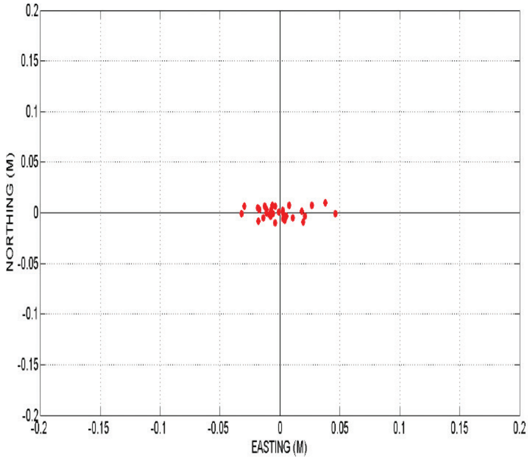

Figure 3. Graph of position repetition within millimeter variation derived from GNSS GPS measurement. An object as small as an ant can be positioned precisely.

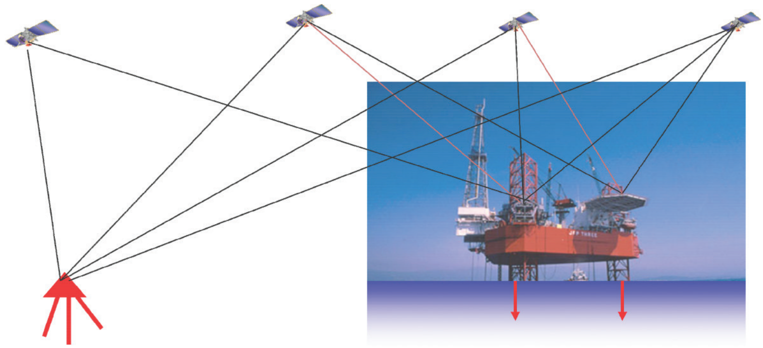

Figure 4. The principle of subsidence monitoring (e.g., platform subsidence) using repeated GNSS GPS survey method or CGPS (continuously operating the GPS receivers).

the area investigation are accurately positioned using GPS survey relative to a certain reference (stable) point. The precise coordinates of the points are periodically determined using repeated GPS surveys with certain time interval. With the same principle as GPS surveys, continuous determination of precise coordinate of point can be achieved by continuous observations. By studying the characteristics and rate of changes of the height component of coordinates from survey to survey or data to data in continuous mode, the subsidence characteristics can be derived. In the recent time, the capability of PPP is also promising to choose for subsidence monitoring.

In the case of studying the subsidence or other high-precision application, there are several advantages of using GNSS GPS survey method that should be noticed, such as the following: it provides the three-dimensional displacement vector with two horizontal and one vertical components, so it will give not only land subsidence information but also land motion in horizontal direction; it provides the displacement vectors in a unique coordinate reference system, so it can be used to effectively monitor land subsidence in a relatively large area like in offshore oil and gas field; the GPS can yield the displacement vectors with a several mm precision level which is relatively consistent in temporal and spatial domain, so it can be used to detect even a relatively small subsidence signal; and the GPS can be utilized in a continuous manner, day and night, independent of weather condition, so its field operation can be flexibly optimized.

The reference point is one important thing in order to have best monitoring of subsidence. We have to make sure the stability of reference point because it will be used to see relatively the subsidence at the monitoring point such as platform oil and gas. Approach of geological and geodetic can be applied. **Figure 5** shows the example of exercise to see stability over reference station by process time series of GNSS GPS data and plot the repeatability of their height component position. InSAR can also be used to see the stability of area where reference station took place. As from geology approach, the information of bed rock will help us on choosing the place for reference station.

