Monitoring Levels of Deformation Within Tarkwa Community: A Multi-Gps Receiver Network System Approach

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SUMMARY

Deformations of engineering structures and the earth crust are often measured to monitor the behavior and safety of constructed structures. Global Positioning Systems (GPS) have evolved as an important tool for monitoring deformation. This study investigated the deformation of the earth's crust using GPS at Tarkwa, an important mining town.

Fifteen control stations were established for the monitoring. Two of these were used as reference stations, eight were established about 200-500 m to mining sites and five others established about 1 000-2 000 m from the mining areas. Field measurements were carried out every two weeks for a period of six months. Analysis of the results revealed both lateral and vertical movements in the area, with average displacement values of 13 mm for most stations close (200-500 m) to the mines and 5 mm for stations relatively far (1 000-2 000 m) from the mines. Lateral movements were the greatest, ranging from 0.00 mm to 19.00 mm and vertical movements were from -1.00 mm to 11.00 mm. Cracks on some buildings in communities closer to mining areas corroborates the results.

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1 Introduction

GPS technology is fast advancing as a tool for monitoring deformation patterns. The earth's crust and engineering structures such as buildings, dams, bridges, mining pit walls are subjected to deformation due to earthquakes, tectonic activities, ground water level changes, tidal phenomena and, mining and quarrying operations. In mining communities, one of the greatest concerns of the inhabitants is the safety of their structures. It is therefore significant to monitor the stability of these structures to assess their level of safety.

Developments in the accuracies achievable by modern GPS have made them reliable tools for effective deformation monitoring both in the horizontal and vertical planes. GPS is capable of providing very accurate positions in three-dimensional space from 0.1 to 3 ppm (Fosu, 2008). Therefore, applying this technology in monitoring movements within the earth's crust and engineering structures offers many advantages over the conventional/traditional surveying techniques which measure relative geometric quantities (distances, angles and height differences) between selected points (Chen *et al*., 2000). The selection of the most appropriate technique or combination of techniques for any particular monitoring exercise will depend upon cost, the accuracy required and the scale of the survey involved. However, the design and execution of the ground measurement procedures for the deformation monitoring and the analysis of the results are key issues which must be carefully considered.

2 Brief Information About the Study Area

This section focuses on the Tarkwa municipality; its location, climate, geography, regional geology and mining history.

2.1 Location, Climate and Regional Geology

Tarkwa, the capital of the Wassa West Municipal assembly of Ghana, is a mining town in the Western Region of Ghana. It is located about 85 km from Takoradi the Regional capital and about 322 km from Accra the national capital. Figure 1 is Map of Wassa West District showing the location of Tarkwa. It lies in the tropical rain forest zone of Ghana and has a characteristic temperature range of 24 ºC to 35 ºC. There is no complete dry season in Tarkwa since the period supposed to be dry, that is, December through February has intermittent rains. Torrential rains are the norm with bright sunshine and a high humidity throughout the year. Tarkwa area experiences a double maxima rainfall. The first and more pronounced rainy season extends from late March to the end of July and the second season is from October to mid-November. The average annual rainfall is about 180 cm. Annual maximum and minimum temperatures are 37 ^{o}C and 26 ^{o}C respectively.

The rock system in the area is known as the Tarkwaian System believed to be approximately 2.1 billion years old (Kesse, 1985). The Tarkwaian System includes the Banket Series in which gold deposits occur as reefs or conglomerate beds. Favourable gold bearing areas are found around the contacts of the Tarkwaian System with the Birimian System (Kesse, 1985). The Tarkwaian strata have been folded into a series of anticlines and synclines. Large thrust faults also exist. As a result of seasonal fluctuations in the water table over time, contrasting weathering types are developed (Kesse, 1985).

