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Movement Within Large Fills
San Luis Reservoir Relocation Project

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16. ABSTRACT

In years past the design and construction of highway embankments in California were based largely on considerations of foundation soil conditions. For the most part the largest fills did not exceed much over 100 feet in height. The normal precautions of providing 1-1/2:1 or 2:1 side slopes and requiring a minimum relative compaction of 90% were generally sufficient, for most soils encountered in fill construction, to provide adequate stability within the embankment. The consolidation and strength characteristics of foundation soils have been of much greater concern, especially where marshy soils were encountered. While elaborate design and construction procedures have been developed for fills as a result of intensive foundation investigations, there has veen very little need or motivation, up to this point, to examine the stress and strain characteristics of embankments.

In more recent times, with the increasing tendency towards designing and constructing embankments from 200 to 400 feet high, there has been cause for concern regarding the structural integrity of the fill itself. On several occasions considerable subsidence of the roadway surface and some bulging of the side slopes has veen observed in moderately high fills, where foundation conditions were apparently sound and firm. This has led to conjecture that compression and horizontal movement or so called "fill dialation" was occurring in these instances. It is considered highly probable that the stresses resulting from high fill loadings could actually exceed the strength of some soils used in embankments under certain circumstances. Various theoretical approaches have been made to the problem but a very serious need is felt for data relating to actual compression and movement encountered in high fills.

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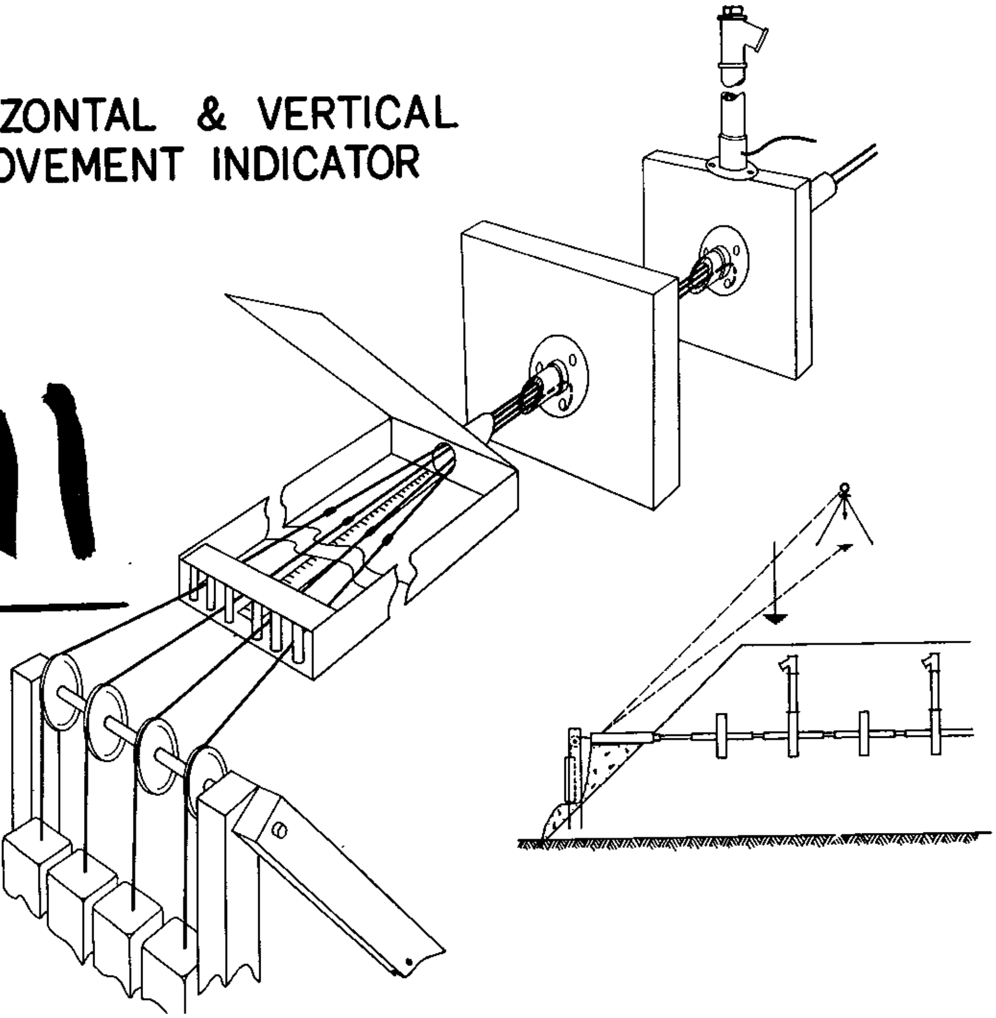
MOVEMENT WITHIN LARGE FILLS

SAN LUIS RESERVOIR RELOCATION PROJECT

HORIZONTAL & VERTICAL MOVEMENT INDICATOR



STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632509–1

December 1966

Prepared in Cooperation with the U.S. Department of Commerce, Bureau of Public Roads

State of California
Department of Public Works
Division of Highways
Materials and Research Department

December 1, 1966

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HPR No. 1(3), D-3-3

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

THE FIRST INTERIM REPORT

concerning

MOVEMENT WITHIN LARGE FILLS

on the

SAN LUIS RESERVOIR RELOCATION PROJECT

Road 10-SCl, Mer-152-P.M. 22.01-34.38

Study made by .... Foundation Section
Under general direction of .... Travis Smith
Work supervised by .... W. G. Weber, Jr.
Report prepared by .... D. R. Howe
L. R. Leech

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attach.
cc: LR Gillis
JF Jorgensen
AC Estep
EF Gregory
RG Elliott
TL Sommers
R Weaver
Prof. Colin Brown, U. C.
CG Beer
Research Files

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ACKNOWLEDGMENTS

The undertaking, described in this interim report, is part of an extensive research project being conducted by the Materials and Research Department in cooperation with the Bureau of Public Roads. This project is financed from the federal 1-1/2 percent research funds under the Bureau of Public Roads authorization HPR No. 1(3), D-3-3.

The contract upon which this study was conducted was under the general supervision of the District 10 construction engineer and the direct supervision of the resident engineer. Recognition is made of the assistance rendered to Materials and Research Department personnel by the resident engineer and his forces during installation of the instrumentation.

INTRODUCTION

In years past the design and construction of highway embankments in California were based largely on considerations of foundation soil conditions. For the most part the largest fills did not exceed much over 100 feet in height. The normal precautions of providing 1-1/2:1 or 2:1 side slopes and requiring a minimum relative compaction of 90% were generally sufficient, for most soils encountered in fill construction, to provide adequate stability within the embankment. The consolidation and strength characteristics of foundation soils have been of much greater concern, especially where marshy soils were encountered. While elaborate design and construction procedures have been developed for fills as a result of intensive foundation investigations, there has been very little need or motivation, up to this point, to examine the stress and strain characteristics of embankments.

In more recent times, with the increasing tendency towards designing and constructing embankments from 200 to 400 feet high, there has been cause for concern regarding the structural integrity of the fill itself. On several occasions considerable subsidence of the roadway surface and some bulging of the side slopes has been observed in moderately high fills, where foundation conditions were apparently sound and firm. This has led to conjecture that compression and horizontal movement or so called "fill dialation" was occurring in these instances. It is considered highly probable that the stresses resulting from high fill loadings could actually exceed the strength of some soils used in embankments under certain circumstances. Various theoretical approaches have been made to the problem but a very serious need is felt for data relating to actual compression and movement encountered in high fills.

Since this factual information is not available from previous experience, it was decided to select a specific "high fill" project and instrument several embankments to obtain vertical and horizontal movement measurements at various points within the fills. The project chosen for this purpose is located approximately 15 miles west of Los Banos and "skirts" along the edge of what will ultimately be the San Luis Reservoir. The project involved the construction of a new four lane divided highway which varies from a minimum elevation of 100 feet to a maximum of 1400 feet at the summit of Pacheco Pass and spans many canyons of the Diablo range. At the lower elevations the vegetation is sparse grass on rolling hills and at higher levels the canyons deepen with rock outcroppings and scrub oak on rather steep walls. Foundation conditions for the embankments are generally excellent with very little settlement anticipated under planned fill heights ranging from 150 to about 250 feet. The location map shown in Figure 1 shows the layout of the project.

The San Luis Reservoir Relocation Project represents the first attempt by the California Division of Highways to obtain direct measurements of both horizontal and vertical movements at various levels within fills. While the instrumentation for vertical movement presented no problems, since settlement platforms of the types employed in many previous foundation studies could be used for this purpose, there was no device immediately available for measuring horizontal movement. After considerable investigation and laboratory trials, an arrangement involving a system of plates, cables and surveying methods was devised to accomplish the purpose. Although preliminary indications were promising for the success of the venture, it remained for the first series of actual field installations to prove the worth of the system.

It is the purpose of this report to describe the installation of the various equipment and discuss the limited test data collected to date. No detailed analysis of data, with respect to stress and strain distribution within the fills, will be made at this time. A future interim report will cover this phase of the study when sufficient data becomes available.

CONCLUSIONS

Approximately two years have elapsed since the intial installation of devices designed to measure horizontal and vertical movements within the two large embankments. The data acquired from the installation is encouraging in that it indicates that movement within high fills can be measured. It is anticipated that movements at one of the test sites may accelerate, upon completion of the filling of the San Luis Reservoir, due to the rise of water part way up the embankment. It is expected that the water level will fluctuate rapidly accelerating the movements through the mechanisms of lubrication and rapid drawdown.

In some instances the data is incomplete for various reasons such as reference points being inadvertently destroyed during contractor's operations, malfunctioning of settlement devices, etc. While numerous technical difficulties were encountered with instrumentation in this first study, we believe that the knowledge and experience gained can advantageously be applied to additional installations on other projects which will effectively produce more complete measurement data.

METHOD OF INSTRUMENTATION

Two embankments were chosen for instrumentation; one at Station 80+00 and one at Station 164+50. The embankment at Station 80+00 has a maximum height of about 260 feet at centerline, with 1-1/2:1 slope, 1000 feet in length and a base width of approximately 1050 feet. The embankment at Station 164+50 has a maximum height of approximately 190 feet at centerline, with 1-1/2:1 slope, 2200 feet in length with a base width of approximately 1000 feet. Ultimate highwater level in the reservoir will occur about 40 feet above the toe of the fill at Sta. 164+50.

Although there are variations of the soil in the area of these fills, it is basically a brown, silty clay containing considerable large rock. On occasions the rock was so massive that blasting was necessary for excavation. Figure 2 illustrates a typical example, showing the character of material making up the embankments. The fill material at the test sites, with the exception of the backfill around the culverts, was excavated from cuts adjacent to the embankments.

