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Control and deformation surveys at the Slumgullion Slide, Hinsdale County, Colorado--a progress report

By

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ABSTRACT

In 1990 control surveys of the Slumgullion Slide, southwestern Colorado, were initiated in support of renewed geologic studies of the area. Aerial photographs taken in 1985 and 1990 were used to produce large-scale (1:1,000) topographic maps and digital elevation models needed for geologic studies of the mechanics of slide activity. In 1991 and 1992 the survey network was expanded in order to monitor movements and deformations of the slide. Preliminary results of level and triangulation surveys below the toe of the active part of the landslide in 1991 and 1992 indicate that measurable deformation is occurring in areas previously thought to be stable.

INTRODUCTION

The Slumgullion Slide[1], located about 7 km southeast of Lake City, in southwestern Colorado, is a world-renowned example of an earthflow. This report describes field survey activities from 1990 through 1992, which were performed to support geologic studies of this landslide. Triangulation-trilateration surveys were performed in July and August 1990 to control the production of detailed topographic maps from aerial photographs taken in August 1985 and August 1990. In 1991 and 1992 additional triangulation and leveling stations were added to monitor slide movement and deformation, especially near the toe of the active portion of the slide.

In 1985, the U.S. Geological Survey was offered the opportunity to share in the results of aerial photography of the Slumgullion landslide to be done under contract to the Colorado Geological Survey. Prior to this photography, a series of points was established around the periphery of the slide, marked with wood stakes, and flagged with plastic aerial target panels to serve as ground control. The criteria for placing these targets were (1) that they be on ground thought to be stable, (2) that they be visible from the air, and (3) that they be distributed over the length of the slide. No consideration was given to the intervisibility of the points and no attempt was made to determine the positions of the control points at that time. The photography was flown August 29, 1985, at a scale of 1:12,000.

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[1] "Slumgullion Slide" is the approved geographic name appearing on official maps.

In 1990, the U.S. Geological Survey renewed geological investigations of the Slumgullion landslide. Prior to new photography being flown, a new system of horizontal and vertical control was established, and many of the points established in 1985 were tied into this new network. The photography was flown on August 25, 1990, at scales of 1:6,000 and 1:14,000.

Two sets of detailed topographic maps (scale 1:1,000) and digital elevation models were produced from the aerial photography. The first set of maps, from the 1990 photography, was produced by the U.S. Geological Survey Plotter Laboratory in 1991. The second set of maps, from the 1985 photography, and both digital elevation models were produced by CompuSyst Inc., of Englewood, Colo., in 1992.

CONTROL SURVEYS

Primary triangulation points are those which have been occupied with theodolite, electronic distance measurement (EDM) instrument, and reflecting prism(s), and whose positions have been calculated and adjusted through the network of triangles or quadrilaterals. Secondary triangulation points are those which have been occupied with prism only, or that were located through an open-ended traverse. Points in the primary triangulation network are generally marked with 18- or 24-inch-long copper-clad steel stakes with 1.5-inch-diameter brass heads, usually driven slightly below the surface and hidden from public view. A punch mark indicates the station. The locations of the primary and secondary control points are shown in figure 1 and listed in table 1, with reference to the local coordinate system.

A local coordinate system was necessary to produce detailed topographic maps from the aerial photographs and to provide a common frame of reference for other studies of the slide. The local coordinate system is a Cartesian north (y) - east (x) - elevation (z) system with coordinates given in meters. Local north agrees approximately with geodetic north. The station at Windy Point Overlook (WINDY), which offers an excellent view of most of the slide, was assigned coordinates of 10,000.000 N; 10,000.000 E. Coordinates (N, E) in this local system are calculated as sea-level positions. Elevations were tied to the U.S. Coast and Geodetic Survey (USC&GS, currently the National Geodetic Survey) second-order level line along State Highway 149, using bench marks G169 (elev. 3085.511 m, 10123 ft) and H169 (elev. 2943.821 m, 9658 ft) (fig. 1). This level line was established in 1934. An attempt was made in 1990 to orient the local system accurately with respect to geodetic north. The theodolite was set up at USC&GS first-order station SLUMGULLION, located on a 3722-m (12,210-ft) peak about 3 km SSE of the slide (fig. 1), with the intent to turn an angle from the azimuth mark to WINDY. Unfortunately, the azimuth mark was not found despite a diligent search conducted according to the published description. Accurate orientation of the local coordinate system is desirable prior to project completion, but this activity is currently of low priority. Angles were turned at SLUMGULLION to other stations in the network and a distance measurement was made from WINDY to SLUMGULLION. The local

1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10 000
FEET
1 .5 0 1
MILES
1 .5 0 KILOMETERS 1 2
1000 0 METERS 1000 2000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

38°00′ N.

