STATE OF MINNESOTA
DEPARTMENT OF HIGHWAYS

in cooperation with

U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS *and*
MINNESOTA LOCAL ROAD RESEARCH BOARD

BACKFILLING TRENCH EXCAVATIONS

INVESTIGATION NO. 610
PROGRESS REPORT 1962

MATERIALS AND RESEARCH SECTION

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Progress Report - 1962

by

MATERIALS AND RESEARCH SECTION

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SYNOPSIS

Engineers who are associated with trenching in public thoroughfares have been striving for many years to find better construction methods and procedures for backfilling these trenches. We cannot expect the public to tolerate detrimental settlement if it can be avoided with a reasonable expenditure of funds.

In this study the presently used procedures of backfilling and compaction were observed. It was found that these procedures can definitely be improved. The major conclusions which can be drawn from the study are listed below.

The layered system is the most reliable compaction procedure for limiting settlement to a minimum. With one compactor type, the Hydra-Hammer, the entire trench backfill can be compacted in one lift irrespective of soil type or traffic volume on the street.

Adequate stability, to prevent detrimental settlement, can be attained with many compactor types if the lift height is adjusted to soil type and condition, and the trench loading conditions. All vibratory type trench compactors should be used strictly on the granular soils and the lift height must be chosen with respect to the particular compactor and the traffic volume. The Pneumatic Button Head compactor can effectively compact all soil types in lifts up to 0.5 feet in thickness. The Plate Tampers are excellent compactors for all soil types and they are capable of compacting soil lifts between 1.0 and 1.5 feet depending upon the traffic load. Heavy construction equipment should be used to compact only the upper lift in a trench and this lift should be restricted to the range of 1.0 to 2.5 feet in thickness depending upon the soil type and the traffic load.

Further research under more controlled field conditions is planned for 1963.

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Investigation No. 610

BACKFILLING TRENCH EXCAVATIONS

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BACKFILLING TRENCH EXCAVATIONS

INTRODUCTION

This study was undertaken to determine the proper construction procedures and equipment for backfilling trench excavations on urban streets. Many utility trenches settle after filling and reduce the serviceability of the road as well as creating an expensive maintenance problem. These settlements are an obvious evidence of instability of the soil backfill and can usually be traced to inadequate or non-uniform compaction. The study was mainly based upon observations of typical construction jobs. Little control existed over the several variables which affect the stability of the completed backfill. This report elaborates on the analysis of data and the observations made at 29 trenches and facts regarding the effectiveness of several compactors studied at 12 test points.

This report includes: a discussion of the theoretical aspects of soil compaction and settlement; recommendations for street preparation, excavation, backfilling and street patching; observation of backfill and compaction procedures and resulting trench settlement; a literature study; and a review of several State Highway Department specifications.

Field observations were limited to "slit type" trenches as opposed to the wide sloping-sided trenches. Compaction stabilization of confined area soils has not been studied as intensively as compaction of large masses of soil.

A great number of services require trenching for their placement. The ever expanding list now includes: sanitary and storm sewers, electrical and telephone cables, water and gas lines, runoff culverts, and oil pipe-lines.

Since the public has already experienced the inconvenience of traffic impairment at the time of trenching, it should not be expected to tolerate a repeat from avoidable settlements such as pictured in Figure 1.

The cost of this project was financed under the Highway Planning Research Program with Federal Aid funds of the U. S. Bureau of Public Roads, with State funds, and with County and Municipal State Aid funds.

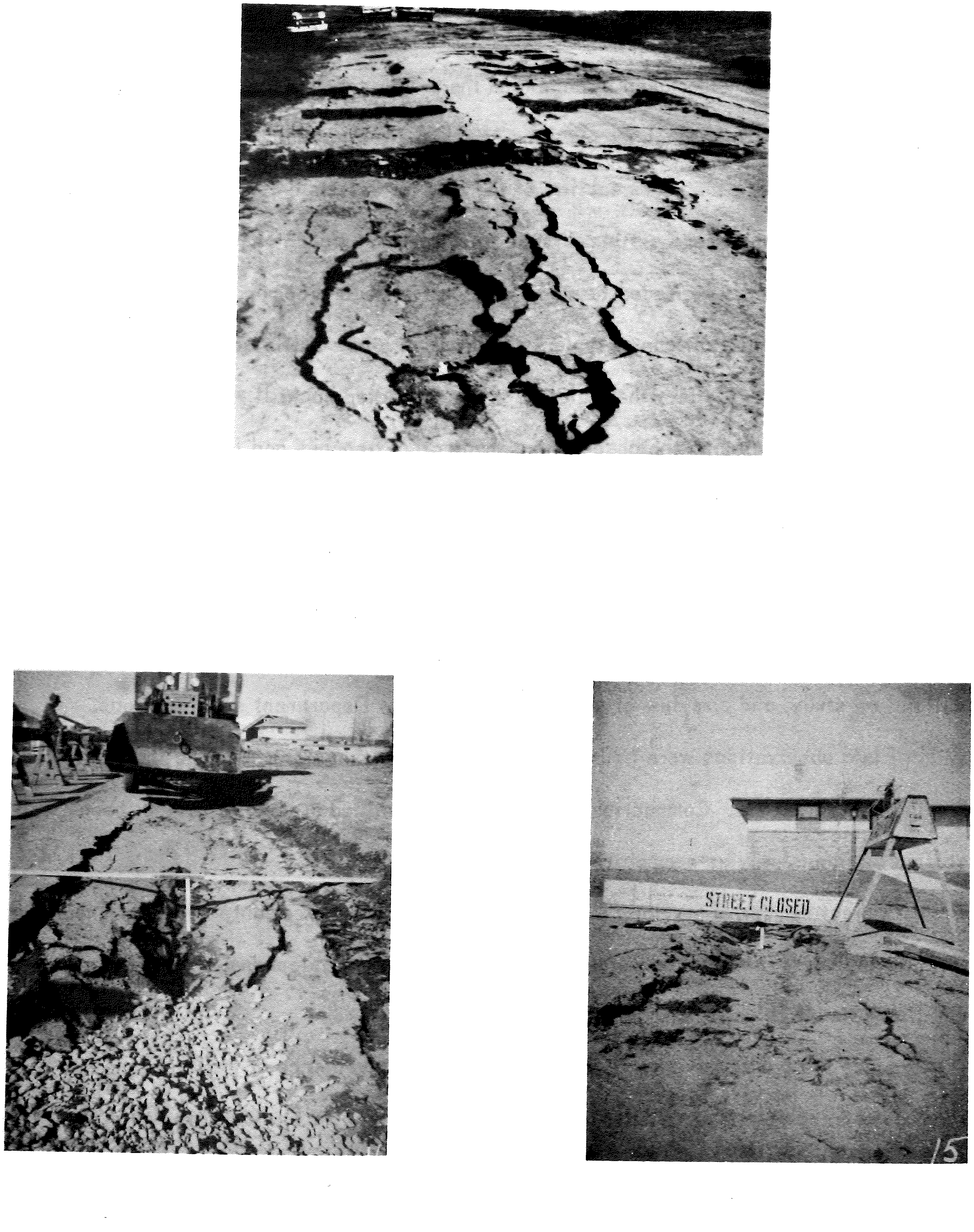

Figure 1. Detrimental Settlements in City Streets

THEORETICAL ASPECTS OF SETTLEMENT AND SOIL COMPACTION

Settlement

Settlement in general is the result of the soil's inability to support its own overburden but is also influenced by side wall friction, surface loading and other minor factors.

Settlement may be minimized by compacting the soil column to high stability. Trenches cut as narrow as possible will have the lowest possible backfill weight and the friction-developing wall area will be identical to a wide trench of the same depth.

The process of natural settlement is accelerated by surface loading of traffic and its impact action. The relative density of a backfill in a heavily traveled truck route should be greater than a backfill in a purely residential street and experience in Minnesota suggests a factor of 5 to 10% would be adequate.

Compaction of Sands

Vibration has been found to be effective in compacting clean sands. The natural friction developed between sand particles is overcome when they are separated by vibration. Vibration compactors tend to be effective in sands to greater depth than other compactors.

The small pad type vibrators normally used in narrow trenches are incapable of compacting sand to any appreciable depth. The sand is not effectively confined by the light weight compactor below a few inches from the compaction face.

The vibratory roller, by contrast, employs a large static weight. Each revolution of the eccentric causes the vertical force to vary from static plus dynamic to static minus dynamic. This large force change causes deep-seated vibration. This effect, coupled with the large confining weight of the compactor, brings about both particle movement and consequent compaction.