Descriptions of Instruments

Several types of devices were installed within or on the chosen embankments. They are: (1) horizontal movement devices, (2) settlement platforms and (3) survey monuments placed at various locations on the surface of the fills. A brief description of the various apparatus involved is given in the following paragraphs.

The lateral movement, within the fills, is measured by means of horizontal movement platforms and associated indicating units. The platforms consist of 12 inch square plates composed of either wood or steel. Placement of these platforms begins with the excavation of a trench (approximately 3' x 3' in section) across the fill, at right angles to the road centerline, when the desired elevation of the embankment is attained during construction (see Figure 3). A series of the plates are then embedded crosswise and on edge in the bottom of the trench at horizontal spacings of about 50±10 feet.

Referring to Figure 4, it can be seen that an individual cable (aircraft type) is attached to each platform and extends to a movement indicator box mounted on the side of the fill. Each plate has a hole in the center to allow passage of cables from platforms located further inside the fill (see Figures 5 and 6). The cables are protected by a plastic conduit, as they extend through the fill, and slip joints are provided at each platform and indicator box (see Figures 7 and 8).

The horizontal movement indicator box (HMI) is anchored in concrete at approximately the same elevation on the fill slope as the platforms are located within the fill (see Figures 9 and 10). The cables extend through the sheet metal indicator box, pass over pulleys and terminate in unsupported 50 pound weights. These weights are provided to eliminate "slack" in the cables and maintain constant positive tension for sensing platform movement. Marker points are affixed to each cable, inside of the indicator box, and are read against a foot scale attached to the bottom of the box for measuring relative platform movement (see Figure 11). The scale is arranged with the zero end toward the fill and with increasing values, in feet, away from the fill.

Both the horizontal and vertical movement of the indicator box, on the outside of the fill, is checked by means of transit and differential level surveys. For horizontal movement, permanent reference points (RP) are established with a transit on original ground, at both ends of the fill, for each level (or group) of horizontal movement platforms. With one of the reference points serving as an instrument point (IP), measurement of horizontal movement is accomplished by sighting a transit on the reference points and lining a plumb-bob over the scale in the instrument box. For vertical movement, differential levels are "pegged" to each horizontal movement indicator from bench marks (BM or TBM) established outside of the fill. Figures 12 and 13 show the locations of reference points, bench marks and survey lines for each embankment.

The measurement of vertical movement within the fill is accomplished by the use of water level type settlement standpipes. For the purposes of this study, these standpipes are mounted on the top edge of every other horizontal movement platform starting with the center platform. When measurements are being made for settlement, the combination of the standpipe attached to the vertical plate is referred to as a settlement platform (SP). When horizontal movement is measured, the vertical plate is called a horizontal movement platform (HMP), even though a settlement standpipe may be connected to the top edge.

Two styles or models of settlement standpipes were employed in this study. The device installed in the fill at Station 164+50 is a model which has been used by this department, for settlement study purposes, over a number of years. As shown in Figures 14 through 16 the device consists of an open overflow standpipe which is connected, by a plastic tube, to a transparent sight tube (indicator) mounted vertically in a protective box on the outside of the fill. Water fills the system and the device's operation is based upon the principle that a liquid seeks its own level. When the ground upon which the platform is resting, settles, the standpipe overflows and the level in the sight tube lowers correspondingly. Measurement of relative settlement, between the standpipe and the indicator unit, is made by simply reading a scale attached to the sight tube. Correction for any settlement (or heave) of the indicator unit, to determine the absolute movement of the platform, is obtained from periodic differential levels.

At the time that the fill at Station 80+00 was constructed, an important modification of the water level type standpipe became available and was installed. This device has an enclosed standpipe equipped with an "air vent" at the top and an overflow "drain" connection at the bottom, as shown in Figure 18. In addition to the water line, plastic tubing is run from these two connections to the outside of the fill. This modification of the standpipe unit (see Figure 17 for photo of standpipe base) has a distinct advantage over the older style design in that the "sealing" of the unit essentially eliminates measurement errors caused by "air locking" and/or "flooding."

Backfilling operations, for the trench, is undertaken after all horizontal movement and settlement platforms have been connected to their respective indicator units and "checked out" for proper operation. Since the fill material in both embankments is quite rocky, it was the practice to backfill the first foot or so of the trench with a fine grained aggregate (generally less than 1/2" max. size) to protect the tubing and conduits from rock damage. In addition, this aggregate was also "piled" up around the settlement standpipes for the same reason. Figures 19 and 20 illustrate this process.

Installation

Installation of the various devices at Station 164+50 began on July 30, 1963, with the placement of two settlement platforms on original ground in the area where the main body of the fill was to be situated. The first unit of horizontal movement platforms and associated settlement platforms were installed on October 8, 1963 when the fill had attained an elevation of about 580 feet. This installation consisted of eleven horizontal movement platforms and five settlement risers attached to alternate horizontal movement platforms. A second group of seven horizontal movement platforms and three settlement risers was installed at elevation 635± on January 9, 1964. Spacing of the platforms is about 40 ft. horizontally and care was exercised to align the plates in this group vertically with those in the previous installation. A third set, consisting of three horizontal movement platforms and one settlement riser was placed at elevation 687± on February 27, 1964. As before these devices were aligned vertically with the previous installations. The total instrumentation at Station 164+50 consists of 21 horizontal movement platforms and 11 settlement platforms. The locations of these installations, as placed, are shown on the accompanying cross-section sheet, Figure 21. General views of typical installations are illustrated in the photographs shown in Figures 22 through 27.

The fill at Station 80+00 was instrumented at two elevations fifty feet apart vertically, as indicated on the attached cross-section, Figure No. 28. Installation of the first group was made on May 16, 1964 at elevation 783±. It consisted of nine horizontal movement platforms and five settlement platforms. The second group was made on July 11, 1964, and consisted of seven horizontal movement platforms and three settlement platforms. Horizontal spacing of these devices is approximately 60 ft.

When the roadway was completed, bronze monuments were set in concrete on top of both fills, along centerline and at the outer edges of the pavement. Seven monuments were set on each of the two test sites to measure the settlement and horizontal spread of the fill surface. See Figures No. 12 and 13 for the locations of the monuments.

DISCUSSION OF TEST DATA

Horizontal Movement Platforms

The horizontal movement platforms were installed to measure the horizontal compression and tension within the fill mass. These readings are shown in Tables I through V. There are two methods of checking the accuracy of these readings. One of thesemethods assumes that the center platform does not move. In this case, the cable and survey measurements, conducted on the outer boxes, should indicate a comparable movement. Examination of the Tables indicates that there are some wide discrepancies within this data. The survey data indicates that movement,in some installations, occurred between the first and second readings whereas the cables do not indicate movement within this time interval. Later survey readings check the cable measurements and indicate that only minor movement has occurred.

The other method of checking accuracy utilizes the fact that the central horizontal movement platform is connected to a "through" cable which extends to the indicator boxes on each side of the fill. Again the cable and survey data are irrational in that the central platform is shown to move in a specific direction at one indicator and in the opposite direction at the other.

It is felt that these discrepancies were primarily due to inaccuracies occurring in the initial surveying conducted shortly after the installations were made. Difficulty was experienced during this period, in establishing good reference points within reasonable sight distances from the indicator boxes.

Several of the established reference points were destroyed by construction operations and accurate re-establishment of these points on the original sight lines was very difficult. In addition, several of the indicator boxes were severely damaged by large rocks rolling down the fill slope during construction. This occurred in spite of the precaution of placing concrete wingwalls above the indicator boxes (see Figure No. 25). While the indicators and reference points were apparently satisfactorily restored, the effect of these disruptions upon the accuracy of readings obtained during the period shortly after installation remains in question.

In spite of these early difficulties however, it is felt that the installations are still capable of providing useful movement data. It appears that the first few readings should be abandoned and subsequent readings referenced to the January 1965 measurements. Unfortunately, this date is after the end of construction and precludes this key period from the study. However, with the ultimate filling of the San Luis Reservoir, it is anticipated that valuable horizontal movement data may well be obtained.

Settlement Devices

The concurrent installation of the various types of settlement devices, along with the horizontal movement platforms, was designed expressly for determining the degree of compression occurring within the embankment. Tables VI through IX show the accumulated settlement measured from settlement platforms, level surveys of horizontal movement indicator boxes, mounted on the slope of the fills and monuments placed on the tops of the fills. The heights of the fills at various stages of construction are also given in Table X.

While considerable settlement data has been acquired, in connection with the two embankments to date, there have been serious problems involved in obtaining rational measurements from many of the individual settlement platforms. As in the case with the Horizontal Movement Platforms, one of the main factors causing the difficulty with the settlement platforms was the repeated extensive damage incurred by the indicator boxes from large rocks rolling down the fill slope during construction, as shown in Figure 25. The frequent upsetting of water levels with the attendant probability of getting air in the water line, along with the discrepancies caused in the surveyed reference elevations of the indicators, sometimes resulted in faulty measurements.

There was another factor which apparently only affected the settlement platforms in the fill at Station 164+50. This concerned the fact that old style water level type settlement platforms, which do not normally have provisions for air venting to the outside of the fill, were used. It appears that the dense character of the soil in the vicinity of several of the settlement platforms prevented the proper equalization of barometric pressure between the standpipe and the outside of the fill and resulted in the development of an "air lock" in the water level system. An air lock will prevent the water from attaining equal levels between the standpipe and indicator tube and thus provide faulty readings. This phenomena apparently caused SP 65, 66 and 67 to go out of service. Since the newer style of settlement platform, which embodies both air vents and overflow water drain lines, was installed in the fill at Station 80+00, this particular problem was not encountered at that location.

Determination of compression in the fills will be rather limited due to the loss of the "out of service" settlement platforms. However with continued acquisition of settlement data from the monuments, Horizontal Movement Indicators and remaining Settlement Platforms, it is possible to derive some useful information on the subject in the future.

Summary

A review of Table I through V reveals that, in general, lateral movement within the fills has been fairly small. Considered on the basis of accumulated movement from the time of installation to December 1965 (about 2 years) the movement of the platforms, relative to the indicator box (cable readings), is in the order of .06 foot at Station 164+50 and .30 foot at Station 80+00. Relative movement from January 1965 to December 1965 (the period after construction) has been .02 foot at Station 164+50 and .04 foot at Station 80+00.

If one considers the absolute movement of the platforms (i. e., corrected for the movement of the indicator boxes) then the values become larger. For the two year period, the accumulated movement at Station 164+50 is about .30 foot and .40 foot at Station 80+00. In the year after construction the accumulated movement was approximately .06 foot at Station 164+50 and .07 foot at Station 80+00.

In looking back at the probems encountered with the instrumentation on this project, it is felt that a lesson has been learned with regard to the making of future installations of this type. Of primary concern is the inherent risk of damage to indicator units, mounted on the sides of the fills, during construction operations.

