Review of Techniques for Measuring and Monitoring Seabed Subsidence

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Underwater subsidence is an event present in several petroleum exploration areas. Early detection of these events minimizes environmental consequences and improves the exploration region's geomechanical model. This material reviews works that present solutions for monitoring and measuring underwater subsidence. It was identified that most techniques use pressure data to monitor the subsidence occurrences, and some use inclination data. The identified techniques include data treatment: for pressure data, a 14 data average, and using a local measurement as a reference, and for inclination data, Kalman filter and integration of angles. It was concluded that using pressure data with a local reference offers the best accuracy.
Keywords: Seabed Subsidence. Subsidence Monitoring. Pressure Sensing. Angle Sensing.

In offshore production, especially in the oil and gas industry, monitoring structures like pipelines and Christmas trees is essential to ensure the safety and integrity of these installations. In addition to these structures, the marine environment is typically monitored by measuring factors such as temperature, acidity, salinity, and the dynamics and characteristics of the underwater soil. Data on seabed depth is also important for environmental monitoring and helps acquire geomechanical models. Depth data and inclination measurements can be used to identify potential deformations in the seabed.

A common deformation in offshore production is seabed subsidence, which is the vertical displacement of soil. Various factors, including the extraction of oil, can cause it. Due to the depth, external influences, and the difficulty of accessing deep regions, obtaining high-accuracy data about vertical displacement is challenging. In addition to direct measurements, in this case, depth measurement, other measurements, and strategies can be employed to detect and monitor vertical deformations in the seabed.

This material reviews leading research, articles, and other scientific materials related to monitoring submarine subsidence. The research provides the latest methods and strategies for measuring vertical displacement to achieve high-accuracy data in monitoring and measurement of seabed subsidence.

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Materials and Methods

The selection of papers followed specific criteria. The materials selected needed to include contents directly related to the development of seabed monitoring and pressure and depth measurement in deep-sea environments.

Keywords such as "submarine subsidence," "seabed deformations," and "subsidence sensing" were used to search for materials in the Scopus bibliographic database. The review included each material if its abstract indicated relevant content about seabed monitoring.

The publications from 2012 to 2024 were obtained from Earthdoc, SEG Library, ScienceDirect, and MDPI. After selecting the materials, analyses were conducted to identify current strategies for monitoring and identifying submarine subsidence.

Results and Discussion

There are many strategies for identifying and monitoring seabed subsidence. Some involve collecting data to measure vertical displacement and modeling the exploration field. Thomas and colleagues [1] presented various strategies for monitoring subsidence were reviewed and presented, including air gap measurements, bathymetry, tiltmeters, and bottom pressure recorders.

As noted by Hatchell and colleagues [2], many strategies use pressure data to monitor subsidence, the most widely used technique for measuring seafloor subsidence. They recommended three strategies for monitoring and measuring subsidence: a self-calibrating system, the placement of a weight collar on PMTS, and pressure measurements with a reference at the seabed.

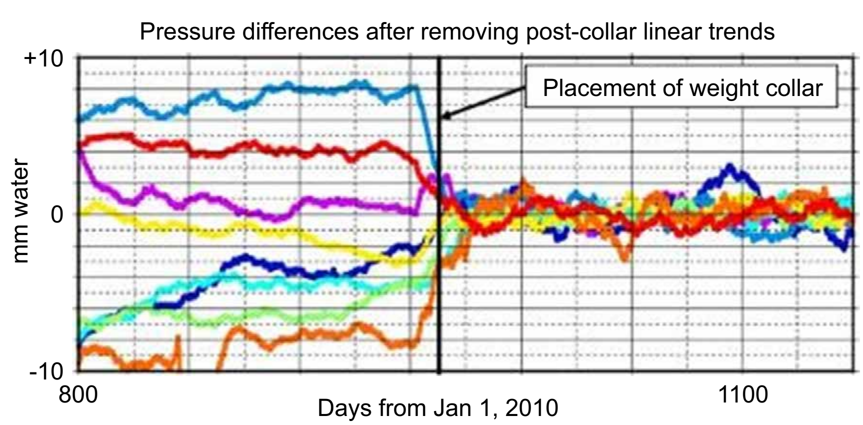
Aimed to acquire high-quality data on pressure measurement, Sasagawa and Zumberge [3] developed a tool, the SCPR, a self-calibrate pressure recorder. This sphere-shaped tool, with a diameter of 41.6 cm, contains two recording pressure gauges to measure ambient seawater pressure. For every ten days, for 20 minutes, the gauges are hydraulically connected to a piston gauge that provides a reference pressure to determine their drift and account for it on the pressure measurement. The result pressure data accuracy is 5 cm.

