

STATE-OF-THE-ART REVIEW OF EXPANSIVE  
SOIL TREATMENT METHODS

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## ABSTRACT

Every year, several millions of dollars worth of damage is done to homes located in states such as California, Colorado, and Texas, where expansive soils are in abundance. Soil treatment using various techniques is commonly used to improve the expansive soil on the site to avoid excessive swelling. The Chemical treatment is the most widely used site improvement technique. A companion report to this presented the results of a thorough laboratory investigation of the effectiveness of Fluid 705, as a chemical agent for expansive soil treatment. In this report, several other expansive soil treatment methods and their effectiveness as determined by a number of investigators are discussed. Also, recommendations for further research for developing more effective treatment procedures for expansive soils are presented.



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## 1. INTRODUCTION

Every year in the United States, several millions of dollars worth of damage is done to homes located in states such as California, Colorado, and Texas, where expansive soils are in abundance. The clay mineral that is primarily responsible for such expansive clay related swelling problems is montmorillonite. In its pure form montmorillonite may swell up to as high as 15 times its dry volume. Most expansive soils contain varying proportions of other clay minerals in addition to montmorillonite, and therefore the typical ground swell is on the order of 15%. However, this small heave can result in significant swelling pressures and loads and usually cause extensive damage to the architectural appearance of a house as well as destroy the structural integrity of buildings in several instances.

Because of their low permeability, expansive soils are incapable of adequate drainage, and swell substantially during wetting and shrink when exposed to a long period of no exposure to water. This continuous seasonal wetting and drying results in large movements in the structural elements in the house and finally causes major cracks to develop. One method of determining the presence of an expansive soil is to use routine laboratory tests on representative samples from the site. McKeen (26) reported that the initial investigation should rate the soil based on plasticity index and linear shrinkage, as summarized in Table 1. Soils that fall in the category of low expansion potential require no special attention during the design of a light structure on them. The soils in the medium to high expansion potential category require special considerations in the design of structures founded on these soils. They

TABLE 1  
Soil Expansion Potential

Soil Property	Soil Expansion Potential (%)		
	Low	Medium	High
Plasticity Index, PI	PI<10	10<PI<20	20<PI
Linear Shrinkage, LS	LS<8	8<LS<12	12<LS

also require adequate precautionary measures to prevent excessive structural damage. Soil treatment using various techniques is commonly used to improve the expansive soil on the site to avoid excessive swelling. Of these treatment methods the most popular methods are as follows:

- (a) Chemical Treatment
- (b) Prewetting
- (c) Soil Replacement
- (d) Compaction Control
- (e) Electrochemical Hardening

The Chemical treatment is the most widely used site improvement technique. A companion report to this presented the results of a thorough laboratory investigation of the effectiveness of Fluid 705, a product supplied by Soil Technology, Inc., as a chemical agent for expansive soil treatment. In this report, several other expansive soil treatment methods and their effectiveness as determined by a number of investigators are discussed.

## 2. CHEMICAL TREATMENT

Chemicals are the most widely used treatments to control expansive soils. Lime and cement are used while salts and various inorganic compounds are being utilized to a lesser degree.

### 2.1 Lime Treatment

The most widely accepted and controversial chemical treatment is lime. The construction trade, according to Winterkorn (47), recognizes certain types of lime for use, these limes are listed in Table 2. The higher the magnesium content of the quick or hydrated lime the lesser is the water affinity and the heat developed in mixing with water. According to Tringale and Mitchell (45), the lime treatment of soils using both hydrated lime ( $\text{Ca(OH)}_2$ ) and quicklime ( $\text{CaO}$ ) has been used extensively in conjunction with pavement construction, embankment lining and repair, and railroad subgrades. The South Dakota Department of Highways has used lime successfully to control expansive soils on ten Interstate and three primary construction projects. Their laboratory tests have shown that lime reduced the amount of expansion in some soils from 41 percent to as low as 3.6 percent. Also their experience has shown that lime-treated roadbeds apparently withstand the freeze-thaw cycles that breakup highways in that state. Tests by other groups have shown that additions of lime from 2 to 8 percent, by weight, decrease the plasticity index, linear shrinkage, liquid limit and swell and increase the permeability and shear strength of expansive clays. Other states including Texas and Colorado with problems related to expansive soils, have used lime stabilization. For instance, the Texas Highway Department, in 1969, used nearly 1/2 million tons of lime for stabilization. The Dallas-Fort Worth Regional

TABLE 2

## Lime Materials Used In Construction

TYPE	FORMULA
Calcia (High-Calcium Quicklime)	$\text{CaO}$
Hydrated High-Calcium Lime	$\text{Ca(OH)}_2$
Dolomitic Lime	$\text{CaO} + \text{MgO}$
Normal Hydrated or Monohydrated Dolomitic Lime	$\text{Ca(OH)}_2 + \text{MgO}$
Pressure Hydrated or Dihydrated Dolomitic Lime	$\text{Ca(OH)}_2 + \text{Mg(OH)}_2$

Airport used about 300,000 tons of lime, in what may have been the world's largest lime stabilization project. For this project 6 to 7 percent of lime was used for stabilization. First the stiff clay subgrade was broken down with a disc harrow and then the lime was applied in slurry form. This project showed that not only can clay be transformed into a non-swelling soil, but also can improve the structural capacity of the treated layer. Kelly and Kelly (18) state that if lime is added and adequately mixed, highly plastic expansive clay can be transformed into a stable, nonswelling mixture. Although lime has been used mainly for the treatment of highly plastic and expansive clays, it can also cause beneficial property changes in soft sedimentary, inactive clays.

A way of mixing the lime that is becoming more popular most recently is by pressure-injection. In this method, the lime is pumped

under pressure through hollow injection rods into the soil, which are spaced 12 inches (31 cm) apart. The lime slurry is injected until:

- (a) The soil will not take any additional slurry.
- (b) Slurry is running freely on the surface or out of previous injection holes.
- (c) Injection has fractured or distorted the natural ground surface.

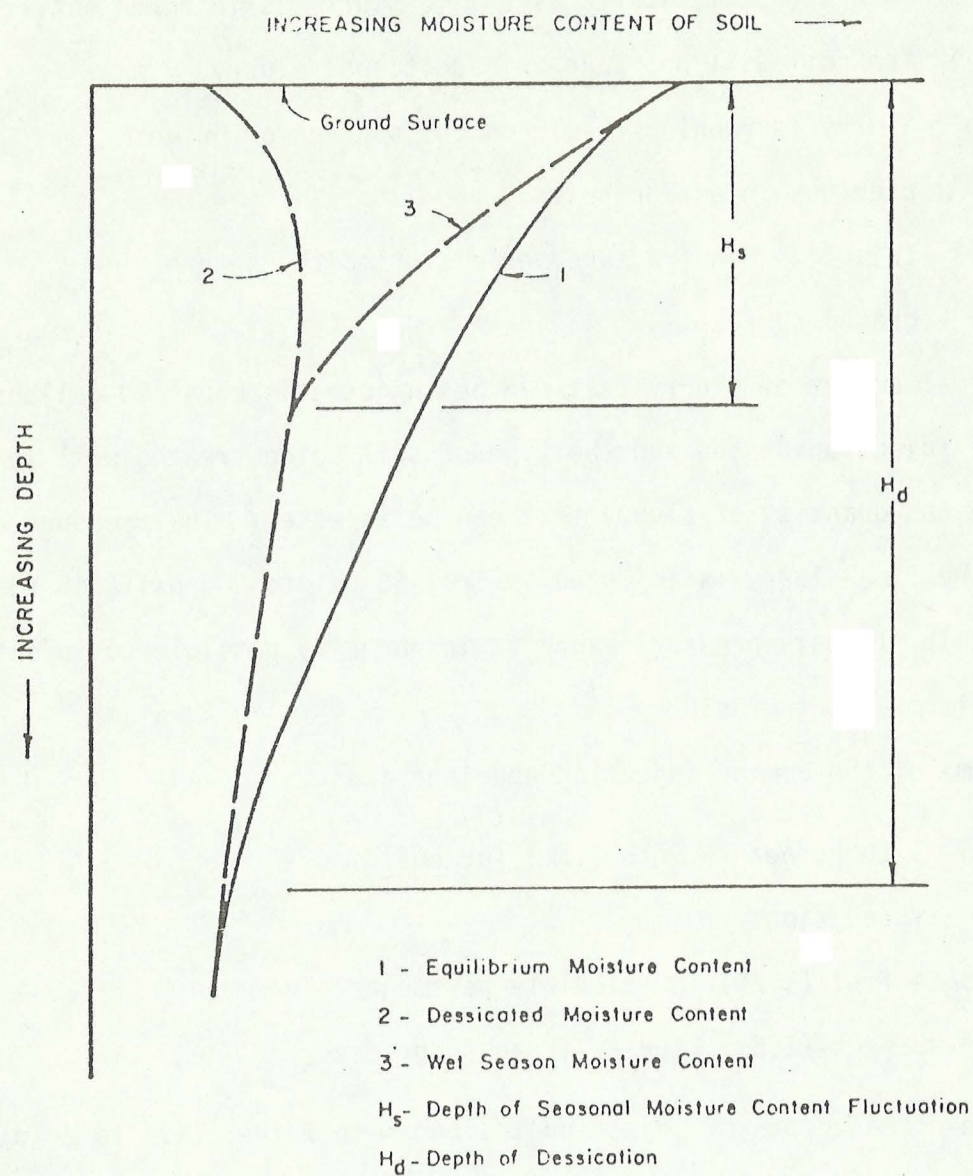
The normal amount of slurry that can be injected is about 10 gallons/foot of injection depth, and the type of soil being treated will influence the quantity of slurry that can be injected. The pressure at which the lime slurry is injected is from 50 psi to 200 psi (345 to 1380 KPa). In this pressure range it is normally possible to inject the maximum amount of slurry.

Some of the common injection spacings are:

- (a) 1 to 5 feet (0.9 to 1.5m) for building foundations.
- (b) 4 feet (1.2m) for flexible pavements.
- (c) 5 feet (1.5m) for railroad subgrades.

The normal depth of injection is from 5 to 7 feet (1.5 to 2.1m). This is below the zone of critical moisture change in most cases. A plot of typical moisture content as it varies with depth is shown in Fig. 1.

The parameters that are used to calculate the amount of lime to use are: quantity per unit time and groutability ratio. The quantity that can be injected in a given period of time, according to Thompson (42), is:



Moisture Content Variation with Depth Below Ground Surface

Figure 1

$$Q = \frac{\rho g}{n} \left( \frac{p}{l} \right) K A t \quad (1)$$

where:

A = cross-sectional area over which pressure acts

n = viscosity of fluid

g = acceleration due to gravity

p = pressure head

$K = cd^2$ , intrinsic permeability of medium, where  
c is a shape factor and d is average pore size  
of medium

l = length over which pressure head acts

Q = quantity of fluid flow

$\rho$  = density of fluid

t = time of pressure application

This equation indicates that the following major factors control the quantity of fluid that is injected.

- (a) Fluid viscosity
- (b) Injection pressure and time
- (c) Intrinsic permeability of the soil medium

The groutability ratio, as recommended by Johnson (15), should be greater than 20 to 25 for successful cement grouting.

$$\text{GROUTABILITY RATIO} = \frac{D_{(15)} \text{ SOIL}}{D_{(85)} \text{ GROUT}} \quad (2)$$

Where:

$D_{(15)}$  = particle size for which 15 percent of the soil fraction is finer, and

$D_{(85)}$  GROUT = particle size for which 85 percent of the cement grout is finer.

As with any method, there are both proponents and opponents to the pressure-injected lime (PIL) method. At a conference in Denver in the early 1970's several papers were presented concerning PIL. Some of the comments were:

- (a) Kelly and Kelly (18) referred to the successful use of PIL to treat the swelling soils under the Dallas-Fort Worth regional airport terminal buildings. A vertical movement of 0.1 foot, was the only swelling reported after the PIL treatment was applied, and this was only in one location.
- (b) Krazynski (20) states that, in his opinion, lime injection efforts are not very effective.
- (c) Teng, Mattox and Clisby (41) indicated that research and experience have shown that lime stabilization provides the necessary moisture barrier to prevent the swelling of a soil.
- (d) Blacklock (2) indicated that, based on results, PIL was definitely a solution to the swelling problem. Some of the good results have been with railroad stabilization (5, 22, 33, 52), subgrade stabilization (17) and earth dike stabilization (17).

According to Graf (10):

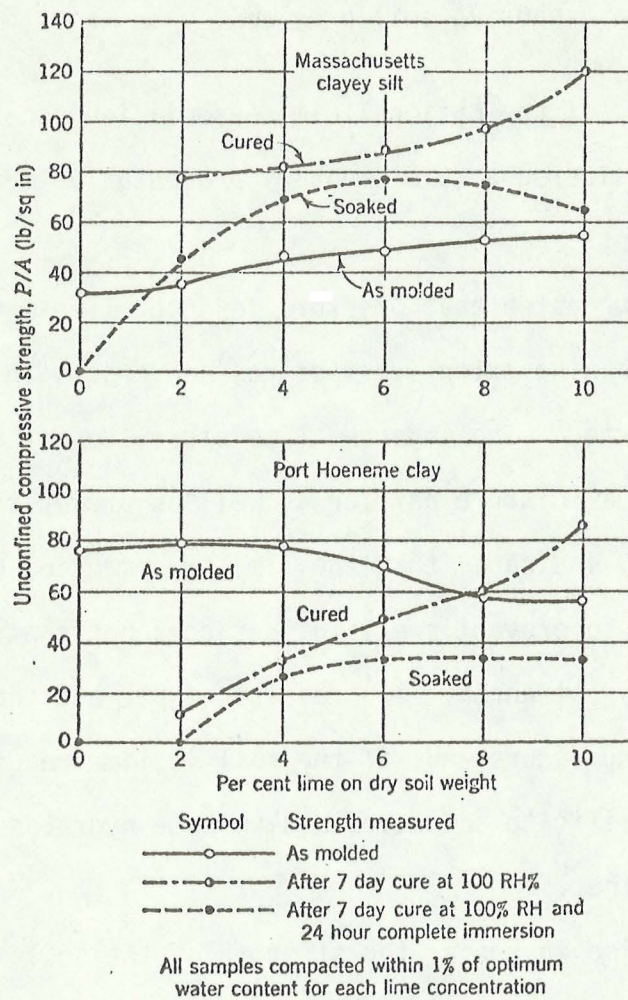
- (a) It is impractical, if not impossible, to treat an entire mass of clay by injection of lime.
- (b) Both lime and portland cement injection have limited use to reduce expansive soil problems.

Gutschick (8), of the National Lime Association, states that lime injection is, "considered a supplementary preventative measure for over-coming soil movement".

It has been suggested that pressure injected lime may be effective in soils containing extensive fissures and cracks into which the slurry can be injected. The injected lime slurry deposited in fissures appears to develop a moisture barrier as well as prewet the soil. However, Stocker (40), indicates that the limited cementing caused by the lime is sufficient to prevent swelling, but does not contribute to increasing the shear strength. Two results of PIL are that a certain amount of prewetting occurs and, if the soil is lime reactive, the formation of calcium silicate and calcium aluminate hydrates to cement the soil minerals together.

In general, lime increases the strength of the soil into which it is injected. This is shown in Fig. 2 and Table 3. Lime also increases the strength of soil over a period of time as shown in Fig. 3.

Further evidence of the desirable effects of lime on montmorillonitic clays have been reported by Borchart (1978), Browns and Boman (1979), and by Handy and Williams (1966) as shown in Figs. 4-6. From Fig. 4 it is clear that the addition of quicklime increases the remolded shear strength of expansive soils in the range of water contents lower than 60%. The reduction in vertical movement under a structure due to



Effect of Lime on Compressive Strength of Two Soils (From Lambe (21))

Figure 2

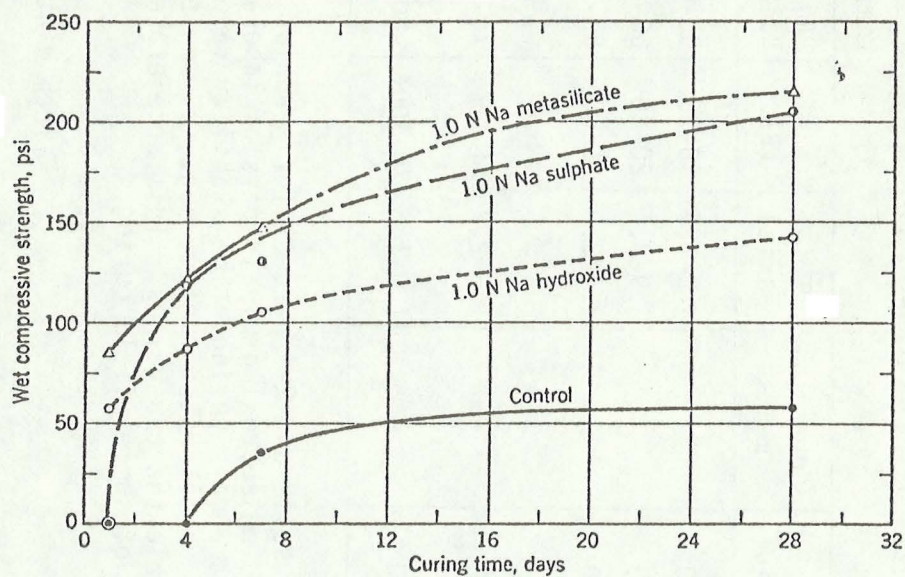
TABLE 3

Approximate Comparison of Stability Test Data, with and without Lime

Type of Soil	Untreated					Lime Treated*				
	Tri-axial	CBR	R-Value	k-Value	Cohesiometer	Tri-axial	CBR	R-Value	k-Value	Cohesiometer
Heavy Clay	5.5	2	20	100	-	3.2-3.5	15-30	55-69	250-350	350-850
Light Clay	4.5	5	35	150	-	2.9-3.4	20-40	60-75	300-400	450-700
Sandy Clay	3.7	12	50	200	-	2.4-3.0	35-60	65-80	400-500	550-850
Granular Soil PI-8+	3.2	30	65	250	-	1.5-2.7	50-75	70-80+	450+	650+
Clay Gravel PI-6 to 10	2.5	50	75	400	-	1.0-1.6	70-100+	80+	500+	800+

\*Based on use of 4-6 percent lime for clay soils and 2-4 percent for granular and clay-gravel types. Triaxial and Cohesiometer values are based on approximately 18 days of laboratory curing. CBR on 4 days curing (soaked), and R-value on about 2 days curing. The stability values of lime-treated specimens increase markedly with longer or accelerated curing, e.g., curing CBR specimens for 2 days at 120°F prior to soaking will nearly double the CBR values. This accelerated curing would correspond approximately to 30 to 45 days of summer field curing.

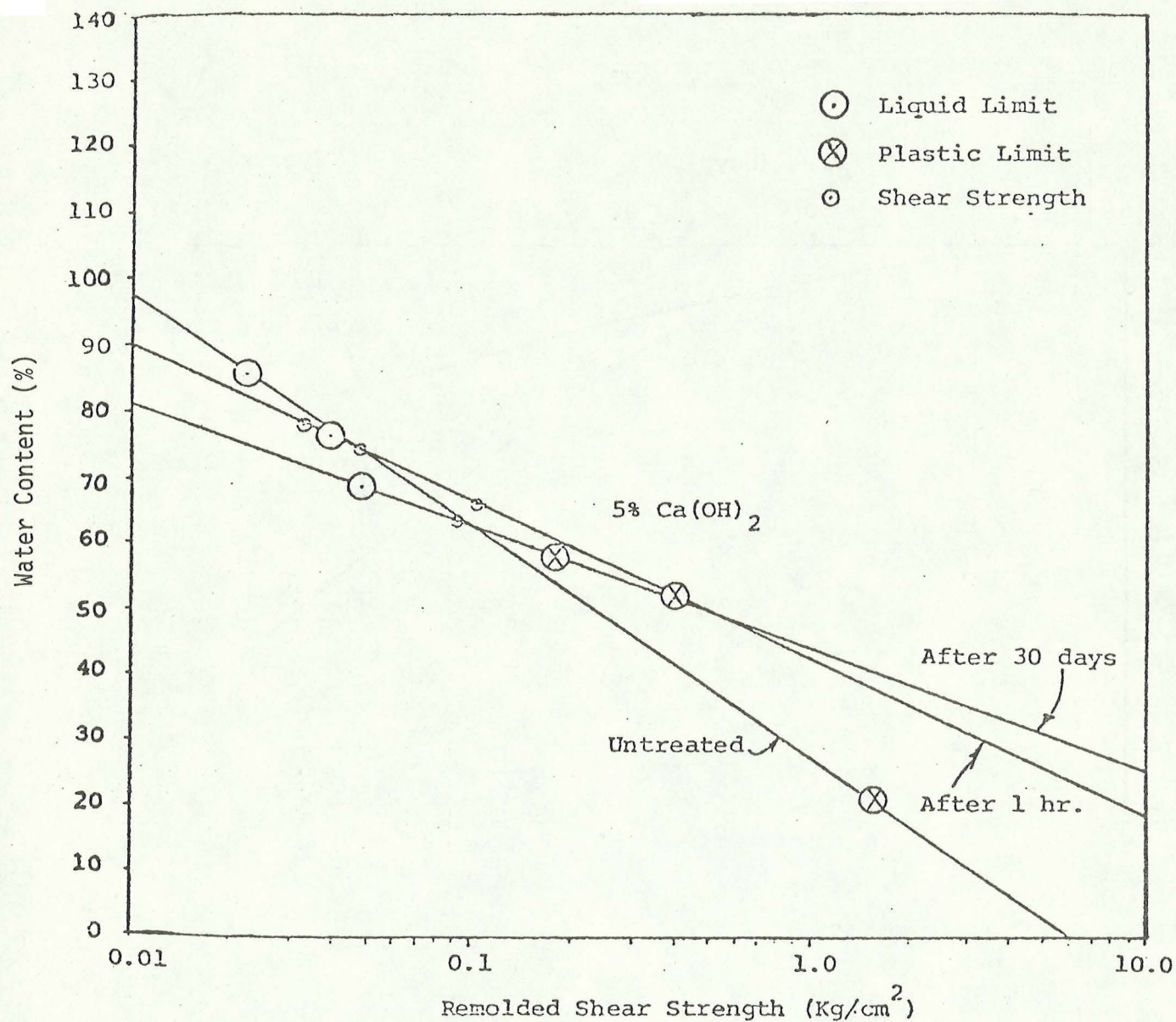
(from Winterkorn (47))



Effect of three sodium compounds on strength development of New Hampshire silt stabilized with 10 per cent hydrated lime.

