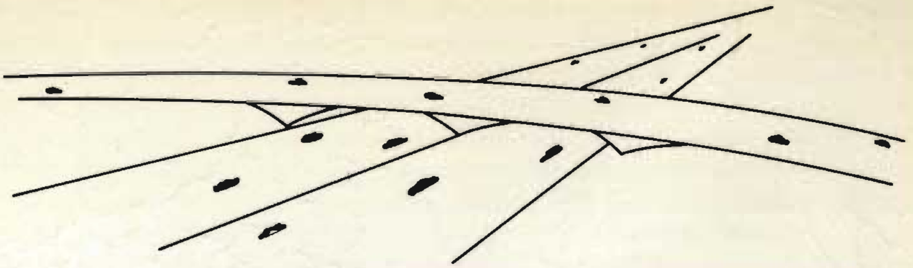


DEPARTMENTAL RESEARCH

Report Number : SS 10.2

A REVIEW OF CONSTRUCTION PRACTICES TO CONTROL HEAVE IN HIGHWAY PAVEMENT

TEXAS HIGHWAY DEPARTMENT

A Review of
Construction Practices to Control Heave
In Highway Pavements

by

Larry J. Buttler
Sr. Designing Engineer

Highway Design Division

Texas Highway Department

November, 1973

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

To the average motorist, heave can be described as irregular but pronounced bumps in the roadway. Evidence of a heaving or swelling roadway is also indicated by asphaltic leveling on short sections of fairly new pavements or a heater-planer at work as it removes the humps caused by swelling. Expansive clays which cause these problems in highways can be defined as a clay which shows extensive volume changes when wetted or dried. True, all soils show some change with changes in moisture content, but the ones which cause damage to the pavement above them can be said to be expansive.

To the engineer, distress caused by expansive soils has been observed in a number of forms, such as

(1) transverse waves or bumps that occur at fairly regular intervals for a significant length of roadway without cracking or visible damage;

(2) general uneveness along the roadway usually without cracking;

(3) longitudinal cracking parallel to the road centerline;

(4) heave in localized conditions, such as distress at culverts which is generally accompanied by lateral cracking; and

(5) uplift of the pavement near bridge ends.

There have been many construction methods tried and used with varying degrees of success. In general the problem starts when a gradeline is cut through a dry expansive clay and then a conventional pavement structure is built above this soil. Moisture can enter the clay by draining through the structure at cracks and joints and by traveling laterally or by capillary movement from the water table. With this water comes heave. If heave or swelling were to occur uniformly there would be no roughness or damage; however, water movement in this nonhomogenous structure causes localized heave which creates bumps and localized cracking. The options for preventing this type of movement are many and can be broken into the following categories of construction:

1. Preswelling of Expansive Soils.
2. Moisture Barrier by Membranes.
3. Stabilization and Compaction.
4. Removal of The Undesirable Material.
5. Maintainable Design.
6. Constrain soil against movement.
7. Design Pavement to Withstand the Stresses.
8. Move to a New Site.

The swelling clay problem is a universal problem and occurs in many states and many countries. However, the evidence found in this review showed few standard construction practices. Most states consider the need for research to be great and most of the types of construction as experimental. A majority of the research is now being conducted by the state highway departments in Arizona, California, Colorado, Oklahoma, Mississippi and Texas. The current construction methods now being used in these states and some of their research will be discussed in Chapter 2.

CHAPTER 2. CONSTRUCTION PRACTICES

In Texas alone it is estimated that expansive clays caused 9 million dollars in damages to state highways annually.(17) This amount of money includes only the maintenance cost caused by the clays and not the loss to the public due to loss of serviceability. However, before choosing a pavement design, total economics should be considered. This may mean a planned maintenance program of overlays, level ups, seal coats and heater-planer operations which will cost less than preventing heave in the initial design and construction. In most cases the most economical solution will be some combination of maintenance and good construction practices.

Mainly, this chapter will discuss initial construction methods with little emphasis on total economics.

Preswelling of Expansive Soils.

As stated before, most of the problems encountered in heaving of pavements occurs in dry clays which get wet after the structure is built. Ponding. Ponding of clay soils is one of the methods used to prewet or preswell the clay. A number of techniques have been used, including regular ponding, ponding with sand drains, ponding aided by electro-osmosis and base exchange of ions, and many other types of ponding techniques.

The Texas Highway Department had one ponding project in Guadalupe county as far back as the late 1920's.(14) After a short ponding period, moisture measurements were continued for more than four years. There was little moisture change 36 inches beneath the pavement; however, observation did show that pavement irregularities were reduced by placing a 6-inch layer of sand between layers of similar clay, the top clay layer being immediately under the pavement. Later testing indicated a stable moisture content occurred after four years. Again in 1958 a ponding project began on 8 miles of Interstate 35 near Waco, Texas in McLennan County.[9] Measurements from this study also showed that ponding did not penetrate more than 4 feet downward during a 24-day ponding period. There was some indication that capillary moisture moved from the 20 feet level upward. Tests indicate that the moisture in the ponded area has remained fairly constant for the 13 years since ponding. The maximum movements observed in the ponding areas were in general agreement with the predictions of the "Potential Vertical Rise Method".

In the years since ponding, several level-ups and overlays were made because of roughness caused by swelling. The thickness of the ACP courses were determined by coring and it was found that the ponded sections had required about 2 inches less thickness. This may or may not be significant since lime stabilization was included in the ponded sections, and delayed lateral movements of water from the ponded to non-ponded may have caused heave in the non-ponded sections.

Again in 1969 and 1970 the Texas Highway Department had another project which included a 30 day ponding and continued measurements of vertical movement as well as moisture movements.[16] Most of the movements had occurred in the top 3 feet and after more than three years there had been small movement at 10 feet and no measureable movement below 10 feet.

Mississippi's State Highway Department conducted an experimental ponding project which started in 1967 with continued ponding for 100 days.[13] The ponded section included approximately 550 feet of fill area and 550 feet of cut area. A grid of 6 inch diameter sand drains was constructed to a depth of 20 feet. As shown in Figure 1, the width of the grid was 44 feet and the spacing of the sand drains was 5 feet. In addition, another two sections of cut and fill were coated with an asphalt membrane as shown in Figure 2. This membrane was placed over the entire width of roadway at the rate of 1.0 gallon per square yard. This section was sealed to prevent surface water from entering the subgrade so that the effect of capillary action could be studied. A control section was also included. Figures 3 and 4 show heave measurements and Figure 5 shows moisture measurements versus depth. The conclusions of this study stated that ponding with the drilled sand drains was effective in reducing the swell potential of the undisturbed Yazoo Clay. It was concluded that sand drains can be used to effectively accelerate movement by either pore pressure or negative pore pressure. In the membrane sections it was concluded that no moisture gains were made by capillary action in the 34 months that measurements were made. Therefore the only method by which moisture can be added to the Yazoo Clay is by surface runoff.

