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REPORTS REFERENCED BUT NOT ATTACHED

<u>No.</u>	<u>TITLE</u>
ABA-1	Investigation of Bench Mark Elevation Changes in Sand Hill Area
ABA-21	A Study of the Use of Pile Supports for the Accelerator Tube
ABA-41	Progress Report on Ground Movement Investigation
ABA-49	Earth Movement Surveys for the SLAC
ABA-52	Horizontal Movement Surveys
ABA-60	Interim Geological Report on the Stanford Two-Mile Linear Electron Accelerator Site, San Mateo County, California
Dames and Moore Report	Foundation Investigation, dated November 14, 1962

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ANALYSIS OF ACCELERATOR HOUSING MOVEMENT TOLERANCES

The following discussion reviews ABA's analysis of the accelerator housing movement tolerances. Since the nature and causes of the anticipated movements are not thoroughly understood, and the site measurement programs have covered a relatively short period of time the conclusions on housing movements represent current judgments.

ABA has been and is conducting a comprehensive site investigation and other engineering studies oriented towards determining probable accelerator housing movements. Briefly the investigations include:

1. A detailed geological and soils investigation.
Reference Dames and Moore Report dated November 14, 1962, and ABA Report ABA-60.
2. Precise level surveys, conducted at intervals from September 1961 to present, of benchmarks established at numerous points on the site. Figure 2(a) presents a plot of cumulative measurements to date. Refer to ABA Reports ABA-1, ABA-41, and ABA-49.
3. Precise horizontal movement surveys by ABA Geodetic Engineering Group from April 1962 to present. Figure 2(d) presents the maximum differential measurements to date. Refer to ABA Reports ABA-49 and ABA-52.

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4. Studies of the use of piles for supporting the accelerator tube or housing, ABA-21 and ABA-62 (attached) and of the rate of change of curvature, ABA-63 (attached).
5. Various consultants have been retained:

Dames and Moore	Soils Engineers (refer to their report dated November 14, 1962.)
Parker Trask	Engineering Geologist (refer to his report dated June 30, 1961.)
Joshua Soske	Geophysicist (letter reports in ABA files.)
U. S. Coast & Geodetic Survey	Letter reports submitted by C. A. Whitten, U.S.C. & G.S. in ABA files
Thomas Thompson	Engineering Geologist (letter reports in ABA files.)
John A. Blume & Associates, Engineers	Seismic Consultant (report to be submitted; also will include report from Dr. Byerly, Seismologist.)

Figure 1 shows ABA's understanding of the SLAC tolerances for differential movements of the Accelerator Housing. The tolerances are discussed in the following sequence.

1. Overall differential movement.
2. Housing vertical location by October, 1965.
3. Maximum deviation per 90 day period.
4. Rate of change of curvature.

OVERALL DIFFERENTIAL MOVEMENT TOLERANCE

^{ABA}
ABA interpretation of this tolerance is that differential movement of any point more than one foot horizontally or vertically from the optimum position would exceed the tolerance. A more liberal interpretation is that as long as the aligned accelerator tube can be enclosed by the two foot square as shown on Figure 1, the tolerance is not exceeded.

Figures 2(a), 2(c) and 2(d) summarize presently available data on differential movements. Figures 2(b) and 4(a) show envelopes based on extrapolation of measured vertical and horizontal differential movements to values for a ten year life. Figure 3(a) shows the addition of Figure 2(b) and 2(c) to provide an envelope of estimated vertical movements applicable ten years after initial alignment of the accelerator tube.

The above figures indicate that vertical soil settlements resulting from earthwork construction, and horizontal movements extrapolated from on site measurements are the prime sources of overall movement.

Soil settlements have a rational explanation, and moderately reliable methods of calculating predictions of these movements have been developed and are accepted by the engineering profession. Although the differential movements expected from soil settlements are known with considerably more certainty than site movements from any other cause, even these predictions are not subject to more than a crude statistical analysis. It is unlikely that soil settlements will be more than double or less than half of predicted maximum values. By the time the housing is constructed the rebound and settlement measurement program will have supplied additional data so that revised estimates of maximum settlement will improve reliability.

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The estimated horizontal movements as shown in Figure 4 are of necessity based on extrapolations of movements measured on the site to date even though the time interval for these measurements is less than one year. At the points of maximum surface movement the measurements have been corrected to apply to the 50 foot deep marks established on the site. There is inherent danger in extrapolating such data as small variations are greatly magnified when extrapolated for a long period.