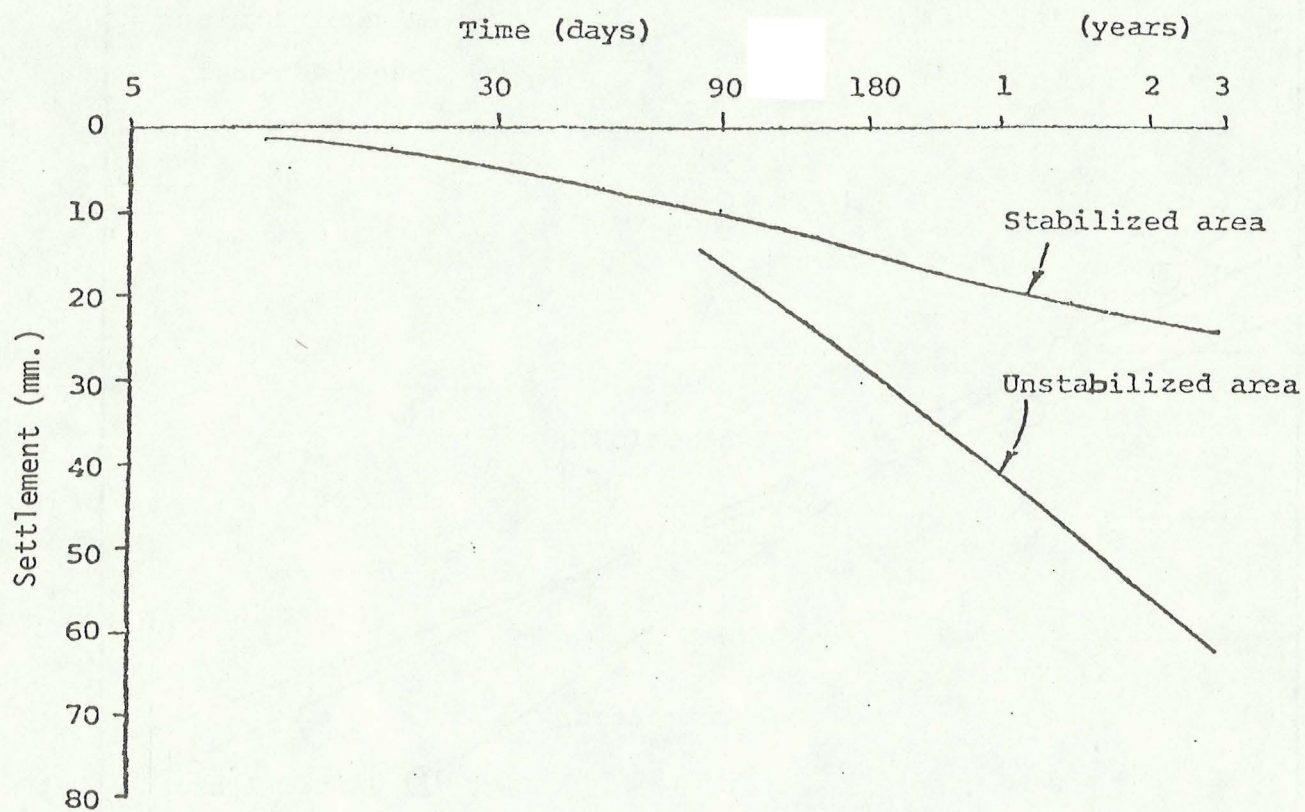
Effect of Three Sodium Compounds on  
Strength (From Lambe (21))

Figure 3



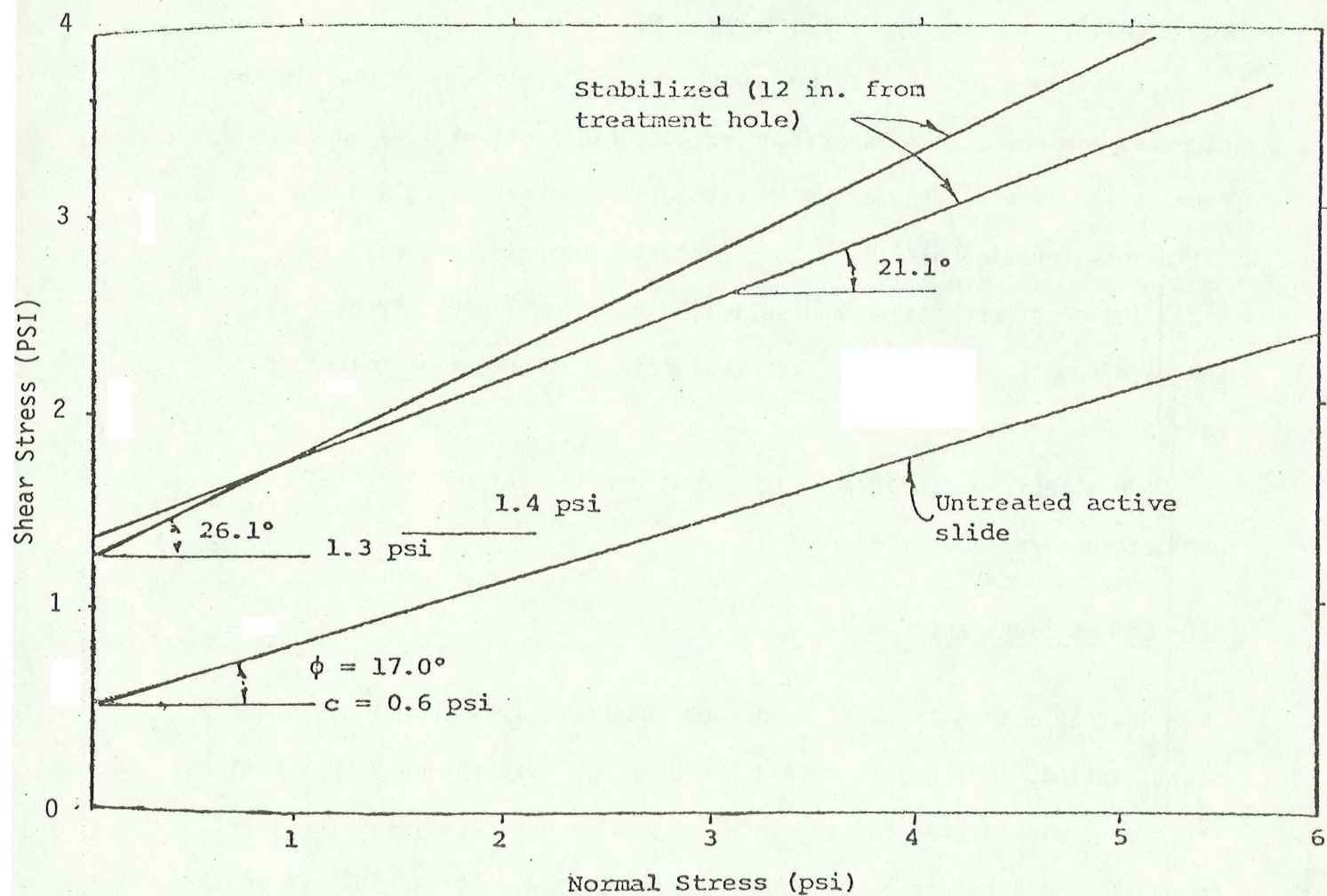
Effect of Mixed  $\text{Ca(OH)}_2$  on Remolded Shear Strength of a Montmorillonitic Clay  
(From Borchardt, 1978)

Figure 4



Effect of Quicklime Columns on Settlement  
(From Broms and Boman, 1979)

Figure 5



Effect of Quicklime Columns on Clay Strength as Determined by Borehole Shear Test (2 years 8 months after treatment) (From Handy and Williams, 1966)

Figure 6

soil treatment with lime is shown in Fig. 5.

The increases in the shear strength parameters ( $C, \phi$ ) due to the addition of quicklime are shown in Fig. 6.

It is suggested that future research and development activities be directed toward further understanding of the effects of lime on expansive soils. Some of the areas that should be investigated are the diffusion-migration of lime, the cementation process, the relative significance of prewetting and soil-lime reactions in PIL treatments, and development of guidelines for evaluating the potential effectiveness of PIL treatment.

The effectiveness of lime treatment and the various methods of application are summarized in Table 4.

## 2.2 Cement Treatment

Another method that has been used successfully is portland cement stabilization. While soil-cement has been employed for many applications, it is most widely used for the bases of roads and airfields. The first controlled soil-cement construction was in a road built in 1935 in South Carolina and thirty years later this road was still giving satisfactory service.

Most soils can be successfully stabilized with cement, but each situation must be analyzed to determine the amount of cement required to provide adequate soil stabilization. The best results are obtained when a well-graded soil is used, but guidelines of other general cases are listed below (from Lambe, 21):

For sands, a cement level of 7 to 12 percent by weight

For silts, a cement level of 12 to 15 percent by weight

TABLE 4  
Effectiveness of Lime Treatment

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	<ul style="list-style-type: none"> <li>-Only suitable for shallow depths</li> <li>-Mixing difficult in highly plastic clays</li> <li>-Delay between initial addition of lime and final mixing and placement improves ease of handling and compaction</li> <li>-2-6% lime usually required</li> </ul>	California (1967) Diamond & Kinter (1966) Harrim & Mitchell (1961) Jones (1958) Mitchell & Hooper (1961) Thompson (1972)
		Deep-plow	<ul style="list-style-type: none"> <li>-Treat depths to 36"</li> <li>-Can use conventional equipment</li> <li>-Requires careful quality control</li> </ul>	
		Lime slurry injection; lime piles	<ul style="list-style-type: none"> <li>-Controversial</li> <li>-Limited by slow lime diffusion rate</li> <li>-May be effective in fissured material</li> </ul>	Ingles & Neil (1970) Lundy & Greenfield (1968)
		Mixing-in-place: piles and walls	<ul style="list-style-type: none"> <li>-Not yet investigated</li> <li>-Might be suitable in highly plastic soils for treatment to large depth</li> <li>-Could use dry lime, lime mortar or slurry</li> </ul>	See Sherard (1969) for technique utilizing Portland cement

(After Mitchell and Raad (29))

For clays, a cement level of 12 to 20 percent by weight

The action of cement on clay is to reduce the liquid limit, plasticity index and potential volume change and to increase the shrinkage limit and shear strength. The resulting product of cement and clay is known as soil-cement.

Some of the successes with portland cement have been reported by Spangler and Patel (38), and by Jones (16). They have reported that addition of 2 to 6 percent of portland cement considerably reduced the volume change tendency of expansive soil. One of the practical limitations of cement stabilization is that the water requirements of the cement may not be met in some soils because of their affinity for water. If the soils can absorb great amounts of water, the water intended for the cement will be used by the soil. This will cause the cement to not set properly and thereby weaken the soil-cement formation.

The methods used to apply cement for stabilization are similar to those used for lime. However, the infiltration of cement into fine-grained soils is not as effective as in the case of lime, due to the poor solubility of cement in water.

The requirements for the AASHTO soil groups and for silty and clayey soils are shown in Tables 5 and 6. These tables present the general relationship of the two groups (soil and cement) required to produce soil-cement of standard quality. The more cement added to the soil, the stronger the resulting soil-cement mixture. The best cement to use is High-Early strength cement, this cement is more effective than normal cement. In general, when a better mixing process is used, a stronger and more durable soil-cement mixture is produced.

TABLE 5

## Cement Requirements of AASHTO Soil Groups

AASHTO Soil Group	Usual Range in Cement Requirement		Estimated Cement Content and that Used in Moisture-Density Test, Percent by Wt.	Cement Contents for Wey-Dry and Freeze-Thaw Tests, Percent by Wt.
	Percent by Vol.	Percent by Wt.		
A-1-a	5- 7	3- 5	5	3- 5- 7
A-1-b	7- 9	5- 8	6	4- 6- 8
A-2	7-10	5- 9	7	5- 7- 9
A-3	8-12	7-11	9	7- 9-11
A-4	8-12	7-12	10	8-10-12
A-5	8-12	8-13	10	8-10-12
A-6	10-14	9-15	12	10-12-14
A-7	10-14	10-16	13	11-13-15

TABLE 6

## Average Cement Requirements of Silty and Clayey Soils

AASHTO Group Index	Material Between 0.05 mm., and 0.005 mm., Percent	Cement Content, Percent by Wt.						
		Maximum Density, lb/ft <sup>3</sup>						
		90-94	95-99	100-104	105-109	110-114	115-119	120 or More
0- 3	0-19	12	11	10	8	8	7	7
	20-39	12	11	10	9	8	8	7
	40-59	13	12	11	9	9	8	8
	60 or more	-	-	-	-	-	-	-
4- 7	0-19	13	12	11	9	8	7	7
	20-39	13	12	11	10	9	8	8
	40-59	14	13	12	10	10	9	8
	60 or more	15	14	12	11	10	9	9
8-11	0-19	14	13	11	10	9	8	8
	20-39	15	14	11	10	9	9	9
	40-59	16	14	12	11	10	10	9
	60 or more	17	15	13	11	10	10	10

TABLE 6 (Continued)

AASHTO Group Index	Material Between 0.05 mm., and 0.005 mm., Percent	Cement Content, Percent by Wt.						
		Maximum Density, lb/ft <sup>3</sup>						
		90-94	95-99	100-104	105-109	110-114	115-119	120 or More
12-15	0-19	15	14	13	12	11	9	9
	20-39	16	15	13	12	11	10	10
	40-59	17	16	14	12	12	11	10
	60 or more	18	16	14	13	12	11	11
16-20	0-19	17	16	14	13	12	11	10
	20-39	18	17	15	14	13	11	11
	40-59	19	18	15	14	14	12	12
	60 or more	20	19	16	15	14	13	12

Chen (4) states that, more research and field studies will be required before cement stabilization can be economically applied. An application method, either mixing or slurry injection, must be perfected before cement stabilization can be used in practice.

The effectiveness of cement treatment and the methods of application are summarized in Table 7.

### 2.3 Salt Treatment

Salt has been used many times for various types of stabilization. The salts that have been used most are sodium chloride and calcium chloride, although barium chloride, copper sulfate, barium sulfate, aluminum sulfate and magnesium sulfate have been used in some instances. These salts, other than sodium chloride and calcium chloride, were found to be ineffective, by the Massachusetts Institute of Technology, as soil stabilizers.

Sodium chloride does reduce the moisture content changes in soils. However, a quantitative assessment of this is not available in the literature. The effect of sodium chloride on the plastic limit and liquid limit of soils varies from no change to significant changes. This seems to be dependent on the soil type, according to Thornburn and Mura (43). For a soil with a high liquid limit the salt treatment is very effective and lasts longer than for soils with a low liquid limit. Sodium chloride also increases the shrinkage limit and decreases the linear shrinkage of soils. The shear strength of an expansive soil is also increased by the addition of sodium chloride. Sodium chloride has proved to be the most beneficial in climates affected by frost and in soils that have sufficient fine-grained material for reaction with the salt.

TABLE 7

## Effectiveness of Cement Treatment

Method or Additive	Effects on Soil	Method of Application	Comments
Cement-Treatment	Reduce or eliminate swelling by cementation, ion exchange, and alteration of clay minerals	Remove, mix, replace Plant mix Deep plow (?)	<ul style="list-style-type: none"> <li>-Cement may be less effective than lime in highly plastic clays</li> <li>-Mixing difficult in highly plastic clays</li> <li>-Deep plow method not yet investigated (?)</li> <li>-Reduction in swelling noticeable for cement contents &gt; 4-6%</li> </ul>
		Mixing in place	<ul style="list-style-type: none"> <li>-No excavation and backfilling required</li> <li>-Has been used for construction of piles and walls</li> <li>-Better, more economical equipment needed</li> </ul>

There has been more research on calcium chloride than on sodium chloride and also there is more agreement concerning the effectiveness of calcium chloride. Calcium chloride will keep a soil mixture at a fairly constant moisture content. However, with time the salt will be leached out. Calcium chloride is able to keep the moisture content constant and therefore the swelling pressures are reduced by its addition. Calcium chloride has also been used for frost heave protection since the late 1920's. The amount of calcium chloride used for stabilization is usually about 1 percent or less of the weight of dry soil. One restriction on the use of calcium is climate conditions, a relative humidity of at least 30 percent is needed before calcium chloride is used. Also, a high water table should be avoided because calcium chloride is easily leached and washed away.

The desirable effects of potassium chloride on active clays are reported by Frydman, et al. (1977), and by Lessard (1978). These results are indicated in Figs. 7 and 8. It is evident from Fig. 7 that an increase in the amount of potassium chloride used in stabilization decreases the plasticity of the soil treated.

Furthermore, Fig. 8 indicates that the presence of potassium chloride in the clay increases the remolded shear strength.

Loken (1971) studied the effect of various cations on remolded undrained shear strength of quick clays and these results are shown in Fig. 9. It is clear from this figure that aluminum salts followed by potassium salts have the most stabilizing effects on active clays.

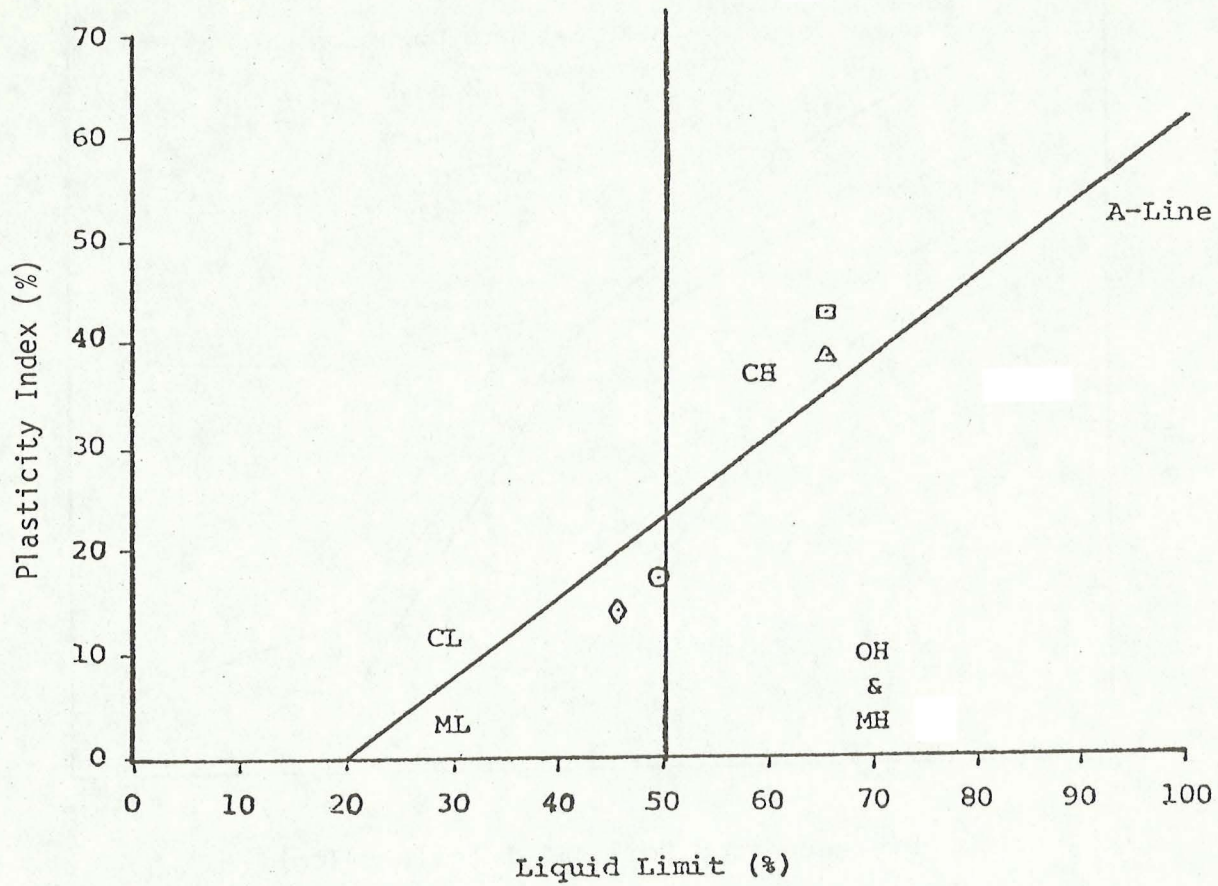
There is inadequate evidence that salts, except sodium chloride and calcium chloride, when used alone have stabilizing properties of

Untreated Soil

2.2% KCl

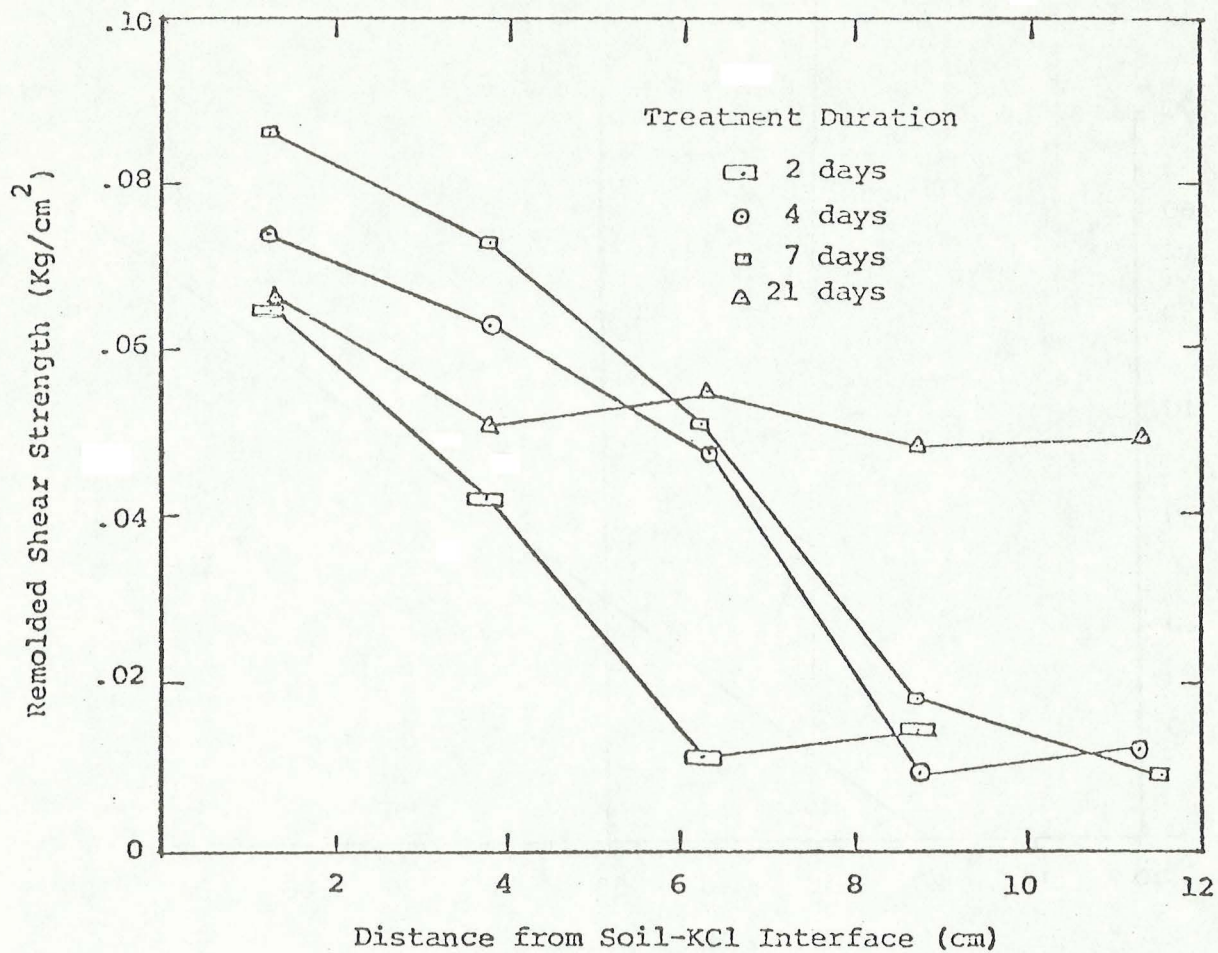
5.5% KCl

8.8% KCl



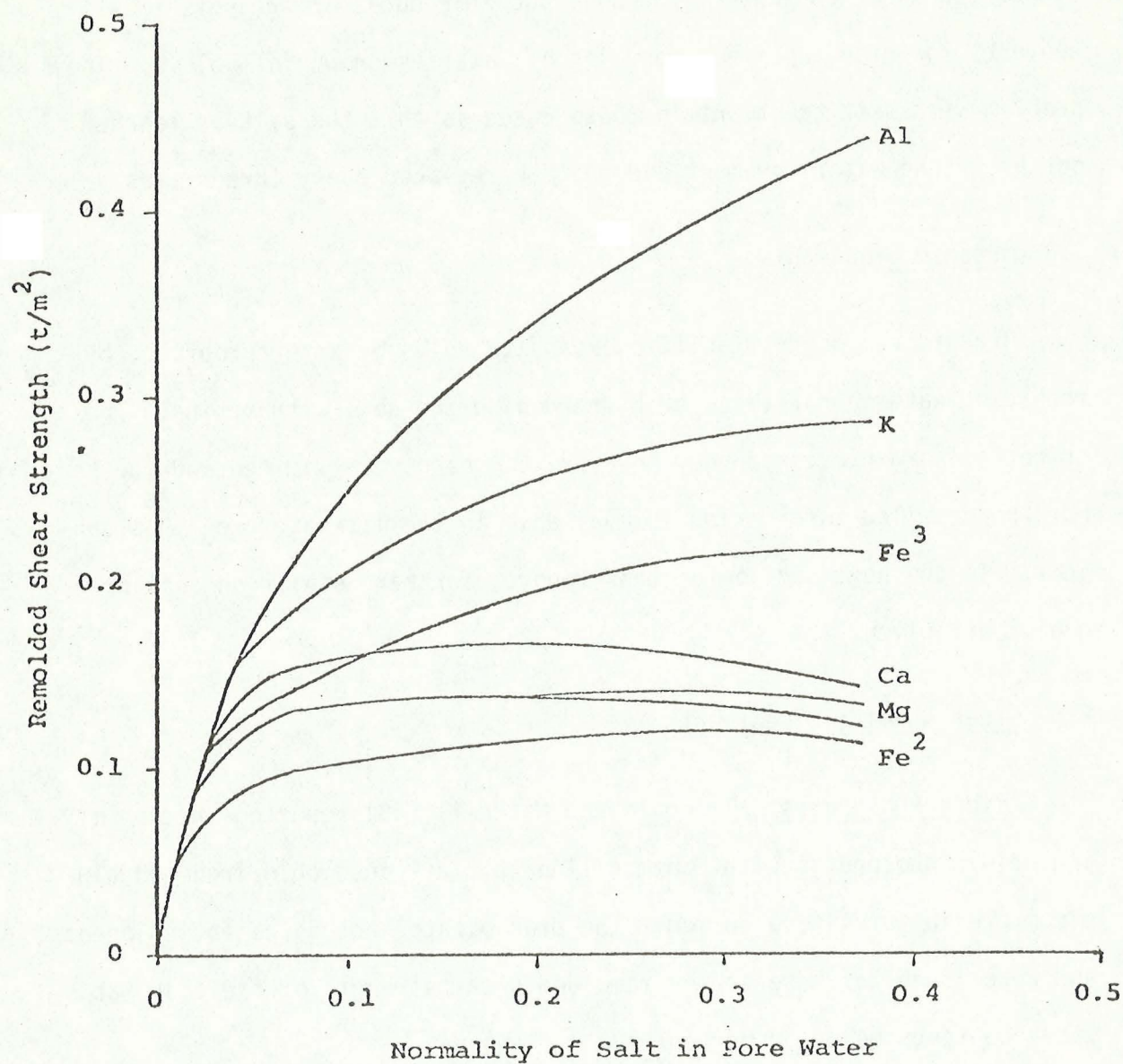
Effect of Mixed KCl on Plasticity  
(From Frydman et al., 1977)

Figure 7



Effect of Diffused in KCl on Remolded Shear Strength of Quebec Quick Clay (From Lessard, 1978)

Figure 8



Effect of Mixed Chlorides on Remolded Undrained Shear Strength of Norwegian Quick Clay  
(From Loken, 1971)

Figure 9

sufficient magnitude to justify their economic use. Although used, salt does not have any strong impact in modern soil stabilization. Salt does reduce the water content of the soil and it reduces or prevents frost heave by lowering the freezing point of water as shown in Table 8. The problem with salt treatment in these cases is that the salt is leached out by ground water movement and must be replaced every three years.