In other studies in Mississippi the serviceability or performance of the Continuously Reinforced Concrete Pavements on different types of untreated (for swell) subgrades was studied. It was recommended that CRCP pavements not be built on expansive clays such as the Delta Gumbo, Yazoo, and Zelpha Clays of Mississippi. [12]

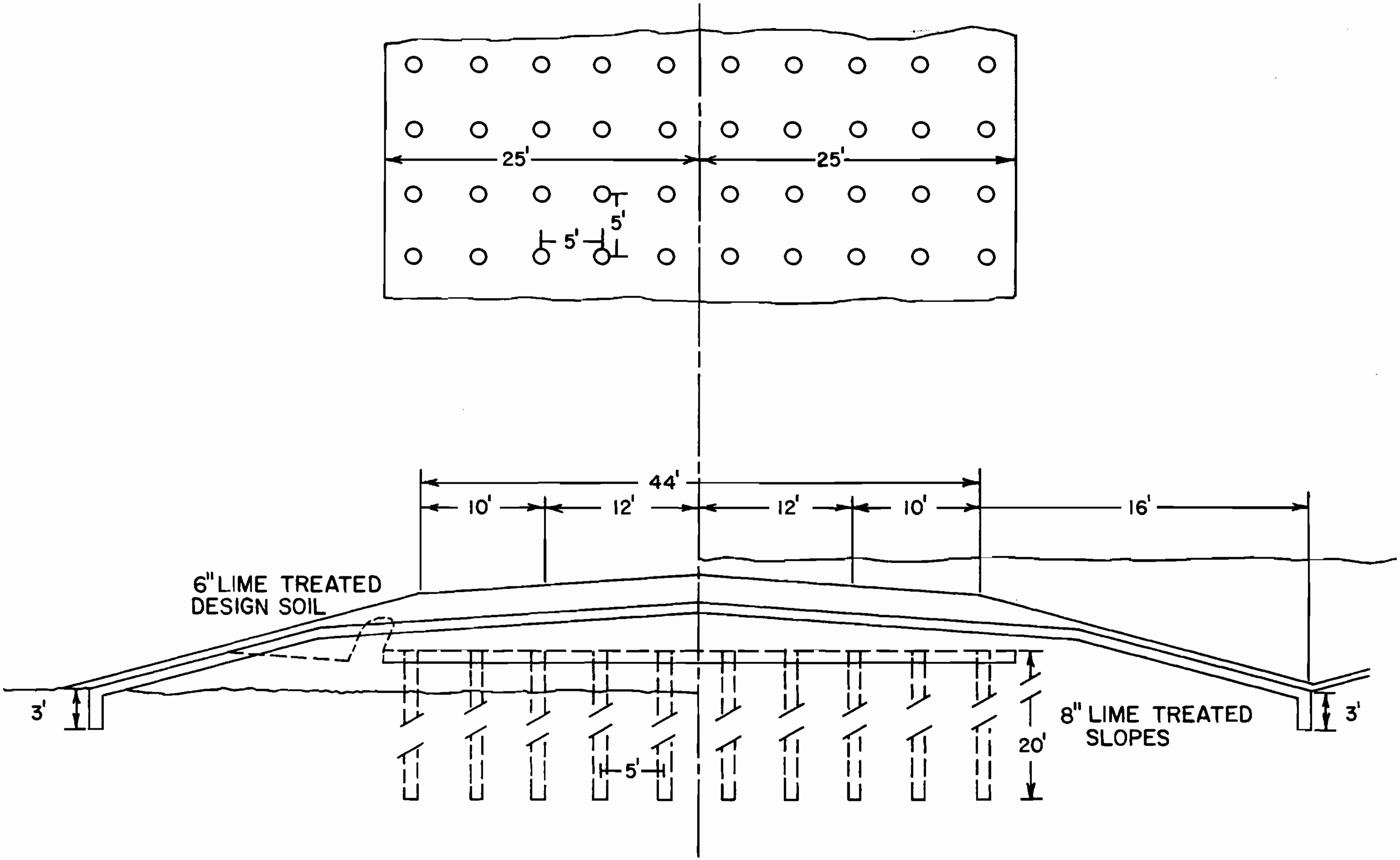


FIGURE I TYPICAL SECTION SHOWING DETAILS OF EXPERIMENTAL (FLOODING) SECTION. BETWEEN STATION 143 AND 154

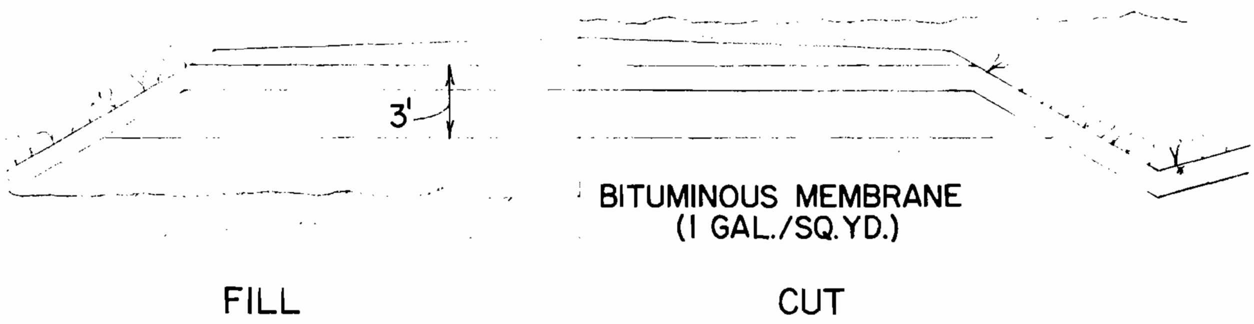


FIGURE 2. TYPICAL SECTION SHOWING DETAILS OF EXPERIMENTAL (BITUMINOUS MEMBRANE) SECTIONS BETWEEN STATION 139 AND 143 AND STATION 154 TO 159

