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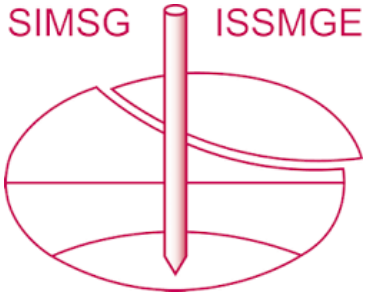

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No. L-1

STUDIES OF FILL CONSTRUCTION OVER MUD FLATS INCLUDING A DESCRIPTION OF EXPERIMENTAL CONSTRUCTION USING VERTICAL SAND DRAINS TO HASTEN STABILIZATION

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Summary. This paper describes studies carried on over a period of several years by the California Division of Highways to develop methods of accelerated foundation dehydration and stabilization of fills constructed over marsh land and includes a detail description of

1. Laboratory tests to determine probable effect of vertical sand drains.
2. Field studies of hydrodynamic pressure under a fill over a saturated foundation preliminary to field construction including the use of vertical sand drains.
3. Construction of vertical sand drains in a fill over saturated marsh land and observation of subsequent fill settlement over an extended period of time.

As a result of the studies conducted under (1) and (2), it was determined that (a) materially accelerated settlement will result from the use of vertical drains and (b) fill slipouts can be eliminated by substrata drainage relieving the hydrodynamic pressure.

Investigations indicate mud deposits up to 50 feet or more in depth can in this way be settled and stabilized in about one year.

General. Within the California Highway System there are many miles of road crossing marsh lands bordering the rivers, bays, and the sea coast of the State. Final completion of an adequate and permanent road bed has often been delayed many years because of the inherent instability and slow settlement of the underlying foundation. The poor condition of the roadway surface suring this period of settlement constitutes a hazard to traffic as well as a difficult and expensive maintenance problem.

Although theoretical knowledge of these foundation problems has increased rapidly in the last few years through the studies of Terzaghi and many other engineers, much remains to be done in correlating theory with practice; and to this end, intelligently designed experimental field projects offer the best means of developing a more accurate and complete understanding of the subject.

Before proceeding with a discussion of an experimental section constructed in 1934 to determine the effectiveness of vertical sand drains in hastening stabilization, a brief description will be given of a standpipe water level test made in connection with foundation studies for the easterly fill Approach to the San Francisco-Oakland Bay Bridge to determine the hydrodynamic pressure. Hereinafter, hydrodynamic pressure will be used to define the pressure taken by the water when the load is in excess of the carrying capacity of a saturated foundation.

A very thorough investigation of the foundation conditions underlying the proposed roadway fill approach to the easterly end of the San Francisco-Oakland Bay Bridge was made during 1933, and the information secured through this investigation was subsequently used in the fill design and construction.

Fig. 1 Showing East Approach to San Francisco-Oakland Bay Bridge Before and after fill construction.

The action of this fill, which has been completed one and one-half years, clearly confirms the dependability of the method of foundation analysis used. Even so, due to the lack of adequate practical tests, some doubt remained regarding the true distribution of pressure and the increased load affecting the foundation structure.

Standpipe Test. The standpipe, subsequently installed on this approach fill, was devised by the writer: first, to check the assumptions and theoretical analyses of foundation pressures previously made; and second, to furnish a practical field demonstration of the nature and intensity of pressure developed by the application of a load to a saturated material, and the principle phenomenon causing consolidation and instability.

