REPORT OF EARTH MOVEMENT

PORTUGUESE BEND, CALIFORNIA

April 26, 1957

MACKINTOSH & MACKINTOSH
Consulting Engineers
Los Angeles 4, California

II-8

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I. GENERAL DESCRIPTION

The present ground movement is of a 200-acre area extending from above the major body of a large fill on Crenshaw Boulevard southward about 3,500 feet to the ocean and extending over a width of about 2,500 feet, and is of an irregular shape. The eastern edge of the movement is most well defined and most rapid. The westerly edge of the movement is not yet clearly defined. The movement is, therefore, partly one of rotation. Portions of the upper northerly edge of the movement are clearly defined, as is the southerly edge. Some of the movement is in the tide area.

The surface of the ground contains some smooth valleys, but is mostly comprised of rounded hills, and it slopes up from the ocean at an average of about 7 degrees. Large areas are presently undeveloped. About 33 per cent is developed and provides the sites for 158 residences more or less, and the Portuguese Bend Club.

Palos Verdes South highway crosses the lower portion of the slide. Crenshaw Boulevard, an unfinished highway, runs generally the length of the slide area. Smaller residential streets are on the westerly and on the southerly sides of the area.

A moist, fine, clay slickensided plane of movement is exposed in portions of the southerly edge of the slide. (See Photos I, II, and III.)

The most rapidly moving portion of the slide has traveled about 22 feet in the seven months between September 17, 1956, and the date of this report.

II. RESEARCH, MEASUREMENTS AND TESTS

Investigation was needed to determine the following:

