

**STUDIES OF DISPLACEMENTS OF GPS STATIONS ON
POLISH COPPER BASIN AREA****Alojzy Wasilewski¹, Zofia Rzepecka¹, Stanislaw Oszczak²***¹Institute of Geodesy**Warmia and Masuria University in Olsztyn**Fax: ++48 89 523 4768, e-mail: alekw@uwm.edu.pl**²Chair of Satellite Geodesy and Navigation**Warmia and Masuria University in Olsztyn**Fax: ++48 89 523 4768, e-mail: stan@uwm.edu.pl***Abstract**

Polish Copper Basin Area (LGOM) is located in the Southwest part of Poland. It covers an area of about 400 km², but indirect influences of mining activities are observed on much bigger area. Displacements of the terrain had been studied since early seventies, using classical surveying methods. In connection with growing range of deformations, there arose the need to carry the reference points out of the influenced area. To measure so long vectors it was necessary to take advantage of the GPS technique. In this work results of deformation studies performed on the terrain of LGOM using GPS are presented. Measurements from the years 1994 – 1998 were used for this purpose. We start with analysis of the reference points stability. Then displacement of each individual point was computed, studied and presented graphically. Up to now, the number of GPS stations is too small to perform analysis of terrain deformation, thus we close the paper with a proposal of arrangement of GPS points to provide a good basis for this task.

1. Introduction

The Polish Copper Basin (LGOM) is located in south-western part of Poland between two towns: Lubin and Glogow. It covers an area of about 400 km². Since the very beginning of mining activity in this area (i.e. since 1960) investigations and measurements aiming at discovering factors shaping the deformation of rock mass and terrain surface processes have been carried out there. On the basis of such a long observation period two kinds of influences of mining exploitation on the surface as well as on the rock mass can be distinguished there: direct, indirect and paraseismic.

Detailed analysis of levelling measurement results from the period of 1960-71 proved that there exists, in higher degree than it was expected, the indirect influence of the copper ore exploitation on the terrain surface caused by rock mass drainage. The vertical movements which followed the drainage process, began to extend and cover bigger area, considerably overrunning the area of the direct influences. Nowadays, all mining plants are within these influences, and even areas out of LGOM borders are also affected by the influences. The greatest subsidence, caused by direct influences, are located along Tertiary outcrops. It crosses the area of LGOM from NW to SE direction. The centers of troughs formed in these regions reach the maximum subsidence of 3000 mm (the state for September, 1999). Subsidence caused by indirect influences alone (East part of LGOM) range between 30 to 450 mm. Interpretation of the subsidence caused by direct and indirect influences was carried mainly on the basis of precise levelling measurements of the vertical network of second class established on this terrain specially for these purposes.