To give clear description on how we measured in the investigation area (e.g., oil and gas platform), we give picture of documentation of real measurement in the field. The GNSS GPS receiver attached to the body of platform (usually on hand fence) is seen. Obviously to be

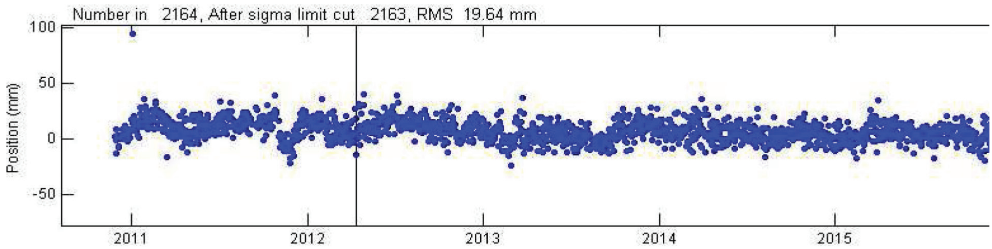

Figure 5. Example of stability of reference station from repeatability of their height component position through years of observation.

assured that it is stable for observation and visibilities to the satellite are good. It is needed also to define the best observation strategies, as it can be seen in **Table 1** (**Figure 6**).

Back to the reference station issue, for Indonesia case it can be interesting to discuss since Indonesia is an archipelago country. Most of the region is water, and many sources of oil and gas are taking place offshore (see **Table 2** and **Figure 7**). Scenario of choosing one reference station for whole Indonesia regions could be used, or we choose reference scenario by cluster. The baseline length will be crucial for both scenarios, since the accuracy theoretically depends on its length. Here we do data processing simulation for each scenario of long and even very long baseline, and the results can be found in **Tables 4** and **5** and **Figures 10–17** chapter data analysis.

Figure 7 shows map of onshore and offshore oil and gas area in Indonesian regions. There are six offshore regions as summarized in **Table 2**, and most of onshore oil and gas area is located in Sumatera, Java, Kalimantan, and Bird Head of Papua. In spite of these potential resources, the areas are prone to subsidence. Monitoring subsidence around these areas is necessary to make sure the safety on exploitation, etc.

Figure 8 shows long baseline concept using one stable reference station for subsidence monitoring (e.g., platform) along large offshore oil and gas area of Indonesia. The GNSS GPS stations with baseline length more than 1000 km are chosen for simulation and analyzed for their accuracy whether it can achieve the requirement for subsidence monitoring on the platform.

Figure 9 shows baseline concept using reference station at clustered offshore regions for subsidence monitoring (e.g., platform) along large offshore oil and gas area of Indonesia. The GNSS

Parameters observation	Observation strategy for millimeter accuracy
1. Receiver/observation signal	Geodetic dual phase L1/L2 obs and CODE
2. Observation times	Continuous or minimum 12 h session
3. Mas angle	15 degrees
4. Observation rate	30 s or higher rate

Table 1. Observation strategy that is generally used in order to derive millimeter accuracy of position such as for platform subsidence monitoring.

Figure 6. Illustration of GNSS GPS data acquisition in the field for oil and gas platform subsidence monitoring.

Regions	Offshore oil and gas area block name
1. Offshore of East Coast of Sumatera	Aceh, Riau, Jambi, Lampung
2. Offshore of North Coast of Java	Bekasi, Blanakan, Gresik, Madura
3. Offshore of Natuna	East Natuna, West Natuna
4. Offshore of East Coast of Kalimantan	Bunyu, Tarakan, Mahakam, Balikpapan
5. Offshore of Maluku	Halmahera, East Maluku
6. Offshore of Bird head Papua	Sorong, Fakfak, Kai, Tanimbar, Biak

Table 2. Offshore oil and gas area in Indonesian regions.

GPS stations with baseline length less than 1000 km are chosen for simulation and analyzed for their accuracy whether it can achieve the requirement for subsidence monitoring on the platform.

All of GNSS GPS data are taken for investigation of the subsidence or other deformation phenomena that require millimeter accuracy usually processed by using scientific GPS software (e.g., Gamit, Bernese, Gypsy Software, etc.). This scientific software is commonly used for achieving the good accuracy level of relative coordinates or point positioning from GPS surveyed data [5]. All of errors and biases (e.g., ionosphere, troposphere biases, cycle slip, phase ambiguity, antenna phase center bias, etc.) will be estimated or modeled and leaving the residual mostly only in few millimeters. Since mostly the baseline from each combination of data will exceed typical of short baseline, in this case good handling of parameter errors