107°15′ W.

Compiled from U.S. Geological Survey 7.5' quadrangles Lake City, Cannibal Plateau, Lake San Cristobal, and Slumgullion Pass.

Figure 1. Topographic map of the Slumgullion Slide and vicinity, Colorado, showing location of triangulation stations used in this study.

Table 1. Coordinates of control stations

PRIMARY TRIANGULATION STATIONS
(Occupied with theodolite, distance meter, and prisms)

Station	Description	North	East	Elev.
CROWN EAST 1	Wood stake	12270.90	10489.87	3718.32
CROWN WEST	Metal stake	12458.25	10146.59	3740.85
FAN	Metal stake	9239.53	5582.37	2762.19
LEVEE (1992)	Rebar w/ Al cap	10497.74	7720.75	3001.26
ROAD	Metal stake	10028.89	5162.87	2889.43
SWITCH	Metal stake	9404.72	6700.43	3003.33
TRES	Metal stake	10341.42	5310.66	2742.92
TWIN	Metal stake	10670.53	6618.67	3008.62
WINDY	Metal stake	10000.00	10000.00	3328.24

SECONDARY TRIANGULATION STATIONS
(Usually occupied with prisms only)

BOB	Wood stake	11495.56	8505.50	3265.19
CABIN[1]	NW end roof ridge	8724.98	5572.52	2746.21
CROWN EAST 2	Metal stake	12271.07	10489.90	3718.36
FLASH	Wood stake	12076.64	11430.73	3661.14
PARK (1992)	Rebar w/ Al cap	10037.09	8149.70	3073.30
REFLECTOR	Wood stake	10030.44	8378.59	3081.82
ROAD A	Wood stake	10019.38	5125.77	2901.74
SADDLE	Rebar w/ Al cap	10858.93	8858.00	3198.
SWITCH CROSS	Wood stake	9360.51	6709.53	3002.88
WINDY NAIL	Nail and washer	9996.61	10008.00	3328.65
T3	Wood stake	11659.88	11020.60	3531.91
T3A	Wood stake	11545.80	10902.62	3531.58
T4	Wood stake	11173.24	9964.07	3423.25
T5	Wood stake	11889.36	9913.17	3524.63
T12	Wood stake	10011.33	8562.24	3084.93
T16	Wood stake	9979.45	7258.95	2943.69

[1] Not occupied, located by intersection.

system was oriented using an azimuth from SLUMGULLION to WINDY of 357.5°, measured on the topographic map. We estimate that local north is within 1° of true north.

SURVEYS BELOW THE ACTIVE TOE, 1991-1992

Introduction

When geological surveys of the Slumgullion earthflow were renewed by the U.S. Geological Survey in 1990, after a lapse of many years, attention was focused on the upper, active part of the landslide. The part below the active toe has been assumed to be stable, for there are no obvious signs of significant movement shown at the ground surface, such as major cracks in the highway that crosses the slide below the active toe. However, there has been no direct measurement, so far as we know, that would confirm that the inactive part of the landslide is indeed not moving.

There has been ever-increasing use of Lake San Cristobal as a major recreation area in southwest Colorado. This required that part of the Survey's effort should be placed on establishing the stability of the lower part of the landslide, which dammed the Lake Fork of the Gunnison River some 700 years ago and formed the lake. Two aspects of this appraisal are being pursued: (1) examination of the landslide dam and its environments, and (2) monitoring of the inactive part of the landslide for possible movement. This progress report concerns only the second item.

Description of the work:

The simplest and most precise method of detecting movement, although in a vertical sense only, is by leveling. So, in 1991, the elevations of 21 permanent level stations in seven closed circuits were determined relative to USC&GS Bench Mark H169, which is also on the inactive part of the landslide near Highway 149 (pl. 1). In order to reveal possible movements of BM H169, four permanent stations (TP70, TP73, TP77, and TP79, pl. 1) were placed in closed level circuits extending from BM H169 along the highway where it leaves the landslide and heads southwest. At least two of these four points are well off the old landslide.