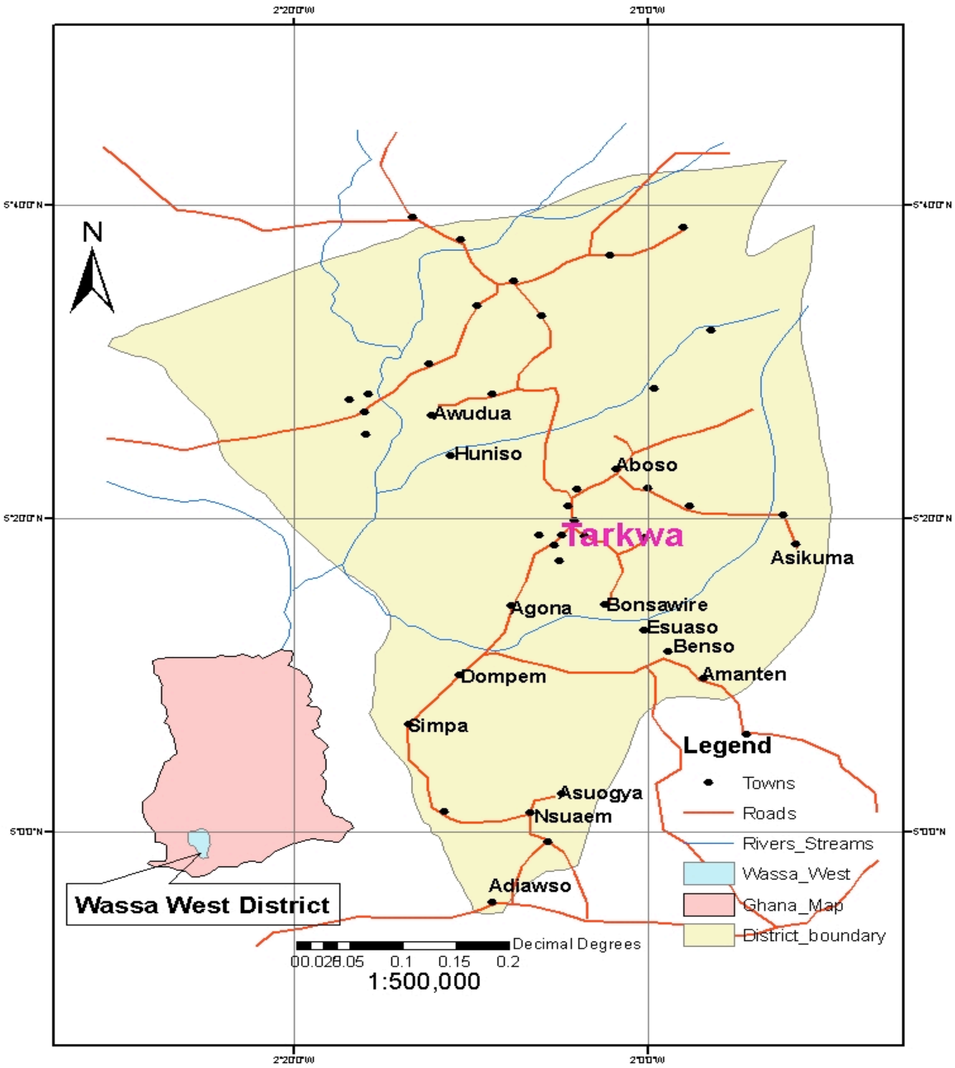


Figure 1 Map of Wassa West District showing location of Tarkwa

2.2 History of Mining in the Tarkwa Area

The Tarkwa Nsuaem municipality attracted attention of the earliest European prospectors and promoters who first entered the hinterlands of the Gold Coast colony in the late 1870s just after it had been declared a British colony. It eventually became an important gold producing district and an administrative centre for the mining industry. Underground mining was carried out for over 100 years during which about 7 million ounces of gold were produced. However, from the late 1960s to the late 1980s, production dropped off dramatically due to a variety of problems. A major revival occurred from the late 1980s when attention was focused on the open-pit potential of the Tarkwaian gold deposit. In the 1990s alone, about 3 million ounces were recovered from the new open-pit operations in the area (Griffis *et al*., 2002).

The activities of mining companies in their bid to exploit the gold include blasting the rocks using explosives. The energy from an explosive once released in the blast hole fragment the rocks (primary energy) and cause ground displacement/vibration (secondary energy). The environmental aspect of blasting deals mainly with the effects of the secondary energy released, which causes ground vibrations and airblast. Noise and dust generated in the process are also consequences of the secondary energy released (Amegbey, 2006). The effect of ground vibration as a result of blasting is the damage caused to buildings. The ground vibrations are seismic movements in the ground and a form of energy transport through the ground that may cause damage to adjacent structures when they reach certain levels (Agbeno and Amegbey, 1999).