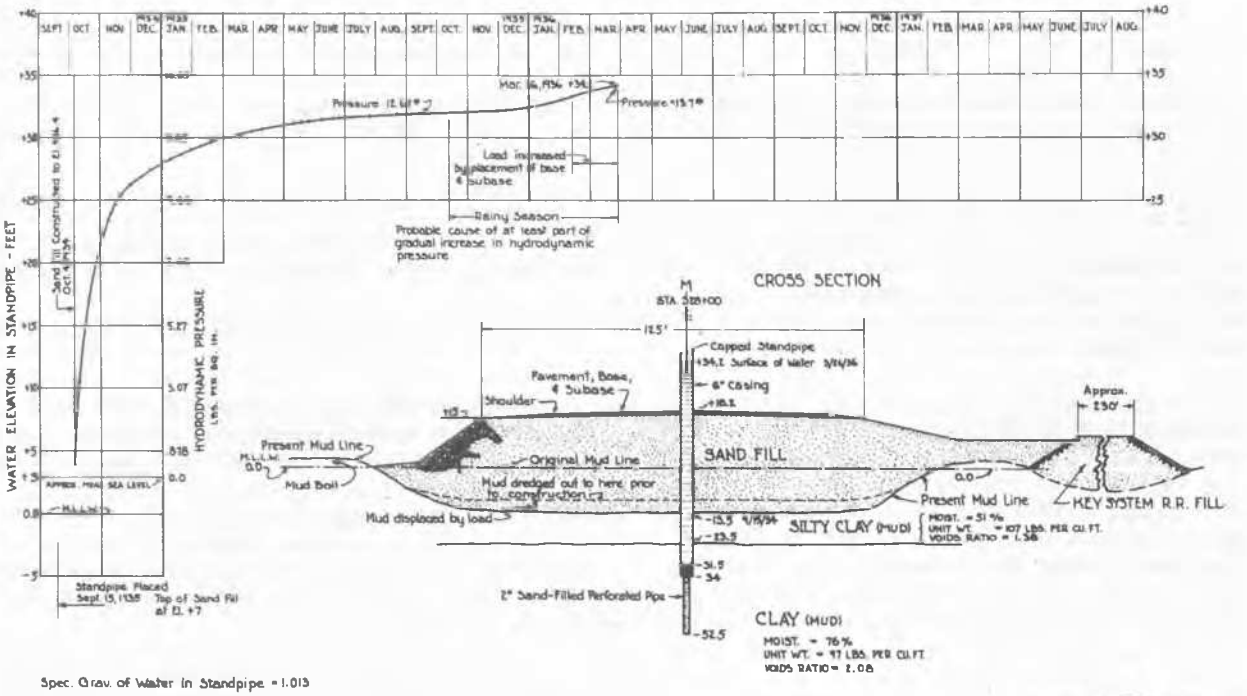
In preparing for the test, a heavy casing 6" in diameter was driven through the fill into an impermeable clay mud stratum, thus preventing water from flowing readily up along the outside of the pipe. Each joint of the casing was heavily leaded and thoroughly tightened in order to insure permanent water tight connections. The casing was then cleaned to the bottom (elevation -34), and continuous undisturbed core samples obtained from the bottom of the casing to elevation -52, in order to check the results of previous borings and to furnish a complete record of the material in the portion under test. Immediately following this operation, a 2" diameter perforated sand filled pipe was placed between elevations -32 and -52.5 to serve as a filter, thus allowing the water below elevation -34 to pass upwards through the standpipe.

FIG. NO. II

DIAGRAM SHOWING RISE OF WATER IN STANDPIPE & HYDRODYNAMIC PRESSURE RESULTING FROM FILL LOAD

EAST ROADWAY APPROACH TO SAN FRANCISCO - OAKLAND BAY BRIDGE

IV - ALA - 5 - OAK.



Spec. Grav. of Water in Standpipe = 1.013

FIG. 2

SUBMITTED BY _____ ASSOC. PHYS. TESTING ENGR.

APPROVED BY _____ MTRLS. & RESEARCH ENGR.

