HORIZONTAL MOVEMENT SURVEYS

FOR THE

STANFORD LINEAR ACCELERATOR CENTER

REPORT TO

STANFORD LINEAR ACCELERATOR CENTER - NO. ABA-52

STANFORD UNIVERSITY SUBCONTRACT S-128

UNDER AEC CONTRACT AT(44-3)-400

Submitted by

Approved by

AETRON-BLUME-ATKINSON

A Joint Venture

ARCHITECT-ENGINEER-MANAGER

580 College Avenue

Palo Alto, California

August 1962
HORIZONTAL MOVEMENT SURVEYS

FOR THE

STANFORD LINEAR ACCELERATOR CENTER

INTRODUCTION

The purpose of this report is to present the field data obtained during the ABA surveys made to determine horizontal earth movement normal to the accelerator centerline and to show in detail the technique of computing these field data. This report is supplemental to report ABA-49, EARTH MOVEMENT SURVEYS FOR THE STANFORD LINEAR ACCELERATOR CENTER, submitted in July 1962.

The general methods used in the field have been described in report ABA-49. An example of the record of field observations, an abstract of data from the field records and summaries of all data obtained through July 26, 1962, are presented herein.

PROCEDURES FOLLOWED

The line of monuments approximately parallel to the centerline of the accelerator was set up as a traverse with sufficient overlap of observations to permit a simple adjustment of the network of instrument stations and computation of probable error for a check on the accuracy of observations. The weekly observations are means (averaged) in groups covering six weekly observations in order to minimize the effects of refraction as well as to obtain values representing possible earth movement with respect to time.

The adjustment and computation of the first group of the series of observations are presented in sufficient detail so that the procedure can be followed by those unfamiliar with geodetic computations but who have some knowledge of least squares. Summaries are given of changes in offset distances between mean period of observations representing movement of the monuments in a direction normal to the accelerator centerline.

Figure 1 presents a page from the field record book. The micrometer noted has 60 principal divisions spanning a two minute graduation of the circle. Two readings are made of each pointing and added to give the correct value of the seconds for the direction. The last column gives the seconds of the directions from the initial station observed. The theodolite circle is graduated clockwise, but for convenience of observing, the initial station used is the one most distant in one direction from the instrument. Other stations are observed in order of distance, working toward the instrument, without regard to their being to right or left of the initial station.
Figure 2, Abstract of Directions, presents a typical page of computations showing the first step in reducing the field data.

Figures 3a through 3d are lists of directions for the four instrument stations, AL 1, AL 4, AL 7 and AL 11, respectively.
HORIZONTAL DIRECTIONS

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<td>60.46</td>
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<td>50.12</td>
<td>59.17</td>
<td>61.14</td>
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</tr>
</tbody>
</table>

**FIGURE 3c**
# List of Directions

<table>
<thead>
<tr>
<th>Station</th>
<th>AL 11</th>
</tr>
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<tbody>
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<tr>
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</tr>
<tr>
<td>3-27-62</td>
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<tr>
<td>4-3-62</td>
<td>00.00</td>
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<td>4-12-62</td>
<td>00.00</td>
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<td>4-19-62</td>
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<tr>
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<td>00.00</td>
</tr>
<tr>
<td>5-4-62</td>
<td>00.00</td>
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<tr>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>6-12-62</td>
<td>00.00</td>
</tr>
<tr>
<td>6-17-62</td>
<td>00.00</td>
</tr>
<tr>
<td>5-21-62</td>
<td>00.00</td>
</tr>
<tr>
<td>5-31-62</td>
<td>00.00</td>
</tr>
<tr>
<td>6-7-62</td>
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<td>6-11-62</td>
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</tr>
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<td>Mean</td>
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<td>Mean</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3d**

- 8 -
ADJUSTMENT OF INSTRUMENT STATIONS

(Mean values between March 22, 1962, and May 4, 1962)