When level circuits (blue, red, and black circuits, pl. 1) in front of the active toe were rerun in May of 1992, it was found that vertical movements in excess of the probable observational error of ±2 mm had occurred at almost all stations. With a few exceptions, the movement was down--as much as 20 mm immediately in front of the raveling front of the active toe and 5-10 mm at stations as much as 150 m away from the toe.

Although the vertical movements are small, their presence over a wide area, and their general decrease away from the toe indicated possible effects from surcharge by the active toe. This toe is a steep front about 30 m high that advances about 1 m per year. Whether the vertical movements are due only to consolidation of the underlying material, to elastic or plastic deformation, or to shrink-swell of expansive soils remains uncertain. In any event, a determination of possible horizontal movements obviously was required.

Horizontal movements are much more difficult to measure than vertical movements, especially in the wooded terrain of the old slide. Triangulation with a large net of closely spaced triangles is here impossible without major deforestation or erection of towers. We elected to pursue two courses. The first was to lay out small triangles or quadrilaterals 25 to 75 m on a side, in front of the active toe and in places where it was practical to clear lines of sight without removing large trees or doing major trimming. These areas of precise survey form large strain sensors and are to be resurveyed at appropriate intervals and also tied to the main overall triangulation net, where possible. The second course of action was to run precise closed electronic distance measurement (EDM) traverses over the level lines, to tie these to the main triangulation net, and to resurvey these traverses at intervals.

Considerable progress has been made on the programs, both of leveling and of placing horizontal control. Listed below are some of the tasks completed or underway, as of October 1992, including some work related to surveys on the active slide.

1. The blue, red, and black level circuits and the green circuit from BM H169, extending along the highway toward triangulation station SWITCH, have been resurveyed after the passage of one year (July 1991-May 1992). Location of the circuits and the changes in elevation are shown on plate 1 and in tables 2, 3, 4, and 5.

2. Leveling at the quadrilateral at POND has been done and repeated after a lapse of about 2 months (May-July 1992). The differences in elevation relative to TP14 are shown on plate 1. All four stations moved up between 1.0 and 2.6 mm relative to TP14 between May and July 1992. TP14 appears to have moved up 2.0 mm between July 1991 and May 1992.

3. Leveling at the quadrilateral near BM H169 and TP1 has been done once in closed circuit and partially repeated (May-July 1992, see fig. 2).

4. Leveling during 1992 in the triangles near TP30 was completed once and parts repeated after about 2 months (May-July 1992, see fig. 3).

Table 2. Blue leveling circuit elevation differences, 1991-1992.

Station	Cumulative number of setups from TP1	Corr. Elev. (m) 1991	Corr. Elev. (m) 1992	Difference (m) 1992-1991
BM H169	0	2943.821	2943.821	0.
TP1	0	2945.48813	2945.48498	-0.00315
TP2	1	2947.34499	2947.33899	-0.00600
TP5	4	2956.30744	2936.30253	-0.00491
TP6	6	2959.63862	2959.63300	-0.00562
TP7	7	2962.09469	2962.12548	+0.03069
TP8	8	2964.39472	2964.38524	-0.00948
TP11	11	2969.43558	2969.42058	-0.01500
TP10	11	2969.87425	2969.86039	-0.01386
TP12	12	2969.24012	2969.23171	-0.00842
TP14	14	2966.17131	2966.17333	+0.00202
TP15	15	2964.39483	2964.38763	-0.00720
TP19	19	2954.59287	2954.58144	-0.01144
TP21B	22	2948.05344	2948.04649	-0.00695
TP1	24	2945.48813	2945.48498	-0.00315
		closure = -0.00075	closure = -0.00233	
		(for circuit TP1-TP14-TP1)		

Table 3. Red leveling circuit elevation differences, 1991-1992.