When granular soils are jetted for compaction, the downward flow of the water causes some rearrangement of the particles. However, further consolidation will occur under traffic impact or ground vibration from industrial installations. These saturated and loosely compacted materials should be further compacted by vibratory rollers or pads during backfilling operations.

Compaction of Plastic Soils

Plastic soils in confined areas such as trenches can be effectively compacted only in shallow lifts and only by the use of large static weight compactors or those of the impact type.

One typical simple specification calls for soil compaction to a density equal to that of the adjacent undisturbed soil. This "end product" specification requires close trench head supervision and periodic density testing of both the undisturbed and the compacted soil. Heavy clayey soils compacted to the density of the adjacent soils do not necessarily have equal stability. This effect of lesser strength following particle rearrangement and compaction is called sensitivity or thixotropy. After some period of adjustment these sensitive soils will attain the stability of the adjacent undisturbed soil. Some settlement may occur during this adjustment period.

Vibration compaction of plastic soils has not been perfected at this time and should be avoided.

Puddling and jetting of clayey backfills are equally ineffective. Much obvious settlement occurs during these compaction processes, but the unstable soil condition caused by these systems brings about additional long term settlement.

GENERAL RECOMMENDATIONS FOR TRENCHING AND STREET RESTORATION

Trenching in a public thoroughfare necessitates proper street restoration following the backfilling and compaction. The surface should be restored immediately and finally to its original riding quality. The following recommendations are presented for street preparation before and during excavation, backfilling and patching the street surface. These recommendations are taken from the specification of the Minnesota Highway Department and numerous other agencies. The literature study and field observations made for this study provided many valuable recommendations. Some parts of the specifications currently used by the cities of Austin, St. Cloud, Fergus Falls and Duluth, Minnesota have been included.

Street Preparation Before Excavation

Trenches cut through surfaces of portland cement concrete and heavy-design asphaltic concrete should be preceeded by outlining the area with a shallow saw cut of approximately 1/3 the depth of the surfacing or by full depth drill holes at short spacing. The remaining area can then be broken out with any available pavement breaker. This procedure will produce a reasonable straight break line and provide enough rough vertical surface so that adequate aggregate interlock is assured when the surface is restored. Thin flexible pavements can be cut with a scoring tool or by a carefully used pavement breaker in order to accomplish outlining of the area to be trenched.

Excavation

The trench should be cut as narrow as practicable to minimize the amount of material to be moved and re-compacted. Constructing a wider trench than necessary increases the load on the service structure, increases the possibility of future settlement and increases the cost of compaction. The materials excavated (surfacing, base and subsoil) should be piled separately so that they can be replaced in their respective positions. The cost of replacing the base with new material may be avoided in this way.

Backfilling-Soils

Soil selected from the excavated stockpile for backfilling should be returned to the trench free of large rocks, wood, rubbish and frozen lumps. Rocks larger than three inches in diameter should be eliminated from the material used in the immediate vicinity of any pipes.

When some natural soil must be wasted, an outside supply of soil is required. This source should be chosen carefully so that the backfilled soil and natural soil are similar. Where possible, the borrow soil should be placed below the frost line and the salvaged natural soil above it so that the characteristics of frost heave, soil swell and shrinkage are similar in the trench and undisturbed adjacent areas.

A number of cities have partially solved their problems associated with small intermittent trenches (discontinuous, individual holes spaced at five to six feet) cut in the winter months. They have determined the soil type or types within the city limits and have stockpiled some of each of the soils indoors. Where frozen clods are encountered the appropriate stockpiled soil is substituted. This procedure has been used very successfully when proper compaction is applied.

If it is discovered that the soil has a moisture content different from that required for good compaction, the soil should be moistened or dried as required before backfilling. The determination of the soil moisture content required for maximum compaction should not be left to a field guess. The fairly simple moisture-density test should be performed to determine the Optimum Moisture.

Backfilling-Compaction

A stable trench backfill can be produced by compacting the soil to a density which will prevent settlement under the anticipated loading conditions. Layered construction is the only practical method of obtaining uniformly high compaction throughout the backfill. The compaction equipment to be used should be chosen with care since many of the individual types of equipment are suitable for use only with specific soils. Field calibration (determination of the number of passes or blows required for the chosen compaction) of a compactor with a particular soil should become the rule so that overcompaction and undercompaction can be avoided.

Adequate stability to prevent detrimental settlement or displacement can be attained with many compactor types if the lift height is adjusted to soil type. The tabulation below, based on this limited study, shows the lift heights that can be effectively compacted by the equipment studied.

TABLE I

SUGGESTED MAXIMUM LOOSE SOIL LIFT HEIGHT (FT.)

	Sands		Plastic Soils	
Compactor Type	High Traffic Volume	Low Traffic Volume	High Traffic Volume	Low Traffic Volume
Hydra-Hammer	8.0	8.0	8.0	8.0
Vibratory Roller	2.0-3.0*	6.0*	**	**
Plate Vibrator	0.75	1.0	**	**
Button Head Pneumatic	0.5	0.5+	0.5	0.5+
Plate Tamper	1.0	1.5	1.0+	1.5
Construction Equipment Traffic	1.5	2.5	1.0-	1.0+

**The study data do not clearly show these values but we feel they are reasonable.*
***Do not use this compactor with this condition.*

Patching the Surface

One phase of the procedure which is often neglected is the final patching of the surface. Personnel who perform the trenching, placement of the service and backfilling should be properly trained in placing the surfacing material. The finished patch should always conform to the existing grade and crown of the street.

Four excellent references for patching concrete and bituminous roadway surfacings are: "Patching Pavements Properly", by G. E. Martin[J]; "Maintenance Practices for Concrete Pavements", Portland Cement Association[E]; "Successful Repair of Street Openings", by E. F. Hensch[G]; and "Maintenance of Asphaltic Pavements", by W. L. Hinderman[I].

The concrete used for patching a concrete street should have a low slump of about 1½ inches to minimize shrinkage and consequently maintain side bond. The bond can be improved by wetting the exposed concrete to prevent the dry pavement from drawing water from the new mix. The use of high-early strength cement content will reduce the curing time and reduce the traffic obstruction period to a minimum. Where development of bond is a recognized problem, epoxy resins can be used to improve the bond strength between old and new concrete.

All joints and cracks in concrete pavements should be constructed through the new patches to maintain the former crack pattern and appearance.

In order to improve the bond between a new asphaltic patch and the existing surface, the vertical sides of the pavement should be painted with a rapid-setting cutback asphalt such as an RC-1. The rake man of a patching crew usually determines the height of loose mixture necessary to make a smooth compacted patch and should be properly trained and experienced in this work. Asphaltic surfacing should be placed in layers not exceeding 2½ inches in compacted thickness.

Sand and gravel base material should be placed and compacted in loose layers of approximately three inches.

J, E, G, I - superscript letters refer to bibliography index

Two pictures, Figure 2 and 3, have been included to indicate what is suggested by well constructed and poorly constructed patches. Note the clean break lines in Figure 2 as contrasted with erratic lines in Figure 3. The excess material placed over the existing bituminous surface in Figure 3 causes a small but offensive bump.