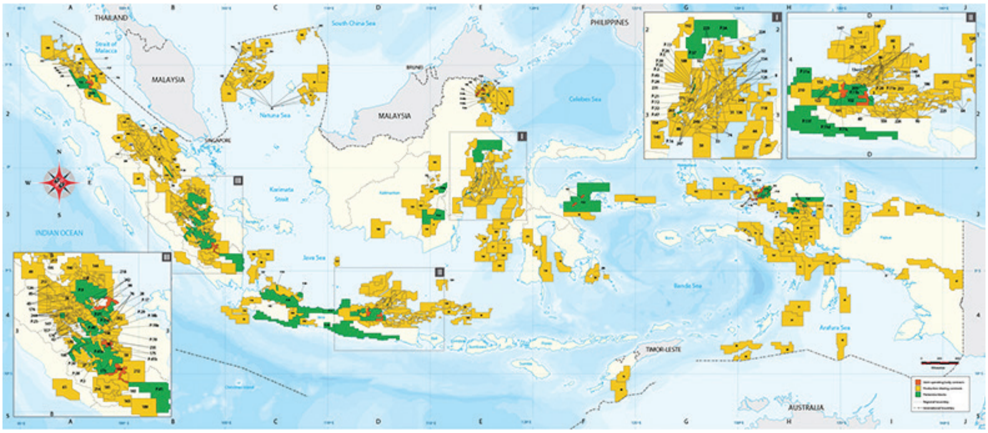

Figure 7. Onshore and offshore map of oil and gas area in Indonesian regions (images courtesy theoilandgasyear).

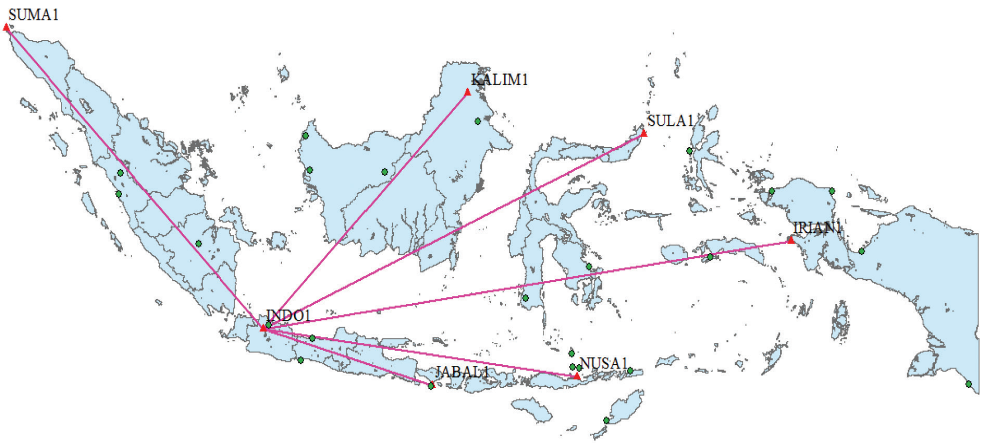

Figure 8. Baseline concepts using one stable reference station for subsidence monitoring along large offshore oil and gas area of Indonesia.

and biases is crucial for high accuracy requirements. **Table 3** shows parameter processing and processing strategy that are used on data processing using scientific software.

Final precise orbit from International GNSS Services (IGS) can be downloaded in every 2 weeks after the observation time, while earth rotation parameter can be downloaded either daily, every 2 weeks, or on yearly basis. As for phase center parameter, we can download from UNAVCO website or Bernese website. Many mirror addresses are also available for downloading GNSS GPS parameter data processing.

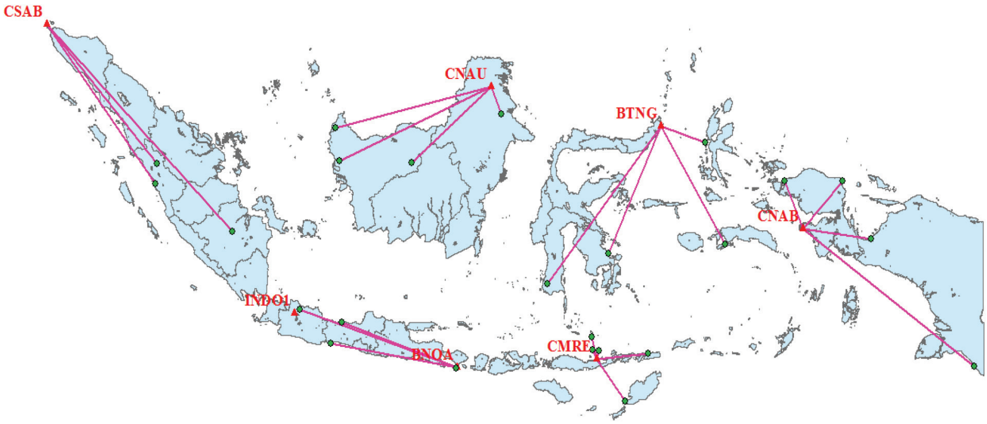

Figure 9. Baseline concepts using reference station at clustered offshore regions for subsidence monitoring around offshore oil and gas area of Indonesia.

