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Seasonal Change of the Bedrock Elevation at the Metsähovi Levelling Test Field

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***Abstract**. Observations at the Metsähovi levelling test field have been carried out since autumn 2000, earlier in spring and autumn, since summer 2003 every month. The test field consists of 21 bench marks, of which 16 in the bedrock. Fourteen bench marks fastened in the bedrock have been stable but two successive bench marks move even three millimetres compared to the others. There exists a strong correlation between the temperature of the bedrock and the elevation of these two bench marks.*

***Keywords:** precise levelling, bench mark, temperature of bedrock, vertical movement.*

1 Introduction

The reliability of the bench marks plays an important role in high precision surveying. The most reliable levelling bench marks are considered to be those fastened in the bedrock.

In Finland Lehmuskoski (1996) has investigated the stability of the precise levelling bench marks fastened in bedrock with the aid of three successive precise levellings. Väisälä (1967) has reported horizontal movements of bedrock in his tests measurements of the interference base line.

The Metsähovi levelling test field was established in autumn 2000 for studying digital levels (Takalo et al., 2001). The measurements in 2000–2002 revealed a remarkable vertical movement of one bedrock bench mark and the movement was dependent on ambient temperature (Lehmuskoski et al., 2003). Since summer 2003, we focused our measurements on the neighbourhood of the moving bench mark by adding four new bench marks around it and by starting regular monthly levellings. Soon we found that also one of the new bench marks, which situated 22 metres from the previously mentioned point, was moving in the same manner. Also we started temperature measurements of the bedrock near by the moving points. In addition, we extended the field of study by examining fractures of the bedrock with radar equipment.

The goal of this study is to outline more accurately the moving area and prove the thermal dependence of the movement. This report treats the results from June 2003 to December 2004 around the moving points.

2 Metsähovi levelling test field

The Metsähovi levelling test field consists of three legs and the field locates in the neighbourhood of the Metsähovi space geodetic station at 24.4°E and 60.2°N (Figure 1). The levelling routes of the test field go mainly along gravel roads. The total length of the test field is 0.98 kilometres and the maximum height difference between the bench marks is about nine metres. The surroundings of the levelling lines are partly forest and open landscape.

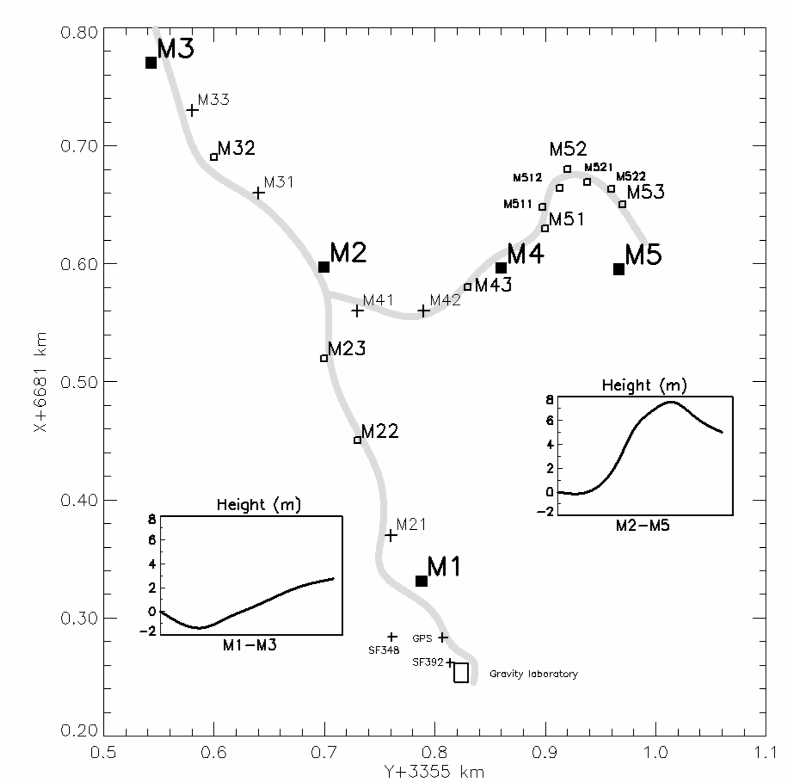

Figure 1. *The Metsähovi levelling test field. ■ = bench mark in bedrock, □ = lock bolt bench mark in bedrock, + = auxiliary bench mark in boulder or support. The coordinates are in the Finnish KKJ-system.*