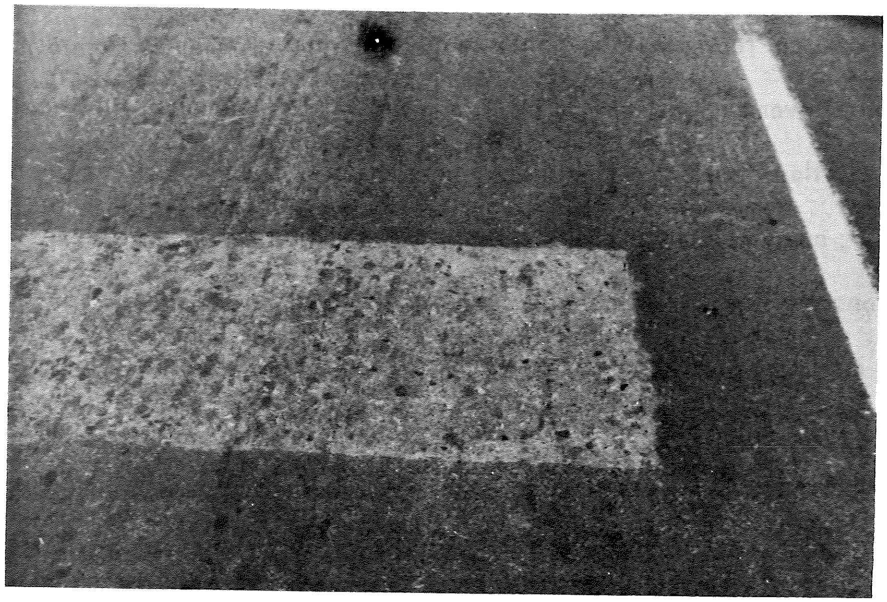

Figure 2. A Well Constructed Asphaltic Patch

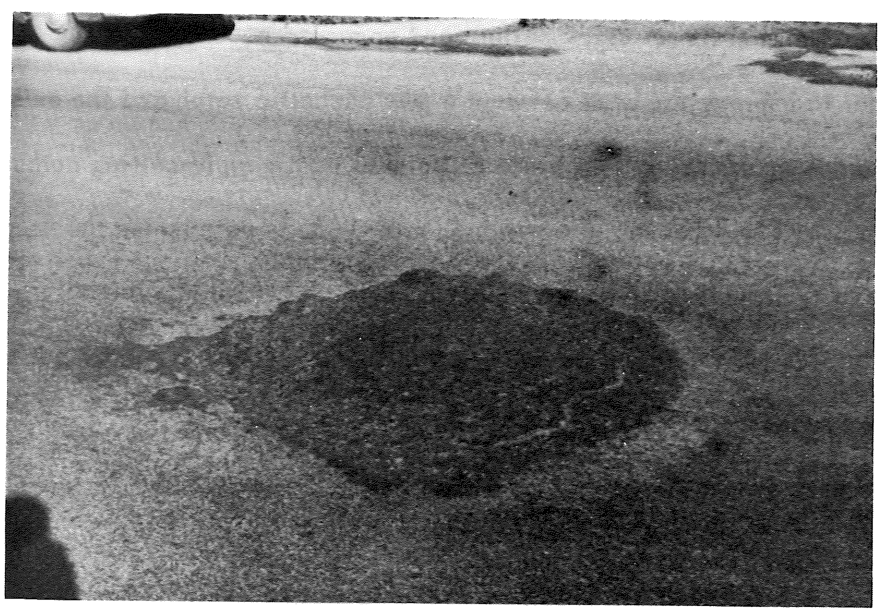

Figure 3. A Poorly Constructed Asphaltic Patch

SUMMARY OF FINDINGS

The majority of presently available trench type compactors will perform acceptably if the various controlling factors are considered carefully. When choosing a trench type compactor the following factors should be considered; soil type, ultimate compaction required, compactive effort required, tolerable trench settlement, traffic volume over the trench, trench dimensions, and type of replacement surfacing.

High traffic volumes necessitate high soil stability and this in turn requires the use of lift compaction. Low traffic volume and its lesser compaction requirements, may permit the use of a compactor designed for use at the street surface only.

Soil type will limit the number of acceptable compactors. Sands compact well using vibratory equipment or the impact type compactors when the sand is somewhat confined. Cohesive soils require the use of an impact type compactor.

Having determined the required density from traffic considerations and after choosing a compactor with soil type as the prime consideration, the number of compacting passes and soil lift heights may be determined. These factors should be resolved by the performance of an inexpensive field study where lift height and the number of compacting passes is varied.

Flooding (or jetting) should only be attempted with soils which are friable and permeable (sand and sand and gravel). These soils should be placed adjacent to permeable soils of the same type.

Construction equipment compaction can produce fairly acceptable density in shallow lifts of all soils and usually produces a stable-backfill in lifts up to 2½ feet in trenches in low traffic volume streets with sand subgrades. For other than these specific conditions construction equipment will not produce acceptable compaction.

PROCEDURES AND OBSERVATIONS

The following generalized observations and tests were made so that the data collected would be similar and comparable:

1. Excavation dimensions;
2. Soil types exposed;
3. Density tests on representative in-place soils;
4. Moisture-density, identification and P.I. laboratory tests;
5. Soil condition and type below excavated depth;
6. Dimensions and type of facility placed;
7. Lift heights of backfilled soil;
8. Density tests in the compacted lifts; moisture content, identification, moisture-density, and P.I. tests of the mixed backfilled soil;
9. Compactor utilized, number of compaction passes (coverages);
10. Settlement measurements;
11. Traffic conditions at the trench site.

Where possible, density tests were made using the sand cone method. When it was not practical to dig test pits in which to make density determinations by this method, thinwall tubes were used to take density samples. In order to eliminate the effect of friction densification during driving and sample extrusion, the penetration was measured in the field for the volume determination and the dry weight was accurately determined in the laboratory.

Periodic settlement measurements were made by string lining across the trench with datum points positioned sufficiently distant from the trench to eliminate the possibility of datum movement. Figure 4, a photo of Trench No. 15, illustrates the string settlement measuring procedure.

Traffic intensity data were collected from city traffic counter records and the low volume residential street traffic volume was estimated when no other information was available.

The Minnesota Highway Department standard for comparison of density and moisture content, described in this report as the "moisture-density" test is basically similar to AASHO T 99-57. This procedure is outlined in the Minnesota Department of Highways Grading and Base Manual in Sections 5-692.240 through 5-692.244.

Figure 4. Settlement-Indicating String Line Procedure Utilized
Note well patched asphalt surfacing, Trench No. 15

EFFECTIVENESS OF THE VARIOUS TRENCH TYPE COMPACTORS

Considerable attention was directed toward the determination of trench backfill stabilities following the use of various trench type compactors. The effectiveness of the compactors was determined from data collected during routine trench soil compaction and also from "Test Points" established for the express purpose of determining the effectiveness of the compactor. The effectiveness and efficiency of compaction are a function of the compactor, the compaction procedure, the type of soil and its moisture content.

The following tabulation lists the trade names under which the various popular compactor types are distributed locally. The compactors are pictured in Figure 5 through Figure 11 on the following pages.

TABLE II
LOCALLY AVAILABLE COMPACTORS

Hydra-Hammers	Vibratory Rollers	Button Head Pneumatics	Plate Vibrators	Plate Tampers
Ottawa	Vibro Plus Terrapac	Le Roi	Maginness	Racine Rapak
Arrow		Worthington	Jay	Kelly
Bantam	Essick Vibrating Compactor	Gardner-Denver	Master	Wacker
		Thor	Kelly	Barco
	Vibrapack	Joy	Jackson	
		Ingersoll-Rand	Wacker Vibro Plate	

Figure 5. Hydra-Hammer Compactor "Ottawa"

Figure 6. Custom Built Power Stomper

Figure 7. Self-Powered Vibratory Roller "Essick Vibrating Compactor"

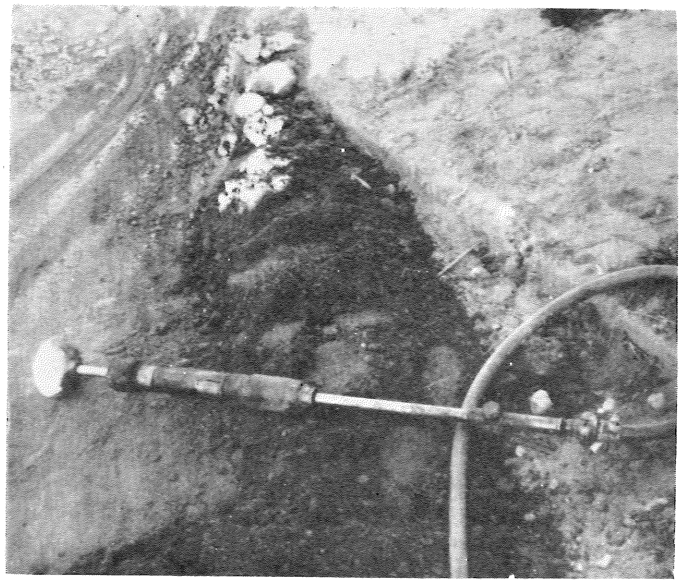

Figure 8. Button Head Pneumatic Compactor "Le Roi"

Figure 9. Plate Vibrator Compactor "Jay Tamper"