Parameter processing	Processing strategy using scientific software
1. Observations	Data phase, L1/L2. Data CODE
2. Earth rotation parameters	IGS. ERP
3. Orbits	Final precise orbit from IGS
4. Ionospheric and tropospheric biases	Data combination, parameter estimation
5. Antenna phase center	Antenna phase correction (PVC)

Table 3. Parameter data processing and processing strategy using scientific software in order to derive millimeter accuracy of position such as for platform subsidence monitoring.

4. Data analysis

Table 4 shows the result simulation of baseline concept using one stable reference station, while **Table 5** shows the result simulation of baseline concept using reference station at clustered offshore regions, for subsidence monitoring around offshore oil and gas area of Indonesia. On each figures we can see the baseline length and the average for height component from simulation result. For baseline with more than 1000 km, the average height component is around 1 cm. For baseline with less than 1000 km, less than 1 cm of average can be seen.

Results from data simulation show that the scenario using reference station at clustered offshore are given better result than scenario using only one stable reference station. Nevertheless with using scenario of only one stable reference station, generally it is sufficient enough for monitoring offshore oil and gas platform subsidence in such large offshore like in Indonesia.

Baseline ID	Baseline length (m)	Observation session	Average for height component from simulation (m)
1. BAKO-CSAB	1,868,631.008	24 h/31 days	0.021
2. BAKO-BTNG	2,207,624.866	24 h/31 days	0.014
3. BAKO-CNAB	3,163,103.652	24 h/31 days	0.011
4. BAKO-CMRE	1,707,364.779	24 h/31 days	0.011

Table 4. Result simulation of baseline concepts using one stable reference station for subsidence monitoring along large offshore oil and gas area of Indonesia.

Baseline ID	Baseline length (m)	Observation session	Average for height component from simulation (m)
1. CNAB-CFAK	359,191.773	24 h/31 days	0.007
2. CNAB-CMAN	319,811.751	24 h/31 days	0.011
3. BNOA-CBTU	934,272.232	24 h/31 days	0.005
4. BNOA-CDNP	100,619.250	24 h/31 days	0.004

Table 5. Result simulation of baseline concepts using reference station around clustered offshore regions for subsidence monitoring around offshore oil and gas area of Indonesia.

For baseline with more than 1000 km when we get 1 cm of accuracy, it is very good indeed. It may give the effectiveness and efficiency to the monitoring projects by the oil and gas company and others.

Figures 10–13 show graphs of repeatability on data simulation processing result for scenario using only one stable reference station for subsidence monitoring with baseline that varies more than 1000 km. A good repeatability on each graph can be discovered. A clear view of accuracy given by this scenario would be achieved. Generally it is sufficient enough for monitoring offshore oil and gas platform subsidence in such large offshore area like in Indonesia.

Figures 14–17 show graphs of repeatability on data simulation processing result for scenario using reference station at clustered area for subsidence monitoring with baseline that varies less than 1000 km. There is a good repeatability on each graph. A clear view of accuracy given

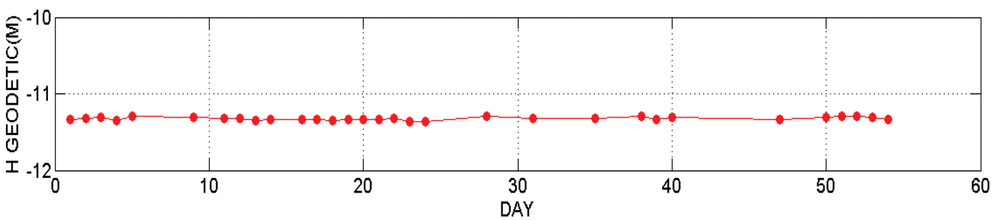

Figure 10. Repeatability of H result simulation baseline BAKO-CSAB 1,868,631.008 m.

