JACKED-IN-PLACE PIPE DRAINAGE

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SYNOPSIS

Control of internal soil stability is chiefly a matter of moisture control. Where the desired drainage is to be installed at a considerable depth below the top of an embankment or where disturbance of a developed surface is not desirable, the economy of introducing drain pipes by static or dynamic jacking should be considered. Jacking of pipes under railroad tracks and under heavy traffic highway pavements has become standard practice. The procedures have developed as an art with little or no attempt to compute expected loads or required installation forces. This report summarizes the practical development of installation methods and evaluates empirical and theoretical resistances which may be used as a guide to the design of jacked-in-place drainage and other pipe.

Pipes may be installed closed end when sufficiently large jacking pressures can be provided and when the soil displacement will not cause undesirable heave at the surface of the fills. Small size pipes, probably not exceeding 4 inches in diameter can be inserted by the vibratory impulses from an air driven jack-hammer. To introduce larger pipe into the soil without removal of the displaced soil requires too high static pressures and has no advantages. Up to about 36 inch diameters, open end pipes must be cleaned of displaced soil by either water jet, preferably combined with compressed air, or by augers, although 24 inch pipe has been installed with hand excavation. Larger pipes can be excavated by hand, with cable drag scoops or small wheelbarrows to remove the spoil. Static pressures are applied with jacks, both screw and pneumatic types are used, modified to provide long movement in each throw to reduce the time loss in re-blocking. The forward end of the pipe is usually reinforced by a cutting edge, and in soft ground is protected by a metal shield overhanging the pipe end. Proper back-pressure resistance must be provided to take the maximum jack pressure, in the form of anchored or braced sheeting in the approach pit, or by deeply inserted piles.

SMALL PIPE INSTALLATIONS

Boring. The simplest method for small pipes is to provide a horizontally bored hole by air driven earth borer. The Hydrauger Corp. of San Francisco lists three models of boring machines which are reported to be consistently straight boring for the underground distances up to 200 ft., at rates from 20 to 40 ft. per hour. Power is provided by air driven motors, using 90 lb. air pressure, and water under pressure clears the hole. Boring bar sections are 2 ft. in length, boring tools are 2 in. diameter and reamers up to 14½ in. diameter are available. Except in liquid soils there is little difficulty in preparing a hole for the insertion of a pipe. For such small diameters, the hole will not close up and there is no danger of excessive pressures on the pipe, so that minimum standard wall thickness, consistent with expected loss from corrosion, chemical and electrolytic, can be used (Fig. 1).

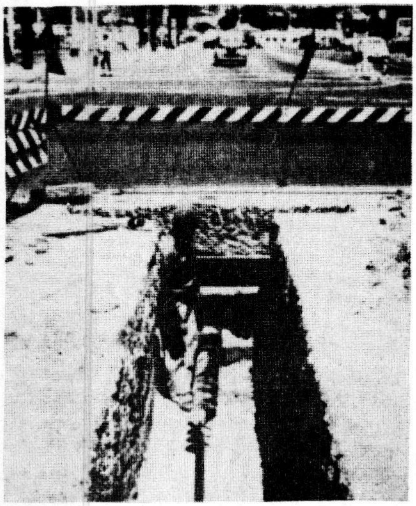

Figure 1. No Traffic Interruption

Vibrating Hammer. Closed end pipe, up to 2-in. diameter, can be inserted in natural or fill ground not containing boulders or rock fill with a standard air driven pavement breaker, using a special driving tool. The length which can be inserted is independent of the depth of cover since the radial pressure on the pipe is small. Careful alignment of hammer and pipe is necessary to prevent the pipe point travelling off line, especially when the amount of cover is small. The Atlantic Steel Co. of New York manufactures driving points and heads to fit from one to two inch pipe sizes, and driving shanks of 1-1/8 and 1-1/4 hexagon sizes to fit standard pavement breakers. The points are truncated cones with a base projecting slightly beyond the pipe. A universal joint is provided between the shank and the driving head to widen the driving range in tight working spaces. Driving speed of 25 ft. per hour in ordinary soils is claimed by manufacturers.

Jacking. Four 6-in. pipes were jacked through a railroad fill at a depth of 19 ft. in 1928, near Birmingham, Ala. Pipe was standard weight wrought iron, equipped with a forged steel point, 2 feet long, welded to a length of extra heavy pipe. Each pipe was pushed under 10 railroad tracks, for a distance of 200 ft. in 15 hours time. The jack was a hydraulic cylinder with 6 in. piston and 5 ft. 3 in. stroke, equipped with a motor driven hydraulic pump. Maximum pump pressure was 4500 lbs. per sq. in. but the usual pressure was 2000 lbs. To maintain proper alignment, about 15 ft. of pipe was held in the open approach trench between steel channel guides. (*1*)[1]

In San Diego, California, 100 ft. of gas main was laid in 1947 across a busy intersection by drilling through the sections of pipe with an auger drill, taking out 3 ft. bites of earth and jacking the pipe into the hole (*2*).

Fusion Piercing. In extremely hard ground, the process of "Fusion Piercing", patented by the Linde Air Products Co. can be employed to penetrate solid strata. The method was developed for reducing the cost and time of drilling blast holes in iron ore. A hole is made by burning a mixture of oxygen and a flux bearing fuel and directing the flame against the end of the cavity. The flame temperature of 4000 F. causes some rocks to spall and flake and others to melt. Pressure of the flame gases forces the flakes or molten material past a water spray. The sudden heat exchange further pulverizes the hot rock or soil and at the same time changes the water into steam under pres-

[1]Italicized figures in parentheses refer to list of references at the end of the paper.

sure within the restricted volume of the excavated hole. Such steam under pressure automatically cleans the hole of rock and soil chips. Six inch diameter holes 30 ft. deep were fusion pierced in a low grade abrasive iron ore at an average rate of 10 ft. per hr. In this type of material ordinary drilling speeds average 1 ft. per hr. Pipes inserted in holes so prepared have no exterior loads to carry, since the fusion of the annular volume around the hole solidifies the material to form, in effect, a structural tunnel which can transfer overburden and lateral loads into the undisturbed soil regions.