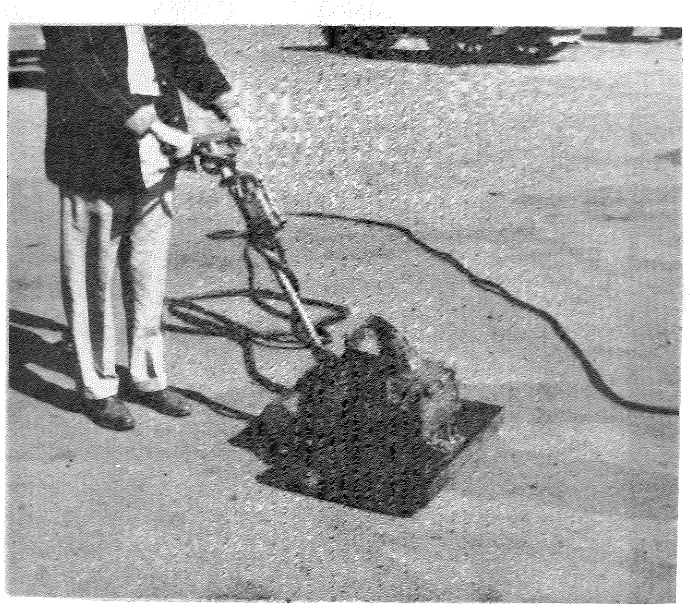

Figure 10. Plate Vibrator Compactor "Jackson Vibrator"

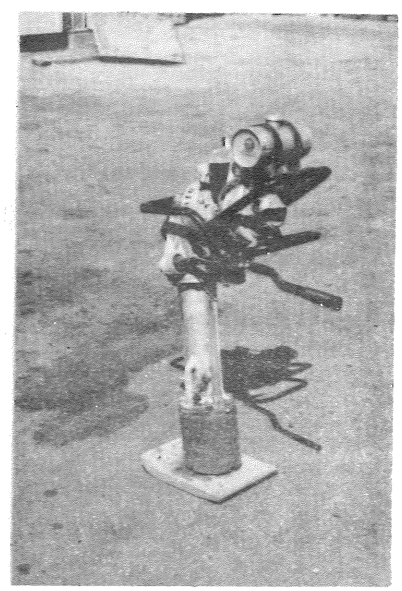

Figure 11. Plate Tamper "Wacker Tamper"

Figure 12 shows the trends of settlement with traffic intensity following the use of three compactor types and compaction by construction equipment. It must be emphasized that the curves are settlement trends observed by us with the actual method of compactor operation, and do not necessarily reflect the settlements to be anticipated with the proper use of the equipment.

Relative density is often assumed to be synonymous with stability. For equal stability, sands apparently require a higher relative density than plastic soils. The settlement trends in Figure 12 suggest extremely high stability of trench soils compacted by the Hydra-Hammer and very low stability following compaction by construction equipment traffic. In general, the soils compacted by the Hydra-Hammer were more plastic than those rolled by construction equipment.

The Button Head Pneumatic compactors, normally used on shallow (approximately 6 inches) lifts of soil, create a backfill with reasonably high and uniform density. This condition is capable of withstanding traffic loads up to 3,000 vehicles per lane per day without causing detrimental settlement.

Plate vibrators showed the lowest compacting effectiveness when compared to the other compactors. The settlement which resulted following compaction of 1½ to 4 foot lifts of soil was high for all traffic volumes.

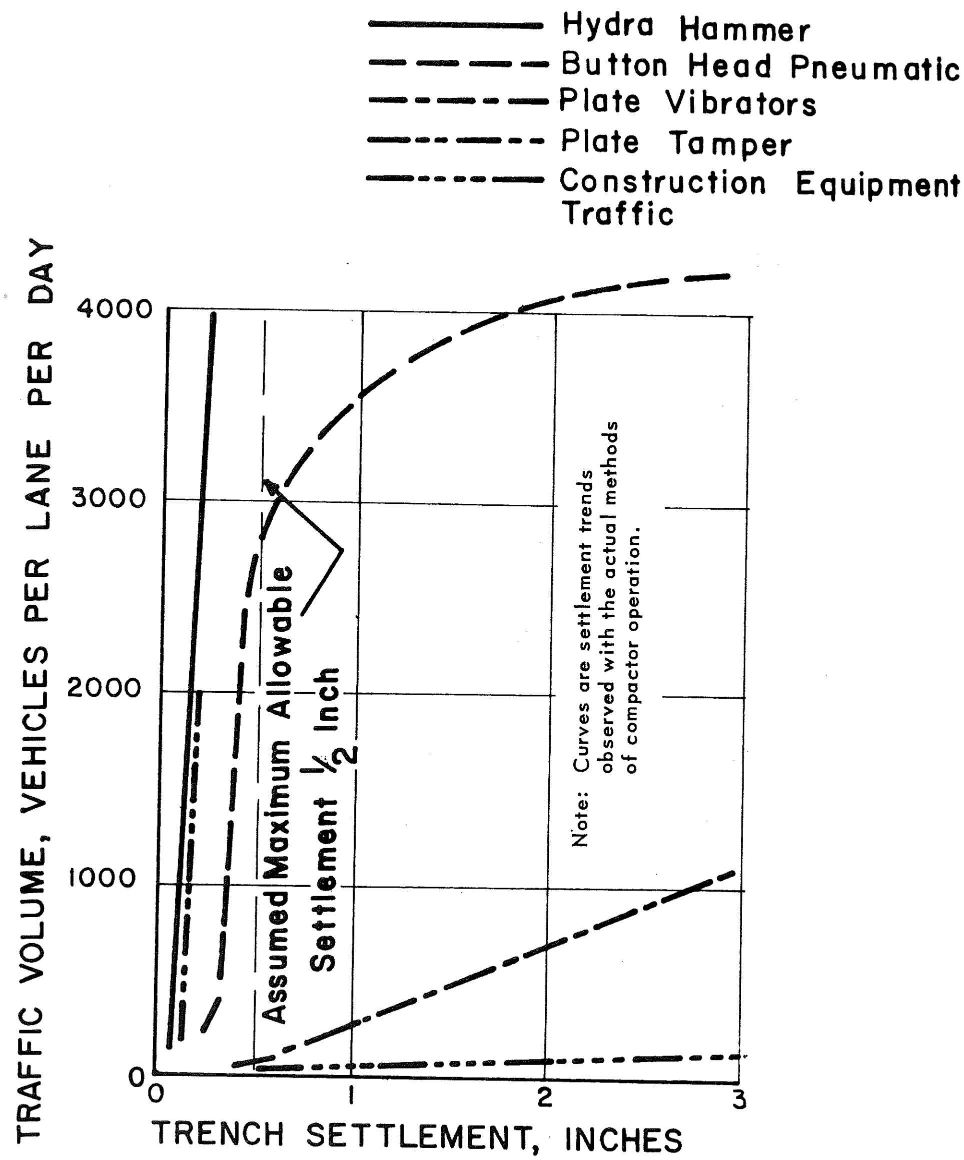

Figure 12. Settlement Trends

Hydra-Hammer

The Hydra-Hammer is used to compact the entire trench backfill in one lift. This is a popular compactor, but many users question its effectiveness in compacting backfill lifts of greater than four or five feet in depth. Frequently trenches exceed a 5-foot depth to avoid frost penetration and for topographic reasons. Conservatively, the Hydra-Hammer can compact fills up to 8-foot depth in one lift and obtain adequate stability.

The Hydra-Hammer is a drop hammer similar to that shown in Figure 5. Compaction is accomplished by a series of low frequency, high energy blows imparted by dropping a large weight (700-1,000 pounds) through a height of 3 to 8 feet. The flat, rectangular compacting shoe of the hammer is usually either 0.6 or 1.0 square foot in area. The one square foot compacting head was used at all but one site.

The standard procedure for the use of the Hydra-Hammer is as follows: Backfill entire trench flush, compact with 4 to 5 blows per compacting face area and a drop height of 4 to 5 feet, refill the depression caused by initial compaction, recompact with 3 to 4 blows per compacting face area and a drop height of about 3 feet.

Several soil types were encountered at the trench sites which received compaction by the Hydra-Hammer. In order of increasing plasticity, the soils compacted were; fine sand, slightly plastic sandy loam, plastic sandy loam, and sandy clay loam. The Hydra-Hammer is equally effective in compacting the friable soils and those of intermediate plasticity when these soils are confined as they are in a narrow trench.

Surface densities averaged 97% of Maximum Density,* followed by 95% at 1 foot, 96% at 2 feet, 92% at 3 feet, 84% at 4 feet and 78% at 6 feet. The recompaction phase often causes a higher relative density at the 2 foot level than at the 1 foot level.

When the standard compaction procedure was followed, the resulting settlement was ¼ inch or less.