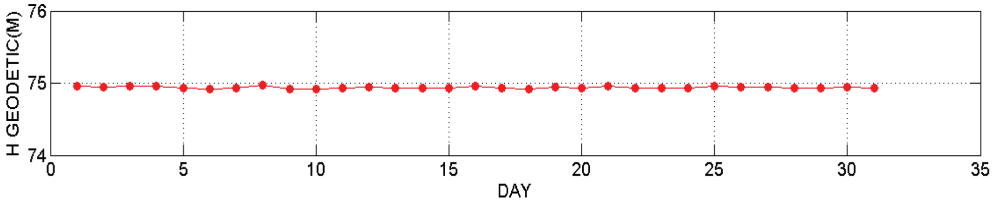

Figure 11. Repeatability of H result simulation baseline BAKO-BTNG 2,207,624.866 m.

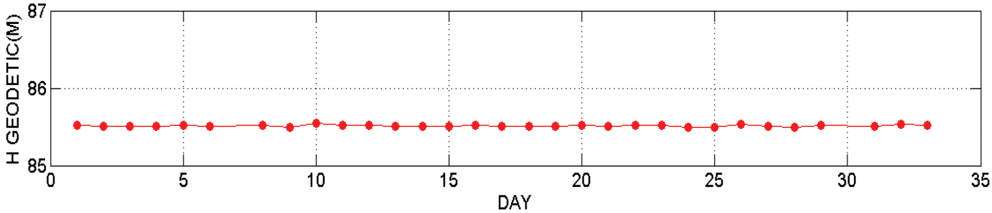

Figure 12. Repeatability of H result simulation baseline BAKO-CNAB 3,163,103.652 m.

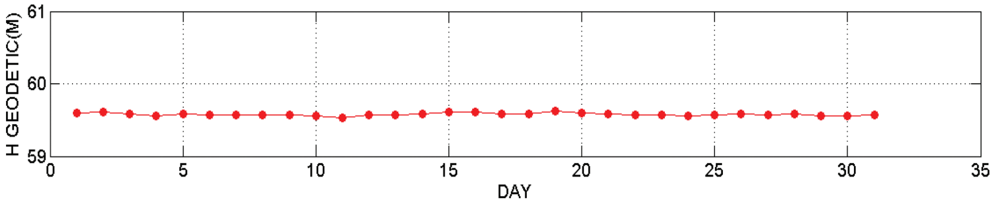

Figure 13. Repeatability of H result simulation baseline BAKO-CMRE 1,707,364.779 m.

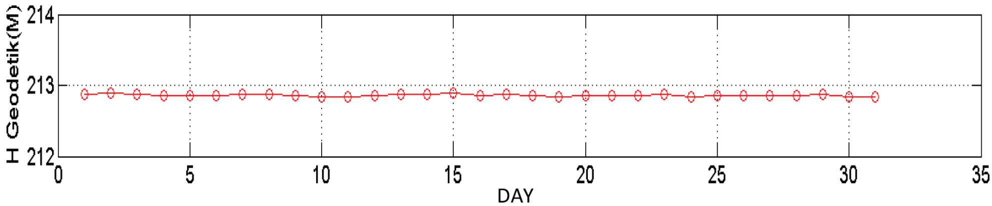

Figure 14. Repeatability of H result simulation baseline CNAB-CFAK 359,191.773 m.

by this scenario has been achieved. There is a high confident to use this scenario for monitoring offshore oil and gas platform subsidence.

From simulation results the capabilities of GNSS GPS technology on monitoring subsidence on oil and gas platform are proven. Indeed the real data observations are available in quite numbers of offshore oil and gas platforms around Indonesia. **Figures 18** and **19** show example of subsidence signal at Platform X and Platform Y somewhere located on classified area. Very

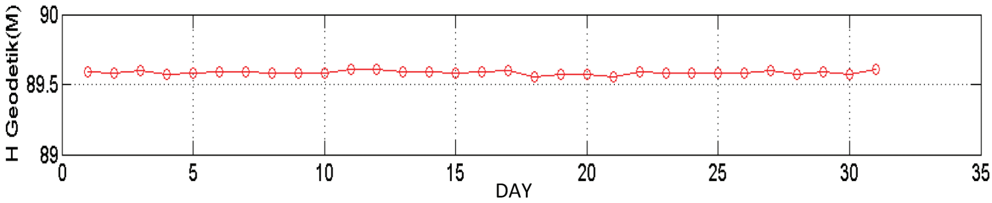

Figure 15. Repeatability of H result simulation baseline CNAB-CMAN 319,811.751 m.