Currently, there are three large scale mining companies namely Goldfields Ghana Limited, AngloGold Ashanti Iduaprim Mine and Ghana Manganese Company around the Tarkwa township. A host of small scale mining groups are also scattered within the township. The activities of these mines have contributed to the socio-economic development of the area.

3 Deformation Monitoring

Ground movement is the result of either natural processes or human activity. Such movements can trigger displacement in the earth's crust thereby causing significant damage to buildings, heavy structures/infrastructure when they are sufficient enough. There have been growing interest in deformation monitoring over the years and many techniques are being adopted for this purpose. Since 1976 till today a number of observation techniques and a mixture of geodetic instruments have been used for monitoring the deformations of the dam and the abutments (Gikas and Sakellarious, 2008). Notable among these are geodetic techniques which, until recently, used conventional surveys. However, GPS technology has overtaken these in recent times.

The processes and activities which can cause ground movements include swelling and shrinkage of clay soils, landslides, dissolution, earthquakes, mining, fluid abstraction and engineering excavation. In some cases, the movements may be of large magnitude. Landslides can move hundreds of meters but may be preceded by smaller ones. In other cases, the movements may be very small. Swelling and shrinkage usually involve small movements of millimeters. Many of the processes that cause ground movements can extend over large areas which might affect many properties such as bridges, buildings and roads. The monitoring of changes in ground surface levels enables damaging movements to be anticipated in order to maximise the opportunity for mitigation (Haynes *et al*., 2001).

Deformation is increasingly receiving much attention in civil engineering and the building profession (Uren and Price, 1994). Of special interest in this area, are the earth's crust and engineering structures such as high rise buildings, dams, bridges, mining and pit walls. Dam walls change shape with varying water pressure, the foundation of large buildings are affected by ground conditions, landslides sometimes occur on embankments and cuttings. Wherever these occur deformation monitoring is essential considering the safety of the inhabitants and the structures they have invested in. As deformation refers to the changes a deformable body (natural or artificial object) undergoes in its shape, dimension and position, it is important to measure this movement for the purposes of safety assessment for preventing any disaster in the future (Anon, 2007).

Deformation monitoring of Tarkwa and the use of GPS technology is very important since the area has many mining activities currently taking place. The area is on record of having had underground mining operations spanning many years (Griffis *et al*., 2002). This implies that beneath the surface of the study area (Tarkwa), are underground tunnels and old stopes which may require monitoring to determine whether movement is taking place and to assess whether the structures in and around the area are safe.

4 Deformation Monitoring Using GPS in Tarkwa

Tarkwa has been chosen for the deformation monitoring study because of the long history of mining in and around the town. The monitoring network consisted of two reference stations, and thirteen monitoring stations. Twelve observation campaigns were made for this study. The first monitoring was carried out in August 2007 and the last in January 2008. Monitoring was undertaken every two weeks within the six months period. All stations were surveyed using four units of Sokkia differential GPS receivers. Static GPS surveying mode with relative positioning was used for all stations. Table 1 is baseline coordinates of stations recorded. Two GPS reference stations, DMP RF 2007/01 and DMP RF 2007/02 were used for each GPS survey. A geodetic control survey was conducted to identify the stability of all the monitoring stations from the GPS observations. Figure 2 shows GPS Network for Deformation monitoring within Tarkwa.

Table 1 Baseline Coordinate of Stations Recorded

STATIONS	EASTING E_o (m)	NORTHING N_o (m)	HEIGHT Z_o (m)
DMP 2007/RF1	**158830.277**	**56842.071**	**35.584**
DMP 2007/RF2	**158887.348**	**56874.684**	**35.707**
DMP 2007/01	162410.924	68573.728	107.671

DMP 2007/02	162001.208	69165.024	126.982
DMP 2007/03	162461.082	70032.069	143.39
DMP 2007/04	163617.737	70763.653	92.44
DMP 2007/05	165109.294	72408.505	90.166
DMP 2007/06	165382.301	69105.194	82.089
DMP 2007/07	163630.247	68630.288	84.072
DMP 2007/08	164571.218	69123.335	95.491
DMP 2007/9	164233.384	68869.265	80.667
DMP 2007/10	163937.872	69884.455	100.681
DMP 2007/11	163338.739	69568.084	75.086
DMP 2007/12	162971.344	69675.351	99.052
SGW 22/62/04	164366.351	70303.335	78.975

