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Structural Settlement Monitoring Using GPS and Conventional Terrestrial Surveying Methods

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Abstract: This paper discusses the use of Global Positioning System (GPS) and accelerometers for the structural settlement monitoring of the Academic Building at Applied Science University. It provides an overview of previous research on building displacement monitoring, including an analysis of the advantages and disadvantages of the measurement techniques, as well as the methodology employed in recent studies. The aim of this review is to assist students and researchers in making informed decisions before embarking on research related to building displacement monitoring. Additionally, the paper examines a case study on structural settlement monitoring using GPS and conventional terrestrial surveying methods. The main goal of the research is to identify the parameters and measurements needed in the structural monitoring of buildings subjected to heavy loads following the completion of construction.

Keywords: Structural Settlement, Foundation, Surveying, Monitoring, GPS, TOTAL STATION.

1 Introduction

Structural settlement monitoring is an important aspect of ensuring the safety and stability of structures such as buildings. Settlement monitoring involves measuring the vertical displacement of a structure over time to determine whether it is settling or sinking into the ground. This is important because the settlement can cause structural damage and compromise the safety of the structure. In this paper, we will discuss the use of GPS and conventional terrestrial surveying methods for structural settlement monitoring [1].

Global Positioning System (GPS) for Structural Settlement Monitoring is a satellite-based navigation system that can be used for precise positioning and tracking. GPS receivers can be used to measure the position of a structure and track its movement over time. GPS is a useful tool for structural settlement monitoring because it provides accurate and continuous measurements of vertical displacement. This is an effective tool when large settlements are expected for the structure under consideration [2].

One advantage of using GPS for structural settlement monitoring is that it can provide remote monitoring of structures. GPS receivers can be set up at a distance from the structure being monitored, which allows for monitoring without the need for physical access to the structure. This can be particularly useful for structures that are difficult to access or for monitoring structures that are in remote locations.

Another advantage of using GPS for structural settlement monitoring is that it can provide high accuracy measurements. GPS receivers can provide measurements with sub-millimeter accuracy, which is important for detecting even small amounts of settlement. GPS also provides continuous measurements, which allows for real-time monitoring of settlement [3].

However, there are also some limitations to using GPS for structural settlement monitoring. One limitation is that GPS measurements can be affected by atmospheric conditions such as ionospheric and tropospheric delays. These delays can cause errors in the GPS measurements, which can affect the accuracy of the settlement monitoring. Additionally, GPS receivers require a clear line-of-sight to the satellites, which can be obstructed by buildings, trees, and other structures. This can limit the effectiveness of GPS for monitoring structures in urban environments [4].

Conventional Terrestrial Surveying Methods for Structural Settlement Monitoring involve the use of surveying instruments such as total stations and auto level to measure the vertical displacement of a structure [5]. Total stations are electronic surveying instruments that measure angles and distances, while levels are instruments that measure height differences [6]. Conventional terrestrial surveying methods are well-established for settlement monitoring and have been used for many years.

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One advantage of using conventional terrestrial surveying methods for settlement monitoring is that they provide high accuracy measurements. Total stations and auto levels can provide measurements with sub-millimeter accuracy, which is important for detecting even small amounts of settlement. Additionally, terrestrial surveying methods are not affected by atmospheric conditions, which can improve the accuracy of the measurements [7].

Another advantage of using conventional terrestrial surveying methods is that they can be used in both urban and rural environments. Terrestrial surveying methods do not require a clear line-of-sight to satellites, which makes them effective for monitoring structures in urban environments where GPS may not be effective. Additionally, terrestrial surveying methods can be used to monitor structures in remote locations where GPS may not be available [8].

However, there are also some limitations to using conventional terrestrial surveying methods for settlement monitoring. One limitation is that they require physical access to the structure being monitored. This can be difficult for structures that are high or difficult to access. Additionally, conventional terrestrial surveying methods require more time and resources compared to GPS, which can make them more expensive.

Both GPS and conventional terrestrial surveying methods have their advantages and limitations for settlement monitoring. Combining these methods can provide a more comprehensive and reliable monitoring system [9].

2 Experimental Program

Figures 1 shows the layout of Applied Science University and Figures 2, 3 and 4 show the instruments used in the conducted research. Four locations were selected for the structural monitoring using the different instruments and over a period from September 2022 to July 2023. Table 1 shows the recorded measurements at the four locations. One approach to combining GPS and terrestrial surveying methods is to use GPS to provide remote monitoring and to use terrestrial surveying methods to provide high accuracy measurements at specific points on the structure. This approach can provide real-time monitoring of settlement using GPS and provide detailed and accurate measurements at specific points on the structure using terrestrial surveying methods. Another approach is to use GPS and terrestrial surveying methods simultaneously to provide continuous monitoring of settlement. This approach can provide the benefits of both methods and can be useful for monitoring structures in both urban and rural environments.