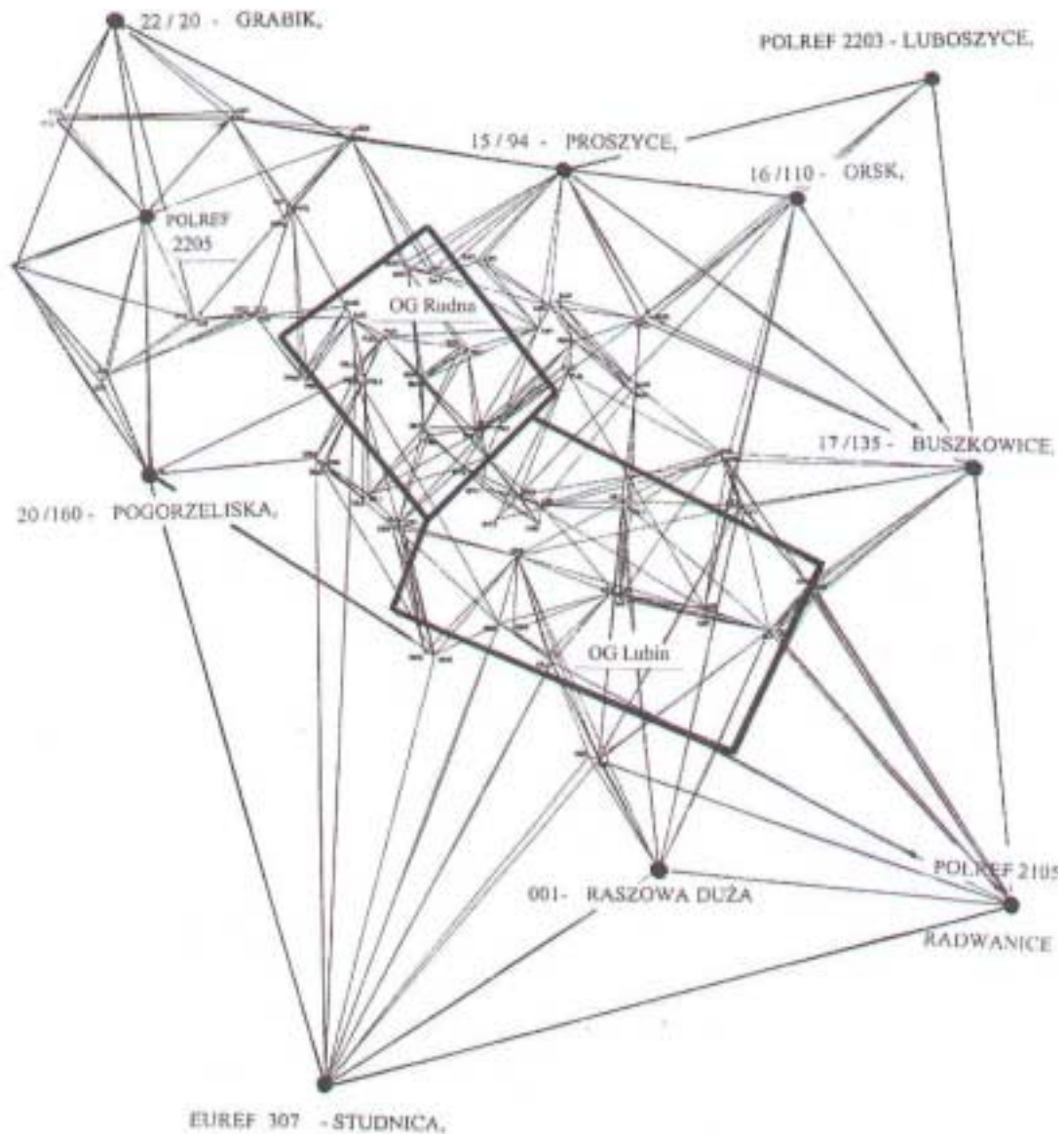


Fig. 1. Primary GPS Network

It is planned to apply GPS results to elaborate a model of deformation on the area of LGOM, taking advantage of the Finite Elements Method approach (Szostak-Chrzanowski, Chrzanowski, 1994). Using GPS technique it is possible to measure horizontal displacement of the ground surface. The FEM provides a powerful technique to study the deformational behaviour inside the mass rock.

In this work, two plants area was chosen for analysis – the division of Rudna and of that Lubin. Their approximate borders are marked in Fig. 1., on the background of the whole area of LGOM. At the area of interest the copper ore deposit is exploited using different systems of mining works, depending on geological conditions. Since the very beginning of mining activity, i.e. since 1975, the system with roof failure was initiated for the parts of the deposit located outside the protecting pillars. Also, the sedimentation system was used in this time. Current exploitation systems are given and analyzed in (Chrzanowski et al., 1999), shortly they can be summarized as:

- chamber pillar system with additional protection of the roof (R-UO),
- two-layers chamber pillar system with hydraulic filling (RG-5),
- picking of the deposit on the basis of splitting of the one-stage chamber pillar system with hydraulic filling,
- two-stage picking of the deposit, in resistance pillar of the excavations.