Also, intending to obtain high-quality pressure data, Vries and colleagues [4] applied a 14-day average to data collected by various pressure monitoring transducers (PMTs) instruments across the Gulf of Mexico. The 14-day average reduced the effect of tides and other external effects. Beyond this smooth method, a weight collard and tripod base were also placed on PMTs to reduce external influences. Figure 1 shows the influence on the data after the weight collar was placed with the tripod; each line on the graph is from a distinct PMT.

Another strategy was developed by Eiken and colleagues [5], using high-precision pressure sensors, concrete monuments, and ROVs. This technique involves moving sensor tools between concrete monuments, some expected to subside and others not. The monuments expected not to subside serve as references to other ones; in other words, it is necessary to assume that some regions of the monitoring target will not suffer from subsidence. Figure 2 shows the results of this technique applied in the Ormen Lange field. The main advantage of this technique is its accuracy, which is less than 1 cm. However, it requires that some areas not suffer vertical displacement and involve high costs due to the need for skilled ROV operators on vessels. Dutta and colleagues [6] also applied the strategy of measuring reference to others. Figure 3 shows the difference in subsidence data after the reference data is considered for all measurements. After the correction, the subsidence data appears more homogeneous and continuous with smoother gradation. This application's resulting accuracy was 3 cm.

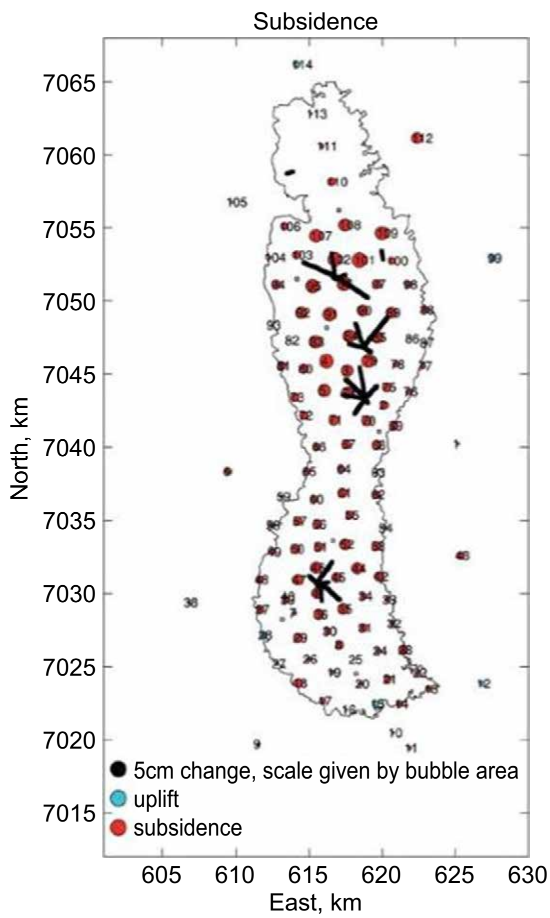
Other sensors may also be employed to aid in monitoring and identifying subsidence.

Figure 1. Pressure data before and after the installation of the weight collar.



Source: Hatchell and colleagues [2].

Figure 2. Subsidence monitoring on Ormen Lange.



Source: Hatchell and colleagues [2].

Inclinometer and accelerometer sensors were used to track ground behavior on top of a tunnel section to monitor ground subsidence [7]. In addition to the data collected by the sensors, filtering was applied to lessen noise in the signal. The filtering process was executed by applying a Kalman Filter to the original signal. Figure 4 presents the graph of the original and the treated data.

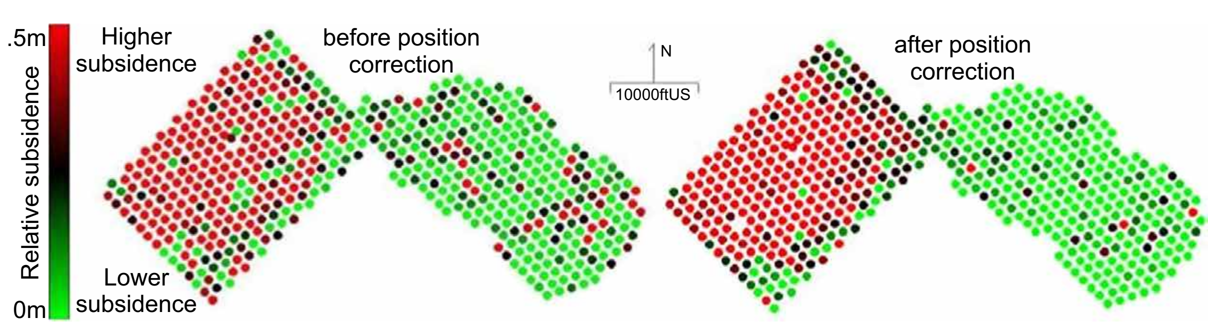
The data from two sensors, the inclinometer and the accelerometer, and the result of the Kalman Filter application are shown. As expected, the data from the Kalman filter had a small noise presence. A significant variation in filtered signal may indicate the occurrence of ground subsidence in the tunnel. The same principle can be used to accuse or identify subsidence at the seabed.

