INVESTIGATION OF BENCHMARK ELEVATION CHANGES IN THE SAND HILL AREA

Submitted by  

Approved by  

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INVESTIGATION OF BENCH MARK ELEVATION CHANGES IN THE SAND HILL AREA

ABSTRACT

Repeated level surveys of bench marks in the Sand Hill area, site of the proposed Stanford Linear Accelerator, disclose a complex pattern of small fluctuating elevation changes, averaging 0.04 feet between successive observations. These movements are apparently taking place in the upper soil layers. A limited correlation is found between the direction of movement and seasonal differences in accumulated rainfall used as an index of soil moisture. Continuation of the study will include a program of precise instrumental observation together with a geologic review of the environment of the site.
I. INTRODUCTION

This report presents the results of an investigation made of bench mark elevation changes in the Sand Hill area near Stanford University at Palo Alto, California. The Sand Hill area is the site selected for the proposed Stanford Two-Mile Linear Electron Accelerator.

Bench mark elevation changes are tabulated in the publication entitled 190 A California, Coast and Geodetic Survey First-Order Leveling, San Jose Area, California, 1912 - 1954 Leveling. In 1931-1932 a re-run of the U. S. Coast and Geodetic Survey's 1912 level lines in the San Jose area disclosed large settlements of some bench marks. Subsequent investigations included re-running a network of first-order levels at irregular intervals. First-order leveling is defined as that category requiring the highest precision of the various classifications of level surveys.

Comparison of levels at the bench marks in the network shows that the elevation changes reach a maximum in the Sunnyvale-San Jose area. These cities are located on an alluvial plain in the northern Santa Clara Valley at the south end of San Francisco Bay. The subsidence of these lands is generally attributed to over-draft withdrawal and depletion of ground water from successively deeper water-bearing layers with subsequent compression of deep compressible layers of alluvium.

Maximum subsidence occurs approximately in the center of the valley where the alluvium is probably deepest, with decreasing settlement observed as the lines approach the bedrock areas bordering the plain. The network of levels has been extended outward to bedrock regions in order to establish the limits of the area of subsidence.
II. SAND HILL AREA

A. BENCH MARK LOCATIONS

The Sand Hill area lies in the foothills bordering the alluvial plain northwest of San Jose. The network of first-order levels extends far enough into the foothills so that a boundary leg, Line 3, running southwest from the city of Menlo Park, encircles the Sand Hill area. The bench mark circuit around the site follows a diamond-shaped road loop, with Alameda de las Pulgas and Alpine Road on the northeast and southeast boundaries, Portola Road and La Honda Road following the San Andreas Rift Zone on the southwest boundary, and Woodside Road forming the northwest leg. Figures 1 and 2 show the bench mark locations on this road loop.

An extension of Line 3 connects the bench mark loop around the Sand Hill area to the city of Menlo Park, but the bench marks along this extension lie in the alluvial plain and their behavior is consequently not typical of the foothill area. The bench mark series encircling the Sand Hill area is called Loop 3 to distinguish it from the entire series in Line 3.

B. GEOLOGIC ENVIRONMENT

The Sand Hill area lies in a region of low, rounded foothills, between the Santa Cruz Mountains to the west and the alluvial plain bordering San Francisco Bay to the east. The rift valley of the San Andreas Fault lies along the base of the Santa Cruz Mountains, separating them from the Sand Hill foothill area.

Loop 3 is the perimeter of a small section of foothills approximately centered on the Sand Hill area. Alameda de las Pulgas, on the northeastern side of the loop, lies generally in the alluvial plain and bench marks on this road are founded on moderately deep alluvium. Loop 3 then follows Alpine Road
and Los Trancos Creek southwesterly across the foothills area to the San Andreas rift valley on the western boundary. Bench marks along this leg are founded in the creek flood plain area in shallow alluvium.

The southwestern leg of Loop 3 lies along Portola and La Honda Roads in the San Andreas Rift Valley. Repeated movement along the active San Andreas Fault has produced typical rift zone material, including crushed sandstone and clay gouge. Thin alluvium overlies the fault zone material.

The closing northwest leg of Loop 3 follows Woodside Road which leads northeasterly to an intersection with Alameda de las Pulgas at the point of beginning. Nearest the rift zone the bench marks are founded on thin alluvium overlying Pleistocene sand and gravel. In the remainder of the leg the monuments are placed in thin alluvium overlying Eocene sandstone and shale. The geologic environment of the bench marks is shown in Figure 1.