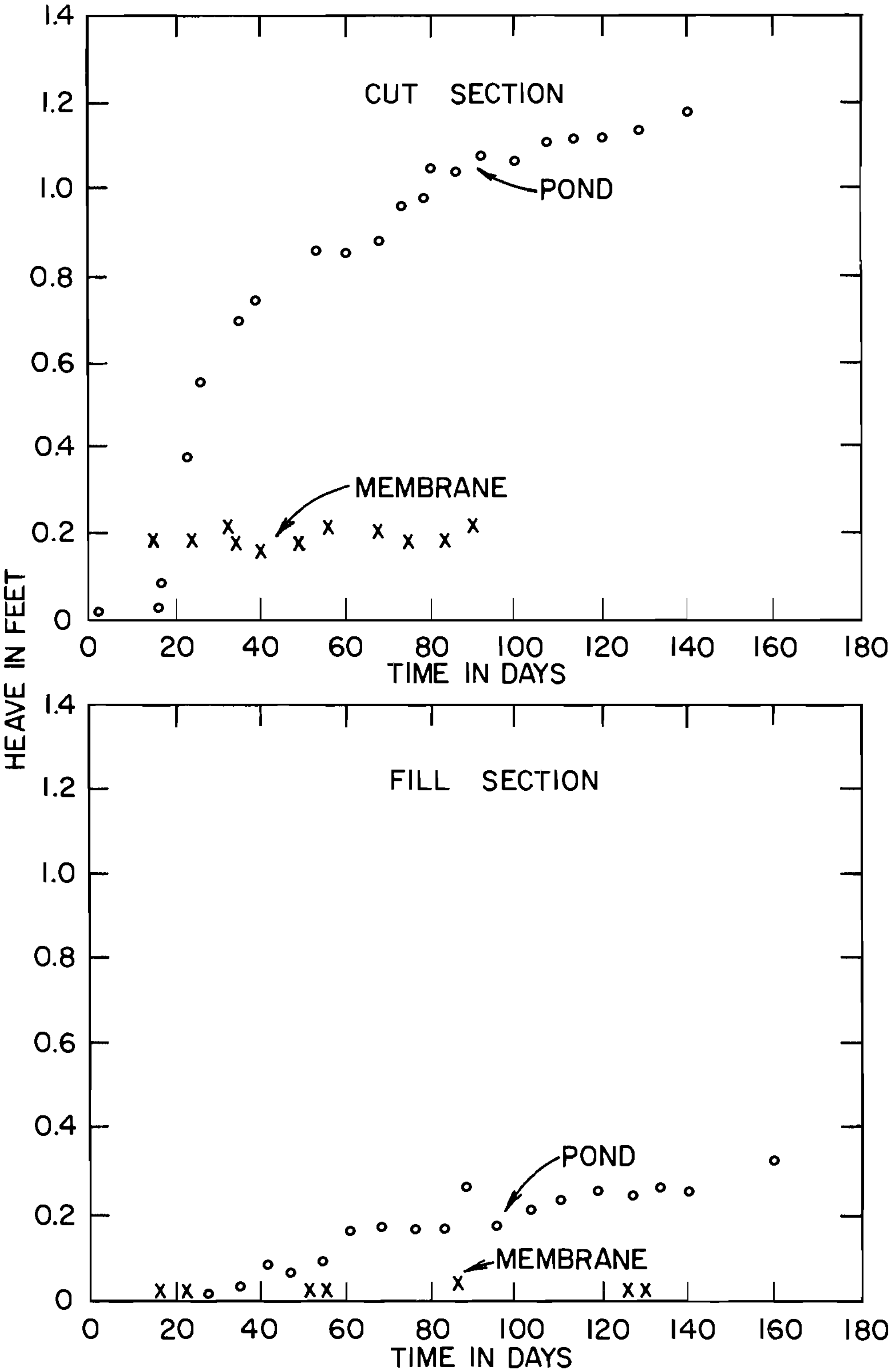


FIGURE 3. HEAVE BEFORE PLACEMENT OF BASE

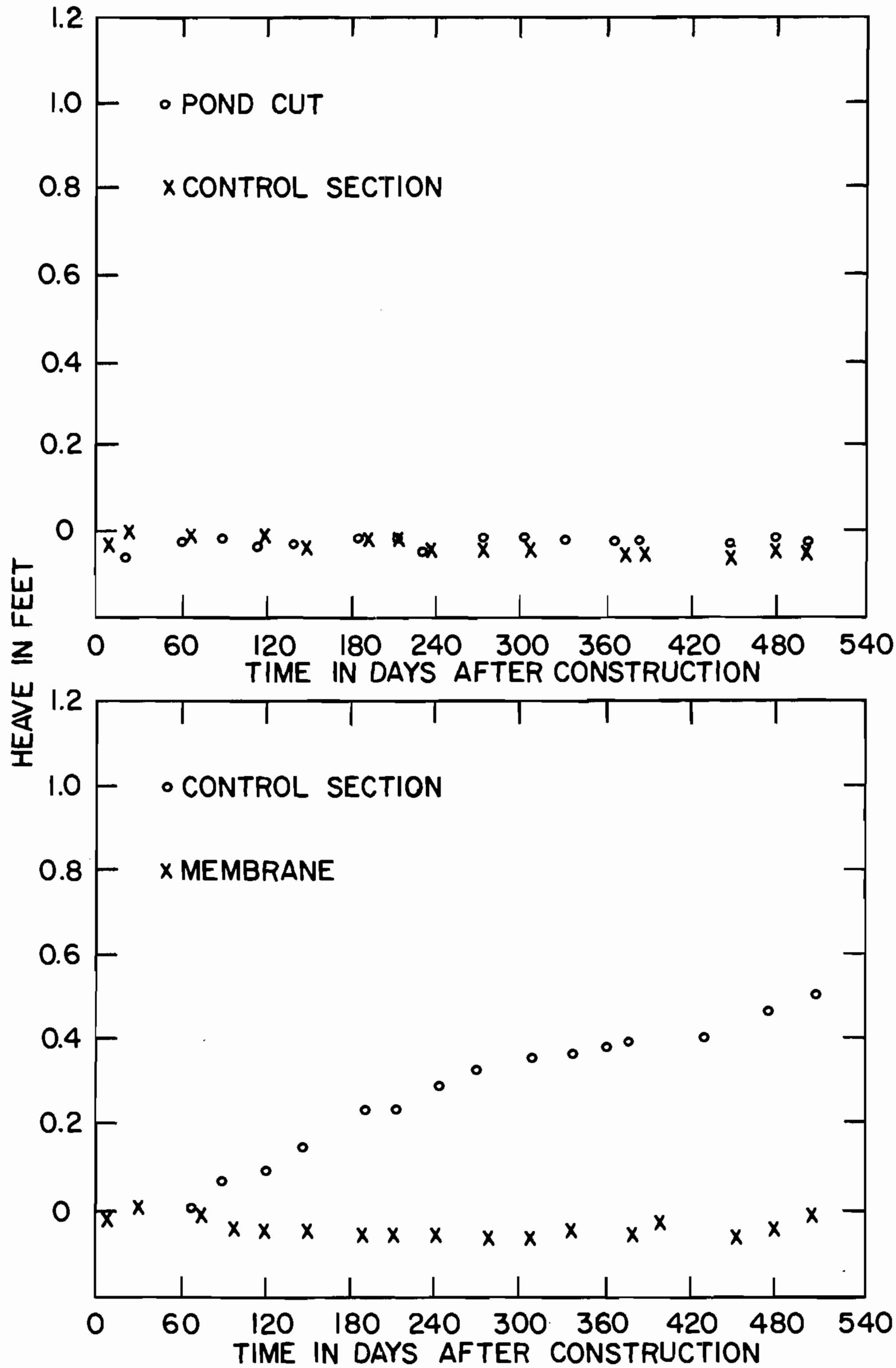


FIGURE 4 HEAVE AFTER COMPLETION OF CONSTRUCTION

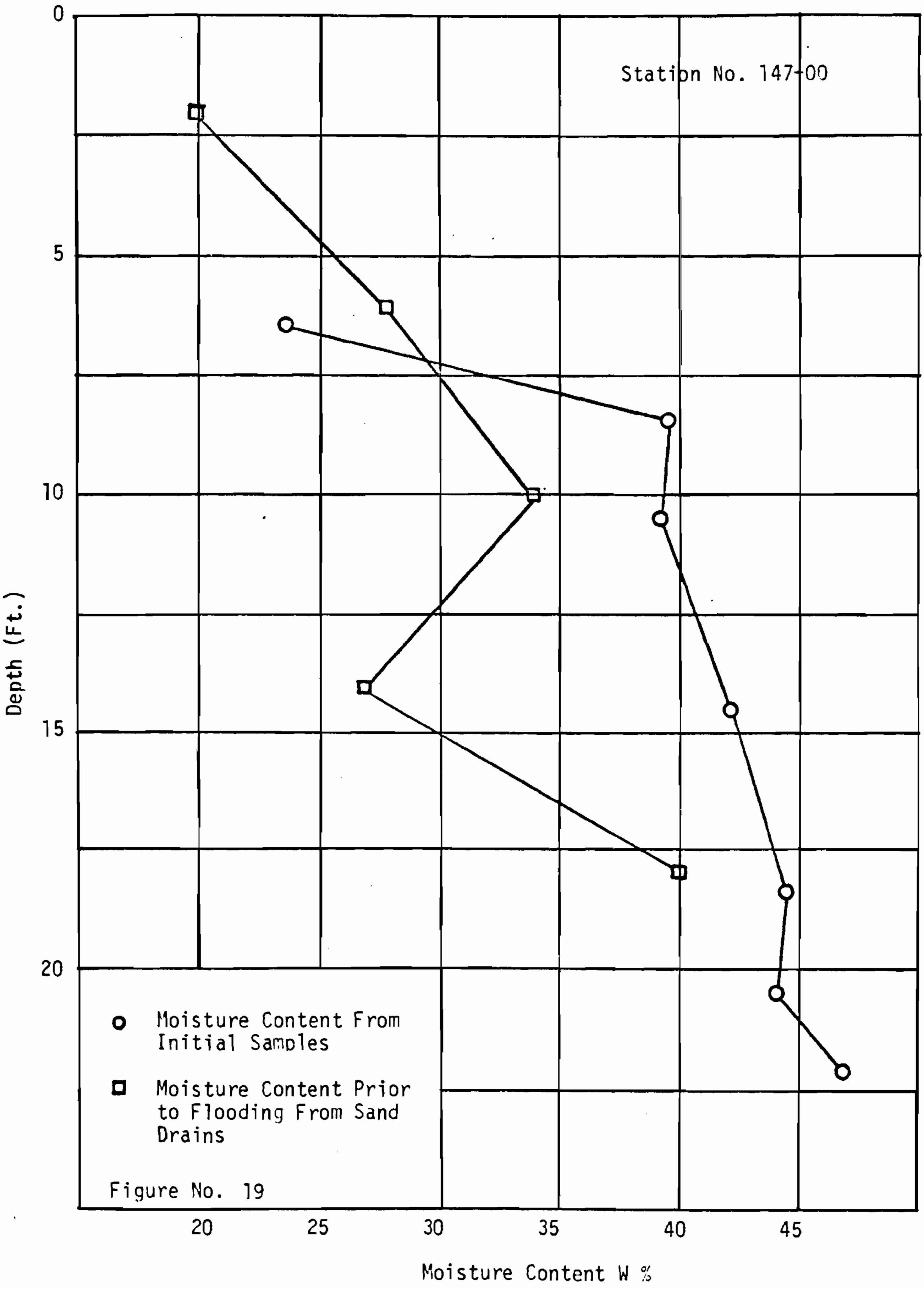


Figure 5. Moisture Versus Depth

Electro-Osmosis. The Arizona Highway Department Research Division during 1972 conducted an experiment to investigate the effect of various wetting agents and geometric arrangements of electrodes to promote the movement of water into the dry Chinle Clay before construction of the pavement.[13] In essence this is one method of ponding. This technique was developed on a small scale and the researchers believe it has promise. It is yet to be proven to be effective and economical for a full scale field test.

Dry-Land Farming. Dry-land farming is based on the farming practice of plowing the ground into furrows to collect rainwater and to increase the bulk permeability of the soil or subgrade and at the same time reduce capillary transport to the surface. In other words reducing evaporation from the subgrade and at the same time letting water in. This was tried on Interstate 30 near Atlanta, Texas.[17] The ground was kept plowed for twelve months before the pavement was added. Unfortunately there was little rainfall during this period. Moisture was only increased to a depth of about 3 feet and about 1 inch of swell due to moisture increases were observed. A strong disadvantage to this method is the long period of delay involved and not being able to control weather. More success might have been derived if some form of irrigation could have been employed.

Moisture Barrier by Membranes.

Moisture measurements beneath pavements in Oklahoma made by Haliburton are shown in Figures 6 and 7.[2] These are typical measurements made under a two-lane AC pavement with improved shoulders over asphaltic stabilized base and no subbase. Figure 8 shows measurement taken under