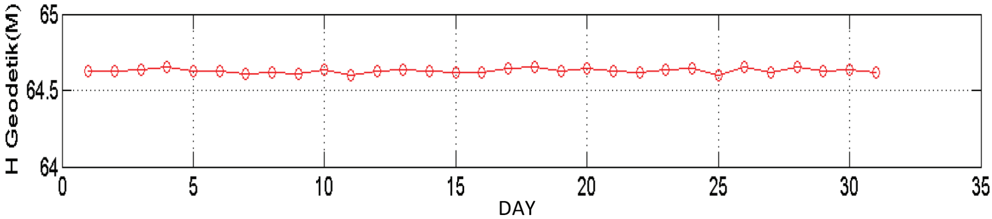

Figure 16. Repeatability of H result simulation baseline BNOA-CBTU 934,272.232 m.

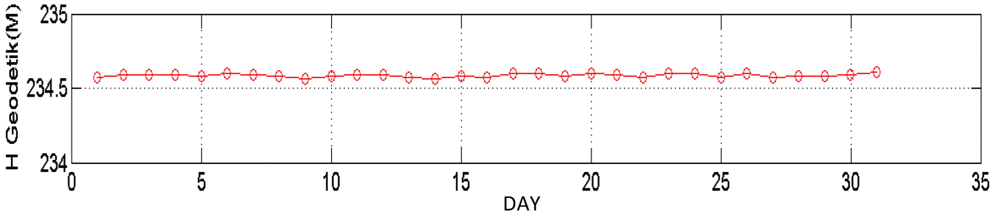

Figure 17. Repeatability of H result simulation baseline BNOA-CDNP 100,619.250 m.

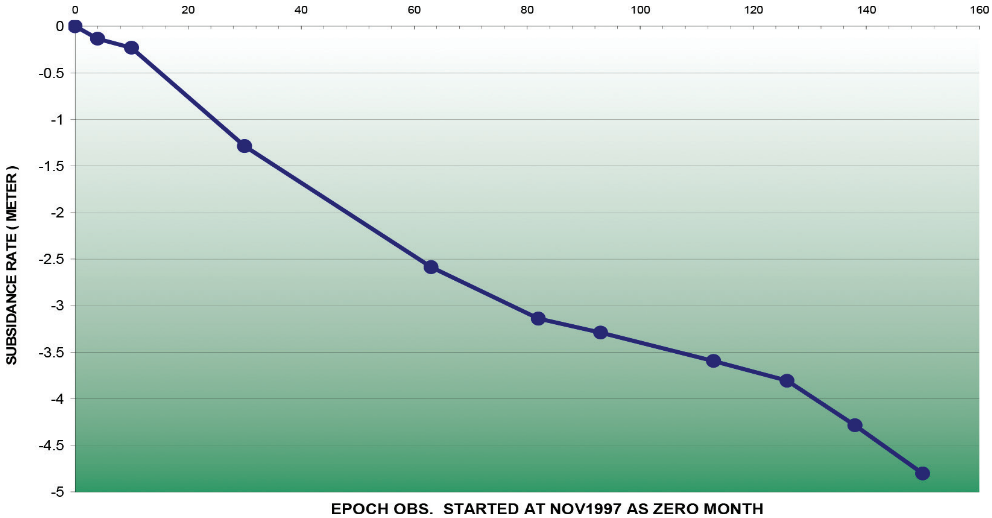

Figure 18. Example of real data of platform subsidence in platform X offshore of Indonesia.