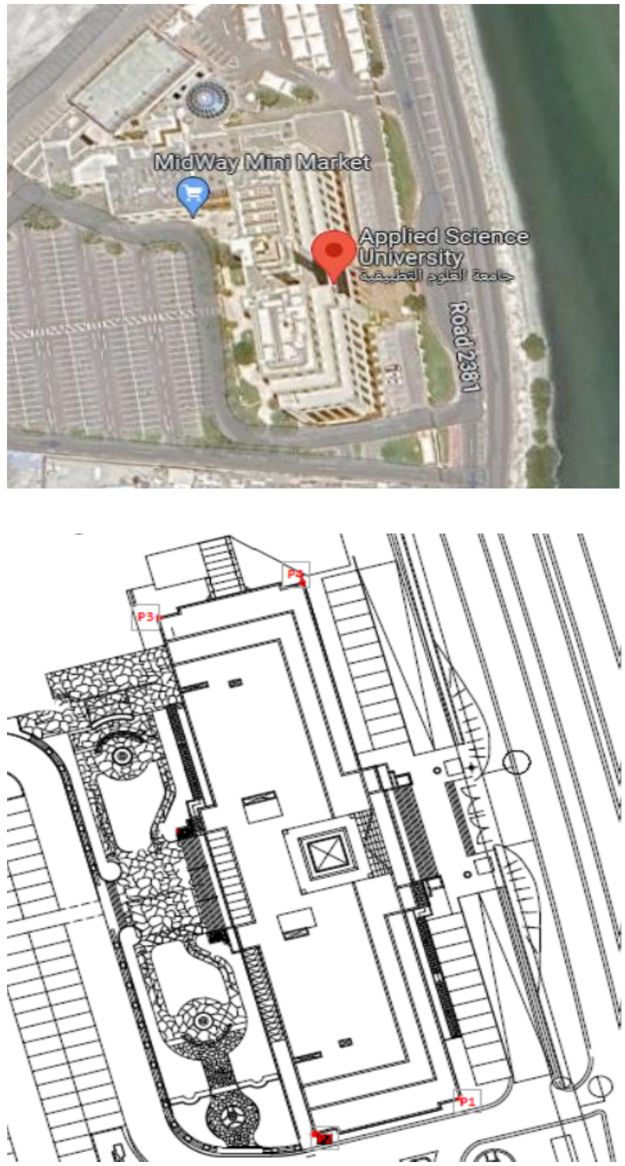

Fig. 1 : Project Layout.

Fig. 2 : LEICA FLEXLINE TS02 PLUS TOTAL STATION used in the conducted research.

Fig. 3: LEICA VIVA GS14 GNSS used in the conducted research.

Fig. 4:LEVEL LEICA VIVA NA N700 used in the conducted research.

Table 1: Recorded Measurements at the Four Locations .

September 2022				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1400mm	1400mm	1575mm	1360mm
Total station	1397mm	1398mm	1577mm	1358mm
GPS survey equipment	1438mm	1448mm	1610mm	1377mm
November 2022				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1401mm	1399mm	1578mm	1361mm
Total station	1398mm	1397mm	1576mm	1357mm
GPS survey equipment	1452mm	1453mm	1603mm	1383mm
January 2023				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1398mm	1401mm	1572mm	1358mm
Total station	1399mm	1400mm	1575mm	1356mm
GPS survey equipment	1447mm	1439mm	1587mm	1391mm
March 2023				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1399mm	1403mm	1573mm	1362mm
Total station	1400mm	1402mm	1575mm	1360mm
GPS survey equipment	1436mm	1437mm	1559mm	1387mm
May 2023				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1400mm	1399mm	1579mm	1365mm
Total station	1398mm	1397mm	1576mm	1361mm
GPS survey equipment	1447mm	1451mm	1597mm	1393mm
July 2023				
Device	Point 1	Point 2	Point 3	Point 4
Auto level	1401mm	1402mm	1574mm	1359mm
Total station	1403mm	1405mm	1571mm	1362mm
GPS survey equipment	1457mm	1457mm	1623mm	1377mm

In this study, the accuracy of total station, auto level, and GPS instruments for measuring the vertical displacements of the test locations was investigated. The instruments were set up at four different measurement points around the structure, and readings were taken at each point. The measurements were repeated three times for each instrument to obtain an average value and to assess the consistency of the readings [9].

3 Results and Discussions

Foundation design is performed to control bearing capacity failures, cracks, and excessive settlement. Deep foundations were used in the design of the ASU building to control settlement based on the encountered ground conditions. The intent of the conducted research is to provide another means of evaluating the effectiveness of the system design at ASU.

Table 1 and Figure 5 show the test results and readings. the results are discussed in the following sections.

Vertical displacements were measured with extreme precision using Total Station and Auto Level instruments. The average measurement range is between 1 and 4 mm. Their dependability in gathering precise data is highlighted by this regularity [10].

On the other hand, differences between GPS and Total Station and Auto Level Instruments are more pronounced. The difference in readings between the GPS and the older devices is between 30 and 80 mm, which suggests a lower accuracy level [11]. These differences in measurement between GPS and conventional devices are caused by a number of factors:

Accuracy of GPS Signals: A number of variables, including signal consistency and quality, can affect how precise GPS measurements are. Reduced accuracy may result from poor signal reception or interference in specific places [12].