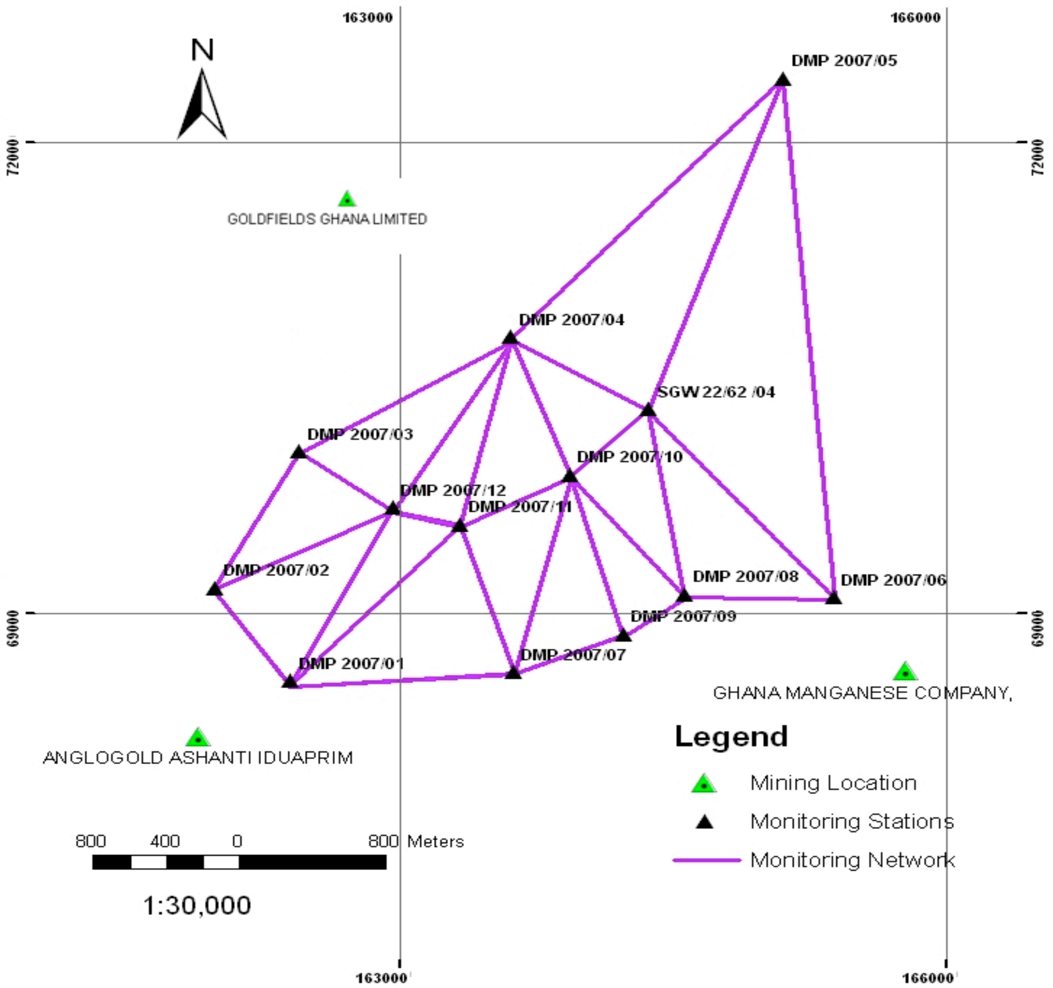


Figure 2 GPS Network for Deformation Monitoring within Tarkwa

4.1 Error Sources and Accuracy in Satellite Survey Techniques

It has been established that satellite positioning is affected by a myriad of factors if care is not taken during collection and post-processing of data. Some of the errors likely to influence the positions are error in the range measurement, satellite–receiver geometry, accuracy of atmospheric refraction, processing software used and multipath.

In order to achieve the maximum accuracy in deformation monitoring, all possible systematic errors were kept constant by: avoiding multipath during the building of monitoring stations using only the same type of receivers in all monitoring process, the same software, similar geometry of satellites in the repeated monitoring of individual baselines, and trying to conduct all survey monitoring in similar environmental conditions. Finally, the data processing and analyses took into consideration the effects of tides on earth movement. These measures taken resulted in an accuracy of 0.01 mm for monitoring excess.