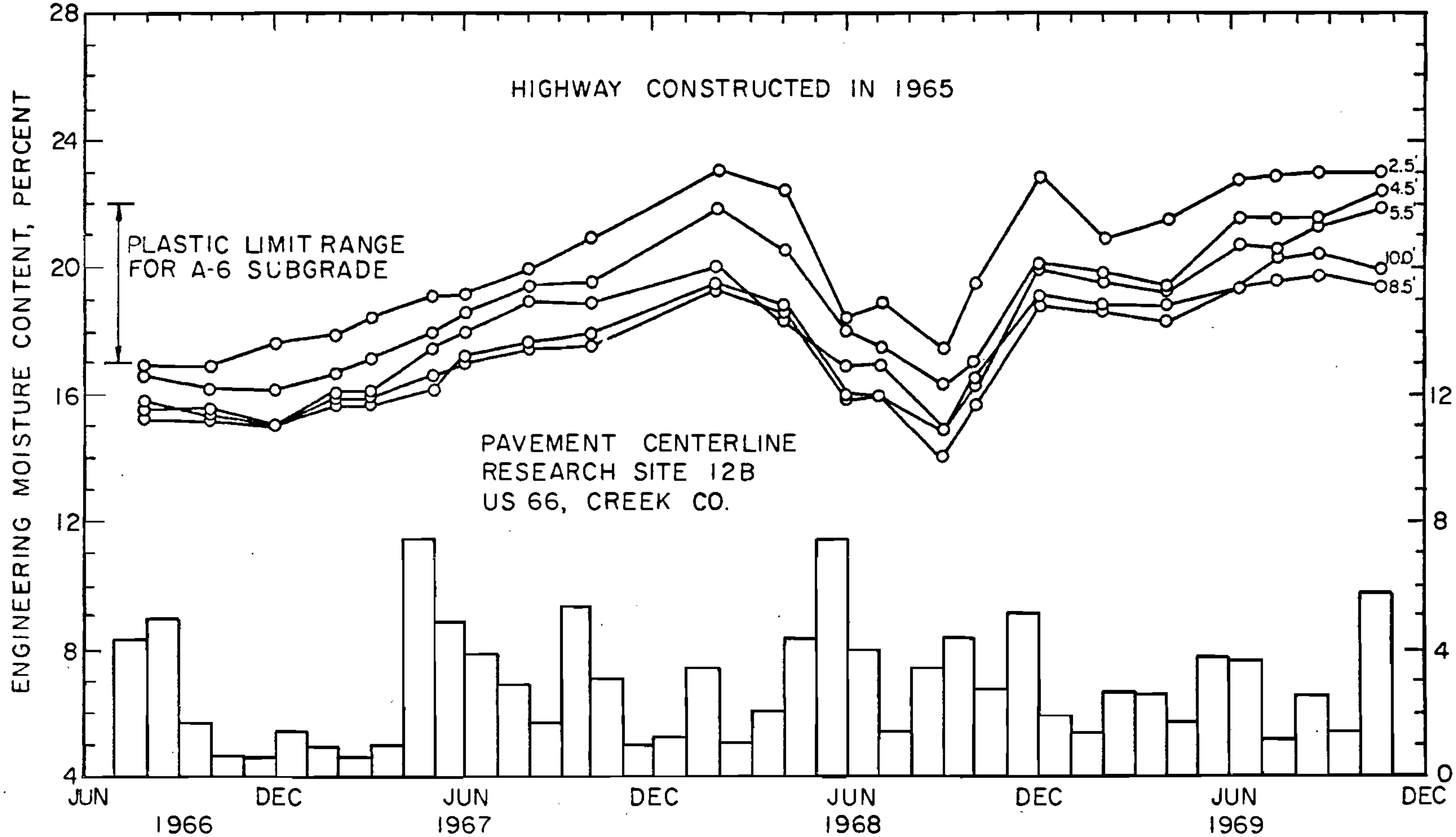


Figure 6. Moisture Variations at Selected Levels Beneath Pavement at Site No. 12

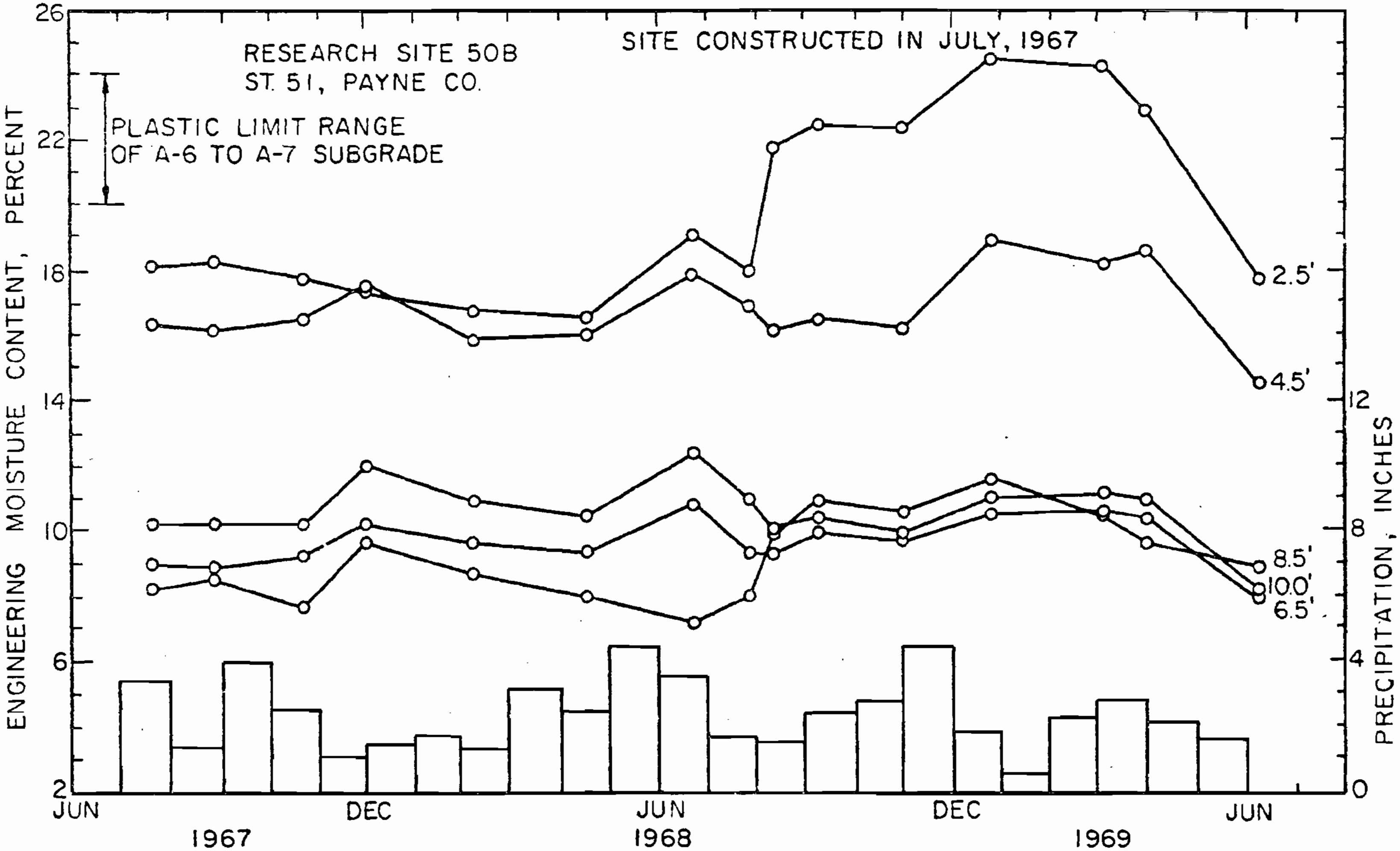


Figure 7. Moisture Variations at Selected Levels Beneath Pavement Centerline and Rainfall at Site No. 50

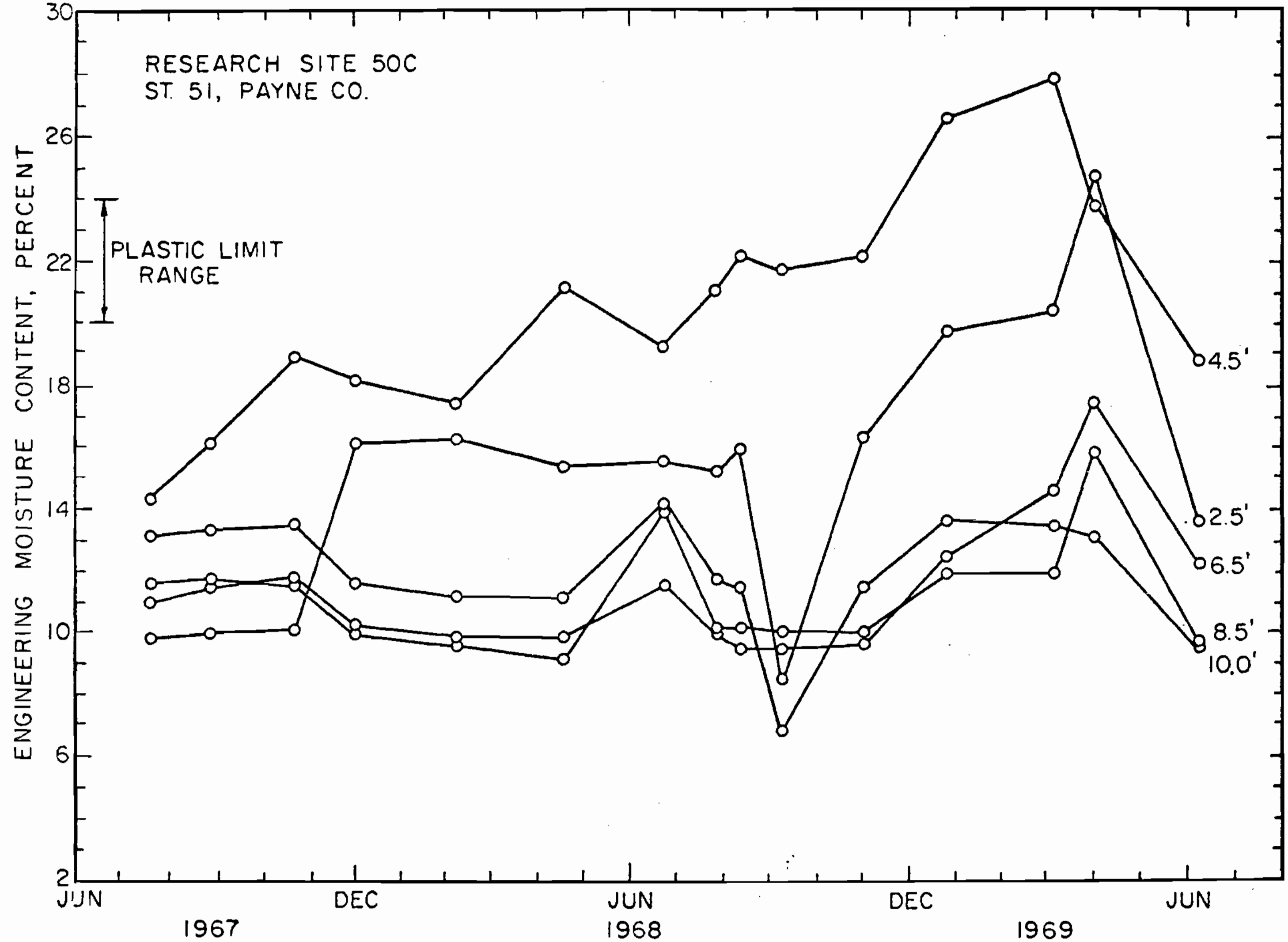


Figure 8. Moisture Variations at Selected Levels Beneath Shoulder at Site No. 50

the pavement shoulders. Moisture variation of this type can cause continued movement in swelling clays. Some states have choosen to try to prevent these types of variations by placing membranes over and sometimes around the expansive subgrades. As stated by Mississippi, the selection of an asphalt membrane will depend on the economics of the project. Their work did show that 1 gallon per square yard of asphalt was effective for 34 months in preventing moisture from entering the Yazoo Clay subgrade.