#### 2.4 Organic Treatment

Organic compounds stabilize expansive soils by water proofing, by retarding water absorption, or by hardening the soil with resins. The success of organic compounds, however, has been very limited and furthermore no detailed information is available in the literature on this subject. In the next section of this report, further details on some organics are given.

#### 2.5 Other Chemical Treatments

Acidic Phosphates - Tringale and Mitchell (45) reported that by mixing acidic phosphates with montmorillonite clay, insoluble iron and aluminum precipitates were formed. The precipitates act as cementing agents and were found to increase the remolded shear strength of the clay, at water contents below 60 percent.

Quaternary Amines - Quaternary amines are widely used by-products of the meat packing industry and form a large group of organic compounds of ammonia. Because of their cationic nature, they react readily with soil clay minerals, producing a strong flocculation and a considerable degree of water repellant, Despite much work, however, by Armour

TABLE 8

## Freezing Point Lowering of Sodium Chloride Solutions

Molality	Grams Anhydrous Salt per 1,000 g Water	Freezing Point Lowering (C)
0.001	0.0585	0.004
0.01	0.5845	0.036
0.10	5.845	0.348
1.0	58.45	3.37
2.0	116.9	6.90
3.0	175.3	10.82
4.0	233.8	15.14
5.2	303.9	21.12

Industrial Chemical Company, General Mills, Inc., and others, the amines were not found to be significantly effective for treating highway soils.

PDC - This product of the Product Development Company is a mixture of portland cement, hydrated lime and casein. During its development and evaluation, the proportions of the ingredients were repeatedly adjusted by the company, and various types of milk casein and soybean casein were tried. The company's test results showed PDC to be an effective stabilizer for clay soils. However, FHWA tests did not show PDC to be significantly more effective than the same cement-lime mixture without casein. A number of successful field sections using this product were constructed on secondary roads through the company's efforts, but the additional cost of the seemingly unnecessary ingredient, casein, could not be economically justified, hence no practical use of the product has resulted.

Terbec - Dow Chemical Company developed a rapid, inexpensive test for evaluating their products and experimental chemicals as stabilizers, and applied the test to thousands of compounds. Although they have not revealed the details of the test, the test results or the identity of the tested chemicals, they advanced Terbec (chemical name -- 4-tert-butylpyrocatechol) for further consideration. In FHWA tests, Terbec was an effective waterproofer, but it did not permanently strengthen or otherwise improve clayey soils, and full attainment of its limited effects required some drying back of originally moist soil mixtures. In cooperation with the Minnesota Department of Highways, Iowa State University, the Iowa State Highway Commission, and various county highway departments, the company installed 25 test projects in six States.

The limited reports provided FHWA indicated that some sections having Terbec-treated soil as base or subbase gave better performance than the control sections having standard construction; however, in other experimental projects the performance of Terbec-treated sections was either inferior or no better than sections having standard design. Initial claims that Terbec provided resistance to frost action were not substantiated by later observations.

Lignin Liquors and Lignin and Cellulose Compounds - The sulfite process in the paper industry, in extracting lignin from wood, produces vast quantities of a liquor containing about 10 percent lignin and 90 percent water. Early efforts were directed to the use of the liquors in palliating dust on unpaved roads, and to reduce the permeability and frost action of the natural soils; hence, they had a widespread, if modest, success. Attempts to use the concentrated liquors in conventional stabilization have not been very successful. Development of the chrome-lignin process was at first promising, but the costs were excessive and effectiveness in producing strength and water resistance depended on at least a partial drying back of treated soil, an impractical requirement in field use.

Rayonier, Inc., exerted major efforts in the early work on lignin liquors and renewed their efforts more recently with cellulose and lignin compounds. The company submitted one material they considered to have merit for waterproofing soils. FHWA tests indicated that the material slightly increased the strength of soils, but that its overall effect on soil improvement was insufficient to warrant field evaluation.

Phosphoric Acid - Monsanto Chemical Company found that phosphoric acid reacted with soils to increase their strength and water resistance. Tennessee Corporation also did considerable experimentation with phosphoric acid. Field test sections were constructed in Georgia and Missouri. Although the acid was fairly effective with soils in eastern United States, the cost was too high for successful competition with lime and cement, and the treated soil was difficult to compact. Test results in the FHWA soils laboratory were encouraging. However, a severe limitation was found with calcareous soils, the acid being consumed by the soil without producing adequate strength. Although the acid could be treated to eliminate the corrosion of road building equipment, its probable effects on workmen discouraged further attempts at its use.

The University of Wyoming evaluated approximately 17 different additives for stabilizing an expansive clay on I-80 west of Laramie. Effectiveness was evaluated by volume expansion tests using a CBR mold and swell pressure tests using a 4-in.-diam Proctor mold. Briefly, the following additives were evaluated:

Alcohols and formaldehyde. Isopropyl alcohol caused the soil to become friable and reduced the swelling as much as lime did for a short period of time. Negative results were obtained with a lime-isopropyl alcohol slurry in an attempt to migrate dissolved lime into the clay. Ethyl alcohol and formaldehyde also reduced swelling, but the tests showed that this reduction was only temporary.

B D Quat 2 CoCo. This agent is a quaternary ammonium chloride and was added to the soil in an attempt to form a water-repellent film covering the clay. Gelatin occurs when CoCo is added to water. Addition of concentrated CoCo-water mixture to the soil caused the soil to

become friable. Reduction in swell compared favorably with lime, but, as with lime, good mixing is required.

Reten. Reten 210 and Reten A-1 are synthetic, water-soluble polymers; the former is cationic while the latter is anionic. They are used as flocculants in sewage treatment and, as expected, when they were added to the soil, a spongy, friable mixture was obtained. However, when very slight amounts were added to water, unmanageable gelation occurred, thereby precluding any migration and ease of mixing.

Nalcolyte. Nalcolyte 605 and 675 are a cationic poly-electrical organic coagulant and a water-soluble polymer flocculant, respectively. Nalcolyte 605 caused the soil to become friable, but failed to reduce swell. Nalcolyte 675 behaved similar to Reten with a considerable loss in density observed.

Silicone. Silicone 770 and 772 are silicone resin concentrates used for waterproofing masonry, and a water-soluble sodium methyl silicate used as a dispersing agent in clays and ceramics, respectively. For the percentages tested silicone 770 failed to provide any appreciable swell reductions. Silicone 772 at 3 percent produced results nearly comparable to lime, but at 0.5 percent little swell reduction was obtained.

Sodium and magnesium chloride. At application rates of 0.5-2 percent by dry weight, only slight improvements were observed.

Phosphoric acid. Phosphoric acid in amounts of 1, 2, and 3 percent by dry weight was added to the soil. When the acid was added to the moist soil instead of being added directly to the mixing water, the soil became friable. However, no reduction in swell was obtained.

"N" sodium silicate. This agent is a concentrated silicate solution which would hopefully cause ion substitution and thereby eliminate swelling.

Several mixing possibilities were attempted, but because of the many variables involved, i.e., polymer size and concentration, pH of water, temperature, calcium or aluminum ions added, and the amount of water used in mixing, the mixing combinations are innumerable. Only slight reductions in swell were obtained for the mixing combinations tried.

Emulsified asphalt SS-K. Asphalt mixed with the mixing water in amounts of 1, 2, 3, and 5 percent by dry weight increased friability, but did not significantly decrease the swell.

Kerosene. Kerosene, when placed on the surface of compacted specimens, was observed to penetrate the soil quickly. However, after the kerosene had completely penetrated the sample, rapid volume increases approaching 10 percent were observed when water was placed on the surface.

Results of this program showed that none of these agents reduced the swell as effectively as lime.

Other chemical additives and their effectiveness on soils as stabilizers are summarized in Table 9.

### 3. PREWETTING

One of the oldest methods used by engineers, contractors and laymen to treat expansive soils is prewetting. Prewetting theory is based on the assumption that if soil is allowed to swell by wetting prior to construction and a high soil moisture content is maintained, the soil volume will remain constant. Since the soil has already achieved its maximum realistic moisture content, there will be no swelling and no structural damage.

The present method of prewetting is by ponding or direct flooding

TABLE 9

## Effectiveness of Chemical Treatment

Additive	Effects on Soil	Method of Application	Comments
-Hydroxides	<p>Various effects have been measured or hypothesized, including:</p> <p>Reduced plasticity</p> <p>Improved Compaction</p> <p>Reduced Swell</p> <p>Waterproofing</p> <p>Preservation of Soil structure</p> <p>Increased strength</p> <p>Increased or decreased permeability</p>	<p>Usually remove, mix, and replace or mix-in-place</p> <p>In some instances spraying or injection is used</p> <p>Electro-osmosis may be useful in special cases</p> <p>Diffusion may be effective</p>	<p>-Problems of mixing or injection may be significant</p> <p>-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.</p> <p>-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.</p> <p>-A number of proprietary formulations have been marketed. The beneficial effects of these materials have not generally been documented.</p>



of the building area. The construction area is flooded by constructing a small dike around the site to impound the water. There are different systems of flooding the foundation site.

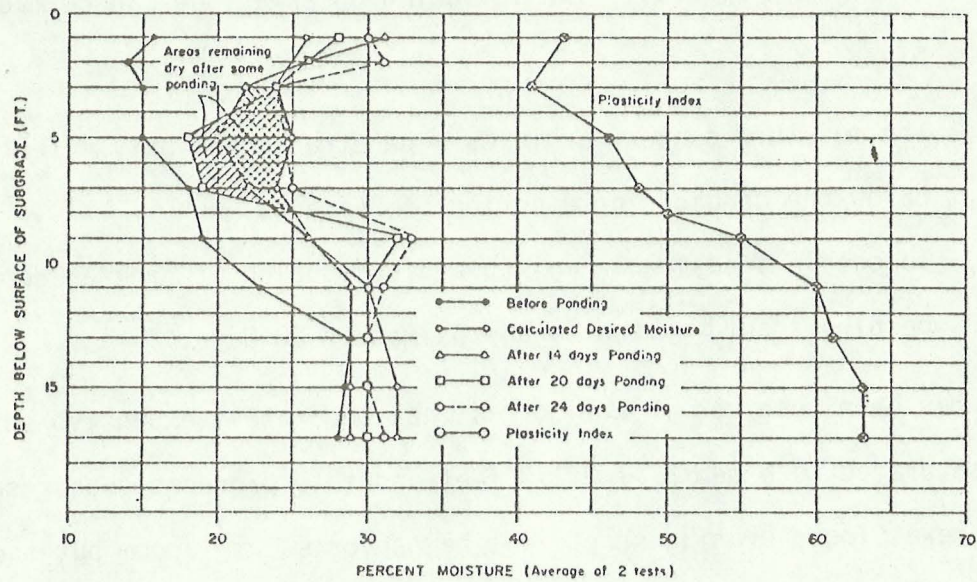
The Texas Highway Department performed an investigation on the effects of ponding on the moisture content at various depths and these results are shown in Fig. 10. The following observations can be made from this study:

- (a) The moisture content achieves a penetration of only 4 feet below the pond during a period of 24 days.
- (b) To obtain a desirable moisture distribution at greater depths, ponding should extend to approximately 30 days.

It has been observed in California that moderately expansive soils can be saturated to a depth of 2 1/2 feet and this produces good results.

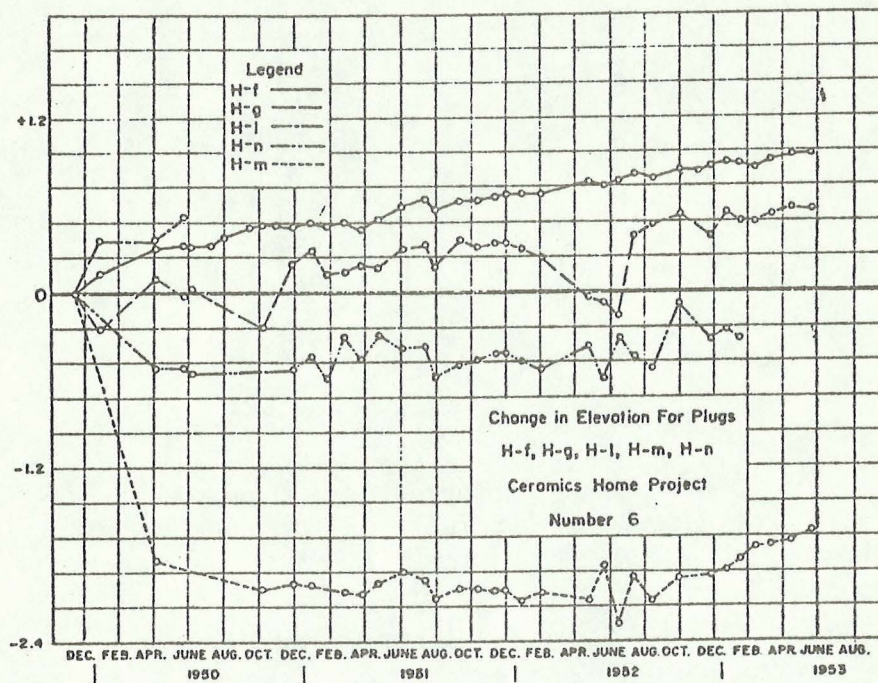
A prewetting operation should not be performed at random but should be based upon an engineering investigation. Also, during the operation the moisture content should be checked frequently to insure proper results.

Ponding has been used satisfactorily for foundations in a variety of places including California and South Africa. However, a ponding project for a house in Austin, Texas reported by Dawson (6), was a failure because the house was subjected to heave both during and after construction. As shown in Fig. 11, a boring was taken, at a depth of 5 1/2 feet from one of the trenches surrounding the foundation and the results are shown in Table 7. From this boring it is clear that the soil was not saturated even one foot below the trench. This shows that it is very difficult to saturate soils with large proportion of clay within any



Subgrade Moisture Movement  
(From Chen (4))

Figure 10



Change in Elevation of Austin House After Prewetting  
(From Dawson (6))

Figure 11

TABLE 10

Moisture Content vs. Depth  
(Boring Austin, Texas House)

<u>Depth (Ft)</u>	<u>Moisture (%)</u>
6.5	20.8
7.5	17.1
8.5	19.7
9.5	19.1
10.5	16.3
11.5	13.3
12.5	13.9

Boring was performed in a trench at  
a depth of 5.5 feet.

(from Dawson (6))

reasonable amount of time.

Some investigators feel that it is not possible to saturate highly plastic clays within a reasonable amount of time. Therefore some heave should be expected after construction due to excess water from the ponding moving into the blocky unsaturated soil masses.

Prewetting by ponding may require many months to be effective unless the soil is highly fissured. Prewetting about 2 to 3 percent above the plastic limit has shown significant improvement in the performance of slabs on grade. However, excessive wetting can actually damage the foundation by migration of moisture to dry soil, at large depths below the foundation, causing excessive heaving.

Prewetting has long been endorsed by most highway engineers, but it is doubtful that this method can be used successfully for lightly loaded structures.

Some of the disadvantages listed by Chen (4) are:

- (a) Ponding of water will cause the soil to expand and later water migrates to lower soil layers and induces swelling. This cycle can continue for as long as 10 years.
- (b) The length of time required for ponding may be too great for most sites.
- (c) It is questionable as to whether a uniform moisture content can be obtained because the water will follow fissures and as such will not reach a great many masses of soil.
- (d) It has been shown that water can penetrate to an effective depth of 4 feet within a reasonable amount of time. Such a depth is insufficient to provide a balanced moisture zone for construction of important structures.

- (e) Prewetting may provide a good stabilized soil beneath a floor slab, pavement or canal lining, but it is doubtful that a footing can be placed on prewetted soil as prewetting reduces the bearing capacity of stiff clay to less than 1,000 psf.

While prewetting has shown to be good for pavements and slabs, it is doubtful that this method can be used for building foundations on expansive soils.

#### 4. SOIL REPLACEMENT

A simple and easy solution for foundations on expansive soils is to replace the soil with non-swelling soil. Chen (4) states, that from experience, if the subsoil consists of more than about 5 feet of granular soils (SC-SP) on top of highly expansive soils, there is no danger of foundation movement when the structure is resting on the granular soils. However, this is not applicable to man-made fills. Man-made fill is usually, for economic reasons, not extended beyond 10 feet past the building line. This, unfortunately, allows the water to seep under the fill to the expansive soil. No guidelines exist as to the thickness requirement of the fill but Chen (4) recommends, "A minimum of 3 feet, although 5 feet is preferred". Thickness is defined as the distance from the bottom of a footing to the top of the expansive soil.

The type of material used for fill should basically be:

- (a) nonexpansive soil
- (b) Granular soils--GW to SC (unified classification system)
- (c) Any soil that meets the requirements listed in Table 11.

But, it is becoming very difficult to locate materials that meet these

TABLE 11

## Soil Replacement for Fill Replacement Materials

<u>Liquid Limit (%)</u>	<u>Percent Passing No. 200 Sieve</u>
50 < LL	15 - 30
30 < LL < 50	10 - 40
LL < 30	5 - 50

(from Chen (4))

requirements in some locations. Denver, Colorado is one such area, according to Chen (4).

The optimum depth of replacement is not known when using this method to control soil swell.

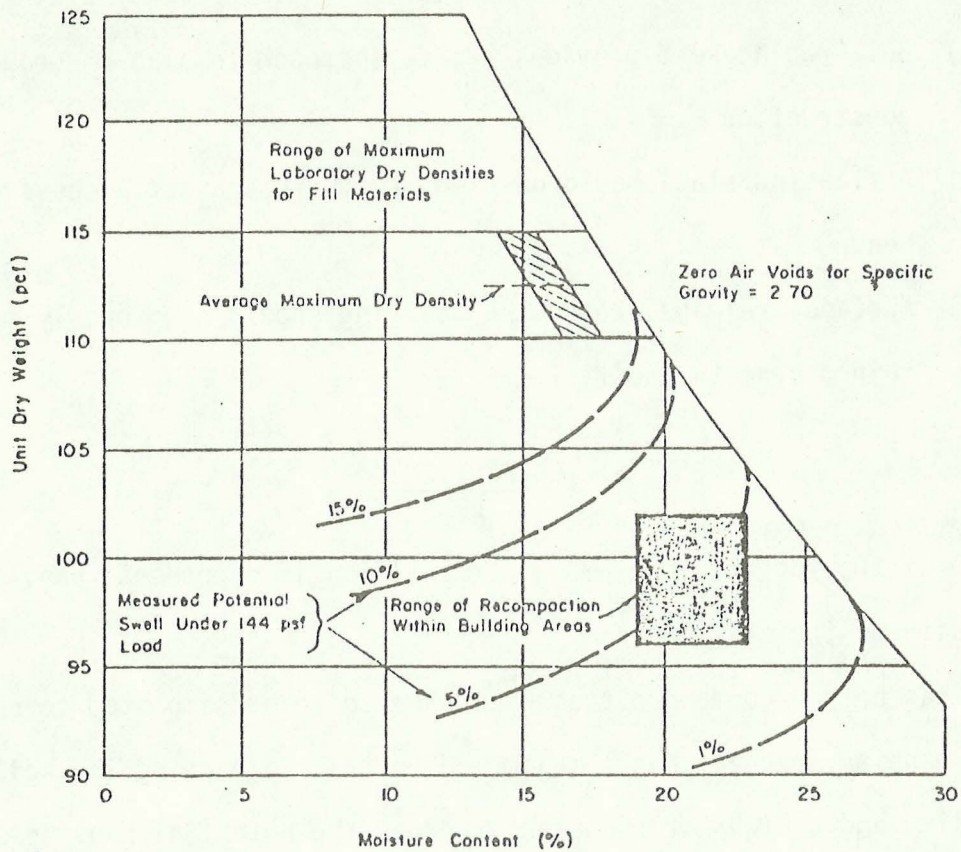
In theory, the uplift can be found by evaluating swell tests and pressure distribution. But, this does not always provide the correct solution, as several investigators have found.

When trying to evaluate the depth to which swell is important, a number of aspects should be taken into consideration:

- (a) Uniform wetting tends to equalize heave.
- (b) There is an advantage to placing a structure on a nonexpansive cushion. If movement occurs, the result will be subdued by the nonswell cushion.
- (c) The depth of fill should never be less than 36 inches and preferably 48 inches.
- (d) Do not allow the excavation to become excessively wetted during construction or excessive heaving will occur.
- (e) The thickness of fill can be reduced if a combination of re-compaction and replacement methods are used.
- (f) The degree of compaction depends upon the type of fill used, as shown in Fig. 12.

At the present time soil replacement seems to be the best method for a stable foundation. The following are some evaluations of the effectiveness of soil replacement:

- (a) By replacing expansive soils with nonexpansive soils, a high degree of compaction can be accomplished and as such carry



Determination of Fill Placement Moisture and Density  
(From Chen (4))

Figure 12

heavy loads.

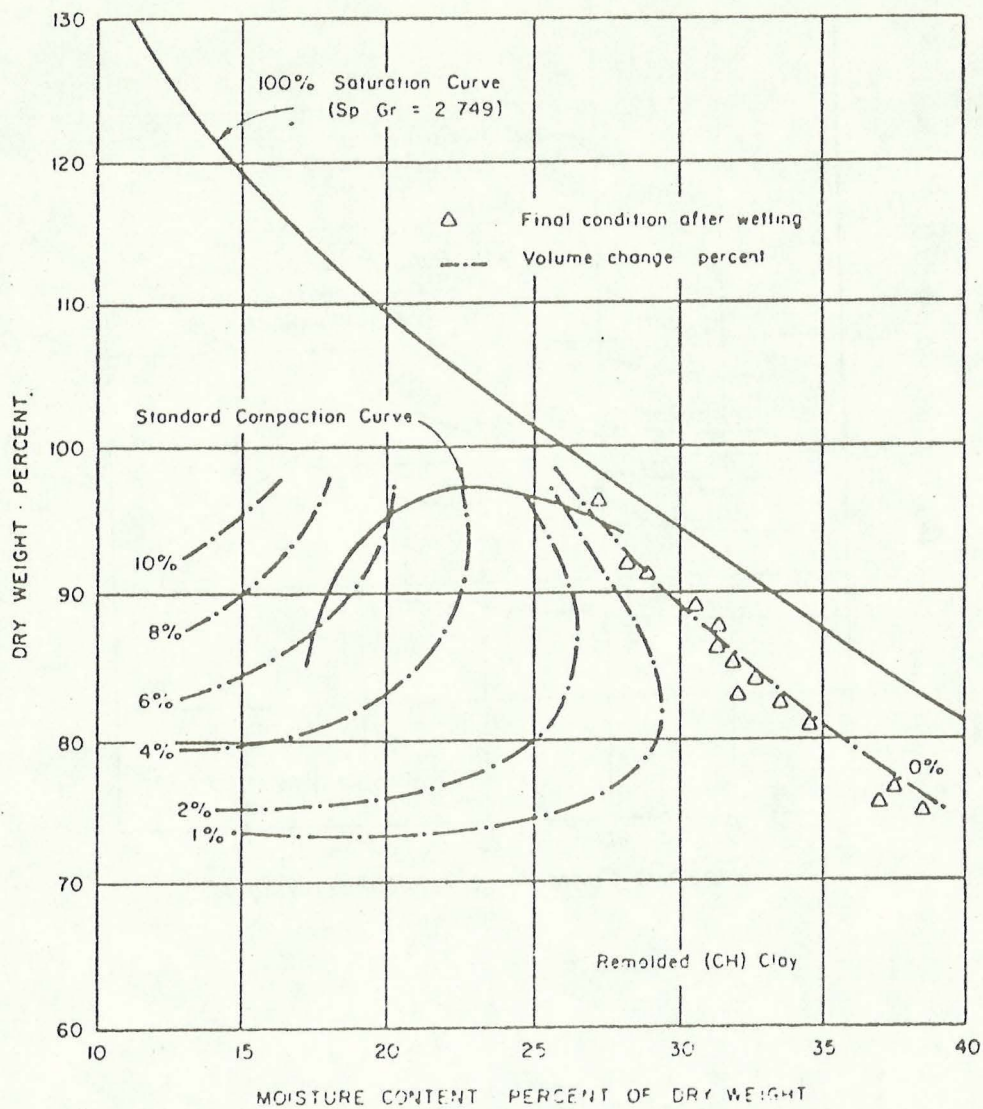
- (b) The cost of soil replacement is relatively inexpensive when compared to other means of soil stabilization.
- (c) The granular soil cushion also serves as an effective barrier against the rise of ground water if it is properly drained.
- (d) Soil replacement provides a safe approach to slab-on-ground construction.
- (e) A floating slab should be used, to guard against excessive heave.
- (f) Surface drainage around the building should be properly maintained beneath the fill.

## 5. COMPACTION

One of the factors the amount of swelling is dependent upon, is the dry density of the soil.