Sketch of network adjusted by method of Condition Equations

Conditions Equations

1. $-4 + 5 - 6 + 8 - 9 + 10 = -1.17$
2. $-1 + 2 - 3 + 5 - 6 + 7 = 1.24$
3. $-2.987(1) + 2.987(2) + 7.953(6) - 7.953(7) + 3.5241 = 0$
4. $-4.833(4) + 4.833(5) + 3.120(6) - 3.120(8) - 0.6188 = 0$

These condition equations consist of two angle equations and two "perpendicular" equations. Equations 1 and 2 express the fact that the sum of the corrections to the directions is equal to the closure. In equations 3 and 4 the only conditions to be satisfied are that the offset distances from the obtuse angle points of the triangles are consistent when computed from either of the other two stations in each triangle. In these equations the coefficients of the directions are the distances in feet divided by 1000. The constants are the differences in offset distances in the same unit. Equations 3 and 4 have been simplified by using the angles in seconds, rather than their sines, since the angles are all very small.

Correlate and normal equations are now formed and solved by the Doolittle method. The C's are then substituted in the correlate equations to compute the v's or corrections to the directions.
v's for mean values, March 22 to May 4, 1962

1. -0.164"  4. +0.172"  7. +0.510  10. -0.343"
2. +0.164"  5. +0.086"  8. -0.463"
3. -0.259  6. -0.057  9. +0.343"

Average mean square error (r) = 0.21

Offsets at Stations AL 2, AL 3, AL 5 and AL 6 are computed by weighting inversely to the distances from observing stations. The computation of corrections to the angles to Station AL 3 is shown below. As in condition equations 3 and 4, the angles rather than the sines of the angles are used since the angles are small.

![Sketch showing layout of triangles for adjustment of intersection station]

\[
\frac{910 \times 2076}{910 + 2076} (6.25 + 3.06) = 644.73 \quad (+0.122 \text{ correction to angle at AL 4})
\]

\[
\frac{910 \times 2076}{910 + 2076} (6.25 + 3.06) = 248.37 \quad (-0.122 \text{ correction to angle at AL 1})
\]

Upon comp

No corrections can be made to observations on Stations AL 8, AL 9 and AL 10 as these are each visible from only one instrument station. This also will apply to Station AL 12, recently included in the program.

Upon completion of the adjustment of the directions and angles at the instrument stations, a revised list of directions was made as shown in Figure 4.
### Revised List of Directions

#### Station AL 1

<table>
<thead>
<tr>
<th>v's</th>
<th>Station</th>
<th>Direction</th>
<th>v's</th>
<th>Corrected</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>o</td>
<td>i</td>
<td>&quot;&quot;</td>
<td>&quot;&quot;</td>
</tr>
<tr>
<td>1</td>
<td>AL 11</td>
<td>90 00</td>
<td>00.00</td>
<td>- .16</td>
<td>59.84</td>
</tr>
<tr>
<td>2</td>
<td>AL 4</td>
<td>90 00</td>
<td>01.50</td>
<td>+ .16</td>
<td>01.66</td>
</tr>
<tr>
<td></td>
<td>AL 2</td>
<td>90 00</td>
<td>01.56</td>
<td>- .25</td>
<td>01.31</td>
</tr>
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<td></td>
<td>AL 3</td>
<td>90 00</td>
<td>04.73</td>
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</tbody>
</table>