A 0.6 square foot compaction head was used at one test site and the resulting relative densities were 91% at the surface, 90% at 1 foot, and the average between the

Basically similar to AASHO T 99-57

2 and 6-foot depth was 80% with only slight variation. Considerable energy was lost as the compacting head would shift horizontally, at impact, into the depression of the previously compacted area. This did not occur when the 1.0 square foot head was used.

Summary, Hydra-Hammer

1. Compacting effectiveness is little affected by soil type.
2. When properly used, settlement will be less than ½ inch.
3. The one square foot compacting head produces superior results to the use of the 0.6 square foot head.

One custom built "Power Stomper" (similar to the Hydra-Hammer) with a 4 square foot compacting face was observed; see Figure 6. Relative densities following compaction of a 2½ foot lift were found to be as follows: surface 99%, at 1 foot 100%, and at the 2 foot depth 94%. No measurable settlement has been noted after 4 months.

Vibratory Rollers

The pull type vibratory roller is occasionally expected to compact the entire backfill placed in one lift. The smaller self-powered units, (Figure 7) are adapted to layer construction. The compacting effectiveness of these machines was tested at 8 sites; 5 in fine sand soils, 2 in slightly plastic sandy loam soils and one in sand and gravel.

These compactors employ both a relatively high static load and high frequency, low amplitude vibrations. Their effectiveness is much a function of soil type, being most effective in granular soils.

The average surface density following compaction of fine sand lifts of 10 inches to 10 feet by 2 to 6 passes (or coverages) of the rollers was 100% of Maximum Density. At the 1 foot depth below the compactor face the average relative density was 99% and at a point 2 feet below the compactor face was 89%. The relative density between 2½ feet and 8 feet below the compactor face averaged 86% which represents about the density expected for this loose uncompacted fill material.

A low plasticity soil, such as the slightly plastic sandy loam compacted at 2 sites, displayed reluctance to densify when a vibratory roller was used. Compactive effort was 2 passes per unit area over lifts of 12 and 19 inches. The average density of the surface soil at these two sites was 82% of Maximum Density and decreased to about 75% at the 1 and 1½ foot depths. These observations indicate that vibratory rollers should not be used with plastic soils and should be limited to compacting sands.

At one site, a 6 inch lift of sand and gravel was compacted with 4 passes of a vibratory roller to 91% of Maximum Density at the surface. This soil required 8 passes of the roller to produce 100% density at the surface. At this site, the amount of compactive effort required was determined by a preliminary study. This system of field determination of required compactive effort is relatively simple and can be extremely rewarding.

Settlement was noted at three trench sites, all receiving their compaction by vibratory rollers. The trench height lifts varied from 6½ to 10 feet. Settlement varied from ½ inch to 2 inches and did not show a definite relationship to traffic intensity.

Summary, Vibratory Rollers

1. Highly affected by soil type.
   a. Effective in friable soils. There are few data on which to base a recommendation of effective depth.
   b. Ineffective in plastic soils.
2. Compactive effort required over sands, about 4 passes.
3. Settlement will be excessive on high traffic volume roadways when used for compacting lifts exceeding 3 feet.

Button Head Pneumatic Compactors

The button head compactors (Figure 8) are handy devices for nearly inaccessible areas. The tools are small and extremely maneuverable. Compaction is accomplished by low frequency, relatively low energy blows. The small impact faces of these devices increase compaction cost due to low production rate. They are generally applicable to only small volume jobs.

The popular "butts" or compacting faces are about 6 inches in diameter. The frequency varies between 600 and 740 blows per minute and the energy at impact ranges from 20 to 50 foot-pounds per blow for the various tampers.

Density data are available from only 3 test sites for study following compaction by the button head types. One site contained a loamy sand soil and 2 sites contained a plastic sandy loam soil. The loamy sand was compacted in 6-inch lifts and attained an average relative density of 92%. At this and other test sites at which the button head tampers were used in friable soils, some shear displacement was noted near the head edge following each blow. The plastic sandy loam, also placed in 6-inch lifts, did not displace horizontally at impact as did the friable soil and, therefore, it can be said that a higher percentage of the energy went into compaction. The surface relative density of 99% in the compacted plastic sandy loam reflected this greater energy usage.

At one site, it was hoped that a 3-foot lift height of plastic sandy loam would be adequately compacted by a button head tamper. Density at the surface reached an adequate 98% of Maximum Density followed by 80% at 1 foot, 73% at 2 feet and a lowly 67% at the 3-foot depth.

Settlement in trenches compacted by button head pneumatic compactors shows a definite relationship to the traffic intensity (Figure 12). Traffic intensity of greater than 3,000 vehicles per lane per day will cause excessive settlement.

These compactors are capable of producing stability if they are used on approximately 6-inch soil lifts irrespective of soil type.

Summary, Button Head Pneumatic

1. Somewhat affected by soil type, but generally effective.
   a. Effective in plastic soils in lifts of less than 6 inches.
   b. Less effective in friable soils due to some edge shear of the soil at impact; lift height maximum 6 inches.
2. Compactive effort required to attain adequate stability, 3 to 4 passes. This amounts to about 10 blows per compacting face area.

3. Applicable to compaction of trench backfills subjected to less than 3,000 vehicles per lane per day.

4. Useful for compacting nearly inaccessible areas; viz, non-horizontal surfaces and somewhat obstructed areas.

Plate Vibrators

These devices are adapted solely to shallow lift compaction. Since the mechanism of compaction is vibration, the application is limited to use on friable soils.

Two types, the Jay and Jackson, are shown in Figures 9 and 10. Most of these machines have a compacting face of 2 to 4 square feet in area. All have a low static soils pressure and between 2,000 and 6,000 pounds of vertically directed force for each vibration. Frequency varies from 2,000 to 7,000 vibrations per minute.

Three soils, sand, slightly plastic sandy loam, and plastic sandy loam, were compacted using three passes per unit area. Table III below presents the relative densities following compaction.

TABLE III
RESULTS OF PLATE VIBRATOR COMPACTION

Depth Below the Compacting Face (Ft.)	RELATIVE DENSITY (%)		
	Sand	Slightly Plastic Sandy Loam	Plastic Sandy Loam
Surface	99	94	82
1	88	84	76
1½	-	76	-
2	-	-	69

With the observed procedures, plate vibrators are capable of developing stability only under low volume streets, (Figure 12). Compaction of 2 to 4-foot lifts of soil at two project trenches was followed by 2½ and 3¾ inches of settlement.

Summary, Plate Vibrators

1. Highly affected by soil type.
   a. Effective in friable soils with slightly less than one foot lifts.
   b. Totally ineffective in plastic soils.
2. Three passes required for adequate stability.
3. Settlement will be excessive under all traffic intensities if the 0.75 to 1.0 foot lift heights suggested are exceeded.

Plate Tampers

Plate tampers proved to be effective compactors for 1-foot lifts of soil. The Wacker tamper (Figure 11) was tested for effectiveness at 3 test sites, one with a plastic sandy loam soil and two in slightly plastic sandy loam.

These compactors utilize a low frequency, long stroke tamping action. The rate varies between 450 and 600 tamps per minute. Tamping shoes are usually ½ to 1 square foot in area. These machines are easily handled and can be used to reach fairly inaccessible areas.

Surface relative density following compaction of the plastic sandy loam was 106% of Maximum Density. Compaction of the slightly plastic sandy loam was also successful as surface relative density averaged 98%. Density at 1 foot was 101% and at the 2 foot level was 86%.

This device will probably produce the minute shear areas along the compacting face edge as do the button heads in the friable soils. The greater density at the one-foot level shown above, may be an expression of this effect. The fact that the plastic sandy loam was compacted at the surface to 8 percentage points higher than the less plastic soil also points to this same reasoning.

Settlement measurements were made at only one trench site following compaction by a plate tamper. This trench did not settle. These tampers were used at two "Test Points" and the resultant relative densities were of such magnitude that stability is implied if lift height is limited to less than one foot.

Summary, Plate Tampers

1. Somewhat affected by soil type.
   a. Effective in plastic soils with lift heights to slightly greater than one foot.
   b. Less effective in granular soils than plastic, but generally acceptable with lift heights of approximately one foot.
2. Two passes required for adequate stability.
3. Settlement will be less than ½ inch if the suggested compactive effort is followed and if lift heights are controlled to one foot or less.
4. Useful for compacting nearly inaccessible areas such as: under and around transverse pipes, beneath the lower quadrants of pipes laid in narrow trenches, under haunches of pipes and culverts.