The Sand Hill accelerator site lies entirely within the foothill area circumscribed by Loop 3. The proposed accelerator alignment lies across steeply-dipping Eocene shales and sandstone in its western portion, and across flat-lying Miocene and Recent sandstone and cemented gravel in its eastern portion. The low rounded foothills are thinly mantled with residual soils from 1 to 5 feet deep. Deeper alluvium is found on three short lengths of the alignment, where the proposed location lies across low valleys.

III. ELEVATION DIFFERENCES

A. CHARACTERISTICS OF CHANGES

U. S. Coast and Geodetic Survey records of first-order leveling in the Loop 3 area show re-runs at irregular intervals from as little as five months
between runs to a maximum of over eight years. The elevations are recorded in feet and in tenths, hundredths, and thousandths of feet. It is noted in the record, however, that elevations should not be considered to be accurate to three decimal places because of adjustments for closure errors.

1. **Net Movements:** Bench mark elevation changes are shown in the graphs and charts accompanying this report. An initial distinguishing characteristic of Loop 3 bench marks is the tendency for elevation changes to be positive about as often as negative. This area is obviously not subject to the deep subsidence typical of the San Jose-Sunnyvale region of deep alluvium. Examination of the graphs of Figure 1 shows that the overall change up to 1954 measurement was downward for 19 monuments, upward for 10, and 6 are approximately at their initial levels. The distribution of changes around Loop 3 is apparently not subject to a geographic control other than a propensity for those bench marks along Portola Road to show an overall subsidence between the initial measurement and that in 1954. Using the 1948 measurements for the Portola Road bench marks essentially destroys even this relationship. Consequently, it does not appear from the available data that there is any simple vertical movement of the entire Loop 3 area such as an overall subsidence or rise. A persistent tendency is noted toward relatively constant elevations of the bench marks near the intersection of Loop 3 and the prolongation of the proposed linear accelerator alignment in the Sand Hill area, suggesting that any simple bodily movement of the entire area might be restricted to a warping or rotation about an axis lying approximately on the accelerator alignment.

2. **Successive Observations:** Elevation changes are shown graphically in Figures 1-12. The maximum change between successive observations is a rise
of 0.10 feet at bench mark N151, a concrete post in the San Andreas rift zone. This monument has subsequently been lost. This change was measured after a five month interval. Bench marks on either side are 0.3 and 0.4 miles distant from N151 and show rises of 0.05 and 0.06 feet for the same period.

In the period between January 1933 and February 1940, Loop 3 was re-rum at relatively frequent intervals ranging from 5 months to 15 months and averaging 12 months between readings. After 1940 the re-runs occurred in 1948, 1954, and 1960. 1960 data is not yet available in a final form. Figures 3-12 show elevation changes in hundredths of feet for bench mark locations in Loop 3 for each interval.

3. Average Changes: In the 1933 to 1940 period the average number of bench marks whose elevations were recorded was 29. The average number showing a rise was 10; the average number showing a fall was 12, and an average of 7 showed no change. The average amount of rise between successive observations was 0.02 feet; the average amount of fall was also 0.02 feet; and the average change in elevation was 0.04 feet, indicating that the general pattern is an alternating rise and fall of about the same amount. This is generally borne out by the appearance of the graphs of the changes in elevation with time. (Figure 1)

4. Amplitude of Change: The amplitude of change is a matter of importance because extensive elevation change in the accelerator might require frequent shutdown for re-alignment if these movements exceed the steering control capabilities built into the machine. For this reason the relationship between type of material and amplitude of movement is important.
The largest differences in elevation apparently occur in the San Andreas rift valley. The average change in these elevations, to three decimal places, is 0.022 feet, whereas in the bench marks not in the rift valley the average difference between successive readings is 0.016 feet. The single bench mark setting most geologically comparable with the western end of the Sand Hill site, in Eocene shale and sandstone, is probably D151, which is located on a bridge abutment on Eocene shale and sandstone. D151 has a record of no elevation change in the period of observation, from 1933 to 1954. There is no comparable deep monument in Miocene materials, characteristic of the eastern end of the Sand Hill site.