The bench marks of the field are categorized into two classes: 1) Main bench marks, denoted by M1…M5, all five are in bedrock and 2) sixteen auxiliary bench marks, eleven of them are set in bedrock. The main bench marks are terminal marks for the lines and auxiliary points are used as rod supports. The bolts of the main bench marks are made of stainless steel, length 150 mm, diameter 22 mm and the head of the bolt is a ball with diameter 38 mm. Auxiliary points are lock bolts made of galvanized steel, length 80 mm, diameter

8 mm, and the diameter of the rounded head is 20 mm. Both types of bolts are set into a drilled hole with cement mortar (Figure 2).

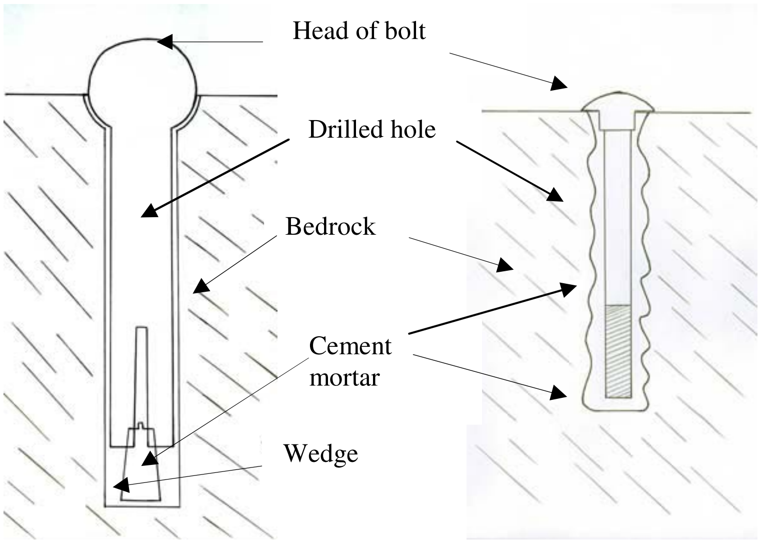

Figure 2. *a) Main bench mark bolt 1:2.* *b) Auxiliary lock bolt 1:2.*

In this report we consider only the line M4–M5, which contains the two moving points, M52 and M521 (Figure 3). The ground surface around the bench marks in the line M4–M5 is as follows: M4 and M5 are surrounded by some few trees and low vegetation, M51, M511, M512 and M522 partly bare rock and moss, M52, M521 and M53 bare rock.

In spring 2004 the four points network (M512A, M52A, M521A, M54) (Figure 4) was established to control horizontal movements of the critical area. The bench marks M512A, M52A and M521A are approximately at one meter distance from the levelling points M512, M52 and M521, respectively.

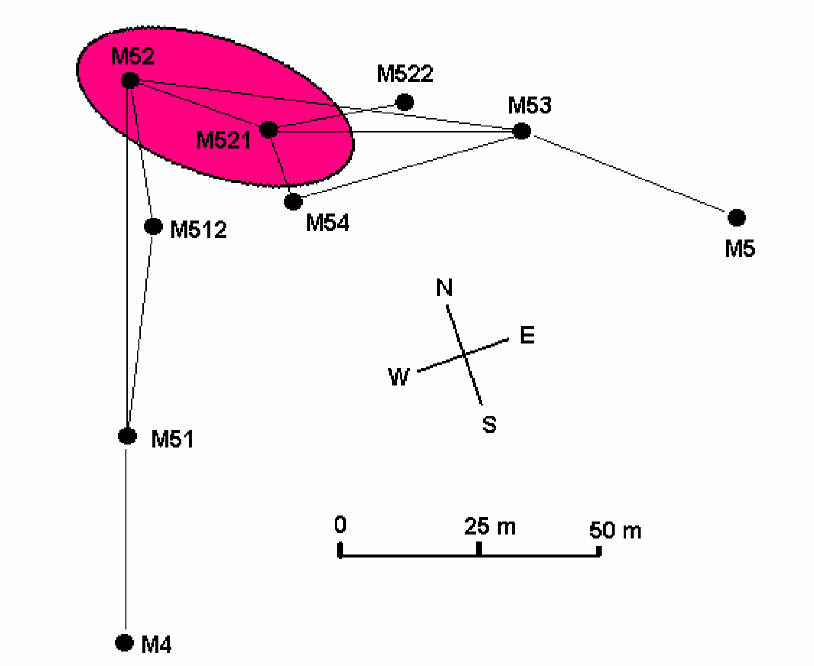

Figure 3. *Configuration of the bench marks in the line M4–M5 and the measured intervals. The critical, i.e., the most moving area is marked with a circle.*