a. rate of movement

b. thickness of moving mass

c. position and inclination of slip-plane

d. location of ground water

e. composition of slip-plane

f. effect of surcharge on slip-plane

g. effect of moisture

h. effect of rate of movement on resistance

i. effect of remolding clay

j. effect of viscosity

k. measurement of unbalanced forces

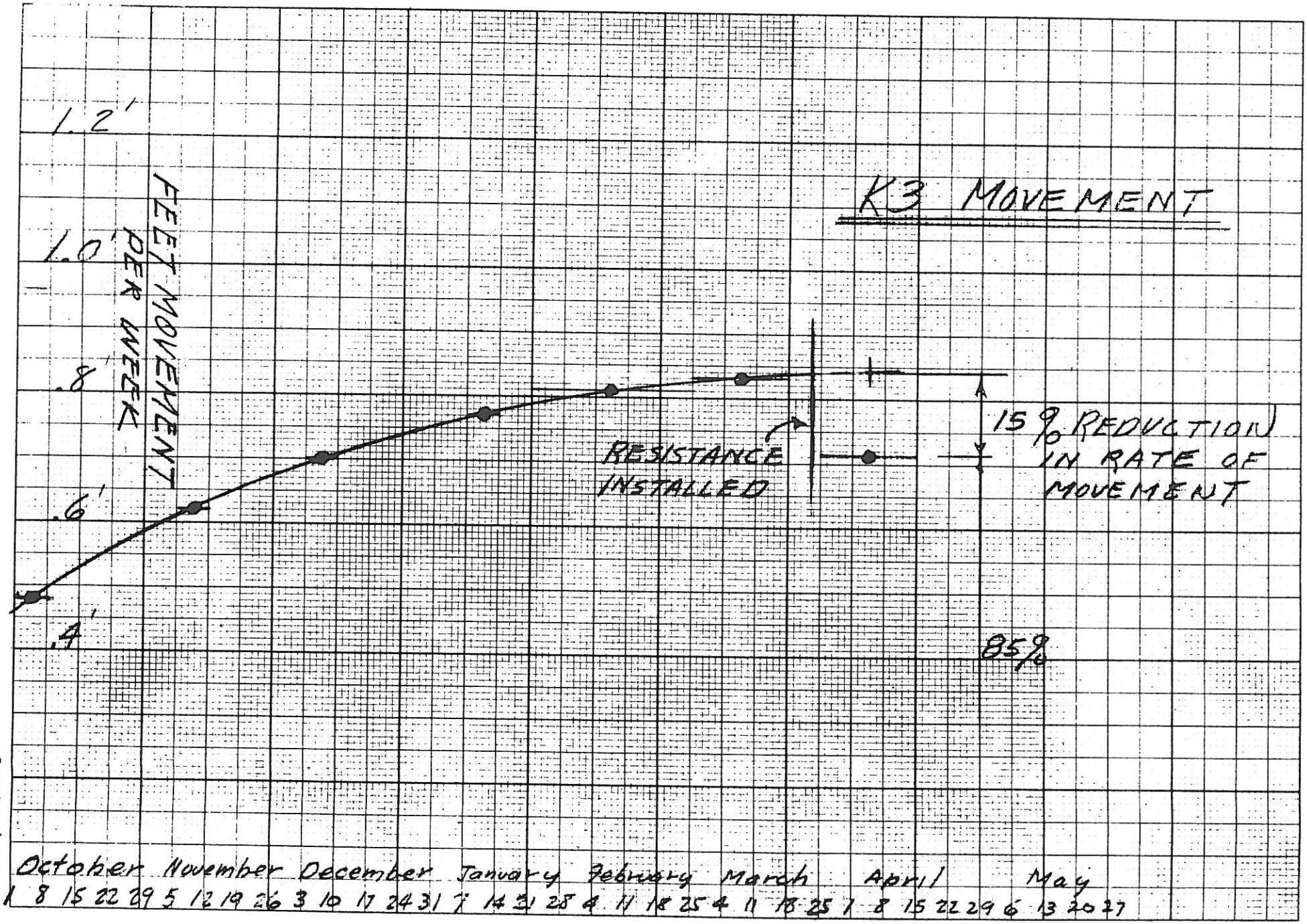
m. previous movement

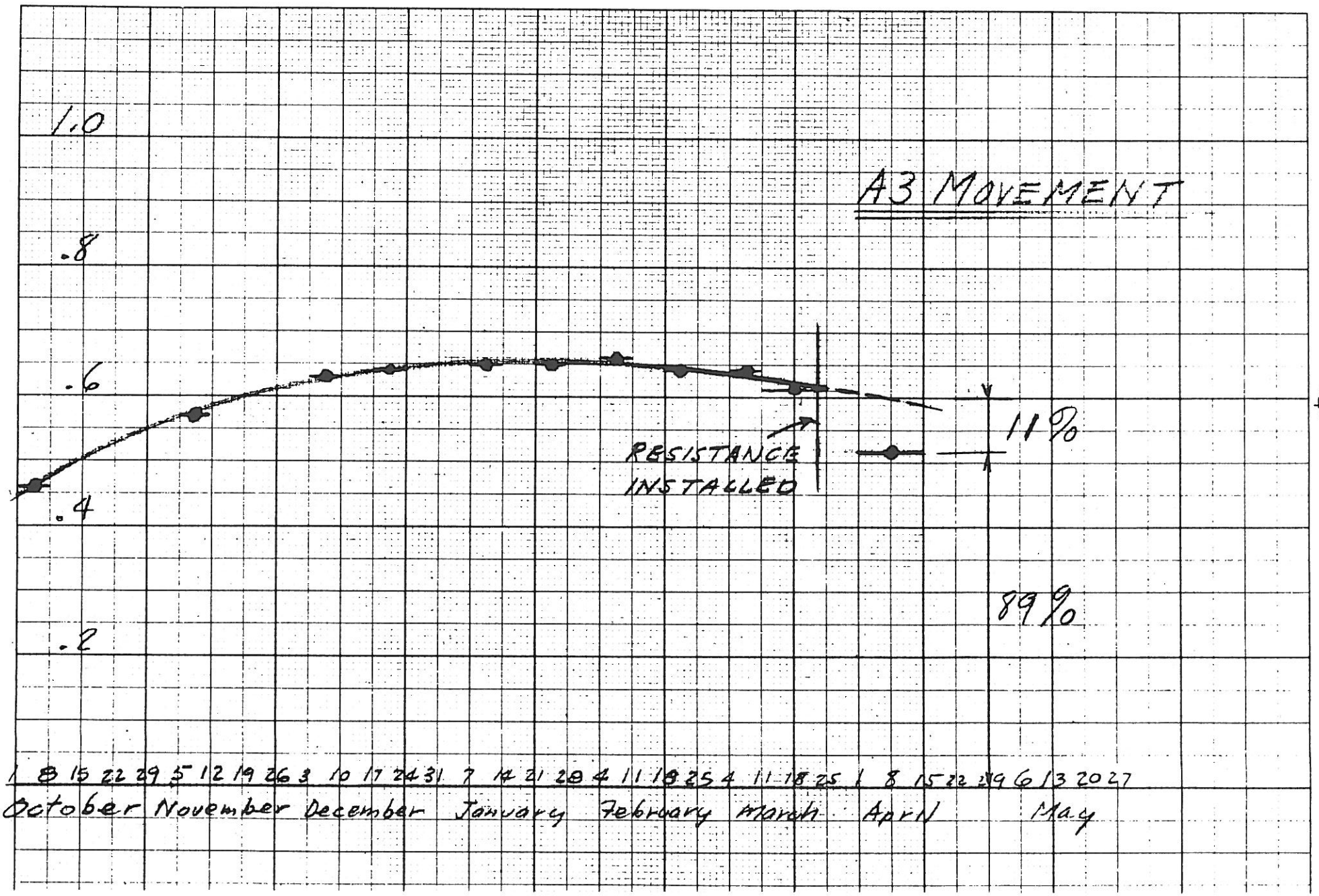
n. comparable movement

o. effect of Crenshaw fill

A brief summary of the results of the investigation is as follows:

a. The rate of movement has generally increased throughout the entire time of observation until certain test resistances were installed, March 22, 1957. The increase has been very uniform and generally at a decreasing rate except for certain portions on the westerly side which have joined the movement from time to time and have tended to "catch up" with the main moving portion. That percentage of the movement which is rotation is thus decreasing as the western side of the movement tends to become more clearly defined.


K3 MOVEMENT
FEET MOVEMENT PER WEEK
1.2'
1.0'
.8'
.6'
.4'
RESISTANCE INSTALLED
15% REDUCTION IN RATE OF MOVEMENT
85%
October November December January February March April May
1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18 25 4 11 18 25 1 8 15 22 29 6 13 20 27


A3 MOVEMENT
1.0
.8
.6
.4
.2
RESISTANCE INSTALLED
11%
89%
1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 4 11 18 25 4 11 18 25 1 8 15 22 29 6 13 20 27
October November December January February March April May

The horizontal movements of many points scattered over the surface of the slide area have been recorded by public and private survey parties. From data of the County Surveyor, seven months movement of K3, a central point near the bottom or south end of the movement, and of A3, a point on the easterly side, 2,300 feet to the northeast, has been plotted on the attached large graph at the back of this report. Graphs I and II have been plotted from this to show the rate of change of movement at K3 and A3 throughout the same period. The maximum movement has increased from about one foot in 15 days the first of October, 1956, to one foot in $8\frac{1}{2}$ days about March 10, 1957.