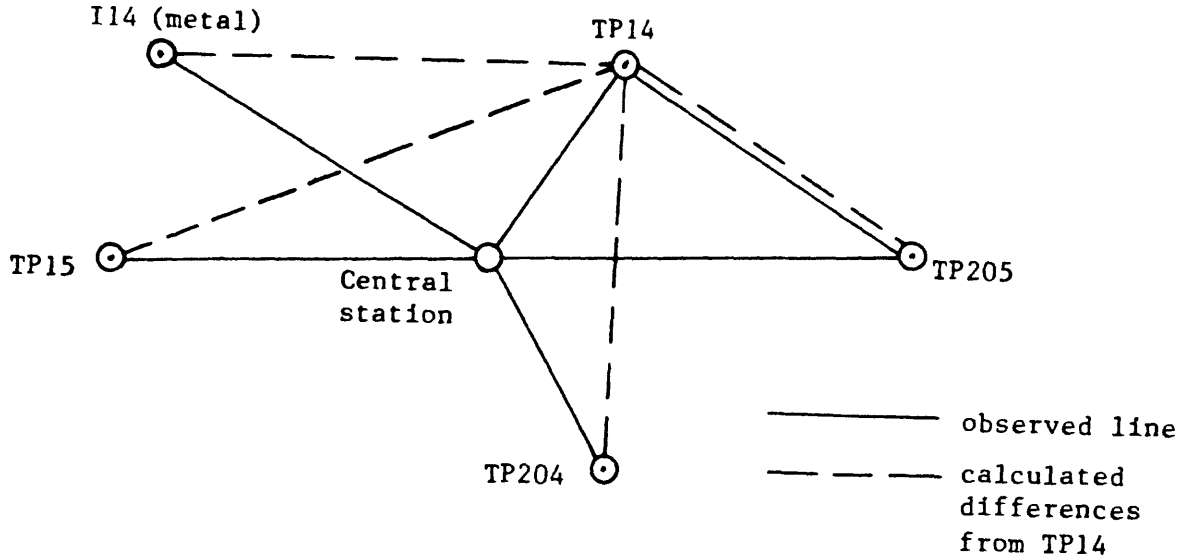
Station	Cumulative number of setups from TP14	Corr. Elev. (m) 1991	Corr. Elev. (m) 1992	Difference (m) 1992-1991
TP14	0	2966.17131	2966.17333	+0.00202
TP32	4	2977.75616	2977.73331	-0.02285
TP32A	5	2977.36667	2977.34782	-0.01885
TP30	5	2976.15574	2976.13558	-0.02016
TP31A	7	2980.04110	2980.02112	-0.01998
TP27	6	2975.97719	2975.96348	-0.01371
TP14	11	2966.17131	2966.17333	+0.00202
		closure = +0.00264	closure = -0.00249	
		(for circuit TP14-TP30-TP14)		

Table 4. Black leveling circuit elevation differences, 1991-1992.

Station	Cumulative number of setups from TP30	Corr. Elev. (m) 1991	Corr. Elev. (m) 1992	Difference (m) 1992-1991
TP30	0	2976.15574	2976.13558	-0.02016
TP27A	1	2975.88581	2975.87520	-0.01061
TP29	3	2981.18318	2981.15983	-0.02335
T13	4	2983.06505	2983.04259	-0.02246
TP60	4	2980.89843	2980.87778	-0.02065
TP61	4	2979.65952	2979.68654	+0.02702
TP62	4	2978.99844	2979.04017	+0.04173
TP30	5	2976.15574	2976.13558	-0.02016

Table 5. Green leveling circuit elevation differences, 1991-1992.

Station	Corr. Elev. (m) 1991	Corr. Elev. (m) 1992	Difference (m) 1992-1991
BM H169	2943.821	2943.821	Assumed stable
TP70	2944.31985	2944.32133	+0.00148
TP73	2951.91421	2951.92017	+0.00596
TP77	2963.21612	2963.22064	+0.00452
TP79	2967.20023	2967.20395	+0.00372
Culvert	2968.76541	2968.76672	+0.00131



Elevation differences with respect to TP14 (m)

	5/25/92	7/30/92	Change
TP15	-1.79780	-1.79629	+0.00151
TP204	+0.31057	+0.31225	+0.00168
TP205	+0.57893	+0.57993	+0.00100
I14	-0.19926	-0.19664	+0.00262

TP14 elevations: 2966.17131 m on 7/6/91,
2966.17333 m on 5/12/92,
based on elevation of BM H169 = 2943.821 m

Figure 3. Leveling at POND.