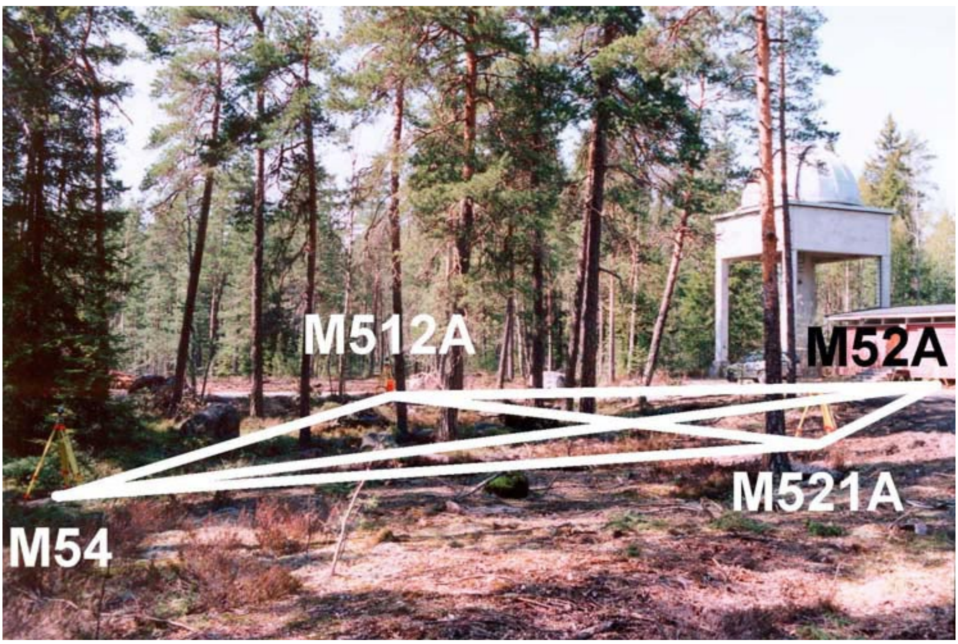

Figure 4. *The four-points network for horizontal measurements in Metsähovi. (Photo Jorma Jokela).*

3 Measurements

Levellings

The digital levelling system Zeiss DiNi12 with 3 m Nedo LD13 bar code invar rods was used in the test field measurements. Air and bedrock temperature and temperature difference between 2.5 m and 0.5 m above the ground were measured with a Fluke 54 II two-channel thermometer.

The sight lengths from the instrument to the rods were observed with the distance meter of the digital level. In the line M4–M5 the maximum sight length was 38 m and the minimum 6.5 m. All sighting lines between instrument and rods ran more than 0.7 m above sandy or gravel road. According to our studies the change of ambient temperature affects on collimation of the digital level, app. 1.3”/°C (Takalo et al. 2001). But, before every levelling, also in wintertime, we have determined the collimation error of the digital level and taken it into account. In addition, at each set up the sight lengths from instrument to the back and fore rod were equal in average within 30 cm. Thus, the effect of ambient temperature to the levelling result is not significant.

The thermometer Fluke 54 II was put up close to the bench mark M4 or M52. Air temperature was automatically recorded every minute. After the levelling sequence the temperature of the bedrock was measured in the bottom of a 40 cm deep borehole just beside the bench mark M52.

Horizontal measurements

In the four-points network (M512A, M52A, M521A, M54) all horizontal and vertical angles and slope distances were repeatedly measured with a precision tacheometer Leica TC2003 (no. 439351). Two Leica GPH1P precision prism reflector equipments were used. An essential tool in centring all the instruments was an automatic nadir plummet Wild NL (no. 95685); the laser plummet of the tacheometer or optical plummets of prism carriers were not used. This reduces uncertainty in centrings to tenth-of-millimetre level. Furthermore, between observation sets forced-centring method was not used, but centring and adjusting were always repeated using different instrument heights. These heights were measured with a tape. Air temperature and pressure were measured with calibrated psychrometers and aneroids.

