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By

Howard M. Williams

And

James F. Haley

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Details of illustrations in this document may be better studied on microfiche

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The technical literature and military annals of recent years bear witness to the rapid development of numerous methods to aid in the quick construction of advance military airfields and roads. This progress has largely been secured through the development of special pavement surfaces such as the pierced steel plank and prefabricated bituminous surfacing (P.B.S.) and through a better and more widespread understanding of soil testing procedures such as the California Bearing Ratio test and the cone penetrometer. However, an examination of these exemplary advances indicates that our emphasis has been primarily on the evaluation of the subgrade's load-bearing capacity and the development of adequate pavement to reduce the surface load down to a safe subgrade stress. Little has been accomplished in improving the subgrade's load-bearing capacity through the reduction of soil moisture to optimum values. It is in an effort to incite some creative thinking and development in this promising phase that this paper has been written.

In conventional peacetime highway or airfield construction, the engineer, when confronted with excessive soil moisture conditions, has a number of potential solutions which may vary from aerating the soil to the installation of an extensive field of pipe subdrains. The military engineer must generally shun such construction both because of time consumed in construction and because of the logistical problem involved in the transportation of necessary pipe. Hence, the present tendency to forego improvement of subgrade qualities by subdrainage and to rely on an unnecessarily heavy surface construction.

In its examination of this problem, the Corps of Engineers has given consideration to borrowing the principle of the farmer's mole drain and adopting it to military construction to secure quick subgrade drainage with a minimum logistical effort.

The origin of the mole drain as applied to agriculture is lost in antiquity. Suffice to say that mole drainage of farm land has been practiced in England and on the Continent for well over a century and is well known in other parts of the world such as Egypt, New Zealand, and in the sugar cane country of our own Gulf States.

Basically, the mole drain is a subsoil drain formed in place by a mole plow pulled through the soil. A typical example of presently available mole plow equipment is shown in Fig. 1. As practiced in agriculture, the success of the mole drain depends largely on the plastic properties of the soil to keep the drain open, since no drain tile or other wall-reinforcing agent is used. Its usefulness is limited therefore to heavy plastic soils. Even so, the durability of a mole drain in heavy soils is remarkable and experience in the Gulf States in this country indicates average drain life of two to three years, with specific instances of as much as fifteen years.

Here, then, appears to be a ready-made device suitable for use in heavy plastic soils. The drain can be constructed as fast as a tractor can operate, permitting large installations in a short time and with a minimum logistic effort. It is recognized that pore water in plastic soils cannot be removed readily by gravity drainage. However, examination of the mole plow equipment and typical mold drain cross sections suggests how soil moisture is reduced.

The passage of the plow through the soil results in an open slot extending from mole to the ground surface. In addition, the movement of the plow results in numerous soil fractures radiating out from the mole drain and from the slot. These openings provide a free passageway for water and air. Subsequent paving operations will, of course, decrease the openings but, in agriculture studies, indications of the slot and incidental soil fractures have been evident in exploratory trenches opened two years after the drains' construction. The result of these underground openings are threefold in that they (1) permit removal of surface water before it has an opportunity to mix into the clay, (2) provide an aerating action which promotes evaporation of pore water, and (3) provide an outlet for release of such subsurface drainage as may occur. These conditions all tend to place the water phase of the soil in tension and cause consolidation and strengthening of the subgrade.

Such a mole drainage system has proved very effective in reclaiming many acres of low-lying, poorly drained agricultural lands and should prove a valuable tool in the construction of airfields under similar conditions. Moreover, it is believed that even in soils containing some sand or silt, the mole drains would greatly increase drainage for short periods of time with resultant construction benefits. The time during which the drain functions would, in a large measure, be reflected by the soil's ability to maintain the drain opening.

At the outset, it was recognized that the mole drain's usefulness was severely limited unless some simple but effective method of making the drain a relatively stable structure in a wide variety of soil conditions could be achieved. It was to study this problem that a series of laboratory investigations and model tests were initiated in the Soils Laboratory of the New England Division, Corps of Engineers, in Boston in 1946. The studies were curtailed for fiscal reasons in 1947 but the limited results, while not at all conclusive, demonstrated the potentialities of developing a successful mole drainage procedure.

The investigations to date have followed two general paths of study: First, to attempt to strengthen the existing soil walls of the mole drain by a coating or liner cast in place during the passage of the mole plow and, second, to insert a suitable prefabricated liner into the mode drain behind the plow.

For the first series of studies a wood test box was constructed with the dimensions of 12 feet in length, 4 feet in width, and 5 feet in height. A track arrangement was constructed along the top of the box to guide and support the mole plow. Provision was made at the ends of the box for entrance of the mole plow. A portable electric winch with necessary blocks and tackles and dynometer were provided to pull the plow through the test box. An isometric view of the test equipment is shown in Fig. 2.

The box was filled with a fine silt representing one of the most severe conditions under which a mole drain would have to be constructed. The characteristics of the soil are indicated in the gradation curve shown in Fig. 3

Details of the test plow used for this phase of the tests are shown in Fig. 4. The vertical shaft of the plow is a built-up section consisting of three vertical steel strips one inch thick and covered with 1/4-inch steel plates welded in such a manner as to provide two vertical channels, approximately one inch by two inches in section, through which lining materials could be supplied the plow.

The mole was made from a section of standard 3-1/2-inch pipe welded horizontally to the lower end of the vertical shaft. The front of the mole was cut on a bevel and a steel plate welded to it to form a cutting surface. A bevel front of this type is commonly used on agricultural mole plows to produce a downward component, thus preventing the plow from riding out of the soil. Braced and welded to the top rear end of the 3-1/2-inch mole was a segment of 4-inch pipe, 2 inches wide and 28 inches long, designed to provide a temporary form for injection of materials at the top of the drain where the soil has been displaced by the vertical shaft. The plow was equipped with suitable frame to permit its movement along the track on the test box. The mole plow was designed to be used with an interchangeable tail section and the five tail sections employed in these tests are shown in Fig. 4. The plow was initially constructed with the so-called asphalt tail assembly, which was used both for asphalt and portland cement mixtures. This tail was constructed of 3-1/2-inch pipe in such a manner that the lining material, pumped down through the plow shaft, was forced through an annular space around the bullet-shaped tail piece and applied to the soil walls of the mole drain. A segment of 3-inch Shelby tubing, approximately 2 inches in width and 4 feet in length, was welded to the rear of this machined bullet section to provide initial support to the drain lining. A view of this tail assembly is shown in Fig. 5.

Alternate Tail Assembly No. 1 was designed for use with portland cement mixtures and was modeled in theory after a proprietary process for placing a thin concrete liner inside of existing metal pipe. The lining mixture was forced down the rear channel in the plow's vertical shaft and out the rear of the plow. The mixture was then forced against the soil walls of the mole drain by a bullet-shaped tail piece and the excess water, in theory, was squeezed out of the mixture through the small sieve-like perforations in the tail piece.

It was believed that there would be a problem of relieving the excess air which would accompany the extrusion of portland cement mixtures which were pumped by air pressure. Therefore, an Alternate Tail Assembly No. 2 was devised by removing the bullet nose from Tail Assembly No. 1 and replacing it with a section of well point lined with a five mesh screen which would allow air trapped in the aggregate to escape through the well point and either out through the completed mole drain or up to the surface through the front vertical channel.

Alternate Tail Assembly No. 3 is a further modification of Alternate No. 1. A 1/2-inch rod, 4 feet long, attached to the front end of the tail was provided to allow the tail to follow the plow at a greater distance than the original design. Two tapered cylindrical sleeves were attached to the rod to center the tail within the drain. The connection to the back of the plow was made semi-rigid to prevent rotation of the tail in order that the skid would cut a longitudinal slot in the bottom of the drain to allow entrance of water into the drain.

In the final design, Alternate Tail Assembly No. 4, the original Asphalt Tail Assembly was modified by provision of helical strips designed to scrape some soil from the drain wall and mix it with the asphalt before reapplying it on the drain wall.

A form of montejus was used to supply the asphalt mixtures wherein the asphalt was heated by steam coils and forced by steam pressure through a pipe line to the mole plow. For the cement grout mixtures, a grout pump operated by air pressure and a hand-operated diaphragm pump were used. For some of the portland cement mixtures a commercial cement gun was used to both mix and transport the lining material. This equipment also used air pressure as the motivating force.

Prior to initiating operations in the large test box, the stability of sand-asphalt mixtures was studied. Sand asphalt mixes were prepared wherein the asphalt by weight was 15, 20, and 30 percent of the weight of sand. These mixtures were placed in test cylinders with removable forms. After cooling to room temperature, the samples were laid horizontally on a board for observation. The room temperature fluctuated from 65° to 70°F. during the test period. Results of these tests are shown in Fig. 6 and indicate the necessity of a low asphalt content to gain appreciable structural stability.

Tests were next initiated in the large test box and the test conditions and results are enumerated in Table 1. Examination of this table will indicate the poor and inconclusive results achieved with asphaltic materials. All tests were hampered by mechanical difficulties incurred in securing satisfactory heating and pumping of the asphalts to and through the mole drain. Supply lines were not steam jacketed or equipped with recirculating devices and the asphalt mixtures tended to congeal before reaching the mole plow outlet. Air used to pump the asphalt tended to bubble through the outlet in the mole plow and resulted in an uneven and discontinuous supply. In the sand asphalt tests it was noted that, to secure the required fluidity for pumping with existing equipment, it was necessary to use excessive amounts of asphalt, overfilling the voids in the sand and destroying all structural rigidity. In the tests using asphalt alone, the excessive moisture of the soil prevented adhesion of the asphalt to the soil particles.

In spite of these poor results, there is evidence that a successful sand-asphalt drain can be constructed; the major problem being one of equipment development. To attain sufficient stability of the drain structure, the mix should contain from 8 to 10 percent asphalt. To overcome mechanical difficulties of transporting a pre-mixed sand asphalt it would appear desirable to cause the mixing to occur below ground in the mole plow.

The tests using portland cement mixtures were not conclusive but they did achieve more spectacular results as is evidenced by the drains shown in Figs. 7 and 8. It was noted that pressure grouting does not permit use of a sufficiently stiff portland cement mix for construction of a drain that will stand unsupported for a considerable period of time, unless admixtures are used to produce quick setting properties. The control of setting time of sand-cement mixtures by admixtures requires a degree of precision difficult to obtain, especially if the mixture is to be pumped some distance to the mole plow. This might be overcome by developing equipment wherein water would be added to a dry mix at or near the point of application in the molo plow.

While the preceding discussions have been limited to the possible use of asphaltic or portland cement mixtures, there is no reason why other lining materials cannot be developed satisfactorily. For example, the use of chemical treatment or of plastic linings formed in place is a definite possibility and is being considered for further investigation by the Corps of Engineers. Likewise, there is a distinct possibility that equipment can be developed to form in place a liner of thin metal or treated paper.

Methods of stabilizing the walls of a mole hole have been used for many years in Europe. The most common procedure consists of pulling tile, wooden drains or metal tubing into the mole hole behind the mole plow. Several ingenious schemes have been employed to attach a string of tiles to the rear of the plow. One of the methods used in Germany is known as the Poppelsdorf drainage system. In this method tiles are threaded onto a wire cable equipped with expanders having the inside diameter of the tiles and are pulled into place behind the mole plow in units 100 feet long. Provision is made for withdrawing the wire and adding additional units of tile. In this way lengths of 400 feet of tile drains have been successfully laid. In some operations where this method is used it is found that a very rapid contraction of the mole drain takes place necessitating a considerable difference in size between expander and tiles. Under German conditions the cost of this method is about 50 percent that of drains laid by hand labor, while regular mole drainage without tile can be put in at only 20 percent of the cost of hand-laid tile.

Because of the difficulties in preventing breakage of the tiles and the uncertainty regarding the intact condition of the installation, methods such as the Poppelsdorf system have not gained widespread acceptance in Europe in spite of their great economic advantage. These methods did, however, suggest that the placing of a preformed lining on the walls of a mole hole was practical and by improvement in methods and materials, the encumbrances which had hampered the existing methods might be eliminated.

During the period that full scale laboratory investigations were in progress to study methods of lining a mole hole by using portland cement and asphalt mixtures, consideration was also given to methods of placing a preformed structural lining to stabilize the walls of a mole drain. The method which was considered to offer the greatest promise was the use of perforated plastic tubing placed either by pulling into the mole hole behind a mole plow or by laying with a cable laying machine similar to those used for placing underground telephone cable. The investigation by the Corps of Engineers was not continued to permit verifying the practicability of this method by field installation; however, investigations of the method at Iowa State College, Ames, Iowa, during the period 1948 to 1951 have demonstrated the method to be feasible and that it offers an appreciable saving as compared to tile drains installed in a trench.

After first considering several materials for use as the preformed lining for the mole drain, a survey was made in the field of plastics to determine the type of extruded plastic tubing which had the desired characteristics. These desired properties were: (1) resistance to corrosion and deterioration from underground exposure, (2) stability against collapse under external pressure, (3) availability in long lengths, preferably in reels, (4) porous or perforated walls, (5) flexibility, and (6) reasonable cost.

There were found to be relatively few commercially available plastic tubings which satisfied these requirements, particularly in regard to flexibility. A thermoplastic tubing, polyethylene, was found to have the physico-chemical properties considered to be most suitable for stabilizing mole drains. The properties of polyethylene are shown in Table 2. A specimen of polyethylene tubing was obtained from the Carter Products Company, Cleveland, Ohio to further investigate its suitability and study possible methods of placing the tubing in the ground.

Since the need of subsurface drainage of the type discussed in this paper is confined to fine-grained, relatively impervious soils, the drains must be closely spaced to be effective and the quantity of flow in each drain is small even for long lengths of drain. Theoretical studies indicated that a drain 2 inches in diameter had sufficient drainage capacity and had considerable stability with wall thicknesses of 0.05 to 0.1 inches. Tubing of this size is also sufficiently flexible to be coiled in reels having a diameter of four feet as shown in Fig. 9. Although the tubing was perforated by the manufacturer after extrusion with 48 1/8-inch diameter holes per foot of tubing, the manufacturer stated that it would be possible with a minimum of tooling to perforate the tubing during the process of extrusion. The approximate cost of 2-inch diameter polyethylene tubing in 1950 was $0.15 per foot for 0.05 inch wall thickness and $0.30 per foot for 0.10 inch wall thickness. This compares with a material cost for 4-inch farm tile of $0.10 per foot. However, the cost of installing farm tile in an excavated trench is considerably higher than the estimated cost of installing the perforated plastic tubing.

The plastic drain pipe could be installed by either of two methods. One method would be to pull long lengths of tubing into the mole hole by attaching the tubing to a standard agricultural mole plow such as shown in Fig. 1. Another method, which shows promise of development, consists of feeding the plastic tubing from a reel down the vertical blade and out the rear of the plow while it is being drawn through the soil.

For this method, a machine similar to the cable laying plows used by the American Telephone and Telegraph Company could be used. The C-48 plow, Fig. 10, is designed to lay one or two cables with maximum outside diameters of 2.5 inches while cutting a trench in the soil 3.5 inches wide. The plow can be set to operate at any desired depth up to 4 feet. It is estimated from other data on mole drainage that the drawbar pull for a C-48 plow in the type of soil being considered would be approximately 15,000 lbs. for average soil conditions. One heavy tractor would thus be sufficient for normal placing of the perforated plastic tubing.

The C-60 plow, Fig. 11, is designed to lay a cable to a maximum depth of 5 feet. The plow is hydraulically controlled and the depths at which the cable is placed can be changed as desired while moving, continuously if necessary, and therefore, a staked grade line can be followed even if the ground surface is very uneven.

Installation of the drain by pulling the plastic tubing into the hole behind a mole plow is considered more suitable for agricultural use as equipment is less elaborate and the drawbar pull would not be as great as required by the C-48 cable laying plow. The use of a plow similar to the C-48 for placing drains for military construction would be advantageous as the 3.5 inch wide trench cut by the plow share could be backfilled with sand and greatly improve the effectiveness of the drainage system. A truck equipped with hopper could follow the plow and backfill the trench with sand so that the complete drain would be installed in a continuous operation. Typical proposed installations of plastic tubing to accomplish subsurface drainage are shown in Fig. 12. The plastic drain tubing being continuous is not susceptible to infiltration at joints as commonly occurs in farm tile installations. Also, the plastic tubing is not subject to breakage, which is particularly desirable at airfields and other locations where heavy superimposed loadings are anticipated.

Three possible conditions were studied by flow nets to determine the maximum theoretical inflow into the drain. It was first assumed that the drains were 3-1/2 feet deep, spaced on 15-foot centers and the width of trench was 3-1/2 inches. It was also assumed that, since the trench was very narrow in relation to the drain spacing and since the ratio of the coefficients of permeability of the sand backfill to the subgrade (k_2/k_1) would usually be large for the subgrade soils in which the drain is to be placed, no appreciable error would result by computing the inflows from the subgrade and the sand backfill as separate quantities and using their sum as the total inflow. The conditions considered were:

1. Ground water with a hydrostatic head at one foot below the ground surface and no infiltration from the surface.

2. Infiltration from a sheet of water maintained on the surface by rainfall and no ground water table.

3. Ground water with a hydrostatic head at the ground surface and infiltration from a sheet of water maintained on the surface by rainfall.

From a study of the flow nets, it was determined that condition 3 would give the maximum theoretical inflow into the drain. The flow net for this condition is shown on Fig. 13 as well as curves of the coefficients of permeability (k_1 and k_2) versus the theoretical inflows per linear foot (q_1 and q_2). The inflow from the subgrade (q_1) is computed from the flow net formula, $q_1 = k_1 h \; n_f/n_h$ where h is assumed 3-1/2 feet and the ratio of number of flow paths (n_f) to the number of equipotential drops (n_h) from the flow net is two. The inflow from the sand backfill was computed by Darcey's formula, $q_2 = k_2 ia$, where "i" is unity for vertical downward flow and "a" is the cross sectional area of the trench normal to the direction of flow.

The curve of maximum length versus total theoretical inflow per linear foot shown on Fig. 13 was computed from the formula $L = \frac{Q}{q_1 - q_2}$, where Q is the capacity of the pipe flowing full and was derived from Manning's formula for 2-inch tubing on slopes of 0.5, 1.0, and 1.5 percent using a value of n = 0.012.

To determine if 2-inch tubing would have sufficient capacity to provide adequate subsurface drainage in the type soils being considered, the coefficient of permeability of the subgrade k_1 was assumed to be 0.1×10^{-4} cm.-sec. and that of the sand backfill k_2 to be 100×10^{-4} cm.-sec. From Fig. 13, the length of drain at which capacity flow would occur, was found to be 260 feet on a 0.5 percent slope or 360 feet on a 1.0 percent slope. Since the assumptions of permeability and inflow are for the most severe conditions under which this type of drain would be utilized, a much longer length of drain could normally be used.

A research program is presently in progress at Iowa State College under the direction of Mr. Glenn O. Schwab of the Department of Agricultural Engineering to investigate the use of plastic tubing to stabilize mole drains. The results which had been obtained up to the Spring of 1951 were presented by Mr. Schwab in a doctoral thesis on file at the Iowa State College Library, Ames, Iowa.

The investigations included studies of: (1) the effect of number and size of perforations on flow into subsurface drain tubes, (2) the effect of deviations from true grade on performance of small perforated drain tubes, (3) stability of perforated flexible drain tubes in mole drains and (4) cost of plastic tube drainage. Investigations included field installations of perforated plastic drains at several locations with varied soil conditions. The drains were placed by pulling the tubing into the mole drain behind a mole plow. Some of the installations have been in the soil for 32 months without visible evidence of deterioration.

From the results of the investigations which have been completed in Iowa State College, it is indicated that 1-1/2-inch to 2-inch diameter plastic tubes are most practical from the standpoint of stability, capacity, and cost. The estimated installed cost of 1-1/2-inch tubing with 0.040-inch wall thickness was approximately one half the cost of 5-inch tile drains, and the cost of 2-inch tubing, 0.050-inch thick, was approximately three fourths the cost of tile drain.

In conclusion, the authors would be the first to admit that mole drainage for military purposes is, in its present state of development, little more then the germ of an idea. However, it is believed that the history of mole drainage in agriculture and the limited investigations described herein do suggest that the successful application of mole drainage to construction is possible and that in that possibility lie great potential advances in securing better, faster and more efficient military construction.

MOLE DRAINAGE INVESTIGATION

TABLE I
RECORD OF TESTS

TEST NO.	DATE	PUMP TYPE	MATERIALS - RATIO BY WEIGHT							TAIL ASSEMBLY	REMARKS
			ASPHALT CEMENT	BLOWN ASPHALT	CEMENT	SAND	PEA STONE	SODIUM BICARBONATE	WATER		
1	27 Jan. '47	Asphalt	120-150 Pen.								Discharge line must be preheated. Temperature 200°F.
2	4 Feb. '47	Asphalt	120-150 Pen.								Discharged asphalt into pails. Temperature 200°F.
3	6 Feb. '47	Asphalt		20-30 Pen.							Pumped into concentric pipes while submerged. Asphalt had no strength. Temperature 250°F.
4	6 Feb. '47	Asphalt		20-30 Pen.							Pumped thru plow into water. Did not cool immediately. Asphalt flowed to surface. Temperature 250°F.
5	13 Feb. '47	Asphalt		1		2 1/2					Asphalt heater not adequate to heat this mixture to uniform temperature required to pump thru plow. (Temp. 260-300°F)
6	25 Feb. '47	Grout			1	2			0.45		Too dry to pump.
7	25 Feb. '47	Grout			1	2			0.54		Clogged discharge line by chips of concrete.
8	26 Feb. '47	Grout			1	2			0.615		Discharge stopped at end of line due to reduction from 1 1/4" pipe to 3/4" pipe.
9	27 Feb. '47	Grout			1	2			0.618	Tail Alt. #1	Pumped thru plow with 1" nipple at top. Mix too wet.
10	28 Feb. '47	Grout			1	2		0.067	0.58	Tail Alt. #1	Too dry to pump full batch. Mix set up quickly in test pipe.
11	28 Feb. '47	Grout			1	2		0.0333	0.618	Tail Alt. #1	Too wet to stand up.
12	3 Mar. '47	Grout			1	2		0.078	0.6	Tail Alt. #1	Wet enough to pour into pump but mix set up too soon to pump.
13	3 Mar. '47	Grout			1	2		0.062	0.6	Tail Alt. #1	Too wet to stand in pipe.
14	3 Mar. '47	Grout			1	2		0.062	0.58	Tail Alt. #1	Too wet to stand in pipe.
15	4 Mar. '47	Grout			1	2		0.018	0.575	Tail Alt. #1	Part of batch pumped OK. Set up quickly. Remainder too stiff to pump.
16	5 Mar. '47	Grout			1	2		0.0267	0.644	Asphalt Tail	Too wet to stand up.
17	7 Mar. '47	Grout			1	2		0.031	0.644	Asphalt Tail	Part of batch pumped into test pipe. Bottom 2/3 of drain formed in test pipe.
18	10 Mar. '47	Grout			1	2		0.028	0.666	Asphalt Tail	Too stiff to pump.
19	12 Mar. '47	Grout			1	2		0.0276	0.69	Asphalt Tail	Too stiff to pump. Suggest increase % of cement.
20	7 Apr. '47	Grout			1	1 1/3		0.0178	0.575	Asphalt Tail	Too stiff to pump.
21	7 Apr. '47	Grout			1	1 1/3		0.0119	0.564	Asphalt Tail	Too soft to stand up.
22	8 Apr. '47	Grout			1	1 1/3		0.0148	0.583	Asphalt Tail	Too stiff.
23	8 Apr. '47	Grout			1	1		0.018	0.515	Asphalt Tail	Too soft. Better than Test #21

NOTE: Pea stone is from Lexington Sand & Gravel Plant.
Sand is plaster sand.
Cement used was High Early Strength.

MOLE DRAINAGE INVESTIGATION

TABLE I

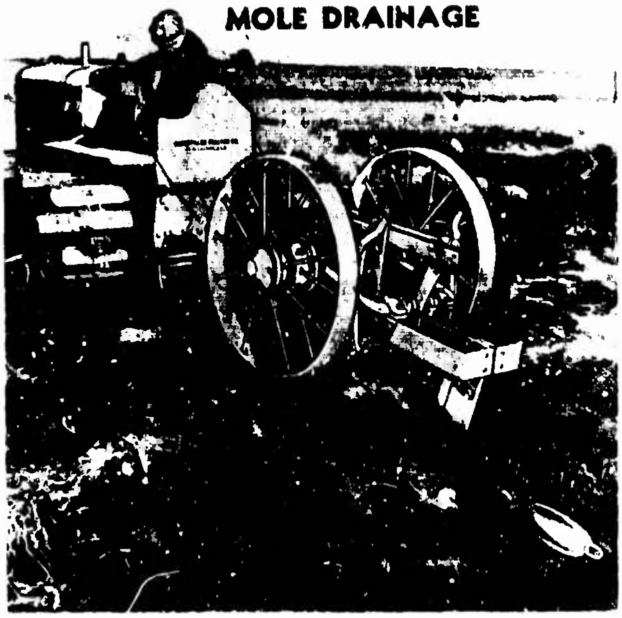
RECORD OF TESTS

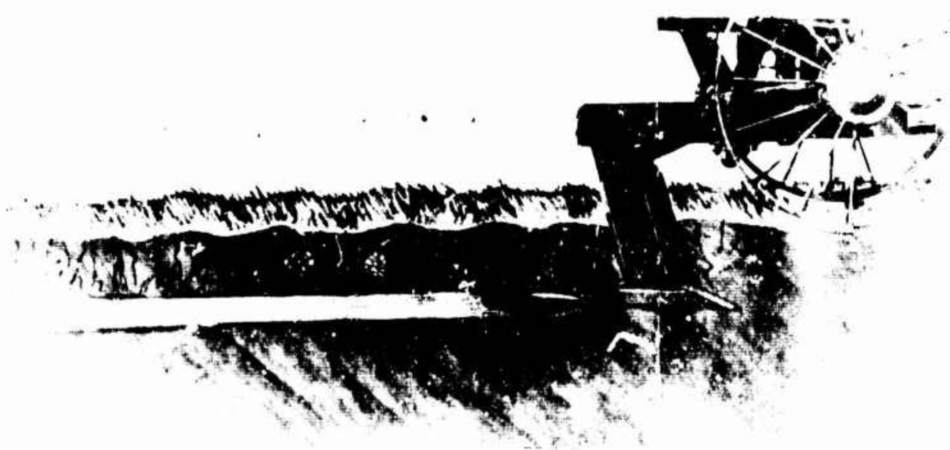
TEST NO.	DATE	MIX TYPE	MIX DATA - RATIO BY WEIGHT: ASPHALT CEMENT	BLOWN ASPHALT	CEMENT	SAND	PEA STONE	SODIUM BICARBONATE	WATER	TAIL ASSEMBLY	REMARKS
24	1[illegible] Apr. '47	[illegible]			1	1			Very liquid		1" outlet pipe. Water, cement, and [illegible] segregated. Pump had to be washed out and disassembled.
25	[illegible] Apr. '47	Grout			1	1 1/3		0.015	0.[illegible]	Asphalt Tail	Quite soft. [illegible]" section of drain made in test pipe. Small quantity not pumped.
26	[illegible] Apr. '47	Grout			1	1 1/3		0.018	0.594		Pumped large test batch into barrel preliminary to pumping thru plow into test box. Valve 1/4 open - 40# pressure.
27	2[illegible] Apr. '47	Grout			1	1 1/3		0.018	0.594	Asphalt Tail	Pumped thru plow into test box. Valve opened too wide. Large quantity poured onto floor at rear end of box. Side walls of drain not thick enough - tail out of line. 7000# ± required to pull plow. 9000# required to open box.
28	[illegible] May '47	Grout			1	1 1/3		0.018	0.594	Asphalt Tail	Pumped thru plow into test box. Winch fouled at midpoint in test run. Remainder of mix pumped while plow was stationary. Drain wall too thin on one side.
29	7 May '47	Grout			1	1 1/3		0.018	0.594	Asphalt Tail	Line plugged with one chip of cement at top of plow. Grout pump tests discontinued.
30	1[illegible] May '47	Cement Gun			1	1 1/3			Nozzle control		Trial pumping to learn operation of cement gun
31	1[illegible] May '47	Cement Gun			1	1 1/3			Nozzle control		Pumped thru 5' long 1" standard pipe into 4" test pipe.
32	1[illegible] May '47	Cement Gun			1	2		0.027	Nozzle control		Gun left open with resultant loss of pressure. Mix appeared to be too sandy.
33	1[illegible] May '47	Cement Gun			1	1 1/2		0.015	Nozzle control	Tail Alt. #2	Pumped thru plow into test pipe. Mix too wet. Tail assembly too close to outlet of plow.
34	19 May '47	Cement Gun			1	1 1/3			0.594		Pumped into pan. Too wet. Pumped too fast.
35	1[illegible] May '47	Cement Gun			1	1 1/3			0.504	Tail Alt. #1	Not as stiff as intended.
36	[illegible]2 May '47	Cement Gun			1	1 1/3			0.412		Too stiff - sand segregated from water and cement.
37	26 May '47	Cement Gun			1		3 1/3		Nozzle control		First of batch too dense with cement, last of batch was clean stone.
38	[illegible] May '47	Cement Gun			1		5		0.624		Pumped very well into test pipe - air jet 3/4 open.
39	26 May '47	Cement Gun			1	1 1/3			0.475		Pumped very well into test pipe.
40	26 May '47	Cement Gun			1	1 1/3			0.475	Tail Alt. #3	Pumped thru plow into test box - best drain to date.
41	2 June '47	Cement Gun			1		5		0.624	Tail Alt. #3	Pumped well. Stone mixed with silt and was left in bottom of drain. No bond between grains. Mix probably too dry.
42	4 June '47	Asphalt		20-30 Pen.						Tail Alt. #4	Pumped small quantity thru plow into test box. After three feet line plugged with cold asphalt. Asphalt did not penetrate silt. Tail produced a thin, incomplete wall with no strength.

TABLE 2.
PROPERTIES OF POLYETHYLENE

Specific Gravity	0.92-0.93
Specific Volume, cu. in./lb.	30.1
Tensile Strength, psi	1800-3000
Modulus of Elasticity, psi x 10^5	0.15 tension 0.13 flexure
Flexural Strength, psi	1500-1700
Impact Strength, ft. lb. per in. of notch, 1/2 x 1/2 in. notched bar, Izod test	3
Hardness, Rockwell	R-25 R-27
Thermal Conductivity, 10^{-4} cal per sec per sq cm/C^o per cm	6.0-8.0
Specific Heat, cal per ^oC per gram	0.53
Thermal Expansion, 10^{-5} per ^oC	18
Resistance to Heat (Continuous), ^oF,	212
Water Absorption, 24 hrs., 1/8 in. thickness, %	0.01
Burning Rate	Slow
Effect of Sunlight	Slight
Effect of Weak Acids	None
Effect of Strong Acids	None
Effect of Weak Alkalies	None
Effect of Strong Alkalies	None
Effect of Organic Solvents	None Below 50^oC
Effect on Metal Inserts	Inert
Machining Qualities	Good
Clarity	Translucent to Opaque
Color Possibilities	Unlimited

MOLE DRAINAGE





MOLE PLOW USED FOR
AGRICULTURAL DRAINAGE

FIG. 1

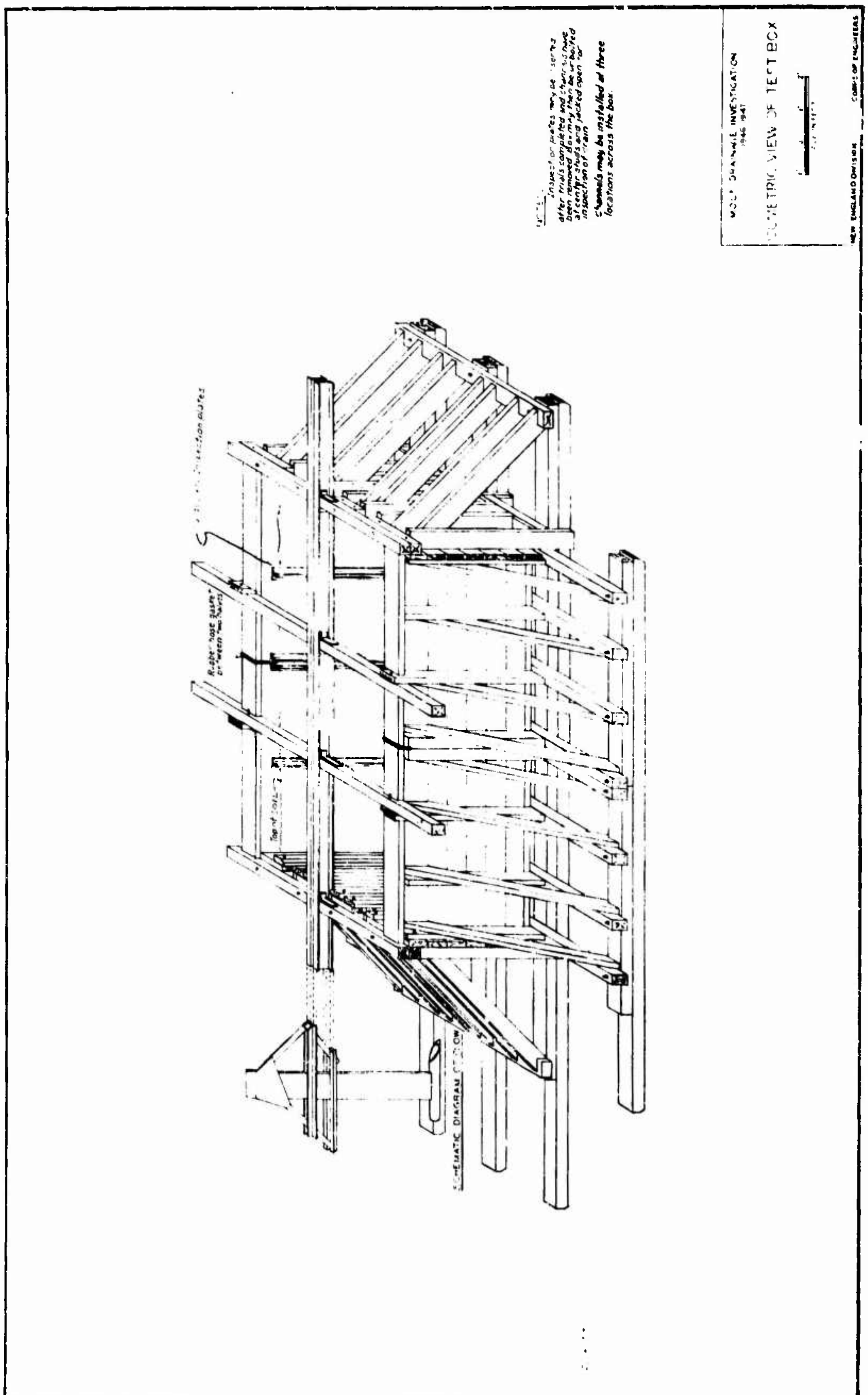
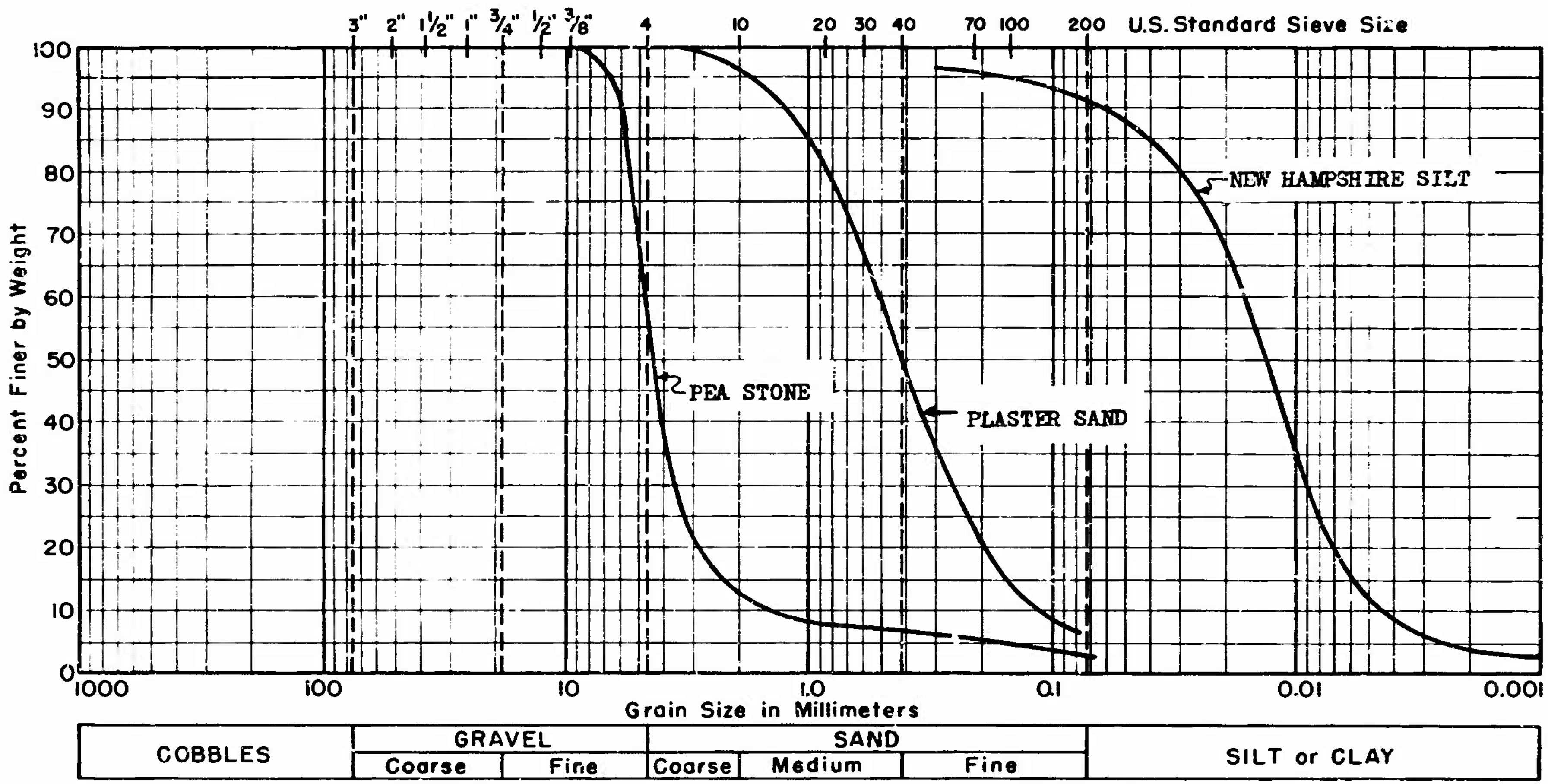

Channels may be installed at three locations across the box.
NEW ENGLAND DIVISION
CORPS OF ENGINEERS

FIG. 2



CHARACTERISTICS OF NEW HAMPSHIRE SILT

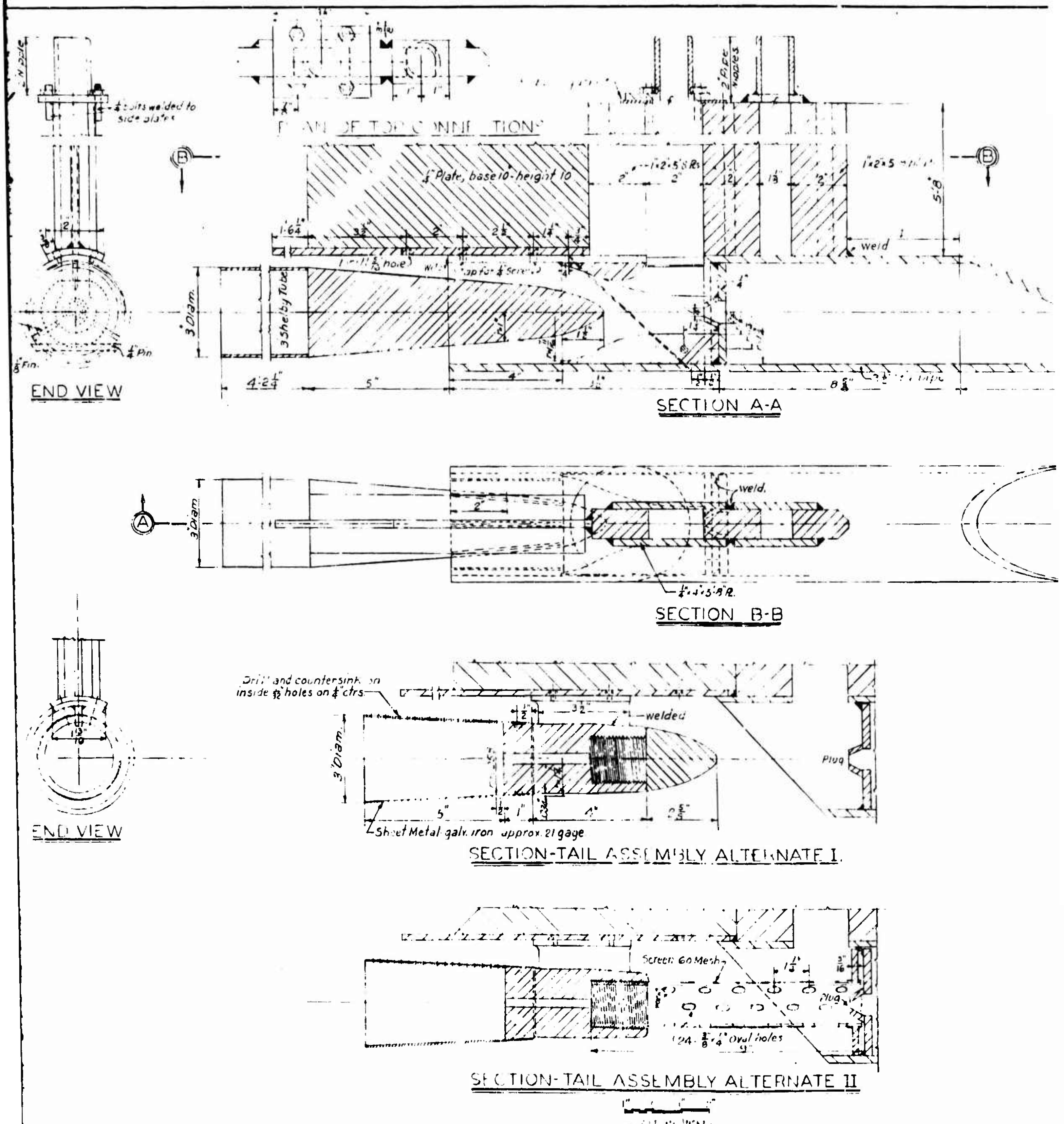
Modified AASHO Density -- 107 pcf.
Optimum moisture content - 17.7 %
Specific gravity (solids) - 2.69

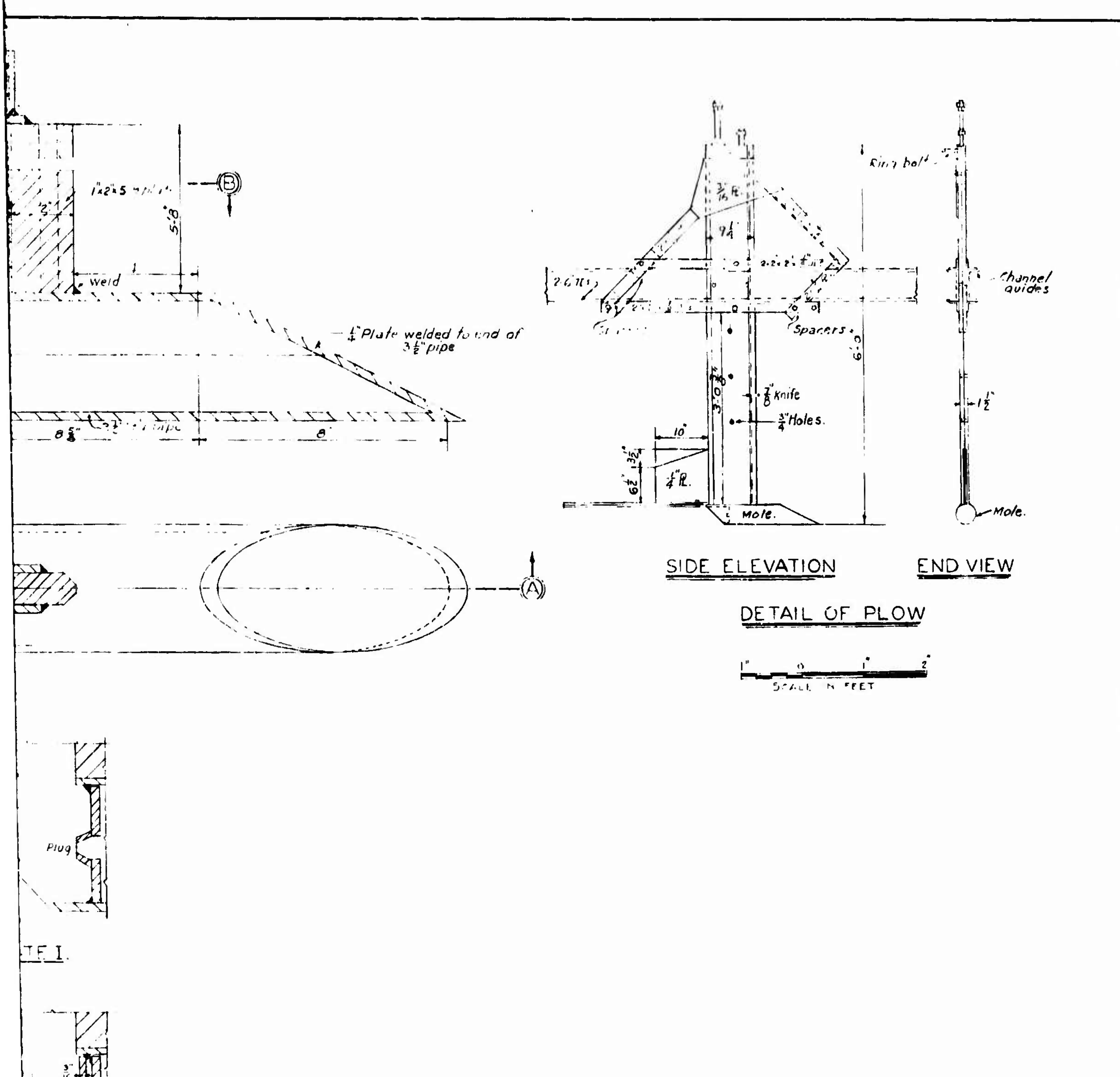
Liquid limit ------ 29 %
Plasticity index --- 5 %
"In place" density 97.8 pcf.

"In place" water content - 22.3 %
Coef. of permeability -- 0.46 x 10^{-4} cm/sec.

GRADATION OF MATERIALS

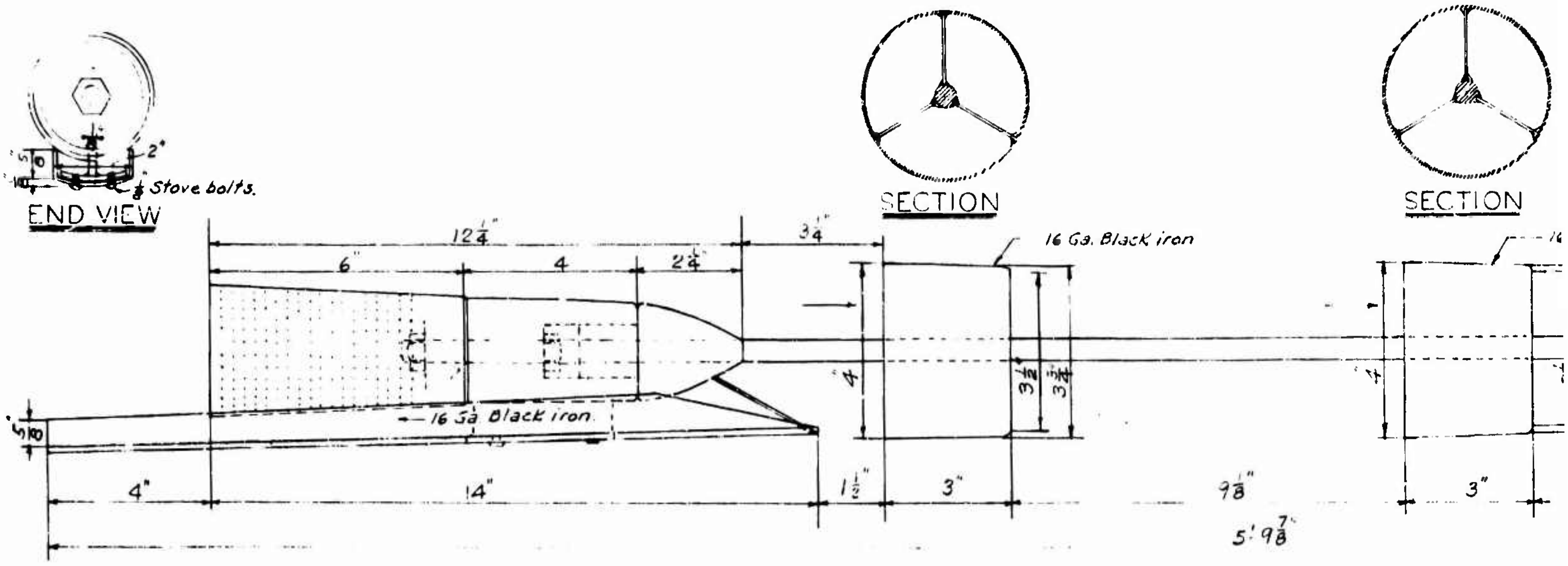
FIG. 3


END VIEW
$\frac{3}{4}$ bolts welded to side plates
PLAN OF TOP CONNECTIONS
$\frac{1}{4}$ Plate, base 10 - height 10
3 Shelby Tube
3 Diam.
2" Pipe
weld
SECTION A-A
SECTION B-B
weld.
Drill and countersink on inside holes on $\frac{3}{4}$ ctrs.
welded
Plug
Sheet Metal galv. iron approx. 21 gage
END VIEW
SECTION-TAIL ASSEMBLY ALTERNATE I.
Screen 60 Mesh
SECTION-TAIL ASSEMBLY ALTERNATE II

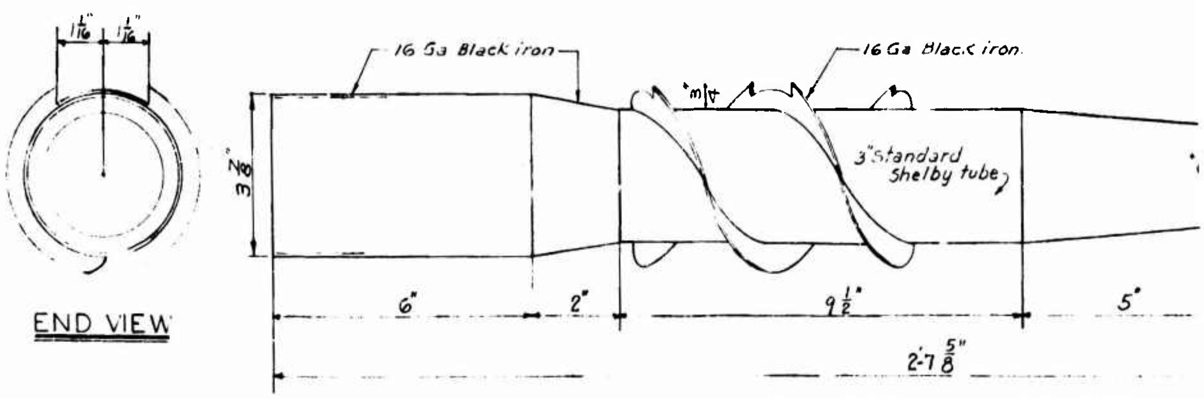


DETAILS OF MOLE TEST PLOW

FIG. 4

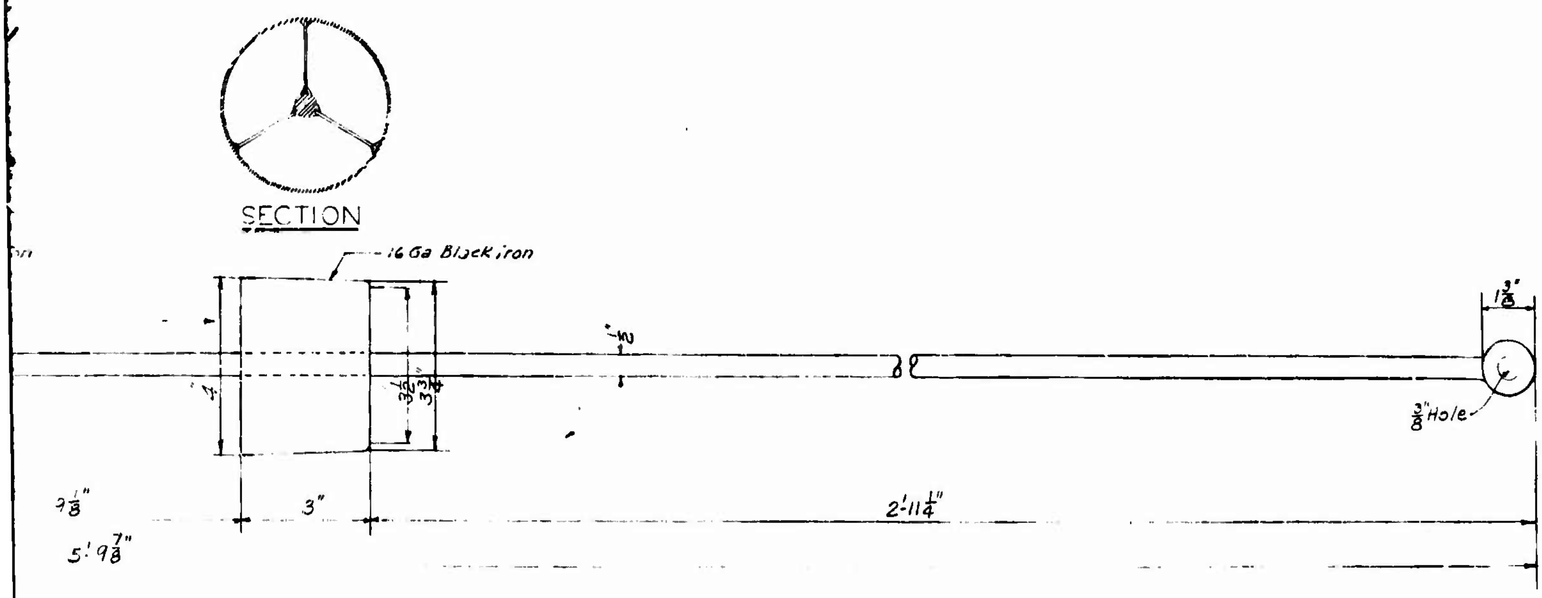


TAIL ASSEMBLY ALTERNATE

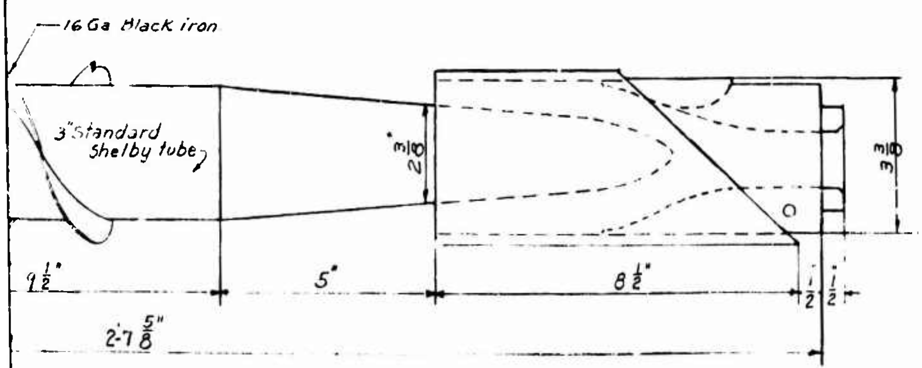


TAIL ASSEMBLY ALTERNATE IV

SCALE IN INCHES



L ASSEMBLY ALTERNATE III



ASSEMBLY ALTERNATE IV

1 0 1" 2"
SCALE IN INCHES

MOLE DRAINAGE INVESTIGATION

DETAILS OF MOLE TEST PLOW

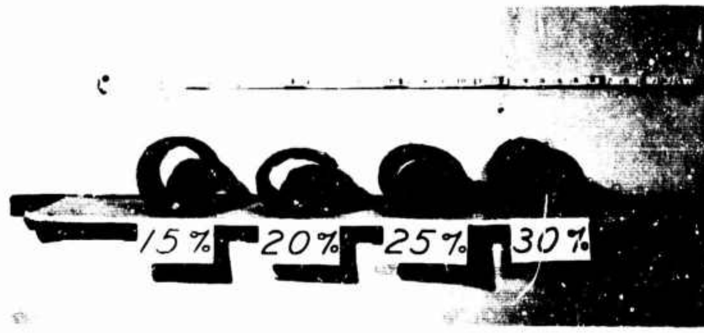
SCALE AS NOTED
SHEET 2 OF 2

NEW ENGLAND DIVISION — CORPS OF ENGINEERS

FIG. 4

Plow with asphalt Tail Assembly Attached

FIG. 5



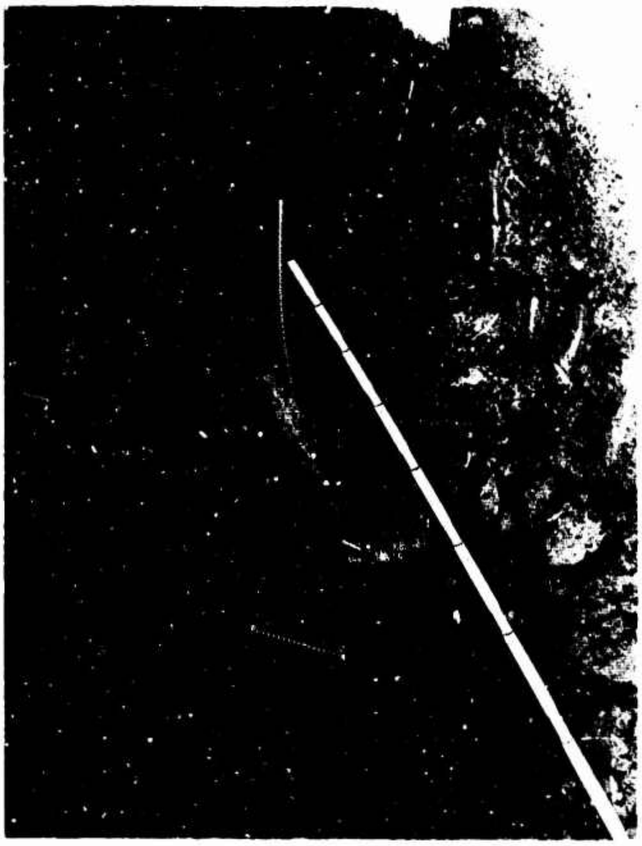
Time after Stripping Forms - 5 Hours

Time after Stripping Forms - 2 Days

Time after Stripping Forms - 7 Days

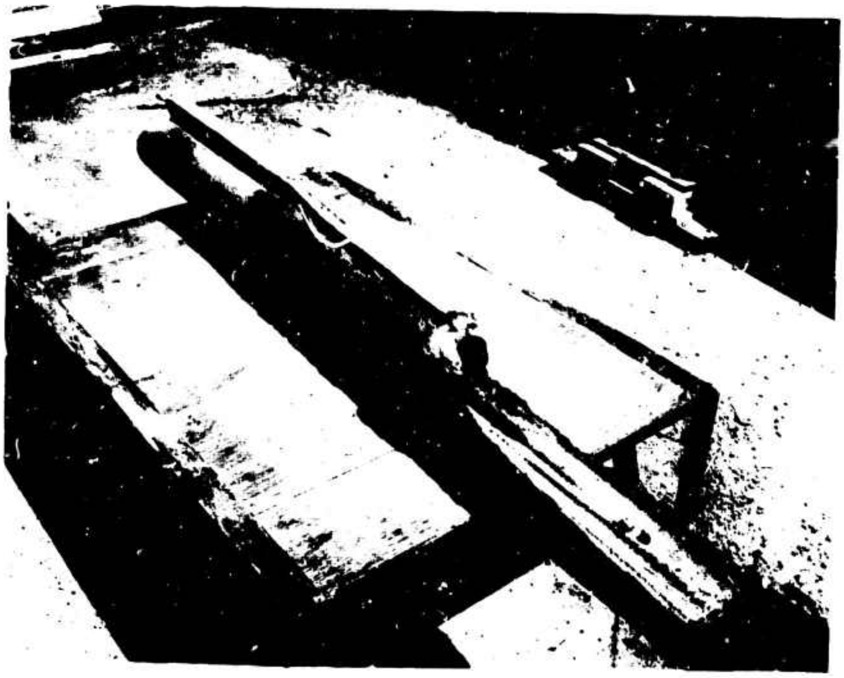
Sand-Asphalt Sample Cylinders showing varying percents of Asphalt

FIG. 6



Concrete Drain after Excavation. Test No. 40

FIG. 7

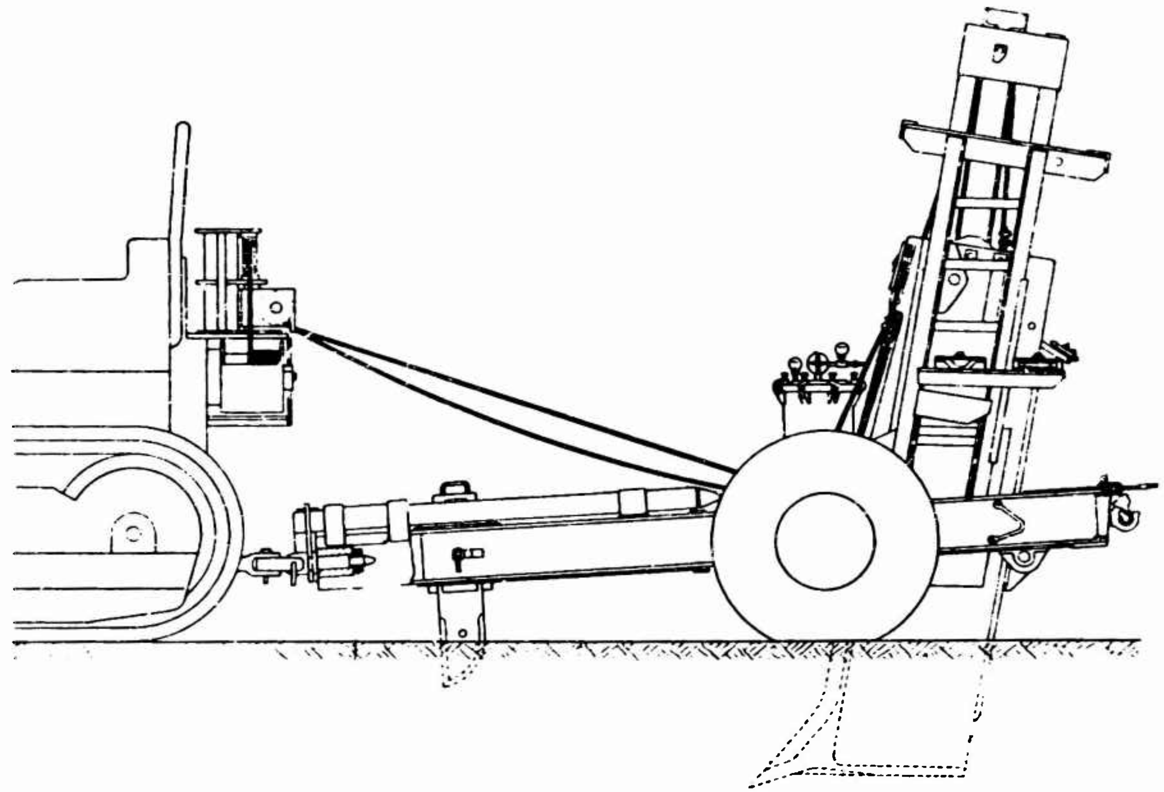


Right side of Concrete Drain after Removal from Test Box. Test No. 40

FIG. 8

4 Foot Diameter Coil of Polyethylene Tubing

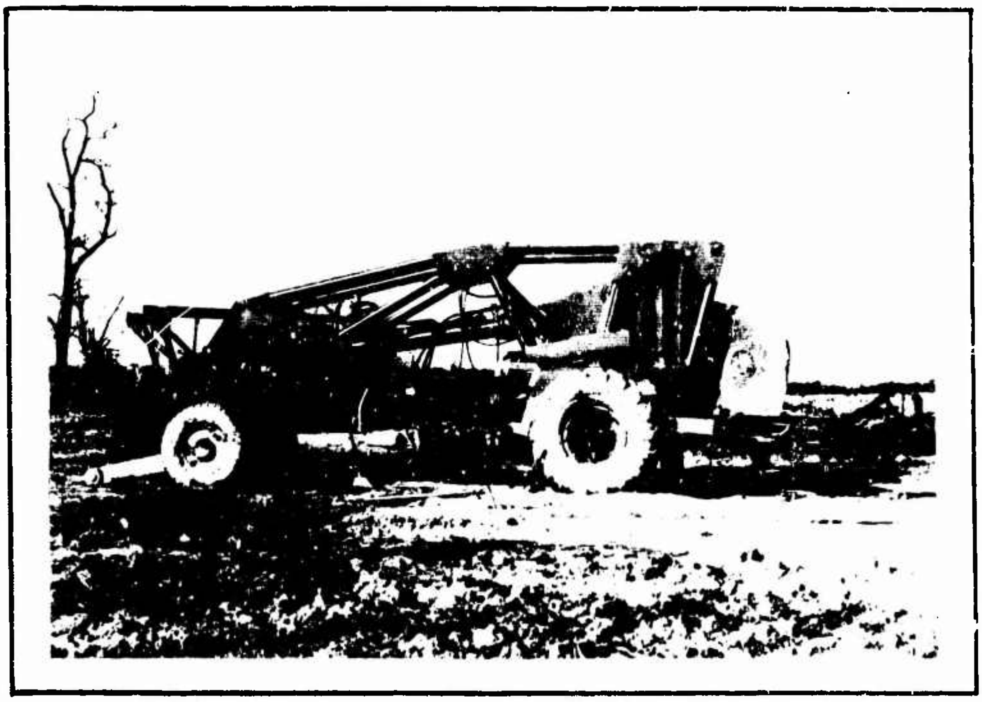
FIG. 9



PLOW EQUIPPED FOR CABLE LAYING

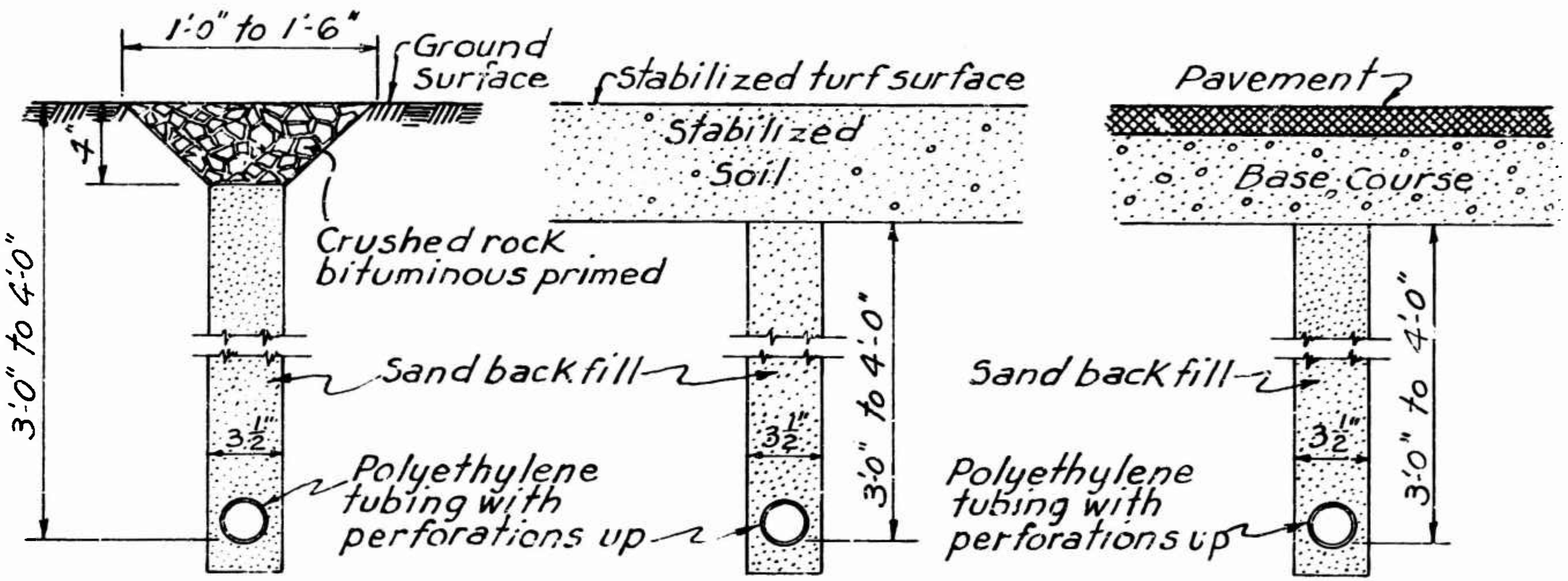
CABLE LAYING PLOW "C-48"
AMERICAN TELEPHONE & TELEGRAPH COMPANY

FIG. 10



CABLE LAYING PLOW "C-60"
AMERICAN TEL PHONE & TELEGRAPH COMPANY

FIG. 11

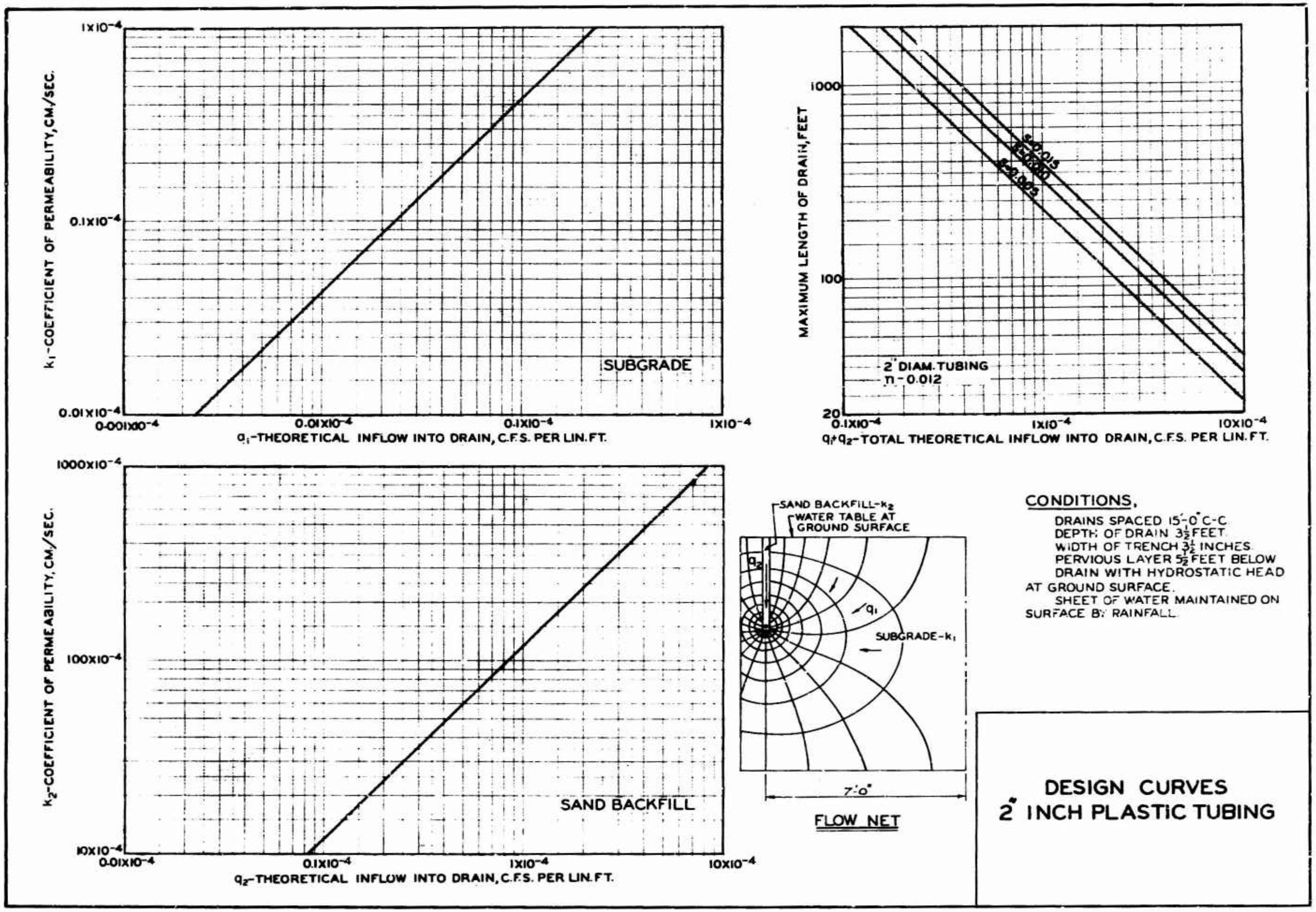


TYPE A   TYPE B   TYPE C

TYPE A	FOR DRAINING TURF SWALES AND FOR PREVENTING SURFACE PONDING
TYPE B	FOR DRAINING SUBGRADES OF TURF RUNWAYS AND SHOULDER AREAS
TYPE C	FOR DRAINING RUNWAY SUBGRADE AND BASE COURSE

TYPICAL SECTIONS
2" INCH PLASTIC TUBING

FIG. 12



DESIGN CURVES
2" INCH PLASTIC TUBING

FIG. 13