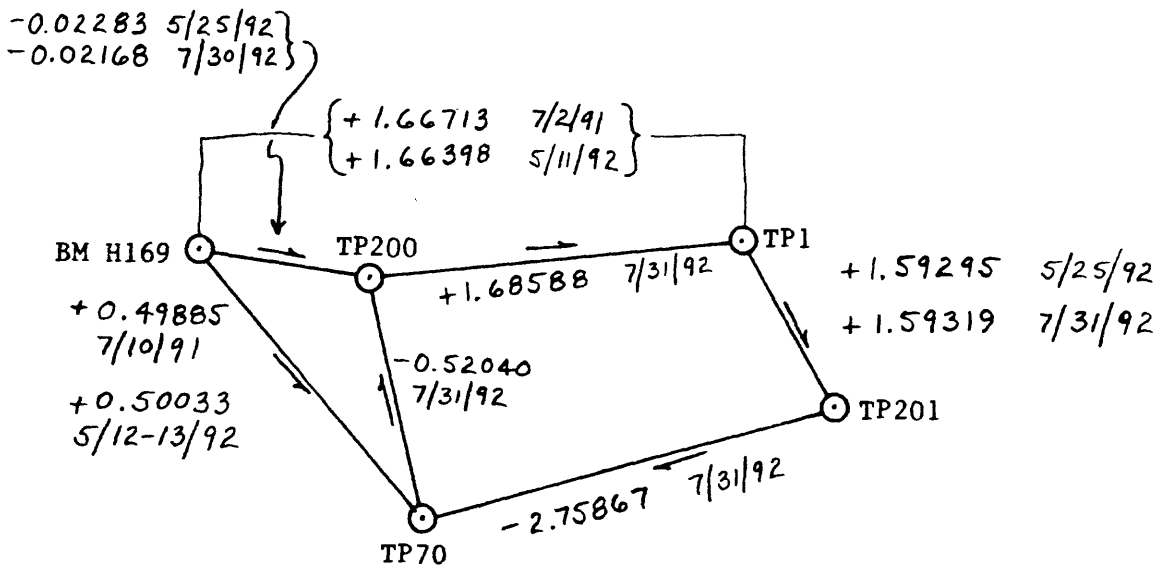


Figure 4. Leveling at quadrangle near BM H169 and TP1.

5. In quadrangle TWIN-TP200-TP70-TP79, all horizontal and vertical angles and side distances were observed and adjusted by computer program (Smith and Varnes, 1987). This has resulted in ties between the main triangulation net and TP200 and the adjacent quadrilateral TP70-TP200-TP1-TP201 (pl. 1). Also, the horizontal coordinates of level station TP79 (the farthest distant along Highway 149 southwest of BM H169) are now known within less than 1.5 cm.

6. Quad TP1-TP201-TP70-TP200 was laid out; all angles, sides, and diagonals measured once and adjusted.

7. For the figure TP14-TP205-TP204-TP15-I14 at POND (pl. 1, fig. 2), horizontal and vertical angles and distances were observed in May 1992 (except TP204 was not occupied owing to a hailstorm) and all adjusted by the computer program. Three stations were occupied in July 1992, including TP204.

8. The four triangles near TP30 were measured in May and remeasured in July 1992. The two surveys and their changes are shown graphically on figure 4.

9. New stable station PARK with local backsight was established along Highway 149 at the Slumgullion Earthflow Viewing Area, near the display board, and tied to the main net via TWIN. This was used for locating stations on the active slide.

10. New stable station SADDLE was established from PARK, from which others are repeatedly observing many stations on the middle reach of the active slide.

11. New stable station LEVEE with distant backsight was established on the northern old levee north of the northern edge of the active toe and tied to the main triangulation net via SWITCH (metal) (pl. 1).

12. A tentative tie from LEVEE to TP30 and the adjacent triangles was made so that they are now provisionally located and oriented.

13. A closed EDM traverse, TP200-TP14-TP200, was made for horizontal control along the blue level circuit (pl. 1) using the permanent level stations and setting new points. The circuit is about 900 m long and involves 18 angles and distances. It closed within 4 mm in distance and 2.25" in azimuth. The circuit is tied to TP200 and thus the main net, and is oriented via a distant backsight, thus relieving some of the necessity in the future for a signal at TWIN. This traverse also allows the quad at POND to be located and oriented relative to the main coordinate net.

14. A tie was made from the triangles near TP30 on the upper bench down to POND, that is, from TP32 to TP15 (pl. 1), thus orienting and provisionally locating the POND quadrilateral with reference to the overall coordinate system by a different route.