Water Jets Jacked. Horizontally driving of well pipes for water collection, a method developed by Leo Ranney of Ontario, Canada, can be used also as drainage pipe installations. At Canton, Ohio, 36 separate 8-in. pipes were jetted outward through the sides of a shaft, 12.5 ft. in diameter and 147.5 ft. deep. The maximum length of 8-in. screen pipe was 175 ft. Each slotted screen pipe was fitted with a hollow cast steel conical digging point having slots in the wall and connected to an interior 2-in. bleeder pipe. As the pipe was projected by hydraulic jacks, the displaced fine soil came through the screen pipe into the shaft; about 3 cu. ft. of sand was removed for each foot of pipe projected from the shaft (*3*).

A similar system was used to dewater the ground in the vicinity of the Brooklyn end of the Brooklyn-Battery vehicular tunnel in New York City. From the bottom of a vertical shaft, 11.5 ft. inside diameter and 70 feet deep, twelve 8 in. screen pipes, totalling 1100 lin. ft. were projected by hydraulic jacks. The digging head was bullet shaped with slots, connected to a 2 in. bleeder pipe to remove the displaced soil, flowing through the slots under hydrostatic pressure. The water table level was about 50 ft. above the pipes. To avoid excessive soil removal, fine screens filtered out all coarse particles which were displaced. The longest pipe projected was almost 200 ft. from the shaft (*4*).

Loads and Stresses. Where holes are prepared for the insertion of a pipe or conduit, whether by auger or fusion methods, no loads are immediately imposed on the pipe. With time, it is possible to have an internal soil readjustment which, from a vertical slip or a lateral squeeze, will impose pressure against the pipe. Since the methods are only applicable to small sized pipes, and the strength under the three edge bearing method of ASTM C-14, which probably duplicates the worst possible load application, is 1100 lb. per lin. ft. for 4- and 6-in. plain concrete pipe, no special investigation is necessary for loading stresses. The stresses of pipes installed by jetting or jacking are similar to those on large pipes, discussed in Section B6 below.

LARGE PIPE INSTALLATIONS

The method of jacking pipes under railroad fills to eliminate the disturbance to track and traffic from open cut trenching was started by the Northern Pacific R.R. prior to 1900. At first this method was limited to cast iron pipe, and soon became standard practice for several railroads. Corrugated iron pipe was first jacked in 1922; precast concrete pipe was first used in jacking operations in 1927. The smallest practical size is 30 in. and the largest size reported is a 96-in. reinforced concrete section used for a pedestrian underpass, and a 96-in.-8 ga. corr. iron culvert. There is a gap in size from 6- to

30-in., because excavation by methods other than hand shovel and and wheel barrow require special equipment. There is no justification for avoiding the sizes smaller than 30-in. because water jet excavation within a pipe can be performed under control without danger of slides and soil failures at the front of the pipe.

Concrete pipe installations are described at length in "Concrete Pipe Lines" 1942, by the American Concrete Pipe Association of Chicago. Some installations of concrete pipe by jacking methods with pertinent data are listed in Table 1.

TABLE 1

CONCRETE PIPE INSTALLATIONS BY JACKING METHOD

Item	Date	Pipe Size in.	Soil Cover ft.	Size of Jacks T.	Lengths Jacked ft.	Cutting Edge	Location
1.	1927	60	RR.	-	80	steel	Coraopolis, Pa.
2.	1930	72	12 & RR.	2-350	105	steel	Youngwood, Pa.
3.	1930	48	4 & RR.	2-screw	48	none	Rochester, N.Y.
4.	1930	42	16 & RR.	2-30 s.	76	none	Belleville, N.J.
5.	1931	30	RR.	2-250 h.	100	none	Quantico, Va.
6.	1931	36	RR.	2-250 h.	100	none	Quantico, Va.
7.	1931	60	RR.	2-250 h.	100	none	Quantico, Va.
8.	1931	66	RR.	2-250 h.	100	none	Quantico, Va.
9.	1931	60	45 & RR.	2-50	96	none	Stockholm, S.D.
10.	1932	84	3 & RR.	-	48	-	Hagerstown, Md.
11.	1932	36	8 & RR.	2-175 h.	40(stopped)	-	King Co., Wash.
12.	1935	60	4 & RR.	2-100 s.	52-32	steel	Rutland, Vt.
13.	1935	60	4 & RR.	2-100 s.	46(stopped)	steel	Rutland, Vt.
14.	1935	36	Street car	50 h.	-	steel	Buffalo, N.Y.
15.	1935	60	30 rock fill	2-100 s.	100	-	Winston-Salem, N.C.
16.	1936	60	slag dump	-	96	-	Rutland, Vt.
17.	1936	42	RR.	-	64	-	Rutland, Vt.
18.	1936	42	Highway	-	72	-	Rutland, Vt.
19.	1936	36	RR.	-	41 & 42	-	Rutland, Vt.
20.	1936	33	RR.	-	88	-	Rutland, Vt.
21.	1938	72	18 & RR.	-	96	none	Huff, N.D.
22.	1939	42	RR.	2-screw	75	-	Henrico Co., Va.
23.	1939	48	8 & RR.	2-75 s.	55	steel	Hammond, Ind.
24.	1939	48	RR.	2-100 air	70	steel	Hammond, Ind.
25.	1939	48	RR.	2-100 air	85	steel	Hammond, Ind.
26.	1939	48	RR.	2-100 air	60	steel	Hammond, Ind.
27.	1939	60	RR.	2-100 s. 4 @	100	steel	Charlotte, N.C.
28.	1939	60	RR.	2-100 s.	168	steel	Greenville, S.C.
29.	1940	96	15 & RR.	4-100 h.	69	steel	Elmira, N.Y.
30.	1942	54	14 & RR.	2-100 h.	148	steel	Warren, O.
31.	1946	48	5 & RR.	265 h.	75	steel	Chicago, Ill.
32.	1934	54		2-100	79	steel	Elwood, Pa.