Colorado has tried encapsulation of soil as shown in Figure 9 as one method of preventing swell.[3] They concluded that this type of construction offers outstanding potential for the control of swelling soils. Recent developments in construction techniques and advances in material development have made this method competitive with other methods of stabilization or control of swelling soils. Colorado has large areas of expansive soils that include the Mancos and Pierre Shales, the Laramie Formation, the Denver Formation and some valleys containing recent deposits of plastic fine-grained soils.[1] Figure 10 shows another experiment tried by Colorado in which they used subexcavation and a membrane of catalytically blown asphalt at a rate of 1.3 gallons per square yard.[15] Full depth asphalt bases were also used. A summary of their conclusions are as follows:

1. Catalytically blown asphalt membranes can be placed for about 50 cents per square yard and are effective in maintaining as-constructed moisture in subgrade soils.

2. Full depth asphalt bases are effective in reducing moisture build-up in subgrade soils. Special precautions are needed to prevent moisture change cycles at the shoulders in order to prevent longitudinal cracking in the pavement a few feet in from the shoulder.

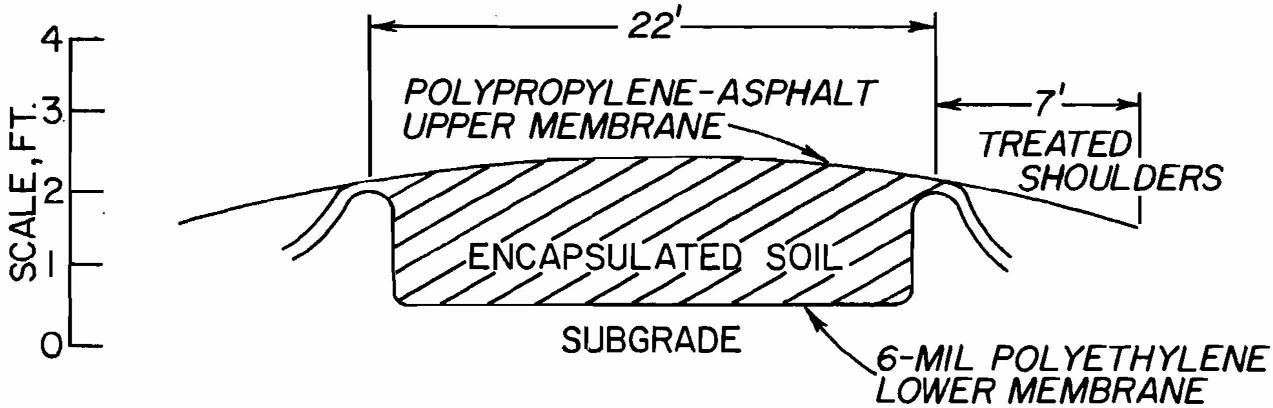


FIGURE 9 TYPICAL CROSS SECTION OF A MEMBRANE SOIL LAYER FOR AIRFIELDS

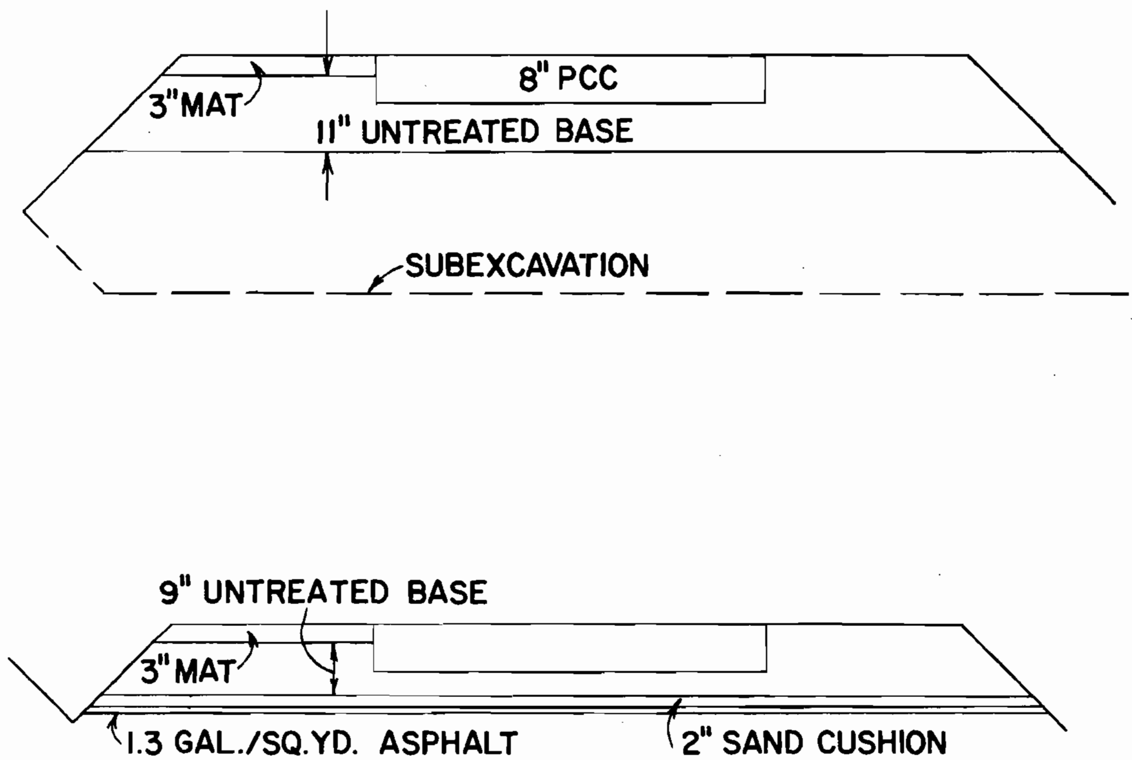


FIGURE 10 TYPICAL SECTIONS

3. Higher moisture build-ups occur under granular untreated bases in comparison to full depth asphalt bases.

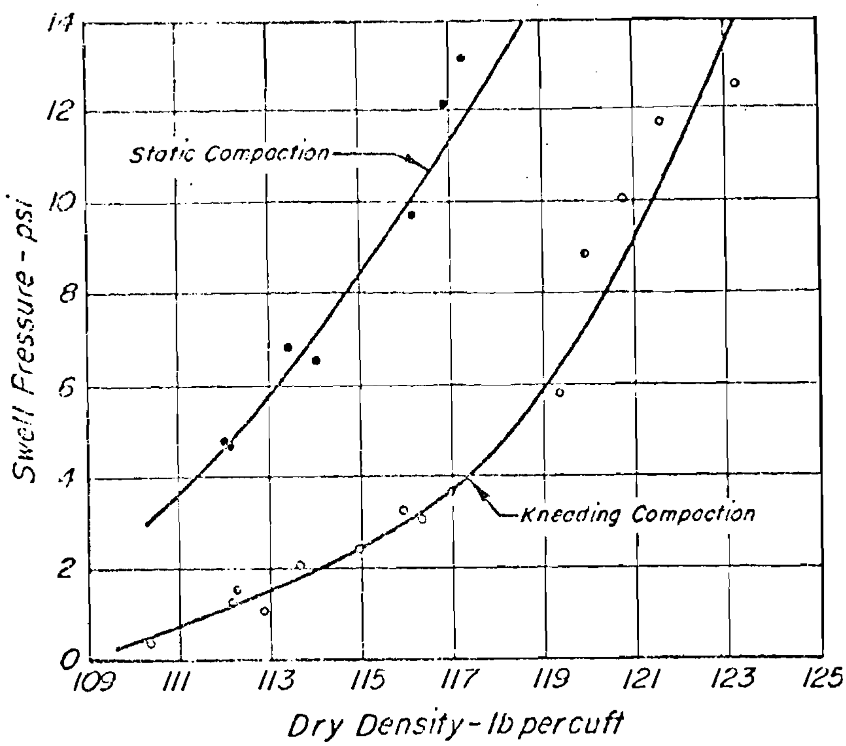
4. Encapsulated or enveloped subgrade soils remain at a lower moisture content. This does not appear to be economically practical. (Their intent with this type design was to increase strength plus prevent swell and it was found that there wasn't much strength increase).