It is now apparent that the concrete "wing walls," provided on the San Luis project for protection of the exposed units, are totally inadequate. As a consequence, special instrument shelters have been devised and are presently being used on the "Ridge Route project" where horizontal and vertical movement devices are being installed.

The shelters are constructed of "ends" cut from steel "surplus" missile containers provided by the U.S. Navy. These sections are about 6 ft. in diamter and 6 ft. long. Due to space limitations it is necessary to provide a spring tensioning system for the cables rather than using dead weight, as was done on the San Luis project. Figure 29 illustrates the arrangement for the horizontal movement indicator and the general configuration of the shelter with a plywood door panel installed on the open end. Adequate space is available on the rear metal wall to mount settlement indicators and other devices, as shown in Figure 30. With the shelter bedded firmly in concrete and covered with fill, as illustrated in Figure 31, a safe housing for the indicator equipment is provided.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

TABLE I (a)

Measurements from Horizontal Movement Devices

San Luis Reservoir Project

Station 164+50
Lower Level at El. 580±, Left Half of Fill

← Outside of Fill ℄

Date	HMI #2 Line Survey		HMP 64 45 feet		HMP 63 85 feet		HMP 62 125 feet		HMP 61 165 feet		HMP 60 200 feet		HMP 54 260 feet	
	H.M.I. Reading	Movement	Cable Reading	Diff. Fr.. Start	Cable Reading	Diff. Fr. Start	Cable Reading	Diff. Fr. Start	Cable Reading	Diff. Fr. Start	Cable Reading	Diff. Fr. Start	Cable Reading	Diff. Fr. Start
10-14-63			2.01	Initial	2.01	Initial	2.02	Initial	2.01	Initial	2.01	Initial	2.01	Initial
10-17-63	1.99	Initial	2.01	0	2.01	0	2.02	0	2.01	0	2.01	0	2.01	0
10-28-63			2.02	+.01	2.00	-.01	2.02	0	2.00	-.01	1.99	-.02	2.00	-.01
10-31-63			2.03	+.02	2.01	0	2.02	0	2.00	-.01	1.98	-.03	2.00	-.01
11-14-63			1.99	-.02	1.97	-.04	2.04	+.02	2.00	-.01	2.02	+.01	2.04	+.03
12-4-63			2.00	-.01	1.97	-.04	2.02	0	2.01	0	2.02	+.01	2.03	+.02
12-16-63			2.00	-.01	1.98	-.03	2.02	0	2.00	-.01	2.01	0	2.02	+.01
1-7-64			1.99	-.02	1.97	-.04	2.02	0	2.00	-.01	2.02	+.01	1.98	-.03
2-17-64			2.00	-.01	1.97	-.04	2.03	+.01	2.00	-.01	2.02	+.01	2.05	+.04
4-15-64			2.00	-.01	1.97	-.04	2.00	-.02	2.00	-.01	2.03	+.02	2.02	+.01
7-31-64			2.01	0	1.97	-.04	2.00	-.02	1.98	-.03	2.01	0	1.98	-.03
1-13-65			2.00	-.01	1.96	-.05	2.00	-.02	1.99	-.02	2.00	-.01	2.03	+.02
1-27-65	1.82	+.17												
4-14-65			1.99	-.02	1.96	-.05	2.00	-.02	1.98	-.03	1.99	-.02	2.02	+.01
8-2-65	1.81	+.18	1.96	-.05	1.95	-.06	1.98	-.04	1.97	-.04	2.01	0	1.99	-.02
12-6-65			1.98	-.03	1.96	-.05	1.99	-.03	1.97	-.04	1.99	-.02	2.01	0

Sign Legend:
Movement to the Outside of Fill = +
" " " Inside " " = -

TABLE I (b)

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation
Project
Station 164+ 50
Lower Level at El. 580± Right Half of Fill

℄ Outside of Fill ⟶

Date	HMP 54 260 feet		HMP 55 200 feet		HMP 56 165 feet		HMP 57 125 feet		HMP 58 85 feet		HMP 59 40 feet		HMI #1 Line Survey	
	Cable Read.	Diff. fr. Start	Cable Read.	Diff. fr. Start	Cable Read.	Diff. fr. Start	Cable Read.	Diff. fr. Start	Cable Read.	Diff. fr Start	Cable Read.	Diff. fr. Start	H.M.I. Read.	Move-ment
10-14-63	1.98	0	2.02	Initial	2.02	Initial	2.01	Initial	2.01	Initial	2.00	Initial		
10-17-63	1.98	0	2.03	+.01	2.02	0	1.98	-.03	2.01	0	2.00	0	1.28	Initial
10-28-63	2.00	+.02	2.03	+.01	2.00	-.02	2.02	+.01	2.01	0	2.00	0		
10-31-63	2.01	+.03	2.03	+.01	2.01	-.01	2.02	+.01	2.02	+.01	2.01	+.01		
11-14-63	2.03	+.05	2.10	+.08	2.03	+.01	2.07	+.06	2.02	+.01	2.01	+.01		
12-4-63	2.02	+.04	2.10	+.08	2.04	+.02	2.07	+.06	2.01	0	2.00	0		
12-16-63	2.03	+.05	2.09	+.07	2.03	+.01	2.07	+.06	2.02	+.01	2.01	+.01		
1-7-64	2.02	+.04	2.11	+.09	2.03	+.01	2.09	+.08	2.01	0	2.01	+.01		
2-17-64	1.97	-.01	2.02	0	1.97	-.05	2.00	-.01	1.97	-.04	1.98	-.02		
4-15-64	1.99	+.01	2.05	+.03	2.00	-.02	2.01	0	1.99	-.02	2.01	+.01		
7-31-64	1.98	0	2.03	+.01	1.96	-.06	2.00	-.01	1.98	-.03	2.00	0		
1-13-65	1.97	-.01	2.02	0	1.97	-.05	2.00	-.01	1.98	-.03	2.01	+.01		
1-27-65													0.70	+.58
4-14-65	1.97	-.01	2.01	-.01	1.95	-.07	1.99	-.02	1.99	-.02	2.00	0		
8-2-65	1.97	-.01	2.02	0	1.96	-.06	1.99	-.02	1.99	-.02	2.00	0	0.68	+.60
12-6-65	1.97	-.01	2.00	-.02	1.96	-.06	1.97	-.04	1.99	-.02	2.00	0		

Sign Legend:
Movement to the outside of fill = +
" " " inside " " = —

TABLE II (a)

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation
Project
Station 164+50

Middle Level at El. 635± Left Half of Fill

← Outside of fill ℄

Date	HMI #4 Line Survey		HMP 76 45 feet		HMP 75 85 feet		HMP 74 125 feet		HMP 73 185 feet	
	HMI Reading	Movement	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start
1 - 7 - 64			2.00	Initial	2.00	Initial	2.01	Initial	2.01	Initial
1 - 14 - 64	2.00	Initial								
2 - 17 - 64			2.00	0	2.00	0	2.00	-.01	2.00	-.01
4 - 14 - 64			2.00	0	1.98	-.02	1.93	-.08	1.92	-.09
7 - 31 - 64			1.85	-.15	1.93	-.07	1.98	-.03	2.00	-.01
1 - 13 - 65			1.99	-.01	1.97	-.03	1.92	-.09	1.84	-.17
1 - 27 - 65	1.77	+.23								
4 - 14 - 65			1.98	-.02	1.96	-.04	1.91	-.10	1.83	-.18
8 - 2 - 65	1.80	+.20								
8 - 6 - 65			1.98	-.02	1.96	-.04	1.90	-.11	1.82	-.19
12 - 6 - 65			1.98	-.02	1.96	-.04	1.90	-.11	1.81	-.20

Sign Legend:
Movement to the outside of fill = +
" " " inside " " = -

TABLE II (b)

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation
Project
Station 164+50

Middle Level at El. 635±, Right Half of Fill

℄ Outside of Fill ⟶

Date	HMP 73 185 feet		HMP 77 125 feet		HMP 78 85 feet		HMP 79 45 feet		HMI #3 Line Survey	
	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff.fr. start	Cable Reading	Diff.fr. start	HMI Reading	Move-ment
1-7-64	2.04	Initial	2.00	Initial	2.00	Initial	2.01	Initial		
1-14-64									2.00	Initial
2-17-64	2.04	0	2.00	0	2.00	0	2.03	+.02		
4-14-64	2.00	-.04	1.96	-.04	1.98	-.02	2.00	-.01		
7-31-64	1.98	-.06	1.98	-.02	1.98	-.02	1.96	-.05		
1-13-65	1.97	-.07	1.98	-.02	1.98	-.02	1.95	-.06		
1-27-65									1.69	+.31
4-14-65	1.95	-.09	1.97	-.03	1.96	-.04	1.94	-.07		
8-2-65									1.64	+.36
8-6-65	1.95	-.09	1.97	-.03	1.97	-.03	1.94	-.07		
12-6-65	1.95	-.09	1.94	-.06	1.96	-.04	1.98	-.03		

Sign Legend:
Movement to the outside of fill = +
" " " inside " " = -

TABLE III

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation Project

Station 164+50

Upper Level at El. 687±

	← Outside of Fill				℄		℄		Outside of Fill →					
	HMI #6 Line Survey		HMP 83 50 feet		HMP 81 110 feet		HMP 81 110 feet		HMP 82 50 feet		HMI #5 Line Survey		Monuments on Top of Fill	
Date	HMI Reading	Move-ment	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	HMI Reading	Move-ment	Movement Between HMM 138 & SM 134, Ft.	Movement Between HMM 136 & SM 134, Ft.
2-27-64			2.02	Initial	2.01	Initial	2.02	Initial	2.01	Initial				
4-28-65	2.00	Initial									2.00	Initial		
7-31-64			2.03	+.01	2.02	+.01	2.02	0	2.00	-.01				
1-13-65			2.03	+.01	2.02	+.01	2.02	0	2.01	0				
1-27-65	1.82	+.18									1.90	+.10		
4-14-65			2.03	0	2.01	0	2.00	-.02	2.00	-.01			Initial	Initial
8-2-65											1.92	+.08	- 0.02	+0.07
8-6-65	1.93	+.07	2.03	+.01	2.01	0	2.05	+.03	1.99	-.02				
12-6-65			2.02	0	2.01	0	2.01	-.01	2.00	-.01			0	+0.06

Sign Legend
Movement to the outside of fill = +
" " " inside " " = -

TABLE IV (a)