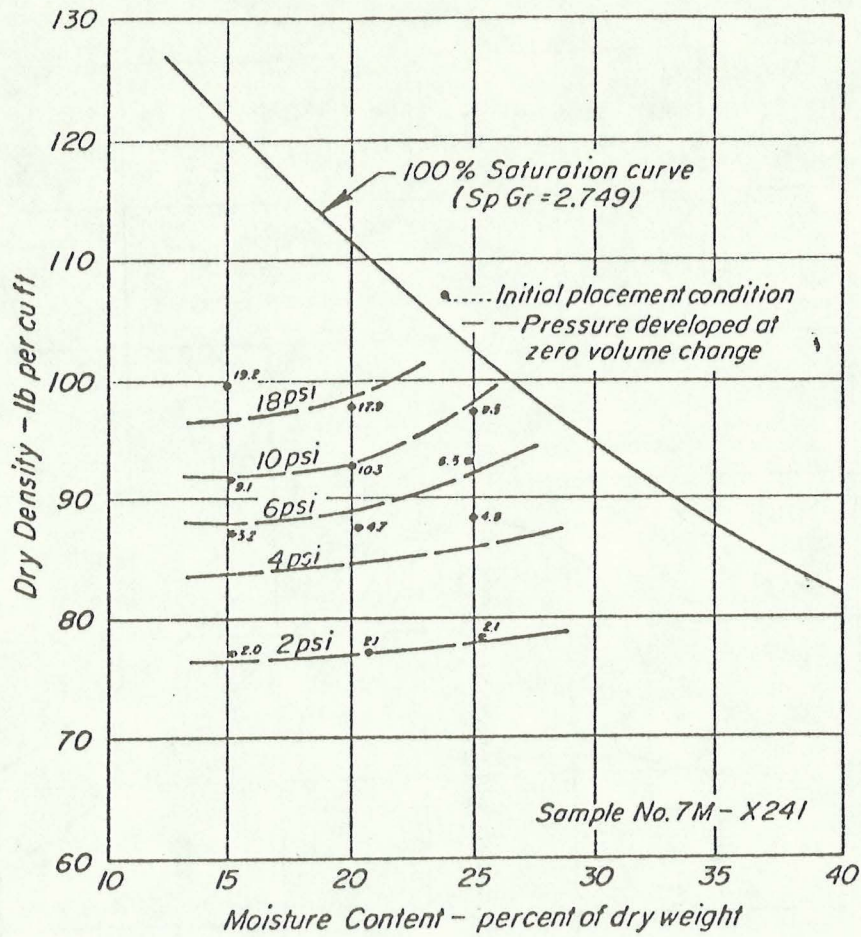
It has been recommended that expansive soils be compacted to some minimum density, rather than a maximum density. Compacting the soil to a low density and a high water content reduces the potential heave of expansive soil. The effect that density and moisture content have on compacted expansive soil is shown in Fig. 13.

It has been shown by Holtz (13), Gizienski and Lee (8), Seed and Chan (36), Holtz and Gibbs (12), and Seed, Mitchell and Chan (35) that by decreasing the dry density of expansive soils, the swell potential can be reduced. A typical expansive soil can, by decreasing the dry density from 109 to 100 psf, reduce the swelling pressure from 13000 to 5000 psf and the swelling potential by 2.5 percent. This can be done without modifying the moisture content of the soil. Fig. 14 illustrates this theory for



Percentage of Expansion for Various Placement Conditions  
(Under Unit psi Load) (From Chen (4))

Figure 13



Total Uplift Pressure Caused by Wetting for Various Placement Conditions. (From Mitchell and Raad (29))

Figure 14

different densities. Gerhardt (7) states that without moisture-density control, non-uniform swell and settlement occur. According to Gizienski and Lee (8), at optimum water content, reducing the degree of compaction reduces the potential swell.

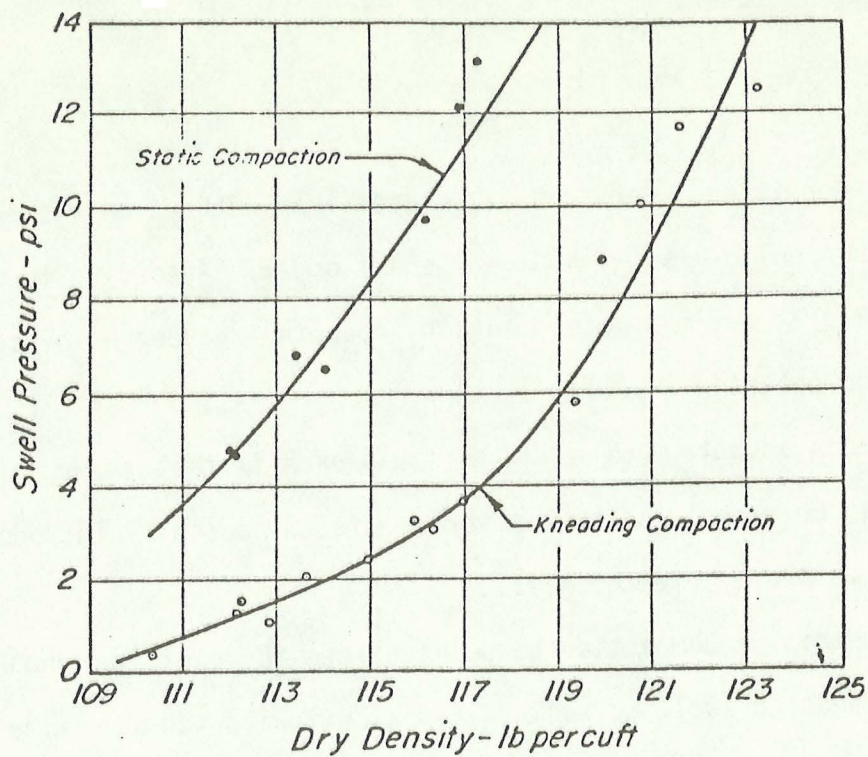
The main advantage of using this approach is that the swelling potential can be reduced without adverse effects caused by introducing excessive moisture into the soil.

The method of compaction also influences the swelling characteristics of compacted swelling soils. For a soil with the same water content and density the swelling is worse for a flocculated structure than for a deflocculated structure. A comparison of the difference in swell pressure for two types of compaction (static and kneading) is shown in Fig. 15. It is shown from that figure that use of compaction equipment producing a kneading action and a dispersed structure, such as a sheepfoot roller, would produce the best results for swell control.

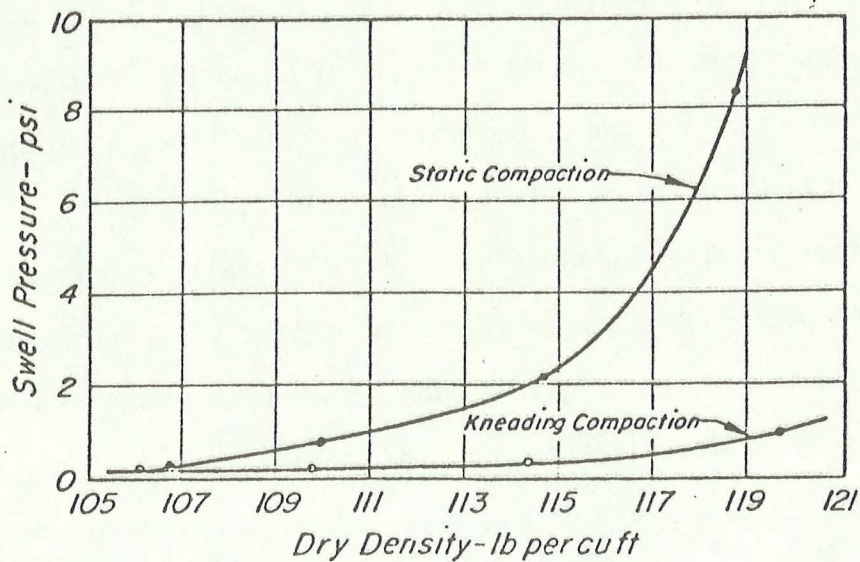
Compaction itself is not useful as a soil stabilization method, since it does not produce enough stability against swelling or contraction. Instead it is used mainly in conjunction with other treatment methods, such as soil replacement or lime stabilization.

The Colorado Department of Highways (37) produced specifications for depth of moisture-density control. The specifications for Interstate and primary highways can be seen in Table 12. But for the secondary and state highways they use different specifications, these are shown in Table 3.

In conclusion, good engineering results on expansive soils cannot be expected without good moisture-density control.



(a) Pittsburgh Sandy Clay



(b) Vicksburg Silty Clay.

Effect of Method of Compaction on Swell Pressure for Samples Compacted to a High Degree of Saturation.  
(From Seed and Chan (36))

Figure 15

TABLE 12

Specifications for Depth of Moisture-Density Control  
(Interstate and Primary Highways)

<u>Plasticity Index</u>	<u>Depth of Treatment (Ft)</u>
10 - 20	2
20 - 30	3
30 - 40	4
40 - 50	5
> 50	6

(from Snethen et al. (37))

TABLE 13

Specifications for Depth of Moisture-Density Control  
(Secondary and State Highways)

<u>Plasticity Index</u>	<u>Depth of Treatment (Ft)</u>
10 - 30	2
30 - 50	3
> 50	4

(from Snethen et al. (37))

## 6. ELECTRICAL STABILIZATION

Electrical Stabilization has been used in the following ways to stabilize soil:

- (a) dewatering by electro-osmosis
- (b) hardening by electro-osmosis

The use of electro-osmosis for dewatering has been investigated by many researchers, Rollins (34), Winterkorn (46), Grey and Mitchell (11), and Mise (29), and they have proposed many theories for the flow rate of pore water. The theory that best predicts the flow rate of the pore-water is:

$$q_e = k_e i_e A \quad (3)$$

in which:

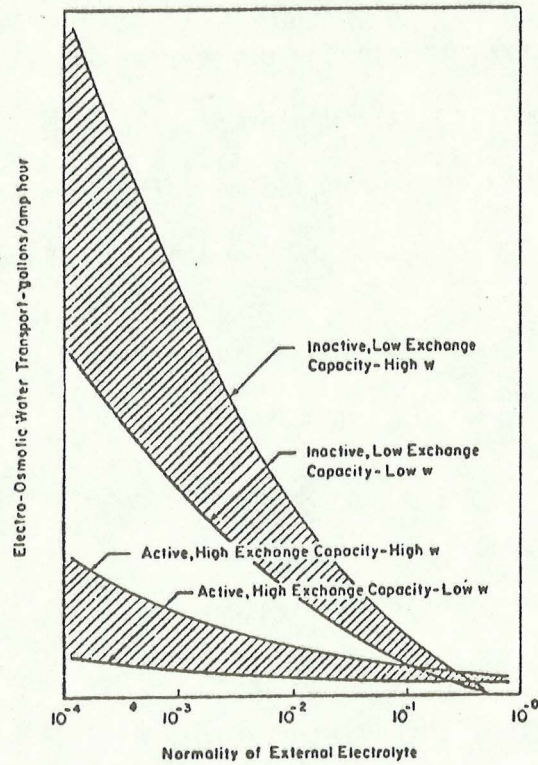
$q_e$  = Electro-osmotic flow rate

$k_e$  = Coefficient of electro-osmotic permeability

$i_e$  = Electrical potential gradient

$A$  = Cross-sectional area of flow

Casagrande (3) established that  $k_e$  for almost all soils, using this method of treatment, is  $5 \times 10^{-5}$  sq cm per sec-v. This value varies by about one order of magnitude for any soil. The ability of water to be transported through a soil mass by electro-osmosis is shown in Fig. 16, as a function of soil type, water content and electrolyte concentration. This figure indicates the following:



Schematic Prediction of Electro-Osmosis in Various Clays According to Dowman Concept (From Mitchell (28))

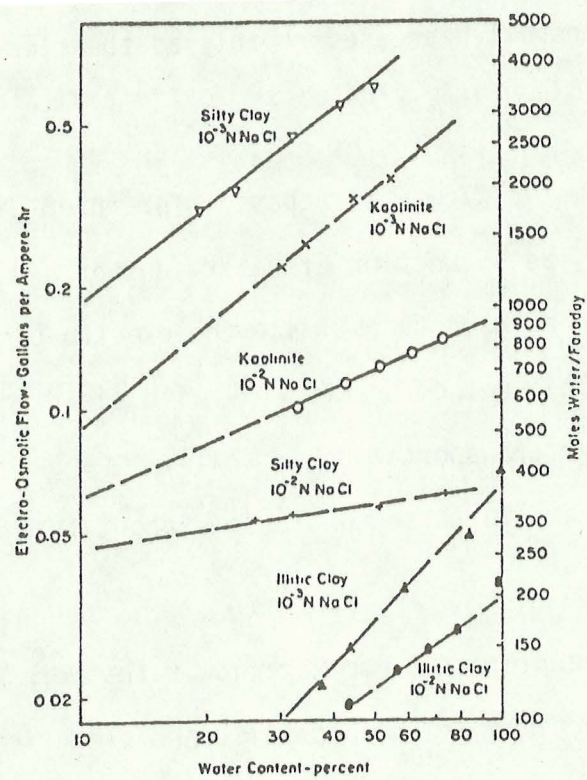
Figure 16

- (a) A decrease in water content decreases the electro-osmosis efficiency.
- (b) Inactive clays have a greater ability to have water transportation than active clays.
- (c) The free electrolyte content does not affect the efficiency of electro-osmosis in active clays, while in inactive clays the water transport decreases rapidly as the electrolyte content rises.

The electro-osmotic flow rate behavior for three different materials is shown in Fig. 17, as a function of water content and electrolyte content. This plot can be used to estimate the electro-osmotic water transport in any soil. This method agrees well with field observations of electro-osmotic water transportation in soils.

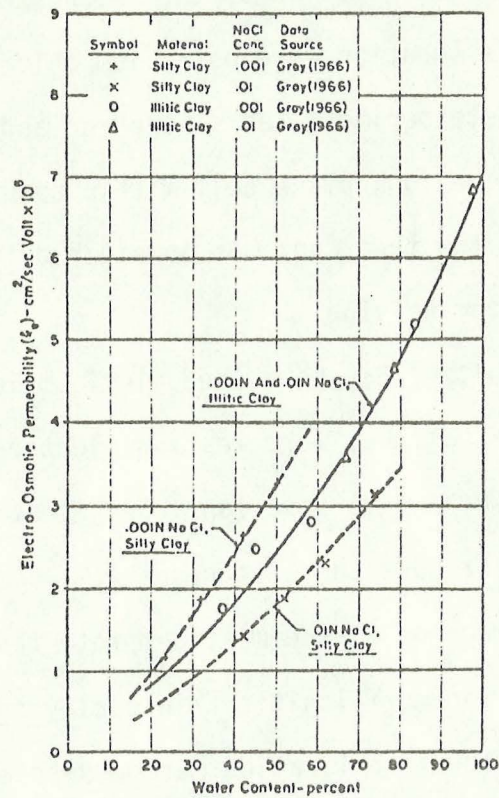
Mitchell (28) came to three conclusions about this method of soil stabilization:

- (a) Hydraulic and electro-osmotic flow rates were observed to be linear functions of the hydraulic and electrical potential gradients.
- (b) There is a direct equivalence between electro-osmotic water transport and streaming potential for soil-water-electrolyte systems.
- (c) The coefficient of electro-osmotic permeability,  $k_e$ , can vary over a significant range with variations in water content. Fig. 18 shows this relationship for illitic clay and kaolinitic silty clay.



Electro-Osmotic Flow Versus Water Content in  
Clay-Water-Electrolyte Systems (From Mitchell (28))

Figure 17



Variation in Electro-Osmotic Permeability with Water Content and Electrolyte Content for Illitic and Silty Clay (From Mitchell (28))

Figure 18

The hardening of clay can be achieved by the use of an electrical current passing through aluminum electrodes. This technique is the basis for the movement of stabilizing chemicals through soil masses to reduce the swelling of clay.

This method was tried on a section of the Friant-Kern Canal, and the chemicals used at this location were potassium chloride and aluminum chloride. A series of postexperiment tests were run and they indicated that favorable stabilization took place only within about 4 feet of the anodes. With this result the treatment was considered inadequate to prevent the canal sections from heaving.

Nettleton (30) and Holtz (13), both used aluminum ions to help stabilize the soil masses that they were testing electro-osmosis stabilization on. Thornburn and Mura (43) have concluded, that for stabilizing clay soil aluminum anodes produce the best results.

O'Bannon (32) performed one of the most complete tests of electrochemical stabilization of montmorillonitic Chinle clay for reduction of swelling under highways. The stabilization method used was a solution of 0.4N KCl and movement of the solution was by electro-osmosis. The results of this test were:

- (a) An average of 36 percent decrease in the percentage of swell.
- (b) A 50 percent reduction in swell pressure of the Chinle clay.

O'Bannon (42) stated that electrochemical soil treatment technology is advanced enough to be used effectively, by the existing work force and material resources.

Satyanarayana and Joshi (1973) performed a detailed investigation of electro-osmotic stabilization of three expansive soils from India.

The mineralogy and index properties of these soils are given in Table 14. The study concluded that electro-osmotically treated expansive soils with chemicals soluble in water such as sodium chloride and potassium chloride exhibited negligible swelling pressures as summarized in Table 15. The confined compressive strength of these three expansive soils increased by 30 to 40% as given in Table 16. The cohesion intercept from triaxial tests increased by 50% to 150%, whereas the angle of internal friction decreased slightly, when treated with potassium chloride using electro-osmosis. These results are summarized in Table 16.

In addition, an increase in permeability values was noticed due to electro-osmotic treatment with various salts and these results are summarized in Table 17.

## 7. THERMAL STABILIZATION

While thermal stabilization has not been used widely in the United States, many European countries have used this method of soil stabilization extensively. Thermal stabilization consists of two types of treatment, heat treatment and stabilization by cooling.

Heat treatment is a modification of expansive soils to reduce the volume change by use of exposure to high temperature. The heating process uses temperatures in excess of  $100^{\circ}\text{C}$  to drive off moisture in the clay and thereby increase the soil strength. These high temperatures may also reduce the swelling characteristics of the soil. When heated to about  $1000^{\circ}\text{C}$  some clays begin to fuse and in effect become bricks.

The problems associated with heat treatment of expansive soils are:

- (a) Only shallow depths of soils can be treated.
- (b) Cost of fuel.

TABLE 14

## Minerology and Index Properties of Soils Investigated

Soil Type	Bhimavaram Soil	Kirkee Soil	Sehore Soil
Source	Hyderabad	Poona	Mysore
Minerological Composition			
Montmorillonite	50%	60%	35%
Illite	20%	20%	15%
Kaolinite	10%	Nil	30%
Principal Exchange Ions	Aluminum	Aluminum	Aluminum and Iron
Atterberg Limits			
Liquid Limit	79.5%	78.5%	62.7%
Plastic Limit	42.25%	43.3%	35.5%
Shrinkage Limit	11.25%	15.2%	14.4%
Plasticity Index	37.25%	35.2%	27.2%
Shrinkage Index	68%	63.3%	48.3%
Free Swell	(Ranganatham and Satyanarayana 1965)		100%
180%		160%	
Specific Gravity	2.70	2.73	2.80
Classification of Soil	Very high swelling type	Very high swelling type	High swelling type
	(Ranganatham and Satyanarayana 1965)		
pH Value	8.8	8.7	8.75
AASHTO Compaction			
Optimum Water Content	26.5%	23.5%	19.5%
Maximum dry Density	97 lbs/c ft	101.5 lbs/c ft	110 lbs/c ft

TABLE 15

Values of Swelling and Swelling Pressure

Sl.No.	Test Details	Bhimavaram soil		Kirkee soil		Sehore soil	
		Swelling %	Swelling pressure Tons/sft	Swelling %	Swelling pressure Tons/sft	Swelling %	Swelling pressure Tons/sft
1	Without Electro-osmosis	17.3	2.5	16.7	2.0	7.6	1.2
2	With electro-osmosis only	12.0	2.0	10.8	1.5	6.4	1.0
3	Electro-osmosis with 2% Calcium oxide	6.7	1.75	8.8	1.2	4.6	0.75
4	Electro-osmosis with 2% Sodium oxalate	6.0	1.5	8.4	1.2	3.2	0.60
5	Electro-osmosis with 2% Sodium chloride	5.6	1.4	7.2	1.0	3.0	0.50
6	Electro-osmosis with 2% Potassium chloride	4.8	1.0	5.2	0.8	2.8	0.50
7	Electro-osmosis with 4% Potassium chloride	3.3	0.80	2.4	0.60	1.6	0.35
8	Electro-osmosis with 2% Potassium chloride (with an initial surcharge of 1/2 Ton/sft).	-4.65 (compression)	Nil	-4.00 (compression)	Nil	-6.50	Nil (compression)

TABLE 16

## Strength Characteristics

Sl.No.	Test Details	Bhimavaram soil			Kirkee soil			Sehore soil		
		c' p.s.i.	$\phi'$ degree	U.C.S. p.s.i.	c' p.s.i.	$\phi'$ degree	U.C.S. p.s.i.	c' p.s.i.	$\phi'$ degree	U.C.S. p.s.i.
1	Without electro-osmosis	9.0	18	15.6	15.0	12	22.6	10	20	13
2	With electro-osmosis only	10.0	15	17.8	17.0	10	24.6	11	17	14.6
	Ratio 2/1	1.11		1.14	1.13		1.09	1.10		1.125
3	Electro-osmosis with 2% Calcium oxide	11.0	16	22.0	19.0	11	30.2	15	17	18.2
	Ratio 3/1	1.22		1.41	1.265		1.34	1.50		1.44
4	Electro-osmosis with 2% Sodium oxalate	11.0	15		18.0	10		12	16	
	Ratio 4/1	1.22			1.20			1.20		
5	Electro-osmosis with 2%	21.0	10		19.0	9		16	13	
	Ratio 5/1	2.33			1.23			1.6		
6	Electro-osmosis with 2% Potassium chloride	21.0	13		22.5	8		18	14	
	Ratio 6/1	2.33			1.50			1.80		
7	Electro-osmosis with 4% Potassium chloride	22.5	11	20.8	23.0	6	27.2	20	12	17.0
	Ratio 7/1	2.50		1.34	1.53		1.20	2.00		1.31

TABLE 17

Values of Permeability and Electro-osmotic Permeability

Sl. No.	Test Details	Bhimavaram Soil (cms/sec)	Kirkee Soil (cms/sec)	Sehore Soil (cms/sec)
1.	Without Electro-osmosis	$0.43 \times 10^{-7}$	$0.69 \times 10^{-7}$	$0.83 \times 10^{-7}$
2.	With Electro-osmosis only	$0.163 \times 10^{-4}$	$0.227 \times 10^{-4}$	$0.287 \times 10^{-4}$
3.	Electro-osmosis and Calcium Oxide (2%)	$0.218 \times 10^{-4}$	$0.229 \times 10^{-4}$	$0.352 \times 10^{-4}$
4	Electro-osmosis and Sodium Oxalate (2%)	$0.276 \times 10^{-4}$	$0.345 \times 10^{-4}$	$0.378 \times 10^{-4}$
5	Electro-osmosis and Sodium Chloride (2%)	$0.324 \times 10^{-4}$	$0.391 \times 10^{-4}$	$0.416 \times 10^{-4}$
6	Electro-osmosis and Potassium Chloride (2%)	$0.380 \times 10^{-4}$	$0.480 \times 10^{-4}$	$0.54 \times 10^{-4}$
7	Electro-osmosis and Potassium Chloride (4%)	$0.470 \times 10^{-4}$	$0.598 \times 10^{-4}$	$0.61 \times 10^{-4}$

Use of this method in the U.S.S.R. has shown that this treatment can only be effective to about 15 m and is good only on dry or partially saturated weak clayey soils and loess.

At this time, this method of soil stabilization is only feasible as a last resort on very large and important jobs. The cost of the fuel and the lack of suitable processing equipment eliminate this as an effective method of soil stabilization.

Stabilization by cooling has been used in many places as a temporary method of stabilizing soils. Freezing the pore water in wet soil produces a rigid material possessing considerable strength. Freezing is accomplished by the circulation of cooled brine and/or ammonia through the soil to freeze the water present in the pores. The soil will remain frozen only while the system is in operation. This method of soil stabilization has been used mainly to support a structure while a new foundation was constructed or repairs were made to the old foundation.

Therefore, freezing a soil is used only as a temporary help while work is being performed for a more permanent solution to the problem.

## 8. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this report has been to explore all possible solutions to the problem of expansive soils, primarily clay. In this pursuit many methods of treatment have been explored and analyzed. These methods are:

- (a) Chemical Stabilization
- (b) Prewetting
- (c) Soil Replacement
- (d) Compaction Control

(e) Electrical Stabilization

(f) Thermal Stabilization

Chemical stabilization is the most widely used and accepted form of soil stabilization, mainly because of the use of lime as a stabilization agent. Deep plowed lime stabilization is an effective technique for stabilization of soil, to a depth of about 36 inches. Pressure injected lime slurry is still debated as to how effective it actually is as a soil stabilization tool. Its effectiveness depends substantially on the existence of a network of cracks and fissures in the soil in which the lime slurry can travel under pressure.

Prewetting is a very useful and effective method of soil stabilization, if time is not critical. The Texas Highway Department has used this method for many years in the construction of highways. This method, however, does not seem to have much use as a building foundation stabilization method unless there is sufficient time for ponding and the water can be kept from drying out subsequently. General considerations for this method can be found in Table 18.