The measurements were computed with a least squares 3D-adjustment program in an arbitrary local coordinate system. Equal (unit) weight was used for every observed horizontal direction, and weights for observed distances (equal for all) were relative to this. For vertical angles smaller weights (equal for all) were used, due to uncertainty in measuring instrument heights.

In 2004, five measurements were performed: on May 5–6, May 11, June 10, July 14 and August 27. Standard errors of unit weight from five adjustments were ±0.6 to ±1.0 mgon, and maximum residuals 0.7 to 1.6 mgon for horizontal directions, 5.0 to 9.3 mgon for vertical angles and 0.3 to 0.4 mm for reduced distances. Standard uncertainties of adjusted coordinates were ±0.1 to ±0.3 mm in horizontal position and ±0.2 to ±0.5 mm in height. These coordinates were used to compute the final results, angles, distances and height differences.

4 Results

Levellings

The levelling results are given in Table 1.

Table 1. *Changes of the height differences in mm in interval M4–M5 of the Metsähovi Levelling Test Field during 8.5.2003–1.12.2004. Bedrock temperatures were observed from borehole close to the point M52.*

Interval	1	2	3	4	5	6	7	8	9	10	11	Temp.
Date												(°C)
08.05.03	**1875.30**			**796.49**						**–1235.51**	**–1300.14**	
10.06.03	0.14	**382.15**	**414.81**	0.47	**–278.69**			**–354.05**	**–957.52**	–0.70	0.41	
16.07.03	0.36	–0.36	1.90	2.01	–0.51			–1.37	–1.51	–2.72	0.64	23.7
05.08.03	0.53	–0.59	1.84	1.73	–0.39			–1.47	–1.69	–2.77	0.88	23.1
14.08.03	0.53	–0.58	1.10	1.00	–0.15			–0.97	–1.13	–1.99	0.78	20.0
29.08.03	0.40	–0.58	0.45	0.33	0.07			–0.46	–0.60	–1.23	0.77	15.8
16.09.03	0.23	–0.54	0.12	0.05	0.16			–0.14	–0.31	–0.85	0.77	13.5
30.09.03	0.37	–0.37	–0.35	–0.25	0.24			0.17	0.08	–0.37	0.53	10.0
23.10.03	0.05	–	–	–0.69	0.12			–	0.93	0.35	0.39	1.0
06.11.03	–0.01	–0.16	–0.75	–0.44	0.10			–	0.74	0.14	0.20	6.0
28.11.03	–0.13	–0.06	–0.92	–0.51	0.03			–	0.98	0.31	0.06	2.4
11.12.03	–0.03	–0.01	–1.14	–0.68	0.03			–	1.18	0.51	0.00	0.6
13.01.04	0.17	–0.01	–1.36	–0.89	0.11			–	1.30	0.71	–0.13	–1.8
13.02.04	0.20	0.03	–1.38	–0.88	0.12			–	1.32	0.74	–0.29	–0.9
16.03.04	0.31	0.17	–1.40	–0.76	0.09			–	1.33	0.72	–0.46	0.0
16.04.04	–0.05	0.21	–0.92	–0.24	–0.17			–	1.20	0.33	–0.07	5.8
30.04.04	0.08	0.21	–0.81	–0.14	–0.09	**–849.71**	**–106.90**	–	0.92	0.13	–0.07	7.4
14.05.04	0.19	0.10	–0.47	0.10	–0.16	–0.34	0.04	–	0.62	–0.24	0.35	10.6
28.05.04	0.22	0.05	–0.24	0.28	–0.04	–0.62	–0.03	–	0.28	–0.46	0.38	13.9
10.06.04	0.19	–0.08	–0.01	0.38	–0.14	–0.82	–0.02	–	0.08	–0.76	0.41	15.0
30.06.04	0.16	–0.22	0.57	0.83	–0.24	–1.29	–0.06	–0.35	–0.43	–1.37	0.47	16.0
14.07.04	–0.04	–0.38	0.82	0.91	–0.15	–1.62	–0.17	–0.69	–0.87	–1.72	0.74	17.2
03.08.04	–0.11	–0.64	1.96	1.79	–0.65	–2.25	–0.29	–1.32	–1.62	–2.96	1.06	19.9
30.08.04	0.06	–0.58	0.86	0.75	–0.16	–	–	–0.72	–0.96	–1.83	0.89	15.1
22.09.04	–0.11	–0.61	0.25	0.11	–0.01	–1.08	–0.26	–0.20	–0.42	–1.13	0.83	11.4
19.10.04	–0.13	–0.35	–0.59	–0.47	0.09	–0.29	–0.22	0.52	0.41	–0.19	0.54	5.8
01.12.04	–0.06	–0.03	–1.21	–0.77	0.11	0.34	–0.09	1.13	1.16	0.57	–0.04	–0.5