The system R-UO is currently the most often used. It is applied to the deposits of thickness of up to 7 m.

2. Methods of monitoring of exploitation effects

As it was mentioned, three kinds of influences of the mining exploitation on the surface as well as on the rock mass can be distinguished:

- **direct influences**, caused by displacement of the rocks towards the post-exploitation free space (filling it with breaking-down rock roofs), they are revealed with continuous deformations,
- **indirect influences**, caused by water escape (draining effects) from the rock mass what results in displacements and deformations of the ground, changes in water conditions in the region, changes of surface properties, etc.
- **paraseismic influences**, caused by mining tremors.

Since the very beginning of mining activity in this area (i.e. since 1960) investigations and measurements aiming at discovering factors shaping the deformation of rock mass and terrain surface processes have been carried out there. The main method for this monitoring is application of geodetic observations. The following geodetic networks are used for these purposes:

- local triangulation control network of LGOM,
- precise levelling networks,
- detailed networks at the mining area, in the form of observational lines and bench marks (ground and wall),
- GPS network,
- detailed classical horizontal and vertical networks of the postflotation reservoir „Zelazny Most“,
- detailed measurement network with its points located at individual shafts.

The local **horizontal triangulation network** of LGOM was established in 1973 and then extended in 1975. It consists of 42 points and covers an area of about 1600 km². Mean position error after adjustment amounts to 15 mm. Subsidence of its points, located within the borders of mining influences ranged from 7 to 30 mm/year. In 1995 it was measured with GPS technique and replaced with a new **GPS network**.

The **vertical network** of LGOM was established in early sixties, as a precise levelling network of II class. It was based on precise levelling polygons of I class. It was then extended, together with progression of mining works. Mean error of height determinations after adjustment amounts to 0.8 to 1.2 mm/km. Due to accuracy and economic reasons, since 1992 the vertical network is tied to stable benchmarks situated at shaft bottoms. This is accomplished with transfer of height from the bottom to the ground, using high precision EDM's. In 1993, after the heights were transferred using this method, also a precise levelling measurement was performed in reference to the ground points. Both sets of results were compared – the differences of computed heights ranged from 0.9 to 2.4 mm, it is a sufficient accuracy for these purposes.

The **detailed networks** at the mining area, in the form of observational lines, were established in 1975, around the town of Polkowice. It was caused by the fact that the exploitation started in the vicinity of the protecting pillar for this terrain, and even in the pillar itself. It was successively extended as the exploitation was spread out. Currently, the networks consist of about 39 km of lines in the form of horizontal control, and of 82 ground and 1150 wall benchmarks. Observations at the points are carried out three times per year at over-built area and two times per years at the protecting pillars, while the whole network is measured once a year.

In the region of **post-flotation reservoir** “Zelazny Most” a separate network was established. It has been observed since 1976. Since 1992 this network is tied to 5 GPS points. Nowadays it covers the full length of the dam (14.3-km).

The above geodetic observations are used, first of all, to determine direct influences. They may also be applied to monitor indirect influences. The paraseismic influences are recorded with 5 seismometers established in the town of Polkowice. This kind of influences has been observed since 1980.

3. GPS measurements and elaboration of their results

In 1992 the GPS technique was introduced as additional tool for deformation monitoring. New GPS network, that covers an area of about 1800 km², was established in 1994. It was an initiative of M.Sc. R. Kurpiński from Rudna Division. This is called the primary GPS control network (Fig. 1). Also some points of detailed geodetic networks, located in close vicinity of mining shafts, were included into GPS measurements. Since that time, the GPS measurements were carried out till 1998, once a year. In Fig. 1 the primary horizontal network is presented. The detailed GPS network is tied to the same tying points: 3 points of POLREF - Polish Integrated Primary Network (Baran, 1995) and 6 points of the I class of the Polish national control network.