When the movement was measured by continuously recording clocks (See par. m) a probable correlation between the hourly movements and the strong tides was found. This indicated that the total unbalanced forces were probably smaller than previously anticipated.

b. The thickness of the moving mass was found to vary usually between 50 and 160 feet. The total weight in motion is therefore about 80 billion pounds. However, since the average rate of movement is one inch or less per day, computations show that the force necessary to overcome inertia is almost negligible.

c. The average inclination of the slip-plane was found to be about 6 degrees. Steeper than average inclination was found along the eastern and northern boundaries and at portions of the south and west boundaries, and also at several interior strips

generally lying underneath areas of surface cracking. The steepest "downward" inclination was found along the north boundary near the location of the maximum depth of Crenshaw Highway fill. The inclination of about 20 degrees has caused a drop in the earth level of as much as 6 feet. The steepest "upward" inclination has occurred at the bottom end of the slide and has caused a 5-foot rise in ground surface level of a portion of the pier.

d. The level of the water table north of Palos Verdes South was in general well below the slip-plane. The water level is above the slip-plane in the area of the Club and also near the south end of the slide generally wherever the slip-plane is below sea level.

e. The composition of the slip-plane was found to be a brownish-gray waxy clay. "The average sliding resistance along the contact plane between the clay and shale in the pier area is approximately a cohesion of 300 pounds per square foot with a sliding angle of six degrees" (Dames & Moore - Report of Soil Sampling and Laboratory Tests). The thickness of the clay varied from perhaps one-hundredth of an inch to twelve inches and appeared to have a uniformity caused by mixing during some previous movement. Eight widely separated holes showed quite similar material in each case.

