EARTH MOVEMENT SURVEYS

FOR THE

STANFORD LINEAR ACCELERATOR CENTER

REPORT TO

STANFORD LINEAR ACCELERATOR CENTER - NO. ABA-49

STANFORD UNIVERSITY SUBCONTRACT NO. S-128

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Submitted by [Signature] Approved by [Signature]

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I. INTRODUCTION

This report covers the ground movement surveys by ABA on the site of the Stanford Linear Accelerator Center for the period February 1, 1962, to July 1, 1962.

Preliminary investigation undertaken during 1961 and early 1962 consisted of several level surveys of the bench mark network over the general area of the site and a horizontal survey consisting of triangulation and trilateration over twelve control stations in the same area. The level surveys started in March 1961 and continued through January 1962. The horizontal control survey was started in December 1961 and was completed early in March 1962. These surveys are reported in detail in "Progress Report on Ground Movement Investigation" (report to SLAC - No. ABA-41) by R. E. Skjei, submitted in March 1962.

In the western portion of the site erratic vertical movements exceeding the allowable limit of movement of the accelerator were indicated by the various level surveys. The December-March survey indicated that conventional triangulation-trilateration surveys would require a long period of time to produce significant results. As time and economy were essential the decision was made to set up an organization within ABA to undertake intensive precision surveys to attempt to define the extent and rate of movement, both vertical and horizontal, within the time available, and to investigate other means of
making measurements. Such a group was organized in February 1962.

Very little field work was accomplished in February. Reconnaissance was made for an alignment test line of monuments approximately parallel to the accelerator. A site for such a line, which was clear of trees, was found about 300 feet north of the proposed accelerator centerline. The topography was satisfactory to enable setting a number of monuments on line and sufficiently intervisible without using towers. The greater part of the month was spent ordering instruments and supplies and contacting experienced personnel.

Heavy rains were prevalent throughout the month of February. During the latter part of the month the roads on the site had deteriorated to a point at which the site was closed to vehicles. Some work was done, however, during the last few days of the month in starting to set monuments along the alignment test line and in building stands for instruments. Materials were hand carried onto the site from Sand Hill Road during the period roads on Stanford University property could not be used.

Work continued with three men until March 15, 1962. At that time the survey group was expanded to seven men. Construction of monuments and stands on the alignment test line was completed on March 22 and observations of angles began that evening.

Leveling instruments ordered in February were received on March 23. Precise leveling over the bench mark network was started on March 27.
II. LEVELING

All level surveys made during the period of this report were made with the same type instruments, techniques and standards established in August, 1961. The Wild N III, shaded when necessary from the direct rays of the sun, and matched invar rods were used. Turning points between bench marks consisted of 1/4-inch rivet punches driven firmly into the ground. Sights were limited generally to 50 feet and foresights and backsights were balanced by taping. Rod readings for foresights and backsights were alternated; that is, on odd numbered setups the backsight was read first and on even numbered setups foresights were read first. Rod temperatures were recorded but not applied as the corrections for the invar rods for the differences in elevation on the site were insignificant.

The standards set by the U. S. Coast and Geodetic Survey for special accuracy leveling surveys were adhered to as to agreement of forward and backward runnings between adjacent marks. In not one instance was this exceeded. In fact, the mean checks were less than 50% of that allowed.

Three level surveys of the bench mark network on the site have been made by ABA since discontinuing the leveling by contract with an engineering organization in San Francisco. The last contract leveling was done in January-February 1962.

The dates of the three level surveys were as follows:

1. March 27 - April 12, 1962
2. April 19 - May 4, 1962

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A. Comparison of March-April 1962 Level Surveys

Comparison between these level surveys and with previous surveys described in ABA-41 have been restricted to the bench marks on the site. The elevation of the January-February 1962 survey, at Bench Mark ALD, the easternmost "deep" bench mark on the site, was held constant. The latter survey is held as the basic leveling as it was the first complete survey of all "deep" marks on the site. Several new deep marks were established following the September 1961 survey.