To estimate horizontal displacements of GPS points, taking measurements from the period of 1994-98, the following computations were performed:

- adjustment of all baselines connecting the points used to tie the GPS networks to the Polish National System „65”; the adjustment was performed in the ETRF’89 system,
- adjustment of all measured vectors in particular years, in reference to the points obtained in the previous stage,
- re-computation of co-ordinates in the Polish „65” system of the tying points through *fitting-in-transformation*
- re-computation of co-ordinates in the Polish „65” system of all other points, using the co-ordinates obtained in the previous stage,
- analysis of accuracy,
- presentation of the results in numerical as well as graphical form.

In the adjustments, the average major semi-axes of the error ellipses ranged from 3 to 6 mm. It is possible to assume that in the stage of transformation the mean error was zero.

This procedure enabled:

- checking stability of the tying points,
- definition of a new local reference system of tying points, obtained on the basis of observations from all the years (1994-98),
- obtaining new co-ordinates of all measured points in the Polish „65” system, in reference to this system, in all particular years,
- elimination of co-ordinate deformations during transformation to the Polish system,
- comparison of the co-ordinates of the measured points, obtained in this period, in one homogenous reference system,
- under these conditions, it is possible to conclude that the obtained differences of co-ordinates determine the horizontal displacements of the GPS points.

169 points were admitted to the analysis, from the whole area of LGOM. It is a total number of points measured more than once with GPS technique. Most of them were measured in only two observational campaigns. In this paper we deal only with the Rudna division, thus results for only chosen GPS points are given.

For the purpose of providing evidence to all points measured with GPS a computer programme was elaborated. It gives a description, both numerical and graphical for each individual point included into GPS measurements (Chrzanowski et al., 1999).

4. Vertical displacements

Some of the geodetic points, belonging to the detailed networks at the mining area, in the form of observational lines, were also measured with GPS technique. The measurements were tied to the same control points, which were elaborated as in Chapter 3 of this paper. The points belonging to observational lines, were periodically leveled, once a year. The vertical tying was accomplished using the benchmarks located at shaft bottoms. For the purposes of performed analysis, we used chosen points, which were measured with GPS as well as with classical means.

In Table 1, the vertical displacements computed on the basis of both GPS and classical leveling are shown. These are data obtained for the years 1996-1997. Looking through the values given in the Table, it is possible to compare the values of subsidence for individual points obtained with GPS and classical leveling. The average difference between results from these techniques is about 18 mm. It is worth to notice that the precise leveling and GPS measurements were not performed at this same time. It can be concluded that determination of height changes using GPS technique, although less accurate than that from precise leveling, is sufficient for these purposes - since the differences are big enough.

Table 1. Comparison of values of subsidence obtained from GPS and precise levelling (years 1996-97) for chosen points

Point ID	ΔH GPS [m]	ΔH levelling [m]	Difference [m]
2272	- 0.083	-0.098	-0.015
M0S2	- 0.036	-0.026	0.010
2035	-0.015	-0.034	-0.019
2022	-0.046	-0.066	-0.020
2377	-0.084	-0.099	-0.015
0P24	-0.013	-0.053	-0.040
1524	-0.045	-0.052	-0.007
1531	- 0.047	-0.065	-0.018
0556	-0.037	-0.025	0.012
0650	-0.023	-0.055	-0.032
1920	-0.286	-0.308	-0.022
1936	-0.455	-0.447	-0.002
2398	-0.411	-0.392	0.019
2195	-0.107	-0.084	0.023

Besides the points given in Table 1, there were also found some points measured with GPS, which showed uplifts – not subsidence. For these points we do not have at our disposal results from precise leveling, thus it was not possible to verify the results. Most of uplifted points are located at protecting pillars, around the edges of deep troughs (see Fig. 2). The uplifts determined with GPS technique reach the value of 6 cm. It seems that the phenomenon of uplift is the reaction of the mass rock on the great subsidence in the neighboring troughs.