Aimed directly at seabed subsidence, Miandro and colleagues [8] show a system that uses tiltmeters to monitor subsidence. The system's principle is to allocate tiltmeters in an array over the field to measure the inclination of the soil at specific points. Integration over distance is used to obtain data about subsidence. Each node of the array is separated by 300 m.

Figure 5 shows the layout of this system. Beyond the array of tiltmeters, a GPS station is presented as central for acquiring data from the sensors. Another strategy for monitoring subsidence is deploying fiber cables, according to Measures [9].

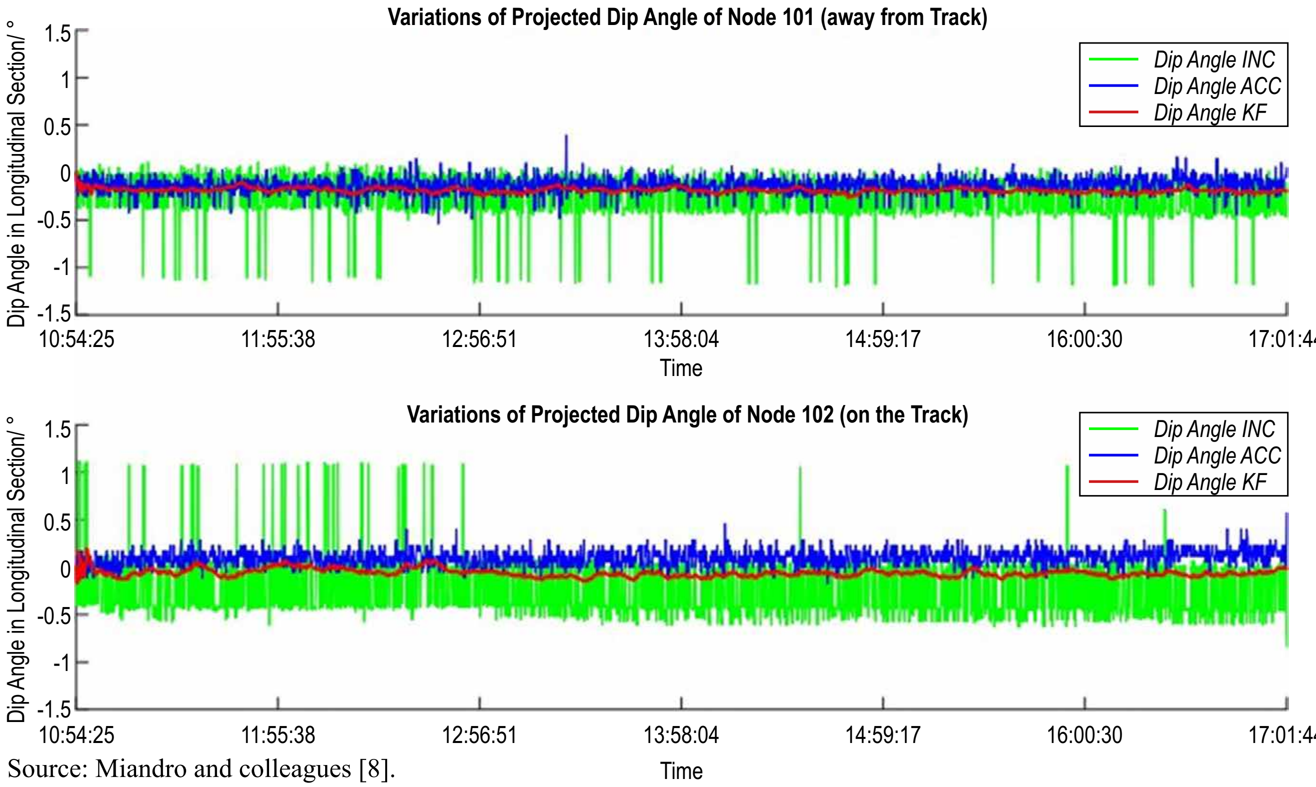
The cable-based subsidence monitoring system was presented in three ways of measurement: strain, cable inclination, and pressure measurement.