Note: All of the above installations are described in "Concrete Pipe Lines", 1942, published by American Concrete Pipe Association, Chapter IV, p. 59-84, except items 11, refer. (5); 30, refer. (6); 31, refer. (7); and 32, refer. (18). Under the Size of Jacks, s. denotes screw and h. denotes hydraulic jacks.

Precast pipe used in jacking installations should be reinforced concrete culvert pipe (A.S.T.M. C76), preferably extra strength. The difference in cost between "extra-strength" and "standard strength" is small insurance for the expensive correction should a pipe section break from unequal jacking strains. Pipe lengths should be 4 ft. and where specially manufactured for the job, longer sections will expedite the work especially if the jacks have a run of more than 4 ft. Since the projections of the bells would greatly increase the soil resistance, pipe joints must not be of greater outside diameter than the pipe being jacked, even though the cutting edge may project beyond the pipe circumference.

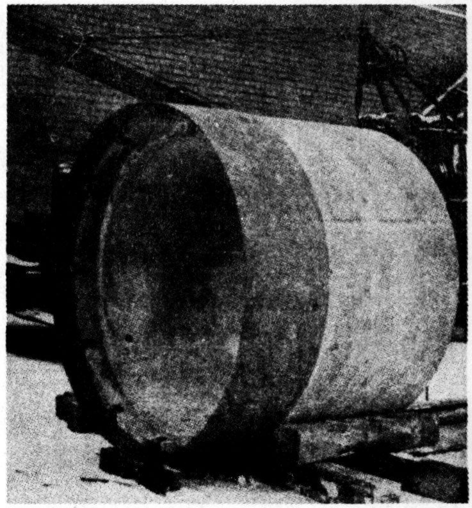

Figure 3. Full Ring Shield

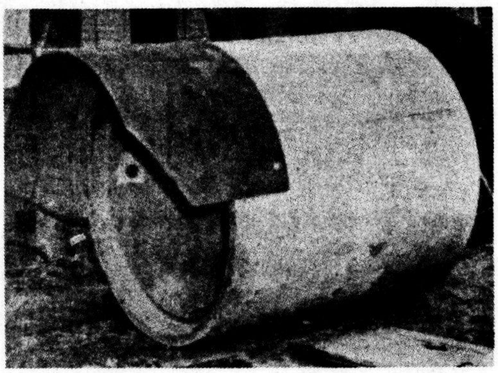

Figure 2. Part Shield

Steel pipe installations are all of corrugated or fluted plate shells, coupling short lengths together. Standard weight steel pipe can be used if the short lengths are either welded together, or for smaller sizes, connected by means of internal sleeves, such as are used for splicing steel shell piles. Some examples of steel pipe installations are listed in Table 2. Standard type Armco corrugated pipes were used, with flat slip plates sometimes covering the end of the leading section. In Item 7, the slip plates were corrugated sheets with ridges running parallel to the pipe axis, but a flat plate could have been used with the same result. In Item 1, the soil was a fine dry sand overlying hard yellow clay, both materials encountered in the heading. The fine sand ran into the corrugations and the joints between sections, causing the pipe to freeze at 26 ft. penetration. Operations were continued from the opposite end and the 100 Ton jacking pressure was sufficient to drive the 54 ft. needed for closure, where special precautions were taken to avoid sand runs into the pipe. Corrugated iron pipe is obtained in sections from 10 to 20 ft. long and provision must be made in the access pit for connection of sections by rivetting or welding to form a continuous compression unit.

Cast iron pipe was used in the earliest jacking installations, by the Northern Pacific R.R. prior to 1900, the Great Western R.R. in

TABLE 2

CORRUGATED IRON PIPE INSTALLATIONS BY JACKING METHOD

Item	Date	Pipe Size in.	Cover ft.	Size of Jacks T.	Lengths Jacked ft.	Location	Reference
1.	1927	60	-	2-50	26, 54	Dover, N. H.	(16)
2.	1929	60	7	2-25 track	80	Lorain, O.	(17)
3.	1930	3-36	5	screw	14, 15, 20	Crosby, Minn.	(8)
4.	1931	52	9	screw	32	Nashville, Tenn.	(15)
5.	1932	36	8	1-200 h.	118	King Co., Wash.	(5)
6.	1936	42	-	-	30-50 -(buckled)	Vermont	(9)
7.	1937	36	66	2-50 h.	210	Pittsburgh, Pa.	(10)
8.	1927	42	5	2-50 s.	4 @ 70	Buffalo, N. Y.	(19)(24)
9.	1927	12	15	1-35 h.	36	Imperial Co., Calif.	(20)
10.	1929	48	34	2-50 h.	126	San Diego, Calif.	(21)
11.	1926	60	30	2-50 s.	68	Plattsmouth, Nebr.	(22)
12.	1926	42	47	{2-50 s.	80	Varna, N. Y.	(23)
				{1-50 s.	25		
13.	1926	42	-	-	56	Claremore, Okla.	(22)
14.	1926	36	11	1-25 s.	40	Exeter, N. H.	(25)
15.	1927	36	-	1-50 s.	35	Sheridan Co., Kans.	(26)

See Table 1 for notation. References to installations are given under numbers in parentheses. Armco Drainage & Metal Products, Inc. report completion of 830 separate pipes totalling about 56,000 lin. ft., in the period 1922-1947, of corrugated metal pipe from 28 to 96 inches in size.