GPS observations were performed at chosen points belonging to observational lines as well as at some points located in close vicinity of Rudna and Lubin shafts. A chosen area with GPS points location is given in Fig. 2 and Fig. 3. Besides GPS points, there are also given horizontal displacements (in scale 1:1) on the background of subsidence isolines obtained from the precise leveling, in the period of 1992-96.



Fig. 2. Example part of LGOM area with GPS Points (Lubin Division)

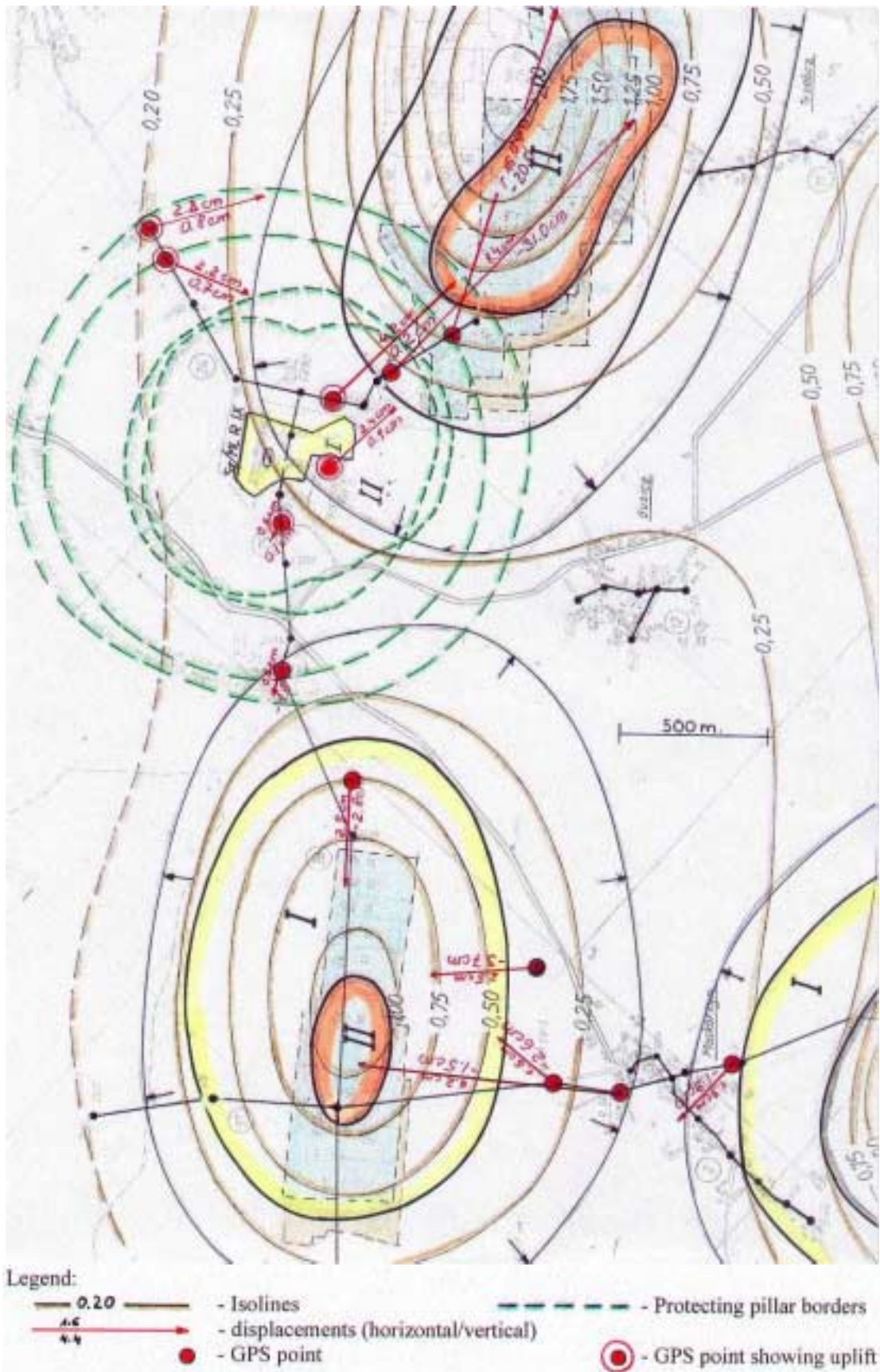


Fig. 3. Example part of LGOM area with GPS Points (Rudna Division)