Figure 3. Measured relative subsidence before (left) and after (right) corrections.



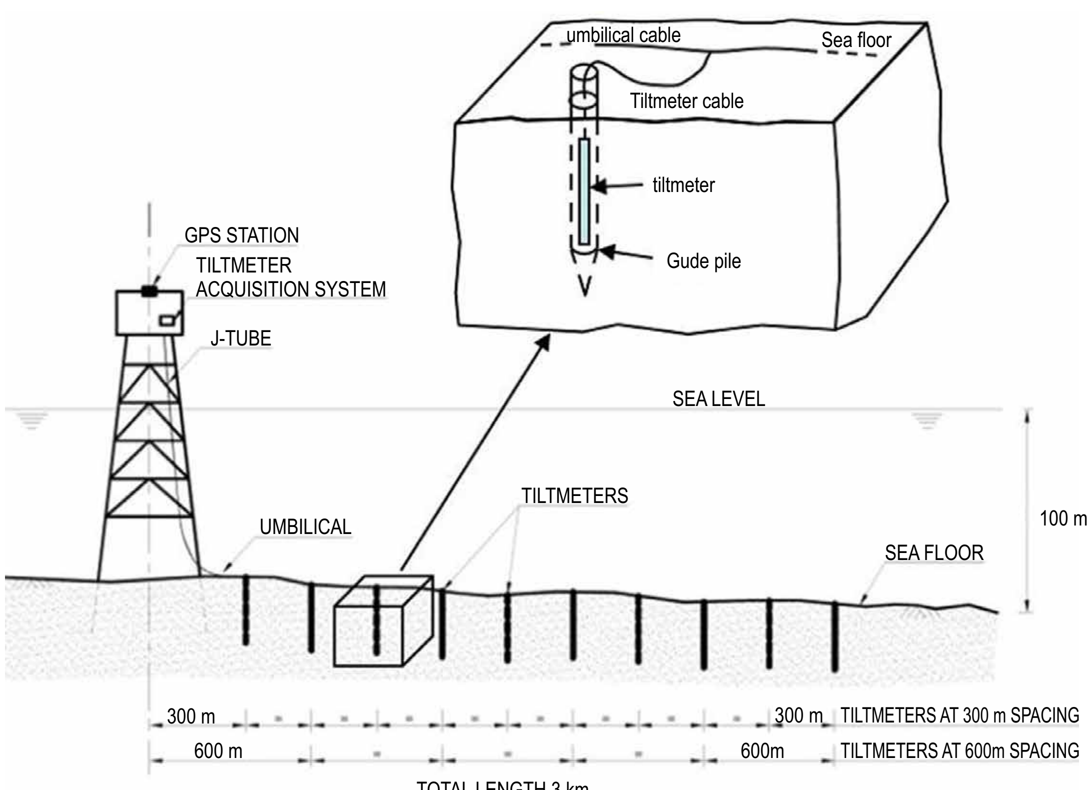
Source: Dutta and colleagues [6].

Figure 4. Data from the accelerometer and inclinometer of two nodes.



Source: Miandro and colleagues [8].

Figure 5. Array of depth sensor.



Source: Measures [9].

The strain measurement considers that the shape of the cable can be obtained through data from optic sensors that consider a certain distance of a neutral line. So, the occurrence of strain on the cable may indicate the occurrence of subsidence. The inclinations measurement considers that an inclination of a part of the cable can result in the vertical displacement of the other part, which can be viewed as a subsidence occurrence. Pressure measurement detects pressure changes across the cable when the cable moves vertically.

Conclusion

There are many strategies for monitoring and measuring subsidence. Most of them use pressure to infer the possible vertical displacement, but sensors that can collect the inclination and angle of soil can also aid in motoring. Beyond the raw measurements, the data treatment also plays an important role in monitoring. The Kalman filter method used on sensors that measure angles and inclination provided a signal with a small presence of noise, which is suitable for monitoring.

Additionally, it was noted that a 14-day average is a good strategy to reduce noise on PMTs, which can result in pressure sensors. As with anyone, pressure data on the seabed suffer from noise and external effects. Using a reference measurement that will not suffer from subsidence to others is a good strategy because it reduces most external effects and has accuracy below 1 cm over 2000 m of depth.

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