It appears that the soil replacement method of soil stabilization is not the panacea it originally was thought to be. The Colorado Highway Department has reported many failures from this technique, Gerhardt (7). However, there are many more reports of success with this method, and therefore care must be exercised as to when and where to use soil replacement. Some success has been reported from the use of a mixture of lime stabilization and soil replacement. The lime is used to help stabilize the replacement soil or stabilize the soil on which the replacement soil rests.

TABLE 18

## Methods for Volume Change Control without Additives

METHOD	GENERAL CONSIDERATIONS	REFERENCES
COMPACTION	<ul style="list-style-type: none"> <li>-Compact wet of optimum to moderate density</li> <li>-Kneading compaction, as by sheep's foot roller, preferable</li> <li>-Low permeability of material, if compacted as above, will cause any subsequent expansion to be slow</li> <li>-Excavation and recompaction of existing soil prior to use as subgrade may be required</li> <li>-Laboratory test methods should duplicate soil structure in the field</li> </ul>	Colorado (1964) Holtz (1959) Holtz & Gibbs (1956) McDowell (1959) Mitchell et al (1965) Seed et al (1962)
PREWETTING	<ul style="list-style-type: none"> <li>-Provides for soil wetting and expansion prior to construction</li> <li>-Spraying or ponding may be used</li> <li>-Requires a long time</li> <li>-Can use to straighten distorted slabs</li> <li>-Loss of strength and increase in stickiness may make subsequent construction difficult</li> <li>-Lime treatment after wetting useful to provide a firm working table</li> <li>-Later drying may cause shrinkage</li> </ul>	Benson (1959) Dawson (1956) Dawson (1959) Haynes & Mason (1965) Holtz (1959) Holtz & Gibbs (1956) McDowell (1965) McDowell (1959)
HEAT TREATMENT	<ul style="list-style-type: none"> <li>-Heating to <math>200^{\circ}\text{C}</math> may significantly reduce swelling characteristics</li> <li>-Heating to several hundred degrees C may eliminate water sensitivity altogether</li> <li>-Soil fusion possible at temperatures of <math>1000^{\circ}\text{C}</math></li> <li>-Heat treatment may improve susceptibility to stabilization by other methods</li> <li>-Practical, economical methods not yet available in U.S.A.</li> </ul>	Aylmore et al (1969) Chandrasekharan et al (1969) Post & Paduana (1969)

(After Mitchell and Raad (29))

Compaction control has shown to have some use as a stabilizing procedure for expansive soils, by controlling the moisture content. The problem with compaction control is that it is often very difficult to hold the moisture content at a certain level that was specified by a laboratory test. The best machine to use for compaction control is a sheepfoot roller, because of the kneading action it produces. General considerations for this method can be found in Table 18.

Electrical stabilization appears to have problems as a soil stabilization method, because of its expense and because of the failures reported by different organizations. Both the University of Wyoming and the Louisiana Department of Highways have reported that electro-osmosis failed to move any appreciable amount of lime slurry into the soil. The successful application of potassium chloride into the Chinle shale in Arizona indicates that it can be done but that it is expensive.

Thermal stabilization appears to have some applications, if the job must be done in a hurry. This method of soil stabilization does not have much of a future, because of the unavailability of equipment and mainly the cost of fuel. As the price of fuel goes up, the future of this method looks very dim. The general considerations for heat treatment can be found in Table 18.

Based on the results reported herein and from the results of other researchers, there are several conclusions that can be reached about the various methods of soil stabilization.

- (a) No single chemical or combination of chemicals is likely to be the cure all, as far as soil stabilization is concerned.
- (b) Chemicals can help to reduce the susceptibility of expansive soil to moisture infiltration. Some chemicals that are used

as soil stabilizers are listed in Tables 19 and 20.

- (c) The type and amount of chemicals most useful in any situation is dependent on the physical, chemical and mineralogical composition of the soil.
- (d) Inorganic salts and bases permit lime treated soil to cure at lower temperatures. The free ions in the salt and base solutions help strengthen the water-soil bonds, as indicated by Thornburn and Mura (43).
- (e) Salts reduce the freeze-thaw effect on soils.
- (f) Leaching of salts will occur if no protective cover is applied.
- (g) Ponding is a viable tool in highway construction for reducing the expansion of soils but not for building foundations, unless the moisture can be kept from drying out subsequently.
- (h) Many cases of where lime and/or lime injection have helped stabilize expansive soil are found in trade journals and publications. Members of Woodbine Corporation, of Fort Worth, have performed many stabilization projects using lime and/or lime slurry, and their results have been very good. Their successes are well documented and can be found in many papers published by Wright (17, 48, 49, 50, 51), and in publications, such as Progressive Railroading (5, 22, 52) and Roads and Streets (23).
- (i) The success of a method of injecting a stabilizing agent into the soil relies upon the existence of a closely spaced network of cracks or seams in the soil mass in which the fluid can travel under pressure. As an alternative, very closely spaced injection holes may be used.

TABLE 19

## Chemicals and Proprietary Products Used as Soil Stabilizers

Name of Materials	Producer or Developer
AM -9	American Cyanamid Company
Aniline - Furfural	H. Winterkorn
Basic (R)	American Basic Chemicals, Inc.
ClaPak	Central Chemical Company
Calcium Acrylate	Rohm and Haas Co. (T. W. Lambe, Jr. M.I.T.)
Fujibeton	Business Development International
Geoseal	Borden, Inc.
Liqui-Road	Humphrey Corporation
Paczyme	Larutan
Permasteer	Terra-Perma, Inc.
Plastmofalt, Plasmossix	Tropical Agricultural Research
Resinol	Golden Bear Oil Company
Reynolds Road Packer	Zel Chemical Company
RX-1 , RX-2	Central Chemical Company
SA-1	Central Chemical Company
SC-50 (silicone)	General Electric Company
Soil Consolid-RSP	Nacco Est.
Soilcrete	General American Transportation Corp.
Soil Seal	Soil Seal Corporation
SSA (178,179,180)	E.I. du Pont de Nemours Company
Terrabind	Deutsche Terrabind-Erdestabilisierungs-GMBH
Terra Firmer	Construction Chemicals, Inc.

TABLE 19 (Con't)

Name of Materials	Producer or Developer
Aliquat H - 226 (Quaternary Amine)	General Mills, Inc.
Arquad - 2HT (Quaternary Amine)	Armour Industrial Chemical Corp.
Cellulose Compounds	Rayonier, Inc.
Chrome - Lignin	Cornell University
Diatol (Emulsified Asphalt)	Unknown
Lignin Liquors and Compounds	Rayonier, Inc. and Various Others
Lime, Hydraulic	Riverton Lime and Stone Company
Lime, Waste (Carbide Lime from Acetylene Plants)	Chemical Lime Corporation and Others
PDC (portland cement- Lime-Casein)	Products Development Company
Phosphoric Acid	Monsanto Chemical Company, Tennessee Corporation
Salt (Sodium Chloride)	The Salt Institute, Morton Salt Co.
Terbec (TBC)	Dow Chemical Company

(After Kinter (19))

TABLE 20

## Results of Tests on Chemicals as Soil Stabilizers

Chemical or Type of Chemical	Results
Quaternary Amine	Because of their cationic nature, they react readily with clay minerals, producing a strong flocculation and a considerable degree of water repellance. These amines, however, were not found to be significantly effective for treating highway soils.
PDC	The Project Development Company's tests show that PDC is an effective soil stabilizer. However, the FHWA tests show that PDC is no more effective than the same lime-cement mixture without the casein.
Terbec	FHWA tests show this chemical to be an effective waterproofer, but it did not permanently strengthen or improve clayey soils.
Lignin Liquors and Lignin and Cellulose Compounds	The costs of Chrome-Lignin are excessive and the effectiveness of producing strength and water resistance is dependent upon a partial drying back of the treated soils. Lignin liquor has proved ineffective from field tests by Iowa State University.
Phosphoric Acid	Monsanto Chemical Company found that this chemical reacted with soils to increase their strength and water resistance. This chemical has been proved effective on soils in the eastern United States, but the cost is too high to be used economically. This chemical has also been proved dangerous to workmen and corrosive to the road building equipment.
Asphalt Emulsions	Some success has been achieved on soils of low plasticity. Field tests have shown that this mixture develops adequate strength quickly.

TABLE 20 (Con't.)

Chemical of Type of Chemical	Results
Special Limes	<p>Hydraulic limes have proved to be an effective stabilizer, because of the high cement content. But it is not as effective as either portland cement or high grade lime. Waste lime has been shown to be about as effective as the equivalent quantity of dry lime. Because waste lime is in paste form difficulties of handling and shipping have caused it to be seldom used.</p>

(After Kinter (19))

- (j) The permeability of a fluid entering a soil depends to a large extent upon the mineralogy of the soil and the chemical composition of the water in the soil and the entering fluid. The mechanism whereby the permeability of soil is altered by organic and inorganic fluids is not understood at present, although it is known that some organic fluids such as carbon tetrachloride and benzene increase permeability of laboratory samples greatly. In order to be an effective permeant, a fluid should increase the permeability of the soil to a level of about  $10^{-4}$  cm/sec. The only way of determining whether a particular fluid will have that effect upon a particular soil at the present state of knowledge is by testing it in the laboratory.
- (k) Electro-osmosis can be effective in driving chemical solutions into soil but requires high DC voltage gradients and is a costly operation. It is generally uneconomical for highway operations but could be considered for spot operations. The effectiveness and voltage gradient requirements of electro-osmotic treatment can be estimated by laboratory tests.
- (l) Moisture can be stabilized beneath a covered area by placing a vertical or horizontal membrane around the area. The membrane should extend to a depth below which moisture does not change substantially ( $\pm 2\%$ ) with the seasons.
- (m) On any given site, or within a particular soil group, the most effective treatment must achieve a reduction in the swelling potential of the soil, a stabilization of the moisture regime beneath the foundation, and an economical operation. These

objectives can only be achieved by matching locally available equipment and trained personnel to the treatment method(s) that are most effective with that particular soil. Effectiveness of such an operation in the field is usually heavily dependent upon the cracked and seamed nature of the soil mass in the field to allow the treatment to be dispersed well throughout the mass.

Further research needs to be done in the area of combining the methods mentioned in this report into an economical and effective soil stabilization method. For example, the combination of lime slurry and soil replacement has been shown to work in problem areas where neither would work independently.

#### Post Construction Remedial Work

Post-construction remedial work is made more difficult by the need to preserve the integrity of the building while the treatment is being applied. Buildings with basements are more difficult to treat than those built on slabs-on-ground because of the problems of accessibility.

Once it has been determined that remedial work must be undertaken, a soil and site investigation should be undertaken to determine the cause of damage. Broken water and sewer lines, high perched water tables, interception of seams or strata of water bearing sands or gravels, downhill creep of the soil, the drying effect of trees, the malfunction or non-existence of drains around the perimeter of the building, poor drainage around the building, including the improper handling of roof drainage, leakage or unwise watering practices with a lawn watering system,

and a host of other such problems may be the cause of the damage. The remedy that is proposed should treat the cause(s) and not the symptoms of the damage, and a site investigation will help to reveal the cause(s). The remedy will usually involve altering one or more of these site conditions before attempting to stabilize the properties of the soil. In some cases, no soil treatment will be necessary if the cause of the problem is corrected.

If soil treatment is indicated by laboratory tests then some determination should be made of how effective the treatment is likely to be. A trench on site will reveal the presence or absence of cracks in the soil mass and seams of gravel or clean sand which are essential to the effective operation of a chemical injection method. There is a possibility that some presently available state-of-the-art wave propagation devices may be capable of detecting the presence of these large cracks or voids non-destructively and thus avoid the need for trenching. The importance of this determination cannot be over-emphasized since it is impossible to tell from laboratory testing alone how effective the envisioned treatment will be in the field. It is certain that a soil with clay content and with only small cracks laced throughout the soil mass will be less effectively treated than the same soil with frequently spaced large cracks or seams of gravel or clean sand. These voids act both as a means of access for the treating fluid and as a reservoir which can continue to feed treating fluid into the intact blocks of soils surrounding the void.

The laboratory tests that should be made to determine the effectiveness of the chemical treatment should be more concerned with reducing the swelling potential than with reducing swelling pressure. The soil

should be allowed to take up the chemical by capillarity for a standard period of time (say 30 min) at a standard temperature and then tested using water as the permeant. This limited period of accessibility to the chemical will tend to simulate the accessibility the fluid will have to the soil in the field.

There are numerous new ideas that may be tried in remedial work. For example, a cable saw could saw a trench inside the basement. The trench will be filled with a thick fluid that sets into a viscous, impermeable vertical membrane. Asphalt rubbers would be very good for this purpose.

Many new chemicals could be tried. One of the potential spinoffs of the current interest in the impermeability of clay liners for toxic and hazardous waste disposal sites will be the identification of those organic fluids that have high permeabilities through clay. If one of the stabilizing salts mentioned in this report can be found to be soluble in one of these organic fluids, a new and possibly more effective chemical treatment method will have been found. The permeability will have to be on the order of  $10^{-4}$  cm/sec in order to be really effective and not need to rely so heavily upon the presence of cracks or gravel seams to become dispersed throughout the soil mass.

Electro-osmosis may be an effective method of driving such a fluid into the soil, but this is speculation that must be proven by testing.

A reservoir of treating fluid connected by manifolds into numerous injection points could provide a steady flow of the fluid into the soil mass and increase the possibility that more of the soil mass will actually come into contact with the fluid and be altered beneficially. The "injection points" could be vertical holes filled with clean sand

that will permit easy permeation of the treating fluid. The spacing of the "injection points" should be closer together as the soil mass is less fractured or more intact.

A slow "trickle charge" of electrical D.C. voltage may assist in driving the treating fluid into the soil but this will require numerous metal rods driven into the "injection points" and other rods to act as the anodes toward which the fluid will flow. The process will take a considerable period of time of low voltage levels but a homeowner may be willing to stand for the expense if the process works. Several of these post-construction treatment techniques are summarized in Table 20.

Numerous other speculative ideas could be suggested. Unfortunately, none of these have been tried in the field and proven to be feasible. Yet the likelihood is there that some combination of these remedial measures will prove to be a generally successful measure for post-construction treatment.

TABLE 21

## Summary of Post-construction Treatment Techniques

Technique	Effectiveness for Post-construction	Comments
Excavate and Replace	Poor	Must remove the structure from site and replace
Drainage Improvements	Fair	Prevents further swell if properly applied
Membrane Placement	Fair	Prevents further swell if properly installed
Drill-hole Lime	Good	Requires special equipment
Pressure Injected Lime	Good	Requires well developed crack pattern in soil. Special equipment needed.
Electro-osmosis	Poor	Localized treatment only
Ion Migration	Good	Not enough data available to accurately choose chemical additive to use.
Vertical Moisture Membrane	Poor	Special trenching equipment needed.
Mudjacking	Poor	Does not solve the problem, but acts as a temporary remedial measure
Overlay	Poor	Does not solve the problem, and usually used for highway pavements.

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APPENDIX A

ABSTRACTS OF LITERATURE  
ON  
TREATMENT METHODS FOR  
EXPANSIVE CLAYS



314630 DA

## DYNAMIC SHEAR MODULUS OF TREATED EXPANSIVE SOILS

Au, WC; Chae, YS

American Society of Civil Engineers

Elton (WD) and Associates; Rutgers University, New Brunswick

ASCE Journal of the Geotechnical Engineering Div VOL. 106  
NO. GT3 Mar 1980 pp 255-273 11 Fig. 3 Tab. 23 Ref.AVAILABLE FROM: Engineering Societies Library 345 East 47th  
Street New York New York 10017

REPORT NO.: ASCE 15287;

SUBFILE: HRIS

Dynamic shear modulus of expansive soils treated with lime, salt, and lime-salt combination has been determined by the resonant column technique to study the parametric effects of confining pressure, shear-strain amplitude, degree of saturation, treatment level, type of additives, and soil structure. The effect of each of these parameters on the dynamic shear modulus was found to be significant and could be explained in terms of the change in macrostructure and corresponding change in physicochemical properties of the soil. It was found that the use of additives to stabilize expansive soils not only improved the static properties by reducing swelling and increasing the shear strength, but also improved the dynamic properties. The treatment with lime-salt combination was found to be the most effective as the addition of salt to bentonite clay-lime mixture produced a catalytic acceleration of pozzolanic reactions and new cementitious minerals. It was also found that the dynamic shear modulus showed a good correlation to the static shear strength of the soil. (ASCE)

## DESCRIPTORS:

DYNAMIC SHEAR MODULUS  
EXPANSIVE SOILS  
LIMING OF SOILS  
MECHANICS (EARTH MASS)  
PHYSICOCHEMICAL PROPERTIES  
PRESSURE  
SALT /SODIUM CHLORIDE/  
SATURATION  
SHEAR STRENGTH  
SOIL SOLIDIFICATION  
STRAINS  
SWELLING SOILS

CONTRACT NO.: AT40 EO 004; RDT&amp;E

SUBFILE: HRIS

The design process for structures on expansive clay should consist of a feasibility study, preliminary design phase to establish the overall concept and a detailed design phase to complete the engineering description of the project. This report provides background information for establishing the preliminary design of structures in swelling soil areas based on field studies conducted by the U.S. Army Engineer Waterways Experiment Station (WES) and experiences of numerous investigators. The overview includes analyses of site and soil investigations, topography and landscaping including drainage and soil stabilization techniques, and selection of the foundation and superstructure. General suggestions for remedial repair of existing structures are also provided. Analysis of the movement of cast-in-place concrete piers in swelling soil are included to provide a basis for design of these foundations. Numerous structures constructed on expansive clay soil have experienced and sustained significant damage from differential heave and settlement. The types of structures most often damaged from heaving soil include highways, foundations and walls of residential and light commercial buildings, canal and reservoir linings, and retaining walls. The leading cause of foundation heave or settlement is change in soil moisture attributed to change in the field environment (e.g., climatic changes, prevention of evaporation beneath covered areas, improper drainage following construction and from usage requirements of the structure.

## DESCRIPTORS:

CAST IN PLACE STRUCTURES  
CONCRETE STRUCTURES  
DESIGN  
DRAINAGE  
EXPANSIVE CLAYS  
FEASIBILITY STUDIES  
FOUNDATIONS /STRUCTURES/  
MECHANICS (EARTH MASS)  
MOVEMENTS  
PIERS  
REPAIRS  
SITE INVESTIGATIONS  
SOIL INVESTIGATIONS  
SOIL STABILIZATION  
TOPOGRAPHY

307535 DA

## OVERVIEW FOR DESIGN OF FOUNDATIONS ON EXPANSIVE SOILS

Johnson, LD

Waterways Experiment Station Geotechnical Laboratory, P.O.  
Box 631 Vicksburg Mississippi 39180; Department of the Army  
Office of the Chief of Engineers Washington D.C. 20310  
Sep 1979 Final Rpt. 108 p. Figs. Tabs. 127 Ref. 4 App.  
REPORT NO.: Misc Paper GL-79-21

263845 DA

## LIME TREATMENT BEING STEPPED UP IN SOUTH DAKOTA

Roads and Streets VOL. 107 NO. 9 Sep 1964 p 82 1964

SUBFILE: HRIS

Lime addition to subbase materials in roadbeds to control expensive (gumbo) soils is apparently working well in South Dakota. As a footnote to the feature report on this stabilization in April Roads and Streets, E. B. McDonald, materials engineer for the South Dakota Department of Highways reports that lime has been recommended for another ten Interstate and three primary construction projects. The Highway Department started the lime treatments on certain projects in 1960. One of the first projects, I-29 south of Worthington in Lincoln County, was tested with the Rough-O-Meter machine and is apparently the smoothest "I" section between Sioux Falls and Sioux City. Prior to 1964 the department has used 58,121 tons of lime in subbase, earth subgrade, base course and mats on 127.8 miles of construction. McDonald said their experience so far has proven their earlier laboratory findings. The lab tests had indicated the possibility of reducing expansion in some soils from 41 percent to as low as 3.6 percent. The soils include the highly-expansive bentonitic types. Now this stabilization is being considered for other parts of the state. The lime-treated roadbeds apparently withstand the freeze-thaw cycles that break up highways across the state, according to McDonald. The extreme temperature differential in this region accentuates collection of moisture vapor in the upper roadbed layer, contributing to instability, uneven swelling and road roughness. Cost of lime treatment is approximately \$50 per ton, including cost of lime, mixing and placement. In a news release to South Dakota newspapers, McDonald said that lime use will be relatively inexpensive over a period of time if it reduces maintenance costs and extends the life of the highway. An experimental project is under construction, designed to serve as an outdoor laboratory for study of long range effects of various stabilization methods. Troublesome gumbo soils are being treated variously with lime stabilization (said to show most promise), phosphoric acid and ferric sulfate, and a lime-asphalt combination. /ART/

## DESCRIPTORS:

ASPHALTS  
BENTONITES  
COSTS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
FREEZING THAWING EFFECTS  
IRON COMPOUNDS  
LABORATORY TESTS  
LIME  
MOISTURE MOVEMENT  
PHOSPHORIC ACID  
ROADBEDS  
SOIL STABILIZATION  
SUBBASE

SUBGRADES  
TEMPERATURE  
TREATMENTS

262907 DA

## ELECTRO-OSMOTIC STABILIZATION OF EXPANSIVE SOILS

Satyanarayana, B; Joshi, DK

Soil Mechanics and Fdn Eng Reg Conf (5th) S Af; .Cape Town; South Africa

VOL. 2 .Proceeding pp 119-23 2 Fig. 4 Tab. 18 Ref. 1973

SUBFILE: HRIS

In this investigation of the possibility of reducing swelling pressure of expansive soils by the addition of various chemicals (sodium oxalate, sodium chloride, lime and potassium chloride) under electrosmotic conditions, potassium chloride treatment proved to be the most successful technique in stabilizing the undesired properties in the filed without disturbance of the soil strata. Three different Indian soils with different expansion characteristics were investigated. Mineralogical, index and other soil properties are tabulated. Details are given of the tests that were conducted. The electro-osmotic treatment is described in detail. The results are tabulated and discussed. Treatment with sodium chloride and potassium chloride resulted in negligible swelling and swelling pressures. The expansion characteristics were completely eliminated when treated with potassium chloride under electrosmotic conditions and acted upon by an initial surcharge load of the order of 0.5 ton/sft. or more. The unconfined compressive/strength of expansive soils is increased by 30 to 40 percent and the cohesion of the triaxial shear strength is increased by 50 percent to 150 percent. The angle of internal friction decreased slightly. These papers were presented at the Fifth Regional Conference for Africa for Soil Mechanics and Foundation Engineering.

## DESCRIPTORS:

ANGLE OF INTERNAL FRICTION  
CHEMICAL COMPOUNDS  
COHESION  
ELECTROOSMOSIS  
EXPANSIVE SOILS  
LOADS  
POTASSIUM CHLORIDE  
SODIUM COMPOUNDS  
SOIL SCIENCE  
STABILIZATION  
SURCHARGE  
TESTING  
THREADS

262556 DA  
**BUILDING A WORKING TABLE WITH LIME**  
 Kelley, CM  
 Ohio State University; Department of Civil Engineering;  
 Columbus; Ohio; 43212  
 National Lime Association  
 Apr 1973 Proceeding pp 75-89 4 Tab. 17 Ref. 4 App. 1973  
 SUBFILE: HRIS

the use of quicklime or hydrated lime for stabilization is discussed with the goal of creating a working table for the pavement structure. Results obtained from lime treatment of a heavy subgrade soil on I-20 east of Dallas, Texas, during the winter of 1954-55 provided a basis for the understanding of improvement due to lime subgrade treatment. First, the lime was mixed and compacted during the wet season of late 1954 and early 1955. At that time Texas was in a critical drought period beginning in 1951 and ending in 1957. It is now apparent that the lime-treated layer formed a moisture barrier and helped maintain a uniform moisture condition below the stabilized layer. On the other hand, the fill sections were constructed with less moisture controls and without adequate subgrade and slope protection and the wet and dry cycles have produced considerable heaving over the 18-year period. Following this illustration, lime stabilization of highly plastic swelling subgrade soils and wet, weak nonswelling subgrade soils is discussed. The remainder of the report deals with design considerations and includes typical pavement sections to assist the engineer in designing a pavement using lime without use of complicated design formulas. The principal factors affecting the pavement design are traffic, subgrade report, and material used in the pavement structure. Proceedings of the Twenty-Seventh Annual Ohio Transportation Engineering Conference. Sponsored, in part, by the Ohio Department of Transportation.

DESCRIPTORS:

FOUNDATIONS (SOILS)  
 HYDRATED LIME  
 LIME  
 PAVEMENT SUBGRADES  
 QUICKLIMES  
 SOIL STABILIZATION  
 SUBGRADE MOISTURE  
 SUBGRADE TREATMENTS  
 SWELLING SOILS

260249 DA  
**LIME IS NOT A PANACEA**  
 Graf, ED  
 Pressure Grout Company  
 ASCE Civil Engineering VOL. 44 NO. 7 Jul 1974 pp 47-49  
 1974  
 SUBFILE: HRIS

reviewed, and the injection of a lime slurry to penetrate a heavy clay is discussed. Portland-cement or lime-slurry pressure injection sometimes works well and sometimes poorly. The use of these methods entails a risk that the soil will not be stabilized. The case is discussed of the Dallas/Fort Worth Airport. The aspect of lime migration is discussed and the observation is made that lime does not migrate to any great extent from the hole where it is placed. It is concluded on the basis of the evidence presented here, that it is impractical, if not impossible to treat an entire mass of clay by injection of lime. Both lime and portland injection have limited use to reduce expansive soil problems under existing structures on a calculated risk basis. They should not be normally recommended procedure for new construction. Costs and benefits should be examined for the choice of either portland cement or lime. The low strength of unreacted lime along the shear seams of lime injected clays, indicates that lime injection should not be used where lateral stability is important. Lime should not be used when the soil is high in sulphates. The use of lime in acid soils and soils with saline-alkali salts involve unknown hazards and the need is indicated for studies in this area. The use of lime must be preceded not only by the conventional soils engineering laboratory tests but also by a rigorous soil chemistry analysis.