Construction Equipment Traffic Compaction

Occasionally, trenches are compacted solely by the construction equipment traffic of backfilling and cleanup. Heavy equipment such as "cats" and large front end loaders produce high surface compaction, but produce relatively low compaction at depths of 2 feet and below.

Densities were taken in 7 trenches following this type of compaction on trench height lifts of soil. The soils encountered were sand, slightly plastic sandy loam, plastic sandy loam, and silt loam.

Table IV shows the effect of this compaction procedure on the mentioned soils.

TABLE IV
RESULTS OF CONSTRUCTION EQUIPMENT TRAFFIC COMPACTION

Depth Below Compaction Face (Ft.)	RELATIVE DENSITY (%)			
	Sand	Slightly Plastic Sandy Loam	Plastic Sandy Loam	Silt Loam
Surface	105		98	102
1	99	90		
2	92	79	88	
3	90			
4				
5				74
6	87		82	
7				

Again, as in the case of vibratory rollers, the density of the sand material below 3 feet is about that expected for the loose uncompacted fill material.

Following the use of this compaction procedure, five of seven observed trenches settled excessively. The trend of settlement with traffic intensity (Figure 12) shows that this procedure is inadequate in nearly all cases. The use of this procedure is, therefore, inadvisable except in those cases where lift height can be controlled at less than 2½ feet in sands and less than 1 foot in plastic soils. Application is limited to either shallow or wide trenches.

Summary, Construction Equipment Traffic

1. Effective in shallow lifts of any soil.
   a. Effective in sands to depths of 2½ feet and 1½ feet in streets of low and high traffic volumes respectively.
   b. Effective in plastic soils to a depth of 1 foot.

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APPENDIX

Individual Trench Narratives

Data were collected at thirty trench sites during the course of the project. The number of different procedures used in backfilling and compacting nearly matches the number of sites observed. For discussion purposes, the information collected has been grouped into the four general types of compaction: viz, roadway surface compaction only, layer compaction, flooding, and construction equipment traffic compaction.

Data from a rather extensive study conducted by the Southern California Gas Company are included in the appropriate section discussions.

Trenches Compacted from the Roadway Surface

Compactors intended for use over full-height lifts of trench backfills are primarily the Hydra-Hammer and drawn type vibratory roller. Other types are occasionally used but they constitute only a small percentage of the total usage.

Of the 11 trenches observed to be compacted from the surface, seven were compacted by the Hydra-Hammer type with 1 square foot compacting faces, three were compacted by vibratory rollers, and one was compacted by a pneumatic button head type.

Trench No. 8, cut in a slightly plastic sandy loam, was compacted by a Hydra-Hammer. This continuous trench was 38 inches deep and 20 inches wide. It was initially backfilled flush and compacted with 4 blows per compacting face area. The trench was refilled and given a superficial compaction of ½ blow per compacting face area. The resulting density at the 1 foot depth was 86% of Maximum Density and undoubtedly was lower than this figure in the upper foot. Following bituminous surfacing, settlement was periodically determined and final settlement of 3½ inches was measured. This high volume street carried 1955 vehicles per lane per day of which very few were trucks. This high traffic volume, traveling over the poorly compacted soil undoubtedly caused the detrimental settlement.

Trench No. 12 was an intermittent type which measured 63 inches wide by 64 inches long and 78 inches deep. The trench was backfilled with one 6½-foot lift of fine sand parent soil and compacted using a Hydra-Hammer. The initial compaction was 4 blows per compacting face area with an 800 pound hammer falling 8 feet. Fine sand soil was backfilled again into the depression caused by the initial compaction. This was compacted by 3 blows per compacting face area and a fall height of 4 feet. Following compaction the surface relative density was found to be 94% of Maximum Density. During the following 4 months, seven settlement profiles were taken which indicated a total settlement of ¼ inch. Even though this trench was cut in a street carrying a large volume of traffic, 2791 vehicles per lane per day, the settlement was negligible.

Trench No. 13 was another of the intermittent type. The natural soil was sandy clay loam. The trench was 84 inches long, 42 inches wide and 48 inches deep. Initial compaction with the Hydra-Hammer amounted to 4½ blows per compacting face area with a drop height of 4 feet. Final compaction was 4 blows per compacting face area with a fall height of 4 feet. Relative density of the compacted soil decreased with depth as usual, being 97% at the surface, 94% at the 1-foot level and 92% at the 2-foot level. Over the following 3 months, 6 settlement readings were made, each showing no settlement. The very low traffic on this residential area trench was estimated to be 50 to 75 vehicles per lane per day.

Trench No. 14 was of the intermittent type and was located in the same area as Trench No. 13. The natural soil, compaction and trench dimensions were similar to Trench No. 13. Rain-soaked natural soil was wasted and sand and gravel backfill was obtained from a local pit. No density tests were made on the compacted soil. Settlement-indicating profiles taken over the following 2 months showed a total settlement of ¼ inch. Traffic again was very low being estimated at 50 to 75 vehicles per lane per day.

Trench No. 25 was cut in plastic sandy loam soil to a depth of 78 inches. Initial compaction of the full-height lift (78 inches) by the Hydra-Hammer amounted to 4 blows per compacting face area with a fall height of 3 feet 6 inches utilizing a 1,000-pound hammer. Final compaction was 3 blows per compacting face area with a fall height of 3 feet. Relative densities following compaction appear encouraging being 100% plus in the upper 2 feet and decreasing to 83% at the 4 foot level. No settlement was recorded during the following

2 months. This trench is located in an area presently being developed so the traffic load is light being approximated at 150 vehicles per lane per day.

Trench No. 29 was cut in a slightly plastic gravelly sandy loam soil to a depth of 40 inches. This shallow trench was compacted by a Hydra-Hammer with an 800-pound head. The full height lift of 40 inches was compacted with 7 blows per compacting face area and a fall height of 5 feet. Relative density of the soil to the 2-foot level averaged 96% of Maximum Density. Traffic on this street is rather light with the volume being approximated at 250 vehicles per lane per day. The settlement during the following month was a nominal ¼ inch which has little effect on the riding quality of the street.

Trench No. 1 was cut in a fine sand soil and received 6 compacting passes of a vibratory roller following the backfilling of a 6½-foot full height lift. Relative density decreased quickly with depth as shown by the 104% of Maximum Density at the surface to 81% at the 3-foot level. Over a period of 4 months a settlement of 1¾ inches was recorded and during the succeeding 4 months an additional ¼ inch was noted. This total of 2 inches would have been very offensive to traffic had the trench not been mounded initially in expectation of settlement.

Trench No. 19 was also cut in a fine sand soil and compaction was accomplished by 2 passes at street level of a vibratory roller. The entire 10 feet of backfill was compacted as one lift. Surface relative density following compaction was a high 104% of Maximum Density. Between the 2-foot and 8-foot levels, the relative density averaged 91% of Maximum Density with little variation. Periodic measurements of settlement showed a movement of ½ inch. The traffic intensity at this location was estimated at 100 to 150 vehicles per lane per day.

Trench No. 27 was cut in a dense fine sand to a depth of 10 feet. The 10 feet of soil was compacted in one lift by 4 passes per unit area of a vibratory roller applied at the surface. This compaction produced an average relative density of 97% between the surface and the 1-foot depth and decreased gradually to the 6-foot depth where only 78%

was found. Traffic intensity was estimated to be between 50 and 75 vehicles per lane per day. Total settlement, 3 months after backfilling, was ½ inch.

On only one other trench, No. 20, was compaction attempted solely from the roadway surface. The trench was cut in a plastic sandy loam soil to a depth of 40 inches and the backfill was compacted by a pneumatic button head type tamper. Each unit area of soil received 3 compacting passes of the tamper operated at normal speed. Compaction decreased with depth logically; and, in this case, it was very pronounced. Surface relative density was 98% and decreased gradually to 67% at the 3-foot depth. Even though traffic was very light, estimated at 50 to 75 vehicles per lane per day, in four months the total settlement amounted to 1 inch. Since the trench was narrow (12 inches wide), the riding quality of the street was impaired.

Mr. W. M. Henderson in a paper presented to the Pacific Coast Gas Association[H] said that of nineteen observations on trenches compacted at the surface by a "Power Stomper" there were no failures. Soils encountered were: sand, three trenches; loam, nine trenches; and clay, seven trenches. The critical trench depth dimensions were not given. Our observations following the use of Hydra-Hammers, were similar.