1911 and Southern Pacific R.R. in California in 1915. Credit is given to Mr. Augustus Griffin, now of Calgary, Alberta, for popularizing the jacking method of pipe installation below railroad tracks. Concrete and corrugated steel pipe have entirely replaced the use of cast iron because of the smaller approach pits necessary and the easier manipulation of the shorter lengths of pipe.

Excavation Methods. Pipes have been jacked in all types of soil, from liquid mud to rock fills. Excavation procedures are dependent upon the soils encountered. Generally drainage of ground water can be automatically provided by starting the pipe from the lower end and pumping from a sump in the access

Figure 4. Excavation at Heading

pit. In very wet areas, well points are used for lowering the ground water and may even be inserted in the heading for stiffening up running soil.

Hand excavation methods are limited to pipe installations of 30 in. and greater sizes. Short handled picks and shovels, not more than 18-in. long can be used to loosen hard soil. In tough clay soils, pneumatic spades cut the heading to proper shape. Boulders can be broken by air hammers or by applying heat and water. Oil torches have been used for this purpose.

The size of the excavation depends upon the soil type and the possible damage from loss of soil. In hard ground, excavations can be as tunnels 4 ft. or more ahead of the lead pipe and several inches larger in diameter, so that the jacking pressures required are low. To prevent the pipe from moving out of line or level, the excavation should be about one inch outside of the pipe at the top and sides, but the bottom must be cut neat. In soft ground, no cutting ahead of the lead pipe is possible, and in very large pipe jobs, timber bulkheads may be needed at the face to brace the heading and prevent cave-ins. In the 8 ft. installation (Item 29, Table 1), a louvre bulkhead was provided, permitting excavation at four different levels.

Excavation in wet and loose soils is difficult and de-watering methods are advisable. Where the ground is soft, or where, as under railroad tracks no loss or loosening of the soil cover can be permitted, a cutting shield should be extended from the lead pipe. The usual shield is a 3/8-in. steel sheet bent to the shape of the pipe and fastened by bolts or otherwise to the outside of the shell. Projection of the shield from 6 to 18 inches has been used in various installations. With a shield, the excavation must not encroach within the normal slope of the exposed soil, with the cutting edge of the shield fully buried. The shield need not extend lower than the mid-height of the pipe.

In plastic clays, even though there are no cave-ins, loss of ground from the expansion of the exposed heading may cause settlement of the supported track or roadway. In such soils a cutting edge is advisable and excavation should not be carried to the end of the lead pipe. Experience indicates that 18 inch unexcavated protection (for a 60 in. pipe) is sufficient to prevent loss of ground.

Pipe lines will not maintain proper alignment as excavation and jacking advance the heading unless proper precautions are taken. In granular soils, if the joints are not kept free of sand grains, the pipe will rise. In clay soils, a shield will keep the pipe in line. In the example listed as Item 2, Table 1, a steel bar 4 feet long was attached to the crown of the lead pipe to act as a guide into the soil and prevented deflection of the pipe from the desired line.

The approach pit excavation must be large enough to enclose a full length of pipe section, the jacks and their back-stops, together with working room for operation of the jacks and for connecting the pipe sections. The subgrade of the pit should provide a guide rail set-up on which the pipe section will rest and slide in the proper direction and desired slope (Fig. 5).