B. POTENTIAL CAUSES OF CHANGES

There are a number of possible explanations for the changes in bench mark elevations. These include natural processes in upper layers, such as volume change with changing moisture content, consolidation, plant and animal-caused disturbances and other physical and chemical changes. Man-caused disturbances may include nearby excavation and road building, settlement of roadway under vehicle and pavement weight, agricultural operations, and vandalism. Large scale tectonic movements and geophysical processes may also be responsible for some part of these movements, although these effects tend to be uniform over fairly large areas. Typical examples are crustal deformation because of differential movement on the San Andreas Fault, orogenic processes, earth tides, expansion and contraction with seasonal temperature changes, and crustal deformation caused by the weight of rainfall and by ocean tide effects. Elevation measurements are also subject to various inaccuracies inherent in the measurement system. In the subject situation it is not likely that much error can be attributed to the measurement system because of the relatively precise character of U. S. Coast and Geodetic Survey first-order leveling.
1. **Rainfall Correlation**: It has been postulated that part or all of the elevation changes might be attributed to volume changes in the underlying materials in response to changing moisture content. Some of the geologically younger materials are known to exhibit this type of behavior in an unconfined state.

The relationship between rainfall as an index of moisture content in the soil, and elevation changes in the bench marks has been investigated. Rainfall records for Palo Alto are available for the period from 1923 to the present, and at Searsville Lake from 1949 onward. Rainfall records are admittedly not the best index of moisture content in the soil but there is no other known source of better information readily available. The western portion of the area is better represented by Searsville Lake records; however, the Palo Alto rainfall shows a fairly reliable proportionality with that of Searsville Lake. Comparisons were made on the basis of direction of change in accumulated seasonal rainfall, and for this purpose the constant proportionality between Palo Alto and Searsville makes the Palo Alto record entirely adequate.

A simple statistical approach to correlation was made by comparing direction of change of accumulated seasonal rainfall between successive elevation measurements with the direction of elevation change. Agreement in direction of change between accumulated rainfall and elevation was listed as a "yes" and of disagreement as a "no" value. For a particular bench mark a correlation index was obtained by summing "yeses" and "noes" and dividing the total "yeses" by the total "noes". A value of 1 for this ratio would suggest a completely random pattern and no correlation. The "yes"/"no" ratio can be considered a form of correlation index.
2. **Physiography:** Relating the correlation index pattern to geology, topography, and type of monument discloses several suggestive characteristics. The series of bench marks along the San Andreas rift zone shows an average correlation index of 1.7, indicating that there probably is some relationship between accumulated rainfall and elevation change in the fault zone.

   a. **Geology:** Three bench marks in thin alluvium over Miocene siltstone have an average index of 0.8; two in alluvium over Recent sandstone and shale have an average of 0.3 and two in deep alluvium have an average ratio of 0.5. These values are all based on so few stations that the findings are not reliable, but the indications from these few stations are that correlation does not exist in these materials.

   b. **Topography:** Topographic settings of the bench marks include two major categories, rift valley and creek valleys, because the roads along which the bench marks are placed are generally in one or the other. Creek valley bench mark indices show an average value of 0.9, indicating a lack of correlation. The rift valley index is again 1.7 because the geology and topography are continuous along the fault zone in this system of classification. The same 15 bench marks make up both categories. The correlation is consequently the same. Other topographic environments are too poorly represented to yield reliable indices.

   c. **Type of Monument:** Monuments were divided into three categories; concrete posts, bridge structures and culvert walls. The concrete post category shows an average index value of 1.4, suggesting a certain degree of correlation. Bridge structure monuments show an average index of 0.5. The index for culvert walls is 1.0.
C. PROBABLE SOURCE OF MOVEMENTS

The moderate correlation which apparently exists between bench marks founded in the uppermost soil layers, particularly in the crushed material of the fault zone, and the moisture content as measured by accumulated rainfall suggests that a likely source of elevation change is variation in moisture content in the uppermost soils, particularly in soils typical of the fault zone. Residual soils of the fault zone are likely to be clayey fault gouge material or highly comminuted rock material, probably with advanced weathering of the fragments and a subsequent development of clayey mineral components. It is noteworthy that those bench marks on bridge structures, founded deeply in the earth, show generally little movement and poor correlation with rainfall, regardless of the type of surface soil at the bridge site. In fact the U. S. Coast and Geodetic Survey publication notes that two of the four bridge locations in Loop 3, D151 and R151, show so little difference in elevation that they have been used as reference elevations and all other local bench marks adjusted to these bridge elevations. The underlying material at D151 is Eocene sandstone and shale; at R151 the underlying materials are crushed sandstone and fault gouge. Residual soils derived from these materials are typically subject to volume change with varying moisture content. Lack of movement at these locations suggests that it is the upper soil material which changes volume with moisture content, thereby causing corresponding bench mark elevation changes.

