PROGRESS REPORT ON

EARTH MOVEMENT SURVEYS

REPORT TO STANFORD LINEAR ACCELERATOR CENTER - ABA NO. 102
STANFORD UNIVERSITY SUBCONTRACT S-136
UNDER AEC CONTRACT AT(04-3)-400

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Approved by R. L. Sharpe

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ARCHITECT-ENGINEER-MANAGER
Palo Alto, California

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INTRODUCTION

This report briefly reviews and summarizes earth movement surveys made since early 1962 on the Stanford Linear Accelerator site by the Aetron-Blume-Atkinson Geodetic Engineering Survey Party working under the direction of Captain J. H. Brittain. The report discusses the surveying program instituted for both horizontal and vertical earth movement measurements and analyzes results obtained to date. In addition, benchmarks established in the accelerator housing and klystron gallery floor slabs are also discussed.

Previously published reports and references, listed in Attachment I, have described in detail surveying procedures followed and have listed data obtained during various phases of the surveying program.

HORIZONTAL EARTH MOVEMENT

Program Conducted

Surveys were started in March 1962, over a line of twelve monuments extending approximately east and west over the length of the accelerator site and some 275 feet north of the proposed accelerator centerline. Four of the twelve monuments were used as instrument observation stations. The surveying program was designed to measure differential movement normal to the accelerator alignment.

Early observations indicated unrealistic differential movement of several of the alignment monuments founded in alluvium in the western half of the site. In order to separate possible superficial soil movement influenced by varying moisture conditions from crustal earth movement, deep (50 feet) reference marks were placed adjacent to three of the four instrument stations. The fourth station, at the eastern end of the line, was set in sandstone and so was considered to be relatively free of superficial disturbance.
Observations over the line of monuments were continued at weekly intervals through April 1963, when building construction obstructed the line of sight to the easternmost monument. Observations were resumed in August 1963, over a revised scheme of monuments. The revised scheme consisted of the three previously observed instrument stations (AL4, AL7 and ALL1) at which deep reference monuments were placed and two additional monuments (East and West) on the extensions of the accelerator housing centerline. The latter two monuments were originally set for control of construction surveys. The layout of the revised scheme is shown below. The revised network was observed at ten-day intervals through November 1963, and monthly thereafter.

Data Analysis

Recently, mathematicians of the U. S. Coast and Geodetic Survey analyzed the observations made from August 1963 through September 1964 over the revised monument network. The twenty-seven surveys made during this period were grouped into nine sets, adjusted by least squares, and the perpendicular distances to monuments AL4, AL7 and ALL1 from the line between the monuments East and West at each end of the accelerator were determined for each set. The deviations of the individual values of each set from the mean value of all the distances to AL4, AL7 and ALL1 were tabulated. (See Reference 7.)

The tabulated values shown in Attachment II of this report are concerned with the perpendicular movement of the ground monuments, holding as fixed the accelerator stations East and West and deep reference marks at AL4, AL7 and ALL1. However, since the movement of the deep reference marks with respect to the
accelerator stations appears to be better representative of deep seated movements that would affect the accelerator, the differences from the means of the perpendicular distances from the line between the accelerator stations to the deep reference marks adjacent to the three alignment stations for each group have been shown in Figure 1(a) attached. The distances used to determine the deviations plotted in Figure 1(a) are the algebraic sum of the adjusted values of column 3 and the measured distances shown in column 6, page 6 of Attachment II. Plus values are to the north.

In addition, the deviations from a mean value for the perpendicular distances of the deep reference mark at AL7 from fixed positions of the deep reference marks at AL4 and AL11 for the period from July 1962 through December 1964 are plotted in Figure 1(b) attached. It will be noted that the deviations, representing movement perpendicular to the accelerator, are in general of the same magnitude as those referred to the accelerator centerline, approximately one quarter inch.

Conclusion

Horizontal differential movement, as shown by the results of the surveys, appears to be random. Any trend, consistent with predictions for differential movement on the site, is so small that it is blanketed by the errors due to refraction and the limitations of surveying accuracy.

VERTICAL EARTH MOVEMENT SURVEYS

Program Conducted

Repeated precision leveling surveys had been made by an outside engineering firm under contract in 1961 and January 1962 over a network of shallow benchmarks covering the Sand Hill site. Analysis of these surveys disclosed changes in elevation that could not be coordinated with any known pattern of deep-seated crustal earth movement. The agreement of successive levelings was within the range of leveling accuracy in the eastern part of the site, but in the western part, changes of four-tenths inch were measured in a three month period.
After one leveling of the existing network in March 1962 by the ABA Geodetic Engineering Survey Party resulted in the same random changes as previously found, a supplemental system of benchmarks was installed. This system consisted of 139 sections of 5/8 inch steel rods, 10 feet in length, driven to full length or refusal, whichever occurred first, at turning point intervals along the leveling routes between the benchmarks already in existence in the western two-thirds of the site. In addition, nine deep benchmarch (at 30 feet depth) were placed, at more or less regular intervals, over the length of the site approximately in line with the horizontal alignment monuments.