#### Station AL 4

<table>
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<tr>
<th>v's</th>
<th>Station</th>
<th>Direction</th>
<th>v's</th>
<th>Corrected</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>o</td>
<td>i</td>
<td>&quot;&quot;</td>
<td>&quot;&quot;</td>
</tr>
<tr>
<td>4</td>
<td>AL 7</td>
<td>89 59</td>
<td>56.43</td>
<td>+ .17</td>
<td>56.60</td>
</tr>
<tr>
<td>5</td>
<td>AL 11</td>
<td>89 59</td>
<td>57.14</td>
<td>+ .08</td>
<td>57.22</td>
</tr>
<tr>
<td></td>
<td>AL 6</td>
<td>90 00</td>
<td>00.06</td>
<td>+ .11</td>
<td>00.17</td>
</tr>
<tr>
<td></td>
<td>AL 5</td>
<td>90 00</td>
<td>07.05</td>
<td>- .26</td>
<td>06.79</td>
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<tr>
<td></td>
<td>AL 3</td>
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<td>53.49</td>
<td>- .22</td>
<td>53.27</td>
</tr>
<tr>
<td>3</td>
<td>AL 1</td>
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<td>00.00</td>
<td>- .26</td>
<td>59.74</td>
</tr>
<tr>
<td></td>
<td>AL 2</td>
<td>270 00</td>
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</table>

**Figure 4**
### Station AL 7

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<th>Direction</th>
<th>v's</th>
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<th>Initial</th>
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<td></td>
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<td>0 &quot;</td>
<td>1</td>
<td>&quot;</td>
<td></td>
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<td>58.90</td>
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<tr>
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<td>AL 5</td>
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<td>57.11</td>
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<td>269 59</td>
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### Station AL 11

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<td>1</td>
<td>&quot;</td>
<td></td>
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<tr>
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<td>00.00</td>
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<td>01.24</td>
<td>00.78</td>
<td>00.27</td>
</tr>
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</table>
COMPUTATION OF OFFSETS

In the computation shown in Figure 5 the line between AL 1 and AL 11 is held fixed so the offsets at these points are zero. Plus offset values are north of the fixed line and minus values are south.

The computation of the offsets from the line AL 1 to AL 11 completes the computations for the first group of mean values. Detailed computations for Groups 2 and 3 will not be given. The results of the computations are listed in Figures 6a and 6b in order to make a comparison of the three groups.
OFFSET COMPUTATION - GROUP 1
(March 22, 1962, to May 4, 1962)

<table>
<thead>
<tr>
<th>Station to</th>
<th>Station</th>
<th>Distance (feet)</th>
<th>Azimuth</th>
<th>Sine</th>
<th>Offset (feet)</th>
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<td>AL 3</td>
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<tr>
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<td>90 00 58.82</td>
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<tr>
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<td>01.28</td>
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</tr>
<tr>
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<td>AL 10</td>
<td>1136.2</td>
<td>269 59 57.98</td>
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<td>+.0108</td>
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</tbody>
</table>

FIGURE 5
RESULTS OF COMPUTATIONS FOR GROUP 2

(Means of observations between May 4, 1962, and June 14, 1962)

Tabulation of v's from adjustment. (See sketch page 10.)

1  -.187 seconds  4  +.027 seconds  7  +.274 seconds
2  +.187 seconds  5  +.184 seconds  8  -.196 seconds
3  -.211 seconds  6  -.078 seconds  9  +.136 seconds
10  -.130 seconds

Mean square error (r) = 0.012 per direction

Offsets from line AL 1 to AL 11

(Plus is north and minus is south. Results in feet)

AL 1    00.0000 (fixed) AL 5    +.0708
AL 2    +.0098    AL 6    +.0801    AL 9    +.0191
AL 3    +.0502    AL 7    +.0025    AL 10   +.0279
AL 4    +.0337    AL 8    +.2096    AL 11   00.0000 (fixed)

FIGURE 6a

RESULTS OF COMPUTATIONS FOR GROUP 3

(Means of observations between June 14, 1962, and July 26, 1962)

Tabulation of v's from adjustment.

1  +.174 seconds  5  -.112 seconds  8  -.061 seconds
2  -.174 seconds  6  +.007 seconds  9  -.010 seconds
3  +.107 seconds  7  -.007 seconds  10 +.071 seconds
4  +.005 seconds

Mean square error (r) = .07" per direction

FIGURE 6b
FIGURE 6b (Cont.)