Measurement from Horizontal Movement Devices

San Luis Reservoir Relocation Project

Station 80+00

Lower Level at El. 783±, Left Half of Fill

← Outside of Fill ℄

Date	HMI #8 Line Survey		HMP 114 50 feet		HMP 113 105 feet		HMP 112 165 feet		HMP 111 220 feet		HMP 106 310 feet	
	HMI Reading	Movement	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start
5-25-64					2.01	Initial	2.00	Initial	2.00	Initial	2.00	Initial
7-7-64	2.00	Initial										
7-31-64												
1-12-65			Cable Destroyed		1.91	-.10	1.70	-.30	1.50	-.50	1.25	-.75
2-1-65	1.47	+.53										
4-14-65					1.98	-.03	1.81	-.19	1.66	-.34	1.34	-.66
8-2-65	1.37	+.63			1.65	-.36	1.80	-.20	1.34	-.66	1.98	-.02
12-6-65					1.65	-.36	1.81	-.19	1.33	-.67	1.98	-.02

Sign Legend:
Movement to the outside of fill = +
" " " inside " " = -

TABLE IV (b)

Measurements from Horizontal Movement Device

San Luis Reservoir Relocation Project

Station 80+00

Lower Level at El. 783±, Right Half of Fill

℄ Outside of Fill ⟶

	HMP 106 325 feet		HMP 107 195 feet		HMP 108 140 feet		HMP 109 85 feet		HMP 110 30 feet		HMI #7 Line Survey	
Date	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	HMI Reading	Move-ment
5-25-64	2.03	Initial	1.94	Initial	1.97	Initial	2.02	Initial	2.05	Initial		
7-7-64											2.00	Initial
7-31-64	2.05	+.02	1.94	0	1.97	0	2.02	0	2.05	0		
1-12-65	1.55	-.48	1.83	-.11	1.97	0	2.06	+.04	2.06	+.01		
2-1-65											2.00*	0
4-14-65	1.52	-.51	1.83	-.11	1.97	0	2.05	+.03	2.06	+.01		
8-2-65	1.52	-.51	1.83	-.11	1.96	-.01	2.05	+.03	2.06	+.01	1.97	+.03
12-6-65	1.51	-.52	1.82	-.12	1.96	-.01	2.05	+.03	2.06	+.01		

*Original RP's for HMI-7 destroyed by construction operations. Reset on 1-27-65

Sign Legend:

Movement to outside of fill = +

" " inside " " = -

TABLE V (a)

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation Project

Station 80+00

Upper Level at El. 843±, Left Half of Fill

← Outside of Fill ℄

Date	HMI #10 Line Survey		HMP 118 50 feet		HMP 119 95 feet		HMP 120 160 feet		HMP 121 225 feet	
	HMI Reading	Movement	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start
7-16-64			1.99	Initial	2.01	Initial	2.00	Initial	2.00	Initial
7-30-64	2.00	Initial								
7-31-64			2.00	+.01	2.03	+.02	2.01	+.01	2.02	+.02
1-12-65			1.95	-.04	1.94	-.07	1.79	-.22	1.64	-.36
2-1-65	2.00*	0								
4-14-65			1.95	-.04	1.92	-.09	1.76	-.24	1.58	-.42
8-2-65	1.97	+.03								
8-6-65			1.94	-.05	1.93	-.08	1.76	-.24	1.57	-.43
12-6-65			1.94	-.05	1.92	-.09	1.75	-.25	1.56	-.44

*Original RP's for HMI-10 destroyed by construction operations. Reset on 1-27-65.

Sign Legend:
Movement to outside of fill = +
" " inside " " = -

TABLE V (b)

Measurements from Horizontal Movement Devices

San Luis Reservoir Relocation Project

Station 80+00

Upper Level at El. 843±, Right Half of Fill

℄ | Outside of fill ⟶

Date	HMI 121 225 feet		HMP 122 165 feet		HMP 123 100 feet		HMP 124 55 feet		HMI #9 Line Survey		Monuments on Top of Fill	
	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	Cable Reading	Diff. fr. start	HMI Reading	Move- ment	Movement Between HMM 133 & SM 139, Ft.	Movement Between HMM 141 & SM 139, Ft.
7-16-64	2.00	Initial	2.00	Initial	2.00	Initial	2.00	Initial				
7-30-64									2.00	Initial		
7-31-64	2.03	+.03	2.02	+.02	2.04	+.04	2.03	+.03				
1-12-65	1.63	-.37	1.99	-.01	1.98	-.02	1.85	-.15				
2-1-65									1.38	+.62		
4-14-65	1.57	-.43	1.98	-.02	1.98	-.02	1.83	-.17			Initial	Initial
8-2-65									1.32	+.68	0.0	-0.01
8-6-65	1.57	-.43	1.98	-.02	1.97	-.03	1.82	-.18				
12-6-65	1.56	-.44	1.97	-.03	1.96	-.04	1.82	-.18			0.0	+0.02

Sign Legend:
Movement to outside of fill = +
" " inside " " = -

TABLE VI

SETTLEMENT OF PLATFORMS AND HORIZONTAL MOVEMENT INDICATORS

San Luis Reservoir Relocation Project

Fill at Station 164+50

Date	Accumulated Settlement, Feet																
	Original Ground Elev. 527+		Lower Level Elevation 580±							Middle Level Elevation 635±					Upper Level Elevation 685±		
	SP 31	SP 32	HMI-2	SP 67	SP 66	SP 65	SP 68	SP 69	HMI-1	HMI-4	SP 70	SP 71	SP 72	HMI-3	HMI-6	SP-80	HMI-5
7-30-63	Installed																
10-31-63	I	I															
11-14-63	*	0.63	I	I	I	I	I	I	I								
12-4-63	0.56	0.74	*	0.04	0.05	0.12	0.35	0.07	*								
12-18-63	*	0.80	*	*	0.14	0.11	0.45	0.30	*								
1-9-64	0.60	0.84	*	0.17	0.17	0.23	0.56	0.50	*		I	I	I				
2-18-64	0.77	0.91	*	0.40	out	out	0.73	0.84	*		0.00	-0.27	0.48				
2-27-64	*	*	*	*			*	*	*		*	*	*			I	
4-15-64	0.75	0.91	*	out			0.98	1.04	*		0.37	0.44	0.92			0.00	
7-31-64	0.79	1.01	*				0.89	1.46	*		0.43	0.50	0.94			0.38	
1-13-65	0.97	1.09	0.28				1.03	1.77	0.59	I	0.66	0.85	1.28	I	I	1.34	I
4-14-65	0.92	1.09	*				1.03	1.76	*	*	0.66	0.85	1.28	*	*	1.43	*
8-5-65	*	*	0.25				0.97	1.88	0.48	0.01	0.75	0.91	1.27	-0.01	0.00	out	0.00
12-17-65	out	1.04	0.31				1.46	1.93	0.49	0.01	0.73	out	1.26	-0.06	-0.06		0.01

I- Initial Reading
* - No Reading obtained
A minus sign indicates upward movement

TABLE VII

SETTLEMENT OF MONUMENTS ON TOP OF FILL

San Luis Reservoir Relocation Project

Fill at Station 164+50±

Date	Accumulated Settlement, Feet						
	Monuments on Centerline					Monuments in Road Shoulder at Center of Fill	
	CHC-17 Sta. 159+96	SM-137 Sta. 162+45	SM-134 Sta. 164+48	SM-135 Sta. 166+48	CHC-18 Sta. 169+98	HMM-138 60' Lt. ℄ Sta. 164+41	HMI-136 48' Rt. ℄ Sta. 164+54
6-17-65	I	I	I	I	I	I	I
8-6-65	0.00	0.02	0.04	0.03	-0.07	0.03	-0.07
12-7-65	0.00	0.01	0.03	0.01	-0.08	0.03	0.01

A minus sign indicates upward movement.

TABLE VIII

SETTLEMENT OF PLATFORMS AND HORIZONTAL MOVEMENT INDICATORS

San Luis Reservoir Relocation Project

Fill at Station 80+00

Date	Accumulated Settlement, Feet											
	Lower Level Elevation 785±							Upper Level Elevation 845±				
	HMI-8	SP-105	SP-104	SP-103	SP-102	SP-101	HMI-7	HMI-10	SP-115	SP-116	SP-117	HMI-9
5-17-64	I	I	I	I	I	I	I					
7-7-64	*	0.88	1.34	*	*	*	*	I	I	I	I	I
1-13-65	0.67	0.97	1.86	Out	*	1.82	0.76	0.68	1.04	1.42	2.62	1.19
8-4-65	0.72	1.31	2.30		1.38	1.94	0.92	0.74	Out	2.74	2.80	1.31
12-7-65	0.71	1.25	2.33		2.64	1.96	0.88	0.76		2.79	2.86	1.33

I - Initial Readings

* - No readings obtained

TABLE IX

SETTLEMENT OF MONUMENTS ON TOP OF FILL

San Luis Reservoir Relocation Project

Fill at Station 80+00±

Date	Accumulated Settlement, Feet					
	Monuments on Centerline				Monument in Road Shoulder at Center of Fill	
	SM-128 Sta. 76+45	CHC-9 Sta. 78+45	SM-139 Sta. 79+27	SM-140 Sta. 81+27	HMM-133 62' Lt. ℄ Sta. 79+42	HMM-141 47' Rt. ℄ Sta. 79+15
6-17-65	I	I	I	I	I	I
8-4-65	-0.01	0.00	0.00	0.02	0.04	0.01
12-7-65	-0.01	0.00	0.01	-0.01	0.03	0.00

A minus sign indicates upward movement

TABLE X

FILL ELEVATIONS AND HEIGHTS ABOVE ORIGINAL GROUND

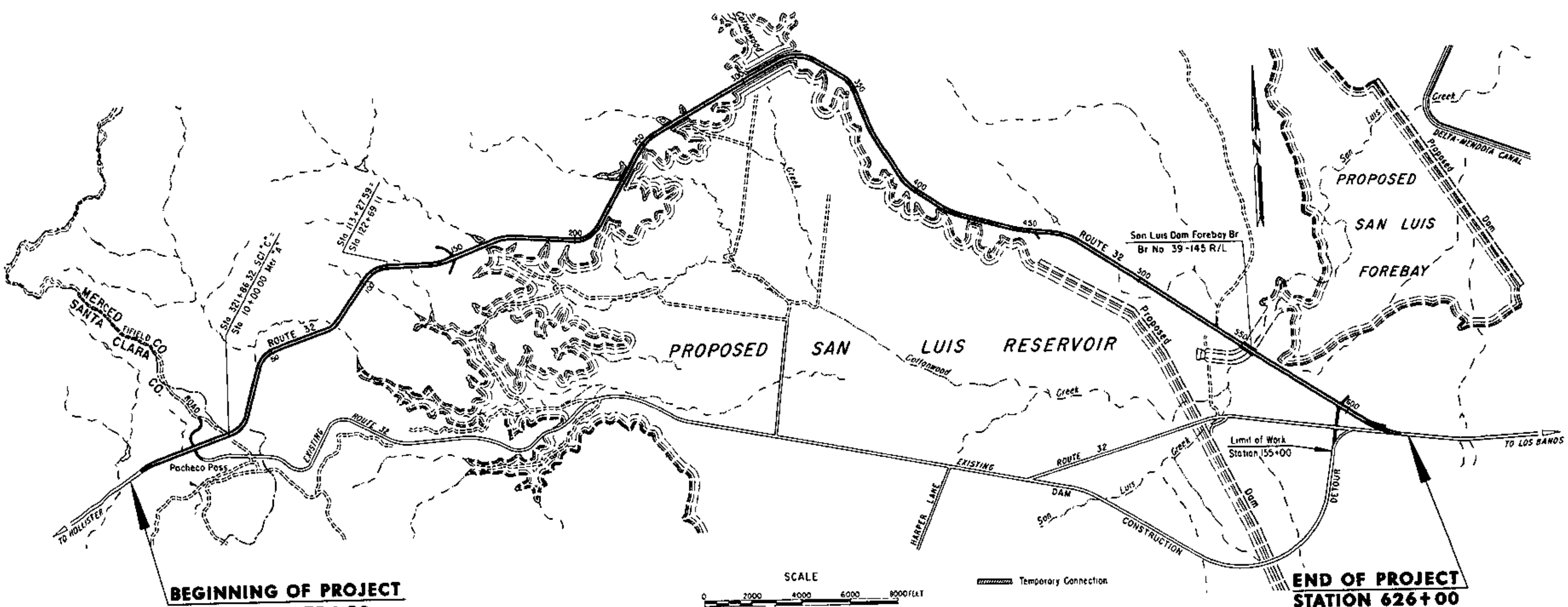
San Luis Obispo Reservoir
Relocation Project