DESCRIPTORS:

ACID SOILS  
 ALKALI SALTS  
 BENEFIT COST ANALYSIS  
 CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 INJECTION  
 LABORATORY TESTS  
 LATERAL MOVEMENT  
 LIME  
 MIGRATION  
 PORTLAND CEMENTS  
 SALTS  
 SEAMS  
 SHEAR  
 SOIL CHEMISTRY  
 SONAR  
 SULFATES

238182 DA

## MEASURING IN-SITU SUCTION OF EXPANSIVE CLAYS

Workshop Proceedings; .Stevens, JB; Matlock, LH

VOL. 1 .May 1973 pp 176-88 10 Fig 1ref 1973

SUBFILE: HRIS

The most promising device for determining in-situ suction of expansive clays appears to be the spanner psychrometer. The advantages of spanner psychrometers for field use include the following points: (1) the psychrometer rapidly attains equilibrium after placement; (2) immediate response to changing conditions; (3) little disturbance of the in-situ conditions; (4) small size; and (5) measurements may be repeated. The principal limitations are: (1) extremely low level signals; (2) subject to contamination; and (3) temperature sensitivity. The spanner psychrometer consists simply of a thermocouple and attendant accessories. A recent variation of the basic device is the double junction psychrometer. Double junction psychrometers have two advantages over the single junction psychrometers generally in use. The first is automatic temperature compensation which reduces the requirement of precise temperature control. The second is the ability to make dual measurements at the same point. This provides a check on the readings obtained. The use of an access tube to install and remove psychrometers is expected to reduce contamination problems in the field use of psychrometers.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL SCIENCE  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

and b-dimension. This hypothesis is essentially as follows. The structures of interlayer water and montmorillonite conform to each other, i.e., epitaxy occurs, because of the hydrogen bonding that exists between them. As the interlayer water increases in thickness, its structure tends to assume a preferred configuration and the montmorillonite structure adjusts accordingly. This adjustment continues until the water achieves its preferred configuration. Or, alternatively, the montmorillonite structure relaxes as stresses acting on it are relieved by the inclusion of water, and the water structure changes conformably. This relaxation continues until the water structure resists further strain. In either event, the b-dimension increases as the interlayer water increases in thickness and its final value is governed by the water. Hence, it is the same for every maximally swollen montmorillonite. The mutual adjustment of the montmorillonite and water structures, which accompanies the absorption of water, necessarily causes a change in their structural energies. The net change in energy is presumed to be negative. Therefore, the water is absorbed spontaneously. Water absorption (swelling) stop when no further structural adjustments occur, i.e., when the b-dimension reaches its final value. Thus, swelling is related to the change in b-dimension.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL SCIENCE  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

238181 DA

## FUNDAMENTAL MECHANISMS INVOLVED IN EXPANSION OF CLAYS AS PARTICULARLY RELATED TO CLAY MINERALOGY

Workshop Proceedings; .Low, PF

VOL. 1 .May 1973 pp 70-91 2 Fig 15 Ref 1973

SUBFILE: HRIS

A new hypothesis is proposed to explain clay swelling which takes into account the observed relation between free swelling

233758 DA

## SUMMARY OF PROCEEDINGS OF WORKSHOP ON EXPANSIVE CLAYS AND SHALES IN HIGHWAY DESIGN AND CONSTRUCTION

Lamb, DR; Hanna; SJ  
Wyoming University; College of Engineering, P.O. Box 3226,  
University Station; Laramie; Wyoming; 82070  
May 1973 22 pp 1973

AVAILABLE FROM: National Technical Information Service 5285  
Port Royal Road Springfield Virginia 22161

REPORT NO.: FHWA-RD-73- 72; PB-226593

SUBFILE: HRIS

Responses to a questionnaire to the state highway departments, District of Columbia and Puerto Rico showed that: (1) 36 highway departments have problems with expansive clays or shales, and (2) 19 highway departments recognize expansive clays in pavement design criteria. General information is given regarding distribution of expansive clays in the United States, including a map showing outcrop-formations having abundant montmorillonite. A discussion of microstructure of clays and relation of soil swelling to structure and interlayer water is given. Some of the laboratory and field methods for measuring swell potential of clays, given in proceedings papers, are mentioned. Eight procedures or techniques for treating expansive soils are listed, and some are briefly discussed. Factors and characteristics that are considered in design on expansive clays are listed, but further research on the effect of some of these factors is needed before a rational prediction method for swell potential can be formulated, basic research on the swelling mechanism is needed. Factors needing evaluation in long-term field studies are listed. Other physical and chemical treatments, particularly thermal or other treatment of clays in place, need to be considered. Guidelines for implementation of known treatment methods for clays are given. /FHWA/

## DESCRIPTORS:

CLAY MINERALS  
EXPANSIVE CLAYS  
MECHANICS (EARTH MASS)  
MEMBRANES  
RESEARCH AND DEVELOPMENT  
SOIL STABILIZATION  
SOIL TREATMENT  
SWELLING SOILS

MEASUREMENTS TAKEN WITHIN EXPANSIVE CLAY SUBGRADE SOILS UNDER TYPICAL OKLAHOMA HIGHWAY PAVEMENTS. THE RESEARCHERS DREW SEVERAL CONCLUSIONS: (1) EXCEPT DURING DROUGHTS, SUBGRADE MOISTURE CONTENT VARIES SEASONALLY, AND GRADUALLY INCREASES TO AN "EQUILIBRIUM" VALUE--NEAR A MOISTURE CONTENT/PLASTIC LIMIT RATIO OF 1.1 TO 1.3. DURING DROUGHTS THE SOIL MAY DRY TO A DEPTH OF 10 FEET. (2) IMPERVIOUS PAVEMENTS WITH WIDE SHOULDERS, WITH IMPERVIOUS AND FLEXIBLE BASE COURSES, AND BUILT ON GRADE OR IN CUT SECTIONS PERFORMED BEST. (3) WIDE SHOULDERS REDUCED MOISTURE VARIATIONS BENEATH THE PAVEMENTS ALTHOUGH MOISTURE CONTENT VARIED SIGNIFICANTLY UNDER THE SHOULDERS. (4) LATERAL AND VERTICAL SWELLING OF EXPANSIVE OKLAHOMA SUBGRADES CAUSED SIGNIFICANT DAMAGE TO SOIL-CEMENT BASE MATERIAL AND TO PAVEMENTS WITHOUT BASE MATERIAL. (5) FLEXIBLE, IMPERVIOUS BASE MATERIALS, SUCH AS STABILIZED AGGREGATE BASE COURSES OR SAND-ASPHALT BASE COURSES, REDUCED INFILTRATION AND RESISTED CRACKING BETTER THAN SAND CUSHION OR SOIL-CEMENT BASE MATERIALS. /BPR/

## DESCRIPTORS:

BASE COURSES  
CLAYS  
EXPANSIVE SOILS  
HIGHWAY PAVEMENTS  
IMPERVIOUS SURFACES  
MECHANICS (EARTH MASS)  
MOISTURE CONTENT  
PLASTIC LIMIT  
SAND ASPHALT  
SEASONAL VARIATIONS  
SHOULDERS  
SOIL CEMENT  
SOIL SWELL  
STABILIZED BASE COURSES /MATERIALS/  
SUBGRADE MATERIALS  
SUBGRADE MOISTURE  
WIDTHS

233728 DA

## INTERIM REPORT VIII - EVALUATION OF COLLECTED DATA 1966-1969

Shaw, LK; Haliburton, TA  
Oklahoma State University; Transportation Department /US/;  
Federal Highway Administration /US/; Bureau of Public Roads /US/

REPORT NO.: 64-01-3;

SUBFILE: HRIS

AN EVALUATION IS PRESENTED OF MOISTURE AND TEMPERATURE

233521 DA

## ARIZONA'S EXPERIENCE WITH SWELLING CLAYS AND SHALES

Workshop Proceedings; Morris, GR

VOL. 2 May 1973 pp 283-5 1973

SUBFILE: HRIS

In Arizona most of the swelling clay lies in a very arid region. Membrane construction, full depth asphalt, widened cut ditches, and moisture control in embankments are being utilized. Two things presently being investigated in Arizona are chemical stabilization and the possible placing of membranes over the entire pavement surface.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233519 DA

## DESIGN OF MONTANA HIGHWAYS IN AREAS OF EXPANSIVE SOILS

Work Shop Proceedings; Hogan, JM

VOL. 2 May 1973 pp 262-73 8 Fig 1973

SUBFILE: HRIS

A brief discussion is given of experience with expansive clays by the Montana department of highways under the following subtitles: distribution of swelling soils; methods of sampling and testing; application of testing data; and evaluation of the expansion index test.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233520 DA

## KANSAS PROCEDURES FOR HIGHWAY CONSTRUCTION IN SWELLING CLAYS AND SHALES

Workshop Proceedings; Clark, GN

VOL. 2 May 1973 pp 274-82 9 Ref 1973

SUBFILE: HRIS

The Kansas approach to problems associated with expanding clays and clay shales has evolved over a period of more than forty years. Tempered by experience, it now includes a combination of lime modification to reduce swell potential and design features and construction controls to minimize the degree to which swell potential will adversely affect the performance of the pavement structure. These measures would probably not be classified as drastic in comparison with measures used in other areas. They have in general, given satisfactory results in Kansas. A significant point is that the higher swelling soils are concentrated in areas of heavier rainfall allowing measures confined to the upper portion of the subgrade to suffice. The same approach in a more severe environment would likely not give the same results.

## DESCRIPTORS:

CLAY MINERALS

233518 DA

## SWELLING SOILS IN NORTH DAKOTA

Workshop Proceedings; .Plummer, DD

VOL. 2 .May 1973 pp 259-61 1973

SUBFILE: HRIS

A few brief comments were made on North Dakota's experiences with swelling clays and shales. It was pointed out that better field tests for identifying swelling soils are needed, and that also the need exists to make the information that is presently available on such soils more usable for the operating or field engineers.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233517 DA

## PROBLEMS OF HIGH-VOLUME CHANGE SOILS IN NORTH DAKOTA

Workshop Proceedings; .Leer, DK

VOL. 2 .May 1973 pp 256-8 1973

SUBFILE: HRIS

Following a brief review of problems encountered in North Dakota in areas with expansive soils, it is concluded that the expansive soils are no longer the problem that they were in 1967 or prior to that time. This is due to the fact that the continuously reinforced paving concept has been employed and new compaction standards, whereby soils are compacted to a lower density and a higher moisture content, have been followed. There may be other problems with the continuously reinforced concrete pavement in the future but for the present, it appears to be the answer to pavement roughness for constructing roadways in the areas having expansive soils.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS

GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233516 DA

## EXPANSIVE SOILS IN WYOMING HIGHWAYS

Workshop Proceedings; .Diller, DG

VOL. 2 .May 1973 pp 250-5 1973

SUBFILE: HRIS

This paper briefly summarizes the problems encountered in constructing highways in Wyoming in areas with expansive soils, and mentions the methods which were used to solve them.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233515 DA

## CALIFORNIA'S GENERAL EXPERIENCES

Shop Proceedings; .Smith, RE

VOL. 2 .May 1973 pp 295-9 1973

SUBFILE: HRIS

A very brief review is presented of california's experiences in constructing highways in areas having expansive soils.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

necessarily dependent on time and at this point it is not possible to know definitely how the two surfacing types will compare.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233514 DA

## REVIEW OF HIGHWAY DESIGN AND CONSTRUCTION THROUGH EXPANSIVE SOILS IN SOUTH DAKOTA ON I-95-MISSIOURI RIVER WEST - 135 MILES

Workshop Proceedings; .Mcdonald, EB; Potter, AW

VOL. 2 .May 1973 pp 230-44 4 Fig 8 Ref , 1973

SUBFILE: HRIS

In this report a review is presented of research studies conducted on expansive soils in South Dakota. Conclusions on the basis of this review are as follows: (1) it is possible to achieve relatively good moisture and density control by designating roller passes and making frequent moisture tests. (2) control of special undercutting and soil selection can be assured by use of specially trained crews from the central materials section, assigned to control the work. (3) extreme warping and heaving of the subgrade, over narrow fault lines, appears to be reduced by deep undercutting of expansive shale and replacement with lower liquid limit soil. (4) definite conclusions on improvement of rideability of the full length of the interstate route, where the special undercut and backfill design were employed, will not be possible until at least five more years have elapsed. At this point in time, the rideability of the surfacing is extremely good and appears to be better than on other similar highways constructed through Pierre shale where specifications did not require deep undercutting and more rigid control of compaction efforts and moisture application. (5) long range cost comparisons are

233513 DA

## UTAH'S PROBLEMS WITH SWELLING SOILS

Workshop Proceedings; Price, DT

VOL. 2 May 1973 pp 220-9 7 Fig 1973

SUBFILE: HRIS

The majority of Utah's problems with swelling soils occurs in the Mancos shale areas. To date a pavement structure which will adequately prevent or suppress heaving to a tolerable level has not been designed. Presently there are approximately 130 miles of state highway and 90 lane miles of interstate through the Mancos shale areas, and it is expected that there will be 80 more lane miles of interstate constructed in the Mancos shale. Utah's problem, therefore, stems from the fact that a considerable maintenance burden will result if the swelling of the Mancos shale cannot be controlled by adequate pavement structures and roadway construction practices. Briefly, this report (1) reviews the properties of characteristics of the Mancos shale, (2) reviews the various designs which have been used in an attempt to prevent swelling, (3) indicates the relative effects of these design methods, and (4) attempts to explain why these designs were not successful.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

compacted clay should enable designs accounting for strength, volume change, and permeability criteria. Prewetting is an effective means of volume change control when time is not critical. Lime treatment of the upper 6 to 12 inches of the wetted soil can be used to increase strength and facilitate construction. Lime continues to be the most effective additive for stabilization, and the deep-plow method provides means for treatment to depths up to 36 inches. On the other hand stabilization using lime slurries and lime piles is of doubtful value, except in dried, fissured materials. No chemicals have been found that are competitive with lime for treatment of expansive clays. Proprietary chemical stabilizers and compaction aids have not yet been shown effective for control of volume change.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233512 DA

## CONTROL OF VOLUME CHANGES IN EXPANSIVE EARTH MATERIALS

Workshop Proceedings; Mitchell, TK; Raad, L

VOL. 2 May 1973 pp 200-19 4 Fig 2 Tab Refs 1973

SUBFILE: HRIS

Methods for the control of volume changes in expansive soils have been divided into (1) techniques that do not require additives: compaction control, prewetting, heating; and (2) techniques using additives: lime, cement, chemicals. Much can be done through control of compaction. A moderate density wet of optimum water content using a sheep's foot roller should minimize swelling.

233511 DA  
 MOISTURE STABILIZATION BY MEMBRANES, ENCAPSULATION AND FULL  
 DEPTH PAVING

Workshop Proceedings; .Brakey, BA  
 VOL. 2 .May 1973 pp 155-89 14 Fig 7 Ref 1973  
 SUBFILE: HRIS

From a review of several experimental projects (at clifton, ordway, elk sprins, and other sites) constructed on expansive soils in various regions of colorado the following conclusions were drawn: (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 buildup in subgrade soils. Special precautions are needed, however, to prevent moisture change cycles at the shoulders in order to prevent longitudinal cracking in the pavement a few feet in from the shoulder. (3) granular untreated bases, either directly or indirectly, are responsible for the higher moistures found under such 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, however, since on the elk springs project, enough additional soil support was not gained over that under asphalt base to offset the extra cost of placing the membrane. (5) soil support values under asphalt membranes and full depth asphalt bases are considerably higher than under granular untreated bases when compared for similar conditions. A new correlation of laboratory stabilometer R values and field soil support values for the drier conditions is suggested. Under conditions similar to ordway and elk springs, this would result in a decreased thickness of the pavement structure of about 0.45 structural number below that called for by the current colorado flexible pavement design procedure. (6) the current colorado design procedure for flexible pavements is reasonably accurate for untreated granular bases and shows no need for adjustment. (7) it is not practical to reproduce field moisture conditions when molding stabilometer specimens in the laboratory to predict actual field soil support values.

DESCRIPTORS:

CLAY MINERALS  
 ENCAPSULATION  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST

SWELLING INDEX  
 SWELLING SOILS

233509 DA  
 MEMBRANES AND ENCAPSULATION OF SOILS FOR CONTROL OF SWELLING  
 Workshop Proceedings; .Hammit, GM; Ahlvin, RG  
 VOL. 2 .May 1973 pp 80-95 3 Fig 12 Ref 1973  
 SUBFILE: HRIS

The advantages of preventing the entrance of moisture from above or below a layer of soil are obvious to designer and construction engineers alike. One procedure used in an attempt to seal out moisture involves the technique of placing impervious membranes between the soil layer and possible sources of moisture. Previously, the major drawback to extensive employment of such construction techniques has been either the lack of integrity of low-cost membrane materials or the relatively high cost of membrane materials having better durability traits. However, recent work completed by the U. S. Army engineer waterways experiment station has developed a durable, inexpensive combination of membranes and proper construction techniques, which together overcome the past restrictions for use of membrane waterproofing. This report describes a membrane- enveloped soil layer (mesl) system. It consists of A subgrade upon which a foundation layer of compacted soil (constructed from natural subgrade or locally available soil) lies between a lower and upper waterproof membrane. The membranes are jointed and sealed along the edges, forming a waterproof encapsulated soil system. Following A brief discussion of materials development, the construction technique for successful installation of a mesal system is presented. Results of structural and cost analysis studies are given and the limitations of the system are pointed out. Brief mention is made of an alternate construction procedure which is currently being investigated.

DESCRIPTORS:

CLAY MINERALS  
 ENCAPSULATION  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST  
 SWELLING INDEX  
 SWELLING SOILS

233508 DA

**OBSERVATION OF EXPANSIVE CLAYS IN ROADWAYS**

Workshop Proceedings; Stevens, JB; Matlock, H

VOL. 2 May 1973 pp 49-65 10 Fig 1 Tab 5 Ref 1973

SUBFILE: HRIS

Expansive clays in Texas are estimated to cause 9 million dollars in damages to state highways annually. This amount of money reflects only the maintenance cost attributable to expansive clays and not the degradation of ride quality and serviceability to the public. One purpose of current studies is to make comparisons of field observations with predictive methods in attempting to reduce this annual maintenance bill and the inconvenience to the motorist. Four different methods are available for reducing the detrimental effects of swelling clays: (1) removal of the clay; (2) chemical alternation; (3) encapsulation in waterproof membranes; and (4) change of the water content to that expected after construction. The last method is being studied most closely at this time. Observations are made in this report of two methods proposed by the Texas highway department for changing the in-situ water content prior to construction: dry-land farming and ponding. A numerical technique for predicting moisture movement in unsaturated soils has already been developed. A long-term field experiment is described in this report which will provide a test comparison under controlled conditions.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

(1) make cuts wide so water is far from pavement and use fill sections only, if possible; (2) subexcavate cuts and replace with nonswelling material; (3) subexcavate cuts and replace with the same material, but treated to be nonswelling; (4) spread some magic fluid or powder over the subgrade that will make the subgrade inert (nonswelling); (5) if this fluid will not soak in, pump it in or drill holes and let it soak in; (6) place an impervious blanket over or around the shoulders and ditches to keep the water out; (7) use a thick impervious pavement as a blanket to prevent water from entering the subgrade (deep strength pavement); and (8) construct the roadway over the swelling soil as economically as possible and when the subgrade reaches moisture equilibrium, place a thick leveling course over it to take out the bumps (compaction without moisture-density control). Since 1962, construction projects have been set up and carried out to test every one of these ideas at least once. This paper describes these projects and presents an analysis of the results in a brief form.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233507 DA

**SOIL MODIFICATION HIGHWAY PROJECTS IN COLORADO**

Workshop Proceedings; Gerhardt, BB

VOL. 2 May 1973 pp 33-48 7 Fig 1973

SUBFILE: HRIS

The high incidence of roadway failures in eastern Colorado due to swelling soils has led to a multitude of attempts to prevent repeat performances. Some of the ideas that have been expressed for reducing subgrade swellings are the following:

233506 DA

USES OF HYDRATED LIME (MOVIE)--AND--LIME STABILIZATION OF  
EXPANSIVE CLAYS AT THE DALLAS-FORT WORTH AIRPORT AND MOVIE  
COMMENTARY

Workshop Proceedings; .Kelley, C  
VOL. 2 .May 1973 pp 28-32 1973  
SUBFILE: HRIS

The design and construction of the dallas-fort worth regional airport is discussed in order to illustrate large-scale soil stabilization and paving problems. Tests have shown that undesirable subgrade soils found in the area can be transformed into a stable, essentially non-swelling friable mixture if lime is added and adequately mixed. Besides stabilizing and improving the structural capability of the treated layer, the lime will also make the treated layer impervious. Various methods utilized in the stabilization process are discussed.

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

## DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233505 DA

## MISSISSIPPI'S EXPERIMENTAL WORK ON ACTIVE CLAYS

Workshop Proceedings; .Teng, TC; Maddox, RM; Clisby, MB  
VOL. 2 .May 1973 pp 1-27 25 Fig 2 Ref 1973  
SUBFILE: HRIS

In the yazoo, porter's creek, and zilpha clay areas that cover large areas of Mississippi, pavements have been badly distorted and destroyed by the behavior of the highly expansive subgrades. An investigation was conducted to produce a definitive study for the prediction of the movement of clays, and to present to the highway engineers a construction method that would eliminate or greatly reduce the heave of the subgrade after the completion of the roadway. The design and construction of the research project are discussed in this report, and the results and subsequent recommendations are presented.

233504 DA  
 PROCEEDINGS OF WORKSHOP ON EXPANSIVE CLAYS AND SHALES IN  
 HIGHWAY DESIGN AND CONSTRUCTION

Wyoming University; .Lamb, DR; Hanna, SJ  
 VOL. 2 .May 1973 318 pp Figs Tabs Refs 1973  
 SUBFILE: HRIS

These proceedings are comprised of technical papers, reports, remarks and discussions presented at the workshop on "expansive clays and shales in highway design and construction," in Denver, Colorado. The proceedings cover the state of the art on highway design and construction on expansive clays and shales. Volume 2 contains papers, reports and discussions regarding: (1) methods of modifying or treating expansive clays and shales to prevent detrimental volume change; (2) factors and characteristics of expansive clays used in highway design on in or with expansive clays and shales; and (3) selected state summaries on problems with expansive clays, and design or treatment methods, including case histories. /author/

DESCRIPTORS:

CLAY MINERALS  
 ENCAPSULATION  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST  
 SWELLING INDEX  
 SWELLING SOILS

Thus the demands imposed upon the soil engineer by owners and builders are ever increasing. It is obvious that new techniques must be developed to better understand the nature of expansive soils in order to meet these demands.

DESCRIPTORS:

CLAY MINERALS  
 ENCAPSULATION  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST  
 SWELLING INDEX  
 SWELLING SOILS

233458 DA  
 THE CURRENT PRACTICE OF BUILDING LIGHTLY LOADED STRUCTURES  
 ON EXPANSIVE SOILS IN THE DENVER METROPOLITAN AREA

Workshop Proceedings; .Sealy, CO  
 VOL. 1 .May 1973 pp 295-314 4 Fig 6 Ref 1973  
 SUBFILE: HRIS

The current practice of building lightly loaded structures on expansive soils in Denver has been relatively successful. Methods and techniques have been developed through experience to help cope with the problems created by swelling soils. Some foundation systems have been over-designed and a few foundations have not performed satisfactorily because the assumptions and the judgements made by the soil engineer were not correct. Sites that were considered not useable in the

189930 DA  
 DESIGN AND CONSTRUCTION OF AIRPORT PAVEMENTS ON EXPANSIVE SOILS

McKeen, RG

Transportation Research Board Special Report N175 pp 57-59  
 13 Ref. 1978

AVAILABLE FROM: Transportation Research Board Publications  
 Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS

This investigation reviewed the current engineering literature and synthesized from it a design procedure for stabilizing expansive soils beneath airport pavements. To do this, the study was divided into specific areas: Methods of identifying and classifying the types of soil that are considered expansive and cause early pavement distress; Laboratory and field test methods to determine the level of expansion and shrinkage, i.e., prediction of heave; and the design of stabilized soil layers including (a) selection of the type and amount of stabilizing agent (such as lime, cement, or asphalt), (b) test methods to determine the physical properties of stabilized soil, (c) test methods to determine the durability of stabilized soil, and (d) field construction criteria and procedures. The conclusions and recommendations are based on the current literature, without laboratory verification. Soil-volume changes caused by factors such as frost heave and salt heave were not studied. It was found that while procedures for soil stabilization have improved significantly, the test methods that were developed do not provide a marked improvement over those currently used. This paper appeared in TRB Special Report 175, Research in Airport Pavement.