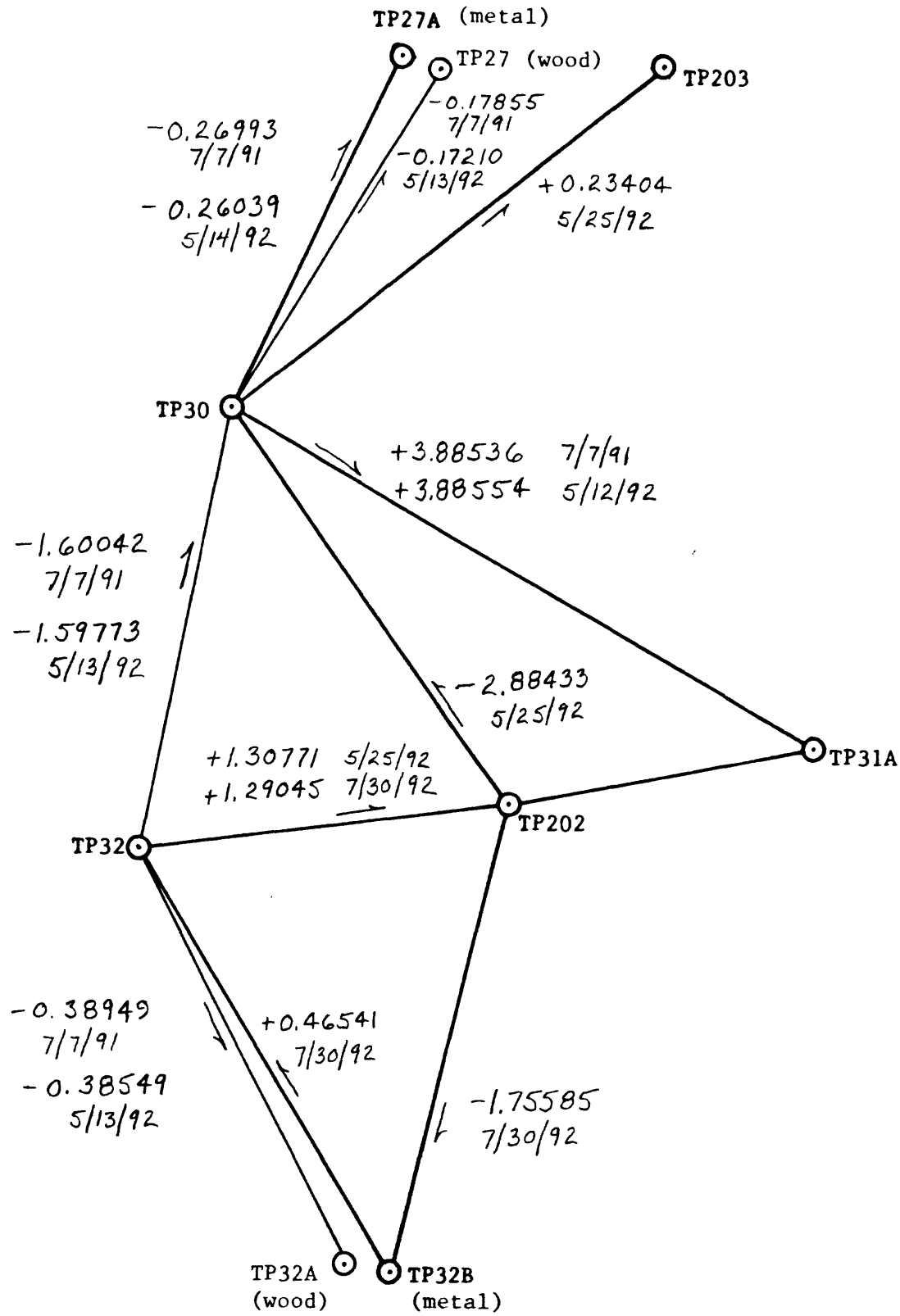


Figure 5. Leveling in triangles near TP30.

15. Horizontal N and E coordinates and elevations of all stations shown on figure 1 have been computed as of the last measurements prior to October 1992. These are summarized in tables 1 and 6.

Interpretation of results

Not much time has passed since the surveys were started and not enough repeat measurements have been made to allow definite and quantitative interpretations. Many of the EDM surveys made about 2 months apart may give more a measure of repeatability of the methods, or of seasonal effects, rather than of actual permanent change. However, some tentative interpretations can be made, as follows:

1. Leveling in front of the active toe indicates general depression with some evidence that the downward displacements decrease with distance from the toe.