5 Results

The GPS network adjustment of data from the monitoring epochs was accomplished using Spectrum survey software (Version 3.3) with constrained network adjustment. The average displacements and graph of average displacements are shown in Table 2 and Figure 3 respectively. The deviations from the 12 observations of 2 weeks interval for all the stations were plotted (Figure 4).

Table 2 Average Displacement of Stations in the Various Directions

STATIONS	VM (mm)	HM (mm)	D (mm)
DMP 01/07	-5	12	14
DMP 02/07	-10	4	11
DMP 03/07	-3	12	13
DMP 04/07	-8	11	14
DMP 05/07	-11	7	13
DMP 06/07	-3	5	5
DMP 07/07	-2	3	2
DMP 08/07	-2	4	4
DMP 09/07	-1	6	6
DMP 10/07	-7	8	12
DMP 11/07	-2	6	7
DMP 12/07	-7	10	12
SGW 04/22/62	-8	5	9

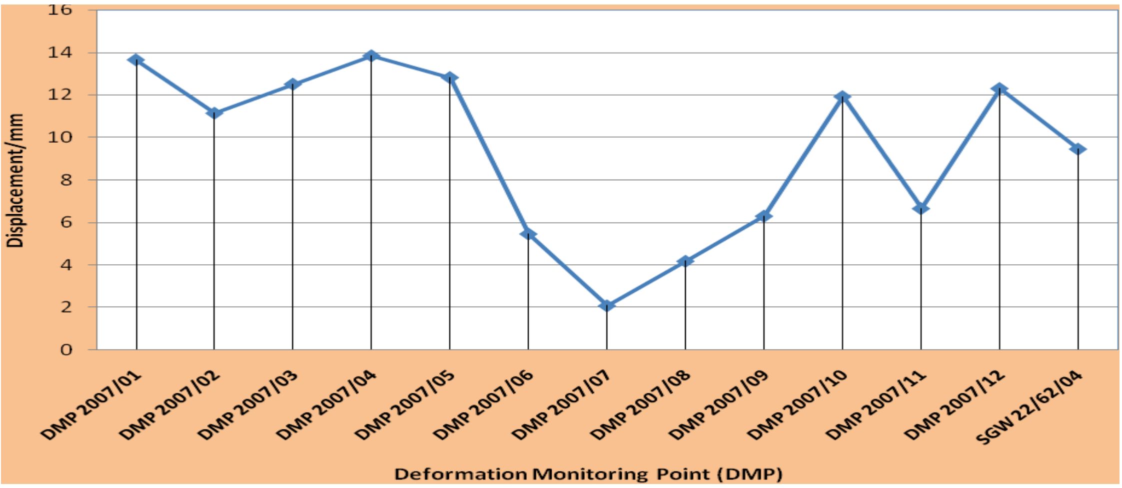
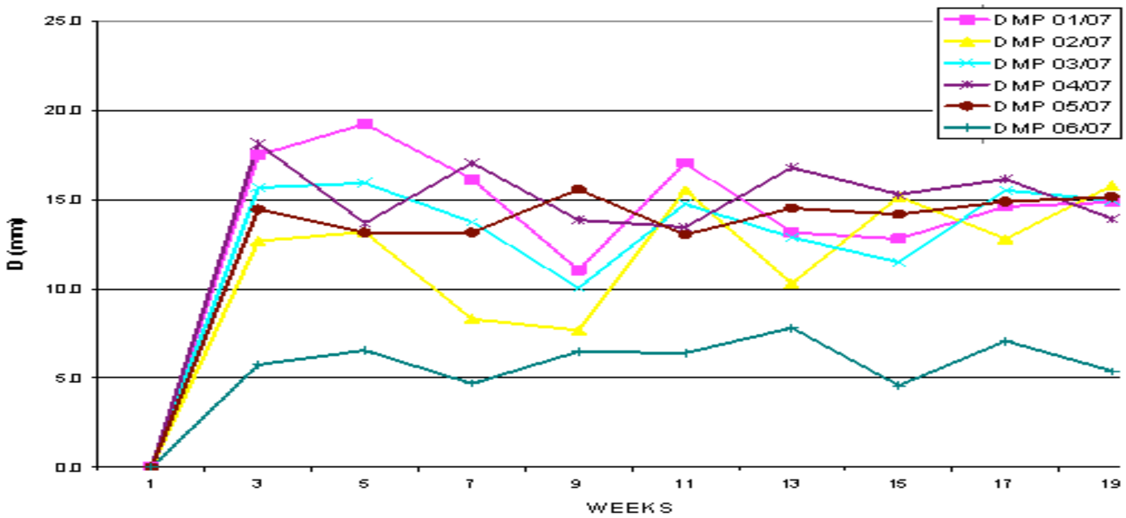