DESCRIPTORS:

AIRPORT RUNWAYS  
 EXPANSIVE SOILS  
 FIELD TESTS  
 LABORATORY TESTS  
 PAVEMENT CONSTRUCTION  
 PAVEMENT DESIGN  
 PAVEMENT DESIGN AND PERFORMANCE  
 PAVEMENT DISTRESS  
 SOIL CLASSIFICATIONS  
 SOIL STABILIZATION

of highway each year. How and why these types of clays expand is explained. How geotechnical engineers in Colorado, Texas and Mississippi are preventing or curing the problems is explained, in case histories and in general guidelines.

DESCRIPTORS:

BUILDING DESIGN  
 BUILDINGS  
 CLAY  
 CLAYS  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 FOUNDATIONS  
 FOUNDATIONS (SOILS)  
 HIGHWAY ENGINEERING  
 RIGHT OF WAY  
 SOIL MECHANICS  
 SOIL SHRINKAGE  
 SOIL STABILIZATION  
 SOIL STRUCTURE INTERACTION

188990 DA  
 EXPANSIVE AND SHRINKING SOILS -- BUILDING DESIGN PROBLEMS BEING ATTACKED

Godfrey, KA, Jr

ASCE Civil Engineering VOL. 48 NO. 10 Oct 1978 pp 87-91  
 1978

AVAILABLE FROM: Engineering Societies Library 345 East 47th  
 Street New York New York 10017

SUBFILE: EIT; HRIS; RRIS

Expansive soils damage thousands of buildings and many miles

20

100

180509 DA

## LIME STABILIZATION ON FRIANT-KERN CANAL

Howard, AK; Bara, JP

Bureau of Reclamation, Denver, Colo. Engineering and Research Center.

Dec 1976 60p

AVAILABLE FROM: National Technical Information Service 5285  
Port Royal Road Springfield Virginia 22161

REPORT NO.: REC-ERC-76-20; PB-279542/5ST

SUBFILE: NTIS

Since construction in the late 1940's, the Friant-Kern Canal has experienced cracking, sliding, and sloughing of the side slopes in areas of expansive clays in both the concrete-lined and earth-lined portions. In the early 1970's, Bureau of Reclamation designers decided to remove portions of the canal lining, flatten the slopes, and reline the canal using a compacted soil-lime mixture in an attempt to stabilize the slopes. The project added 4 percent (based on dry soil weight) granular quicklime to the soil. Laboratory tests on the compacted soil-lime mixture showed that (1) soil-lime was about 20 times stronger than the untreated clay, (2) the strength of the soil-lime increases with time, (3) the plasticity index of the natural soil was reduced from 40 to 10 or less after adding the lime, and (4) the compressive strength of the soil-lime was dependent on the compacted density.

## DESCRIPTORS:

CALCIUM OXIDES  
CALIFORNIA  
CANALS  
CLAY SOILS  
EMBANKMENTS  
EXPANSIVE SOILS  
FRIANT KERN CANAL  
SLOPE PROTECTION  
SOIL PROPERTIES  
SOIL STABILIZATION

predictions or as criteria for initiating a detailed soils investigation. Test methods considered involve measurement of the volume response of soils to moisture and load changes. Phase 3- Provide procedures for studying in-situ moisture retention force profiles and their variation with climate. Procedures are intended to produce design data. Study the load-retention force-volume relationship for various soils and the influence of chemical stabilizers on this relationship. Phase 4--Conduct a study of airport pavement roughness already measured on some twenty runways with subgrade properties in order to quantify the influence of pavement stiffness on heave-roughness relationships. A report also on Phase II (March 1976 to November 1978); Phase III (December 1978 to January 1980).

## DESCRIPTORS:

AIRPORT RUNWAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
PAVEMENT CONSTRUCTION  
PAVEMENT DESIGN  
PAVEMENT DESIGN AND PERFORMANCE  
PAVEMENT THICKNESS  
RESEARCH PROJECT  
SOIL MOISTURE  
SOIL STABILIZATION  
SOIL SWELL  
SUBGRADES

177801 PR

DESIGN AND CONSTRUCTION OF PAVEMENTS ON EXPANSIVE SOILS  
(EVALUATION OF THE SWELL CHARACTERISTICS OF AIRFIELD PAVEMENT  
SUBGRADES)

INVESTIGATORS: McKeen, RG

PERFORMING ORG: New Mexico University, Albuquerque P.O. Box  
25, University Station Albuquerque New Mexico 87131SPONSORING ORG: Federal Aviation Administration Department  
of Transportation; Department of the Air Force Civil and  
Environmental Engineering Development Office

CONTRACT NO.: F29601-76-6-0015; Contract

SUBFILE: HRIS

PROJECT START DATE: 7702

PROJECT TERMINATION DATE: 8101

22 148367 DA

**ELECTROCHEMICAL HARDENING OF EXPANSIVE CLAYS**

O'Bannon, CE; Morris, GR; Mancini, FP

Arizona State University, Tempe; Arizona Department of Transportation.

Transportation Research Record N593 pp 46-50 5 Fig. 1976

AVAILABLE FROM: Transportation Research Board Publications Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS

This paper is concerned with a large-scale swelling soil stabilization project that was undertaken by the Arizona Department of Transportation in July 1973. The site chosen for the study was approximately 146 m (480 ft) of the westbound lane on I-40 about 56 km (35 miles) east of Holbrook, Arizona. The stabilization technique used was electroosmosis and a 0.4 N KCl solution for inundating the clayey mass of the site. This resulted in an average 36 percent decrease in the percentage of swell and a 60 percent reduction in swell pressure of the Chinle clay. X-ray diffraction and electron micrograph data indicated possible causative factors of the reduction in swell pressure and percentage of swell.

## 102 DESCRIPTORS:

CHINLE CLAY  
ELECTROCHEMISTRY  
ELECTRON MICROGRAPHS  
ELECTROOSMOSIS  
EXPANSIVE CLAYS  
HARDENING  
SOIL SCIENCE  
SOIL STABILIZATION  
SWELLING SOILS  
X RAY DIFFRACTION

22 144026 DA

**FIELD STABILIZATION OF CHINLE CLAY BY ELECTRO-OSMOSIS AND BASE EXCHANGE OF IONS**

Mancini, FP; O'Bannon, CE

Arizona Department of Transportation; Research Branch, 206 South 17th Avenue; Phoenix; Tempe; Arizona; 85007; 85281

Oct 1975 Final Rpt. 138 pp 1975

AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

REPORT NO.: FHWA/AZ/RD-145; PB-258616/2ST

SUBFILE: NTIS; HRIS

A large scale soil stabilization project was initiated in July 1973. A 500-foot section, which is part of a 1300 foot cut on I-40 35 miles east of Holbrook, Arizona, was selected as the test site. The natural soil in the area is Chinle clay, a highly expansive Montmorillonite clay. The stabilization technique used on the Chinle clay was treatment with a 0.4N solution of KCl and electrochemical action. Results show that this method of soil stabilization produced a moderate decrease

in the swelling characteristics of the Chinle clay, i.e., about a 50% decrease in expansive pressure and a 36% decrease in percent swell. Moreover, the electron micrographic and x-ray diffraction data have indicated some probable causative factors for the decrease in the swelling characteristics of the Chinle clay. Prepared in cooperation with Arizona State Univ., Tempe.

## DESCRIPTORS:

ARIZONA  
BASE EXCHANGE  
CHINLE CLAY  
CHINLE CLAYS  
CLAY SOILS  
ECCENTRICITY  
ELECTROOSMOSIS  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
ION EXCHANGE REACTIONS  
ION EXCHANGING  
MONTMORILLONITE  
SOIL STABILIZATION  
SOIL SWELL  
SWELLING  
X RAY DIFFRACTION

142755 DA

## FOUNDATIONS ON EXPANSIVE SOILS

Chen, FH

Elsevier Scientific Publishing Company 335 Jan Van  
Galenstraat, P.O. Box 211 Amsterdam Netherlands O-444-41393-6  
Chen and Associates, Incorporated  
1975 Monograph 28 pp Figs. Tabs. Photos. Refs.  
REPORT NO.: Report Number 12;  
SUBFILE: TRRL; IRRD; HRIS

The first part of the book deals with the nature of expansive soils and the mechanics of soil swelling. The merits of using drilled pier foundations to overcome the swelling problem for a lightly loaded structure are discussed. Other foundation systems, such as pad and wet foundations, are also discussed. The difficulties of slab-on-ground construction on swelling soils are considered, together with the solution of the problem by means of soil prewetting, the installation of a moisture barrier and by adequate drainage. Soil stabilization by compaction control, by replacement and by chemical admixture are still in the experimental stage in this connection. In the second part of the book case studies concerned with building foundations are presented. /TRRL/

## DESCRIPTORS:

ADMIXTURE  
ADMIXTURES  
BEARING CAPACITY  
CLAY  
COMPACTION  
DRAINAGE  
EXPANSION  
EXPANSIVE SOILS  
FOUNDATION  
FOUNDATIONS  
FOUNDATIONS (SOILS)  
SOIL  
SOIL COMPACTION  
SOIL MECHANICS  
SOIL STABILIZATION  
SWELLING  
TEST METHOD

and the effects of treatments with pressure-injected lime are discussed. Typical field experiences with pressure-injected lime are summarized, and the factors that appear to influence the effectiveness of the technique are identified. There are conflicting reports concerning the effectiveness of pressure-injected lime treatment of expansive soils. The condition most favoring the achievement of successful pressure-injected lime treatment of expansive soils is the presence of an extensive fissure and crack network into which the lime slurry can be successfully injected. The proposed treatment mechanisms (prewetting, development of soil-lime moisture barriers, and effective swell restraint with the formation of limited quantities of soil-lime reaction products) have validity. The relative significance of the prewetting and soil-lime pozzolanic reaction aspects of pressure-injected lime treatment has not been established. The various statements and reports in the literature and the information presented in the paper suggest that pressure-injected lime may not be effective under all circumstances but that in appropriate conditions it can be satisfactorily and economically used. It is indicated that appropriate guidelines and principles should be developed for evaluating (on a site-by-site basis) the potential effectiveness of pressure-injected lime treatment. Report prepared for the 54th Annual Meeting of the Transportation Research Board.

## DESCRIPTORS:

CLAYS  
EXPANSIVE SOILS  
FISSURES  
FOUNDATIONS (SOILS)  
LIME  
POZZOLANIC ACTION  
PRESSURE  
RIGHT OF WAY  
SOIL MECHANICS  
SOIL MIXES /PROPORTIONING/  
SOIL STABILIZATION  
SOIL TREATMENT  
SWELLING SOILS

138137 DA

## PRESSURE-INJECTED LIME FOR TREATMENT OF SWELLING SOILS

Thompson, MR; Robnett, QL

Illinois University, Urbana

Transportation Research Record N568 pp 24-34 2 Fig. 32 Ref.  
1976

AVAILABLE FROM: Transportation Research Board Publications  
Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS; RRIS

The pressure-injected lime technique for treating swelling soils is described and evaluated. Basic mechanisms of

26

094027 DA

**A REVIEW OF ENGINEERING EXPERIENCES WITH EXPANSIVE SOILS IN HIGHWAY SUBGRADES**

Snethen, DR; Townsend, FC; Johnson, LD; Patrick, DM; Vedros, PJ

Waterways Experiment Station; Soil Mechanics Division; Vicksburg; Washington; Mississippi; D.C.; 39180; 20590

Jun 1975 139 pp 1975

AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

REPORT NO.: FHWA-RD-75- 48; PB-248658/7ST

SUBFILE: NTIS; HRIS; RRIS

Volume change resulting from moisture variations in expansive soil subgrades is estimated to cause damage to streets and highways in excess of \$1.1 billion annually in the United States. Expansive soils are so extensive that rerouting highways to avoid the material is virtually impossible. This report presents the results of a review of current literature combined with details of experiences of selected state highway agencies on procedures for coping with problems associated with expansive soil subgrades. The report discusses the geologic, mineralogic, physical, and physicochemical properties which influence the volume change characteristics of expansive soils. Currently used techniques for sampling, identifying, and testing expansive materials are reviewed and discussed. Treatment alternatives for the prevention or reduction of detrimental volume change of expansive soil subgrades beneath new and existing pavements are presented and discussed.

**DESCRIPTORS:**

DAMAGE  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
MECHANICS (EARTH MASS)  
MINERALOGY  
MOISTURE CONTENT  
PAVEMENT SUBGRADES  
PHYSICAL PROPERTIES  
PHYSICOCHEMICAL PROPERTIES  
RIGHT OF WAY  
SAMPLING  
SOIL LIQUEFACTION  
SOIL STABILIZATION  
SOIL TESTS  
SUBGRADE TREATMENTS  
SUBGRADES  
TESTING  
TRACK SUBGRADE STABILIZATION  
VOLUME CHANGES

Illinois University, Urbana

AREA Bulletin NG28 Jun 1970 pp 846-855 8 Fig. 1 Tab. 8 Ref. 1970

AVAILABLE FROM: Engineering Societies Library 345 East 47th Street New York New York 10017

SUBFILE: RRIS

The stabilization of soils with lime has been extended to a broad range of projects including highways, airports, railways and building sites and its use is growing rapidly. Since quicklime is more dangerous to workmen and therefore more difficult to work with, hydrated lime is commonly used to modify lime-grained soils by the addition of three to eight percent lime by weight. When added to plastic soils, lime generally reduces the plasticity and increases the friability thus improving workability. Lime treatment also reduces both expansion and shrinkage of swelling soils and tends to form a barrier to keep excess water from reaching untreated subsoils. Lime stabilization also increases the strength of soils. Lime requirements and methods of applications are given. This article is also contained in "A Bibliography on the Design and Performance of Rail Track Structures", Sept. 1974, #072794.

**DESCRIPTORS:**

LIME  
RIGHT OF WAY  
SOIL MECHANICS  
SOIL STABILIZATION

104

080103 DA

**SOIL STABILIZATION. LIME USED FOR SOIL STABILIZATION**

Ireland, HO

127532 DA

**IMPORTANCE OF ACTUAL BEHAVIOR IN SHAPING DESIGN CRITERIA**

Ahlvin, RG

National Crushed Stone Association; 1415 Elliot Place, NW;  
Washington; Silver Spring; Alexandria; D.C.; Maryland;  
Virginia; 20007; 20910; 22314

Waterways Experiment Station

pp VII1-9 11 Ref. 1974

SUBFILE: HRIS

This paper which describes the Corps of Engineers continuing program of pavement condition evaluation, stresses the need to examine the performance of full scale pavements to verify design criteria, and lists 14 modifications to the the Corps' CBR design system. The elements of behavior or design are discussed and include the analytical model which describes the manner in which the parameters controlling design interact; the constitutive behavior which relates the stress, strain or equivalent behavior of the individual elements or materials of which the pavement is constructed; and the terminal condition description considered to represent failure. The CBR test was adapted as a means of assessing the strength of materials in flexible pavements. To provide the comparisons between full scale pavements under traffic with expected behavior as predicted by the design method, the Corps of Engineers undertook two efforts. The first which gives immediate comparisons, in the full scale accelerated traffic tests, many of which have been conducted to establish or extend the CBR design methods. A survey program was undertaken to provide information on the behavior of pavements in serving their intended purpose. Actual pavement characteristics in relation to design considerations (layer thickness, characteristics of materials, strength, bituminous surfacings and stabilized layers, subgrade strength) traffic loading, special contributing factors (such as construction deviations, swelling soil, etc.), and the observable pavement condition should be studied and compared with prior examinations in an attempt to determine at what point in its overall life the pavement is at the time of examination. Based on the data, a design can be projected using existing pavement characteristics, and this will indicate an expected part of the total pavement life to be used. Proceedings from a conference on Utilization of Graded Aggregate Base Materials in Flexible Pavements, March 25-26, 1974, Oak Brook Hyatt House, Oak Brook, Illinois.

**DESCRIPTORS:**

BASE

CBR TESTING

COMPARATIVE ANALYSIS

CONSTRUCTION MATERIALS

DESIGN CRITERIA

FAILURE

FLEXIBLE PAVEMENT DESIGN

FOUNDATIONS (SOILS)

GRADED COARSE AGGREGATE

GRADED FINE AGGREGATE

**MODELS**

PAVEMENT DESIGN AND PERFORMANCE

PAVEMENT EVALUATION

PAVEMENT PERFORMANCE

PREDICTIONS

TRAFFIC LOADS

138135 DA

**MORPHOLOGY AND PEDOLOGIC CLASSIFICATION OF SWELLING SOILS**

Bartelli, LU; McCormack, DE

Department of Agriculture

Transportation Research Record N568 pp 1-8 4 Fig. 2 Tab. 17  
Ref. 1976AVAILABLE FROM: Transportation Research Board Publications  
Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS; RRIS

Swelling soils occur in nature in a predictable manner. The pedologist identifies, classifies, and characterizes these unique soils and delineates their occurrence on the landscape. The concept of Vertisols, for example, is that of a soil that is unstable because of a high content of expanding lattice clay. The morphology is marked by intersecting slickensides, parallelpiped structural aggregates, and horizons that are thin and poorly expressed near microhighs but that are thick and well expressed in microlows only a few feet (meters) away. Where not destroyed by man, these soils have gilgai relief. Soils having swelling potential but lacking the other features of Vertisols are classified in vertic subgroups of other soil orders. By definition, these soils have more than 35 percent clay within a designated control section and a coefficient of linear extensibility of 0.09 or more or a potential linear extensibility of 2.4 in. (6 cm) or more. Vertisols and soils in vertic subgroups of other orders have the common property of instability because of swelling. They have a high plasticity index and a high liquid limit. They are characterized by a high content of expanding lattice clays, particularly montmorillonite. The micromorphology of swelling soils reveals a fabric of oriented clay particles along short-range shear planes. Report prepared for the 54th Annual Meeting of the Transportation Research Board.

## DESCRIPTORS:

CLAYS

EXPANSIVE CLAYS

INSTABILITY

LIQUID LIMITS

MONTMORILLONITE

MORPHOLOGY

PEDOLOGICAL CLASSIFICATION SYSTEMS

PLASTICITY INDEX

RIGHT OF WAY

SOIL MECHANICS

SOIL SCIENCE

SOIL STABILIZATION

SWELLING SOILS

165172 DA

**PROCEEDINGS OF THE PAVING CONFERENCE, 14TH, 1977**

Martinez, JE

New Mexico University, Albuquerque; .Bureau of Engineering Research; Albuquerque; New Mexico; 87131

Univ of NM, Dep of Civ Eng, Albuquerque

Proceeding 1977

AVAILABLE FROM: Engineering Societies Library 345 East 47th Street New York New York 10017

SUBFILE: EIT; ATRIS

Proceedings include 14 papers that deal with bituminous, concrete and lightweight aggregate road and pavement building materials, testing and application of materials, and recycled pavement systems. Methods of road and soil stabilization are discussed. Selected papers are indexed separately. Proceedings of the 14th Paving Conference, University of New Mexico, Albuquerque.

**DESCRIPTORS:**

AIRPORT RUNWAYS  
AIRPORTS  
ASPHALT  
BITUMENS  
BITUMINOUS  
CONCRETES  
CONSTRUCTION  
LIGHTWEIGHT AGGREGATES  
PAVEMENTS  
RECYCLING  
RECYCLING PAVEMENT SYSTEMS  
ROADBUILDING MATERIALS  
ROADS AND STREETS  
SOIL STABILIZATION  
SOILS  
STABILIZATION  
SWELLING SOILS

change behavior were considered. An attempt was made to establish tolerable levels of subgrade heave from the literature. Proceedings of the 14th Paving Conference, University of New Mexico, Albuquerque, 1977.

**DESCRIPTORS:**

AIRPORT RUNWAYS  
AIRPORTS  
CLAY  
CLAYS  
EXPANSIVE CLAYS  
FOUNDATIONS (SOILS)  
HEAVE  
LOADS  
PAVEMENT DESIGN  
PAVEMENT DESIGN AND PERFORMANCE  
PAVEMENTS  
ROADS AND STREETS  
SOIL STABILIZATION  
SOIL STRUCTURE  
SOIL SURVEYS  
SOILS  
STABILIZATION  
SUBGRADES  
SWELLING SOILS  
THICKNESS  
WATER TABLES

165159 DA

**PAVEMENT DESIGN FOR SWELLING SOILS: A REVIEW**

McKeen, RG

New Mexico University, Albuquerque; .Bureau of Engineering Research; Albuquerque; New Mexico; 87131

Proceeding pp 88-131 75 Ref. 1977

AVAILABLE FROM: Engineering Societies Library 345 East 47th Street New York New York 10017

SUBFILE: EIT; HRIS; ATRIS

A literature review was conducted for the purpose of determining the most reasonable procedure for the design of airport pavements on expansive clay subgrades. Specific study areas were identification/classification systems, prediction of heave, setting acceptable levels of heave, and the design of stabilized soil layers. The effects of layer thickness, water table depth, initial load and suction, final load and suction, soil structure, seasonal variations and soil volume

167832 DA

**ENGINEERING BEHAVIOR OF PAVEMENT MATERIALS: STATE OF THE ART**

Chou, YT

Waterways Experiment Station; Soils and Pavements Laboratory, P.O. Box 631; Vicksburg; Monticello; Mississippi; Illinois; 39180; 61856

Feb 1977 Final Rpt. 409 pp Figs. Tabs. Refs. 1977

AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

REPORT NO.: FAA-RD-77-37; AD-A045272/2ST

CONTRACT NO.: DOT-FA73WAI-377; Contract

SUBFILE: HRIS; NTIS; ATRIS

This report reviews the engineering behavior of pavement materials with respect to highway and aircraft loadings and environmental conditions. The materials covered are bituminous mixtures, portland cement concrete, granular materials, chemically stabilized soils, and fine-grained soils. Basic properties of each are discussed. For bituminous mixtures, emphasis is placed on the characteristics of permanent deformation, fatigue, and rheological properties and the application to pavement design of accumulative damage theory based on Miner's hypothesis. Discussions are presented on the development of fatigue criteria from laboratory fatigue tests and design curves. For portland cement concrete, concrete strengths determined by various tests are discussed. Test procedures for determining the modulus of elasticity and Poisson's ratio are presented, together with discussion of factors affecting these values. The fatigue property of concrete and its relationship to pavement design are discussed. For granular materials, the resilient and plastic properties are discussed. Constitutive stress-strain relations proposed by many agencies are presented and compared. The relations consist of resilient, plastic, shear, and dynamic stresses and strains. Because of the highly nonlinear nature of granular materials, the validity of the superposition principle is applied to pavement design is discussed. For soil stabilization, the mechanisms of stabilization are explained, which included soil-cement, soil-lime, lime-fly ash, and lime-cement-fly ash and bituminous materials. Factors influencing engineering properties and properties of stabilized soils with respect to strength, modulus, and fatigue are discussed. For fine-grained subgrade soils, discussions also concentrate on the resilient and plastic properties. Constitutive stress-strain relations are presented with respect to resilient, static, viscoelastic, plastic, dynamic, and shear properties. The modulus of subgrade reaction used in rigid pavements and the nature of expansive soils in relation to rigid pavement design are discussed. /Author/

**DESCRIPTORS:**

AIRCRAFT LOADING  
AIRPORT PAVEMENTS  
AIRPORT RUNWAYS  
AIRPORTS  
BITUMENS

BITUMINOUS MIXTURES

CHEMICALS

DEFORMATION

FATIGUE /MATERIALS/

FLY ASH

GRANULAR MATERIALS

HIGHWAYS

LIME

MODULUS OF ELASTICITY /SOIL/

PAVEMENT DESIGN

PAVEMENT DESIGN AND PERFORMANCE

PAVEMENTS

POISSONS RATIO

PORTLAND CEMENT CONCRETE

PORTLAND CEMENT CONCRETES

RIGID PAVEMENT DESIGN

RIGID PAVEMENTS

RUNWAYS

SOIL STABILIZATION

STATE OF THE ART

STATE OF THE ART STUDIES

STRESS STRAIN RELATIONS

VISCOELASTICITY

177120 DA

**PONDING AN EXPANSIVE CLAY CUT: EVALUATIONS AND ZONES OF ACTIVITY**

Steinberg, ML

Texas State Department of Highways &amp; Public Transp

Transportation Research Record N641 pp 61-66 8 Fig. 9 Ref.

1977

AVAILABLE FROM: Transportation Research Board Publications  
Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS

The use of ponding water on a clay subgrade of high swelling potential to cause soil heaves before pavement was successful on an expressway project outside San Antonio, Texas. Expansive soils are a worldwide problem and cause over \$2 billion damages/year in the United States. Their effectiveness of controlling the clay was measured, and the depth of the movements was determined. Observations began in 1968 and continued through 1976, both inside and outside the ponded area. The elevation rods were set at depths of 0.6 to 5.8 m (2 to 19 ft), and the moisture measurements were taken in the same zones. The ponding generally resulted in an upward movement of the elevation rods. The maximum movement was that of the shallower set rods in all areas. It now exceeds 0.12 m (0.42 ft) in the area where the predicted vertical rise is 0.15 m (0.5 ft). The moisture variations were greatest at depths up to 3 m (10 ft), where the rods exhibited maximum movement. This was the zone of activity. Pavements in the ponded areas have shown less distress and less major cracking and have required less major maintenance work than those in the nonponded areas. The relation of rainfall measurements to rod movements is not definite. A trend may be developing that shows upward movement to follow rainfall after prolonged dry periods. Ponding does seem to help curb the destructive movements of expansive clays. This article appeared in Transportation Research Record No. 641, Stabilization of Soils.