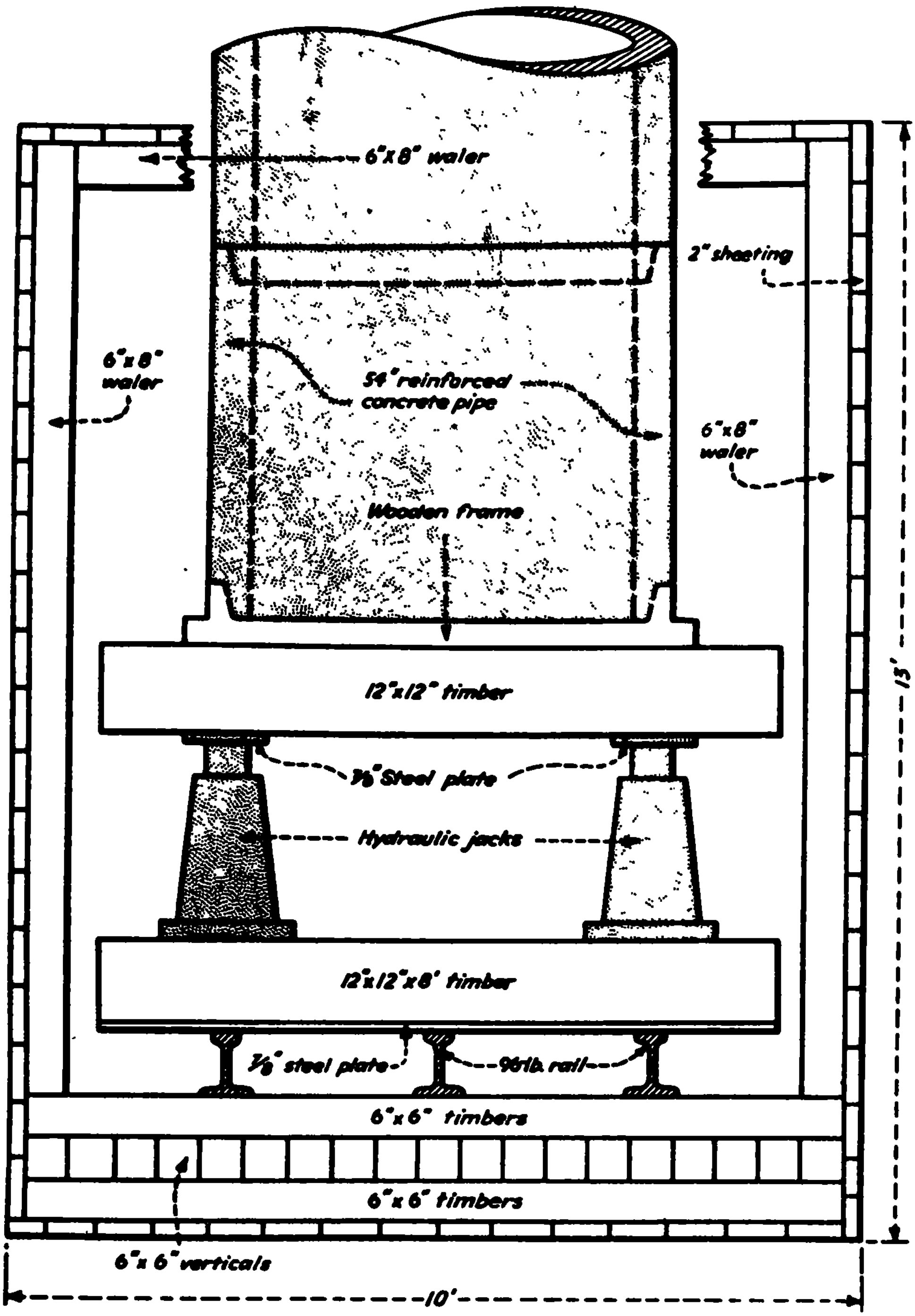

Figure 5. Typical Access Pit Set-up

Progress of pipe installation is dependent upon speed of excavation. In the Pittsburgh job (Item 7, Table 2) a 36-in. corrugated iron pipe progressed about 10 ft. per 3 shift day average during the 200 ft. of jacking. Similar progress rate is reported in the 36-in. corrugated iron pipe line 118 ft. long installed in King Co. Washington, in water-bearing clay and fine sand strata (Item 5, Table 2). In

Lorain, Ohio, a 60-in. Armco pipe in very compact clay was advanced 1.22 ft. per hour (Item 2, Table 2). In Hammond, Ind., work (Items 24, 25 and 26, Table 1) 48-in. concrete pipe was advanced from 14 to 17 ft. per 8 hr. day in water bearing sandy soil, with water table lowered by well-points, and no excavation allowed ahead of the lead pipe. Daily progress in completing 60 and 72-in. concrete pipe under railroad tracks (Items 21, 27 and 28, Table 1) varied from 5 to 7 ft. although the earlier recorded installations seemed to tend to continuous operation, to avoid "freezing of the pipe", the time interval between single shifts per day is not sufficient to allow an appreciable consolidation of the disturbed ground at the pipe surface, and no trouble has been found from the more economical single shift per day work schedule.

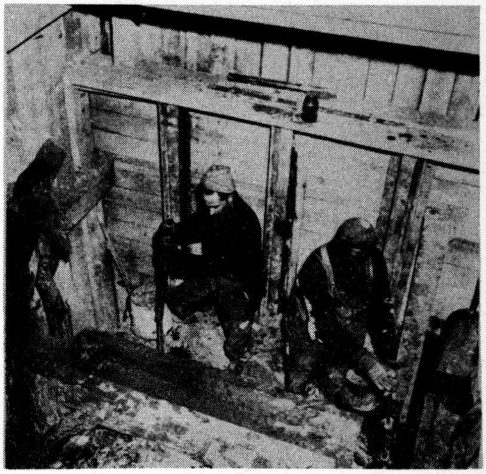

Figure 7. Access Pit Arrangement

Note: Fig. 6 from Armco Culvert Mfts. Co.
Figs. 1-2-3-4-5-7 from Eng. News-Record.

Jacking devices employed are screw jacks, ratchet jacks, air piston cylinders and hydraulic jacks. Only in a well made hydraulic jack can any record be made of acting pressures. The greater ease of operation and better control make it advisable to use hydraulic jacks exclusively.

The operation is an intermittent pushing of the pipe forward to the full stroke of the jack piston, retraction of the piston and insertion of blocking, then another push forward. The longer the jack stroke, the fewer stops in forward motion. The ideal set-up is to have a jack stroke somewhat longer than the pipe sections, so that no intermediate temporary blocking is required (Figs. 6 and 7).

Correction of alignment can be accomplished by eccentric pressure application, with single jacks. This is done by offsetting the con-

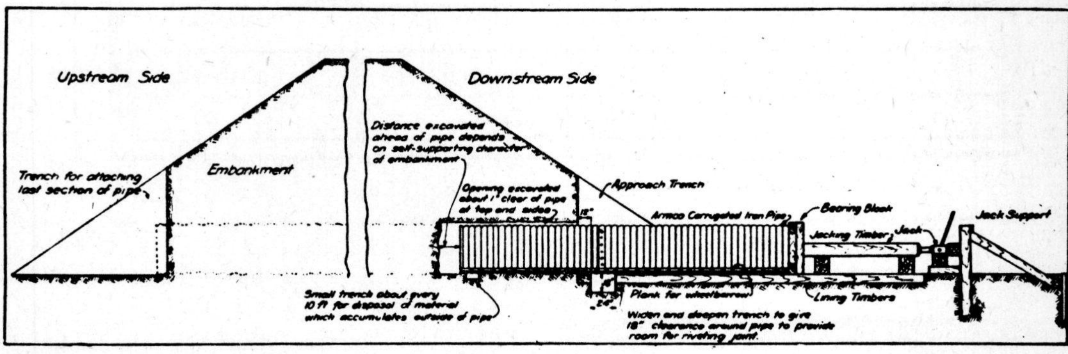

Figure 6. Diagram of Operation for "Armco" Pipe

tact between jack and jacking frame. With multiple jacks, the eccentricity can be applied by varying individual jack pressures, without changing the set-up of equipment. Another advantage of multiple jacks is the possibility of "rocking" the pipe to reduce surface friction, by working the jacks separately for short periods (*11*).