Fill at Station 164+40			Fill at Station 80+00		
Date	Average Elevation (ft.)	Height Above O.G. (ft.)	Date	Average Elevation (ft.)	Height Above O.G. (ft.)
8-1-63	537	0	3-23-64	695	0
8-26	552	15	5-22-64	795	100
9-2	554	17	7-16-64	850	155
9-6	558	21	Sept. 64	950±(S.G.)	255
9-10	561	24			
9-19	564	27			
9-25	568	31			
10-1	577	40			
10-10	583	46			
10-18	586	49			
10-31	593	56			
11-7	601	64			
11-12	606	69			
11-15	610	73			
11-19	613	76			
11-22	617	80			
11-29	620	83			
12-6	626	89			
12-13	630	93			
12-20	636	99			
12-30	641	104			
1-8-64	647	110			
1-15	653	116			
1-24	659	122			
1-28	661	124			
2-5	667	130			
2-14	676	139			
2-27	685	148			
3-20	708	171			
4-15	719(S.G.)	182			

FIGURE 1

In Santa Clara and Merced Counties
between 1.0 mile west of Santa Clara-Merced County Line and
1.8 miles west of Route 121, about 15 miles west of Los Banos

FREEWAY
by resolution of the California Highway Commission
August 31, 1960

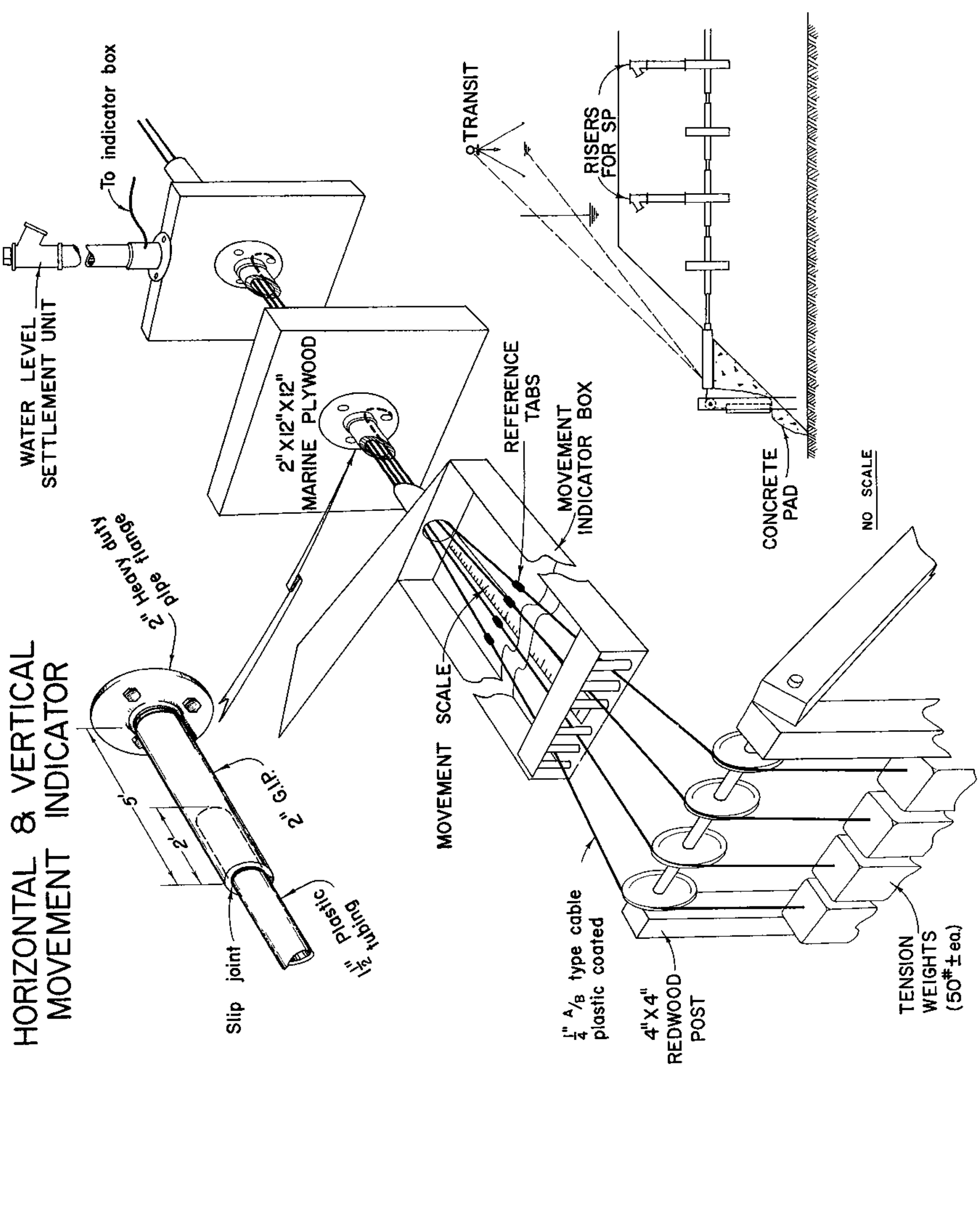


Length of Project 65,294.80 feet = 12.37 miles

Figure 2. Typical example of soils composing the fills at Station 164+50 and 80+00

Figure 3. A view looking down on the trench, being excavated, at Station 80+00 for the horizontal and vertical movement installations.

FIGURE 4


HORIZONTAL & VERTICAL
MOVEMENT INDICATOR
To indicator box
WATER LEVEL
SETTLEMENT UNIT
2"X12"X12"
MARINE PLYWOOD
2" Heavy duty
pipe flange
5'
2'
2" G.I.P.
Slip joint
1½" Plastic
tubing
MOVEMENT SCALE
REFERENCE
TABS
MOVEMENT
INDICATOR BOX
TRANSIT
RISERS
FOR SP
CONCRETE
PAD
NO SCALE
¼" A/B type cable
plastic coated
4"X4"
REDWOOD
POST
TENSION
WEIGHTS
(50# ± ea.)

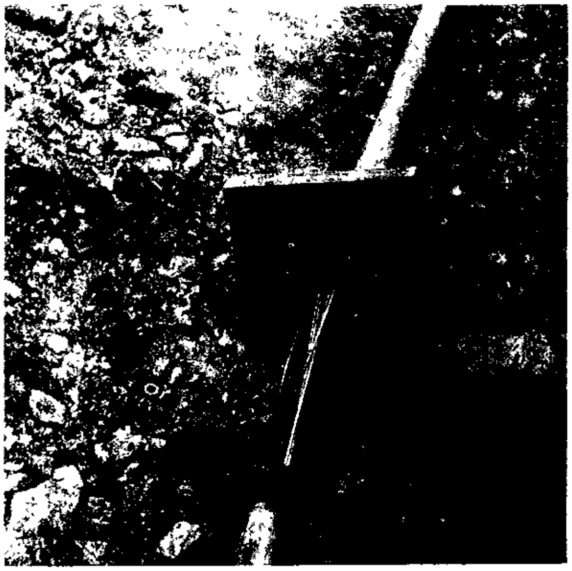


Figure 5. Horizontal movement platform constructed of wood. Note cable attachment and pipe flange arrangement. Used at Station 164+50.

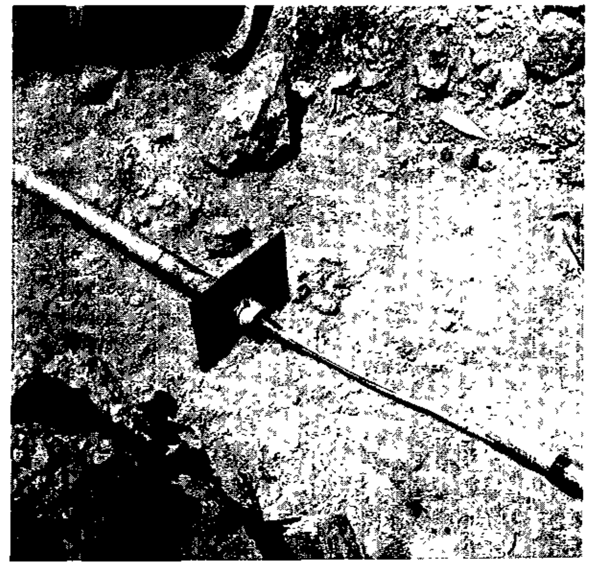


Figure 6. Horizontal movement platform constructed of 3/8" steel plate. Used at Station 80+00.

Figure 7. Laying of the 1-1/2" plastic conduit, for containing the cables, in the trench bottom.

Figure 8. Horizontal movement platform in place ready for backfill. Note slip joint where rag "stuffing" is exposed.

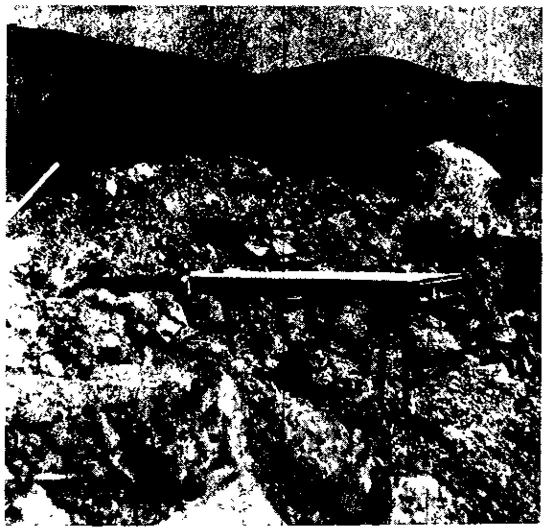


Figure 9. Horizontal movement indicator box supported on iron "chairs" in preparation for placin the concrete foundation.