DATE APRIL 3, 1936

TIME CONSOLIDATION CURVES

SHOWING EFFECT OF VERTICAL SAND DRAINS ON RATE OF CONSOLIDATION

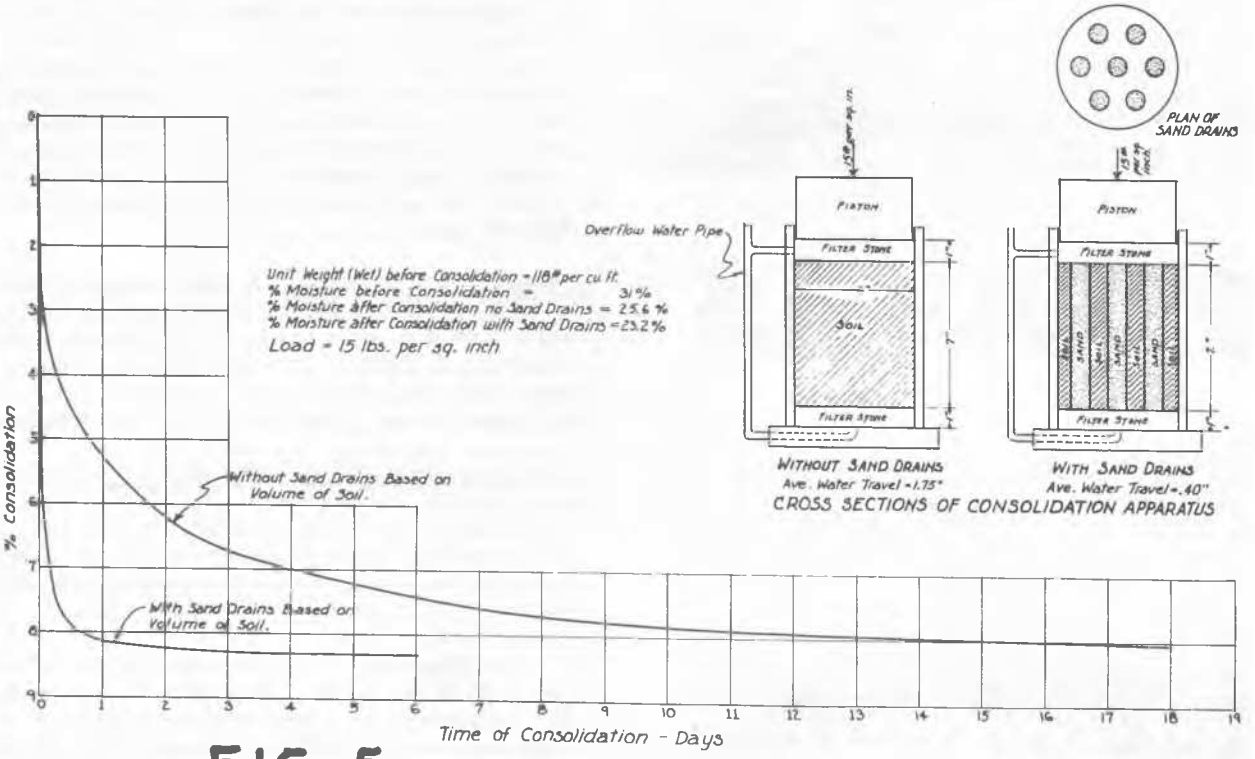


FIG. 5

The bottom 2' of the 6" casing was also filled with sand to prevent mud from entering.

A hydrodynamic pressure (Fig. 2) of approximately one ton per square foot was developed at the point tested. This is practically equal to the vertical load applied. As this hydrodynamic pressure operates laterally as well as vertically, it is deemed proper to assume that such pressure is a vital factor in connection with fill slipouts.

The standpipe test furnished reliable information regarding the active pressures producing consolidation and instability of saturated soil. The test promises to be useful for measuring the rate of core solidification and the horizontal component in hydraulic fill dams, and the distribution of foundation loads on saturated compressible soils to the end that definite information may become available to assist in clarifying the foundation problem as a whole.

Fill Slipouts. Slipouts may result from several distinct causes, not the least important being the lateral movement of a saturated foundation soil when the fill load produces a horizontal component greater than the shearing strength. The horizontal component causing this type of failure may be entirely due to hydrodynamic pressure.

The hydrodynamic pressure, demonstrated by the standpipe test, was first observed during investigations of large fill slipouts on saturated clay soils. Test holes made through these embankments, to determine the cause of slippage, encountered pressure which raised the water through the boring up to the top of the fill even though the water level in the adjacent ground remained many feet below.

Stabilization of the foundation under such conditions can be accomplished only by special drainage treatment. Where the surrounding ground is under water and the bottom of the soft mud below economical trenching depths, the problem becomes particularly difficult of solution.