Figure 3 Graph of Average Displacements of Stations



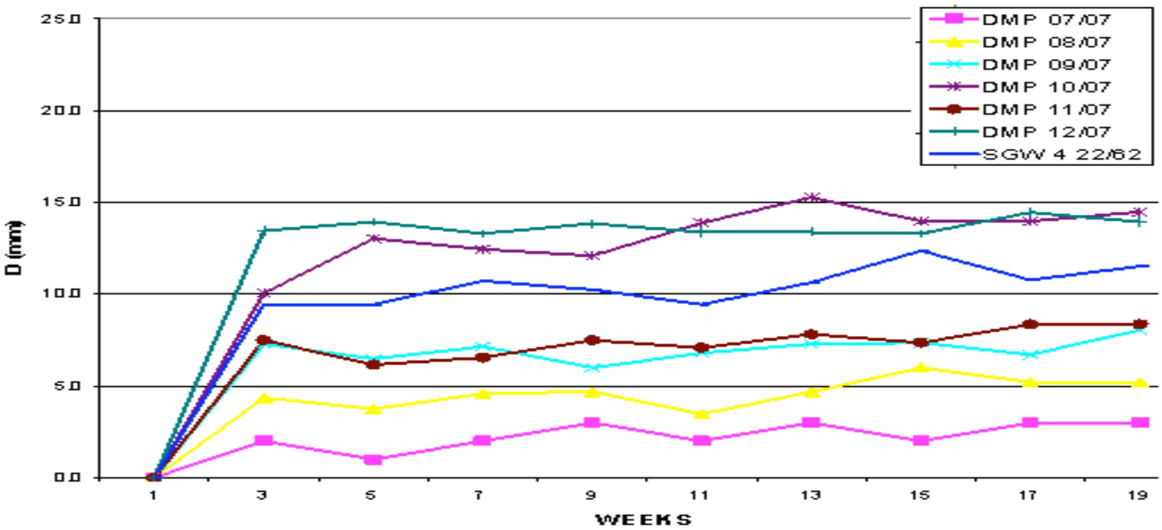


Figure 4 Graphs of Displacements

6 Discussions

The deformation levels found for all the points were within the range of 0.00 to 19.00 mm. The deformation levels found for all the points were within the range of 0.00 to 19.00 mm. The high levels of deformation occurred in the points DMP 01/07, 02/07, 03/07, 04/07, 05/07, 10/07, 11/07, 12/07 and SGW 04/22/62. These points are very close to the mining areas. These results suggest that blasting has an influence on the stability of these points due to continuous fluctuations obtained in the deformation values. This may be attributed to the fact that the charge for the blast varies every time. The graph of displacement (Figure 4) depicts the scenario of continuous changing of displacement values. Though the maximum deformation is relatively small, it is necessary for measures to be taken to reduce these levels of impact on the earth's surface. Other points such as DMP 6, 7, 8 and 9 had relatively small deformations. These points were relatively far away from the mining operations area. This suggests that the blasting activities do have effect on the pillars established close to the mines.

7 Conclusions

GPS is a very useful tool that can be utilised for a wide range of scientific applications. This technology increases the accuracy, productivity, monitoring capability, rapidity and economy of surveys and it is often better than techniques in classical geodetic surveys. This research evaluated local area deformation monitoring using the static GPS technique in the Tarkwa area. The results show that the GPS is very reliable for earth surface crustal monitoring, due to the accuracy of 0.01 mm obtained.

Since the deformation values fluctuate from 0.00 to 19 mm it implies that structures within the area should be built away from the active mining sites or built with reinforced foundation so that they can withstand these deformation levels.

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