Stabilization and Compaction.

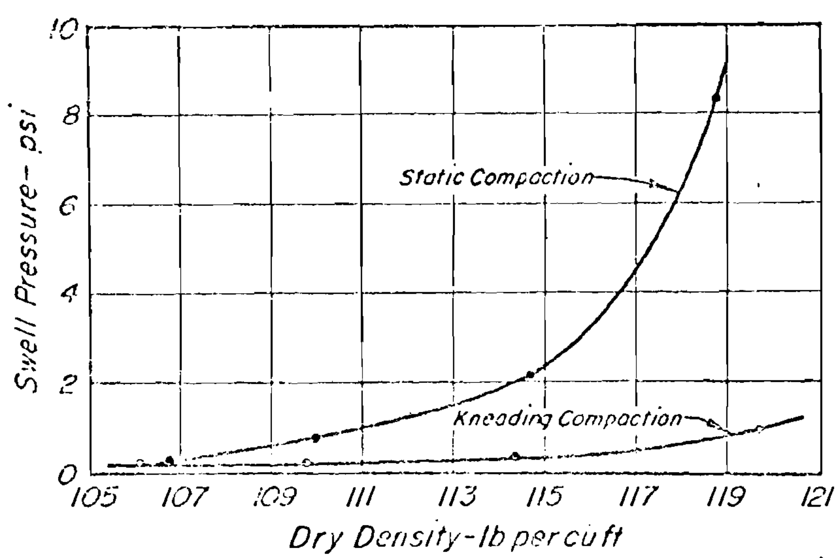
For a number of years in Texas it has been common practice to lime stabilize the top 6 to 8 inches of the subgrade where clay soils are encountered. The percentage by weight of lime is in the general range of 2 to 5. This depends mainly on engineering judgement. The main purpose of this treatment is to provide an all weather working table for the contractor and the plus of preventing swelling is not usually considered. Oklahoma in the late 60's introduced deep lime plowing in which lime stabilization was added in one pass for a depth of up to 2 feet.(4) Large tractors equipped with special rippers were used to mix the lime and soil. A 2 percent mixture of lime is added to the soil either by water slurry or dry. This method has had moderate success depending on the ability of the contractor to get a uniform distribution of lime for the entire depth and width. Texas tried this once as a corrective measure on a project under construction in the Dallas - Fort Worth area. In this project two to three inches of heave were observed before the base was applied after subgrade compaction. A field change added the deep plowed lime to this project and swell was sufficiently decreased to continue construction. Indications are that moderate heaving is now occurring on this project after about three years of performance.

High-Pressure Lime Slurry Injection. In the past there have been attempts to stabilize with lime injection under pressure for the purpose of adding stability and for the most part have been unsuccessful in dense clays.[5 & 10] At the present this is not a popular technique for heave control. California states that stabilization lime piles and lime slurry injection has questionable effectiveness except at times of maximum dessication when the soil is fissured. Many other chemicals have been investigated as stabilizers for expansive soils and none have been found that can compete with lime in terms of cost, effectiveness and practicality of application. Proprietary chemical soil stabilizers have not been proven to be effective against volume change.

Compaction. Placement moisture content and density and the method of compaction all have effect on the amount and rate of swelling that develops upon subsequent wetting of the soil. For example, Figure 11 shows the effect of static and kneading compaction on swell pressures. For many soils the method of compaction influences the soil structure for compaction wet of optimum. In such materials kneading compaction leads to a deflocculated structure and less swell and swell pressure, than for the static compaction and a flocculated structure. For soils of this type the soil should be compacted to a moderate density at a water content greater than optimum. This will also produce a soil with less permeability and prevent water from entering. One disadvantage is that soil will be weaker when compacted to this higher degree of saturation than soil compacted on the dry side of optimum.



(a) Pittsburg Sandy Clay



(b) Vicksburg Silty Clay.

Fig. 11. Effect of Method of Compaction on Swell Pressure for Samples Compacted to a High Degree of Saturation.

The Texas Highway Department for many years has used the generalized method known as the "Compaction Ratio"[6, 7 & 8] for selecting compaction densities. This method was based on construction and performance of numerous highways having been in service for many years and has application to soils varying from clays, silts and sands, to flexible base materials. This method was found to obtain the highest practical strength and that over-densification of swelling clays would not be permitted. The degree to which soils are compacted is based on the compactibility of the materials involved.

Remove the Undesirable Material.

Because of the costs involved in excavation, hauling and wasting soil, this has not been desirable from an economic standpoint. However in numerous cases this type of construction has been successfully used. Using select material and raising the grade line where possible is also common. Removing this material and mixing it with the desired water content and recompacting at the desired density is another method also used. Each of these methods should be considered based on the economics involved. Usually, replacing the bad material at the proper moisture content is not desirable without some other form of stabilization. It is common to use these types of treatment in combination with an asphalt membrane; one example is shown previously in Figure 10. In Texas in the very active clays where high serviceability is required both subexcavation and select fill of 3 and 4 feet respectively have been used. For the backfill and select-material highly permeabile material which might serve as a transporter of water to the lower lying clays should be avoided.

Maintainable Design.

Many designers have faced the fact that for certain situations there is no practical way to eliminate swell in the initial construction. If money is available, then time of construction may not be and in some cases money is just not available. In these cases the pavement is built so that it can be maintained or reworked with the least interference to traffic. In some cases this means stage construction with the addition of future overlay which will serve as Level-up and as structure. In some cases this may mean building a thick asphaltic concrete surface which can be heater-planned when bumps occur.

In most cases where swelling cannot be eliminated, pavement structures which cannot be maintained should not be built. Some states have gone as far as not building concrete pavement when swelling clays are encountered.

Other Procedures.

Designing a pavement to withstand the stresses in swelling or to constrain the soil against movement would produce costs out of the range of money available for highway pavement construction. If possible, moving to a new site to avoid the clays would be desirable but in most cases a highway that cuts across country can not avoid all bad clays.

CHAPTER 3. SUMMARY

Construction practices to prevent heave should be based on total economics just as all types of engineering should be. Most states consider this type of construction to be experimental and many states have research going at this time. The literature at the present time indicates that an asphalt membrane at the top of the subgrade is a promising and economical way of reducing swell. Ponding with sand drains looks very good according to Mississippi's research on the Yazoo Clay. The most common method of handling heave is to construct a pavement structure which can be maintained if necessary.

An excellent summary of considerations that can act as good check points in selecting a method of controlling heave is included in the Appendix. This summary was taken from Mitchell's paper that was presented to the Denver Workshop last December.[10]

REFERENCES

1. Brakey, Bud A., "Moisture Stabilization by Membranes, Encapsulation and Full depth Paving," Colorado Division of Highways, Presented to the FHWA Workshop on Expansive Clays and Shales in Highway Design and Construction at Denver, Colorado, December 1972.