In connection with the fill construction on the easterly roadway approach to the San Francisco-Oakland Bay Bridge, Mr. Daniel E. Moran, Consulting Engineer for the Bridge, suggested the use of sand piles for stabilizing the foundation by draining and laterally compacting the mud. The experiments described herein were undertaken in an effort to determine the suitability of vertical drains for accelerating settlement and stabilizing the foundation.

Fig. 3
Showing relative height of fill above marsh land at low tide stage, East Approach to the San Francisco-Oakland Bay Bridge

Fig. 4
Showing standpipe installed in mud foundation, East Approach San Francisco-Oakland Bay Bridge. The mark on pipe indicates the water level on January 2, 1936.

Observations indicate that the settlement period of construction over marsh land may vary from a few months to many years. A study of these projects has clearly indicated that the permeability and depth of the mud are definitely related to the length of settlement period. Theory, substantiated by experience on construction work, indicates that the time required for consolidation is proportional to the square of the depth of the layer. This suggests the possibility of greatly reducing the length of the normal settlement period for deep mud deposits by construction of vertical drains, thus permitting horizontal flow to the drains and reducing the distance the water would otherwise travel through impervious material before elimination.

Vertical Drain Tests. A small-scale laboratory experiment (Fig. 5) was conducted in 1933 to determine the effect of properly spaced sand drainage columns on the settlement rate. The specimen with sand drains consolidated 20 to 25 times faster than the untreated specimen.

Vertical Sand Drains Installed in Beatrice Marsh. Opportunity developed in 1934 for testing vertical drains under actual field conditions in connection with a foundation investigation for proposed reconstruction across the Beatrice Marsh, a portion of the Redwood or Coast Highway near Eureka, California.

The roadway for a distance of about two miles over marsh land had settled unevenly. The lowered grade line subjected the roadway to flooding and saturation whenever a high tide occurred concurrently with a heavy run-off from the adjacent hills. This, together with the roughness and deterioration of the temporary surface, resulted in high maintenance costs.

Soil profiles and theoretical pressure contours, together with complete test data, were prepared and analyzed prior to constructing the experimental sections. Typical test data

and the general foundation conditions are shown in Table I and Fig. 8, 9, 10, and 13.

Three test sections totaling 431 lineal feet of roadway were constructed during November and December of 1934. A total of 84 holes, 28 inches in diameter, averaging 42 feet in depth and aggregating 3530 lineal feet, were bored at a cost of 22 cents per foot ($9.24 per hole). Clean, river-run sand, similar to a very coarse concrete sand, was used to backfill the holes and provide drainage.

Test section No. 1 was constructed in the stiffest muds encountered in the marsh. Test Sections No. 2 and 3 were placed in softer material, and in the case of No. 2 at the point where the mud depth was maximum.

The spacing of the drains and general data for Test Section No. 3 are shown in Fig. 13. The construction on the other sections was similar, except that all longitudinal spacing between drains was either ten or twelve feet.

The settlement of the roadway for both treated and untreated portions of each test section is shown in Fig. 14. These curves, together with the complete profiles of progressive settlement, show that the vertical drains have functioned satisfactorily, and materially accelerated the settlement.

Conclusions. 1. Substrata drainage is necessary to relieve hydrodynamic pressure and stabilize impermeable saturated ground.

Fig. 6
Showing vertical section through consolidated specimen containing vertical sand drains. This specimen consolidated more than 20 times as fast as a similar sample without the drains.

Fig. 7
Showing roughness and surface failures resulting from unequal settlement of the roadway across Beatrice Marsh near the location of Test Section No. 3.