Key to columns and notations of the Table1: Intervals and their levelled length: 1 = M4–M51 (54 m), 2 = M51–M512 (38 m), 3 = M512–M52 (22 m), 4 = M51–M52 (60 m), 5 = M52–M521 (22 m), 6 = M521–M54 (13 m), 7 = M54–M53 (41 m), 8 = M521–M522 (21 m), 9 = M521–M53 (41 m), 10 = M52–M53 (61 m) and 11 = M53–M5 (76 m); 1875,30 = initial height difference of interval in mm and used as reference for calculating change values in time series;
Temp. = Temperature of the bedrock.

The following corrections for the rod readings were taken into account: refraction correction with the Kukkamäki formula (Hytönen, 1967), rod correction (Takalo, 1985), tidal correction (Heikkinen, 1978) and zero point correction for the rod pairs. Before mentioned corrections are included to the values in Table 1, but the role of them is small, less than 0.08 mm for the longest interval M53–M5 and only 0.007 mm when we treat the most moving intervals

M512–M52 and M521–M53. The rod calibrations and the zero point determinations were carried out in May and in November 2003 and 2004 using the FGI rod comparator (Takalo, 1999). Since 23.10.2003, occasionally there were log piles covering bench marks M511, M512 or M522 and therefore some observations are missing as shown in Table 1.

The levellings in 2000–2002 (Lehmuskoski et al., 2003) showed that vertical movements of the bench marks compared to the previous reference M2 were within 0.5 mm, except the bench mark M52, where the movement was app. two millimetres. One of the four new bench marks established in summer 2003, M521, moves similarly as M52 (Figures 5 and 6). The vertical movement of M52 is even more than three millimetres compared to our new reference M4. The thermal dependence of the movement is clear as shown in Figure 5. Hence, the change in height is app. +0.12 mm/°C for M52 (Table 1). This is clearly not caused by thermal expansion of the bedrock, because for example one metre thick layer of rock would expand app. 0.01 mm/°C. According to the Table 1 the movements of the M51, M511, M512, M54, M522, M53 and M5 stay within 0.5 mm as previously in 2000–2002 and they belong to the unmoving area (Figure 3). So the moving area is restricted by points M512 and M53.

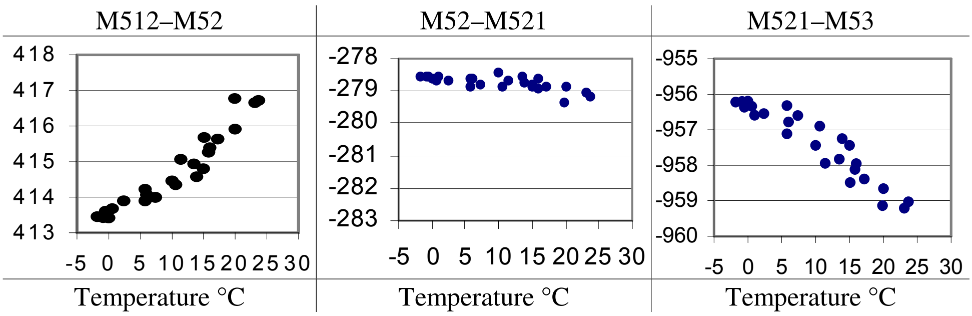

Figure 5. *The height difference of M512–M52, M52–M521 and M521–M53 in mm as a function of bedrock temperature.*