Nine levelings, extending from June 1962 to October 1963 and a partial leveling in March and April 1964, show agreement in elevation of the new benchmarks within the range of leveling accuracy except for a few of the rods driven in areas of deep alluvium near San Francisquito Creek. However, the shallow concrete benchmarks showed the same general pattern as before. For the series of levelings, the benchmarks held fixed in elevation were those at the extreme eastern end of the site. These benchmarks had shown excellent stability with respect to one another and the U. S. Coast and Geodetic Survey Benchmark D-151 on a bridge over San Francisquito Creek near the junction of Alpine Road and Junipero Serra Boulevard.

**Conclusion**

The agreement of levelings over the rod and deep benchmarks has proven without doubt that, differentially at least, in the absence of pronounced seismic activity in the area, there is little or no regular deep seated upheaval or sinking along the length of the accelerator. See References 5 and 6 of Attachment I for details of movement of representative benchmarks. The movement of the shallow marks comprising the original network is undoubtedly due to variation of the moisture content of the surface layers of the site.
BENCHMARKS ESTABLISHED DURING ACCELERATOR HOUSING AND KLYSTRON GALLERY CONSTRUCTION

Accelerator Housing

As the accelerator housing was constructed, stainless steel rivet benchmarks were set in the concrete floor near the south wall. The marks are spaced at about 40 foot intervals, opposite the center of the unistruts for anchoring the accelerator tube support jacks, for convenience in locating and placing the rivets in the fresh concrete. As construction progressed, the marks were re-leveled at approximately two-week intervals, and differential movement was plotted against time.

By June 1964, the invert of the accelerator housing had been completed. Since then, all leveling for differential earth movement on the site has been over the benchmarks set in the housing floor except for ties between these benchmarks and six of the deep benchmarks set on the site in 1962. These marks are designated DBM's 201, 204, 205, 207, 208 and 209. The leveling has been extended from the benchmark set 80 feet below the housing floor at the west end of the accelerator. The elevation of this mark was initially determined from adjacent benchmarks of the site network.

The mean of the various levelings through the housing has established satisfactory elevations for the other deep benchmarks founded below the housing floor. These benchmarks are at accelerator Stations 52+78, 89+45 and 100+00. The differences in elevation of these marks as determined by the various levelings are well within the accuracy of the leveling, indicating excellent relative stability.

Leveling data, beginning with leveling over the housing floor within a few days after the benchmarks were set, and periodically thereafter, has been furnished to Mr. Gordon Ratliff, SLAC Plant Engineering. Mr. Ratliff has plotted this data showing graphically the accelerator housing elevation profile on the dates for which the information was furnished. Settlement due to shielding fill and subsequent settlement are shown on the graph, designated as Reference C of Attachment I.
Klystron Gallery Floor

Elevations also have been determined for benchmarks set in the Klystron Gallery floor near the beginning of each sector. Repeat levelings have been made over these benchmarks for the length of time the Klystron Gallery floor has been in place, with progressively shorter leveling periods toward the east. For instance, the benchmark in Sector I has been leveled fourteen times beginning in January 1964 and the benchmark in Sector 10 only four times beginning in October 1964.

None of the benchmarks has shown a settlement trend. The differences between levelings are random and within a range of 1/8 inch which probably is about the order of accuracy of the leveling. The control for this leveling has been the same as for the leveling in the accelerator housing, with ties between the two leveling lines made at approximately 1,000-foot intervals through either accelerator service shafts or the man accessways, depending on accessibility at the time of leveling.
# ATTACHMENT I

## LIST OF REFERENCES SHOWING INFORMATION ON EARTH MOVEMENT SURVEYS

<table>
<thead>
<tr>
<th>Reference Number</th>
<th>ABA Report No.</th>
<th>Date</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>ABA-41</td>
<td>March 1962</td>
<td>R. E. Skjei</td>
</tr>
<tr>
<td>(2)</td>
<td>ABA-49</td>
<td>July 1962</td>
<td>J. H. Brittain</td>
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<tr>
<td>(3)</td>
<td>ABA-52</td>
<td>August 1962</td>
<td>J. H. Brittain</td>
</tr>
<tr>
<td>(4)</td>
<td>ABA-67</td>
<td>January 1963</td>
<td>J. H. Brittain</td>
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<tr>
<td>(5)</td>
<td>ABA-80</td>
<td>July 1963</td>
<td>J. H. Brittain</td>
</tr>
<tr>
<td>(6)</td>
<td>Progress Report (No Number)</td>
<td>January 1964</td>
<td>J. H. Brittain</td>
</tr>
</tbody>
</table>

**Others:**

| (7)              | Analysis of Stability of Triangulation Stations at Stanford Linear Accelerator Center | January 1965 | U. S. Coast & Geodetic Survey |
| (8)              | Accelerator Housing Floor Elevation Profile | February 1965 | G. Ratliff - SLAC Plant Engineering Department |

*Reference (7) is included as Attachment II of this report.*
1(a): Deviations of Monument Distances from Accelerator Centerline (deep reference marks at monuments AL-4, AL-7 and AL11 were adjusted to fixed positions of accelerator alignment towers east and west.)

AL4 (Accelerator Station 86+00)

AL7 (Accelerator Station 37+00)

AL11 (Accelerator Station 6+00)

1(b): Deviations of Monument AL7 from Fixed Positions of Monuments AL4 and AL11. (Deep reference mark at AL7 was adjusted to fixed positions of deep reference marks at AL4 and AL11.)

FIGURE 1

ANALYSIS OF OBSERVED ALIGNMENT MONUMENT MOVEMENT
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