2. Theoretical advantages of vertical drains in connection with fill construction over deep marsh land have been confirmed by the experimental construction described herein. Further construction will be necessary, however, to determine the practicability of a broader application of this type of treatment and the economic limitations:

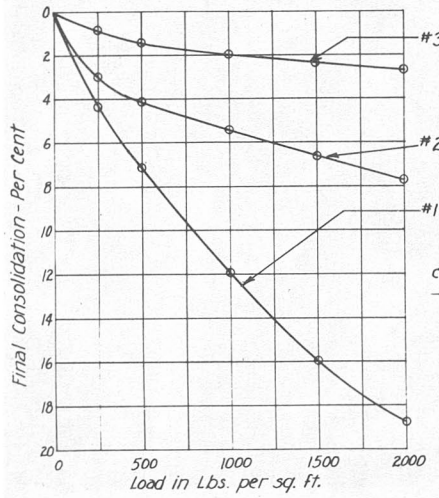
3. It is possible, with proper spacing of the drains, to obtain practically all of the settlement during six months to one year's time following construction.

4. Water usually travels through soil deposits more readily horizontally (with the bedding) than vertically. In addition to the increased rate of movement resulting from a decrease in the distance the water must travel through impervious material to be eliminated, the drains may accelerate the rate of settlement by providing an outlet for horizontal movement of excess moisture.

5. Drains, with a spacing consistent with the type of material and the desired rate of loading, readily release the excess water, relieve the hydrodynamic pressure, and thus prevent lateral displacement during fill construction. In some cases, therefore, the saving in fill yardage alone may economically justify the added expense of this type of construction.

All of the foundation studies described were carried on by the Materials and Research Department of the California Division of Highways under the general direction of Thos. E. Stanton, Jr., Materials and Research Engineer. Studies for the Easterly Fill Approach to the San Francisco-Oakland Bay Bridge were made in cooperation with District Engineer J. H. Skeggs and Assistant Engineer P. O. Harding, District IV. The study of the marsh construction near Eureka was made in cooperation with District Engineer J. W. Vickrey, District I.

AVERAGE LOAD CONSOLIDATION CURVES
BEATRICE MARSH TEST SECTION
I-HUM.-1-G



LEGEND

CURVE NO.	SAMPLE NO.	STATION	ELEV.	UNIT WT.	% H2O
1	9-2-I	430+30	-8.4	88	92
	9-2-II	430+30	-8.2	84	107
	9-3-XI	430+30	-11.4	84	121
2	9-6-VI	430+30	-44	107	45
	10-5-III	468+90	-40	113	42
	10-7-VIII	468+90	-65	107	48
3	8-5-V	372+00	-11	126	23
	8-6-I	372+00	-17	116	36

Test made on undisturbed cylindrical sample 1.93"x1" ht.

FIG. 8

TYPICAL TIME CONSOLIDATION CURVES
BEATRICE MARSH TEST SECTION I-HUM.-1-G
SAMPLE NO. 9-3-XI STA. 430+30 ELEV. -11.4
Unit Wt = 84 lbs. per cu. ft. % H2O = 121

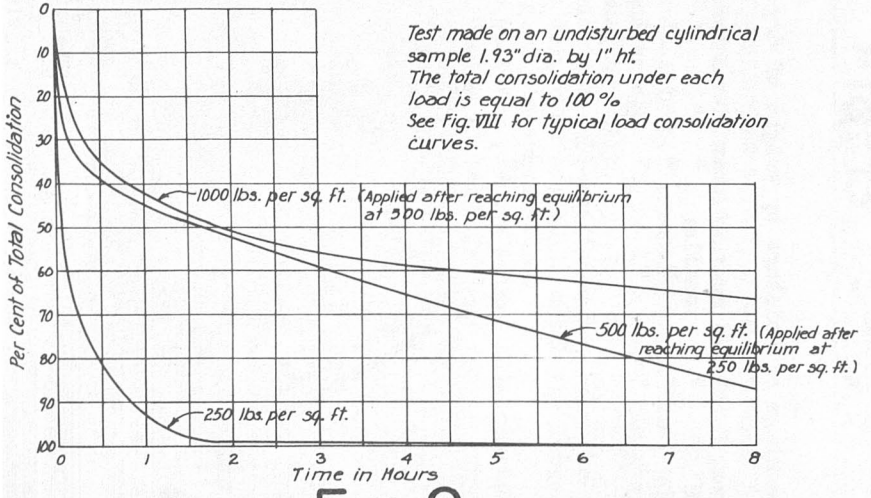


FIG. 9

TYPICAL TIME CONSOLIDATION CURVES
BEATRICE MARSH TEST SECTION I-HUM-1-G
SAMPLE NO. 10-5-III STA. 468+90 ELEV. -40
Unit Wt.= 113 lbs. per cu. ft. % H2O = 42