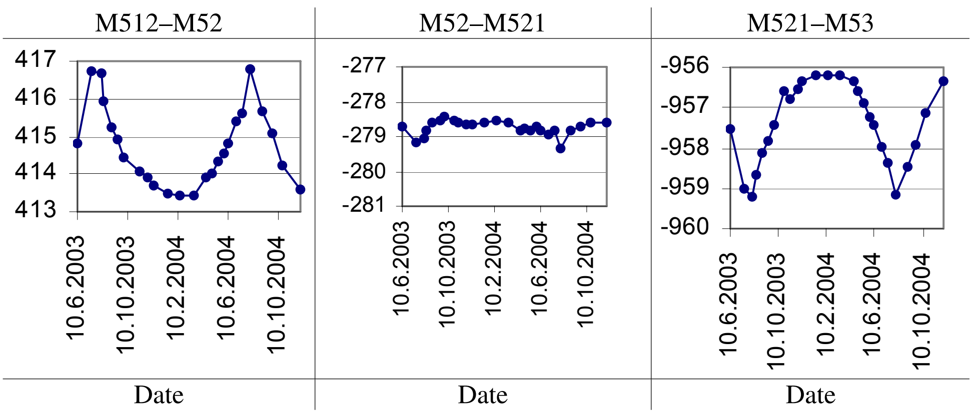

Figure 6. *Changes of the height differences of M512–M52, M52–M521 and M521–M53 since 10.6.2003 in mm.*

To analyse the movement of bedrock points, we select 1) the mean of two maximum absolute values of changes in height difference of intervals M512–M52, M51–M52, M52–M53 and M521–M53, which cross the border of moving area and 2) the values from interval M52–M521, inside the moving area and 3) values outside. The corresponding values (Table 1) are

$$\delta\Delta H_{1)} = 2.09 \text{ mm}, n_{1)} = 8$$
$$\delta\Delta H_{2)} = 0.16 \text{ mm}, n_{2)} = 25$$
$$\delta\Delta H_{3)} = 0.31 \text{ mm}, n_{3)} = 76.$$

Hence, we get differences for statistical tests

$$\text{Diff}_{1)-2)} = 1.93$$
$$\text{Diff}_{1)-3)} = 1.78$$

The standard uncertainty of Zeiss Dini12 levelling in the Metsähovi test field derived from the results of the whole test field measurements in 2001 (Takalo et al. 2001) is ±0.10 mm per interval of the test field and hence the uncertainty of the difference in Table 1 is $\pm 0.10\sqrt{2}$ mm = ±0.141 mm. Further for difference the uncertainty is

$$S_{\text{Diff}} = \pm 0.141\sqrt{2} \text{ mm} = \pm 0.20 \text{ mm}$$

To examine the significance of the bedrock movement of the critical area compared to the corresponding of the surroundings, we form the test hypothesis

H0: Diff = 0 and there is essentially no movement of the bedrock
H1: Diff ≠ 0 and there is essentially movement of the bedrock

Using the *t*-test with 95% confidence, we compute the statistical values

$$T_{1)-2)} = (\text{Diff}_{1)-2)} - 0) / \{S_{\text{DIFF}}\sqrt{(1/n_{1)} + 1/n_{2)})}\} = 23.7$$
$$T_{1)-3)} = (\text{Diff}_{1)-3)} - 0) / \{S_{\text{DIFF}}\sqrt{(1/n_{1)} + 1/n_{3)})}\} = 23.9$$

Because the both Student *t*-test values are larger than the critical values

$$T(10+2-2, p=0.05) = 1.7$$
$$T(35+2-2, p=0.05) = 1.6,$$

we can conclude that the movement of the bedrock in the critical area of the Metsähovi levelling test field is significant.

When we consider the intervals M512–M52, M51–M52 and M52–M53 crossing the unstable area (Figure 3), as function of temperature, the inclinations of the thermal dependences (Figure 5) are +0.131, –0.020 and –0.124 and their sum –0.013 and the correlation coefficients 0.98, 0.69 and 0.99, respectively. When we consider the changes of the height differences of the same intervals

(Table 1), they range from –0.31 mm to +0.19 mm and the mean change is –0.04 mm. Crossing the unstable area of the test field (Figure 3) proved that the "shore" bench marks M512 and M53 are stable.

Horizontal measurements

All horizontal variations during summer 2004 were within 0.6 mm; vertical variations are not comparable with levelling results. Considering uncertainty of the measurements, no horizontal benchmark movement can be proved. However, the exhaustive measurements and good repeatability ensure that if millimetre-level movements occur, they will be discovered.

5 Structure of the bedrock

To find an explanation for the vertical movement of the bedrock and its thermal dependence, the whole test field was investigated using a Ramac Ground Penetrating Radar with 500 Mhz frequency in April 2003 (Figure 7).