Obstacles Affecting Signal Reception: The ability of GPS to function depends on signals sent by satellites, which might be distorted or hindered by things like vegetation,

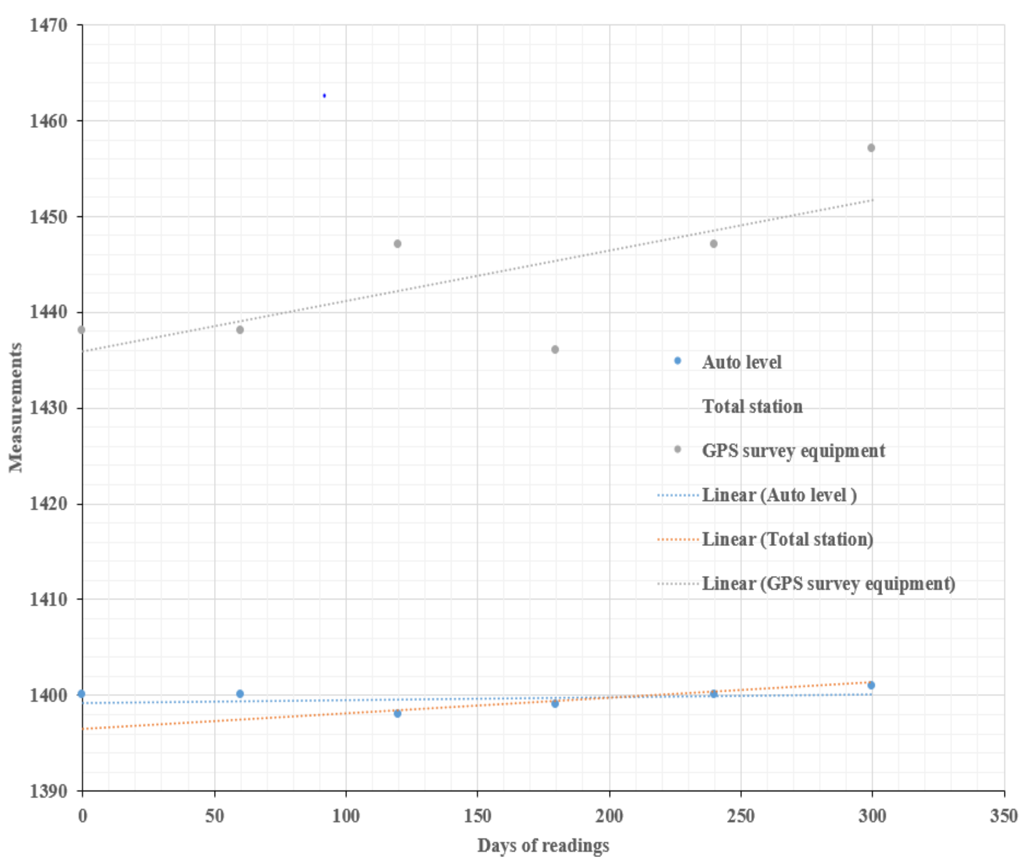

Fig. 5: Recorded Measurements for point 1.

buildings, or geographical features. These impediments have the potential to cause errors, a phenomenon known as multipath error.

Limitations of GPS Devices: When compared to instruments designed specifically for precise surveying activities, the accuracy of GPS devices may be limited by their capabilities and design. The accuracy of some GPS systems' measurements is impacted by their preference for broad navigation over careful surveys [13].

Based on the test results, GPS readings show greater disparities than Total Station and Auto Level Instruments, which regularly provide extremely precise vertical displacement measurements. These variations are probably caused by signal accuracy issues, reception difficulties, and the intrinsic limits of GPS devices. When choosing the best instrument for their measurement goals, researchers should take these observations into consideration, especially in situations where the highest level of precision is required [14].

Our findings indicate that Total Station and Auto Level Instruments outperform GPS for precise vertical displacement measurements of structures. These instruments provide improved accuracy, resistance to environmental variations, and increased precision. Nonetheless, the choice of instruments should be determined by the individual surveying context and structural factors. Using various instruments and cross-validating results can improve the breadth and reliability of vertical displacement measurements. Furthermore, while older buildings with established settlement patterns may benefit from traditional equipment, GPS could be essential for monitoring settlements in newly constructed buildings on difficult soils and subjected to heavy loads [15; 16].

4 Conclusions

Accurate measurement of vertical displacement of structures is crucial for ensuring their stability and safety. Our study showed that total station and auto level instruments provide the most accurate measurements compared to GPS. Therefore, we recommend the use of these instruments for accurate and reliable measurement of vertical displacement of structures. Further research may be needed to investigate the factors that affect the accuracy of these instruments and to develop improved techniques for measuring vertical displacement. GPS and conventional terrestrial surveying methods are both useful tools for settlement monitoring, each with their own advantages and limitations [17].

Combining these methods can provide a more comprehensive and reliable monitoring system. The choice of method depends on factors such as the location and accessibility of the structure being monitored, the level of accuracy required, and the budget available for monitoring [18]. It is important to carefully consider the advantages and limitations of each method when selecting a monitoring approach, to ensure that the monitoring system is effective and meets the requirements of the structure being monitored [19].

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