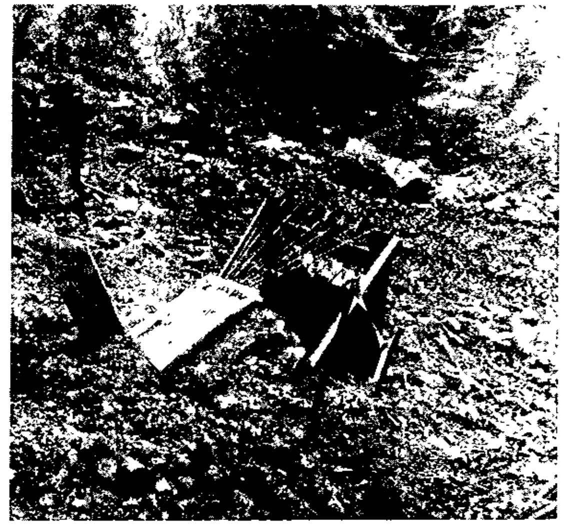


Figure 10. View of horizontal movement indicator assembly, from the fill above, after placement of the concrete foundation.

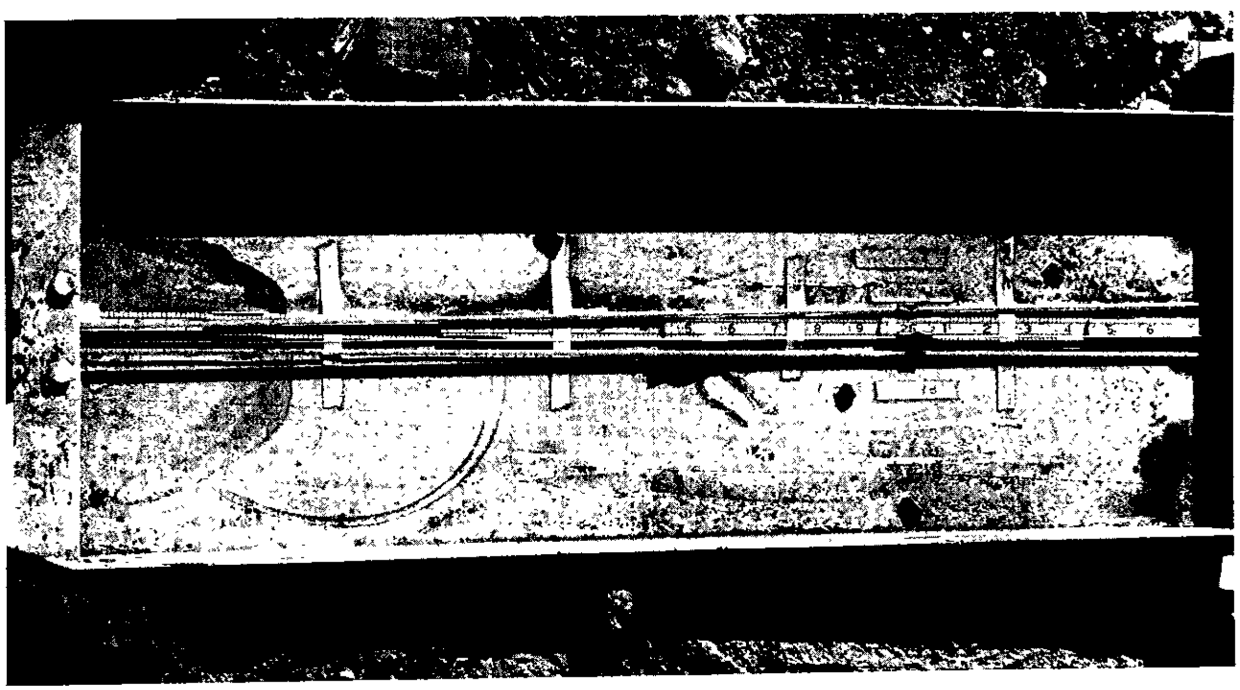
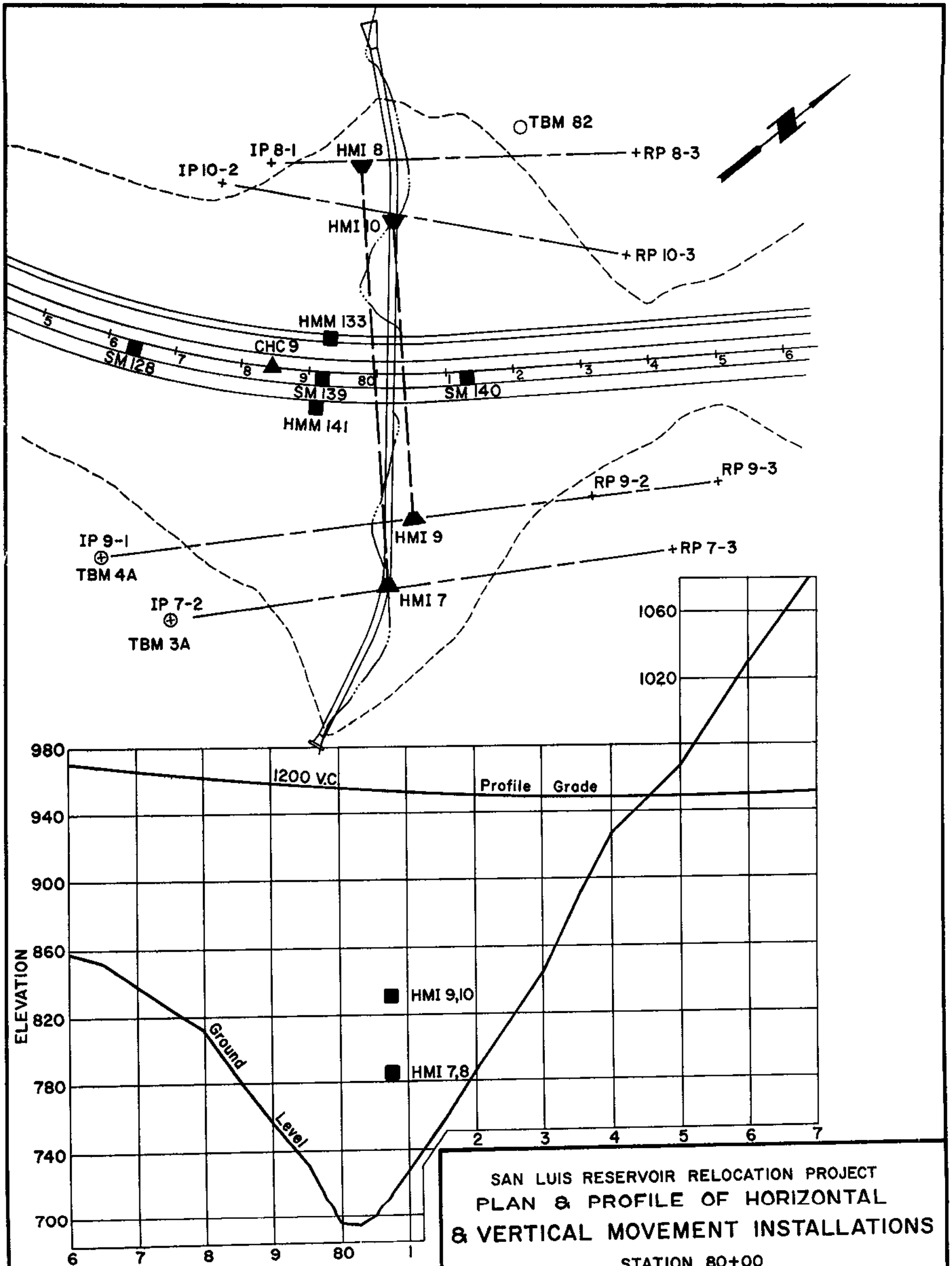


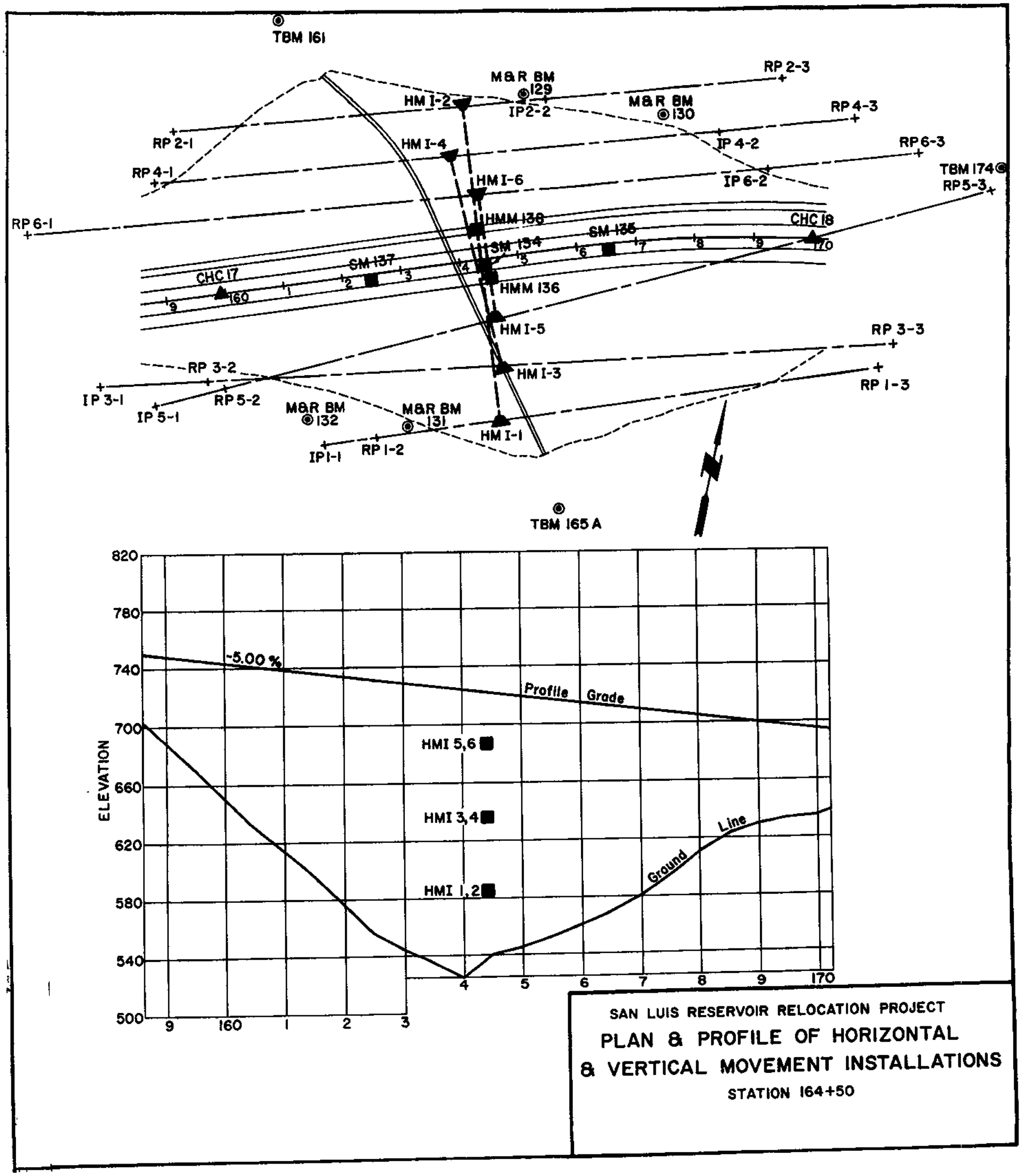
Figure 11. View looking down into a Horizontal Movement Indicator box showing the arrangement of cables, scale and marker points.