Figure 7. *Ramac Ground Penetrating Radar in use.*

The surface of the bedrock around the bench mark M52 seems unbroken but the radar image reveals that there are several fractures under the surface (Figure 8). In summer 2004 the area around the moving points M52 and M521 was investigated in more details using the ground penetrating radar. Observations revealed the block construction of bedrock and some contours of its borders (Figure 9).

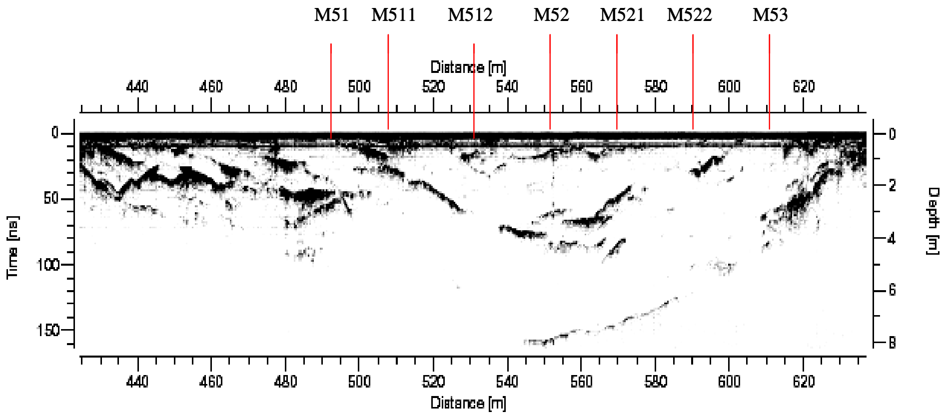

Figure 8. *Structure profile of the bedrock around bench mark M52. The fractures are shown by dark smudges.*

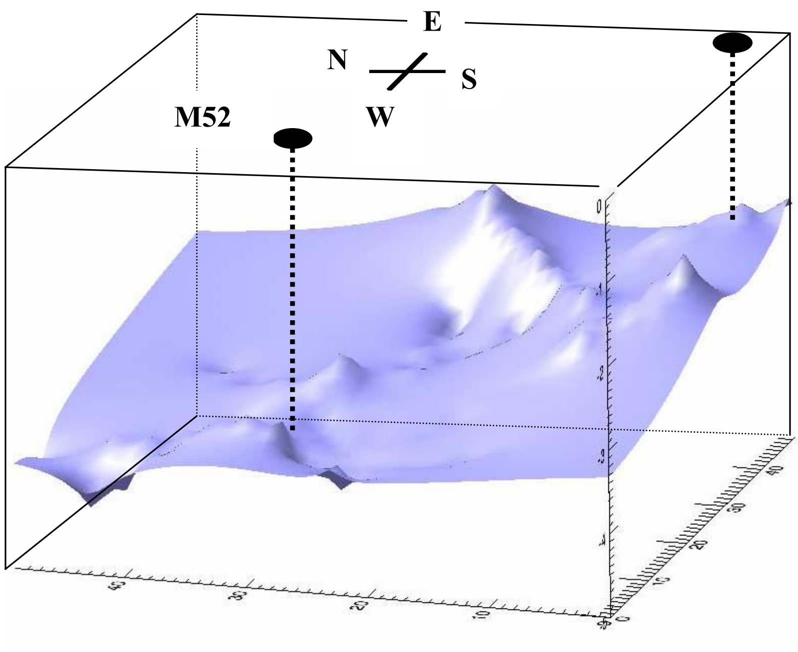

Figure 9. *Bottom surface of the bedrock block around the critical area of the test field.*

Some cross section profiles reveal that the shape of block is wedge-like in SE–NW direction and slightly wedge-like in SW–NE direction. A rough estimate of the dimensions of the block is:

– volume 1,200–2,400 m^3
– width 20 m
– length 30 m
– thickness 2–4 m.

6 Summary

In the Metsähovi test field there exists a clear seasonal vertical movement of the two bedrock bench marks. This phenomenon is strongly correlated with the temperature of the bedrock, but it is not directly due to vertical thermal expansion of the bedrock nor the bolts. There are some fractures in the bedrock a few meters below the surface. So far according to the knowledge on hand we are not able to explain their effect. In order to understand better the mechanism in the bedrock, more ground penetrating radar observations are needed. Also the horizontal angle and distance measurements of the bench marks will be carried out simultaneously with the vertical control.

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