The method of construction proposed for the accelerator includes stripping surface soils along the entire alignment and excavating the deeper alluvium in the low points. This material will be replaced with compacted select material not subject to a large variation in moisture content nor to significant changes in volume with changing moisture content. Compaction to 95 per cent maximum
modified AASHO density as proposed plus the extensive surface and subsurface drainage system planned should eliminate essentially all elevation changes attributable to varying moisture content in alluvial surface soil. A program of rigid control of foundation material selection, placement and compaction will be employed in the accelerator housing construction. Emphasis will be placed on the exclusion of all material susceptible to significant volume change with varying moisture content. Furthermore, the control of foundation material will result in a relatively uniform material along the accelerator length, so that any small volume change in the uppermost material will occur uniformly along the entire length of the accelerator. This type of movement will not affect the beam alignment, especially in the small range of overall movement likely to occur.

IV. SUMMARY AND CONCLUSIONS

Bench marks in Loop 3 show elevation changes averaging 0.022 feet between successive measurements along the San Andreas Rift Valley and 0.016 feet in other areas. Those in line with the accelerator show relatively little movement. Cause of these movements is not known, but the fluctuating nature of the changes suggests a seasonal variation, perhaps moisture content in the surface soil layers. There is no firm overall relationship demonstrated between the changes and the seasonal rainfall, or geology, or topography. The greater movements of the shallower concrete monuments as compared to essentially negligible differences in elevation of bench marks on the larger, deeply founded concrete bridges suggests that the movement is primarily confined to upper layers. In view of the apparent proclivity for these movements to occur in the upper soil layers, the location of the accelerator in the thinly-mantled
Sand Hill area together with the proposed removal of all surface soil and replacement with engineered fill should essentially eliminate this cause of elevation variation. Consequently, it is felt that the anticipated elevation variation in the finished accelerator structure will not require realignment at other times than during normal maintenance shutdowns for other causes.

The major conclusions of this investigation are as follows:

1. The Sand Hill site is in a bedrock region at the edge of the San Jose subsidence area.

2. U.S. Coast and Geodetic Survey re-leveling data for bench marks around the Sand Hill site show a pattern of fluctuating small-scale vertical movements, suggesting response to some form of seasonal control.

3. No firm relationship was found between accumulated rainfall, as a measure of soil moisture, and elevation change for any of the several geologic or geographic environments except for an apparent correlation in the group of bench marks along Portola Road, in the San Andreas rift zone.

4. Bench marks on deep foundations show essentially no change in elevation in comparison with the small vertical movements of marks on shallow foundations, suggesting that movements in upper soil layers are responsible for the measured elevation differences.

5. Indicated average movements are within the tolerances allowed by steering element control together with routine maintenance adjustments.

6. Proposed foundation construction measures should eliminate most of the minor changes that could be caused by upper soil movements.
V. CONTINUATION OF INVESTIGATION

A. INSTRUMENTAL OBSERVATION

A series of bench marks was established during the 1960 second-order level survey of the Sand Hill site for Volume IV of the Blume report. A first-order re-leveling of these bench marks has recently been completed. Exact comparison of these two surveys is not possible because of the difference in precision between first-order and second-order leveling. The results do show, however, that no significant changes in bench mark elevations have taken place. Minor differences in elevations are noted of about the same order of magnitude as in the U. S. Coast and Geodetic re-leveling of Line 3. Since a major part of the measured differences lie within allowable second order survey error, precise differences cannot be determined.

The first-order level survey will be repeated early in May 1961. It is also proposed that the first-order level survey be re-run at bi-monthly intervals to establish the order of magnitude, within first-order survey error, of any movement that may be occurring. If no movement is found, the first-order survey will be repeated at longer intervals. If some movement is found, a more accurate measurement technique may be employed to establish magnitude and rate of change so that project design criteria can be adjusted to compensate for the indicated movement.

B. GEOLOGY REVIEW

In addition to the program of continuing bench mark level observation a consulting engineering geologist of national repute has been retained to review the geologic information gathered to date. Preliminary results of this review will be available in the near future.
CHANGE IN HUNDREDTHS OF FEET

FIGURE 3

JAN. FEB. 1933
JUNE JULY 1934
Note: This reading ruled out because of exposed position in parking area and apparent disturbance by sewer construction.

CHANGE IN HUNDREDTHS OF FEET

JUNE - JULY 1948
APRIL - MAY 1954

Palo Alto Rainfall