Trenches in which Stage Compaction was Utilized

Most trench type compactors are intended for use over shallow lifts of soil. Equipment applicable to this compaction procedure are plate vibrators, pneumatic button head types, plate tampers, and power stompers similar to the Hydra-Hammer. Of the trenches observed, nine were backfilled and compacted in stages. Of these nine trenches, three were compacted by plate vibrators of the Jay type, one was compacted by a plate tamper, one by a power stomper similar to a Hydra-Hammer, and four by pneumatic button head types.

Trench No. 5 was cut through four layers of differing soil. The 3 feet of basement soil was saturated silty clay loam which exuded water when exposed. This 14-foot deep trench was backfilled with coarse sand and compacted in 2-foot lifts by a "Jay Tamper" plate vibrator. No reliable density tests were made during the inclement weather which prevailed. During the following 8½ months the trench required frequent maintenance as total settlement over this period amounted to 3¾ inches. Traffic volume is relatively high at this location being 1156 vehicles per lane per day.

Trench No. 7 was cut to a depth of 12 feet through 3 feet of plastic soil underlain by 9 feet of stratified sand and gravel. In backfilling, two sand and gravel lifts 3 feet in thickness were placed and compacted individually, then a 4-foot lift of plastic sandy loam with approximately 20% large frozen clods was placed and compacted and finally the upper 2 feet was backfilled with sand and gravel. All lifts received 2 passes of compactive effort using a Jay Tamper. During the following 4 months, settlement totaled 2½ inches. No density tests were made. The traffic volume over this trench was 1038 vehicles per lane per day.

Trench No. 22 was cut to a depth of 9 feet through graded and coarse sand layers. The lower 4 feet of the trench was backfilled in two 2-foot lifts and compacted with 4 passes of a plate vibrator. The average relative density in this 4 feet of soil was 94% of Maximum Density. The upper 5 feet of backfill was placed in two 2-foot lifts and a 1-foot lift with each compacted by multiple passes of a D-6 Caterpillar. Over the succeeding 4 months, only ½ inch of settlement was measured. Traffic volume is very low at this residential location and was estimated at 50 to 100 vehicles per lane per day.

Trench No. 21 was a large trench (top width 9 to 10 feet) cut in a fine sand to a depth of eight feet. A home-made "Power Stomper", See Figure 6, was used to compact lifts of soil measuring between 2.5 and 4 feet in depth. With its 4 square foot compacting head, considerable soil was compacted per tamp. Each compacting face area was tamped 9 times. Between the surface of any lift and the one-foot depth, the relative density averaged 99% of Maximum Density and at the two-foot depth a relative density of 94% was found. The traffic volume at this site was estimated at 300 to 400 vehicles per lane per day. The well compacted trench backfill had not settled during 4 months of observations.

Trench No. 6A and 6B were intermittent types cut in a very high traffic volume city street, state highway combination. The soils encountered were graded sand from 1 to 4 feet and slightly plastic sandy loam from 4 to 6 feet. These excavated soils were mixed and the bottom 5 feet was backfilled in two 2-foot lifts followed by a 1-foot lift. The upper foot was placed in 2-inch lifts. All of these lifts were compacted with a pneumatic button head type compactor. Monthly determinations of settlement disclosed a total of 2 inches of sinking at Trench 6A. The traffic intensity at this trench site was 4085 vehicles per lane per day. Trench 6B received the same traffic load and was backfilled and compacted in a similar manner to 6A but sank 4½ inches.

Trench No. 10 was cut to a depth of 42 inches in a slightly plastic sandy loam soil. This soil was backfilled and compacted in 6-inch lifts using a pneumatic button head type compactor. The average relative density of these 6-inch lifts following compaction was 92% of Maximum Density. Traffic volume was rather high being 3328 vehicles per lane per day of which 70 were large transit company busses. Even though the trench was shallow and the soil was fairly well compacted, ¾ inch of settlement was observed.

Trench No. 11 was again one of the intermittent type. It was cut in a loamy sand to a depth of 9 feet. This soil was backfilled and compacted in 1-foot lifts. The compactor used was a pneumatic button head type. No density tests were made at this site. The volume of traffic was rather high over this trench location being checked at 2791 vehicles per lane per day. Total settlement measured over a period of 3 months was ½ inch.

Trench No. 26 was cut to a depth of 5 feet through plastic sandy loam and a light clay. These excavated soils were mixed (40% plastic sandy loam and 60% clay) and backfilled in 6-inch lifts. Compaction of these lifts was accomplished by 3 passes of a pneumatic button head type compactor. The average relative density following this effective compaction was 100% of Maximum Density. This high density, coupled with the very low traffic volume of less than 25 vehicles per lane per day, caused a reaction of only ¼ inch of settlement.

Trench No. 17 was cut in a slightly plastic sandy loam soil to a depth of 7 feet. Lifts of approximately 9 inches in depth were placed and compacted by 3 passes of a plate tamper, specifically, a Wacker Tamper. It was found that the upper half of these lifts had been compacted to 106% of Maximum Density. The upper 3½ feet of soil was backfilled as one lift and compacted by 6 passes of a vibratory roller. This trench is located in a residential area and traffic probably did not exceed 50 vehicles per lane per day. Over the succeeding 4 months the trench showed no measurable settlement.

Mr. Henderson reported on 69 trenches compacted in stages (lift construction) by pneumatic tampers. When the soil type was considered, it was found that pneumatically tamped sands produced 25% "sunk" trenches. Similarly compacted loams brought about 10.5% "sunk" trenches and clay soils tamped with these devices had 39% failures or "sunk" surfaces.

Trenches Compacted by Flooding

When carefully applied, flooding can be an effective method of compacting free draining trench soils when they are bounded by free draining soils. By contrast, one trench observed during this project which was flooded to achieve compaction proved to be a failure.

Trench No. 30 was cut to a depth of 7 feet in a light clay. Approximately 6 feet of soil was pushed into the excavation. The jetting pipe was sunk into the loose backfill to a depth of 4 feet and allowed to flow until water appeared at the surface. Spacing of the jetting holes was about 4 feet. This clay soil, having a very low permeability, did not allow the flooding water to flow away at a reasonable rate of speed, and thus the soil became very unstable. The exceedingly slow loss of water trapped the unstable condition for some time and eventually caused a settlement of 4 inches. Traffic volume at this site was estimated at 150 vehicles per lane per day.

Mr. Henderson's report showed that 27 of 44 trenches (or 61%) observed following flooding failed. When soil type was considered, 18% of the trenches filled with sand failed, 75% of the trenches filled with loam failed and clay soil flooding caused failures in 76% of the cases observed.

Trenches Compacted by Construction Equipment Traffic

It has been frequently stated that static weight will compact soil to a high degree at the level of load application but cannot be expected to effectively compact soils at any significant depth.

Trenches No. 2, 18, and 28 were all excavated in fine sand to depths varying from 8 to 12 feet. Surface rolling by construction equipment produced average relative densities of 105% at the surface to 87% between 4 and 6 feet. The average settlement following back-filling of these three trenches was 1¼ inches. On each of these residential streets traffic volume was low being approximately 150 vehicles per lane per day.

Sands show a tendency to produce a higher relative density in the uncompacted state than do the plastic soils. Friable soils do not trap the large air voids as do the plastic soils. The following two trenches show this adequately along with the obvious settlement differences.

Trench No. 16 was cut to a depth of 5 feet through slightly plastic sandy loam. Relative densities between the 1 and 2-foot depths averaged 85% of Maximum Density. Settlement over a period of 12 months totaled 6¼ inches and was not caused primarily by traffic, since this trench is located in a residential area where the volume was estimated to be less than 100 vehicles per lane per day.

Trench No. 15 was cut in silt loam soil to a depth of 14 feet. Relative density at the surface was an adequate 102% of Maximum Density following rolling by construction equipment, but this decreased quickly at the lower levels. Between the 3 and 6-foot depths, the average relative density was only 74%. This trench showed 4 inches of settlement during the 7 month observation period. Traffic volume of 1510 vehicles per lane per day was taken from city traffic counter data.

PUBLISHED INFORMATION OF VARIOUS AGENCIES

Soil compaction specifications of various agencies differ somewhat because of the differences in their intended purpose. Highway Departments attempt to obtain a strong roadway structure and avoid detrimental settlement. Pipe companies, by contrast, are primarily concerned with the pipes' structural stability. The following recommendations of various agencies are, therefore, discussed separately.