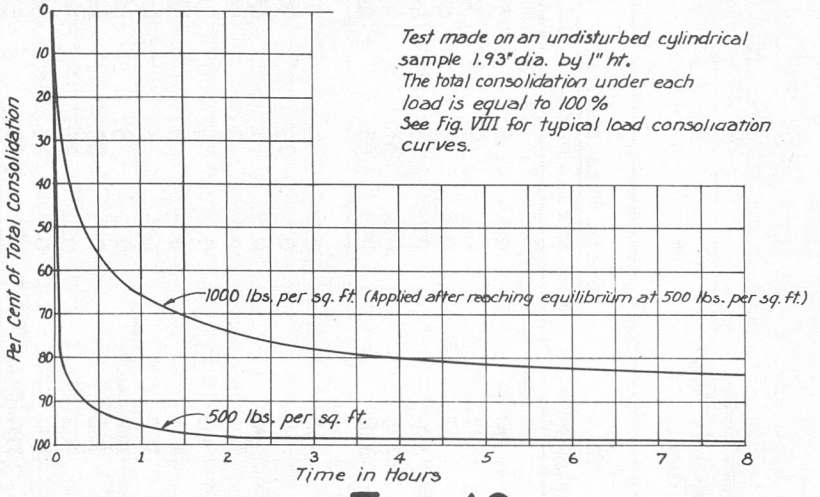
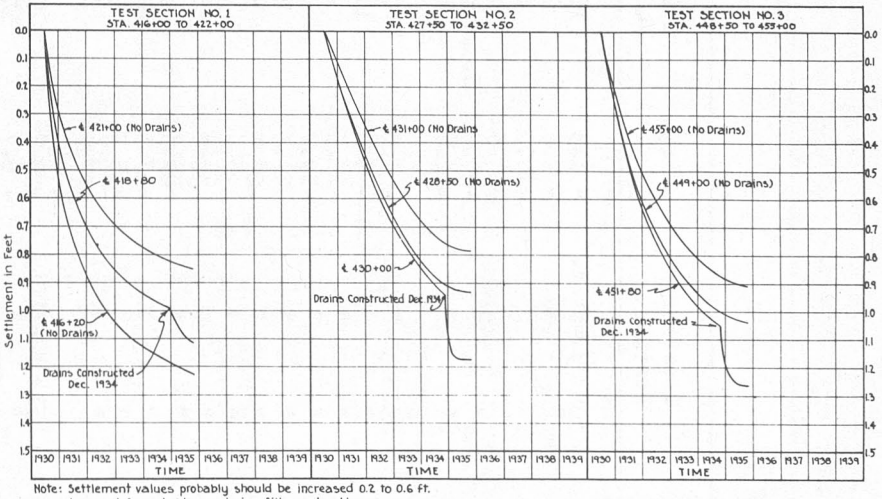


FIG. 10

TIME SETTLEMENT CURVES
SHOWING THE RATE OF SETTLEMENT OF FILL WITHOUT DRAINS & THE ACCELERATION OF SETTLEMENT RESULTING FROM THE CONSTRUCTION OF VERTICAL SAND DRAINS
BEATRICE MARSH TEST SECTION - I-HUM-1-G



Note: Settlement values probably should be increased 0.2 to 0.6 ft. to correct for subsidence during fill construction.