The movement is on a slickenside either in the clay or at the juncture of the clay and an underlying reddish-brown softened shale. Photo I shows a piece of the upper surface of the slickenside. Photo II shows the projecting upper surface of the slide

west of the pier. Photo III shows the lower surface of the slide exposed between Palos Verdes South and Yacht Harbor Drive.

f. The effect of surcharge was laboratory-tested and since the smallest sliding angle which could be obtained was six degrees, surcharge would tend to increase sliding if it is placed over a steeper portion of the slip-plane and conversely would retard sliding if it is placed over a flatter portion of the slip-plane.

g. "The natural moisture content of the brownish-gray clay ranged between 26 and 37 per cent of the dry weight. . . . A change in moisture content from the field condition to saturation reduced the shear strength approximately 7 per cent. . . . It is believed that the soil forming the contact plane is now nearly saturated. If it were possible for additional water to seep into the contact plane, the sliding resistance might be reduced. However, if the soil forming the contact plane could be dried out, the sliding resistance might be increased." (See Dames & Moore - Report of Soil Sampling & Laboratory Tests.)

h. No effect of rate of movement on resistance was found by laboratory tests. This indicates that any such effect is probably on the order of less than 1 per cent of the frictional resistance for the slow velocities under consideration.

i. The effect of remolding the brownish-gray clay was such that "a reduction in shear strength of approximately 6 per cent occurred. . . . The average shear strength of the brownish-gray

clay determined by direct shear tests for various condition of moisture and remolding is approximately a cohesion of 1,000 pounds per square foot at an apparent friction angle of 30 degrees. . . . A reduction in shear strength of approximately 37 per cent occurred when the shear planes of the remolded samples were artificially smoothed."* No remolding or smoothing was able to produce a friction angle as low as that found by carefully hand-carving specimens and orienting the surfaces in their natural positions.

j. The force to overcome viscosity was investigated by test. The term viscosity is used in this report to indicate those resistances which vary with velocity, whereas the term friction is reserved for those forces which vary with pressure or surcharge. It is assumed that the term cohesion may best be applied to those forces which give shear strength to the unbroken or unsheared or remolded specimen.

Since the thickness of the viscous material of the slickenside could not be determined with any degree of accuracy, a direct test was made to determine the change in velocity which would be produced by the insertion of a relatively small resistance. It was assumed that the friction on the slickensided plane was equal and opposite to the horizontal component of the weight of the moving earth on its 6-degree slope. The friction of the area of movement was estimated on January 28, 1957, to be about 7 billion pounds. The viscosity effect was assumed to be not more than one per cent of the friction as mentioned in paragraph "h" above,

*Dames & Moore - Report of Soil Sampling and Laboratory Tests

that is, not more than 70,000,000 pounds and not less than 10,000,000 pounds.

k. Measurement of unbalanced forces. Two twenty-foot-long reinforced concrete pins, 4 foot in diameter, and designed to produce 1,000,000 pounds of resistance as shown on page 10, were inserted and grouted in holes which were drilled vertically across the slip-plane at a convenient location near the bottom end of the slide in a region of maximum movement. (See Photos IV & V.) The stress in the steel shell was measured with strain gages.

The velocity of the slide was measured by continuously recording clocks placed at two locations along Yacht Harbor Drive near the south of the slide and at one location near the gardener's cottage 3,000 feet to the north. Additional measurements were made by surveyors and by scribe-tables and by other clock recording devices.

Photo IV shows the holes being prepared for the pins. The hole in the foreground is covered by a hinged protective gate. A segment of the hard earth encountered below the slip-plane is in the foreground by the gate. Standards on which to mount the recording gage box appear as ladder in the left rear and the 4-foot diameter 8-foot section of pipe at the rear was used to trim the hole.

Photo V shows one of the precast reinforced pins being lowered into one of the drilled holes.