SAN LUIS RESERVOIR RELOCATION PROJECT

PLAN & PROFILE OF HORIZONTAL & VERTICAL MOVEMENT INSTALLATIONS

STATION 80+00

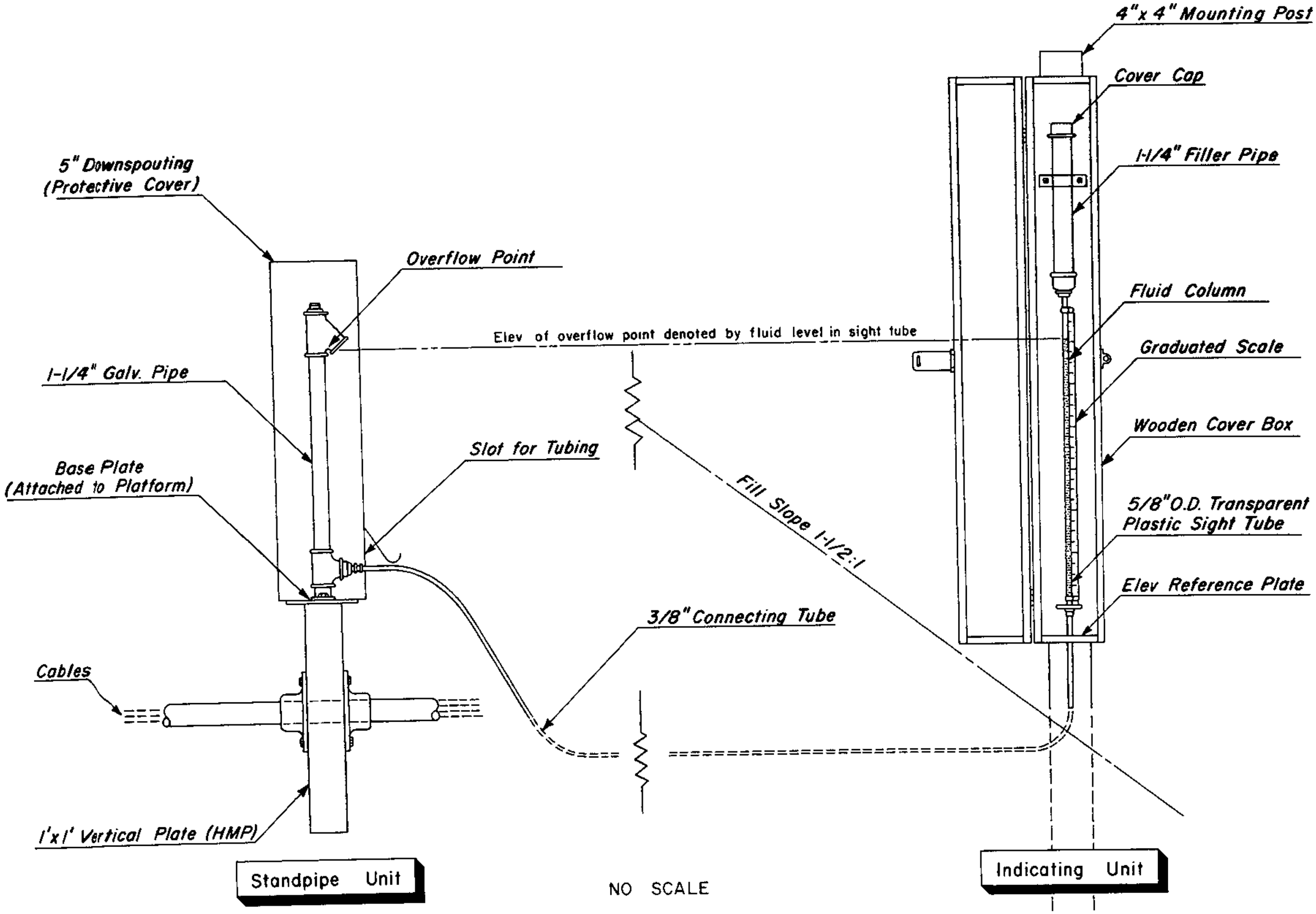


SAN LUIS RESERVOIR RELOCATION PROJECT

PLAN & PROFILE OF HORIZONTAL & VERTICAL MOVEMENT INSTALLATIONS

STATION 164+50

FIGURE 14



NO SCALE

SAN LUIS RESERVOIR RELOCATION PROJECT

Schematic Diagram

SETTLEMENT INDICATING DEVICE
FLUID LEVEL TYPE – OLD MODEL
INSTALLED IN FILL AT STA. 164+50

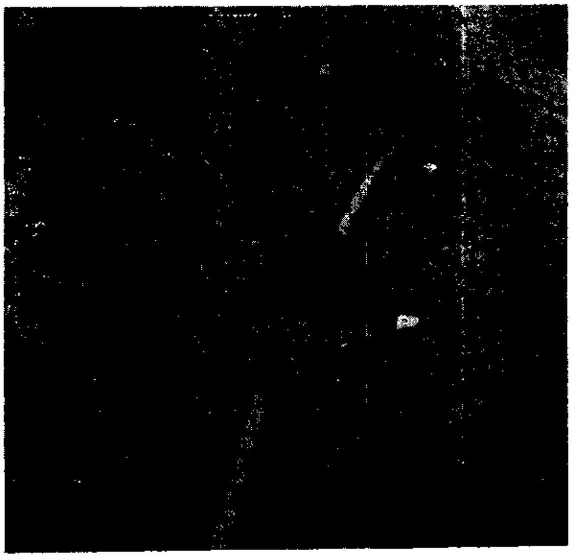


Figure 15. Settlement standpipe (old model) mounted on a wooden vertical plate to form a settlement platform unit.

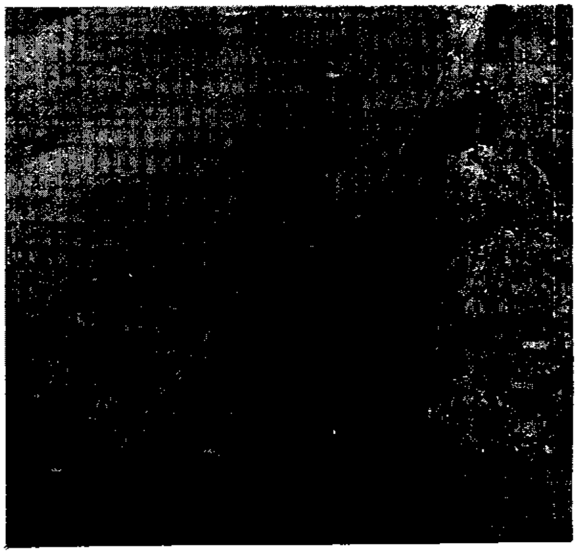


Figure 16. Settlement platform with protective "downspouting" cover in place, ready for backfill. Note plastic tubing for settlement platforms on either side of the trench.

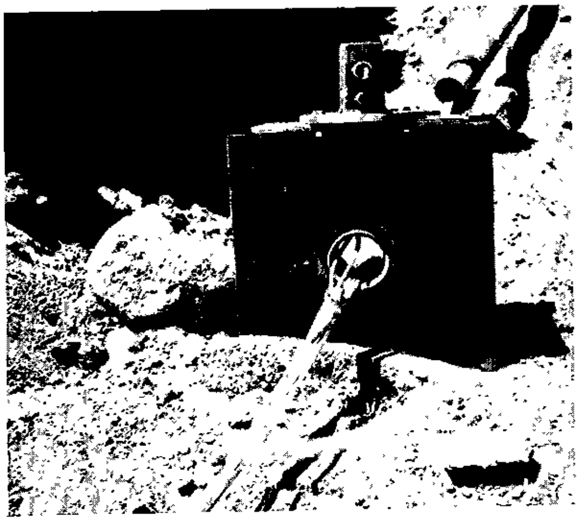
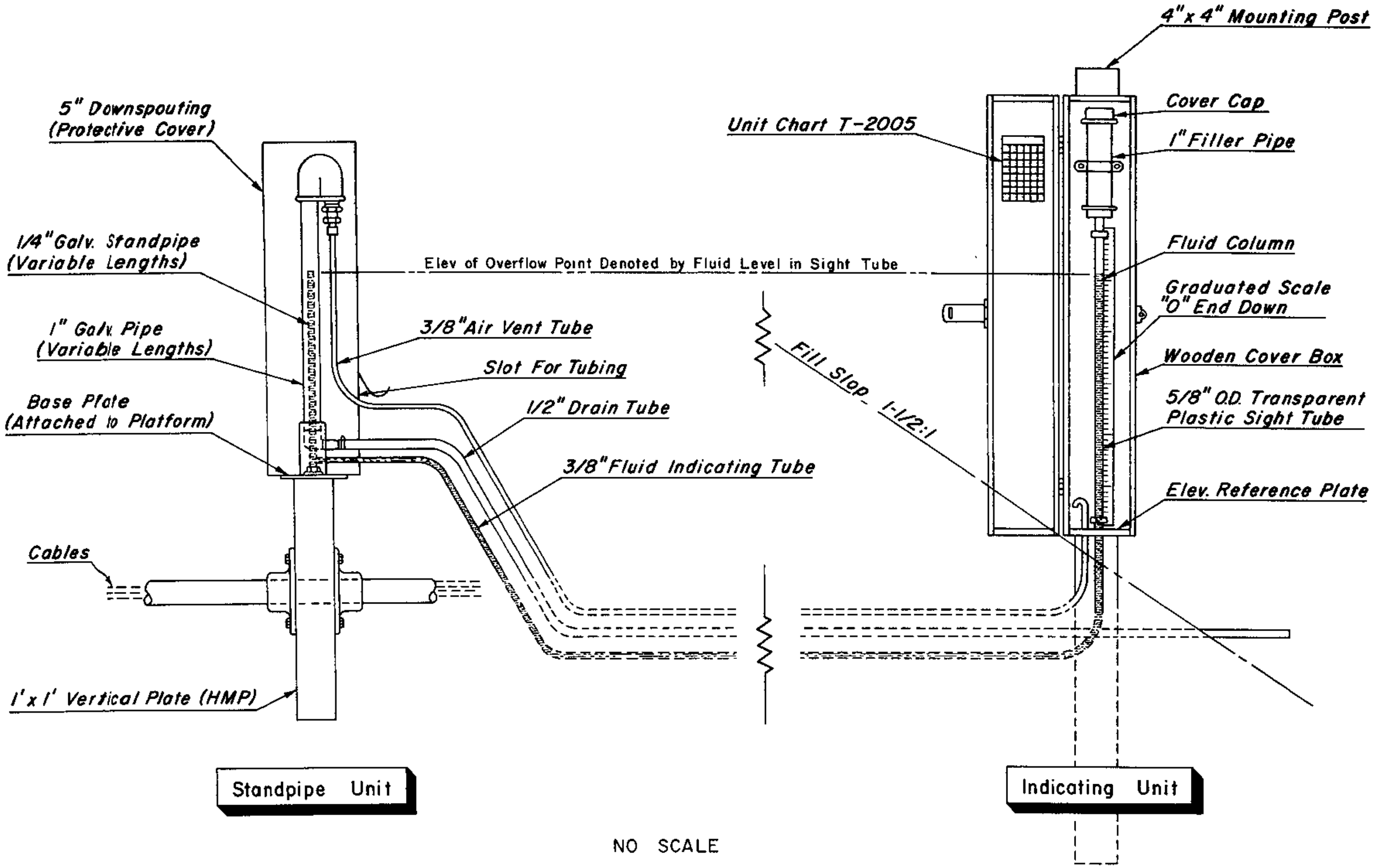