The frame distributing jack pressure into the pipe should be designed to transmit the maximum jack force into the pipe without too much deflection, which would mean a loss in jack extension, and with fairly uniform load application on the full perimeter of the pipe. A wood ring frame to fit the groove of the pipe section, with grillage beams for taking the jack concentrations is found most suitable.

Sufficient passive soil resistance must be developed for the reaction of the jacks. This is usually accomplished by tight sheeting at the back of the access pit, with vertical beam or rail framework, against which the jacking support rests. Where no access pit is required, a backstop of timbers, often railroad ties is set into the ground, with a diagonal support for the top reacting against imbedded anchorages. The amount of resistance to be used should be half of the maximum passive soil resistance on the imbedded sheeting area, to avoid excessive deflections and movements into the soil. Resistance of various types of soil and the resisting value of imbedded anchors and piles are summarized in Proceedings Highway Research Board, 1943, p. 403 (*12*).

An unusual type of resistance was devised at the Quantico, Va. installation of four concrete pipes running through a railroad fill located in tidal swamp lands (Items 5, 6, 7 and 8, Table 1). Four 2-in. iron pipes were first pushed through the fills at each installation, so located that they are outside of the pipe diameter. Cables were threaded through the pipes, anchored to a timber bulkhead at the far end and tied to a timber backstop against which 2-250 Ton hydraulic jacks reacted.

Loads and Stresses which must be considered in a jacking installation depend on the type of soil and the method of operation. The earth load carried by a pipe during installation is probably less than the load after the disturbed soil volume has consolidated. The amount of jacking pressure required to overcome frictional resistance is also dependent upon the type of soil and the method of operation, as well as the length of pipe imbedded. There are a number of cases which must be separately considered.

Case A. Open end pipe jacked through a bore excavated ahead of the pipe.
Case B. Open end pipe jacked into the soil with excavation inside the pipe only.
Case C. Closed end pipe jacked through the soil without any excavation.

Little empirical data is available to check theoretical analysis of any of these cases. Where the amount of jacking pressure at any stated conditions is known, the total radial earth pressure on the pipe can be computed, if the weight of the pipe and the coefficient of friction between pipe and soil, and the coefficient of internal friction of the soil have been recorded. Some idea of the range of probable values can also be obtained from the pulling resistance of piles and from the recorded data on shield tunnel jacking pressures.

The penetration of a pipe laterally into the ground is a somewhat different case than the introduction of a pipe vertically into the ground. The frictional resistances, however, are similar, even though in the former case the internal stress of the soil penetrated, prior to the disturbance, is fairly constant, because both are problems in viscous flow. In viscous or linear flow, displacements result from shearing forces acting over a time interval. The frictional resistance of the soil is then

(1) independent of the external loads on the surface of failure.
(2) equal to zero if the velocity is zero and is directly proportional to the velocity of relative displacements along the surface of failure.
(3) proportional to the area of the surfaces in contact.

The determination of bending stresses in the pipe during installation is not necessary, since the loadings are much more uniform than under the worst possible static loading after the surrounding soil has consolidated around the complete pipe. The pipe strength as a column must be investigated, although experience shows that the adjacent soil, even if the pipe is being pushed into a pre-excavated tunnel, provides sufficient lateral support to prevent buckling.

Case-A. The amount of jacking pressure required for any set of conditions can only be approximated. In Case A, the only resistance is along the outside of the imbedded pipe and that can act only where the soil is in contact with the pipe. Where the ground penetrated has sufficient internal shear resistance to permit the excavation of an unlined tunnel without tension failure and falling down of the overhanging material above the tunnel and without lateral squeeze at the sides, the only starting resistance to be overcome is the frictional component of the pipe weight resting on the bottom of the excavation. Krynine in 1945 analyzed the internal soil conditions which are necessary for such behaviour (*13*). Light weight corrugated iron pipe requires less jacking force than concrete pipe, where the soil can be put into a self-sustaining tunnel, because of smaller contact surface with the soil. This excavation procedure must not be allowed where any lateral soil movement to fill the voids along the perimeter will cause settlement of track or pavement at the top of the fill, and, of course, is especially dangerous in shallow fills.

In four examples of Case A installations, there are enough recorded data to evaluate the surface resistance:

(1) Item 7, Table 2, a 36-in. corrugated pipe penetrated 210 ft. in a compacted earth fill 66 ft. deep, with only 100 Ton jack pressure available. If all the pressure was used, and the entire perimeter were in contact with the soil, the resistance was 101 lbs. per sq. ft. of pipe surface.
(2) Item 5, Table 2, a 36-in. corrugated metal pipe penetrated 117 ft. in wet clay and mostly running sand, with a 8 ft. cover under railroad tracks. During the first 60 ft. jacking at the rate of less than one foot per hour, pressure increased uniformly to a 20 Ton Value, or 50 lb. per sq. ft. of the exterior pipe surface. Rate of progress for the rest of the job was increased to 1-1/2 ft. per hour. The jacking pressure still increased uniformly with distance, but at the rate of 0.5 tons per ft. penetration, or 106 lb. per sq. ft.

resistance.

(3) Item 30, Table 1, a 54-in. concrete pipe with 5-1/2-in. wall thickness penetrated 148 ft. in a dry clay soil with a large percentage of gravel, 14 ft. deep, with an actual maximum jack pressure of 1,60 Tons. If the entire pipe perimeter were in contact with the soil, the resistance was 127 lb. per sq. ft. of pipe surface.

(4) Item 9, Table 1, a 72-in. concrete pipe with 7-in. wall thickness penetrated 96 ft. in compacted dry black loam and clay, a maximum of 45 ft. cover, with only 100 Ton jack pressure available. If all the jack pressure was used, and the entire pipe perimeter was in contact with the soil, the resistance was 92 lb. per sq. ft. of pipe surface.