FIG. 14

TABLE I

Typical Test Data
Beatrice Marsh Borings
1-Hum 1-G

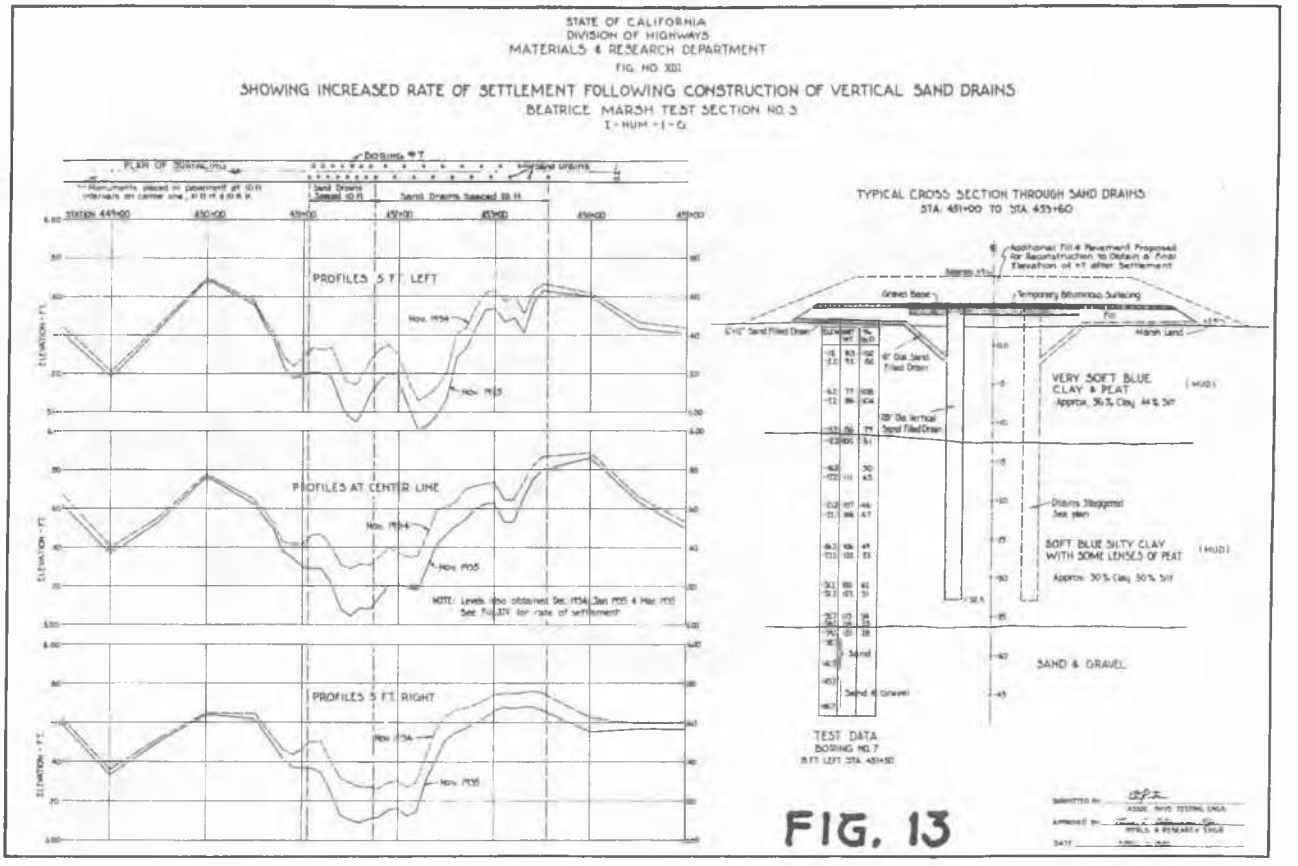
Sample No.	Location Station	Elev.	% (1) Water	Unit Weight-Wet	Grain Size Analysis (2) Gravel	Sand	Silt	Per cent Clay
12-1-X	398+50-8'Lt.	- 1.3	100	90	0	6	37	57
12-1-IV	" "	- 2.5	92	92	0	9	32	59
12-4-VI	" "	-10.0	82	97	0	5	40	55
12-4-I	" "	-11.3	43	120	0	5	49	46
12-3-XVI	" "	-20.5	43	115	0	33	41	26
12-3-VIII	" "	-22.0	42	112	0	55	22	23
9-1-VI	430+30-8'Lt.	- 2.0	94	90	0	4	31	65
9-2-III	" "	- 8.0	100	88	0	19	32	49
9-3-V	" "	-12.5	90	98	0	1	45	54
9-4-I	" "	-19.0	43	112	0	8	50	42
9-5-VIII	" "	-27.3	69	91	0	4	42	54
9-5-VII	" "	-27.5	55	103	0	3	44	53
9-6-VIII	" "	-37.4	42	107	0	3	40	57
9-6-IV	" "	-38.2	64	102	0	5	34	61
9-7-XIX	" "	-45.3	43	106	0	20	40	40
9-7-IX	" "	-47.3	48	102	0	11	39	50
9-7-III	" "	-48.3	56	100	0	1	38	61
9-8-IV	" "	-58.6	26	120	0	20	51	29
7-1-III	451+50-8'Lt.	- 0.7	102	83	0	5	29	66
7-2-I	" "	- 6.7	104	86	0	4	23	73
7-3-III	" "	-11.2	79	86	0	4	36	60
7-8-III	" "	-36.0	33	114	0	19	49	32