5. Horizontal displacements

Analyzing the horizontal displacements obtained from GPS measurements it can be seen that horizontal displacements are directed to the centers of the subsidence troughs. Points located on the protecting pillars do also change their horizontal position, but in much smaller degree. During this period, the horizontal displacements range in Rudna division from 2 to 14 cm. Also, the ratio between the values of horizontal displacements and that of the subsidence/uplift (independently) was analyzed ($\Delta P / \Delta h$, where both ΔP and Δh - on the basis of GPS). The obtained values do not show any stability (see Fig. 2 and Fig. 3). Looking through the given plots it can be seen that in the case of subsidence (total number of points: 63 – Rudna and 28 - Lubin):

- ratio between 0.0 to 0.5 was obtained for 44% (Rudna) and 0% (Lubin) of analyzed points,
- ratio between 0.5 to 1.0 – for 22% (Rudna) and 0% (Lubin) of analyzed points,
- ratio between 1 to 3 – for 22% (Rudna) and 31% (Lubin) of analyzed points,
- ratio greater than 3 – for 12% (Rudna) and 47% (Lubin) of analyzed points.

In the case of uplift (total number of 34 – Rudna and 7 – Lubin points):

- ratio between 0.0 to 0.5 was obtained for 35% (Rudna) and 0% (Lubin) of analyzed points,
- ratio between 0.5 to 1.0 – for 29% (Rudna) and 0% (Lubin) of analyzed points,
- ratio between 1 to 3 – for 18% (Rudna) and 3% (Lubin) of analyzed points,
- ratio greater than 3 – for 18% (Rudna) and 19% (Lubin) of analyzed points.

There is big discrepancy in obtained values, perhaps the period taken to analysis was too short. Also, differences between percents obtained for Rudna and Lubin are due to unequal number of points at these two divisions.

6. Practical remarks

As it has already been mentioned, the vertical displacements were determined on the basis of precise leveling of points belonging to the observational lines. Having these results it was possible to elaborate maps showing terrain deformations in the shape of isolines (see Fig. 2 and 3). The maps do not contain any information on horizontal displacements. The full information on behavior of the points belonging to observational lines (both vertical and horizontal displacements determined at the same time) can be provided by GPS technique. Arrangement of points on observational lines does not guarantee true determination of terrain deformation. The number of points should be greater.

To provide a proper basis for deformation analysis the points should be completed as follows:

- additional chosen points of observational lines,
- additional points located over the protecting pillars,
- points located around individual troughs, along their edges.

The conclusion can be derived that such studies should be carried out for a longer time span, performing measurements once a year. It is planned to organize such campaigns in future. GPS observations should be performed according to local requirements, but at least once a year.

7. Conclusions

1. GPS technique provides a very powerful tool for deformation and displacement (both vertical and horizontal) monitoring on such a terrain, which undergoes influences of mining activity.
2. GPS technique allows for choosing tying (control) points far outside the influenced region.
3. This technique is quick and not very expensive, it enables to measure the whole terrain of interest during one observational campaign lasting for only some days.
4. The obtained accuracy of GPS measurements using tripods, can be estimated for about 10 mm for horizontal and 20 mm for vertical displacement determinations.

5. To improve vertical determinations, the points having heights determined with precise leveling technique, should be used as vertical tying.
6. Monitoring of displacements and deformations would be quicker and more efficient if at least two permanent reference GPS stations would be established at this terrain, properly located to serve for the whole area of interest.

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