In installation of Case A type, it would seem to be sufficient to expect a jack pressure requirement of 100 lb. per sq. ft. of total soil imbedment of the pipe perimeter, with provisions for about 25 percent overload. The actual resistance per sq. ft. of contact is probably three times this value, but contact over more than 1/3 of the surface is not possible in Case A.

After completion, the soil will eventually come into intimate contact with the pipe over its entire length. In the type of soils where Case-A method can be used, the probability of load first coming on the roof of the pipe is great. This will be equivalent to the loading known as "Minnesota Bearing" in the laboratory tests of pipes. Spangler (*14*) evaluates this loading as 1.37 times the severity of the sand bearing test and 0.91 as severe as the three-edge bearing test. The comparable pipe bedding condition for the most favorable result after soil consolidation above the pipe is what Spangler calls "First Class", ditch bedding, (*14*), but there is the possibility of the more severe loading, especially if rigid pipe is used. A maximum load, lb. per ft. of pipe, of 400 d^2, where d ft. is the outside diameter, seems to be a reasonable value for the necessary strength of the pipe.

Case-B. In Case B, in addition to the friction along the outside of the imbedded pipe length, there is the force necessary to squeeze out the soil immediately in front of the wall thickness of the lead pipe. A shield or cutting edge reduces the letter resistance by separating the soil to be placed into (1) an annular ring under compression, and (2) interior soil in motion towards the excavation bounded on the outside by the steel cutting plate. The stress conditions in this case, after completion, are substantially identical to those in a shield driven tunnel, where no compressed air is used and the excavation is 100 percent of the tunnel section. During installation, the jacking pressure for a shield from 16 to 20 long advanced 20 to 30 inches is not comparable with the case of a pipe, 100 ft. or more in length, being moved bodily. The soil immediately adjacent to the pipe circumference is in viscous motion, during the jacking operation, and the shear resistance of the soil is independent of the depth of the cover, and is a direct function of the area of imbedded pipe and of the velocity of propulsion. The effect of vibration, from traffic at the surface of the fill, is to reduce the viscosity of the soil in motion, and therefore reduce the necessary jacking pressure. This result was noted in several of the installation records. Another favorable factor often mentioned is the surprisingly small load required to start the pipe moving again, at the beginning of the shift, and the lack of "freezing" over night. The explanation is, of course, the low velocity of motion at the resumption of work.

In two examples of Class B type, the actual jacking pressures required were measured and recorded:

(1) Item 29, Table 1, a 96-in. concrete pipe with 9-in. wall thickness penetrated 69 ft. with jacking pressures increasing almost exactly with length of imbedment at the rate of 4.5 tons per lin. ft., in a miscellaneous fill 6 ft. deep and under a series of railroad tracks. The resistance at the pipe surface in contact with the soil was 300 lb. per sq. ft.

(2) Item 31, Table 1, a 48-in. concrete pipe with a 5-in. wall thickness penetrated 75 ft. in fine sand and some gravel, drained by well points, with 5.5 ft. cover under a series of railroad tracks. At 55 ft. imbedment, the jacking pressure was 127 tons, or 300 lb. per sq. ft.; at 75 ft. the jacking pressure was 185 tons, or 325 lb. per sq. ft. Necessary pressure to maintain forward motion decreased as trains passed over the site, and the pressure necessary to start motion after a period of stoppage, was less than that required to maintain constant forward movement.

The jacking pressure capacity for a shield driven tunnel, where forward shield motion is about 2 inches per minute, is from 3 to 4 tons per sq. ft. of shield perimeter surface, although actual pressures required are only a part of the capacity. The problem differs from that of pipe jacking because of the tunnel face resistance developed by the rigid shield pressing against the outside soil, and the stiffening up of the subaqueous silt, sand or clay by the constant leaching of the compressed air through the face of the shield. Rate of progress during jacking is at least ten times as fast as the normal pipe operations.

Jacking pressure for a Case-B pipe installation should be provided to allow from 300 to 350 lb. per sq. ft. of imbedded surface. This value is substantially equal to the ultimate resistance of average type clay and silt soils.

After completion, the pressure on the imbedded pipe, with the outside surface in intimate contact with the soil on the entire perimeter, is less than in the most favorable ditch condition analysed theoretically and experimentally by Spangler, (*14*), so that the standard reinforced concrete or steel drainage pipes can be safely used.

Case-C. Pipes introduced with closed ends by either static or dynamic loads are similar to piles being jacked or driven horizontally. Considerable resistance to penetration can be eliminated with water jets, although normal conditions will not require such aid. The closed end pipe must be pushed by a force larger than the frictional resistance acting on the surface of the entire length of imbedded pipe plus the force necessary to squeeze the displaced soil into the adjacent volumes. The frictional resistance to overcome can be reduced, during the driving period, by adding an oversized cutting ring at the forward end of the pipe; but, of course, this increases the volume of soil to be displaced. Tests with vertical piles and undermined caissons indicate that the frictional resistance on such vertical structures is of the order of 600 lb. per sq. ft. of imbedded surface. For horizontally imbedded pipes, a similar value should be expected, except at large depths. The 6-in. lines noted above required a maximum force to overcome a frictional resistance of 405 lb. per sq. ft. of embedded surface, if the displacement factor is disregarded. It would therefore seem sufficient, in planning this type of jacking, to provide equipment and back-stop resistance equal to 600 lb. per sq. ft. of maximum imbedded surface.

Costs. The cost of installing pipes below railroad tracks or developed pavements carrying considerable traffic volume by the jacking method is less than the cost of open cut methods when the backfilling and restoration are included, even if no allowance is made for delay and inconvenience of traffic. Actual costs reported in several of the installations listed in the tables were:

Table 1, Item 16, 60-in. concrete pipe, 96 ft. long in a slag dump fill, $25.55 per lin. ft. total cost (1936).

Table 1, Item 12 and 13, 60-in. concrete pipe, 84 and 88 ft. long, $25.98 per lin. ft. total cost (1935).