In making comparisons of elevation differences shown by the various level surveys, the stations along the accelerator centerline are referred to. The stations are numbered west to east. For example, Station 20+00 is 2,000 feet east of the zero end of the accelerator line. While the bench marks are scattered some distance north and south of the accelerator centerline, this fact is taken into account only by specific mention. Comparison of differences in elevation for the various level lines is shown in Appendix I.

Using the fixed elevation for Bench Mark ALD, the comparison between the January-February leveling and that of March-April shows small variations, within limits of observation errors, westward to Station 96+00 where the latter leveling indicates a difference of +3 millimeters (1/8"). This separation reaches a maximum at Station 84+00 of +3.5 mm. The differences become random thereafter to Station 13+00, varying from +2 mm to -1.5 mm. Westward of Station 13+00 the differences increase rapidly through the next three bench marks (BM 106, BM 1GD and BM 114D), all grouped about a low hill whose summit is at about Station 6+00 and 300 feet north of the accelerator line. For these three marks the differences are +16 mm, +17 mm, and +31 mm respectively from the January-February elevations. The first two named are
+12 mm and +6 mm compared with the September leveling. BM 114D was not established in September. Bench Mark 106 is set in out-cropping rock, possibly a large boulder, and BM 1GD and BM 114D are "deep" marks previously described in ABA-41. Bench Mark 115, south of the accelerator centerline at about Station 3+00 and almost directly south of BM 114D, showed a change of -3 mm compared with the January-February work. This mark was not yet established in September 1961.

In only one place is the March-April leveling east of Station 13+00 above the September values, and this is only +0.2 mm at Station 8h+00.

B. Comparison of April-May 1962 Level Surveys

Following the March-April survey, 139 reinforcing bars 5/8" in diameter and 10 feet long were driven with an air hammer to their full length or refusal, whichever occurred first, at turning point intervals along the leveling routes between bench marks west of Station 90+00. Three of these "rod" bench marks were established west of BM 114D. The most western one, number 139, was located at about Station -3+00. All the rod marks were included in the April-May leveling of the network.

The elevations measured during this survey agreed substantially with those of March-April except as follows:

1. There was approximately 2 mm subsidence at Stations 96+00 and 8h+00, bringing the elevations about midway between those of January-February and March-April.

2. From Station 3h+00 to the west end of the site the April-May survey was consistently 1 mm to 2 mm above that of March-April.

Following the March-April leveling, when excessive movement was noted about the aforementioned hill near the west end of the site, a decision was
made to establish a number of marks in bore holes at a safe depth below the weathering zone of the topsoil. These marks were to be used for reference to the surface leveling network, as it was suspected that much of the movement of the 1/4 inch allowable tolerance for the accelerator might be confined to the upper layers and, therefore, might not be a problem to the accelerator where founded in excavation. To this end the rotary drilling equipment which was moved on the site to drill for geological exploration was used to drill holes for nine marks at a 30-foot depth along a line some 3000 feet north of the accelerator centerline. Seven of the marks were set west of Station 70+00 with the eighth at Station 86+00 and the ninth at Station 115+00.

These marks, consisting of steel rods projecting 12 inches above a concrete plug in a 6-inch bore hole, are accessible for leveling through a 4-inch steel pipe hung from the ground surface with the pipe just clearing the concrete plug (the steel rod projects into the pipe). Elevations are determined by means of an invar tape secured to a weight resting on the mark and tensioned in accordance with the manufacturer's specifications for a tape supported throughout its length. A graduation on the tape is read by the levelman as he would a leveling rod.