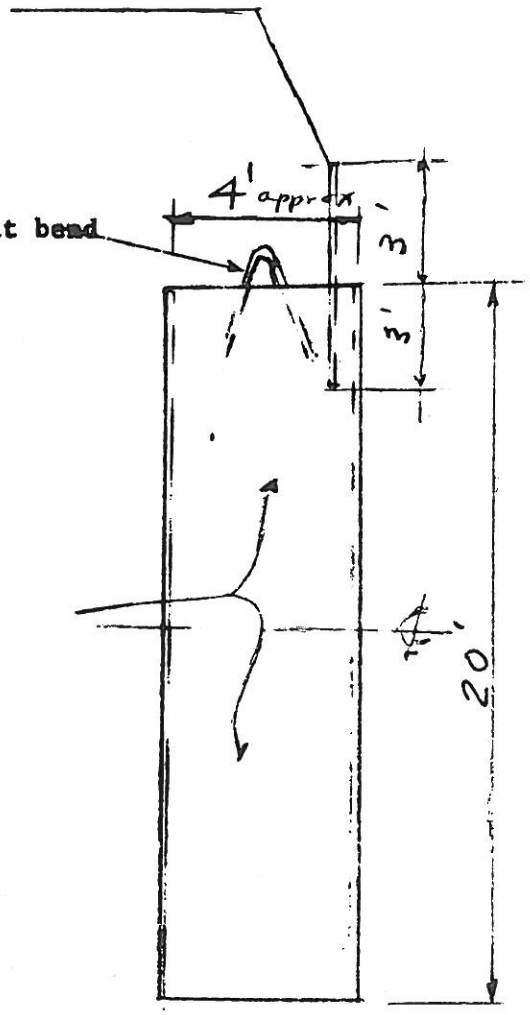
The ground underneath the slip-plane at the locations chosen was found to be exceptionally firm and the strain gages show that

LOT_____ BLOCK_____ TRACT_____ JOB NO. LC-CI6-780 C

JOB ADDRESS_____ FOR Palos Verdes Properties

Portuguese Bend

Let 2" threaded pipe project from top of cylinder and provide extensions for easily observing tipping movement.

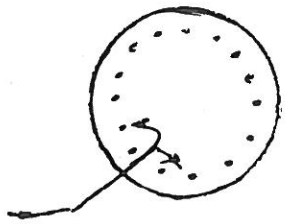


Pipe of approx. 4' dia. and of ~~1/4"~~ used 3/16" thickness shall be clean and free from grease, to provide concrete bond. Avoid circumferential welds in the middle half of the length.

Fill with about 1,000# of ~~used~~ new reinforcing steel,
(no pipe) and with high early strength vibrated 2,000#/sq. in. - 7 day concrete of not over 4 in. slump. Do not splice rein. near slip plane.

Drill hole to depth which will place c.l. of pipe length approx. at the slip plane

Approx. 6 SR4 or other strain gages to be installed on steel pipe by testing laboratory which shall take readings twice daily for at least one week.



Reinforcing

20 — #11 BARS

BY [signature]

DATE 1/28/57

MACKINTOSH & MACKINTOSH
CONSULTING ENGINEERS
306 NO. VERMONT AVE. LOS ANGELES 4. NORMANDY 2-1184

SHEET NO. 1

the steel was stressed well beyond its elastic limit, so that a total resistance of over 2 million pounds was secured by the test. This force reduced the velocity of the earth movement generally throughout the slide by approximately 15 per cent as shown on graphs I, II, and III, the first 2 graphs being plotted from survey points and the latter graph being prepared from the clock-recorded data. The difference in the percentages shown is not surprising since the surface measurements were made at different points at different times and with different accuracy and there is some distortion in the mass as it moves, caused by the variations in shape and slope of the slip-plane. However, the fact that the slowing movement was immediately evident at widely separated points indicates that the resistances had, as was expected, caused a general slowing down rather than any purely local effect.

A 12% to 15% reduction in velocity caused by a 2 million pound force would indicate that the total unbalanced horizontal force is on the order of 15,000,000 pounds. This is, of course, a rough figure influenced by a number of factors. One variable, for example, is that the certain shearing resistances which are now available will be reduced as the westerly boundary becomes well defined.

m. That a previous movement has occurred some time in history over the same slip-plane over a much larger area in the immediate vicinity to the west is shown by the geology of the area. One recently discovered evidence of this is an extensive

3-foot-wide crack reported found during the new improvement of Palos Verdes South.