2. All elevations are relative to BM H169 on the old slide. The stations along the highway off the old slide all went up. This suggests that BM H169 may be going down.

3. The second EDM survey of triangles in the area of TP30 shows some changes in 2 months that appear larger than our usual survey error (see fig. 5). These include an increase of 27.4" in the angle TP32-TP202-TP30, an increase in the distance TP202-TP31A of 6.5 mm, and a decrease in angle TP202-TP31A-TP30 of 31.0". The triangle TP30-TP31A-TP202 was not well observed during the first measurement, so the differences may not be entirely real. But there is a suggestion that TP202 is moving toward TP30 and that triangle TP32-TP202-TP32A is rotating counterclockwise relative to adjacent areas.

Suggestions for further study:

1. All level circuits should be remeasured, including all triangles and quadrilaterals and, in the blue circuit, the new stations placed at the time of the EDM traverse.

2. The ties from LEVEE to TP30 and from TP32 to TP15 should be redone using all Leica targets and prisms. There was a mix with old Lietz prisms and Leica prism-targets during the measurement, which may account for the calculated coordinates of TP15 via LEVEE and via the EDM traverse differing by 0.131 m in easting and 0.218 m in northing. The azimuth from TP15 to TP14 via the two routes agree very well, differing by only 0.00025 degree or 0.90 seconds.

3. A new primary triangulation station should be placed at area A (see pl. 1 about 170 m due west of TP15, and then the triangle SWITCH-TWIN-area A completely observed (all angles and sides).

Table 6. Summary of coordinates of permanent turning points and EDM traverse stations.

Station	Location or Series	North	East	Elevation
BM H169	Blue circuit			2943.821(00)
TP1	do.	10008.746	7313.659	2945.48498
TP5	do.	10016.951	7410.776	2956.30253
TP6	do.	10048.378	7442.447	2959.63300
TP7	do.	10080.850	7455.212	2962.12548
TP8	do.	10097.728	7449.703	2964.38524
D10	do.	10136.958	7435.875	2968.010
D11	do.	10154.040	7452.722	2969.787
TP10	do.	10162.106	7459.402	2969.86093
TP11	do.	10136.202	7475.063	2969.42058
TP12	do.	10163.701	7474.461	2969.23171
D4	do.	10191.413	7468.918	2969.229
TP14	do.	10279.743	7472.476	2966.17333
TP15	do.	10258.393	7404.437	2964.38763
D5	do.	10286.732	7400.824	2963.282
D6	do.	10171.724	7358.267	2960.552
TP19	do.	10133.242	7329.769	2954.58144
D7	do.	10081.389	7309.232	2948.0770
TP21B	do.	10073.035	7308.521	2948.04649
D8	do.	10028.540	7306.201	2946.894
TP27A	Black circuit	10367.559	7552.407	2975.87520
TP30	Red circuit	10340.417	7539.013	2976.13558
TP31A	do.	10314.316	7584.337	2980.02112
TP32	do.	10306.750	7531.593	2977.73331
TP32B	do.	10274.102	7551.141	2977.26791
TP202	do.	10310.169	7560.648	2979.02376
TP203	do.	10366.772	7572.735	2976.36962
TP29	Black circuit	10391.5	7601.5	2981.15983
TP60	do.	10382.0	7622.5	2980.87778
TP61	do.	10379.5	7613.5	2979.68654
TP62	do.	10370.0	7596.5	2979.04017
TP201	Quad at TP1	9996.439	7334.829	2947.07817
TP200	do.	9979.214	7263.530	2943.79932
TP70	do.	9948.985	7303.015	2944.32133
TP73	Green circuit	9860.535	7231.027	2951.92017
TP77	do.	9753.813	7131.012	2963.22064
TP79	do.	9715.624	7095.791	2967.20395
I14	Quad at POND	10284.386	7423.080	2965.97669
TP204	do.	10228.300	7472.746	2966.48558
TP205	do.	10259.781	7493.923	2966.75326