Table 2, Item 2, 60-in. Armco pipe, 80 ft. long with 7 ft. cover, showed a labor cost of $5.20 per lin. ft. (1929), and Item 10, 48-in. Armco pipe, 126 ft. long with 34 ft. cover also shows a labor cost of $5.00 per lin. ft. (1929).

Table 1, Item 30, 54-in. concrete pipe, 148 ft. long, showed a labor cost of $4.31 per lin. ft. (1942).

Table 2, Item 5, 36-in. corrugated pipe, 200 ft. long and 66 ft. deep, $24.50 per lin. ft. total cost, half of which was for direct labor in jacking and excavation (1937).

Table 1, Item 32, 54-in. concrete pipe 79 ft. long, in good soil fill, $18.45 per lin. ft. total cost (1934).

CONCLUSION

The procedure of jacking pipe for drainage connections and as sleeves to carry sewer, water, gas or electrical utilities across heavily travelled roadways and through high fills has been developed to a point where costs and construction requirements can be closely approximated. The method should be carefully considered before cutting through an important highway because it will eliminate traffic hazards, delay and accidents so common in the vicinity of detours and construction operations.

REFERENCES

1. Eng. N-R., June 14, 1928, p. 45, M.P. Mellon: "Pipe Lines Jacked for 200 ft. through Railroad Fill".
2. Eng. N-R., Aug. 14, 1947, p. 8, "No Traffic Interruption".
3. Eng. N-R., Jan. 6, 1938, p. 25, C.M. Maratta: "Industry Taps an Underground Lake".
4. Eng. N-R., Apr. 20, 1944, p. 94, Ross Nebolise: "Ground Dewatering for Construction".
5. Engr. & Contr. Sept. 1932, p. 209, "Pressures Required for Jacking Corrugated Iron Pipe are Registered".
6. Eng. N-R., July 2, 1942, p. 74, W.S. Harvey: "Jacking a Sewer Under a Railroad".
7. Eng. N-R., Sept. 5, 1946, p. 87, "Concrete Pipe Jacked Under a Railroad".
8. Engr. & Contr. June 1931, p. 151, Holman I. Pearl: "Jacking Conduit Saves Closing Main Thoroughfare".
9. "Concrete Pipe Lines", 1942, American Concrete Pipe Assn. Chicago, p. 67, letter from Edward L. Tracy.
10. Eng. N-R., Dec. 2, 1937, p. 904, John Scotzin: "Long Culvert Built by Jacking".
11. Eng. N-R., May 30, 1946, p. 64, J.B. Hoffmier: "Concrete Pipe Sections Jacked Vertically Provide Machinery Foundations".
12. Proc. Highway Research Board, 1943, p. 403, Jacob Feld: "Abutments for Small Highway Bridges",

part A. Forces and Resistances.
13. Proc. Highway Research Board, 1945, p. 413, D.P. Krynine: "Transfer of Earth Pressure by Shearing Stresses".
14. Proc. Am. Soc. C.E., 1947, p. 873, M.G. Spangler: "Underground Conduits - an Appraisal of Modern Research".
15. Public Works, June 1931, p. 51, F. Beazley: "Jacking a Storm Sewer Under a Busy Street in Nashville".
16. Public Works, Dec. 1931, p. 24, W.S. Wheeler: "Sewer Construction Through Embankment and Soft Ground".
17. Engr. & Contr., June 1929, p. 253, C.C. Miller: "Installing a Sewer Under a Busy Street without Interrupting Traffic".
18. Public Works, Nov. 1936, p. 16, L.W. Monroe: "Jacking 54 inch Concrete Pipe 79 feet under Railway Tracks".
19. Eng. N-R., June 9, 1927, p. 953, O.F. Flumerfelt: "Jacking Culvert Casing under Railroad Tracks".
20. Engr. & Contr., Mar. 1927, p. 143: "Jacking Culvert under Road".
21. Eng. N-R., Oct. 24, 1929, p. 663, W.M. Angas: "Cost of Jacking Culvert Through Fill".
22. Railway Engr. & Maint., Mar. 1926, W.C. Swartout: "Jacking Culvert through Embankments".
23. Railway Engr. & Maint., May 1926, E.J. Cullen: "Culvert Pipe 105 ft. long is Jacked through 47 ft. Fill".
24. Gas Age Record, May 1927, O.F. Flumerfelt: "Installing 42 in. Culvert Casing under R.R. Tracks".
25. Eng. & Contr., Oct. 1927, H.C. Archibald: "Culvert Installation by Jacking".
26. Highway Mag., Feb. 1928, A.J. Mowry: "Jacking a Culvert under Traffic".

DISCUSSION

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In practice the concrete pipe manufacturer finds that the use of heavier jacks rather than lighter jacks facilitates the jacking process greatly because of the added speed of operation. In general, in jacking concrete pipes in sizes 36 inches and over, the contractor likes to use two 100 ton hydraulic jacks irrespective of the exact jacking pressures needed.

Of practical importance in maintaining the grade is care in starting the process. This can be facilitated by constructing a timber saddle at the start, long enough to hold two lengths of pipe which are set at grade before the jacking starts. In excavating inside the pipe as the process proceeds it is generally helpful to excavate about an inch outside the outside diameter of the pipe at the top, leaving about an inch of material in the bottom higher than the finished gradient.

The smallest concrete pipe jacking operation on our records is the 18-inch reinforced concrete pipe at West Memphis, Arkansas, and in this case excavation was accomplished by using a 15-inch post hole digger.

The largest concrete pipe jacking operation on our records is the 96-inch Pedestrian Underpass under the R. F. & P. Railroad at the Potomac Yards near Alexandria, Virginia. The top of this concrete pipe is only 2½ feet below the base of rail subjected to extremely heavy traffic.

Since receiving the original