Several arguments can be advanced as to whether extrapolation gives conservative or unconservative results. Among the arguments that the results are conservative are the following:

1. To date there is no conclusive evidence as to what the precise horizontal measurement program has measured. Probably it is crustal movement of a tectonic nature, some of which is shear strain connected with block movements on opposite sides of the San Andreas rift zone, and some of which may be more local in nature and attributable to the heterogeneous geology in the western portion of the site. Another possibility is that a portion of the observed differences might be caused by a seasonal variation in horizontal refraction, however, the movements measured between adjacent deep and surface marks involve no refraction hence a portion of the measured movements is definitely not refraction.

2. U.S.C. & G.S. measurements of horizontal shear strain caused by block movements connected with the San Andreas rift zone have been in the order of 2 or 3 seconds of arc per 10 year interval, or about 1/10 the magnitude of on-site measurements to date. Their measurements in this general area extend back about 70 years to the original first order triangulation net and since the 1906 earthquake have been concerned with detecting crustal shear strain caused by block movements associated with the San Andreas rift zone.

3. A straight line extrapolation of random effects can give conservative predictions because a short period of observation does not ensure a good estimate of long term trends.

4. It is not yet possible to obtain measurements at the housing level. Since the present measurement program restricts reference marks to ridges and the relatively deep reference marks show attenuation with depth, the movements at housing level may show additional attenuation.

On the other hand several arguments can be advanced that the results are not conservative:

1. The U.S.C. & G.S. measurements of shear strain have all involved comparatively long sights of several miles in length in order to obtain the required accuracy of angular measurements. To obtain meaningful measurements a minimum time interval of several years between observations has been used.

It does not seem surprising, therefore, to observe rates of movement of relatively large magnitude under the present program where the measurements are made between points considerably closer together, and at shorter intervals between measurements. The long distances between the U.S.C. & G.S. marks would tend to mask non-linearity of strain between the marks.

2. In a similar manner site measurements to date have been restricted to relatively high points which provide inter-visibility. It is quite possible that reference marks are not at the points of maximum movement and a denser spacing of reference marks would reveal larger movements.
3. Although soil settlements show attenuation with time, tectonic movements do not behave in a similar manner. Earthquakes along the San Andreas fault system tend to relieve shear strain in the adjacent blocks by slippage along the fault. Data on such phenomena, however, is still so meager that forecasts of such action are not attempted.
4. A straight line extrapolation based on a short period of observations can also give an unconservative estimate.

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HOUSING VERTICAL LOCATION TOLERANCE BY OCTOBER 1965

As stated in the Dames and Moore report the specified tolerances can be attained. At each point along the housing the construction elevation will be adjusted to compensate for the predicted settlement by Oct. 1965 at that point. The ability to meet this tolerance is contingent on further refinement of present soil settlement predictions. As outlined in ABA Report ABA-64 a detailed program of measurement of rebound and settlement markers will verify foundation properties along the accelerator alignment thereby improving the accuracy of settlement predictions.

MAXIMUM DEVIATION PER NINETY DAY PERIOD

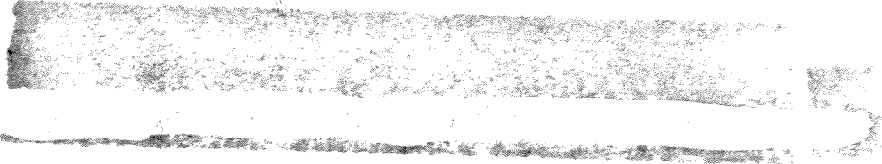
Investigations to date indicate this tolerance can be met. A maximum differential movement of $\frac{1}{4}$ inch in 90 days implies less than 10 inches in 10 years at a relatively constant rate, and is somewhat more restrictive than the tolerance of plus or minus one foot differential movement in ten years. The vertical soil settlements generally follow an exponential decay curve and will probably exceed the tolerance rate immediately following construction but prior to October, 1965. Near Station 60, the area of maximum predicted soil settlement, the decay curve slope is expected to be relatively constant following October, 1965 and is not expected to exceed the $\frac{1}{4}$ inch in 90 days tolerance. The horizontal movement data for this tolerance are still meager, but measurements to date indicate this tolerance will not be exceeded.

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RATE OF CHANGE OF CURVATURE TOLERANCE

Report ABA-63 discusses this tolerance. It appears quite certain that the 0.01 inch in 40 feet in 90 days criteria cannot be met at the site. Further refinements of the estimated behavior will be possible as additional information is developed. At the present time a rate of 0.05 inches per 40 feet in 90 days appears a reasonable estimate.

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REPORT TO STANFORD LINEAR ACCELERATOR CENTER - NO. ABA-65

STANFORD UNIVERSITY SUBCONTRACT S-136

UNDER AEC CONTRACT AT(04-3)-400

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