(1) Percentage of moisture by weight of dry soil sample.

(2) Gravel Particles coarser than 2000 microns.
Sand " smaller " " " and coarser than 50 microns.
Silt " " " 50 " " " " 5 "
Clay " " " 5 " .

Fig. 11
Showing the rotary type drill outfit used in connection with the installation of vertical sand drains. Holes, 28 inches in diameter, were bored to a depth of about 50 feet

Fig. 12
Removing mud from rotary bucket. Bottom of bucket and cutting blades are hinged to permit quick removal of the mud



No. L-2 EXPERIMENTAL ROAD FOR HEAVY TRAFFIC ON A VERY COMPRESSIBLE SOIL (PEAT-BOG-GROUND)
J. A. Royer, Civil-Engineer of the "Provinciale Waterstaat in Zuid-Holland", the Hague.

In a part of the Province Zuid-Holland with a very compressible soil, consisting of peat-bog-ground of a depth of 8 to 10 m and where the firm foundation is situated about 10 to 12 m below the ground-surface (fig. 3b), a number of new roads for heavy traffic must be built.

Till now the usual construction of earth-works in this sort of soil-condition has been the tipping of sand on the peat-bog-ground, which is pressed away by the weight of the sand, until the latter had reached the firm foundation. In this way the railroad on Fig. 1 was constructed.

Apart from the damage caused to the surroundings by the peat-bog pressed aside, this construction has the drawback, that in this case, where the firm foundation is situated very low, a huge quantity of sand has to be used for the laying-down of the road-embankment, which is very expensive.

As the projected roads are to have an embankment of about 18 m (20 yards) wide, so that each m length of the road would require 150 to 200 m^3 (5000 to 7000 cubic feet) sand for the building of the embankment, the construction-costs would be too high. Hence the possibility was faced to get to a less expensive construction, without exposing the stability of the embankment to danger.

Therefore was looked for a construction, which would make it possible, that the peat-bog was only compressed and not pressed away. In this case the sand-body penetrates much slower into the peat-bog and even if the peat would be compressed at the end to a thin layer on the firm foundation, the sandfill will be divided over so many years, that already by that means only is saved considerably on the building-expenses.

As a method to attain this (slow) compression of the peat was chosen a layer of fascine (fascine mattress), built on the top of the peat as foundation for the sand-body, which was gradually tipped on the mattress after it was constructed.

For investigation purposes a road of about 200 m of this system was constructed. It was layed out alongside of a rather narrow many centuries old road and after completion traffic has been directed over it. (Fig. 1)

As at the beginning there were no indications how far within a certain time the mattress would settle in consequence of the weight of the road-embankment and the traffic and as for the preservation of the fascinage it is necessary, that within a few years the top of the mattress is lying beneath the underground water-level, the peat was dug out over a depth of 1 m (Fig. 4a & 5a). On that level the fascine mattress was constructed, so that the top came till 0.10 m above the water-level.

The fascine mattress (Fig. 2, 4 & 5a) is made entirely of fascines or brushwood and consists of 3 main parts, to wit: