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MOLE DRAINAGE INVESTIGATION 1946 - 1947

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SYNOPSIS.

The purpose of this investigation is to develop a method of placing a strengthening liner on the walls of a hole made by a mole plow and to determine the feasibility of adapting this type of drainage to airfield subgrades and shoulders, both as an aid during construction and as a method of installing permanent subsurface drainage systems.

A mole plow with provision for pumping asphalt and cement mixtures out of the rear was constructed and used in a large scale test box filled with a fine silt. Tests were made with various extruded materials. An investigation was made concurrently to determine the possibility of using a flexible perforated plastic tubing to be placed by a cable laying machine.

Basic conclusions determined from these tests are as follows:

a. It is believed that some type of mole drainage can be adapted as an economical and feasible method of draining airfield subgrades and shoulders.

b. The use of sand asphalt mixture as a liner is not practical as a mixture possessing the minimum stability requirements cannot be made sufficiently fluid by heating to allow pumping by the pressure method.

c. Field installations of strengthening liner of portland cement mixtures in the walls of a mole drain by use of either pressure grouting or cement gun is believed impractical due to the difficulty in controlling setting time or maintaining uniform flow and the uncertainty of obtaining a continuous drain.

d. Direct worm feed that can be sychronized with plowing speed is believed to be the practical method for extruding a portland cement misture to insure a continuous drain.

c. Placing a perforated plastic tubing by a cable laying machine appears to be a promising and economical method of strengthening the walls of the mole hole.

I. INTRODUCTION

1. Authority. The Mole Drainage Investigation was initiated by the Office of the Chief of Engineers by letter to the Division Engineer, New England Division, subject: "Mole Drainage Investigation", dated 25 April 1946. Approval of "Instructions and Outline, Mole Drainage Investigation" was given at a meeting held in the Office of the Chief of Engineers, 7 August 1946, attended by representatives of the New England Division. Final authorization and allocation of funds was given by Directive Consecutive No. 7 A 24,875 of 12 August 1946 from the Office of the Chief of Engineers to the Division Engineer, New England Division, subject: "Funds for Investional Program for Fiscal Year 1947".

2. Purpose. Mole drainage as used in agriculture consists of towing a specially constructed plow through the earth to make a hole three or four inches in diameter, parallel and approximately two to three feet below the ground surface with a narrow slot to the ground surface cut by the vertical blade of the plow. The purpose of this investigation is to develop a method of placing a strengthening liner on the walls of a mole hole and to determine the feasibility of adapting this type of drainage to airfield subgrades and shoulders, both as an aid during construction and as a method of installing permanent subsurface drainage systems.

3. Scope. To accomplish the purpose as stated a mole plow and a large scale laboratory test box were constructed. A fine silt was placed in the test box and the mole plow was used to make mole drains in the silt. The holes formed were left with plain earth walls and attempts were also made to strengthen the walls by extruding asphalt and portland cement grout out of the rear of the plow. Observations were made on the various

mole drains thus constructed. An investigation is also being made concurrently to determine the possibility of using a flexible perforated plastic tubing to be placed by a cable laying machine. All available literature was reviewed for possible application to the problem.

4. Definition of Terms. The terms as used in this investigation are defined as follows:

a. Mole Drainage is the collection and carrying away of sub-surface water in an underground channel which has been formed by a mole plow.

b. Mole Plow is a machine with a cartridge or mole at the base of a vertical blade, which is pulled through the soil so as to form a channel from three to six inches in diameter at a depth of one to four feet below the ground surface.

c. Test Box is a wooden box four feet deep, five feet wide and twelve feet long with provisions at each end for inserting and withdrawing a mole plow and facilities for applying surface loads and opening the box for examination of the mole drain.

5. Historical Background.

a. Mole Drains. Mole drainage has been used extensively in Europe and New Zealand as a means of both subsurface and surface drainage, and there have been good results with it in a few places in this country, mostly in the heavy agricultural soils along the Gulf of Mexico, particularly in Florida and Louisiana where mole drains have remained in satisfactory operation for periods of as long as 15 years.

The United States Sugar Corporation employs mole drainage to quite an extensive degree in the muckland areas of their plantations. This has been quite satisfactory in their farm land drainage, both as to effectiveness and durability. Commonly, moles in muck lands are effective for several years. Plate 1 shows the mole plows used. H. A. Bester of that company said, "This method is particularly adaptable to our muck type soil and is superior to any type of tile drain. I believe it could be successfully applied to other soil types such as gumbo or loams under favorable conditions and proper power."

Plate 2 shows a mole plow developed by the Division of Agricultural Extension, State College, Penna. Plate 3 shows a mole plow as manufactured commercially in the United States and Plate 4 shows some mole drains made by this equipment.

Reports of various demonstrations and experiments with mole drains, mostly in England, are given in several of the articles listed in the bibliography. From these reports the following conclusions may be drawn:

(1) Heavy silt and clay soils are usually suitable for mole drainage but Mr. M. A. G. Johnson, Deputy Chief Drainage Engineer of the Ministry of Agriculture and Fisheries, England, states that the physical characteristics of the clay are not an adequate guide to determine the suitability of the method for any particular location. Mole drainage frequently fails in one clay and is successful in another clay where the physical analysis of the two clays shows no appreciable differences in the characteristics. In a few cases, mole drains in friable soils have been successful. In friable soils more slope is required to prevent water standing in the mole drain which would tend to make the walls fall in.

(2) The best time to place mole drains is from October to May when the land is fairly wet. The resistance to the plow at that time

is not high and the slit made by the vertical blade will seal up quickly. If a hot dry period follows the placing of mole drains the slit will not close and the drain is apt to silt up during the next rain.

(3) If plowing is done in moist soil the sides of the mole drain are smooth, but in dry soil the sides fray and lead to deterioration.

(4) Drains drawn uphill clear the water at a greater rate and silt up less quickly than do drains drawn downhill.

(5) For effective drainage the channels should be spaced from 10 to 25 feet apart being closer together in the heavier soils.

(6) The placing of permanent main drains and the placing of pipes at the outlet of the mole drains to prevent clogging are important.

(7) Mole drains usually give an average of from three to ten years of satisfactory service before it becomes necessary to plow new channels.

b. <u>Alternatives to Mole Drainage</u>. In order to extend the useful life of the drains and also to make them useful in all fine grained soils, various methods of pulling tile, wooden boxes, and metal tubing in behind the plow have been used to some extent in Europe. According to Mr. Johnson, an economical suitable method does not appear to have been developed yet. Some of the methods are described below.

(1) A Scottish firm used a mole plow with two vertical blades and cartridges mounted on the frame, one a little behind the other. The rear cartridge was slightly larger than the front one and to it a wire cable was attached in such a way that it would be detached by withdrawing a pin in the blade above ground level. Twelve tiles were threaded on the wire cable, and at that point the cable had a collapsible clip which was

opened and fitted over the end of the last tile. Then a further length of cable was connected by means of a link and twelve more tiles were threaded and another clip fitted. The maximum pressure that the tiles were subjected to was thus never more than that necessary to push twelve of them along the hole formed by the mole plow. The collapsible clips were so designed that a forward pull caused them to grip and push forward the tiles ahead of them, while a backward pull caused the clips to collapse. The tiles were drawn into the mole hole down a wooden slipway which insured alignment. At the end of the run the pin was withdrawn on the rear blade of the mole plow and the cable drawn backwards to the starting point. The separation of the tile laying blade and cartridge from the mole-draining blade and cartridge proper allowed any obstruction hit by the latter to be removed without disconnecting the train of tiles. The mole plow was about $1\frac{1}{2}$ inches larger in outside diameter than the tiles.

(2) Another method known as the Poppelsdorf drainage system was quite similar to the Scottish method but had a special feature. The wire cable by which the tiles were drawn into the mole drain had attached to it a series of sheet-iron egg shaped spacers which exactly fitted the inside of the tiles. The cable and spacers were threaded through the tiles with the aid of a long wire needle and the tiles so threaded were laid out in lengths of 100 ft. in parallel V-shaped wooden channels. The channels and spacers insured correct alignment of the tiles. A detachable disk was fastened to the cable after the last tile. The cable was attached to an expander which was larger than the tiles and this was hinged to the rear end of the cartridge of a mole plow. The tiles were drawn by the mole plow from the wooden channels down a sloping trench into the mole drains and as the last tile entered the mole hole, the disk was

removed and a further 100 ft. length of cable carrying tiles was connected by a special link which was outwardly the same size and shape as the spacers already mentioned. The disk was reattached to the end of the last tile. The detachment of the cable from the expander at the end of the run was rather ingenious. The blade and cartridge was raised to the ground level by gearing or other device on the mole plow. The expander followed the cartridge and this inclination automatically detached the cable as shown in Plate 5. The cable was withdrawn leaving a plug in the mouth of the first tile. It was pulled back to the starting point by a hand or horse operated windlass. In this way lengths of 400 feet of tile drains have been successfully laid. In some operations where this method was used it was found that a very rapid contraction of the mole drain took place necessitating a considerable difference in size between expander and tiles. Under German conditions the cost of this method was about 50 per cent that of drains laid by hand labor, while regular mole drainage without tile could be put in at only 20 per cent of the cost of hand laid tile.

(3) Dr. Janert of the Department of Agriculture, Leipzig University, Germany, devised a machine for laying a continuous length of concrete pipe, which he described in England in 1933. It consisted of a mole plow so designed as to form a porous concrete pipe along the walls of the mole hole formed by the cartridge. The essential feature of the machine was that a mixture was fed to the mole drain in a dry state and this was then wetted from the inside by water supplied from a porous stone tail attached to the rear of the cartridge. Smearing of the walls was avoided and the pipe retained its permeability. This was controlled to a great extent by varying the proportions of cement and soil in the mixture.

From a hopper at the top of the mole plow blade the mixture was fed down a tube attached to the back of the blade to a point behind the cartridge. Here there was a hollow conical plug which forced the mixture into the annular space between the plug and the walls of the mole hole. Water was supplied from a tank on the hopper through a tube running down inside the blade to the inside of the pipe through a ping of artificial pumice in the hollow plug. This water thus supplied the mixture with enough rigidity to stay in place while it absorbed sufficient moisture from the surrounding soil to set hard.

It was requested that the United States Army Occupation Forces attempt to obtain further details on this method and this information has just been received. Dr. Vormfelde, the inventor of the Poppelsdorf Method of Mole Drainage has been dead for the past three years. However, his former assistant Dr. Dencker, professor of agriculture at the University of Bonn, Germany was interviewed on 26 February 1947. He stated that results of field experiments proved that in wet soil, the concrete would not dry and thus cave in under surface load. Field experiments conducted at a later date proved that the system could be used in sand or dry terrain for irrigation purposes and that the system was then changed from a drainage system to a method of irrigation. From all information gathered from Dr. Dencker, the above system is not in the least a practical nor an efficient means of land drainage.

(4) Wooden drains with a square cross section made out of long battens have also been pulled into the mole hole behind the plow. The cartridge was square and tapered down to a horizontal knife edge at the forward end. The box drain fitted into a hollow metal box which was drawn behind the cartridge.

(5) Mole drains have also been reinforced by mild steel tubing. This method, perfected by Dr. Hans Sach, according to Dr. Doncker is by far the most practical and efficient means of land drainage. Cold mild steel in the form of a flat strip 6-3/8 inches wide and 1/32 inch thick was fed from a drum through rollers and dies by which it was formed into a tube. The tube was oval in section and the longitudinal edges could be made to overlap slightly or left with a small gap between them. The metal could also be perforated if required. The forming machine in which this operation took place remained stationary at the lower end of the drain. The tube was drawn into the mole drain by the mole plow, the cartridge of which had an expanding cone at the rear end. This covered a special chuck by means of which the metal tube was attached to the cartridge. The metal tube could be detached from the chuck at the end of the run by tripping a lever on the blade of the mole plow above the ground. The metal used was particularly resistant to corrosion and was covered with a high grade of Japanese varnish. The expanding cone was four inches in diameter and the metal tube two inches in diameter. This was regarded as equivalent to a larger tile drain by reason of the smoother surface of the metal tube and avoidance of any irregularities. The depth of the cartridge could be varied by hydraulic pressure, which was supplied either by hand pump when the mole plow was stationary or by a pump driven by the front axle of the mole plow when it was moving. The drain could be laid at a fixed grade irrespective of irregularities of the ground by means of an optical device. The makers of the device (Rud, Sack, Leipzig, Germany) claim that 1200 to 1500 yards of drain can be lain per day with a 50 - 60 H. P. tractor and a crew of five or six men. The costs are claimed to represent a saving of 40 to 20 per cent on draining by hand labor in Germany. The

mole plow used in this method can also be used for laying cable inside the metal tubing and for laying tiles by the Poppelsdorf method.

A photostat copy of a German book describing this method has just been received. It will be translated and any information of interest will be included in the final report.

(6) In a Danish method, the blade of the mole plow was in the form of a hollow tube elongated horizontally in section. To the front of this was welded a steel knife edge or alternatively two knife edges. The blade had no cartridge at the bottom but a hole cut at an angle to the vertical. The blade could be rotated in a vertical plane by means of a horizontal screw adjustment, and in this way the depth of working was regulated. The blade carried a hopper at the upper end and fine gravel was fed from this down the blade. The blade thus made a slit in the ground on the bottom of which several inches of the gravel were deposited. This was covered by loose soil which fell in on top of the gravel. With a single knife edge the blade which was $1\frac{1}{2}$ inches thick made a slit by compression; with two knife edges a wider slit was made by excavating the soil, which slid up the inclined blade to the surface. The drain was started at the opposite end from the outlet and with the blade at the minimum desired depth. As the mole plow moved forward, the depth was increased by means of a screw adjustment until the blade was vertical when the outlet end of the drain was reached. This insured a fall in level ground and also an increasing depth of gravel as the drain approached its outlet. The maximum depth of gravel was about seven to eight inches. A later development was the laying of a strip of asphalt paper, which was fed down behind the blade on top of the deposited gravel to prevent the introduction of loose soil into the drain.

c. Cable Laying Plows. Another method which shows promise of development consists of strengthening the walls of a mole hole by feeding a perforated flexible 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 a cable laying device can be used. Plates 6 to 8 illustrate a simple cable laying device that was developed by the Wood Electrical Construction Company, contractor for the Runway Contact Lighting System, Standiford Field, Louisville, Ky., for the Louisville District, Corps of Engineers, War Department. The cable laying plows used by the American Telephone and Telegraph Company would accommodate larger diameter tubing and be more suitable as the depth at which the tubing can be laid is greater and can also be varied.

The C-48 plow, Plate 9, is designed to lay one or two cables with maximum outside diameters of 2.5 inches. The depth of placing can be set to any desired depth up to 4 feet before commencing to plow. A cut away view of the plow share showing the way the cables pass through the vertical blade is given in Plate 10. A pit must be dug before the cable placing is started. The plow share is then lowered into the pit to the desired depth as shown in Plate 10. Usually a pit at least 3 feet deep is required. 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. One heavy tractor would thus be sufficient for normal placing of perforated plastic tubing.

The C-60 plow, Plates 11 and 12, is designated 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. These controls are located on a trailer behind the plow so that operations are possible even if the tractor is detached.

II LABORATORY INVESTIGATION

6. Description of Test Box and Accessories.

a. Test Box. A test box with inside dimensions of twelve feet in length, five feet in width and four feet in depth was constructed of wood as shown on Plates 13 and 14. This test box was made with two removable channels attached longitudinally on top of the box. The vertical shaft of the test plow was supported and guided by these channels as the plow was drawn through the box. It was possible to install the channels at eigher one of three positions over the top of the test box. Since the plow can be used at two depths, a maximum of six tests can be made before the test material need be removed and replaced. Below each of the three channel positions an opening in the ends of the box was constructed which could be sealed during saturation and just previous to the test run the doors on eigher end of the box were removed to allow the plow to pass through the soil. In order to inspect test drains without the necessity of removing the soil, the box was built in two sections, one of which was placed on skids, thus permitting separating the box at the midpoint of the long axis. Four sets of guides for two 3/16 inch plates were provided on the sides of the test box next to this joint. The two plates were inserted into the guides, after constructing a drain, and jacked vertically downward through the soil to a point just above the drain to be inspected. These plates held the soil in place while the box was separated for inspection of the test drain. The plow was drawn through the test box with a portable electric winch by means of a block and tackle.

b. Dynamometer. A dynamometer was constructed from three coil springs and was placed in the drawing line to measure the drawbar pull required to pull the plow through the test material. Plate 18 shows details of the dynamometer and a photograph is shown on Plate 19. Readings were made by recording the difference between two points on the end plates. The device was calibrated in a compression machine. It was determined that a deflection of 3/8 inch was produced by a load of 1,000 pounds. This relationship remained constant up to a total load of 9,000 pounds.

c. Test Pipe. In order that the pumping of injection materials could be observed visually, an apparatus through which the plow could be drawn, was made to simulate the walls of the drain. This apparatus consisted of four inch standard pipe with a two inch longitudinal strip removed for its full length. The pipe was attached to three timber supports which were bolted to the floor. Details are shown on Plate 20. The plow was placed in a temporary wood frame with casters attached for mobility. The plow was adjusted in the frame by means of wedges to fit into the four inch slotted pipe and it was pushed through the pipe as injection materials were pumped out the rear of the plow. Details and a photograph of the plow frame are shown on Plates 19 and 20.

7. Description of Test Plow. Detail drawings of the test plow are shown on Plate 21. The vertical shaft of the plow is a "built up" section consisting of three vertical one inch by two inch steel bars with 1/4 inch plates welded to the sides. The steel bars are spaced so as to give two vertical rectangular channels from top to bottom, the dimensions being 1 inch wide by 2 inches long and 1 inch wide by 1 1/8 inches long. The top of the shaft was fitted with one inch nipples over each channel opening.

The front 1 inch by 1 1/8 inch vertical channel was provided for future development of the plow for a possible worm feed mechanism or water supply line. The rear one inch by two inch channel was utilized to feed injection materials down to the mole in order to place a strengthening liner on the walls of the drains made by the mole. The mole was made by a section of standard 3 1/2 inch pipe welded horizontally at 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 up out of the soil. Openings in the top of the pipe were provided to coincide with the vertical channels through the shaft. Braced and welded to the top rear end of the 3 1/2 inch mole was a segment of a 4 inch pipe two inches wide and 28 inches long designed to provide a temporary form for injection materials at the top of the drain where the soil had been displaced by the vertical plow shaft. The plow was fitted with a removable frame which could be placed at two locations on the vertical shaft to allow constructing drains with invert depths of either two feet or three feet. This frame was made basically of 2 inch by 2 inch angles which provided running surfaces for the plow on the channels of the test box as the plow was drawn through the box.

8. Description of Test Plow Tail Assemblies.

a. Asphalt Tail Assembly. The plow was constructed originally with a tail assembly intended for use with asphalt. It was later used for portland cement mixtures as well as asphalt. Construction details of the tail attached to the mole plow are shown on Plate 21 and photographs are shown on Plate 23. This tail was constructed of a piece of 3 1/2 inch standard pipe cut to fit the rear of the plow. Within this pipe a machined insert was made with an open channel which connected to the one inch by two inch vertical opening in the plow shaft. The injection material which was pumped through the plow shaft passed through this channel and was forced into an annular space around a bullet shaped tail supported by three 1/8 inch fins in the rear of the pipe section. A four foot length of three inch Shelby tubing was welded to the rear of this machined bullet section for the purpose of providing initial support to the inside of the drain pipe.

b. Alternate Tail Assembly No. 1. This tail was designed to function on the same theory as that used in the patented "Tate" process which is used to place a concrete liner inside of existing metal pipe lines. In this process two five foot lengths of pipe are removed from the pipe line at distances averaging 350 feet apart. A cable is threaded through the section of pipe selected and cleaners, brushes, and plungers are drawn through the pipe by means of power winches. A mixture of two parts of specially selected and graded sand and one part of portland cement is mixed with water to give a slump of eight to 8 3/4 inches. A quantity of this mixture is fed by gravity into the pipe line and the "Tate" lining machine, consisting of a bullet shaped mandrel with a perforated sheet metal tail flared out to a diameter slightly smaller than the inside of the pipe, is pulled through behind the plug of cement. The cement is forced out the annular space between the tail of the machine and the pipe and plastered to the wall of the pipe with a pressure equal to approximately 130 lbs per square inch. Excess water is squeezed out of the mixture through the small perforations in the tail and flows along the pipe invert. The problem of lining mole drains is quite similar to lining metal pipe and therefore the tail assembly was constructed similar to the

"Tate" lining machine. This tail, shown on Plates 21 and 24, was attached approximately four inches behind the opening of the vertical one inch by two inch channel.

c. <u>Alternate Tail Assembly No. 2.</u> 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, especially when a cement gun was used. Therefore, the Tail Alternate No. 1 was modified by removing the bullet nose and replacing it with a section of a well point with a fine mesh screen which would allow the air trapped in the aggregate to escape through the well point and out either through the completed pipe or up to the surface through the front 1 inch by 1 1/8 inch vertical channel. Details and photographs are shown on Plates 21 and 24.

d. <u>Alternate Tail Assembly No. 3.</u> This assembly is a further modification of Alternate No. 1 (See Plates 22 and 25). A 1/2 inch round rod 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 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.

e. <u>Alternate Tail Assembly No. 4.</u> The original Asphalt Tail was modified by removing a part of the Shelby tube, adding a tapered section and a 3 1/2 inch cylinder section. Around the Shelby tube were welded two 3/4 inch high helical strips with an outside diameter 1/2 inch greater than the diameter of the drain made by the plow. These strips were designed to scrape the soil from the side walls down into the path of the liquid asphalt where, it was believed, the soil would mix sufficiently with the asphalt before being pressed back against the walls of the drain. Details and photographs are shown on Plates 22 and 25.

9. <u>Description of Pumps and Equipment.</u>

a. <u>Asphalt Pump.</u> An asphalt pump shown on Plates 26 and 27 was constructed from a piece of 12 inch diameter pipe held in a vertical position. A plate was welded to the bottom with a plugged two inch nipple in its center. Two one inch nipples were welded horizontally on the side of the pipe about one inch up from the bottom. One nipple was used for a thermometer well and the other was the asphalt discharge line. A flange was attached to the top of the 12 inch pipe on to which a cover was bolted. The cover had an air inlet and a 2 inch asphalt inlet. Two copper steam coils were installed in the pump, one within the other. The pump was fitted with steam and air pressure gages.

b. <u>Asphalt Test Mold.</u> In order to observe the action of asphalt when pumped with the asphalt pump, a test mold was made with the use of short sections of four inch pipe and 1 3/4 inch pipe. The smaller pipe was held within the larger pipe by means of a reducing coupling at one end. Over this end was welded a one inch nipple onto which the pump discharge was attached. A photograph of apparatus dismantled after a test is shown on Plate 28.

c. <u>Grout Pump.</u> The grout pump whose details and photographs are shown on Plates 26 and 29 consisted of a reinforced vertical cylinder with a hand operated pressure-tight cover and a cone shaped bottom. Air pressure could be admitted through the side at the top and up through the discharge pipe at the bottom. Discharge was controlled by a quick acting valve at the base of the machine and air valves at the top and bottom air inlets.

d. Diaphragm Pump. The diaphragm pump used was a small hand operated machine manufactured by the Edson Company. Inlet and outlet pipes are two inches, but the outlet was reduced to one inch to fit the nipple on top of the plow. Photographs of the pump assembled and dis-assembled are shown on plate 30.

e. Cement Gun. The cement gun used was a Model N-1. The machine is made exclusively by the Cement Gun Co. of Allentown, Penna. The materials, normally mixed dry are introduced into the upper chamber which acts as an air lock. From the upper chamber materials flow into the lower chamber which is continuously under pressure. An air motor rotates the feed wheel which carries the material to the outlet, where compressed air flowing through the goose neck carries it out the machine through the hose. In the normal use of the cement gun the water is added at the nozzle resulting in hydration coincident with deposit. In this process the water content is controlled visually by the nozzle operator. Plate 31 shows a photograph and diagramatic drawing of the cement gun.

10. Test Materials.

a. Asphalt. Two types of asphalt were used, one an asphalt cement with a 120-150 penetration and the other a blown asphalt with a 20-30 penetration.

b. Concrete Sand. Sand used in portland cement and asphalt mixes was a standard commercial plaster sand. A gradation curve is shown on Plate 32.

c. Pea Stone. The material used with portland cement in an attempt to produce a porous wall mole drain was a pea stone. A gradation curve of this material is shown on Plate 32.

d. Portland Cement. The cement used in the portland cement mixtures was a standard high early strength portland cement.

e. Air and Steam. Compressed air with pressure up to 100 lbs per square inch, and steam with an average pressure of 80 lbs per square inch were available in distribution lines close to the test area.

f. Test Box Material. The material used in the test box was a fine silt obtained near Manchester, New Hampshire. The gradation curve is shown on Plate 32. The following characteristics were determined in the laboratory:

Modified AASHO density- -107.2 p.c.f.

Optimum moisture content- 17.7 per cent

Specific gravity- - - - - 2.69

Plasticity index- - - - - 5.0 per cent

Liquid limit- - - - - - - 29.1 per cent

Plastic limit - - - - - - 24.1 per cent

"In place" density- - - - 97.8 p.c.f.

"In place" water content- 22.3 per cent

k at "in place" density - 0.46×10^{-4} cm/sec

11. Tests Using Asphalt.

a. Preliminary Tests. Procedure. The 20 - 30 penetration asphalt cement was heated and then poured into the annular space formed by placing a three inch paper cylinder within a four inch metal cylinder. After cooling, the inside form was removed and the sample cylinder of asphalt was left lying on its side.

Results. Within 24 hours after stripping inside form the sample had slipped out of its original shape within the metal cylinder.

b. Tests No. 1 and 2. Procedure. The 120 - 150 penetration asphalt was heated with a steam coil and introduced into the asphalt heater which brought its temperature to approximately 200°F.

Results. Details of tests are recorded on Tables 1 and 2. At 200°F the asphalt was liquid enough to pump but it cooled quickly while passing through the discharge hose and the line became clogged. In Test No. 2 this condition was remedied by passing steam through the discharge lined prior to pumping the asphalt.

c. Test No. 3. Procedure. Blown asphalt was pumped into the test mold as shown on Plate 28. The test mold was placed under water to produce the cooling effect which the wet soil would give in actual practice.

Results. The asphalt partially coated the inside pipe as it flowed to the open end of the mold. The thickness of the asphalt varied from 1/8 inch to 1/2 inch. When the outer pipe was removed and the sample was left standing vertically at room temperature the asphalt ran to the bottom of the mold.

d. Test No. 4. Procedure. The action of the blown asphalt was observed as it was pumped through the plow with the Asphalt Tail Assembly installed. The base of the plow was submerged in water.

Results. The asphalt started to flow after having some difficulty in passing through the long discharge line. The asphalt was extruded out the rear of the tail assembly very rapidly and was accompanied by bursts of air. The asphalt was not cooled immediately by the water and consequently it rose to the surface of the water and no pipe was formed. Within the tail assembly the asphalt cooled except in narrow channels where it continued to flow. This cooling prevented the forming of a complete drain lining by the asphalt.

e. Sand-Asphalt Tests. Procedure. Due to the lack of strength of asphalt it was decided to mix different percentages of the blown asphalt with the sand. A weight of asphalt equal to 15, 20, 25, and 30 per cent of the weight of sand were mixed with sand and four test cylinders were made in removable forms. After cooling to room temperature the forms were stripped and the samples were laid horizontally on a board for observation. The room temperature fluctuated from 65° F to 70° F during period of test.

<u>Results</u>. Photographs are shown on Plate 33. None of the samples were capable of standing without support of sides or top. This test is possibly too critical as the pipe in place would receive support at the sides due to passive soil pressure.

f. <u>Test No. 5</u>. <u>Procedure</u>. A mixture consisting of sand and blown asphalt equal to 40 per cent of the weight of the sand was heated in a roofers asphalt heater and introduced into the asphalt pump. Three blow torches and a plumbers furnace were used in addition to the two copper coils with steam at approximately 60 lbs per sq. inch in an attempt to heat the sand-asphalt mix to a uniform temperature which would enable it to be pumped through the discharge line.

<u>Results</u>. When pumping was started a small quantity of sand asphalt in a semi-liquid form was discharged after which the air pressure forced out separate particles of sand coated with asphalt at a very slow rate. The quantity discharge during this test was approximately 10 per cent of the total quantity heated in the pump.

g. <u>Test No. 42</u>. <u>Procedure</u>. Blown asphalt was pumped through the plow as it was drawn through the test box with the tail assembly, Alternate No. 4, installed.

<u>Results</u>. Only a small quantity of the asphalt heated was pumped before discharge was stopped due to cold asphalt in the line.

Portions of the drain wall were lined with approximately 1/16 inch asphalt. Cavities and cracks made by the plow shaft were filled with asphalt. The channels between the helical strips of the tail were filled with layers of asphalt and silt which prevented the flow of asphalt. The silt was in lumps and lenses throughout the asphalt. Photographs of asphalt drain, Test No. 42 are shown on Plates 34 and 35.

12. Tests Using Portland Cement Mixture.

a. General. Preliminary tests were made to determine satisfactory mixes of cement and sand; cement, sand, and sodium bicarbonate; and cement and pea stone before pumping tests were initiated. From these tests it was decided to use a cement-sand ratio of 1:2.

b. Grout Pump.

(1) Tests No. 6, 7 and 8 were conducted with the grout pump above to study the operation of the pump.

Results. Details of all tests performed are recorded on Tables 1 and 2.

(2) Test No. 9. Procedure. The plow was set up in the temporary frame and the tail assembly Alternate No. 1 installed. Test No. 9 was made to observe the mix as it was discharged from the plow.

Results. This mix was very liquid and would not stand up as a drain lining. In order to produce a mix which would pass through the discharge line and plow as a semi-liquid and would harden immediately upon being deposited and form a pipe in the drain, sodium bicarbonate, in a water solution, was introduced into the wet mix just prior to pumping.

(3) Tests No. 10 to 15 inclusive. Procedure. The plow was placed in the test pipe and Tests No. 10 to 15 inclusive were conducted with the tail alternate No. 1.

Results. Tail Alternate No. 1 was found not suitable for the procedure used. The grout pump forced the mixture out the back of the pipe with such force that it was carried back beyond the tail assembly before sufficient quantity was deposited in front of the tail assembly. Less air pressure in the pump resulted in the lines becoming clogged.

(4) Tests No. 16 to 23 inclusive and 25. Procedure. Tests No. 16 to 23 inclusive and 25 were made using the asphalt tail assembly set in the test pipe (See Plate 36). Oakum was forced into the annular space between the tail piece and the four inch test pipe to provide a back stop for the aggregate at the start of the t sts. As the test pipe became filled, the plow was drawn through the pipe. After Test No. 19 the cement sand ratio was changed to 1:1 1/3.

Results. From an inspection of the remarks column on Tables 1 and 2, it can be seen that the control of the mix was extremely difficult. A mix which gave satisfactory results in the test pipe would not be completely pumped through the grout pump before hardening had taken place due to the sodium bicarbonate.

(5) Test No. 26. Procedure. A large batch of the same mixture as used in Test No. 25 was pumped into a waste barrel to learn control and observe discharge of a large batch.

Results. Satisfactory results were obtained with this mix.

(6) Test No. 27. Procedure. A similar batch to that used in Test No. 26 was prepared and pumped through the plow as the plow was drawn through the test box. After a 48 hour curing period the inspection plates were installed and the box opened for inspection.

Results. No difficulty was experienced in pumping due to the fact that the discharge valve was completely opened, however discharge was so rapid that a large percentage of the batch ran out the end of the drain. Upon inspection it was found that the side walls were too thin. A thick section was formed on the bottom as shown in the photographs on Plates 37 and 38. Practically no material was forced into the top of the hole.

A draw bar pull of approximately 7,000 lbs. was required to pull the plow through the box of silt at its lowest depth. Approximately 9,000 lbs were required to open and close the box for inspection of the drain.

(7) Test No. 28. Procedure. An attempt was made to correct the alignment of the asphalt tail to produce a complete drain section. A 1/2 inch by 2 inch strip of wood was attached longitudinally to the bottom of the plow tail to eliminate the thick section in the bottom of the drain and to provide an entrance for the water into the drain.

A mix similar to that used in Test No. 26 was pumped as the plow was drawn through the test box. The winch line fouled as the plow reached the mid-point of the box and pumping was stopped. After approximately five minutes the plow was pulled the remainder of the remainder of the distance through the test box.

Results. No conclusions may be drawn from this test as the plow was stationary at the center of the box which provided an inside support for approximately five minutes during which time the mixture hardened. Photographs of the test are shown on Plate 39.

(8) Test No. 29. Procedure. A third attempt to pump a mix similar to that used in Test No. 26 was made as the plow was pulled through the box.

Results. After the trail it was found that a small chip of concrete had blocked passage of the batch at the top of the plow and no mixture was pumped. Tests with the grout pump were discontinued due to difficulty of control.

c. Cement Gun.

(1) Test No. 30 to 33 Inclusive. Procedure. In Test No. 30 a cement-sand mixture of the proportion 1:1 1/3 was pumped through the cement gun to study operation of the gun and nozzle. The mixture was dry and water was added at the nozzle with the water controlled visually. A similar mix in Test No. 31 was pumped through the cement gun using a one inch pipe six feet long as a discharge nozzle. The mix was discharged into the test pipe to check quantity, rate of discharge and characteristics of the mix. In Test No. 32 a 1:2 mix with sodium bicarbonate added as a powder to the dry aggregate was pumped through the one inch discharge pipe with water controlled at the nozzle. Test No. 33 was conducted with a 1:1 1/2 mix with sodium bicarbonate added dry. The mix was pumped through the plow which was fitted with tail assembly Alternate No. 2.

Results: Tests No. 30 to 33 inclusive were conducted to determine a suitable mix for nozzle control to be used with tail Alternate No. 2 with no success. It was decided that the well point section of the tail was unnecessary and that the rear section of the tail assembly was too close to the discharge point of the plow. Tests using cement-sand mixtures with nozzle control of water were discontinued.

(2) Tests No. 34, 35, 36 and 39. Procedure. Three tests were performed to determine the proper water content to be used in a 1:1 1/3 cement-sand mixture. In Test No. 35 the tail assembly Alternate No. 1 was attached and the test pipe used.

Results. A satisfactory mix of cement, sand and water was determined in Test No. 39. It was decided from these tests to design and construct the tail assembly Alternate No. 3 for further tests in the test box.

(3) <u>Test No. 40.</u> <u>Procedure.</u> A similar mix to that used in Test No. 39 was pumped through the plow as it was drawn through the test box. Tail assembly Alternate No. 3 was used with the plow.

<u>Results.</u> No difficulty was encountered in the operation of this test. For a distance of approximately 2 1/2 feet at the end of the trial run a complete lining was made. The remainder of the drain collapsed when water was allowed to pass down to the drain through the cut made by the plow shaft. This failure was due to the fact that the lining on the sides and top of the drain was very thin. Wall thickness varied from 1 inch down to 1/16 inch and in some spots no lining was formed. It is believed that a longer tail piece with less side slope and a smaller diameter at the rear end would have been more effective. The centering cylindrical sleeves of the tail device caused a stone to be drawn into the drain from the side walls and resulted in a hole in the lining where it had been moved as the tail piece passed by. Photographs of the drain in place and after removal are shown on Plates 34, 35 and 40.

(4) <u>Test No. 37.</u> <u>Procedure.</u> A 1:3 1/3 dry mixture of cement and pea stone was pumped with the water added at the nozzle.

<u>Results:</u> The mix segregated with the first of the batch discharged as a dense mix with an excess of cement and the last part was clean, wet pea stone with no cement.

(5) <u>Test No. 38.</u> <u>Procedure.</u> A wet mix of 1:5 of cement and pea stone was made and pumped into the test pipe for observation prior to a test with the plow.

<u>Results:</u> This mix was pumped with no difficoutly with a well mixed porous mixture as a result.

(6) Test No. 41. Procedure. The same proportions of pea stone and cement as used in Test No. 38 was pumped through the plow as it was drawn through the test box. The tail assembly Alternate No. 3 was used.

Results: This test was not successful. The centering cylinders of the tail assembly cut material from the side walls of the drain and mixed it with the cement and pea stone. As the tail was drawn through this mixture of silt, cement, and pea stone, it forced the mixture to the bottom of the drain rather than to distribute it evenly around the sides of the drain. The mix left in the bottom of the drain had practically no bond due to the addition of the silt. A photograph of the drain in place in the test box partially excavated is shown on Plate 35.

d. Edson Diaphragm Pump.

(1) Test No. 24. Procedure. A 1:1 mix of cement and sand was made and an attempt was made to pump it through the Edson disphragm hand pump. The mix was made extra wet to facilitate pumping.

Results: The water, cement, and sand segragated in the pump. The water and cement passed through the discharge line and the sand filled the pump both below and above the diaphragm. Pumping of a grout containing as much as 50 per cent sand was found to be impossible.

III INVESTIGATION OF OTHER METHODS

13. Plastic Tubing

a. General. One proposed method for strengthening the walls of the mole drain is the use of a perforated flexible plastic tubing. Letters were sent to manufacturers of plastics and extruders of plastic tubing requesting information on any suitable porous or non-porous plastic tubing about three inches outside diameter with sufficient flexibility to pass around a 90° bend with a radius of approximately two feet without kinking or breaking. Further study indicated that two inch diameter tube would have sufficient capacity to provide adequate subsurface drainage in the type soils being considered. Two products, "Tulox" manufactured by Extruded Plastics Incorporated, Norwalk, Conn., and Polyethylene by the Carter Products Corporation, Cleveland, Ohio, appeared promising in regard to cost. The Tulox tubing was approximately $0.40 per foot including the drilling and perforated. Polythylene tubing was approximately $0.30 per foot. The Tulox tubing, however, does not have the required flexibility to be placed by a cable laying machine, but being very light weight, and supplied in 20 feet lengths which are easily coupled, it can be economically placed by the conventional open trench method.

b. Properties of Polyethylene. Ployethylene tubing is sufficiently flexible to be coiled on reels having a diameter of 4 feet, as shown on Plate 41, and can thus be placed by a cable laying machine. As it is a relatively new product, its expected life can not be determined from actual experience, however, as shown in the table of properties supplied by the manufacturer, its resistance to acids and alkalies indicates that the material should have an exceptionally long life when used as a drain pipe. Properties of Polyethylene are shown on Tables 3 and 4.

To supplement the table of properties, two tests were performed in the laboratory on samples of Polyethylene tubing. One test was conducted to determine the brittleness of the tubing at very low temperatures. One inch lengths of the tubing were cooled to -10°C. On one length a 10 pound weight was dropped from a distance of 18 inches, and on another length a 30 pound weight was dropped from 4½ feet. In both cases the tube showed no apparent damage. The other test was conducted to determine the deformation and rebound of the tubing under alternate loading and releasing of the load. Plate 42 shows the test apparatus. A load was applied and allowed to remain until there was no change on the deflection dial. The deformation was recorded and then the load was released and the rebound was recorded. In the same manner, increased loads were applied and released with the deformation and rebound being recorded for each loading. Curves of load versus deflection for two samples are given on Plate 43.

In addition to the above tests, an accelerated leaching test is being conducted at the present time. The apparatus was made as shown on Plate 44. One four inch sample of Polyethylene tubing was placed in each section and four samples of corrugated metal; one each of plain galvanized, plain galvanized asphalt coated, single bonded asphalt coated, and double bonded asphalt coated; were placed in each large section. Three leaching solutions, hydrochloric acid, sulphuric acid, and sodium hydroxide are being used. A 5 per cent solution of each is used in the three small sections and a 15 per cent solution of each in the three large sections. The sand is kept covered by adding leaching solution as required. The samples will be removed at monthly intervals and examined for any visible signs of failure as well as loss of weight. The results of this test will be included in the report "Mole Drainage Investigation, 1947-1948."

c. <u>Design Data.</u> 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 3½ foot deep, spaced at 15 feet C.C. and the width of trench was 3½ 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 ($\frac{k2}{k1}$) would usually be large for the subgrade soils in which this

this drain is to be placed, no appreciably 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 asheet of water maintained on the surface by rainfall.

From a study of the flow nets, it was determined that condition (3) will give the maximum theoretical inflow into the drain. The flow net for this condition is shown on Plate 45 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, $q_1 = k_1 h \frac{n_f}{n_h}$ where "h" is assumed $3\frac{1}{2}$ 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 is computed from Darcy's formula, $q_2 = k_2 ia$ where "i" is unity for vertical 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 Plate 45 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 two inch I.D. tubing on slopes of 0.005, 0.010, and 0.015 using a value of n = 0.012.

To determine if two inch I. D. 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 x 10^{-4} cm./sec. and that of the sand backfill (k_2) to be 100 x 10^{-4} cm./sec. From Plate 45, the length of drain at which capacity flow would occur, was found to be 260 feet on a 0.5 per cent slope or 360 feet on a 1.0 per cent 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 which would possibly result in a slight amount of surface ponding.

d. Placing. It is proposed to place perforated Polyethylene tubing by feeding it from a reel down the vertical blade and out the rear of a cable laying machine as described in Section 4c. In this manner the trench will be dug and the tubing laid in one continuous operation. A truck equipped with a hopper will follow the cable laying machine and backfill the trench with sand. In turf areas or swales where encroachment of the turf may seal the top of the drain, it may be desirable to widen the top of the drain trench and place a layer of bituminous primed crushed stone as in Type A, Plate 46. Types B and C, Plate 46, are proposed for use in draining subgrades under stabilized turf surfaces or paved runways.

Tentative arrangements have been made to secure the use of a C48 plow (See Section 4c) for a short period in either the fall of 1947 or spring of 1948 so that test drains may be installed. Three Sites will be selected preferably in airfield shoulders where soggy or wet surface conditions exist and the effectiveness of this type of drainage can be observed. Observation wells will also be put in so that the effect of the drains on the ground water table may be recorded. Results of these tests will be included in the report "Mole Drainage Investigation, 1947-1948".

e. Possible Uses.

(1) To drain turf areas at existing airfields where surface ponding occurs.

(2) In place of field drains in turfed areas between runways.

(3) To prevent surface ponding in shallow turf swales parallel to runways.

(4) To provide subgrade and base drainage of large apron areas.

(5) To drain and stabilize subgrades both as an aid to construction and as permanent drainage.

(6) To drain the runways of an all turf field.

f. Economic Considerations. Although the investigation of the use of plastic tubing for drainage deviates from the original scope of this report, it is so closely related that it was considered advisable to include it in the report to provide a promising alternative to mole drainage. It is economically feasible as shown in the following table of estimated costs of various type drains and of a drain made by laying perforated flexible tubing by means of a cable laying machine. The cost of the plastic drain is based on present costs of labor and rental of construction equipment. From the following table it can be seen that the cost of plastic drains is less than 50 per cent of the cost of any of the other type drains.

COMPARATIVE COST ESTIMATE

Type of drain	Cost per foot of drain in dollars				
	Material	Placing	Trenching & Backfill	Filter Material	Total
4" Farm tile	.11	.09	.60	.20	1.00
4" Bell and Spigot V.C. pipe, open joints.	.22	.12	.60	.20	1.14
4" Perforated V.C. pipe, closed joints.	.32	.14	.60	.20	1.26
4" Skip drain	.28	.12	.60	.20	1.20
6" Plain concrete pipe, open joints	.38	.12	.60	.20	1.30
6" Perf. Corr. Metal pipe.	.58	.07	.60	.20	1.45
4" Orangeburg pipe. perforated	.30	.07	.60	.20	1.17
2" Plastic tubing	.30	.05		.07	0.42

14. <u>Fusion</u>. Inquiry was also made as to the possibility of strengthening the walls of mole drains by fusing the soil with a high temperature flame. A letter was sent to the Linde Air Products Company, developers of Fusion Piercing, requesting their comments on this subject and they replied, "We think we have nothing to offer as your letter stated that the ground would be usually saturated with water. Further technical obstacles would be tremendous, with the hole wall weak rather than strong if a thin fused wall were possible and practical".

It is believed that the heat would cause slaking of the walls [illegible] shrinkage of the soil and to expansion caused by formation of steam behind the fused inner surface of the mole hole.

IV. SUMMARY OF RESULTS OF INVESTIGATIONS

15. Tests using Asphalt Mixtures.

a. A sand asphalt that has the necessary fluidity to pump when heated requires a quantity of asphalt which overfills the voids of the sand and results in segregation of the sand and asphalt when the mixture is heated and remains stationary.

b. Sand asphalt pipe, containing low penetration asphalt in a sufficient quantity to allow pumping, collapses at room temperatures when not supported laterally.

c. An intimate mixture of the wet silt and the asphalt could not be obtained as the asphalt would not penetrate the silt and mixing resulted in lumps of silt in an asphalt mattrix.

d. Field equipment to pump low penetration asphalt should include a method of circulating asphalt through steam jacketed pump and piping.

16. Tests using Portland Cement Mixtures.

a. 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 after being extruded out the rear of plow unless admixtures are used to produce quick setting qualities.

b. The control of setting time of sand portland cement mixtures by the use of calcium chloride or bicarbonate of soda admixtures requires a degree of precision in batch preparation that would be difficult to attain in the field.

c. Sand portland cement mixtures of the proper consistency for construction of drain lining can be pumped by use of cement gun.

d. Uniform flow of sand portland cement mixtures by use of either pressure grouting or cement gun methods is difficult to maintain.

e. The speed of prime mover and pumping rate must be synchronized.

17. Perforated Plastic Tubing.

a. The use of perforated plastic tubing placed by a cable laying plow shows promise of being a practical and economical method of strengthening the walls of a mole drain.

18. Fusion.

a. The use of a high temperature flame to strengthen the walls of a mole drain by fusion is not considered feasible.

V. CONCLUSIONS

Based upon the results of this investigation and laboratory tests the following conclusions are presented:

a. It is believed that some type of mole drainage can be adapted as an economical and feasible method of draining airfield subgrades and shoulders.

b. The use of asphalt, and asphalt-sand mixtures for a strengthening liner of the walls of a mole drain is not practical. As a mixture possessing the minimum stability requirements can not be made sufficiently fluid by heating to allow pumping by pressure methods.

c. Field installation of a strengthening liner of portland cement mixtures in the walls of a mole drain by use of either pressure grouting or a cement gun is believed impractical due to the difficulty in controlling setting time or maintaining uniform flow and the uncertainty of obtaining a continuous drain.

d. Direct worm feed which could be synchronized with plowing speed is believed to be a possible method of extruding a portland cement mixture for a strengthening liner of a mole drain to insure a continuous drain.

e. The placement of a perforated plastic tubing by a cable laying machine appears to be the most promising and economical method of strengthening the walls of a mole drain.

VI RECOMMENDATIONS

From the results of the laboratory investigation and from review of available literature, the following recommendations are submitted:

a. Further experimentation with asphalt and portland cement be discontinued unless a more practical and positive method of placing can be devised from data obtained from European sources.

b. Theoretical study be continued on the design and spacing of field drains.

c. Experimental field installation of perforated polyethylene tubing to determine its effectiveness and the feasibility of the method of placing.

d. Further investigation be made of the Hans Sack method and other methods of drawing prefabricated liners into the mole hole.

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MOLE DRAINAGE INVESTIGATION

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 floated 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. 280-300°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		0.0353	0.618	Tail Alt. #2	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	5 Mar. '47	Grout			1	2		0.062	0.6	Tail Alt. #1	Too wet to stand in pipe.
14	[illegible] Mar. '47	Grout			1	2		0.062	0.56	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		0.0139	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. Grain size on Plate 32
Sand is plaster sand. Grain size on Plate 32
Cement used was High Early Strength.

TABLE I

MOLE DRAINAGE INVESTIGATION

RECORD OF TESTS

TEST NO.	DATE	PLUG TYPE	MATERIALS - RATIO BY WEIGHT: ASPHALT CEMENT	MATERIALS - RATIO BY WEIGHT: [illegible] ASPHALT	MATERIALS - RATIO BY WEIGHT: CEMENT	MATERIALS - RATIO BY WEIGHT: SAND	MATERIALS - RATIO BY WEIGHT: PEA STONE	MATERIALS - RATIO BY WEIGHT: SODIUM BICARBONATE	MATERIALS - RATIO BY WEIGHT: WATER	TAIL ASSEMBLY	REMARKS
24	1[illegible] Apr. '47	Diaphragm			1	1			Very liquid		1" outlet pipe. Water, cement, and sand segregated. Pump had to be washed out and disassembled.
25	[illegible] Apr. '47	Grout			1	1 1/3		0.01[illegible]	0.594	Asphalt Tail	Quite soft. 8" section of drain made in test pipe. Small quantity not pumped.
26	2[illegible] Apr. '47	Grout			1	1 1/3		0.018	0.594		Pumped large [illegible] 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# [illegible] required to pull plow. 5000# 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	14 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	[illegible] May '47	Cement Gun			1	1 1/3			0.594		Pumped into pan. Too wet. Pumped too fast.
35	[illegible] May '47	Cement Gun			1	1 1/3			0.534	Tail Alt. #1	Not as stiff as intended.
36	22 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	28 May '47	Cement Gun			1	1 1/3			0.475		Pumped very well into test pipe.
40	28 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. #1	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.

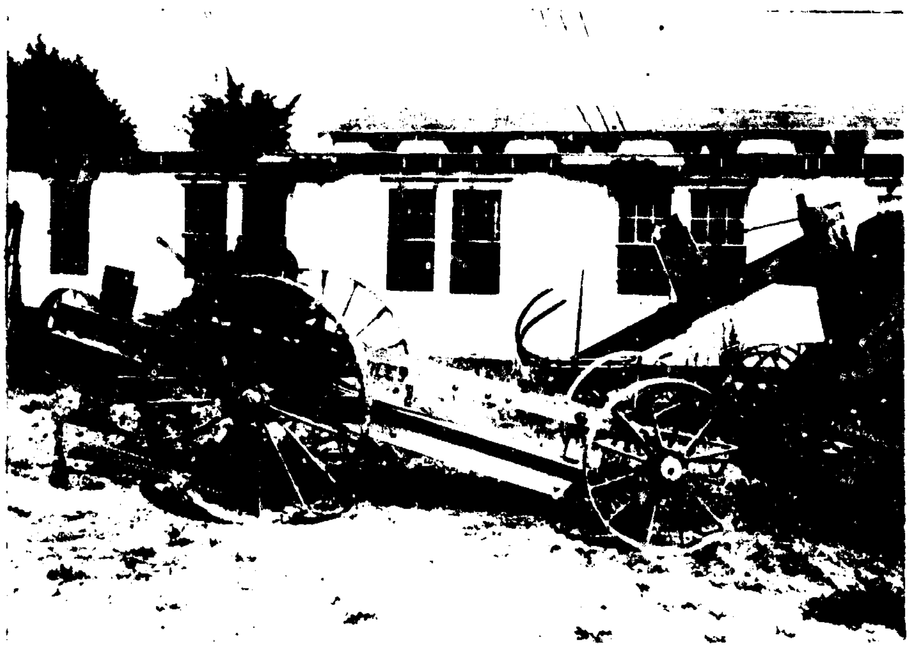
TABLE 2

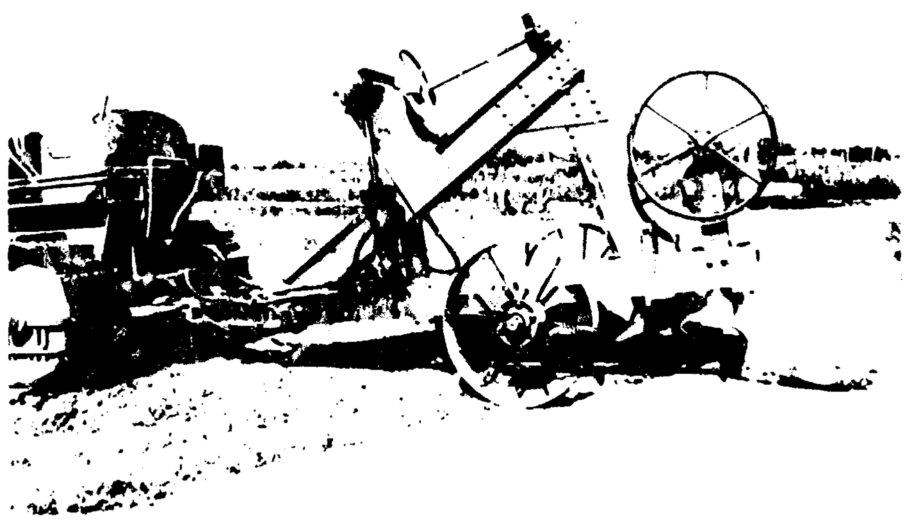
TABLE 3.
PROPERTIES OF POLYETHYLENE.

Specific Gravity	0.92-0.93
Specific Volume, Cubic Inch per Lb.	30.1
Refractive Index, ND	1.52
Tensile Strength, lbs. per sq. inch	1800-3000
Elongation, percent	50-600
Modulus of Elasticity lbs. per sq. inch x 10^5	0.15 (tension) 0.13 (flexure)
Flexural Strength, lbs. per sq. inch.	1500-1700
Impact Strength, Ft. lbs. per in. of notch ½ x ½ in. notched bar, Izod test	3
Hardness, Rockwell	R-25 R-27
Thermal Conductivity, 10^{-4}cal. per sec. per sq. cm/1 C°per cm.	6.0-8.0
Specific Heat, cal. per °C per gram	0.53
Thermal Expansion, 10^{-5}per °C.	18
Resistance to Heat, °F,(Continuous)	212
Distortion under heat, °F.	122(66 psi)
Volume Resistivity, ohm-cms. (50% relative humidity and 25°C)	10^{15}
Dielectric Strength short-time volts per mil, 1/8 in. thickness	500-700
Dielectric Strength step-by-step volts per mil. 1/8 in thickness	450-600
Dielectric Constant, 60 cycles	2.25-2.3
Dielectric Constant, 10^3cycles	2.25-2.3
Dielectric Constant, 10^6cycles	2.25-2.3

TABLE 4.
PROPERTIES OF POLYETHYLENE. (Cont'd.)

Power Factor, 60 Cycles	0.0003
Power Factor, 10^3 Cycles	0.0003
Power Factor, 10^6 Cycles	0.0003
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°C
Effect on Metal Inserts	INERT
Machining Qualities	GOOD
Clarity	TRANSLUCENT TO OPAQUE
Color Possibilities	UNLIMITED





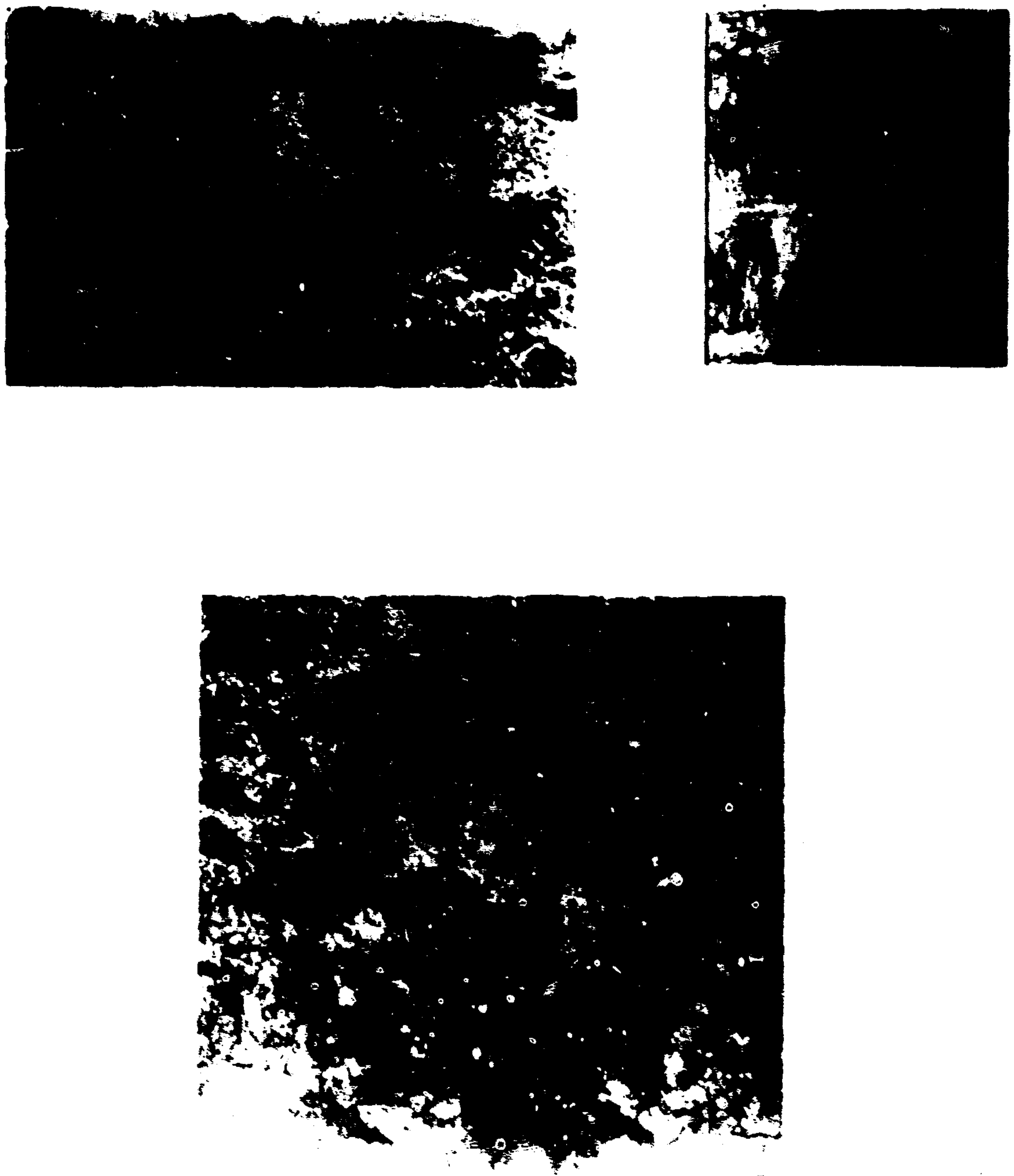
MOLE PLOWS USED IN FLORIDA BY
UNITED STATES SUGAR CORPORATION

PLATE I.

MOLE PLOW DEVELOPED BY
DIVISION OF AGRICULTURAL EXTENSION,
STATE COLLEGE, PENNSYLVANNIA

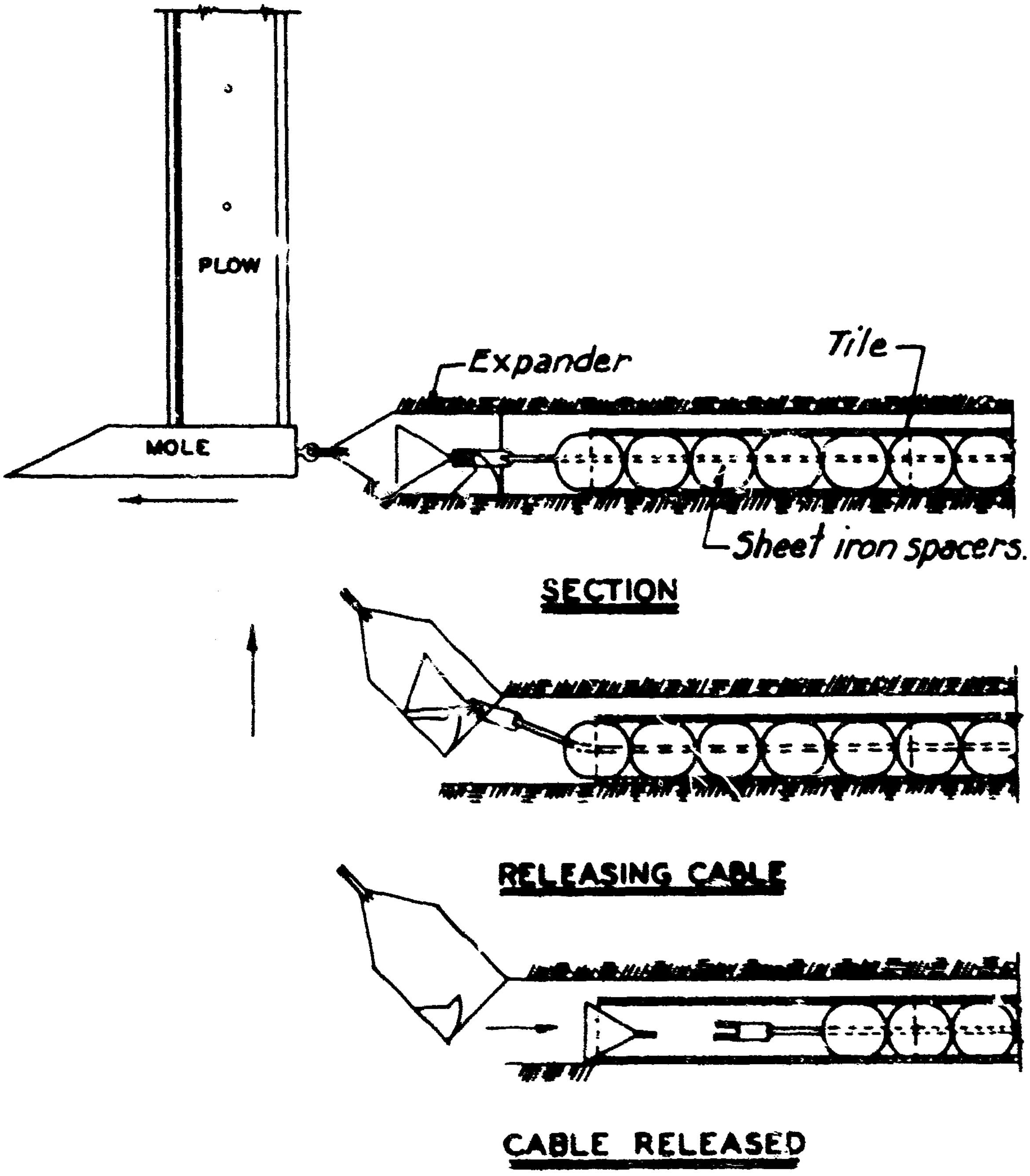
PLATE 2.

MOLE PLOW USED FOR
AGRICULTURAL DRAINAGE



MOLE DRAINAGE OF
AGRICULTURAL LAND

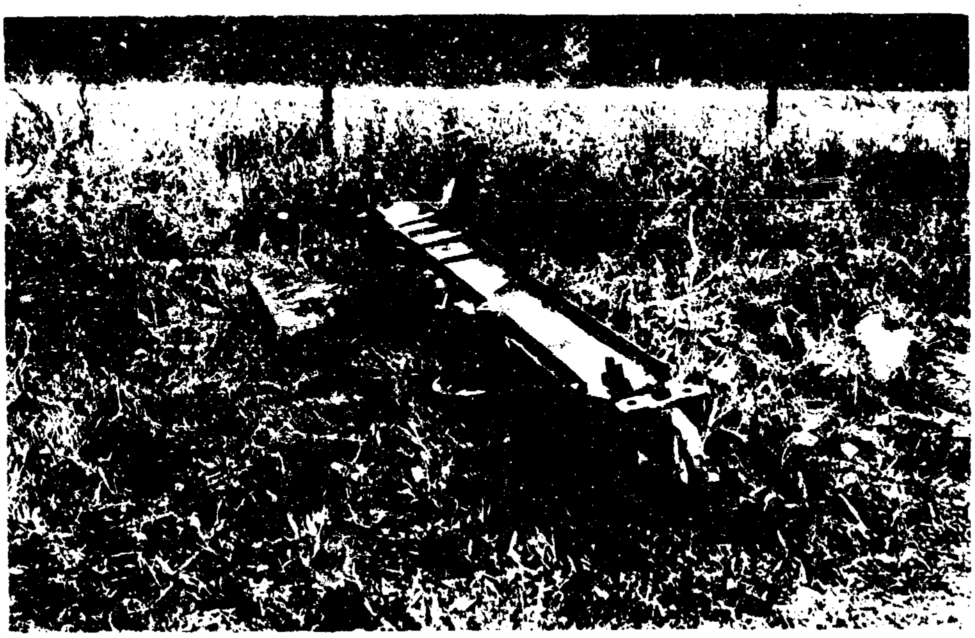
PLATE 4



SELF RELEASING ACTION OF THE CABLE
IN THE
POPPELSDORF DRAINAGE SYSTEM

PLATE 5.

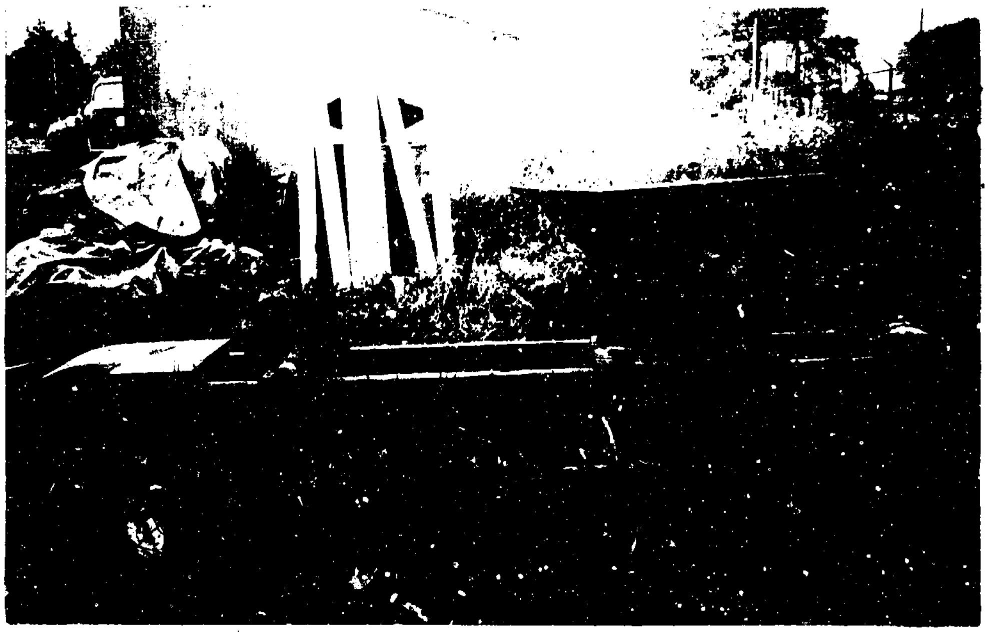
TOP VIEW OF CABLE LAYING DEVICE LYING ON ITS SIDE



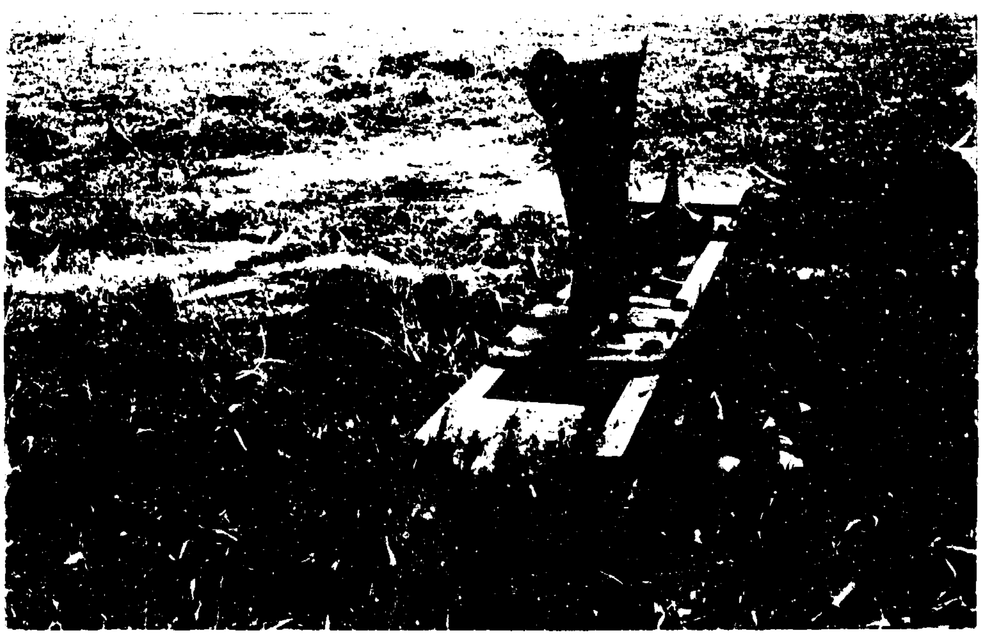
FRONT VIEW OF CABLE LAYING DEVICE LYING ON ITS SIDE

CABLE LAYING DEVICE DEVELOPED BY WOOD ELECTRICAL CONSTRUCTION COMPANY WHILE ON A CONTRACT FOR THE LOUISVILLE DISTRICT, CORPS OF ENGINEERS, WAR DEPARTMENT

PLATE 6.



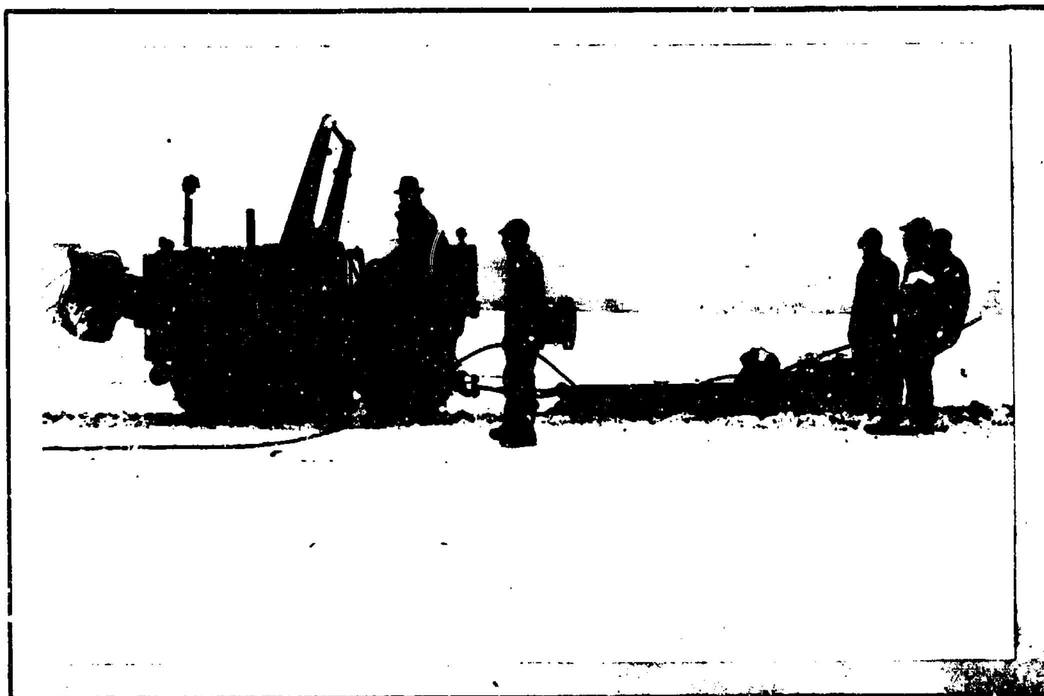
SIDE VIEW OF CABLE LAYING DEVICE TURNED UPSIDE DOWN



REAR VIEW OF CABLE LAYING DEVICE TURNED UPSIDE DOWN

CABLE LAYING DEVICE DEVELOPED BY W[illegible]
CONSTRUCTION COMPANY WHILE ON A CONTRACT FOR THE
LOUISVILLE DISTRICT, CORPS OF ENGINEERS, [illegible]

PLATE 7.

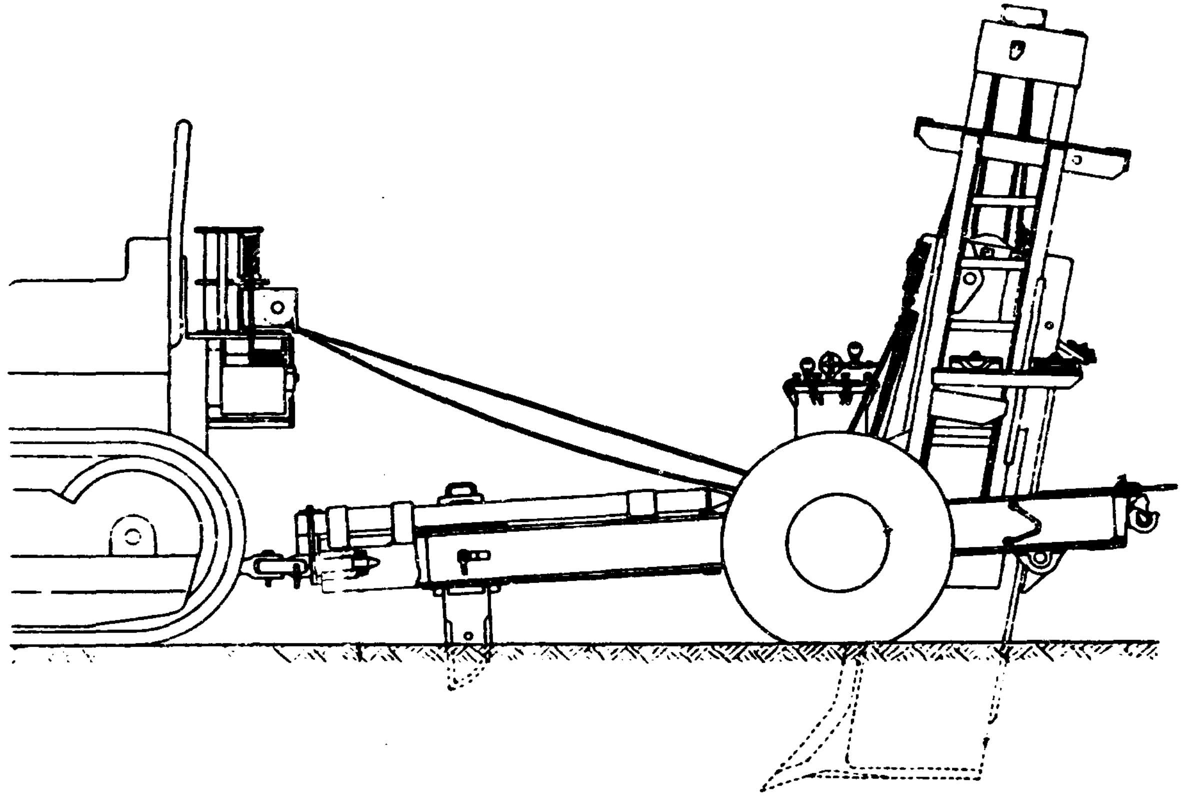


CABLE LAYING DEVICE IN OPERATION

SLOT MADE IN FROZEN SOIL BY CABLE LAYING DEVICE

CABLE LAYING DEVICE DEVELOPED BY WOOD ELECTRICAL CONSTRUCTION COMPANY WHILE ON A CONTRACT FOR THE LOUISVILLE DISTRICT, CORPS OF ENGINEERS, WAR DEPARTMENT

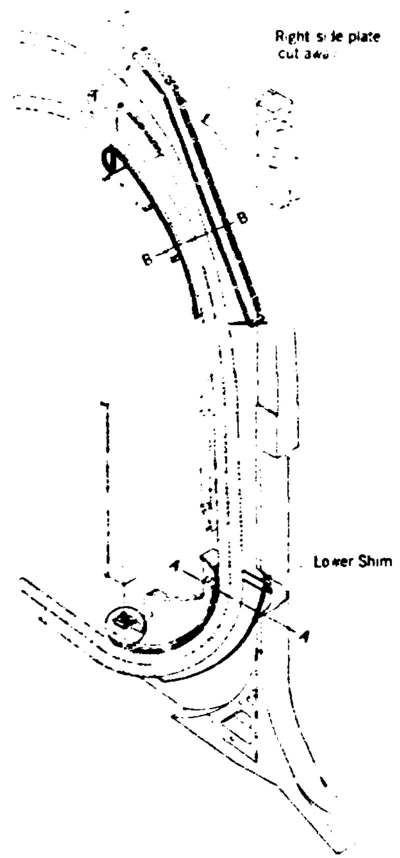
PLATE 8.



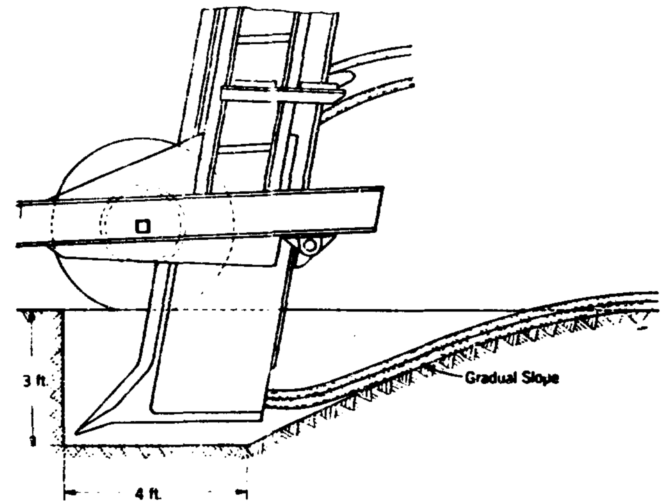
PLOW EQUIPPED FOR CABLE LAYING

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

PLATE 9.

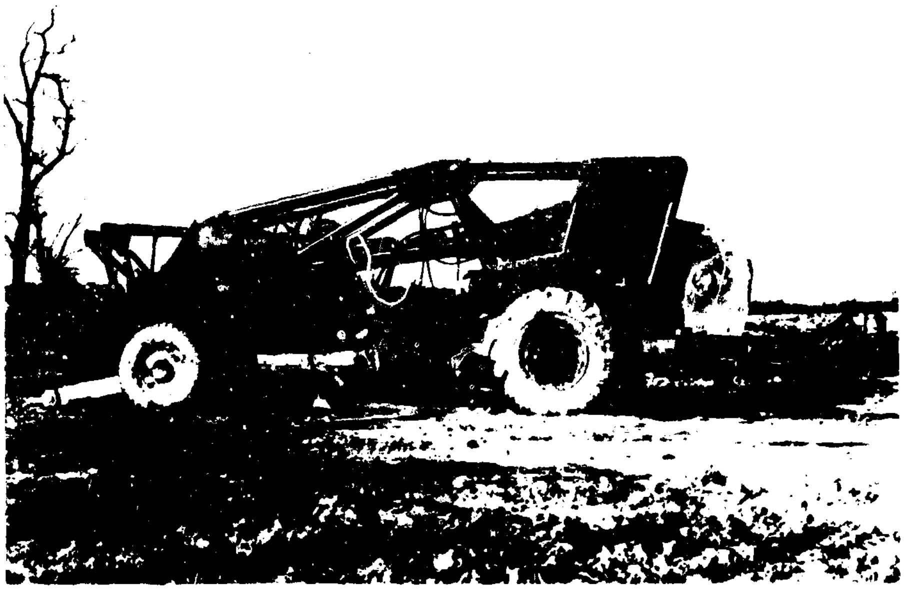


CUT-AWAY VIEW
OF PLOW SHARE



PLOW SHARE IN
STARTING PIT

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



SIDE VIEW

REAR VIEW

CABLE LAYING PLOW "C-60"
AMERICAN TELEPHONE & TELEGRAPH COMPANY

PLATE II.

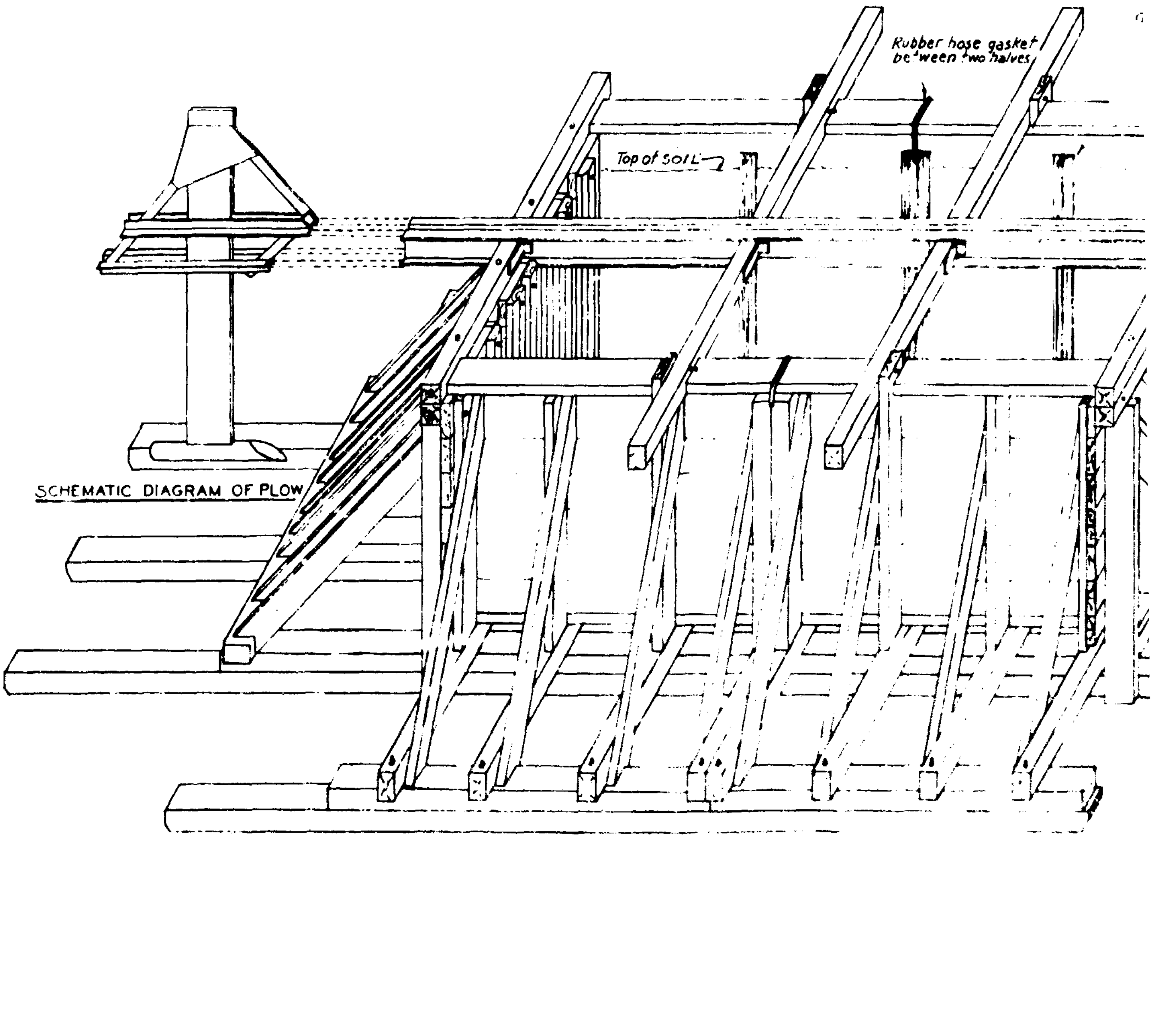
CABLE LAYING PLOW IN OPERATION

RESULT OF PULLING PLOW THROUGH BOULDERS

CABLE LAYING PLOW "C-60"

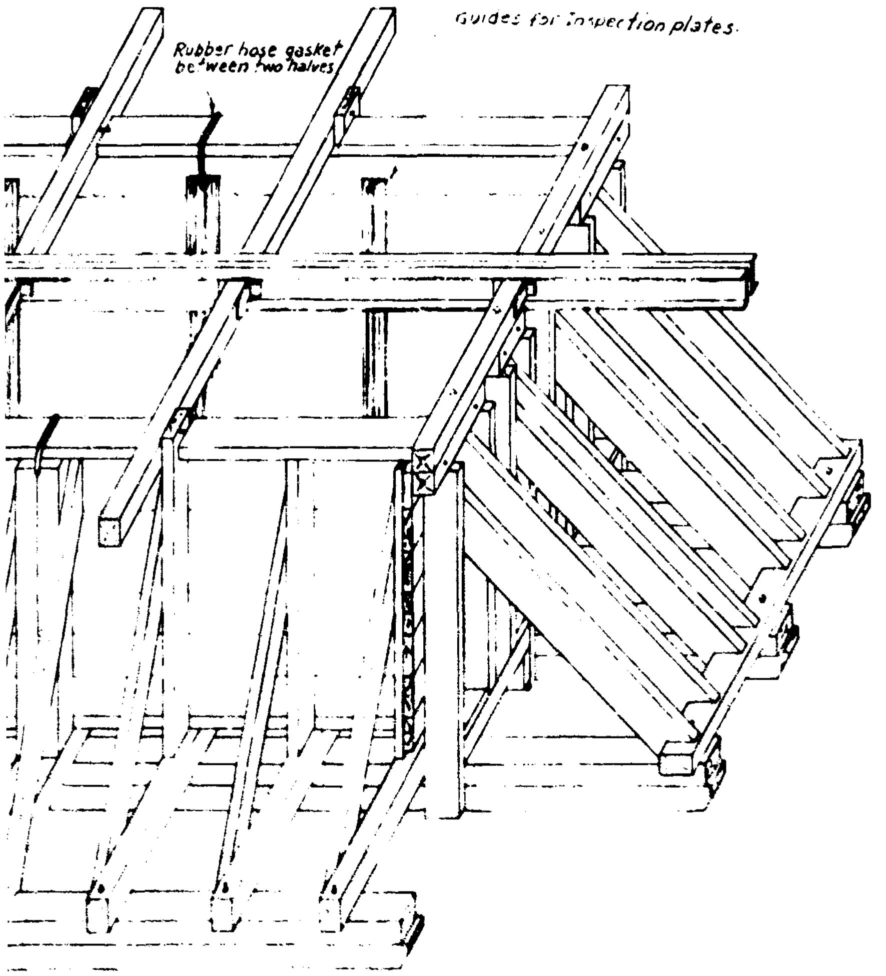
AMERICAN TELEPHONE & TELEGRAPH COMPANY

PLATE 12.



Rubber hose gasket between two halves
Top of soil
SCHEMATIC DIAGRAM OF PLOW

A



NOTES:

Inspection plates may be inserted after trials completed and channels have been removed. Box may then be unbolted at center studs and jacked open for inspection of drain.

Channels may be installed at three locations across the box.

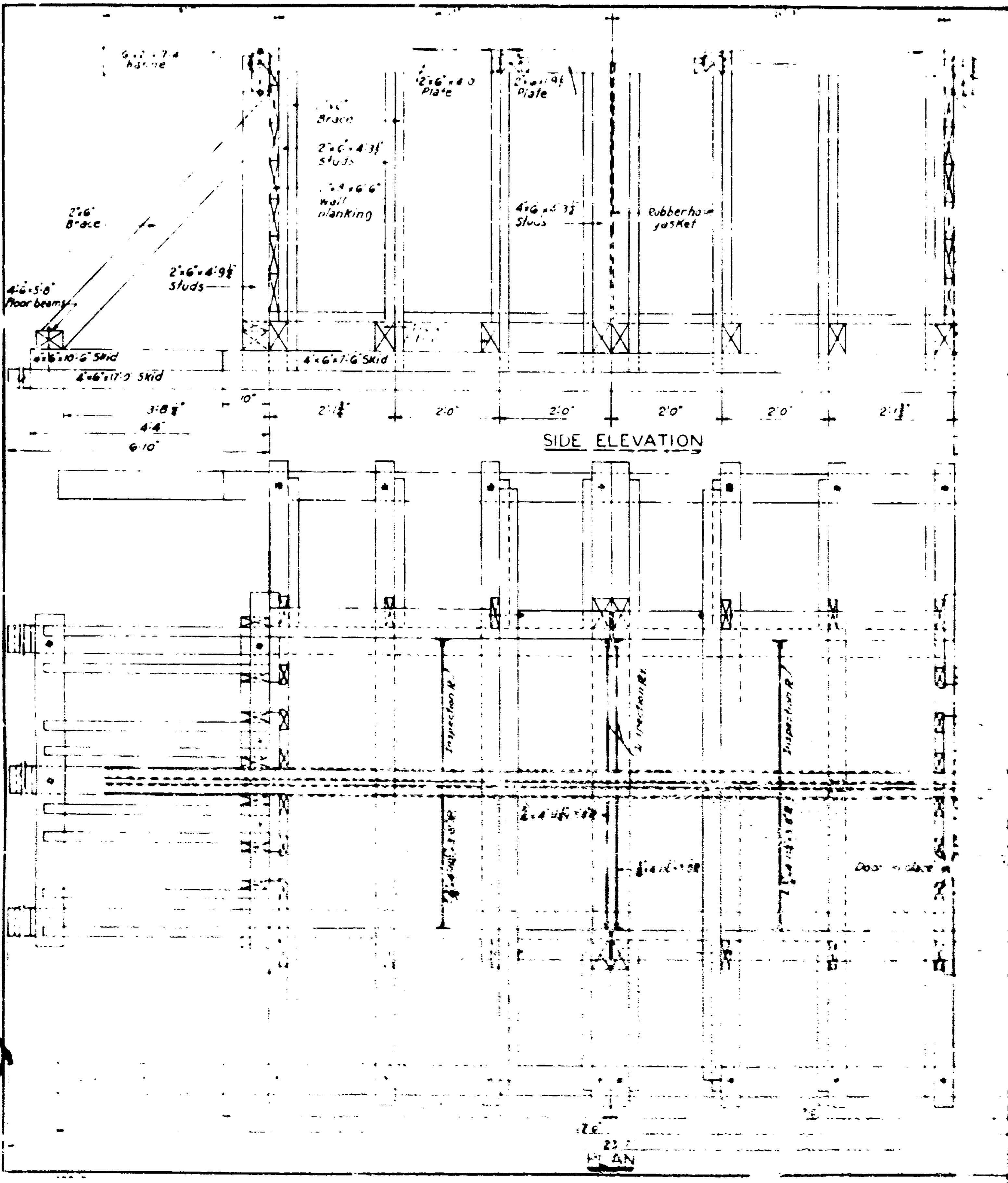
MOLE DRAINAGE INVESTIGATION
1946-1947

ISOMETRIC VIEW OF TEST BOX

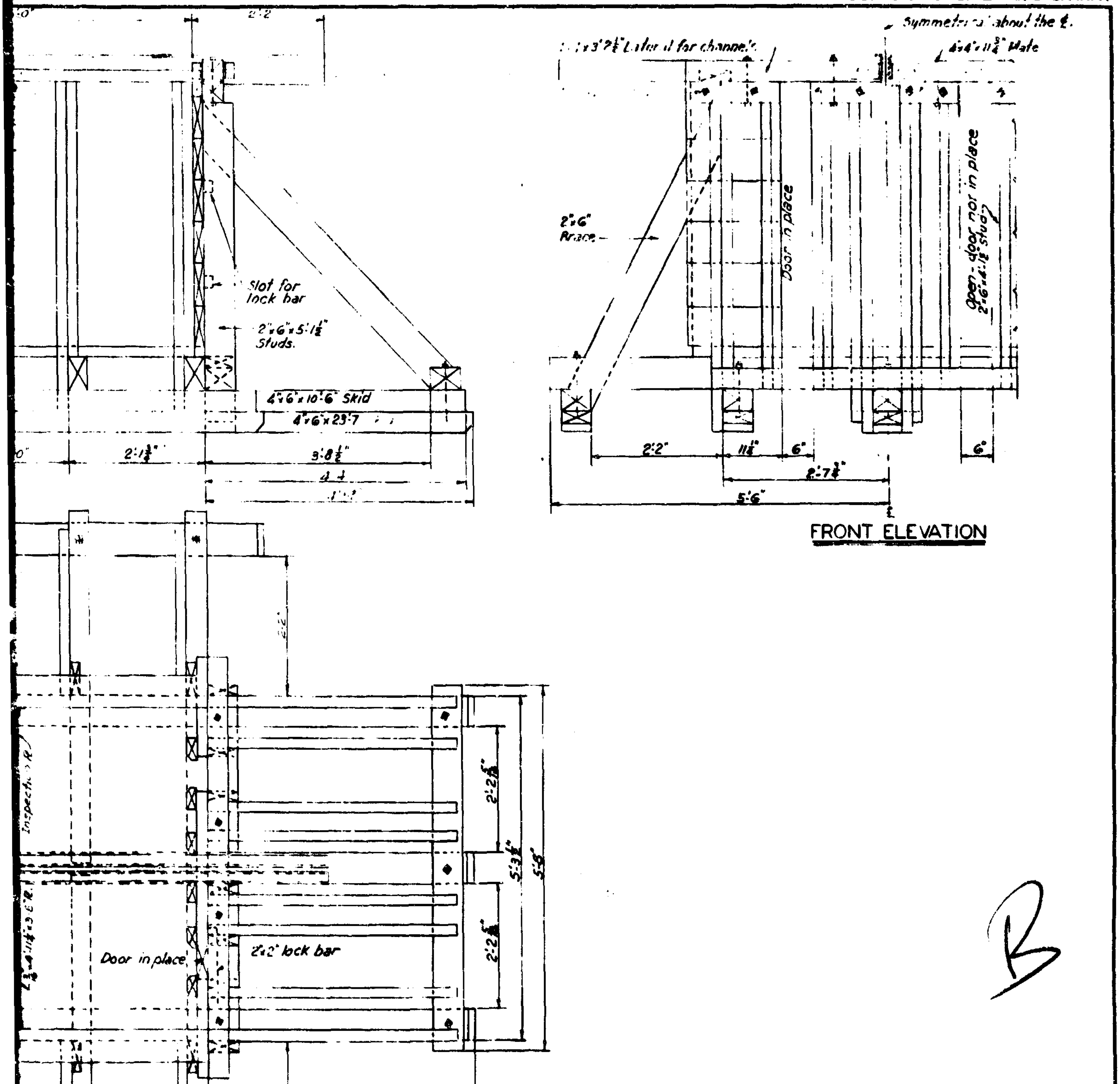
NEW ENGLAND DIVISION — CORPS OF ENGINEERS

PLATE 13

WAR DEPARTMENT



CORPS OF ENGINEERS, U. S. ARMY



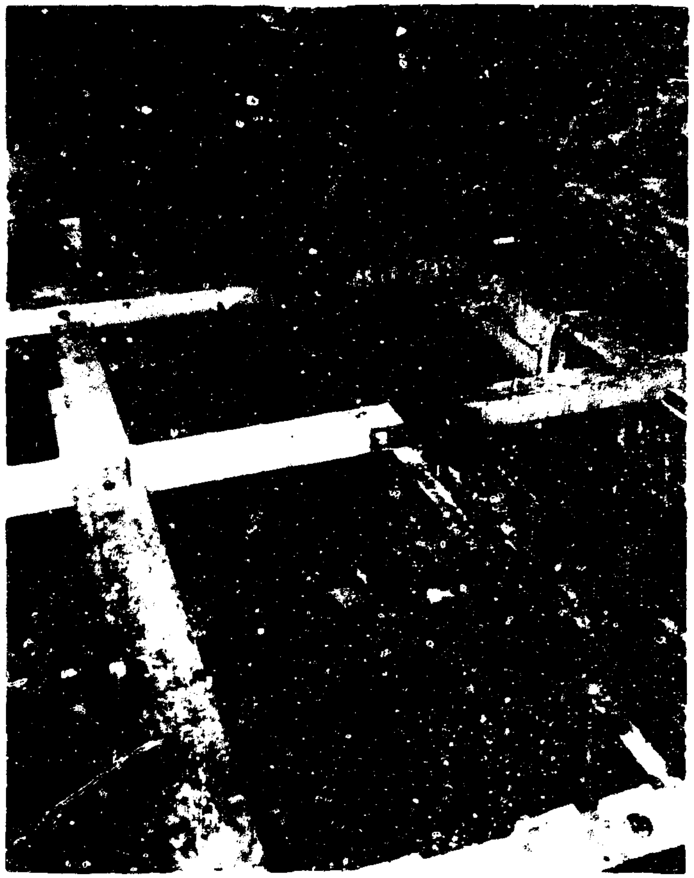
MOLE DRAINAGE INVESTIGATION
1946-1947

DETAILS OF MOLE TEST BOX.

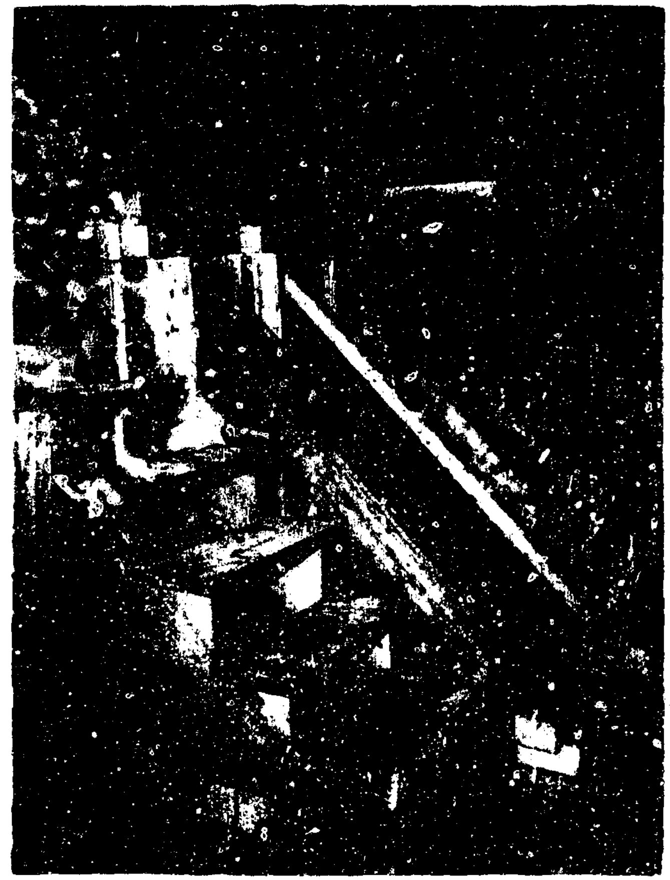
SCALE IN FEET

NEW ENGLAND DIVISION — CORPS OF ENGINEERS

PLATE 14



Top View of Test Box



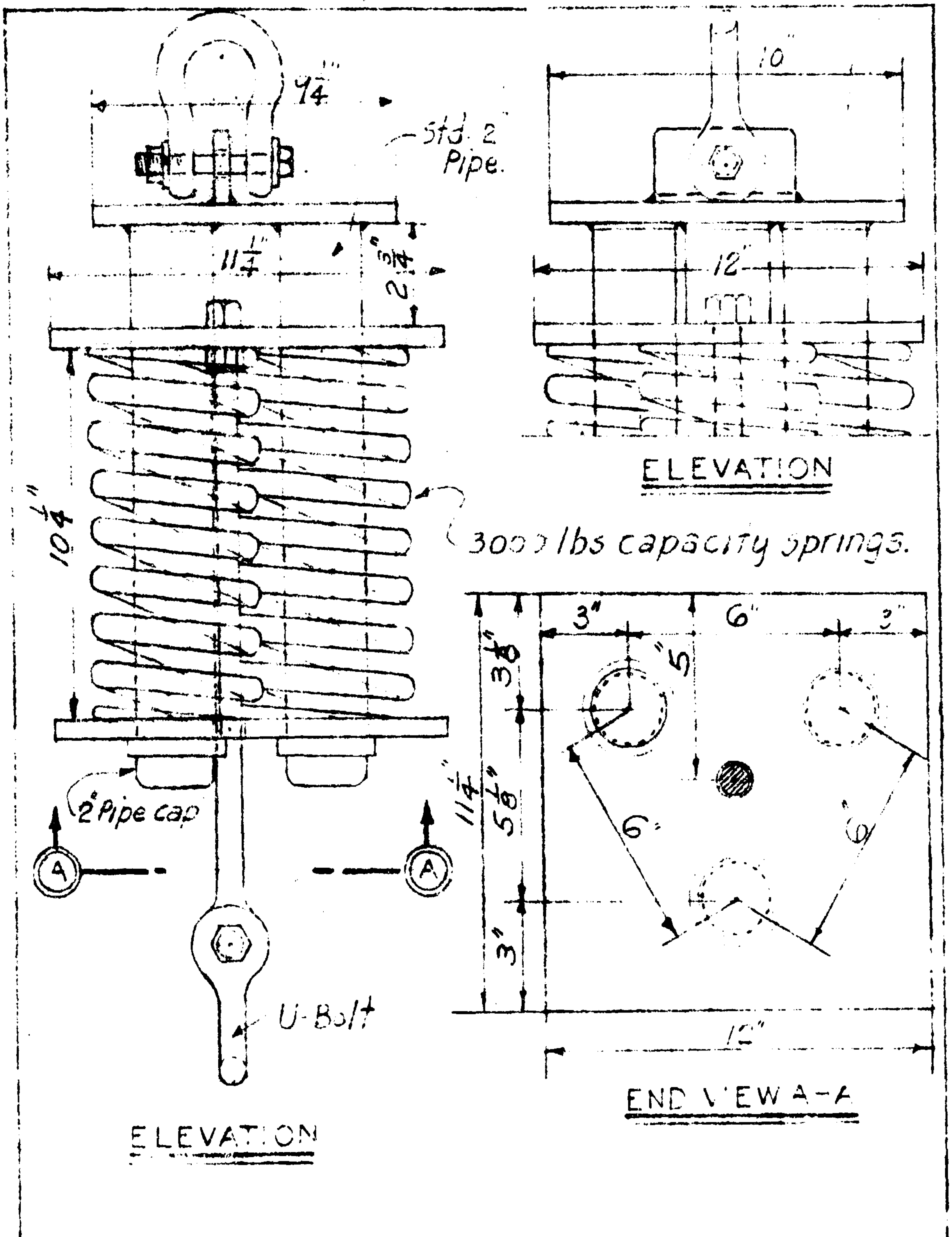
Plow on Channel Tracks at start of Test in Box

Plow about to enter Test Box at start of Test

Plow entering Test Box at start of Test

Rear View of Test Box after Entrance of Plow Into Test Box

Top View of Test Box after Plow had passed through Soil



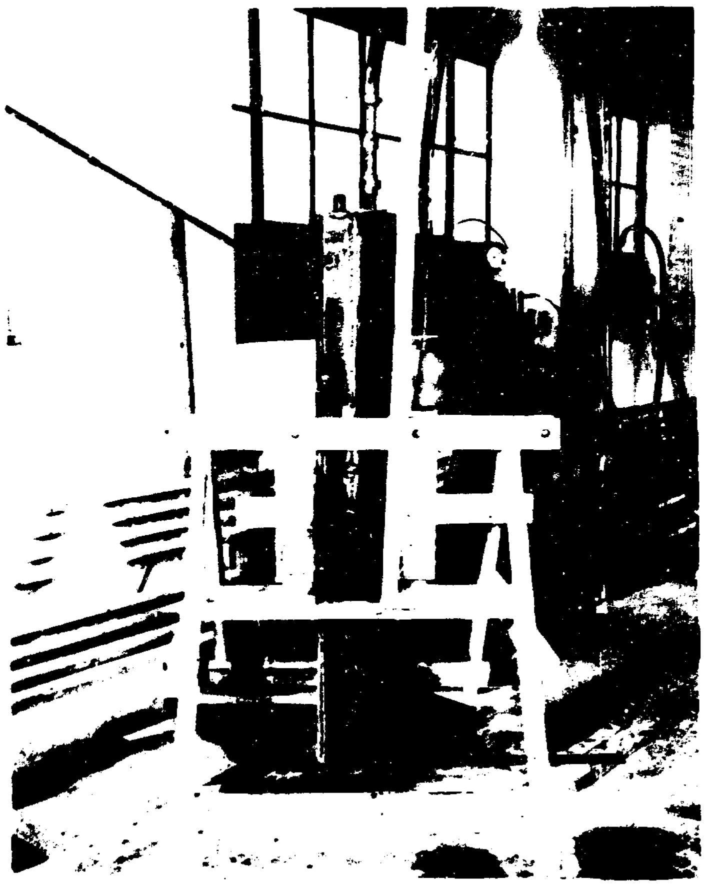
Note:
Deflection of 3 springs in Dynameter found to be 3/8" per 1000 lbs load by calibration

MOLE DRAINAGE INVESTIGATION
1946-1947

DYNAMOMETER

NEW ENGLAND DIVISION
CORPS OF ENGINEERS

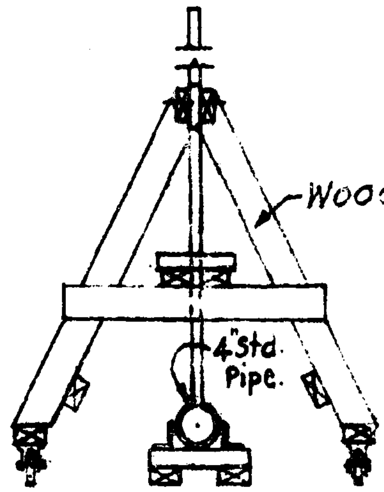
PLATE 18



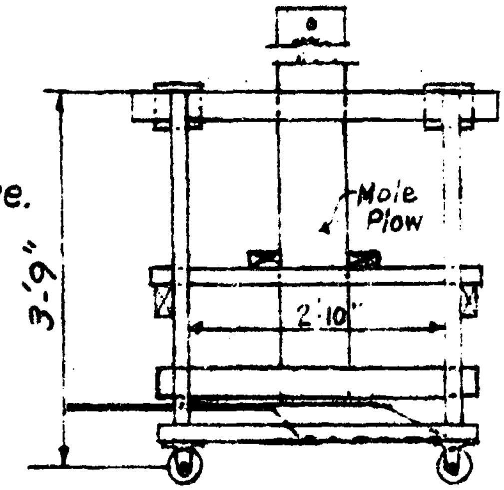
Temporary Plow Frame

Dynamometer

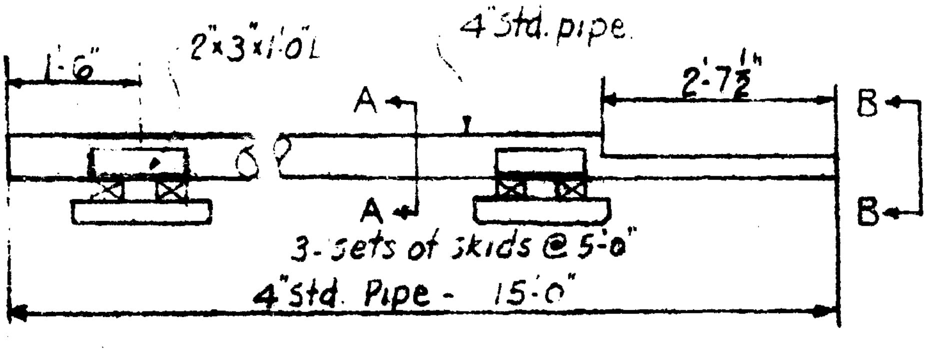
PLATE 19



END ELEVATION



SIDE ELEVATION



A-A B-B

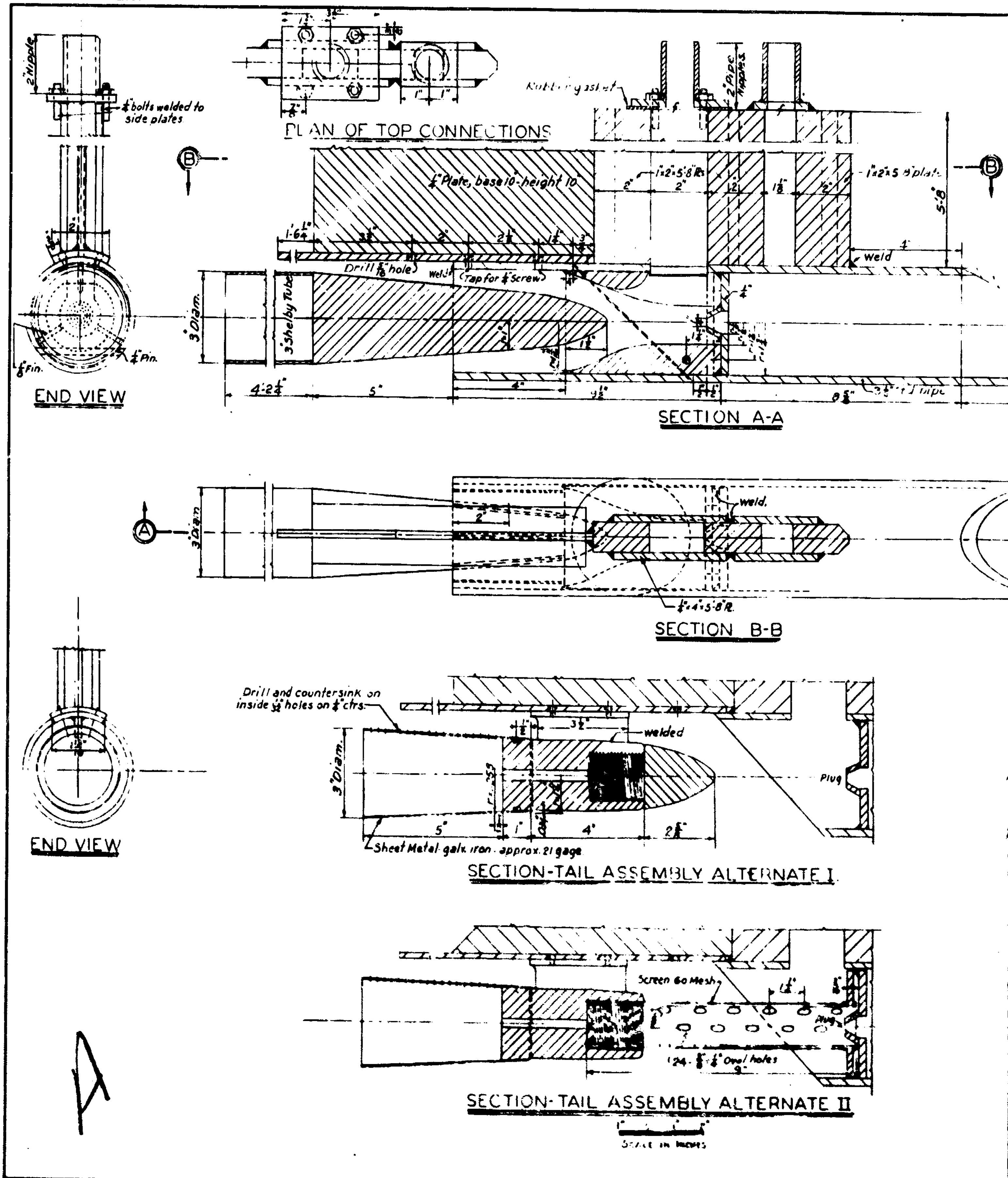
MOLE DRAINAGE INVESTIGATION
1946-1947

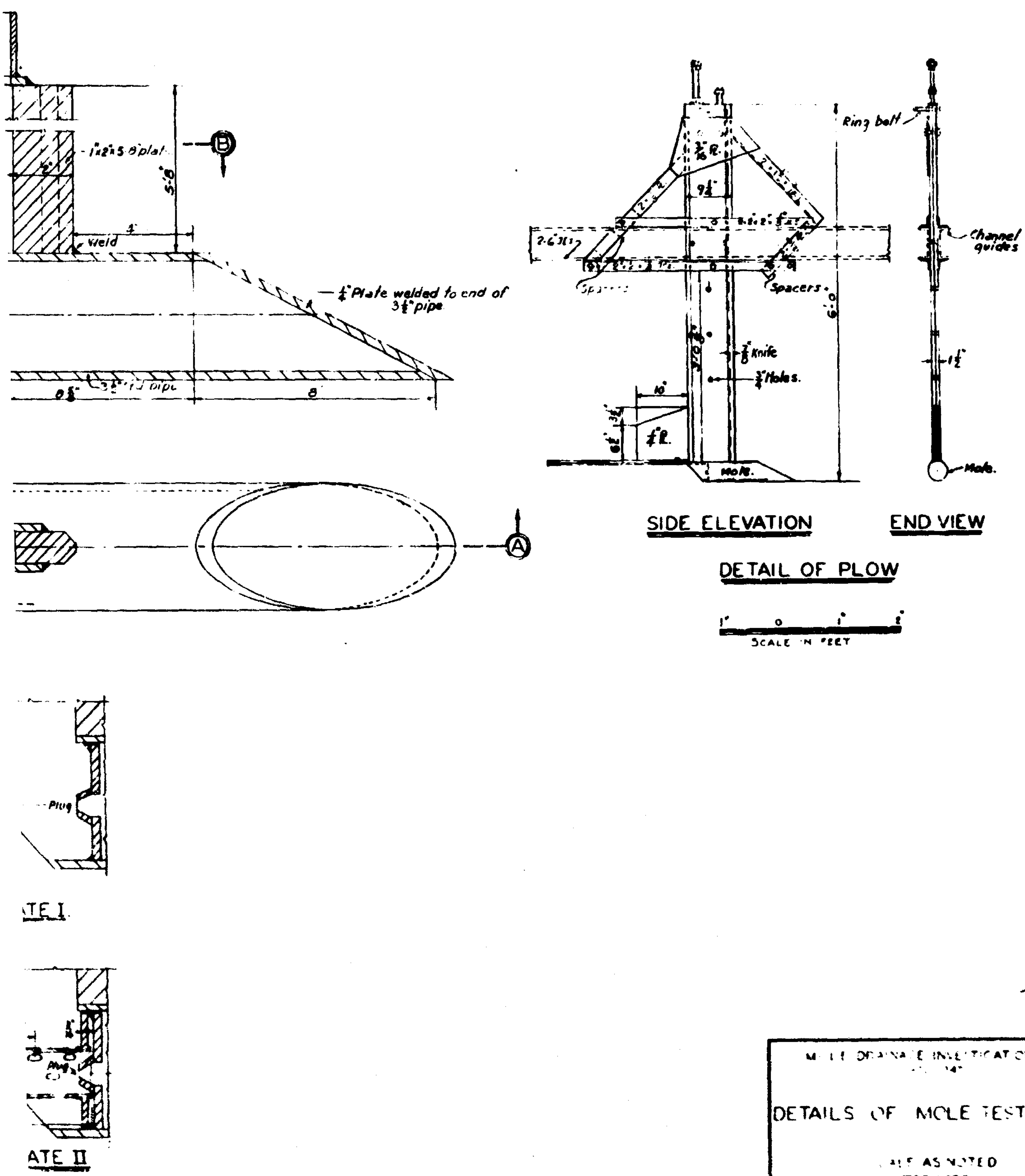
TEST APPARATUS

NEW ENGLAND DIVISION
CORPS OF ENGINEERS

PLATE 20

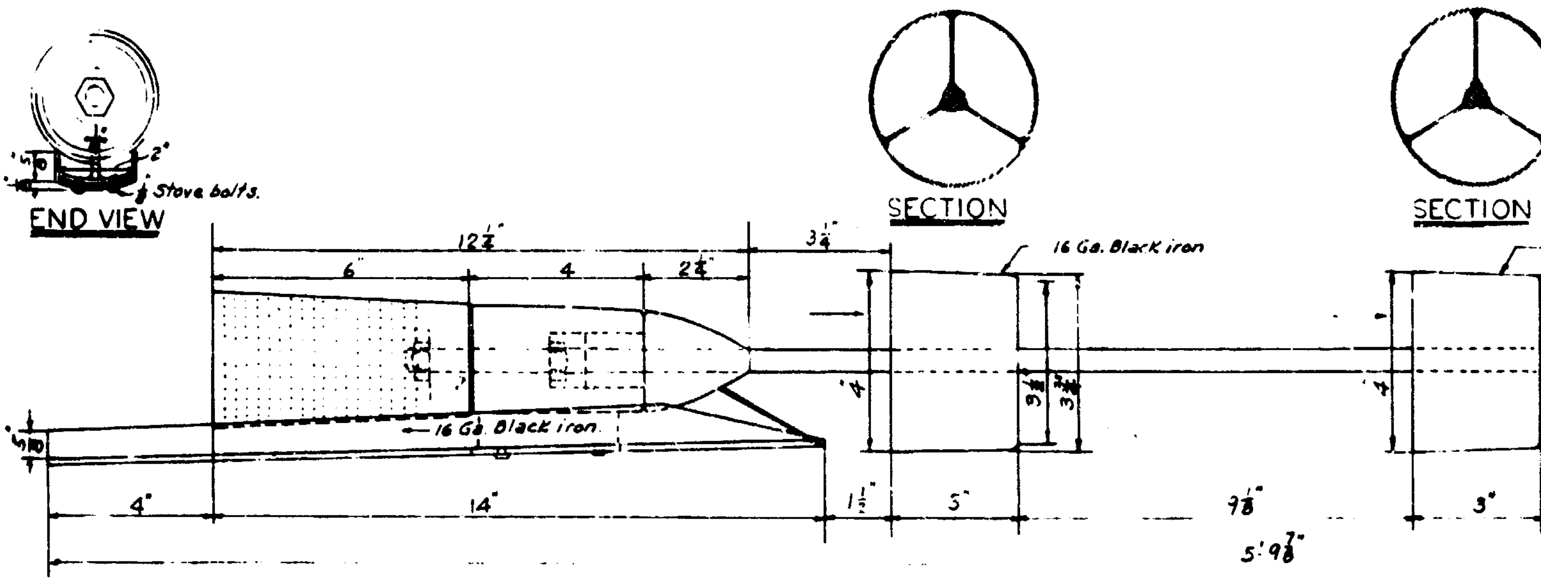
WAR DEPARTMENT



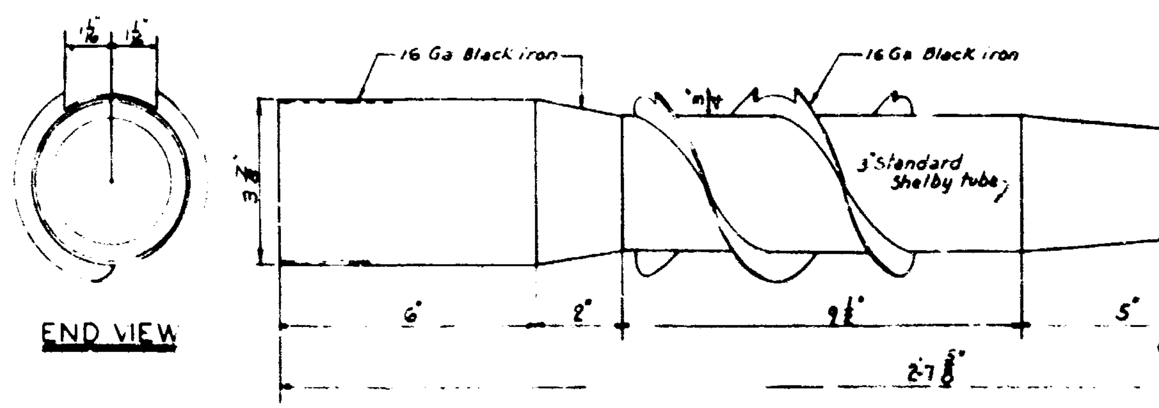


DETAILS OF MOLE TEST PLOW

SCALE AS NOTED
SHEET 1 OF 2

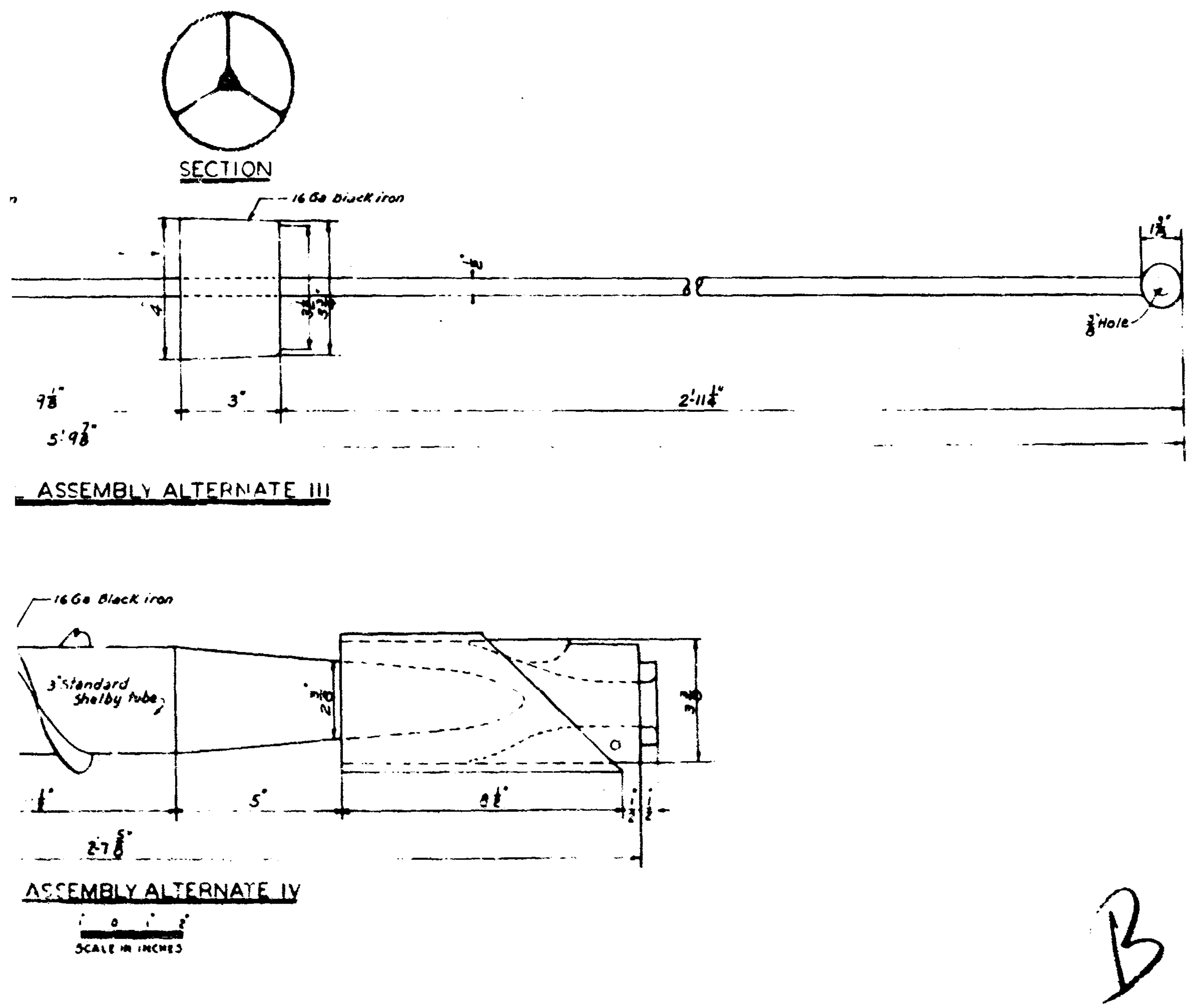


TAIL ASSEMBLY ALTERNAT



TAIL ASSEMBLY ALTERNATE

SCALE IN INCHES



MOLE DRAINAGE INVESTIGATION

DETAILS OF MOLE TEST PLOW

SCALE AS NOTED
SHEET 2 OF 2

NEW ENGLAND DIVISION — CORPS OF ENGINEERS

PLATE 22

Plow and Asphalt Tail Assembly

Plow with asphalt Tail Assembly Attached

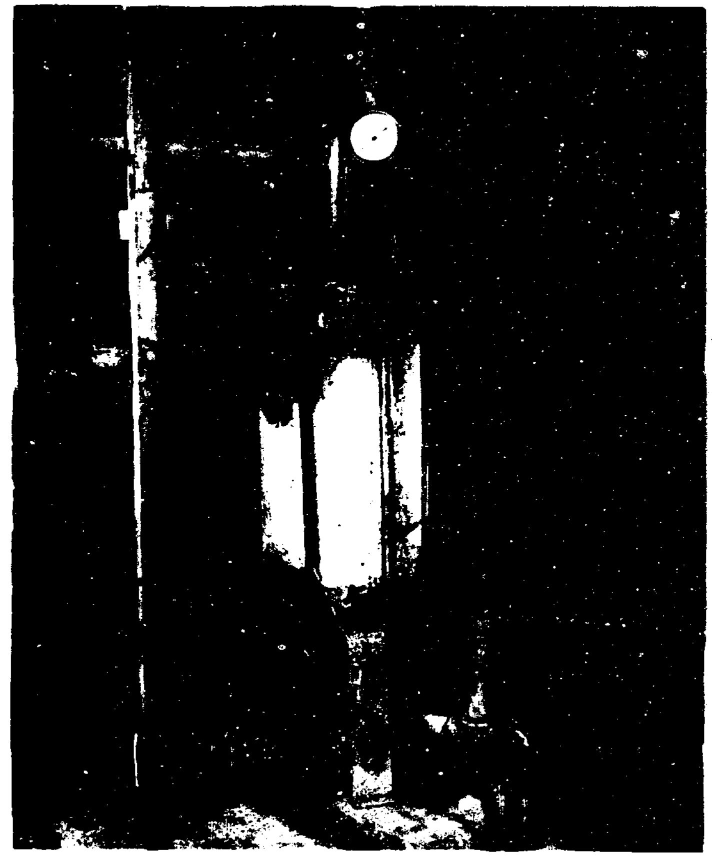
Plow with Tail Assembly Alternate No. 1 Attached

Plow and Tail Assembly Alternate No. 2

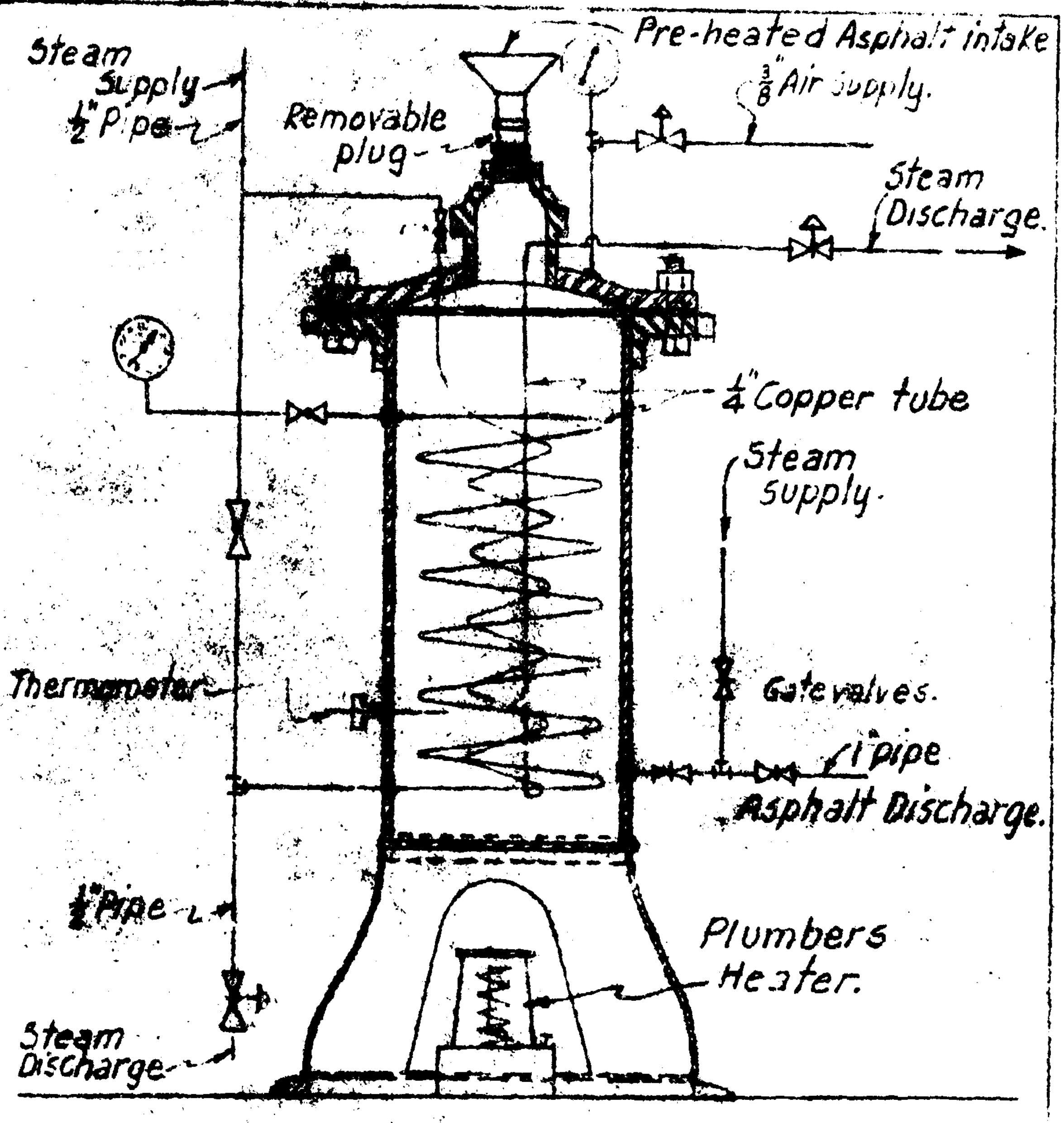
Modified Concrete Aggregate Tail Assembly -
Alternate No. 3

Modified Asphalt Tail Assembly - Alternate No. 4

Asphalt Pump with Steam Coils



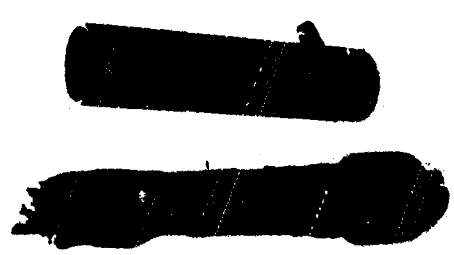
Grout Pump



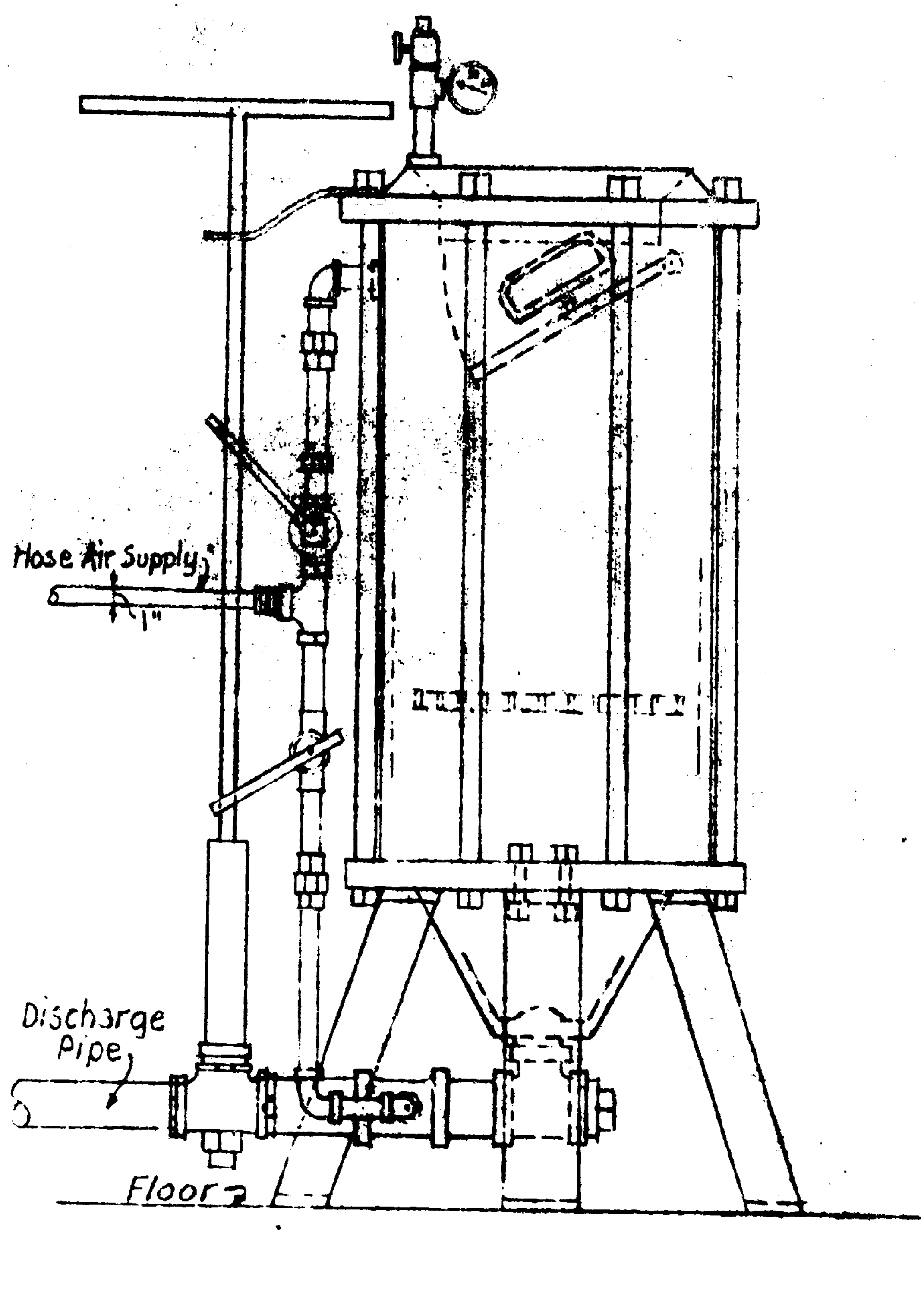
MOLE DRAINAGE INVESTIGATION
194[illegible]-194[illegible]
SCHEMATIC DIAGRAM
ASPHALT PUMP
NEW ENGLAND DIVISION
CORPS OF ENGINEERS

PLATE 27

General View of Test Area Showing Test Box in Center behind Concrete Mixing Platform

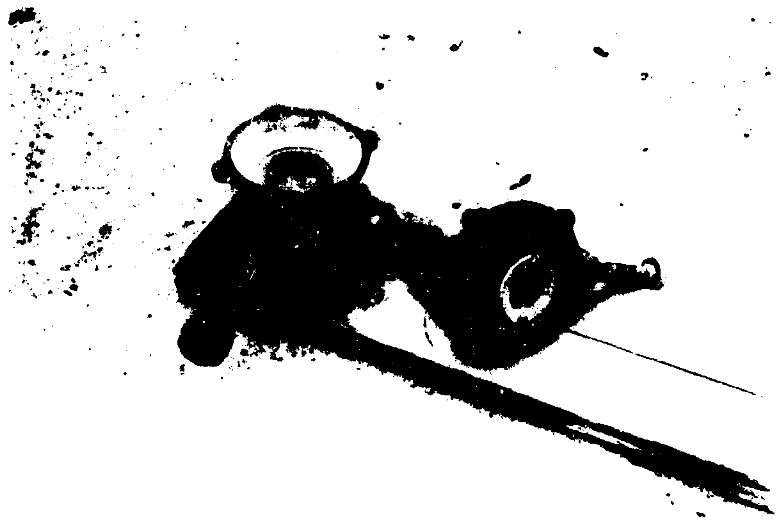


Concentric Pipe Mould - Disassembled after Test No. 3



MOLE DRAINAGE INVESTIGATION
1946-1947
SCHEMATIC DIAGRAM
GROUT PUMP
NEW ENGLAND DIVISION
CORPS OF ENGINEERS

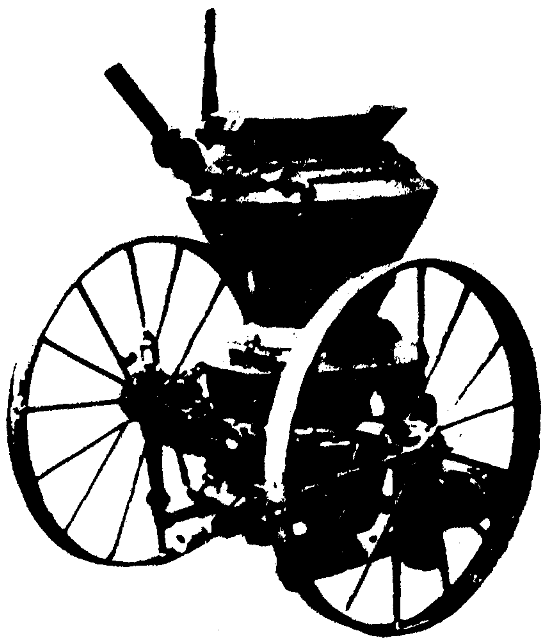
PLATE 29



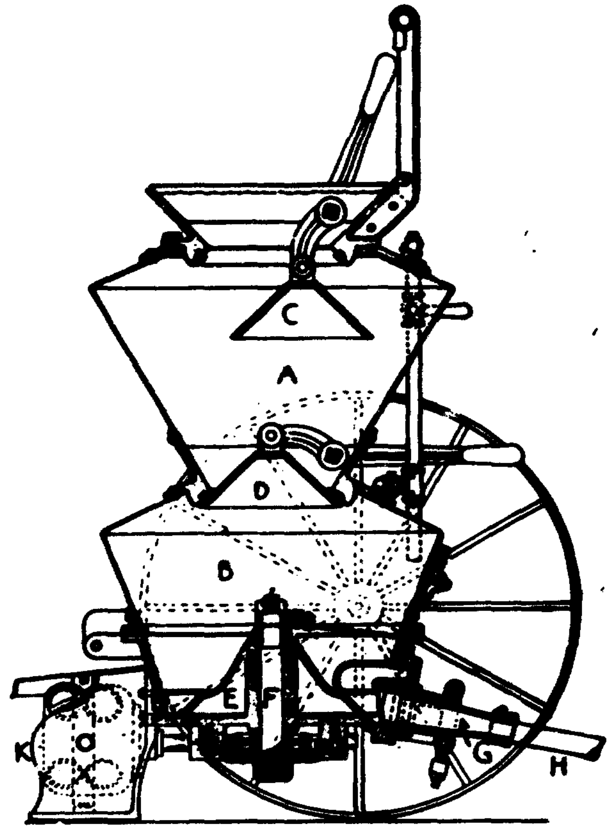
Edson Diaphram Pump Disassembled

Edson Diaphram Pump

PLATE 30

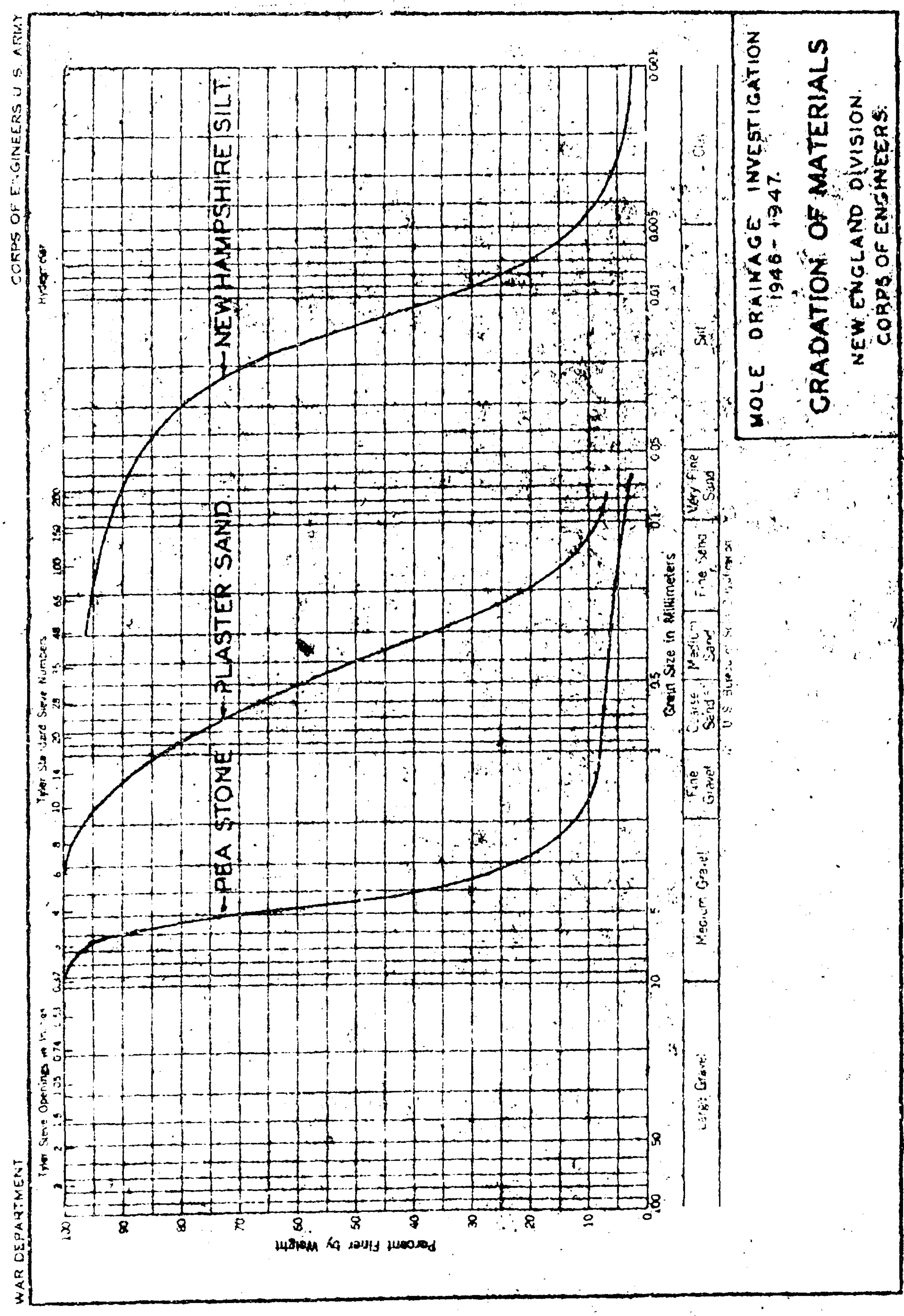


CEMENT-GUN MODEL N-1

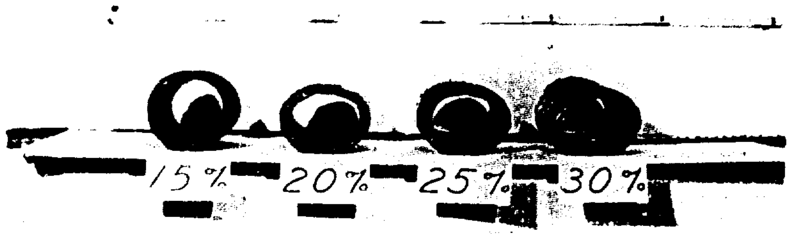


CROSS SECTION OF CEMENT-GUN

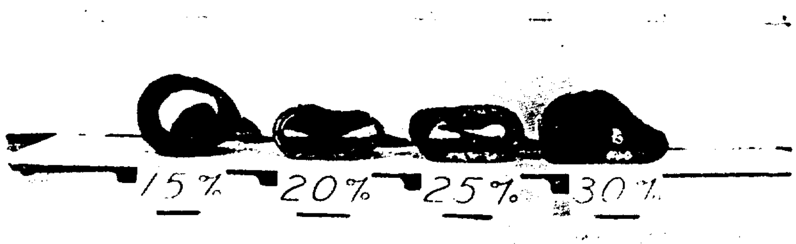
PLATE 31



Best Available Copy



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

Concrete Drain after Excavation. Test No. 40

Asphalt Drain after Excavation. Test No. 42

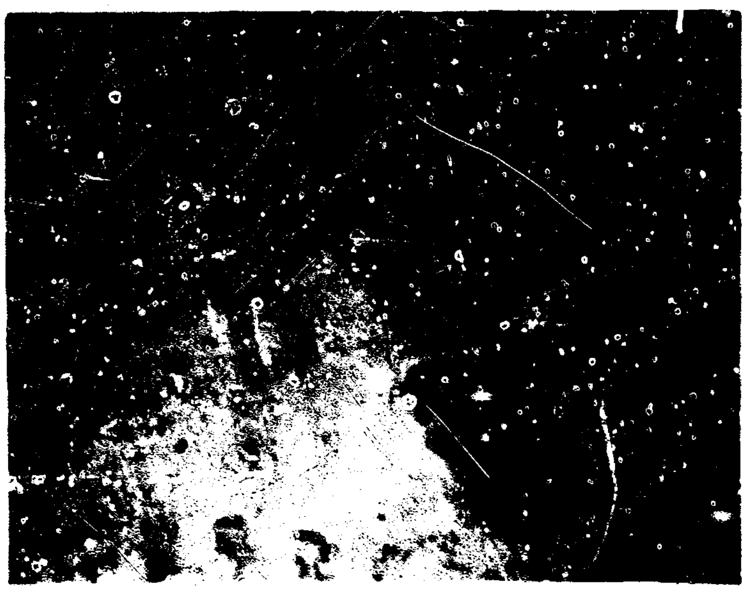
Partially Uncovered Drains In Place. Left - Test No. 41. Right - Test No. 42

View looking through Concrete Drain after removal Test Box Test No. 42

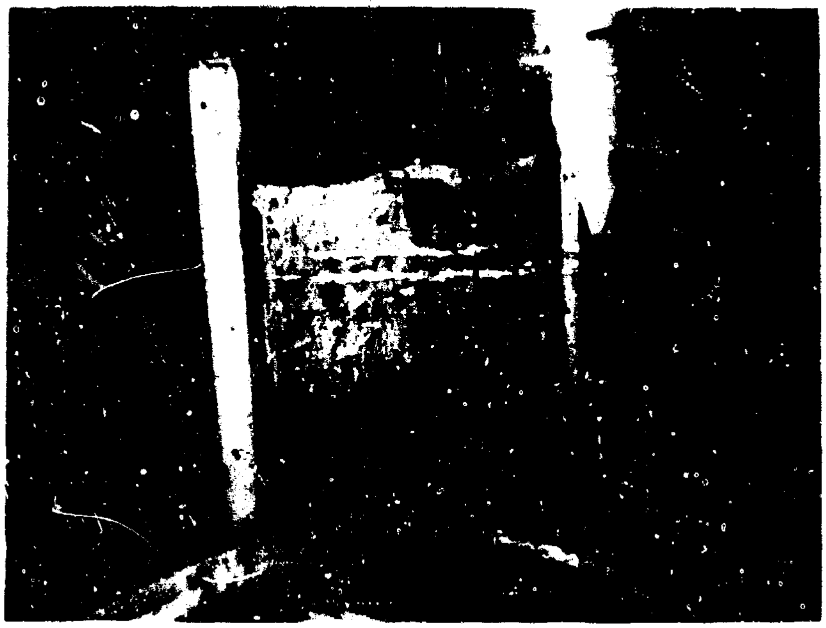
Plow with Asphalt Tail, being moved through Slotted Test Pipe

Section of Drain made in Test Pipe. Test No. 25

Close-up of Incomplete Drain, Test No. 27

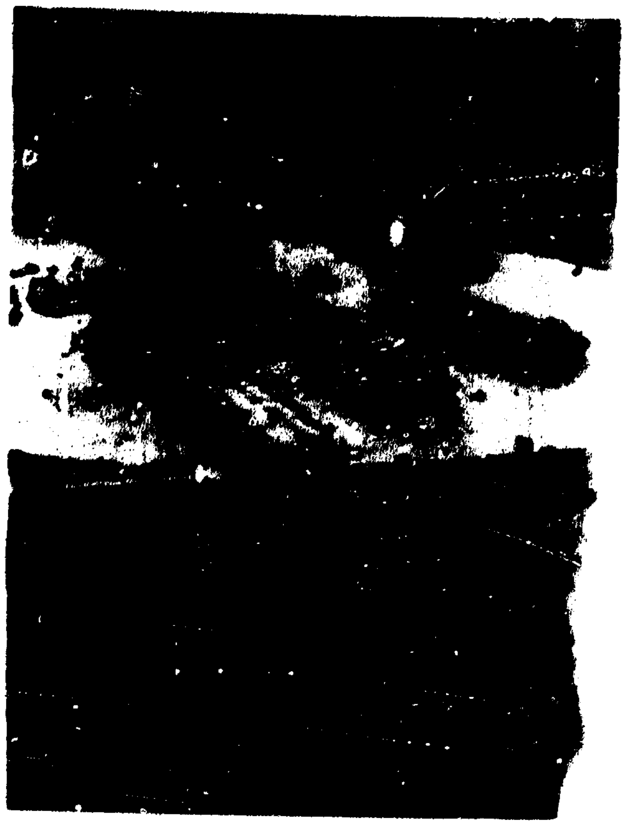


Segments of Drain after Removal from Test Box, Test No. 27



Oblique View of Center of Test Box after Test No. 27 with Box opened for Inspection

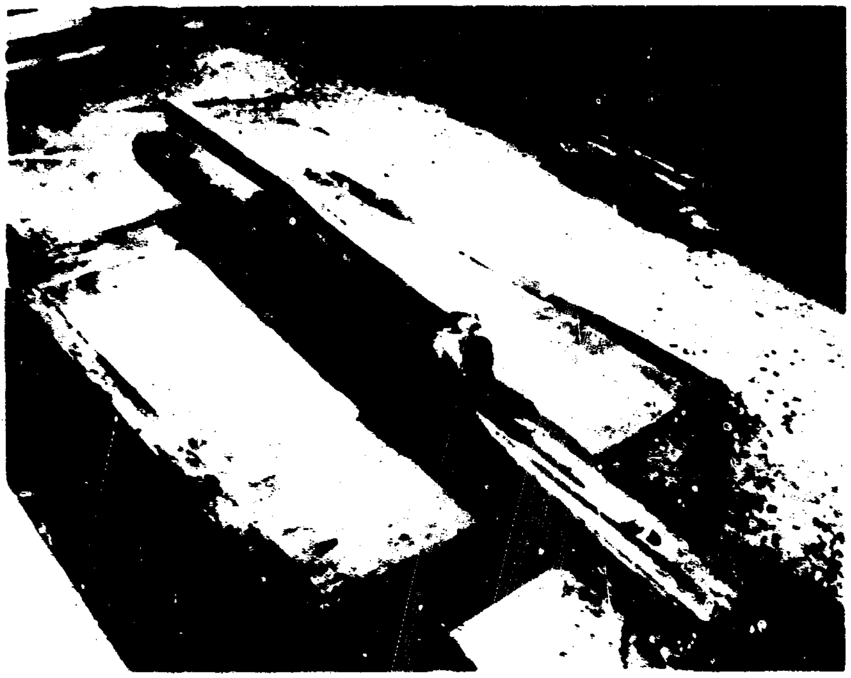
Close-up of Incomplete Drain, Test No. 27



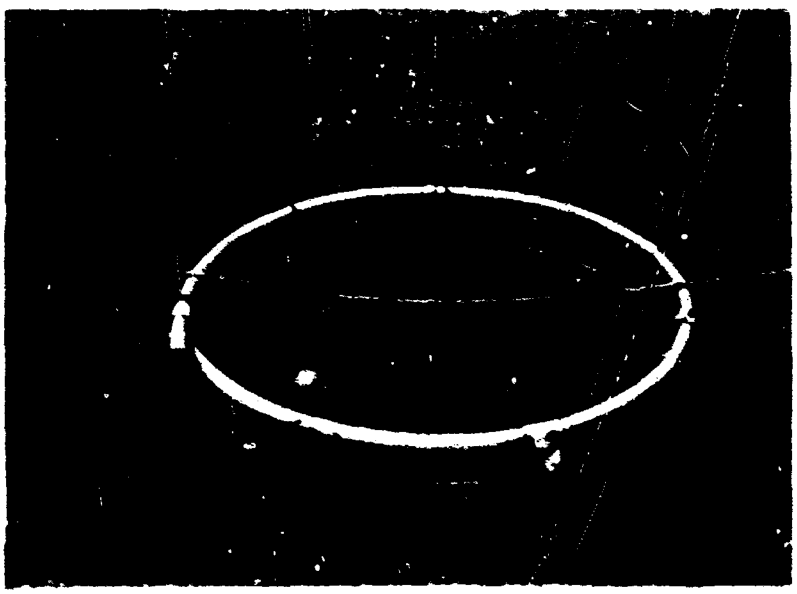
Segments of Drain after Removal from Test Box, Test No. 28

Segments of Drain after Removal from Test Box, Test No. 28

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

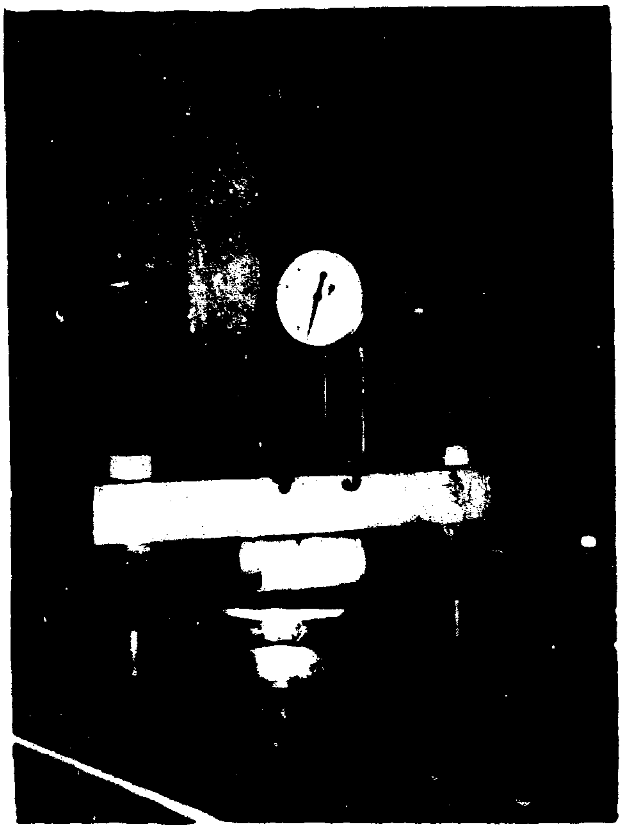


Right side of Concrete Drain after Removal from Test Box. Test No. 40



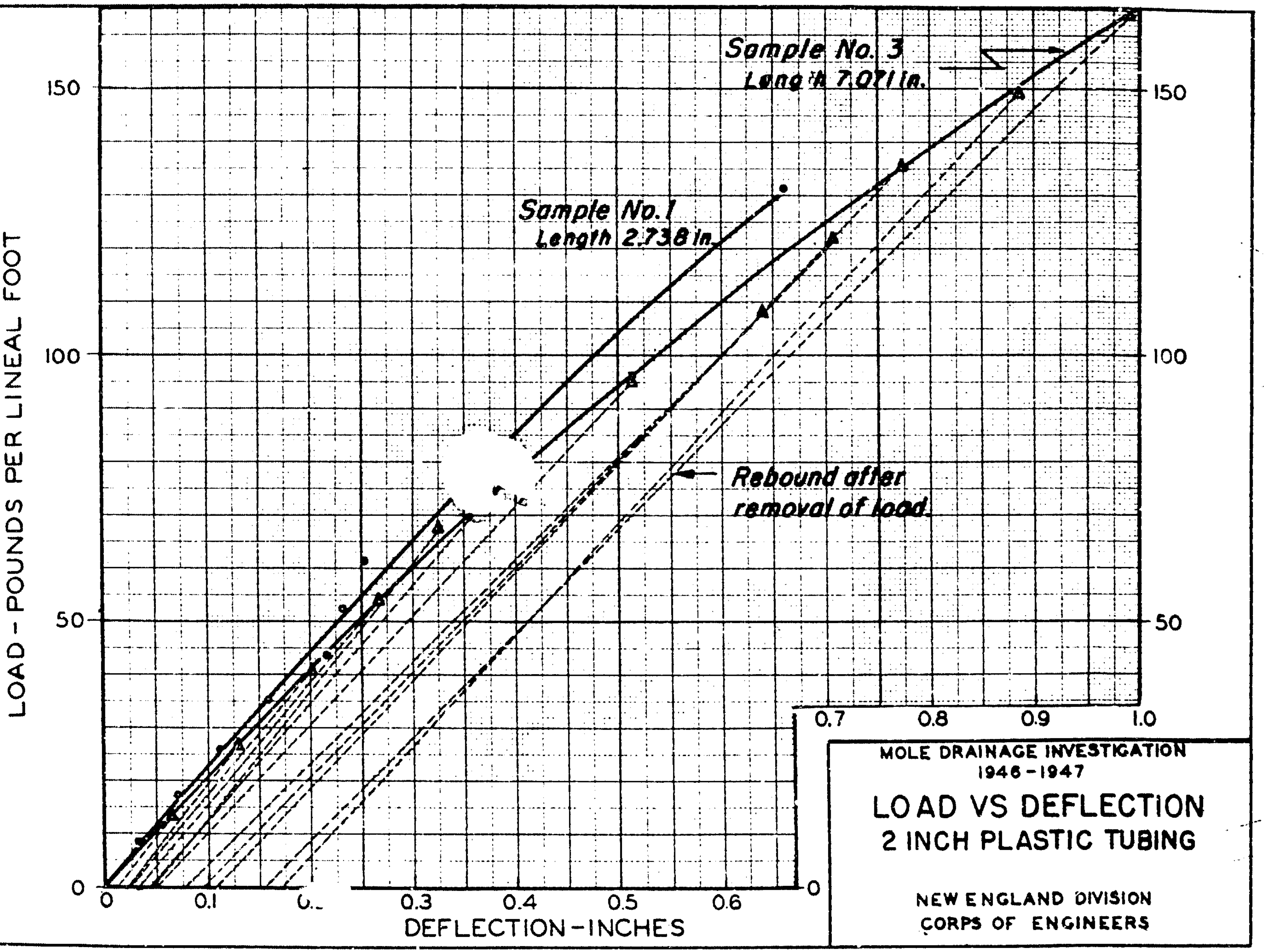
4 Foot Diameter Coil of Polyethylene Tubing

PLATE 41



Samples of Plastic Tubing undergoing Test of Loading vs. Deformation

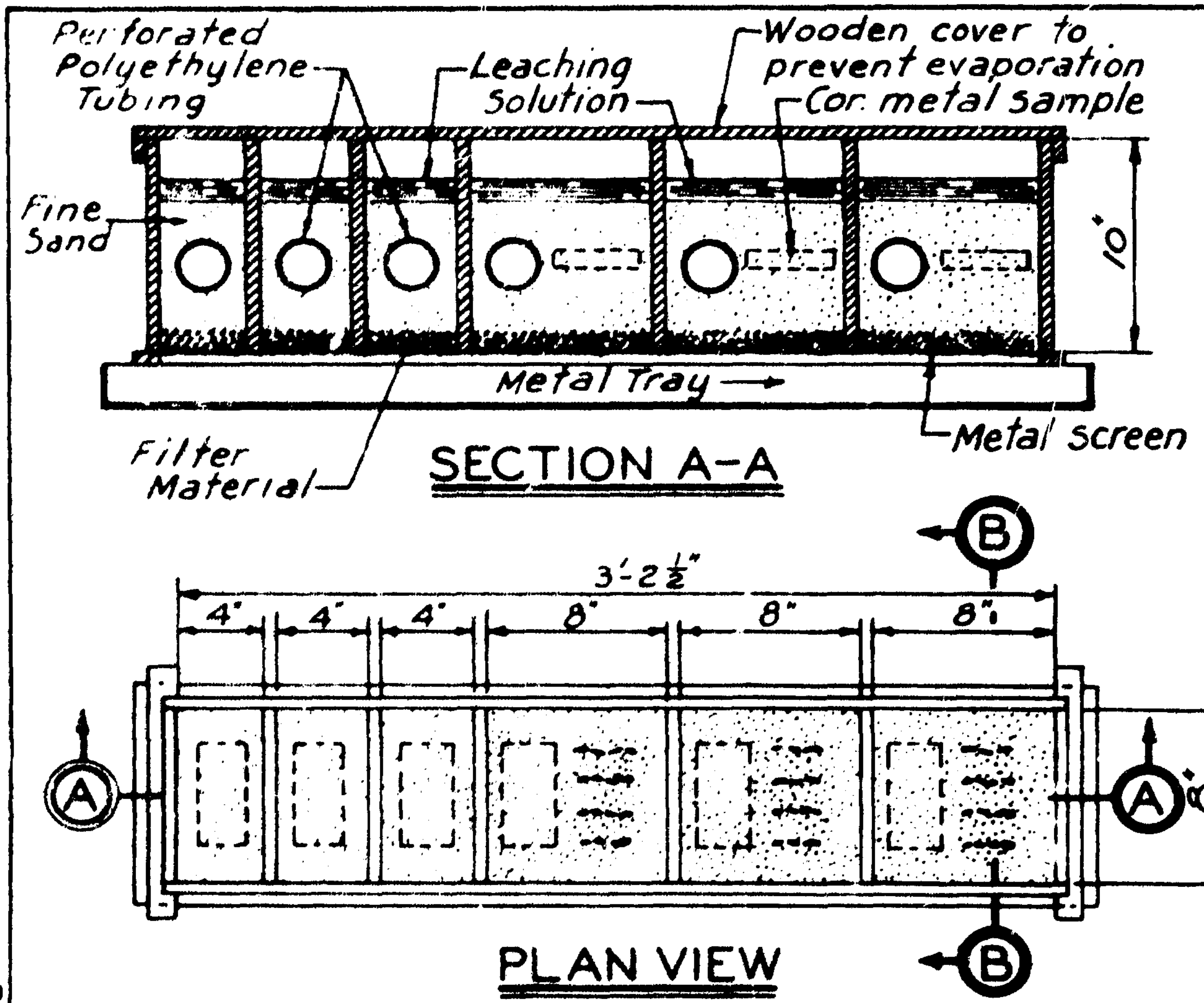
PLATE 42

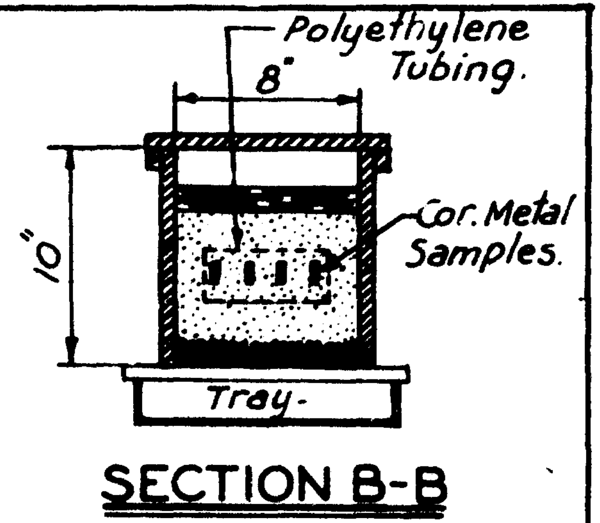


MOLE DRAINAGE INVESTIGATION
1946 - 1947

LOAD VS DEFLECTION
2 INCH PLASTIC TUBING

NEW ENGLAND DIVISION
CORPS OF ENGINEERS





Note;-
Leaching box made from ½" Plywood.
The complete apparatus coated with parafin.

MOLE DRAINAGE INVESTIGATION
1946 - 1947

LEACHING TEST

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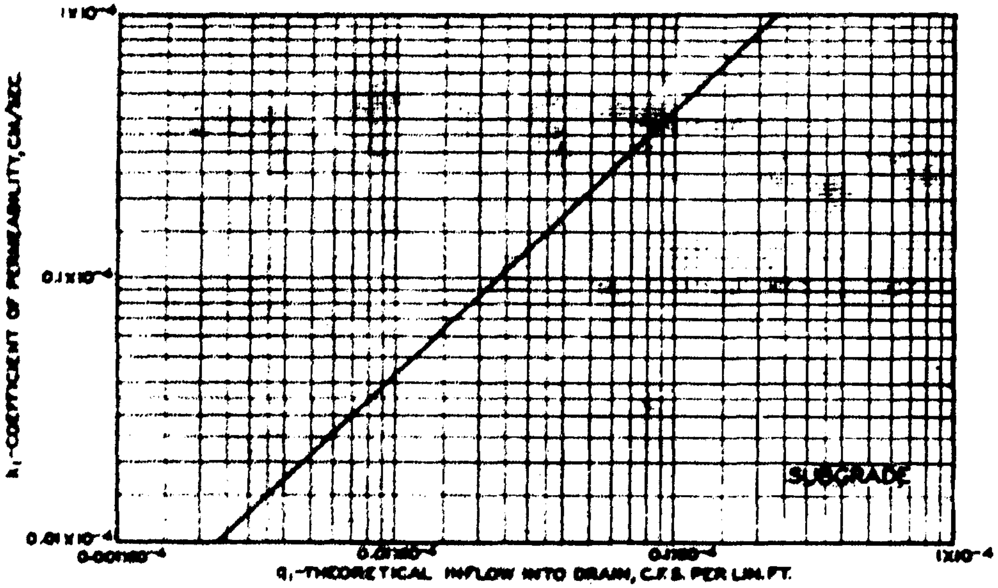

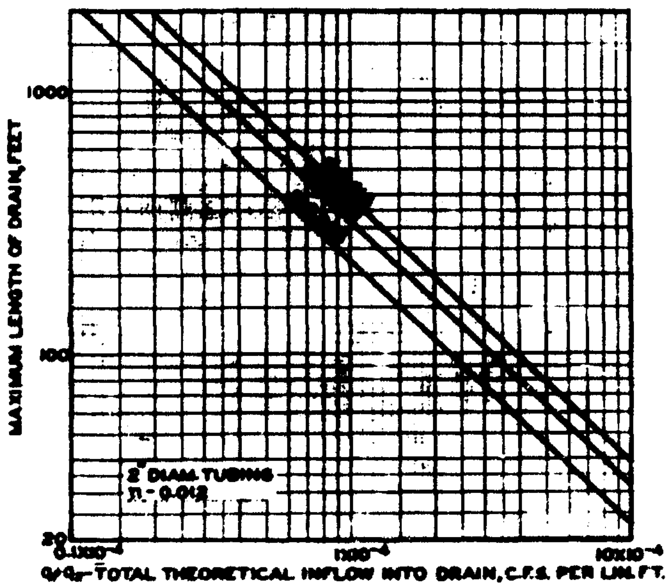

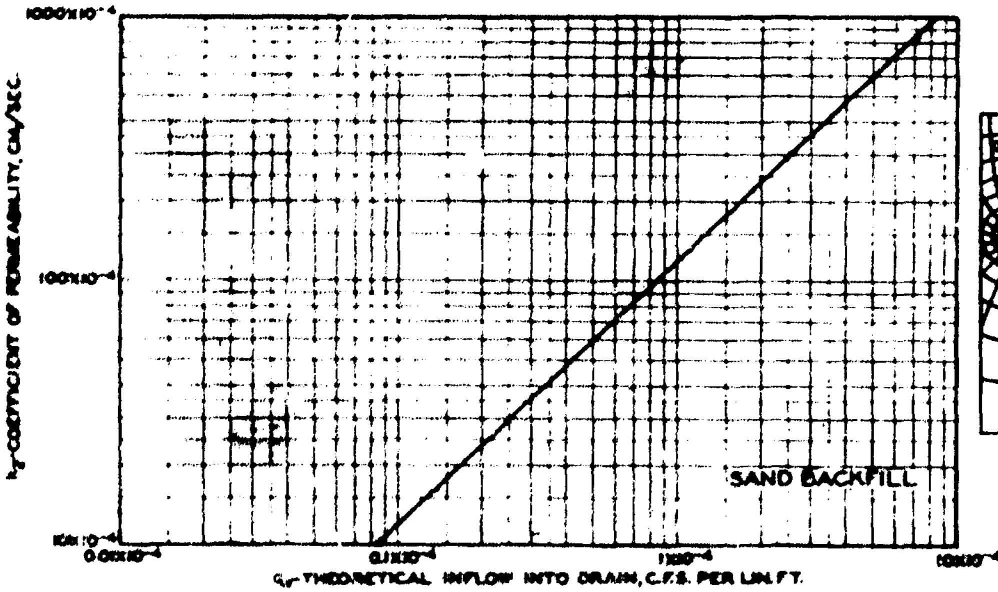

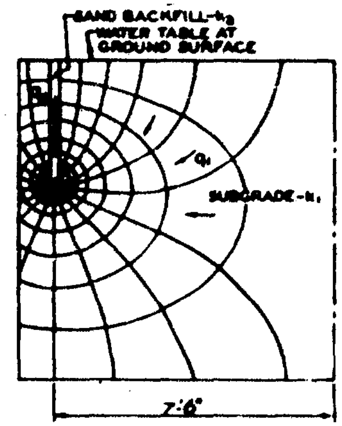

FLOW NET

CONDITIONS.

DRAINS SPACED 15'-0" C-C.
DEPTH OF DRAIN 3½ FEET.
WIDTH OF TRENCH [illegible] INCHES.
PERVIOUS LAYER 5½ FEET BELOW DRAIN WITH HYDROSTATIC HEAD AT GROUND SURFACE.
SHEET OF WATER MAINTAINED ON SURFACE BY RAINFALL.

MOLE DRAINAGE INVESTIGATION
1946-1947

DESIGN CURVES
2 INCH PLASTIC TUBING

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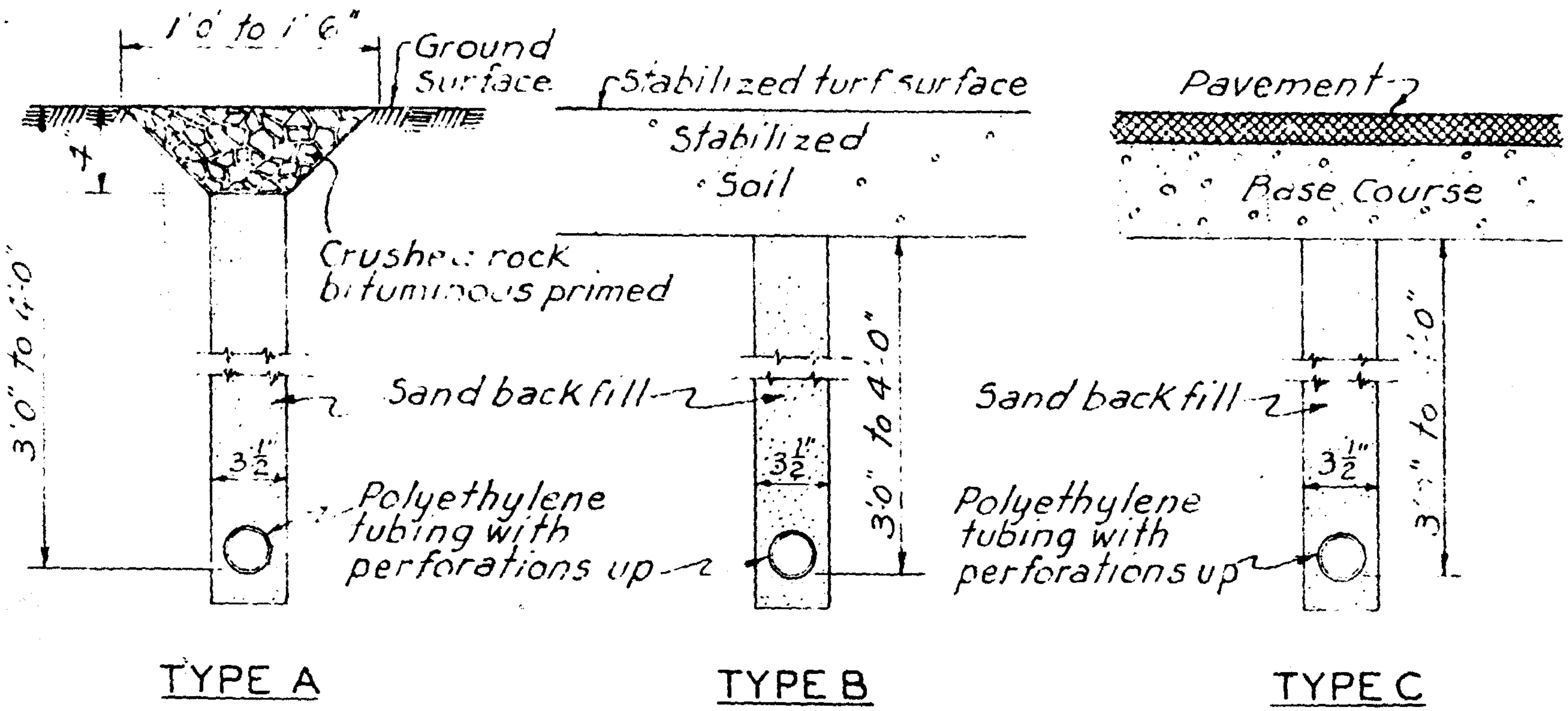

TYPE A — FOR DRAINING TURF SWALES AND FOR PREVENTING SURFACE PONDING

TYPE B — FOR DRAINING SUBGRADES OF TURF RUNWAYS AND SHOULDER AREAS

TYPE C — FOR DRAINING RUNWAY SUBGRADE AND BASE COURSE

MOLE DRAINAGE INVESTIGATION
1946 - 1947

TYPICAL SECTIONS 2 INCH PLASTIC TUBING

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