Offsets from line AL 1 to AL 11

AL 1  00.0000 (fixed)  AL 5  +.0685  AL 9  +.0384
AL 2  +.0111
AL 3  +.0509  AL 6  +.0925  AL 10  +.0589
AL 4  +.0298  AL 7  +.0226  AL 11  00.0000 (fixed)
AL 8  +.2226  AL 12  +.0217

AL 12 has been observed since July 6, 1962, only.
## COMPARISON OF OFFSET MEASUREMENTS

<table>
<thead>
<tr>
<th>Station</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
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<td>+.0040</td>
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<td>+.0208</td>
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<td>fixed</td>
<td>+.0138</td>
<td>+.0351</td>
</tr>
<tr>
<td>AL 10</td>
<td>fixed</td>
<td>+.0171</td>
<td>+.0481</td>
</tr>
<tr>
<td>AL 11</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
</tr>
</tbody>
</table>

**FIGURE 7**
RESULTS

Apparent displacements of monuments as listed in Figure 7 are shown graphically in Appendix No. 1 of this report together with the relationship of the alignment test line to the accelerator centerline.

A study of the observations made at the various instrument stations indicates a definite southward trend for Station AL 11. This is particularly noticeable in the observations at AL 11 to AL 10. At AL 11 the directions to AL 10 were random until May 17, then they changed to the north an average of 1.34 seconds per week for six weeks when they again became steady. (See list of directions for Station AL 11, Figure 3d.)

The first horizontal tie between AL 11 and the 50-foot-deep horizontal reference mark some six meters to the south was made on June 12 and then weekly thereafter. The horizontal measurements are listed in Figure 8.

The measurements listed in Figure 8, although somewhat irregular, show a southward movement of AL 11 with respect to the deep reference mark since the latter is south of the alignment station. The total difference between June 12 and July 23 is 6.5 mm (0.0212 feet). During the same period the angular change from AL 11 to AL 10 was a total of 8.07 seconds to the north. This represents a total lateral displacement between the two monuments of 13.5 mm (0.0445 feet), approximately double that shown by measurements between Station AL 11 and the deep reference mark, but in agreement as to direction. (The angular measurements to AL 10 were with respect to AL 1, at the eastern end of the line, so the change in itself would indicate either AL 11 moving southward or AL 10 moving northward, or a combination of the two.)

| 6 - 12 - 62 | 5.7899 meters | 7 9 9 - 62 | 5.7861 meters |
| 6 - 18 - 62 | 5.7878 meters | 7 - 16 - 62 | 5.7835 meters |
| 6 - 25 - 62 | 5.7869 meters | 7 - 23 - 62 | 5.7834 meters |
| 7 - 2 - 62  | 5.7860 meters |

FIGURE 8
CONCLUSIONS AND RECOMMENDATIONS

From the foregoing one of two conclusions can be drawn. The first is that the total movement is at Station AL 11. If that is the case, movement also exists at the 50-foot-depth, although apparently only about one-half as much as at the surface. This would mean that the hill on which the monuments are located has tilted in a general southward direction during the period between May 17 and June 228.

The second possible conclusion is that all the movement at AL 11 is superficial, that the deep mark at 50 feet is relatively stable and that the difference between 13.5 mm and 6.5 mm (0.0233 feet) can be attributed to the northward movement of the area in the vicinity of AL 10. The writer is inclined toward the latter hypothesis since movement on the site, with the exception of the hill on which AL 11 is located, conforms with that normally expected due to the proximity to the San Andreas fault. It is recommended, however, that further study should be made before arriving at a definite conclusion.

Wherever the movement occurred, it seems to have stopped for the present as indicated by both the horizontal angles and the measurements between Station AL 11 and the adjacent deep reference mark.

While two other deep reference marks, of the inverted pendulum type, are presently in operation to the east, the period of operation has been too short to recognize a trend. Differences observed are within the range of observing errors.