Figure 17. Settlement standpipe (new model) base mounted on a steel vertical plate to form a settlement platform unit. Note cable tie to plate.



NO SCALE

SAN LUIS RESERVOIR RELOCATION PROJECT

Schematic Diagram

SETTLEMENT INDICATING DEVICE
SEALED FLUID LEVEL TYPE – NEW MODEL
INSTALLED IN FILL AT STA. 80+00

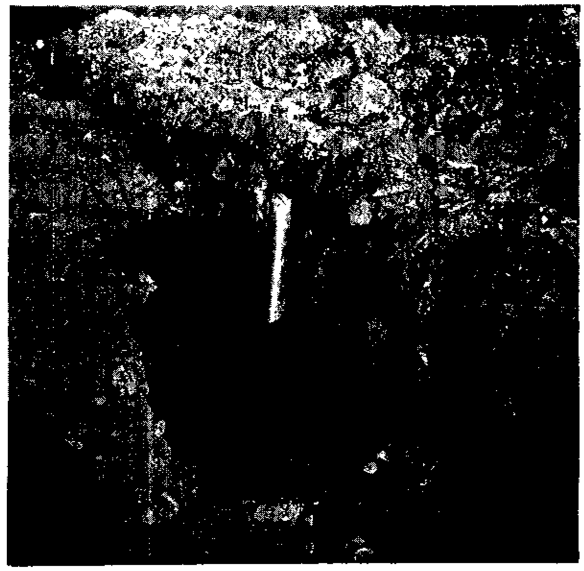


Figure 19. Placement of backfill material in the trench and around the settlement platforms. Note rocky condition of fill.

Figure 20. Background: Completion of backfill with material excavated from trench. Foreground: Aggregate backfill material is yet to be placed around conduit in the trench bottom.

Figure 22. General layout of horizontal movement and settlement indicator assemblies.

Figure 23. View showing the protective concrete wingwall arrangement behind the installation.

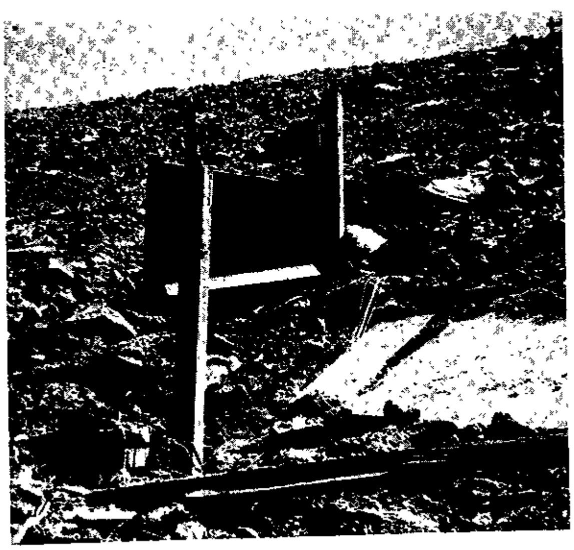


Figure 24. A typical example of the severe damage often inflicted on installations from large rocks rolling down the fill slope during construction. Compare with Figures 22 and 23. Note the almost complete destruction of the "protective" wingwall.

Figure 25. A completed installation with "boxed in" cable, pulley and weight assembly.

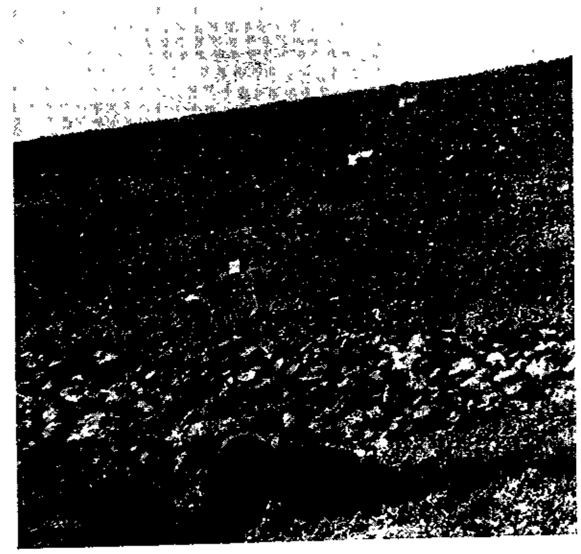


Figure 26. An "up slope" view of the completed installations at Station 164+50.

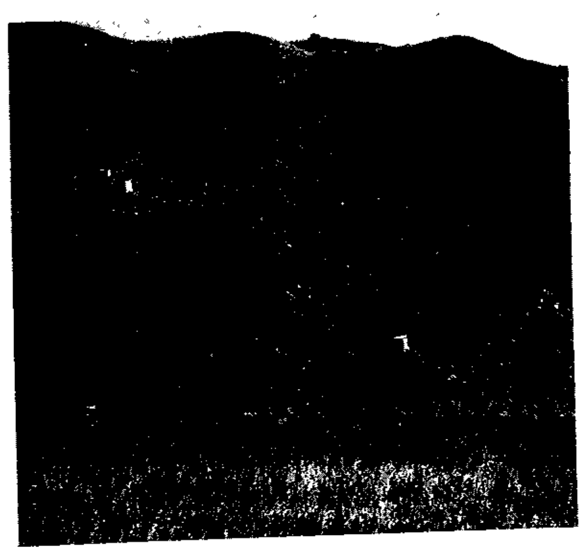


Figure 27. A view looking along the fill at Station 164+50 in an easterly direction.

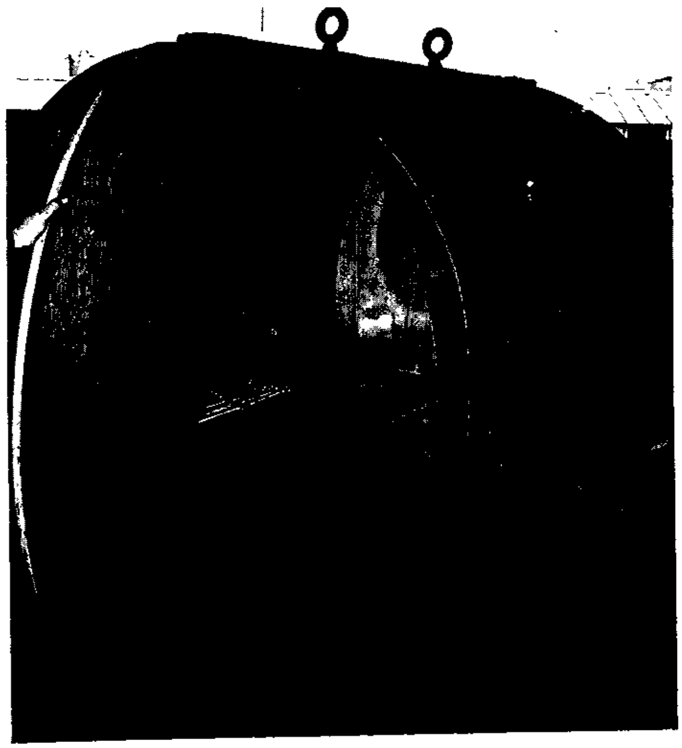


Figure 29. Instrument shelter showing the placement of the horizontal movement indicator inside, along with the attendant spring tensioning arrangement.

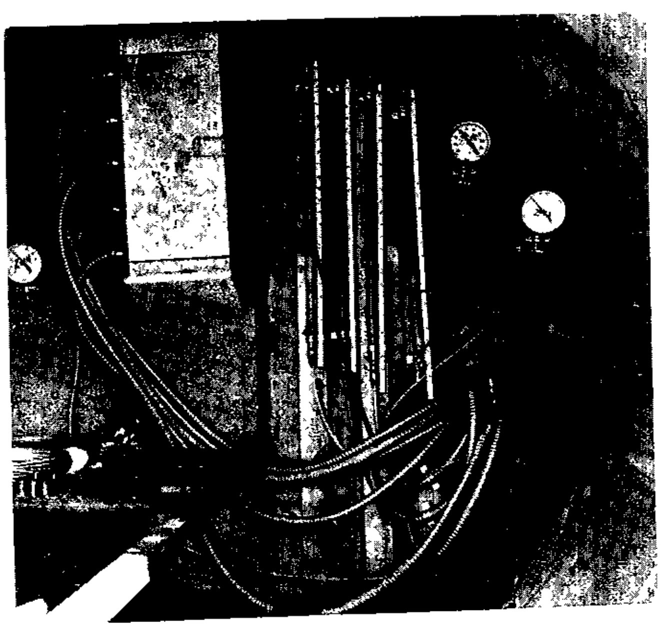


Figure 30. Settlement indicators and other instrumentation mounted on the back wall of the shelter.

Figure 31. A view of an instrument shelter installed in a fill on the Ridge Route project.