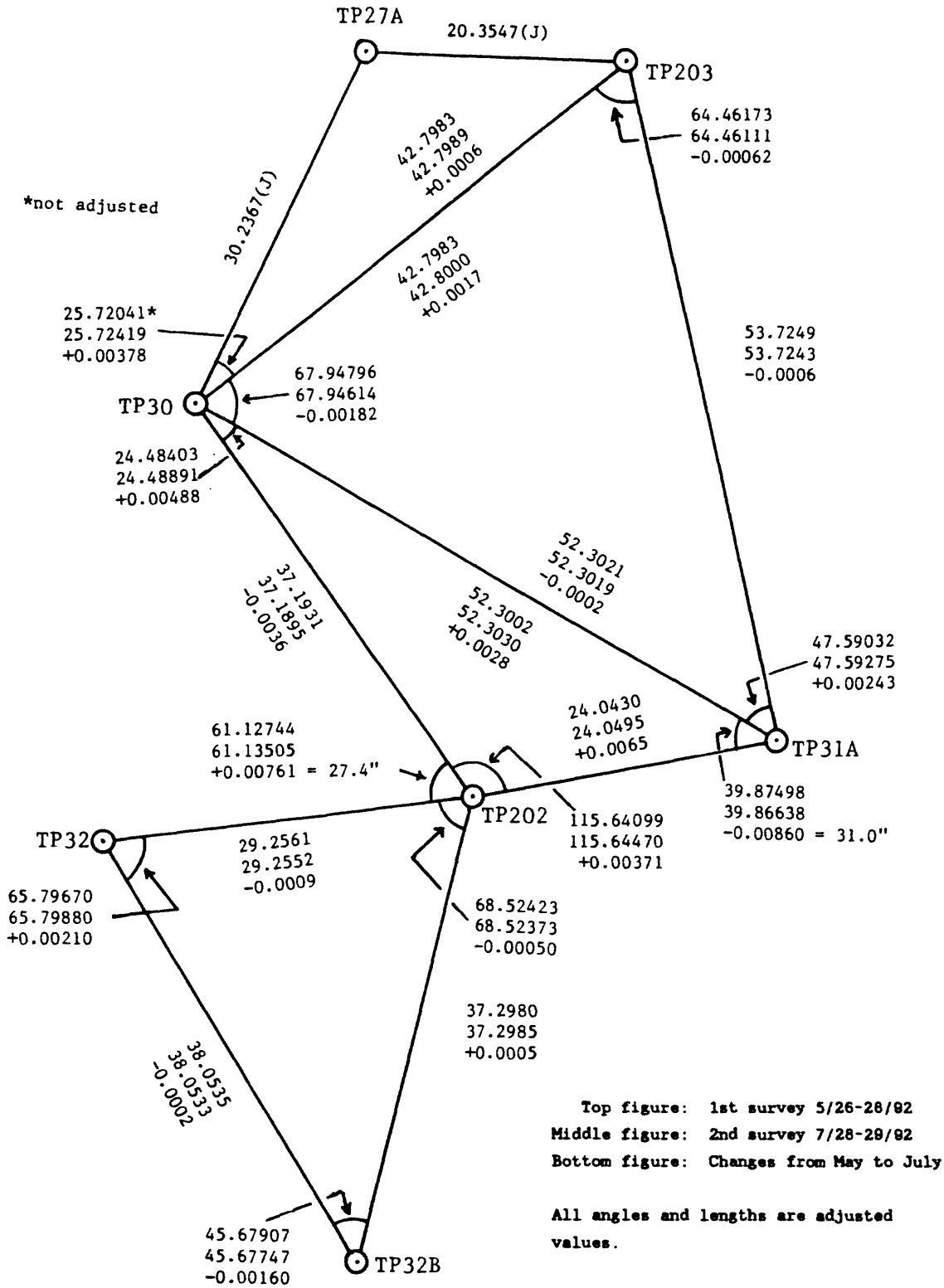


Figure 6. Triangles near TP30 -- measurements and changes from May to July 1992.

4. A level circuit and EDM traverse should be extended westward from POND to area A, then southeastward to connect with the main blue circuit at TP19. The old dry pond area west of POND should be studied for geomorphic evidence of uplift.

5. An EDM traverse should be made to determine more closely the horizontal positions of points along the black leveling circuit, such as TP29, T13, TP60, and establish permanent points on the rolls at the active toe.

6. Extend the level line southwestward along Highway 149 at least one more circuit beyond TP79.

7. Establish a level line at the northwest entrance of Highway 149 onto the landslide, extending from stable points, on bedrock if possible, southeastward onto the old slide inside the right flank (north) levee complex.

8. Put in new stations with horizonal and vertical control in the unsurveyed area in front of the active toe between TP12 and TP32. This could be done by starting a triangle or quad using D4, TP204, or TP205, whose coordinates are now known.

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