2. Haliburton, Allan T., "Subgrade Moisture Variations," Research Project 64-01-3, Oklahoma State University, August 1970.

3. Hammitt, George M., and Richard G. Ahlvin, "Membrane And Encapsulation of Soils for Control of Swelling Soils," U. S. Army Engineer Waterways Experiment Station, Paper presented to the FHWA Workshop in Denver Colorado, December 1972.

4. Hartronft, B. C., etc., "A Study of Lime Treatment of Subgrades to Depths of Two Feet," Research and Development Division, Oklahoma Highway Department, Oklahoma City, 1969.

5. Lundy, H. L. Jr. and B. J. Greenfield, "Evaluation of Deep In-Situ Soil Stabilization by High-Pressure Lime-Slurry Injection," HRB Record 235, 1968.

6. McDowell, Chester, "Compaction Control by Ratio of Volume of Gyratory Specimens to Volume of Test Holes," Texas Highway Department, TP 9-69E, September 1969.

7. McDowell, Chester, "Principles of Controlled Compaction," WASHO Proceedings 1957.

8. McDowell, Chester, "Selection of Densities for Subgrades and Flexible Base Materials, HRB Bulletin 93, 1954.

9. McDowell, Chester, R. L. McKinny, Jr., and J. E. Kelly, "The Waco Ponding Project," Research Report No. 118-8, Center for Highway Research, The University of Texas at Austin, September 1969.

10. Mitchell, James K., "Control of Volume Changes in Expansives Earth Materials," University of California, Berkeley, Paper Presented to the FHWA Workshop in Denver Colorado, December 1972.

11. O'Bannon, Charles E., "Stabilization of Chinle Clay by Electro-osmosis and Base Exchange of Ions," Arizona State University, February 1973.

12. Paul, T. C., etc., "CRCP in Mississippi," A Paper Submitted for Presentation at HRB, January 1974.

13. Paul, T. C., etc., "Mississippi Experimental Work on Active Clays," Paper Presented to the FHWA Workshop at Denver, Colorado, December, 1972.

14. Stevens, John B., and Hudson Matlock, "Observations of Expansive Clay in Roadways," Center for Highway Research, University of Texas at Austin, Paper Presented to the FHWA Workshop in Denver, Colorado, December, 1972.

15. "Treatment of Swelling Soils West of Agate, Colorado," Division of Highways, State of Colorado, 1st Interim Report, February, 1969.

16. Watt, W. G., and M. L. Steinburg, "Measurement of a Swelling Clay in a Ponded Cut," Center for Highway Research, University of Texas and The Texas Highway Department, Report No. 118-6, June, 1972.

17. Wise, John R., and W. R. Hudson, "An Examination of Expansive Clay Problem in Texas," Center for Highway Research, The University of Texas, Report No. 118-5, July, 1971.

APPENDIX

Methods for Volume Change Control

TABLE 1

METHODS FOR VOLUME CHANGE CONTROL WITHOUT ADDITIVES

METHOD	GENERAL CONSIDERATIONS	REFERENCES
COMPACTION	-Compact wet of optimum to moderate density -Kneading compaction, as by sheepsfoot roller, preferable -Low permeability of material, if compacted as above, will cause any subsequent expansion to be slow -Excavation and recompaction of existing soil prior to use as subgrade may be required -Laboratory test methods should duplicate soil structure in the field	Colorado (1964) Holtz (1959) Holtz & Gibbs (1956) McDowell (1959) Mitchell et al (1965) Seed et al (1962)
PREWETTING	-Provides for soil wetting and expansion prior to construction -Spraying or ponding may be used -Requires a long time -Can use to straighten distorted slabs -Loss of strength and increase in stickiness may make subsequent construction difficult -Lime treatment after wetting useful to provide a firm working table -Later drying may cause shrinkage	Benson (1959) Dawson (1956) Dawson (1959) Haynes & Mason (1965) Holtz (1959) Holtz & Gibbs (1956) McDowell (1965) McDowell (1959)
HEAT TREATMENT	-Heating to 200°C± may significantly reduce swelling characteristics -Heating to several hundred degrees C may eliminate water sensitivity altogether -Soil fusion possible at temperatures of 1000°C -Heat treatment may improve susceptibility to stabilization by other methods -Practical, economical methods not yet available in U.S.A.	Aylmore et al (1969) Chandrasekharan et al (1969) Post & Paduana (1969)

TABLE 2

METHODS FOR VOLUME CHANGE CONTROL USING ADDITIVES

METHOD OR ADDITIVE	EFFECTS ON SOIL	METHOD OF APPLICATION	COMMENTS	REFERENCES
Lime Treatment	Reduce or eliminate swelling by ion exchange, flocculation, cementation, alteration of clay minerals	Remove, mix, replace or mix-in-place	-Only suitable for shallow depths -Mixing difficult in highly plastic clays -Delay between initial addition of lime and final mixing and placement improves ease of handling and compaction -2-6% lime usually required	California (1967) Diamond & Kinter (1966) Herrin & Mitchell (1961) Jones (1958) Mitchell & Hooper (1961) Thompson (1972)
		Deep-plow	-Treat depths to 36" -Can use conventional equipment -Requires careful quality control	
		Lime slurry injection; lime piles	-Controversial -Limited by slow lime diffusion rate -May be effective in fissured material	Ingles & Neil (1970) Lundy & Greenfield (1968)
		Mixing-in-place: piles and walls	-Not yet investigated -Might be suitable in highly plastic soils for treatment to large depth -Could use dry lime, lime mortar or slurry	See Sherard (1969) for technique utilizing portland cement

METHOD OR ADDITIVE	EFFECTS ON SOIL	METHOD OF APPLICATION	COMMENTS	REFERENCES
Cement-Treatment	Reduce or eliminate swelling by cementation, ion exchange, and alteration of clay minerals	Remove, mix, replace Plant mix Deep plow (?)	-Cement may be less effective than lime in highly plastic clays -Mixing difficult in highly plastic clays -Deep plow method not yet investigated (?) -Reduction in swelling noticeable for cement contents >4-6%	Highway Research Board (1961) Moh (1962)
		Mixing in place	-No excavation and backfilling required -Has been used for construction of piles and walls -Better, more economical equipment needed	Sherard (1969)
Chemicals -Hydroxides -Chlorides -Phosphoric Acid -Carbonates -Sulfates -Lignins -Siliconates -Asphalts -Quaternary Ammonium Chloride Proprietary: -"Compaction Aids" -Other	Various effects have been measured or hypothesized, including: -Reduced plasticity -Improved compaction -Reduced swell -Waterproofing -Preservation of soil structure -Increased strength -Increased or decreased permeability	Usually remove, mix, and replace or mix-in-place In some instances spraying or injection is used Electro-osmosis may be useful in special cases. -Diffusion may be effective.	-Problems of mixing or injection may be significant -No chemical additives for control of volume change appear to be available that are effective, permanent, and economically competitive with lime or cement when large volumes of soil must be treated -Calcium chloride may be effective at least temporarily in soils with expanding lattice clays. It may be useful in soils with a high sulfate content. -A number of proprietary formulations have been marketed. The beneficial effects of these materials have not generally been documented.	Katti & Barve (1962) Blaser & Scherer (1969) Hoover et al (1960) Freitag & Kozan (1961) Anday (1970) Landrum et al (1971) Larutan Corp. U.S. Patent Office (1968) Zel Chemical Co. Central Chem. Co. Ion Tech (1970)