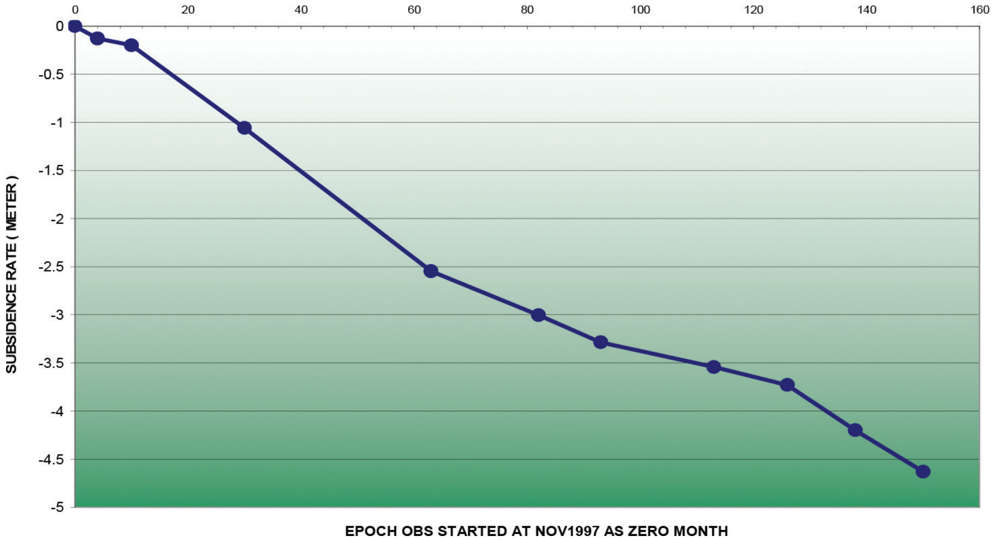

Figure 19. Example of real data of platform subsidence in platform Y offshore of Indonesia.

clear subsidence with rates of about 10–20 cm per year can be seen on the graphs. Some platforms have trend of few centimeters per year; it depends on how much oil and gas are being exploited, etc. In a detailed viewing, fluctuation on the trend can be seen. Sometimes it is accelerating, while in some cases, it is slowing or linier.

Large rates of subsidence are usually taking places in old oil and gas platform where depletion on reservoirs is more due to decrease in pore pressure, etc. There are already quite number for old oil and gas platform in Indonesia region. In this case monitoring program is quite important today. GNSS GPS is mostly the chosen technology for the programs. Nevertheless in many cases, the methodology on data acquisition and data processing is not correct. That is why it is necessary to write this kind of paper to help people on understanding more the capabilities of GNSS GPS technology on monitoring subsidence on oil and gas platform, as well as share the more correct concept and methodology. There are other methods that have been implemented together side by side with the GNSS GPS such as using altimeter and pressure gauge. They rely on identification the changing on MSL through times.

5. Closing remarks

Due to oil and gas exploitation, offshore oil and gas platform may experience subsidence. It has been observed from the real measurement that the rates can be varying from 1 to 10 centimeters per year and even more for certain places. In a detailed viewing, we can see fluctuation on the trend. Sometimes it is accelerating, while in some cases, it is slowing or linier. This situation will depend on how much oil and gas are being exploited and also how much pore pressure left, the fluid injection, etc. This subsidence information is mandatory for risk assessment and safety requirement. Continuing subsidence may deform the platform infrastructures, adding the risk for any failure on the platform objects. With surrounding full of gases and oil, the failure may cause fatality.

The capabilities of GNSS GPS technology on monitoring subsidence on oil and gas platform have been proven. By observing enough satellites, and measuring their distance, in this case the coordinate on location at the earth can be calculated precisely and even with precision in the order of millimeter. This technology can measure accurately an object as small as an ant. To get information of subsidence signal or any deformation signal, we just repeatedly or continuously monitor accurate positions on the objects investigation, and the changing of positions is representing subsidence and/or deformation.

For Indonesia case it can be interesting to discuss about the reference station for monitoring subsidence on the platform since Indonesia is an archipelago country. Most of the region is water, and many sources of oil and gas are taking place offshore. The scenario of choosing one reference station for whole Indonesia regions or by cluster can be used. Results from data simulation show that the scenario using reference station at clustered offshore are given better result than scenario using only one stable reference station. Nevertheless with using scenario of only one stable reference station, generally it is sufficient enough for monitoring offshore oil and gas platform subsidence in such large offshore like in Indonesia. For baseline with more than 1000 km when we get 1 cm of accuracy, it is very good indeed. It may give the effectiveness and efficiency to the monitoring projects by the oil and gas company and others.

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