Asphalt Institute [F]

Listed below are a number of generalities concerning compaction equipment which the Asphalt Institute feels are relevant to the problem of soil compaction in trenches.

1. Weight alone will give maximum compaction near the surface only.
2. Vibration tends to compact deeper in granular soils than other compactors.
3. Vibration compaction is most effective in granular soils. It decreases in effectiveness as the cohesion of the soil increases.

California Institute of Technology [B]

A study conducted by the U. S. Navy Bureau of Yards and Docks, in cooperation with the California Institute of Technology, attempted to demonstrate the practicality of compacting cohesive soils by vibration. It was concluded that the tested range of 5.2 p.s.i. to 19.5 p.s.i. compacting pressure (dynamic load plus static load) was inadequate to cause significant densification.

An additional study concluded that:

1. Vibration frequency must be near resonance (frequency of vibration at which a particular soil will vibrate most strongly).
2. The dynamic force must be nearly equal to the vibrator dead weight.
3. The dead weight pressures must be near the following:

Sand	3 p.s.i.
Sandy Loam	4 p.s.i.
Clay Loam	8 p.s.i.

During one phase of the study, the effect of the addition of wetting agents was studied. It was found that the density could be increased by the use of some additives. Compaction resulted but the immediate and permanent stability must be determined to accurately assess the benefits.

Highway Research Board[C]

A 1952 Highway Research Board review of State Highway Department specifications for backfilling excavations brought out the following information. Permissible lift heights varied from 4 inches to 12 inches loose measurement and 3 states specified backfilling in 6-inch compacted lifts. Of the 45 states which measured loose lift thickness, 4 specified 12-inch thickness, 1 specified 10-inches, 2 specified 9-inches, 6 specified 8-inches, 24 specified 6-inches, 1 specified 5-inches, and 7 specified 4-inches. Compaction requirements varied from "thoroughly compacted" in 26 states to a specified percentage (90-102) of Maximum Density in 22 states. Moisture control was unspecified in 21 states and 27 required or suggested some moisture control. All states suggested some general type of compacting equipment. During the elapsed time of 10 years, some states have written more stringent requirements.

Minnesota Highway Department[D]

The 1959 Specifications of the Minnesota Highway Department (2110.C1 & 2110.C2) call for 100% of Maximum Density in the upper 3 feet of the backfill and 95% below the 3-foot depth. Moisture content control must now be adjusted to between 65% and 102% of Optimum Moisture in the upper three feet of the backfill and must not exceed 115% of Optimum Moisture below the three-foot level. The lower limit of 65% applies only to those soils having an Optimum Moisture greater than 12%.

The Minnesota Highway Department Specification 2501.3B3 requires that material used for backfill be free from stones and lumps larger than 3-inches in greatest dimension.

Armco Drainage & Metal Products, Inc. [A]

In order to guarantee structural stability, no large rocks, clods, frozen lumps of soil greater than 3-inches in diameter are allowed in contact with the pipe. The sequence of placement and compaction of the soil adjacent to the pipe is the primary concern. Relative density following compaction of the major backfill above the pipe zone is required to be similar to that in the adjacent embankment. Choice of the compactor to be used is governed by the soil type. Puddling or jetting is not allowed unless the soil is sandy, or sand and gravel.

TABLE V
DATA COMPILATION

Compactor Type	Trench or Test Point No.	Relative Density, % Depth Below Compacting Face (Ft.) 0	1	2	3	4	5	6 & below	Traffic Intensity, Vehicles Per Lane Per Day	Settlement Inches	Soil Type*	Lift Height	Remarks
Hydra-Hammer Type	Tr. 8		86		**(3'-2")				1955	3½	sl.pl.SL	3 ft.	Poor Compaction procedure
	Tr. 12	94						**(6'-5")	5560	¼	FS	6½ ft.	
(12" x 12" compacting head)	Tr. 13	97	94	92		**(4'-0")			50-75	0	SCL	4 ft.	
	Tr. 14					**(4'-0")			50-75	¼	S&G	3 ft.	
	Tr. 21	99	100	94				**(8'-0")	300-400	0	LFS	3 ft.	
	Tr. 23	79(1)		97(1)							sl.pl.SL	4 ft.	
	Tr. 25	101	102	100	92	83		**(6'-2")	150	0	pl.SL	6 ft.	
	Tr. 29	96		96	**(3'-4")				250	¼	sl.pl.GSL	3½ ft.	
	TP 6(2)	91	90	79		84		78 **(9'-0")			sl.pl.SL	9 ft.	
Button Head Pneumatic Type	Tr. 6A							**(6'-0")	4085	2	sl.pl.SL	2-2 ft. lifts bottom 1-1 ft. lift & 6-2 in. lifts surface	
	Tr. 6B							**(6'-0")	4085	4½	sl.pl.SL		
	Tr. 10	91			**(3'-6")				3328	¾	LS	6 in.	
	Tr. 11							**(9'-0")	2791	½	LS	1-2' lift, 3-1' lift	
	Tr. 20	98	80	73	67 **(3'-6")				50-75	1	pl.SL	3½ ft.	
	Tr. 26	100					**(5'-0")		25	¼	pl.SL	6 in.	
Plate Tamper Types	Tr. 17	106						**(7'-0")	50	0	pl.SL	9 in.	
	TP 2	98		86							sl.pl.SL	19 in.	
	TP 3	98	101								sl.pl.SL	8 in.	

* *Symbol explanation* *sl.pl.SL = slightly plastic Sandy Loam*
FS = Fine Sand
SCL = Sandy Clay Loam
S&G = Sand and Gravel
LFS = Loamy Fine Sand
pl.SL = plastic Sandy Loam
sl.pl.GSL = slightly plastic Gravelly Sandy Loam
LS = Loamy Sand
SiL = Silt Loam

**(*Trench Depth*)
(1) *Compactor hit asphalt slab, density values are not representative and were not included in average.*
(2) *7 inch x 12 inch compacting head.*

TABLE V (Cont.)
DATA COMPILATION

Compactor Type	Trench or Test Point No.	Relative Density, % Depth Below Compacting Face (Ft.) 0	1	2	3	4	5	6 & below	Traffic Intensity, Vehicles Per Lane Per Day	Settlement Inches	Soil Type	Lift Height	Remarks
Vibratory Rollers	Tr. 1	104			81			**(6'-6")	50-75	2	FS	6½ ft.	
	Tr. 19	104		89		91		93 **(10'-0") 91 at 8	4275	½	FS	10 ft.	
	Tr. 27	96	98	92		86		78 **(10'-0")	50-75	½	FS	10 ft.	
	TP 1	88 @ 2 passes 91 @ 4 passes 98 @ 6 passes 102 @ 10 passes									S&G	6 in.	
	TP 7	75	74								sl.pl.SL	12 in.	
	TP 8	88		76							sl.pl.SL	19 in.	
	TP 11	96	101								FS	10 in.	
	TP 12	97		86							FS	19 in.	
Plate Vibrator	Tr. 5							**(14'-0")	1156	3¾	S	2 ft.	
	Tr. 7							**(12'-0")	1156	2½	sl.pl.SL	3-2' lifts & 1-4' lift	
	Tr. 22(3)	99	88					**(9'-0")	50-100	½	S	1½ ft.	
	TP 4	99	82								sl.pl.SL	8 in.	
	TP 5	90	86	76							sl.pl.SL	17 in.	
	TP 9	82	76								pl.SL	10 in.	
	TP 10	82		69							pl.SL	21 in.	
Construction Equipment Traffic	Tr. 2	106	97	92	91	85		89 **(7'-6")	150	2	FS	7½ ft.	
	Tr. 3	97		90		90		97 **(10'-6")	25	2½	pl.SL & FS	10½ ft.	
	Tr. 4	98	88		89		83	80 at 7	150-200		pl.SL	12½ ft.	
	Tr. 15	102			70			79 **(14'-0")	1510	4	SiL	14 ft.	
	Tr. 16		90	79			**(5'-0")		100	6¼	sl.pl.SL	5 ft.	
	Tr. 18	107	103		88		86	**(8'-0")	150	1½	FS	8 ft.	
	Tr. 22(3)	101 95	 98					**(9'-0")	50-100	½	S S	1½ ft. 3½ ft.	
	Tr. 28	104	97					**(12'-0")	25-50	¼	FS	12 ft.	

***(Trench Depth)*

(3) Compacted by Plate Vibrator below 5' depth. Compacted by Construction Equipment Upper 5 feet.