C. June 1962 Level Survey

Upon completing the setting of the 30-foot deep marks another leveling of the site was undertaken. This survey provided repeat values for the original network with the exception of D-151, tied the new 30-foot deep marks to the network, and gave repeat observations on the rod marks set in April. The leveling was started on June 11 and completed on June 26.
The elevation determined in January 1962 for Bench Mark AlD was held constant in all subsequent surveys. Using the elevation of BM AlD as a reference, the June survey was compared with previous surveys. The elevations of marks at the eastern end of the site agreed closely with the previous surveys, except at Station 64+00 the bench mark elevation was +3.5 mm above the January leveling and +2 mm compared with that of April-May. The remaining marks east of Station 13+00 were consistent with the previous leveling within the range of leveling errors, about 1 mm. Bench Mark 106 of the group near the hill at the west end had changed -8 mm from the previous leveling; BM 1GD was found to agree within 0.4 mm of the previous leveling; while BM 11hD changed -6 mm, agreeing fairly well with BM 106. Mark 115, located south of the accelerator line in out-cropping rock, had shown good stability since December, when it was first leveled. It showed a change of +10 mm since April-May. This mark is on a spur line which was double run. While the forward and backward runs agree very closely, there is a possibility of a compensating error of 1 centimeter. The next leveling should prove or disprove this. The new rod mark set at the extreme western end of the site agreed closely with BM 1GD.

A comparison was made of differences in elevation between adjacent rod marks observed in the two levelings over these marks. Except in four instances all agreed within about 0.5 mm. One of these marks had been definitely disturbed in discing a fire break and one was in alluvial soil in a low area. The other two showed nothing to account for the differences of elevation of about 1 mm. It also was noted that marks adjacent to Bench Marks 106 and 11hD agreed closely with each other but differed with these bench marks by 8 mm and 6 mm respectively, the amount of change in elevation
of these marks. Agreement with BM 1GD was good. The change in elevations of BM 106 and BM 11hD is a definite indication that these two marks are unstable.

D. Conclusion

The site from Station 13+00 eastward is believed to be sufficiently stable to meet the requirements of 1/4 inch movement within a 90-day period. The only section approaching this limit is in the vicinity of Station 35+00 and concerns only one bench mark. All other marks show a movement only slightly in excess of 1/8 inch, taking into account what is considered to be tilting of an area at the western end. There is some doubt that the marks west of Station 13+00 show the true condition at accelerator grade since two of the marks have definitely given indications of being unstable. There still is a possibility that the movement is confined to the upper layers of the ground, which should be proved or disproved by repeat leveling over the bench marks set at 30-foot depth.

It is recommended that monthly leveling be continued for two more months to check on the reliability of the marks set at 30-foot depth as compared with the rod marks, and then at three month intervals thereafter for another year. The latter recommendation is subject to change, depending upon what is found with respect to the 30-foot deep marks in the western part of the site. If the differences in elevation between the 30-foot marks remains constant through several levelings, it would appear that the movement heretofore observed is superficial and will cause little trouble to the accelerator alignment.
III. HORIZONTAL MOVEMENT SURVEYS

Eleven monuments, each consisting of a 5-foot-long concrete post cast in place and projecting a few inches above the ground have been placed on line approximately parallel to and about 300 feet north of the accelerator centerline. These monuments are as uniformly spaced as topography will permit without using tall towers. Nine of these monuments are on ridges or low hills and two are on slopes, each intervisible with one or more of the other stations. Five-foot wood tripods were originally erected over the monuments to support instruments and targets, but those at three instrument stations have since been replaced with towers 12 to 15 feet high to give better ground clearance.

Four of the stations were selected for instrument stations. These consist of the two end stations numbered "1" and "11" and intermediate stations "4" and "7E". The intermediate instrument stations are as close to the third points as topography would permit. These stations were selected for instrument observations as they have sufficient intervisibility between them to allow some redundancy of observations and thus permit adjustment by least squares and computation of probable error. Of the remaining seven stations four are observed from two instrument stations and three from one station only. It would have been desirable to have check observations on all stations but is not necessary in view of the techniques used.

Observations are made at night with a Wild T-3 theodolite on lighted slit-type targets. Some of the targets are modified Wild traverse targets and some are of a similar type built to specifications in a local precision
tool shop. The slits in the targets vary from 1/4 inch to 1-1/2 inches in width depending upon the distance between instrument and target. The distances vary from approximately 725 feet to 11,000 feet.