Many aerial photos have been taken in Southern California over the years. Several have been discovered which include the subject area. Comparative analyses of 1930, 1952 and 1953 photos now indicate that a movement probably took place during this time on a small portion of the same slide now active around the Club buildings, south of the abandoned portion of Yacht Harbor Drive. This is corroborated by the report that a repair has been required on the Pier at the same point now being damaged. This Club slide area is small and since it is located at a south corner of the main slide it can move without movement of the general area to the north. However, when the general northerly area does move, it forces this small slide to move with it.

n. A recent comparable movement of a very similar slide occurred in 1954 at the Marquez Avenue School playground in Pacific Palisades, about 30 miles to the north. This slide also moved slowly with the first cracks in the ground occurring about 4 months after fills up to 30 feet in depth were placed in order to level the playground. The movement was on a slickenside estimated to be at a slope of 6 to 7 degrees and of the same brownish, waxy, clay appearance. The movement was stopped by placing compacted fill in a ravine at the toe of the movement. (See Report July 9, 1954, by Frederick J. Converse on "Investigation of Site at Marquez Avenue School.")

It is quite possible that the same volcanic action provided the source of bentonitic tuff at Portuguese Bend and at Pacific Palisades and that similar earth movements later occurred. The mound of resisting earth at the bottom of the Portuguese Bend slide has been in past centuries largely washed away by the ocean and the resistance at the bottom of the Pacific Palisades slide was similarly washed away over a long period by the water which created the ravine. In both conditions a state of balanced equilibrium was easily disturbed by the addition of quantities of earth fill.

o. The effect of the fill on Crenshaw Boulevard at the upper end of the slide was investigated. By comparing aerial contour maps which were made both before and after the placement of the fill, determination of the area and depth of moving fill was possible. The area of slide covered by this portion of the main fill averages about 250 feet in width and 500 feet in length, or 125,000 square feet in area, with an average depth of 25 feet, and has a volume of approximately 3 million cubic feet and, assuming 100 pounds per cubic foot, a weight of approximately 300 million pounds.

Due to the steep inclination of the slip-plane under this area (see par. "c") the horizontal component of force over and above an assumed resistance equal to 6 degrees of inclination is 78 million pounds. This force is somewhat more than one per cent of the friction estimated for the entire slide. (See par. "j.") Also an additional horizontal force may be contributed from the body of fill placed somewhat to the west of the above and lying on a slip-plane which is steeper than the average.

III. CONCLUSIONS

Immediate Cause of Slide

In the light of the results of the research measurements and tests which have been conducted on the earth movement at Portuguese Bend, and which have been summarized in the preceding portion of this report, it appears evident that the area now sliding had a very small factor of safety in 1955 and that the immediate cause of the movement in 1956 and 1957 was the placement of the Crenshaw fill noted in paragraph "o."

Remedial Measures

In order to quickly stop the slide, the tests indicate that the placement of reinforced concrete precast pins is most economical and effective. These should be placed at the most convenient locations along the bottom of the movement since, because of the unity of the mass, they will control all of the area above them.

In order to provide a reasonable degree of stability, it is necessary to remove the causative force and to place a body of resistance. This may be done in one operation by trucking the fill from the beginning of the slide at the top down to the foot of the slide at the beach, together with the use of proper revetment, compaction, etc.

Since a great deal of additional damage can be avoided by immediate action, it is important to carry out remedial measures promptly.

IV. RECOMMENDATIONS

It is recommended that immediate emergency action be undertaken in order to protect the large investment in homes, streets, sewers, communication lines, and other utilities and improvements. The sequence of operations should be as follows:

1. a. Install sufficient reinforced concrete pins to bring the slide movement to a temporary stop. (Fifteen or more will be required at an estimated installed cost of $3,000 each.)

   b. Place temporary piping to conduct major sources of sewage to sewers and away from septic tanks.

2. a. Place approximately 30,000 yards of rock (which we understand is available without cost from the Livingston Quarry) as a revetment along the tideland on a line joining the approximate extremities of the southern boundary of the movement, and place a roughly equal amount in the lower areas inside of this boundary to form a base for soil fill.

   b. Remove the major portion of the Crenshaw fill located on the moving slide and place and compact it on and south at the toe of the movement between Yacht Harbor Drive and the rock revetment aforementioned. Place and compact tidal areas at low tide.

c. Remove earth where practical from those areas which are above adjacent ground level and which overlay slip-planes of more than 10-degree inclination to equal with item 2b a total of 200,000 yards.

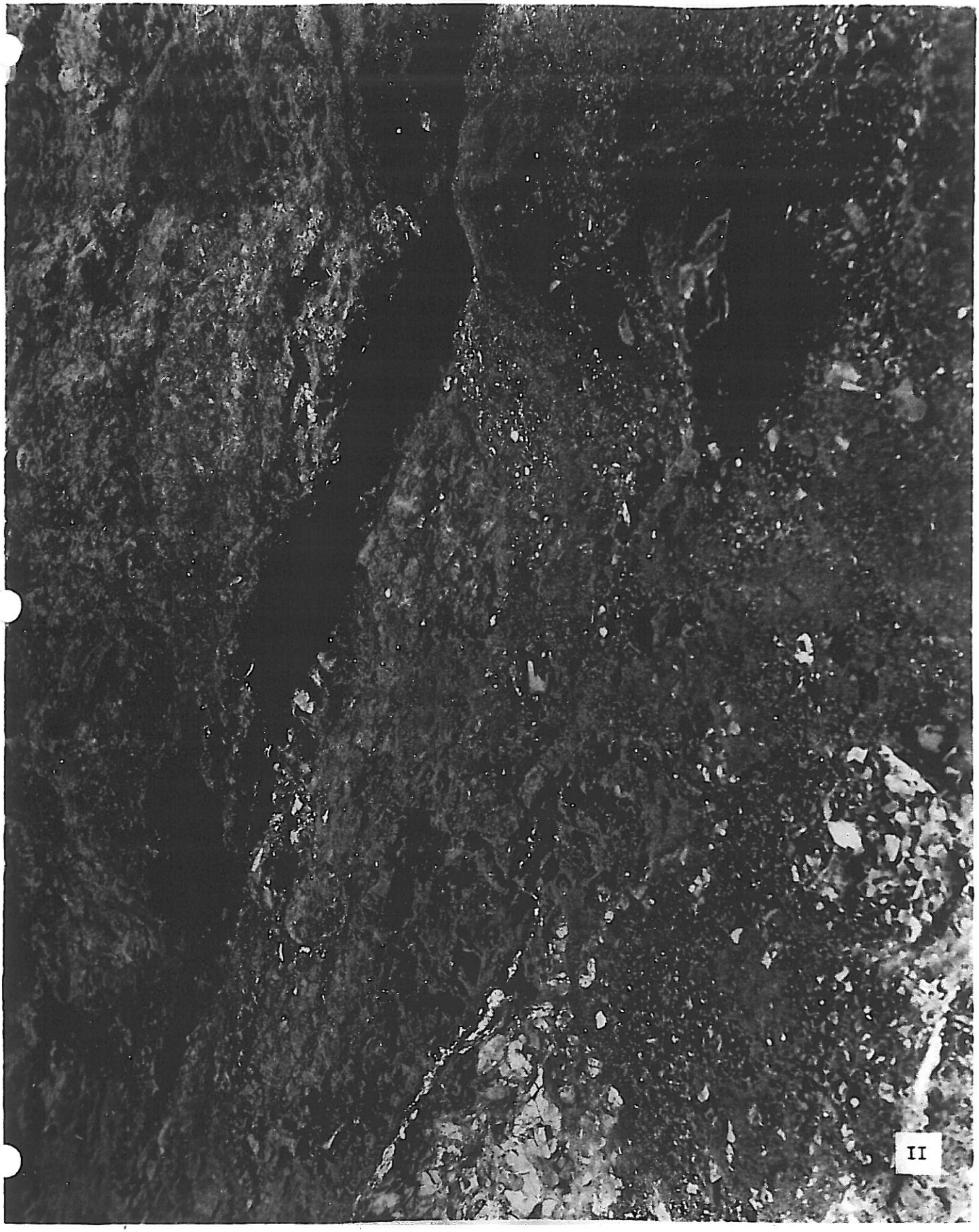
3. Check and improve all water channels as necessary to provide rapid runoff.
4. Grout the known existing surface cracks with a pumped mix of fine sand and cement in a 10-to-1 ratio to deter water from reaching the slip-plane.
5. Install sewers to service residences and all other buildings.
6. Reroute Crenshaw Boulevard through Livingston Quarry to Palos Verdes South.
7. Direct that all future improvement in the area shall be examined to see that it does not reduce the stability of the land mass.

The first of the above recommendations, items 1a and 1b, should be carried out as an emergency measure to bring a stop to the daily damage occurring. It is recommended that items 2, 3, and 4 be pushed to completion before the fall rains. Time is not the essence in items 5, 6, and 7.

* * * * *

MACKINTOSH & MACKINTOSH

By _____
CHARLES MACKINTOSH
Structural Engineer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