All monuments, with one exception, are within 12 seconds of arc of being on line. The exception is approximately one minute of arc off line.

Standard first-order triangulation observation procedures are followed with one exception. That is, instead of using a different part of the circle for each of the 16 positions observed in one night at a station, the initial circle setting is confined to a two minute graduation, varying the setting slightly before each position in order to distribute the 16 positions over the range of the micrometer.

Each instrument station is occupied weekly. When six weekly observations at each station are completed, a mean is taken of the results for the period; a least square adjustment is made involving the instrument stations; angles or direction are corrected accordingly; and offsets from a line between the end stations determined by traverse computation methods.

To date two groups of observations have been computed and compared. Results indicate that offsets are consistent to within 1/8 inch. An analysis of the differences in offsets show the line to be reasonably rigid from the eastern stations to about Station 17+00 of the accelerator. The one station west of that, on the hill at Station 6+00, appears to have moved south some 5 mm (0.2 inch) in the mean six weeks period, all movement occurring after May 20. Observations made since the computation of the last group of six showed continued movement southward but at a diminishing rate. The next six week group should be quite informative.
As with leveling, horizontal control surveys must necessarily be made over monuments set in the surface layers of the ground, where they are subject to disturbance by various causes. The horizontal movement of the marks is ordinarily considered to be too small to affect positions appreciably in first-order control, but in precision surveys such as being made on the accelerator site, small movements detected at ground level could be misleading with respect to those actually existing at accelerator grade in deep cuts.

In view of the movement found to exist at Station 6+00, three deep horizontal reference marks were proposed to spot check the relationship of horizontal movement at the surface with that at depth. This was done at the CERN synchrotron site by establishing a deep reference mark near each triangulation station.

After considerable difficulty in boring vertical holes through sloping beds of sandstone, casings for three of these deep reference marks were installed, one each near Stations 6+00, 35+00 and 89+00, and at depths of 50 feet, 40 feet and 60 feet, respectively. The intention was to go to 60 feet with all three but this could not be accomplished except at great additional expense in preparing the holes.

The deep mark near Station 6+00 consists of a target set in the center of the bottom of a 6-inch steel pipe. Measurements are made to the surface monument by bringing the position of the underground mark to the surface with a Wild ZNL16 vertical collimator and taping from the collimation line to the surface mark. This mark has been observed weekly for a period of three weeks. The deep mark is south of the surface mark. The horizontal distance between the deep mark and the surface mark is decreasing, suggesting
that the surface mark is moving south. Measurement with the Wild T-3
theodolite from the other surface marks also showed a southward movement
of this surface mark as discussed above. Both methods of measurement find
about the same amount of southward movement in the last three week period.
This southward movement could be explained by either a southward creep of
the surface layers or by a tilting of this area to the south.

The other two deep horizontal reference marks, now being installed,
will each consist of stainless steel wire fastened to the bottom in a con-
crete plug and stretched to the top by a hollow plastic sphere 10 inches
in diameter floating in a tank firmly set in the ground. The sphere will
follow the movement at the bottom of the pipe. The positions of the reference
mark on the top of the sphere will be tied in periodically to the adjacent
alignment monument.

Definite conclusions regarding horizontal movement cannot be made at
this time as the period of observation has been relatively short. The
condition found to exist near the west end of the accelerator will require
considerably more investigation. To this end an additional alignment test
line monument has been established at the extreme west end of the site in
order to investigate the behavior beyond the hill located at about Station
6+00 of the accelerator. Horizontal distance measurements between the deep
reference marks and the surface reference marks adjacent to them will be
continued to check on the relationship between deep and surface horizontal
movement. It is further proposed to make use of all suitable open bucket
auger holes along the accelerator to determine the relationship of surface
behavior to that at depth.
Preliminary results indicate that the area east of Station 13-90 of the accelerator centerline will be sufficiently stable to maintain alignment of the accelerator within the 1/4 inch tolerance for the 90-day period. The period of observation, however, is too short to determine if there are irregular movements occurring that could be troublesome.