**DESCRIPTORS:**

CLAY SOILS

CORRUGATED METAL CULVERTS

EXPANSIVE CLAYS

FOUNDATIONS (SOILS)

HEAVE

MEASURING

PAVEMENT CRACKING

PAVEMENT DISTRESS

PONDING

SOIL SCIENCE

SOIL VOLUME CHANGES

SUBGRADES

WATER

230238 DA

**TRIAXIAL CLASSIFICATION OF THE SURFACE SOILS OF TEXAS AS GROUPED BY SOIL CONSERVATION SERVICE SERIES**

Texas State Department of Highways & Public Transp; .Smith, AW; Dyer, KA

Jan 1973 10 pp 1973

SUBFILE: HRIS

Laboratory and field studies on 710 soil series have been conducted in order to secure triaxial classifications for as many as possible. Of these 710 soils, 46 percent were classified as a result of the survey of estimates and tests contained in the files of the materials and tests division. Tabulation of additional information increased the classifications to over 70 percent. Triaxial classifications also increased from 303 to 498 as a result of the additional information. The study revealed that clay subgrades, with high p.i. And resultant swelling, presented the most serious problems to highway construction. Houston black - Houston clay which is a prime example of this type of material, has a triaxial classification of 5.4 based on a total of 247 tests. Triaxial classification's for subgrade soils are obtained by a combination of tests published in the manual of testing procedures of the materials and test division. Location of soil materials are made by station numbers on large-scale maps used by the project engineer during construction of the roadway. The mapping and classification of soils is reviewed as is also the use of information in load zoning. Results of the study are tabulated and discussed. Control of moisture content both before and after compaction of the subgrade soils, together with proper compaction is the most economical method of stabilization. The second best method is to stabilize these materials with lime, cement or asphalt. Suggested usage of the study data is outlined.

**DESCRIPTORS:**

ASPHALTS  
CEMENTS  
CLASSIFICATION  
CLAYS  
COMPACTION  
EXPLORATION CLASSIFICATION (SOILS)  
FIELD LABORATORY  
LABORATORY STUDIES  
LIME  
MOISTURE CONTROL  
SOIL CLASSIFICATIONS  
SOIL CONSERVATION  
SOIL MAPS  
STABILIZATION  
SUBGRADES  
SWELLING SOILS  
TRIAXIAL TESTING

**DENSITY CONTROL: ITS BENEFITS AND COMPLEXITIES**

McDowell, C

Highway Research Record, Hwy Res Board 1967 No 177, pp 197-209, 13 FIG, 2 TAB, 4 PHOT, 5 REF

SUBFILE: HRIS

Texas employs the compaction ratio (the ration of the difference between roadway as compacted density (D sub A) and the loose dry weight of the soil (D sub 1) determined by the Texas method to the difference between the max. Laboratory density (D sub D) under a compactive effort of 30 ft-lb/cu in.). The method results in high density requirements for non-swelling soils and lower, more suitable densities for swelling soils. Soils and base materials are placed in three groups: uniform, nonuniform and erratic depending on the relation of their respective values to the D sub a density. Plots are made of the deviation from average D sub a vs percent of average D sub a representing the three types of material. Reasonable compaction ranges are established for each group for use as a basis for control. Design and construction recommendations have been prepared for different types of soil and for some soils containing admixtures of stabilizing agents. Use is made of the Texas gyratory method for erratic materials. Data have shown that increasing compactive effort from 4 to 30 ft-lb/ cu in. Increased density of a sandy soil by 9 pcf and increased the shearing resistance from 19 to 30 psi (for 20 psi normal stress). The paper concludes that the compaction ratio method establishes the degree of density that is required and that is practical, that the results of high compactive effort tests are more nearly reproducible than those for lower effects, that density control of erratic materials is wishful thinking and that the Texas gyratory compactor offers good promise for measuring density properties. /author/

**DESCRIPTORS:**

BASES  
COMPACTION  
CONSTRUCTION  
DENSITY  
DESIGN  
DRY WEIGHT  
FOUNDATIONS (SOILS)  
GYRATORY COMPACTION  
LABORATORY TESTS  
RATIOS  
SOILS

230349 DA

**THE NEED FOR UNIFORMITY IN TESTING OF EXPANSIVE SOILS**

Workshop Proceedings; .Krazynski, LM

VOL. 1 .May 1973 pp 98-136 Figs 23 Ref 1973

SUBFILE: HRIS

Numerous and widely different methods are currently available for testing and classifying potentially expansive soils and although there is considerable overlap and some basic agreement between these methods, there is also a simultaneous lack of consistency and great opportunity for error. In many practical problems involving expansive soils, an erroneous misclassification of the soil leads to a level of treatment which is needlessly costly, either due to subsequent damage and repairs, or due to unwarranted overdesign. The existing methods for recognition and classification of expansive soils can be divided into three main categories as follows: (1) indirect methods, or those which employ a measurement of a related soil property as an indication of swell potential; (2) direct measurement of one-directional swell in a loaded swell test; and (3) methods of tests and analyses for quantitative prediction of the expected magnitude of heave in any given field condition. In order to evolve (or evaluate) a suitable method for testing and classification of potentially expansive soil, the factors which may influence the results obtained must be understood and taken into consideration. The following factors are known to influence the results obtained in loaded swell tests on soils of any given composition: (1) initial water content; (2) initial dry density; (3) soil structure; (4) surcharge load; (5) solution characteristics; (6) time allowed for swell; (7) curing time for sample; (8) stress history; (9) sample size and shape; and (10) temperature. It is the author's opinion that a reliable and reproducible test which is to be considered as a basis for the classification of potentially expansive soil must standardize at least these variables: initial water content, initial density, method of compaction, surcharge load or loads and sequence of application, time allowed for the test, time required for sample curing and sample size and shape. Standardization of these factors in one test and classification procedure is long overdue and would be of significant value. Two test methods are discussed; one is the test method evolved in Los Angeles in the late 1960's, and the other is the test method proposed by W. G. Holtz and published in ASTM STP 479, special procedures for testing soil and rock for engineering purposes, fifth edition, 1970.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION

**MEMBRANES**

PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

230348 DA

**GEOLOGIC ORIGIN AND DISTRIBUTION OF SWELLING CLAYS**

Workshop Proceedings; .Tourtelot, HA

VOL. 1 .May 1973 pp 44-69 8 Fig 17 Ref 1973

SUBFILE: HRIS

All clays undergo volume changes in response to environmental changes brought about by engineering activities. These changes include consolidation volume changes and hydration volume changes. In considering consolidation changes, one must review the "stress history" or geologic processes through which an earth material has passed. In the case of clays of sedimentary origin, this geologic history involves chiefly the record of sedimentation and erosion. Hydration volume changes often are measured by determining the free-swell capacity. The large swelling capacity of montmorillonites, particularly sodium montmorillonites, marks these minerals as the most troublesome ones with respect to engineering design and construction.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

230350 DA

**CONTROLLED FIELD TESTS OF EXPANSIVE SOILS**

Workshop Proceedings; Johnson, LD; Mcanear, CL

VOL. 1 Apr 1973 pp 137-59 6 Fig 6 Tab 24 Ref 1973

SUBFILE: HRIS

Research is being conducted by the waterways experiment station (wes) to investigate techniques for reliable and rapid laboratory and field measurements of total suction by thermocouple psychrometers. A laboratory psychrometer, two field psychrometers (prototype p and type F), and A commercially available psychrometer were chosen for study. The field thermocouple psychrometers were installed at various depths near Jackson, Mississippi, and on lackland air force base (lafb) near San Antonio, Texas. From the test results obtained the following conclusions were drawn: (1) in the laboratory, total suction readings by thermocouple psychrometers are in good agreement with matrix suctions measured by pressure membrane apparatus after considering the osmotic suction. Psychrometric readings are made rapidly after equilibrium is attained. Equilibrium is attained in the laboratory within 24 hours. (2) in situ suction data show good agreement between the different types of field psychrometers. The psychrometer readings at lafb show a recent drying trend which is generally consistent with piezometric and field water content data obtained from nuclear probe measurements. (3) the lifespan of the commercial psychrometer was limited at the Jackson and lackland test areas, due to corrosion of the one-mil-diameter thermocouple, with some failing within three and nine months after installation.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

230352 DA

**USE OF CONSOLIDOMETER FOR MEASURING EXPANSION, POTENTIAL OF SOILS**

Workshop Proceedings; .Gibbs, HJ

VOL. 1 .May 1973 pp 206-13 1973

SUBFILE: HRIS

The consolidometer device described in this report has the soil specimen enclosed between two porous plates. The soil can be wetted from the bottom or top. An important aspect of the device is the ability to hold the upper loading bar at a constant volume, permitting measurement of the maximum uplift pressure of the soil with no volume change. With this equipment it is also possible to load the sampler with various small loads to observe the amount of expansion. Three examples were given which illustrated the use of the consolidometer. In the first example, a deteriorating shale from a tunnel was tested to determine what expansion characteristics could be related to its deterioration. The second example involved a clay gouge material between the rock seams in a tunnel. The material was bulging out appreciably. It was tested to determine if this condition was an expansive clay problem or was due to the stress relief of the tunnel. The third example was a moderately expansive clay in a canal. It was desired to show that this material, although a moderately expansive material, if kept at that condition could be tolerated without appreciable damage to the canal linings.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

strata, such as may be encountered in the placement of a roadway, bridge, or building foundation. A short example is given which illustrates how the test method works. By using the determination of pvr in conjunction with the unit loads to be imposed by the structure, the engineer can make choices on the methods of construction to be employed and the remedial procedures to use in securing the greatest value for his construction money. Some of the choices, dependent upon the depth, amount of swelling clays, and other conditions are as follows: (1) removal of near the surface clay layers and replacement with granular material; (2) ponding with water for thirty or more days to bring drier clays toward optimum conditions; (3) stabilization or modification of clay layers near the surface usually using lime; (4) utilization of density and moisture control methods and moisture preservation such as asphalt membranes or wide granular sections, which is of great merit after ponding; (5) employing in buildings the use of ample steel in grade beams, top and bottom, or the use of heavy steel in foundation shafts and insulating them from the clay; and (6) such other measures as leaving air space under grade beams, suspension of floors from foundation shafts or the use of expansion joints to separate the floor from foundation grade beams.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

230351 DA

**METHOD FOR DETERMINING THE POTENTIAL VERTICAL RISE, PVR (TEXAS TEST METHOD TEX-124-E)**

Workshop Proceedings; .Smith, AW

VOL. 1 .May 1973 pp 189-205 3 Fig 2 Tab 4 Ref 1973

SUBFILE: HRIS

A procedure is presented which provides a means for the determination of the potential vertical rise (PVR) of a soil specimen.

230353 DA  
EVALUATION OF LABORATORY TECHNIQUES FOR MEASUREMENT OF SWELL  
POTENTIAL OF CLAYS

Workshop Proceedings; .Obermeier, SF  
VOL. 1 .May 1973 pp 214-47 7 Fig 16 Ref 1973  
SUBFILE: HRIS

In evaluating the heavy potential of a soil, it is desirable to do as much testing as possible in the laboratory, where the parameters that affect swelling can be controlled. A research effort oriented toward the evaluation of some newly developed types of laboratory apparatus, and the development of testing techniques to assess the swell potential arising from some of the different sources of swelling is currently being conducted by the office of research of the federal highway administration. The study has four principal goals: (1) evaluation of the osmotic cell-consolidometer apparatus as a device for controlling soil suction; (2) development of techniques to expedite laboratory examination of the influence of suction on the heave potential of soils; (3) development of techniques to estimate the heave potential of well-bonded, overconsolidated plastic soils, subjected to stress release; and (4) assessment of the influence of cyclic drying and wetting on the heave potential. These goals are discussed in this report and the following conclusions are reached: (1) the osmotic cell-consolidometer apparatus has the potential of being a useful apparatus for laboratory investigations of the influence of the state of suction on one dimensional swelling. The apparatus is simple and inexpensive. The technique, however, may require unduly long equilibration periods, especially at higher suction level. (2) it has been reported that poor contact between a soil specimen and the semipermeable membrane in the osmotic cell device, or between a soil specimen and the ceramic plate in the pressure plate device, results in long equilibration periods. It may be possible to reduce this testing time for some combinations of changes in loading and suction. (3) the time-dependent heaving of overconsolidated well-bonded plastic clay-shales involves a number of interdependent phenomena. Both shear and tensile stresses may be important contributors to the heaving of such clay-shales. There is a need for techniques that can be used to predict the long term heave potential that arises from stress release during the excavation of clay-shales. (4) drying and wetting can be an important contributor to the swelling potential of plastic soils having either weak or well-developed diagenetic bonds. There may be field situations where drying and wetting is responsible for significant heaving of pavements founded over such soils.

DESCRIPTORS:

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
EXPLORATION CLASSIFICATION (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION

HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

232108 DA

**DESIGN DATA FOR LIME-SOIL BASES AND SUB-BASES (IN PORTUGUESE)**

Nat Lab Civil Eng, Lisbon /Port/; .Branco, FF; Dasilva, DP  
 23 Pp, 8 FIG, 3 TAB, 7 REF  
 SUBFILE: TRRL; IRRD; HRIS

lime stabilization of soils has been studied with a view to using materials not meeting current road specifications. Different soil types were stabilized with different percentages of high calcium hydrated lime and with monohydrated dolomitic lime and the characteristics of the resulting soil mixes were determined. With a view to applications in road pavement design, the strength of the soil mixes was studied by the CBR method. The results obtained are promising, in particular for very plastic expansive soils. The CBR test seems significant for assessing the bearing capacity of lime-soil mixes, compacted after their plasticity has been reduced. /lnec/rri/

**DESCRIPTORS:**

BASE  
 BEARING CAPACITY  
 CALCIUM /SOIL STABILIZER/  
 CBR TESTING  
 DOLOMITE  
 EXPANSIVE SOILS  
 FOUNDATIONS (SOILS)  
 HYDRATED LIME  
 LIME  
 PAVEMENT DESIGN  
 PLASTIC SOILS  
 SOIL STABILIZATION  
 SUBBASE

230355 DA

**A NEW APPROACH FOR THE IDENTIFICATION OF SWELL POTENTIAL OF SOILS**

Workshop Proceedings; .Basu, R; Arulanandan, K  
 VOL. 1 .May 1973 1973  
 SUBFILE: HRIS

The dielectric dispersion characteristics obtained on several artificial and natural soils give evidence to the fact that the magnitude of dielectric dispersion is a useful parameter which describes mainly both the amount and type of clay. A classification of soils based on the amount and type of clay is proposed. The usefulness of the new classification is evidenced by the fact that the swell potential can be qualitatively evaluated from a knowledge of amount of clay and the magnitude of dielectric dispersion, which can be easily determined.

**DESCRIPTORS:**

CLAY MINERALS  
 ENCAPSULATION

EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 EXPLORATION CLASSIFICATION (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST  
 SWELLING INDEX  
 SWELLING SOILS

230354 DA

**SIMPLE TECHNIQUE FOR IDENTIFYING HEAVE POTENTIAL**

Owrkshop Proceedings; .Vijayvergiya, VN  
 VOL. 1 .May 1973 pp 275-94 6 Fig 1 Tab 19 Ref 1973  
 SUBFILE: HRIS

Identifying surface heave of an expansive clay is of considerable help in selecting an appropriate foundation system to avoid costly damages to light structures. A correlation is developed between percent swell, liquid limit, and dry unit weight from a retrospective analysis of many swell tests performed in connection with routine foundation investigations along the texas-louisiana Gulf Coast area. Empirical criteria are presented for recognizing heave potential of the beaumont clay from estimated near-surface swell. High heave potential should be anticipated when the near-surface swell exceeds about 4 percent.

**DESCRIPTORS:**

CLAY MINERALS  
 ENCAPSULATION  
 EXPANSIVE CLAYS  
 EXPANSIVE SOILS  
 EXPLORATION CLASSIFICATION (SOILS)  
 GEOLOGY /SOILS/  
 HIGHWAY CONSTRUCTION  
 HIGHWAY DESIGN  
 MEMBRANES  
 PAVEMENT SUBGRADES  
 SHALES  
 SOIL LIME MIXTURES  
 SOIL STABILIZATION  
 SOIL STRUCTURE  
 SWELL TEST  
 SWELLING INDEX  
 SWELLING SOILS

232747 DA

**THE EXPANSIVE SOIL PROBLEM-ON SUBGRADES OF PAVEMENTS AND STRUCTURES FOR ROADS AND AIRFIELDS**

Turnbull, WJ

Limestone, Nat Limestone Institute Vol 6, No 21, PP 18-21, 25-27, 43-50, 10 PHOT, 168 REF

SUBFILE: HRIS

THE EXPANSIVE SOIL PROBLEM IS REVIEWED BY PRESENTATION OF: (1) THE STATE OF THE ART ON EXPANSIVE SOILS, (2) A FAIRLY DETAILED STATEMENT OF THE PROBLEMS ON EXPANSIVE SOILS, THEIR RELATIVE PRIORITY AND SOMETHING OF WHAT IS BEING DONE, (3) AN EXTENSIVE BIBLIOGRAPHY GIVING TITLES AND REFERENCES TO WHERE INFORMATION ON THE VARIOUS SUBJECTS CAN BE OBTAINED. POSSIBLE DEFINITIONS ARE GIVEN OF EXPANSIVE SOILS. THE FOLLOWING RESEARCH PRIORITIES ARE EMPHASIZED: (1) CORRELATION OF LABORATORY AND IN-SITU SUCTION PRESSURES AND THESE CORRELATED WITH PROTOTYPE BEHAVIOR, OR LARGE-SCALE FIELD TEST SECTIONS, (2) STUDIES OF DESIGNED AND INSTRUMENTED PROTOTYPE STRUCTURES OR FIELD TEST SECTIONS SHOULD BE CONDUCTED, (3) INTENSIVE STUDY OF PROBABLE ENVIRONMENTAL CHANGES INDUCED BY CONSTRUCTION TECHNIQUES AND PROCEDURES SHOULD BE ACCOMPLISHED ON MORE PROTOTYPE STRUCTURES, (4) COMMUNICATION BETWEEN THE SOIL SCIENTIST AND RESEARCHER AND THE SOILS ENGINEER INVOLVED IN DESIGN, SPECIFICATIONS AND CONSTRUCTION, (5) PREDICTION OF MOISTURE AND HEAVE TO IMPROVE FOUNDATION DESIGN IN THE SELECTION OF THE PROPER FOUNDATION FOR THE STRUCTURE IN QUESTION, (6) IMPROVEMENT NEEDED IN STABILIZING SUBGRADES BENEATH PAVEMENTS AND CANAL LININGS, AND (7) A COMMITTEE SHOULD BE ASSIGNED BY THE INTERNATIONAL SOIL MECHANICS AND FOUNDATION ENGINEER ORGANIZATION TO STUDY AND MINIMIZE THE LEGAL DIFFICULTIES FACING THE SOIL MECHANICS ENGINEER.

**DESCRIPTORS:**

BIBLIOGRAPHIES  
CANAL LININGS  
DESIGN  
ENVIRONMENTAL EFFECTS  
EXPANSIVE SOILS  
FOUNDATION SOILS  
FOUNDATIONS (SOILS)  
FOUNDATIONS /STRUCTURES/  
SOIL MECHANICS  
SOIL SCIENCE  
STABILIZATION  
STATE OF THE ART STUDIES  
SUBGRADES  
SUCTION /SOIL WATER/  
SUCTION FORCES

the present report analyses the action of calcic and dolomitic lime on various types of soils. The influence on plasticity, volumetric changes through water absorption, grain size distribution, suction and absorption are studied. Other aspects such as the influence of curing time and cationic exchange capacity are considered. It is concluded that stabilization with lime is particularly well suited for very plastic and expansive soils. /TRRL/

**DESCRIPTORS:**

ABSORPTION  
CATION EXCHANGE  
CURING  
FOUNDATIONS (SOILS)  
GRAIN SIZES  
LIME  
PLASTICITY  
SOIL STABILIZATION  
SUCTION /SOIL WATER/  
VOLUME CHANGES  
WATER

232363 DA

**STUDIES OF SOIL STABILIZATION WITH LIME /IN PORTUGUESE/**

Nat Lab Civil Eng, Lisbon /Port/; .Castro, E

VOL. 1 .May 1966 22 pp 34 Fig 12 Tab 9 Ref

SUBFILE: TRRL; IRRD; HRIS

232935 DA

**THE EXPANSIVE SOIL PROBLEM ON SUBGRADES OF PAVEMENTS AND STRUCTURES FOR ROADS AND AIRFIELDS**

Turnbull, WJ

Limestone, Nat Limestone Institute 1969 Vol 6, No 21, PP 18-21, 25-27, 43-50, PHOTS, 168 REF

SUBFILE: HRIS

RESEARCH WAS CONDUCTED ON THE PROBLEMS OF EXPANSIVE SUBGRADE SOILS WHICH CONSISTS OF: (1) THE STATE OF THE ART ON EXPANSIVE SOILS, (2) A FAIRLY DETAILED STATEMENT OF THE PROBLEMS ON EXPANSIVE SOILS, THEIR RELATIVE PRIORITY, AND (3) AN EXTENSIVE BIBLIOGRAPHY IS PRESENTED GIVING TITLE AND REFERENCES WHERE INFORMATION ON THE VARIOUS SUBJECTS CAN BE FOUND. THE EXPANSIVE SOILS ANALYZED ARE THE MANY CLAY SHALE SOILS IN THEIR NATURAL STATE WHICH SWELL DUE TO RELEASE OF LOAD AS IN DEEP EXCAVATIONS. MANY OF THEM CONTAIN MONTMORILLONITE TO VARYING DEGREES AND SWELLING WILL CONTINUE AND CANNOT BE ACCURATELY PREDICTED BY THE CONSOLIDATION TEST. THESE SOILS EVEN SHRINK DETRIMENTALLY AND QUITE OFTEN HAVE A HIGH COLLOIDAL CONTENT. THE PERMEABILITY IS VERY LOW EXCEPT WHEN THE SOIL IS DRY AND CRACKED AND WATER CAN PASS THROUGH THE OPEN CRACKS. SUCH EXPANSIVE SOILS ARE USUALLY HIGHLY SLICKEN-SIDED. A NEGATIVE PORE PRESSURE LAYER MAY DEVELOP OVER BROAD AREAS AND HAVE A FREE WATER TABLE ABOVE IT. EQUILIBRIA AND MOISTURE CHANGES IN SOILS BENEATH COVERED AREAS ARE DISCUSSED WITH ENGINEERING EFFECTS OF MOISTURE CHANGES IN SOIL. THE GENERAL ITEMS OF RESEARCH CONDUCTED ON SOIL EXPANSION ARE REVIEWED. THE FOLLOWING-PRIORITY STUDIES ARE NEEDED: (1) CORRELATION OF LABORATORY AND IN-SITU SUCTION PRESSURES WITH PROTOTYPE BEHAVIOR, OR LARGE SCALE FIELD TEST SECTIONS, (2) MORE STUDIES WITH DESIGNED AND INSTRUMENTED PROTOTYPE STRUCTURES OR FIELD TEST SECTIONS, (3) INTENSIVE STUDY OF PROBABLE ENVIRONMENT CHANGES INDUCED BY CONSTRUCTION TECHNIQUES AND PROCEDURES, (4) COMMUNICATION BETWEEN THE SOIL SCIENTIST AND RESEARCHER AND SOILS ENGINEER INVOLVED IN DESIGN, SPECIFICATION AND CONSTRUCTION NEEDS, (5) PREDICTION OF MOISTURE AND HEAVE TO IMPROVE FOUNDATION AND DESIGN IN THE SELECTION OF THE PROPER FOUNDATION FOR THE STRUCTURE IN QUESTION, (6) IMPROVEMENT IS NEEDED IN STABILIZING SUBGRADES BENEATH PAVEMENTS AND CANAL LININGS, AND (7) A COMMITTEE SHOULD BE ASSIGNED BY THE INTERNATIONAL SOIL MECHANICS AND FOUNDATION ENGINEER ORGANIZATION TO STUDY AND MINIMIZE LEGAL DIFFICULTIES FACING THE SOIL MECHANICS ENGINEER.

## DESCRIPTORS:

AIRPORT RUNWAYS  
CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
MOISTURE CONTENT  
MONTMORILLONITE  
NEGATIVE PORE PRESSURES  
PAVEMENT SUBGRADES  
SHALES  
SOIL ANALYSIS

SOIL PERMEABILITY  
SOIL SHRINKAGE  
SUBGRADE MATERIALS  
HIGHWAY PAVEMENTS

232802 DA

**IN-PLACE TREATMENT OF FOUNDATION SOILS**

Mitchell, JK

ASCE Journal of Soil Mechanics Division Vol 96, No SM1, PROC PAPER 7035, PP 73-110

SUBFILE: HRIS

THE STATE-OF-THE-ART OF SEVEN SPECIAL METHODS FOR THE TREATMENT OF SOILS FOR THE SUPPORT OF STRUCTURES IS REVIEWED. WHEREAS VIBROFLOTATION, COMPACTION PILES, BLASTING AND GROUTING ARE LIMITED MAINLY TO THE TREATMENT OF COHESIONLESS SOILS, ELECTRO-OSMOSIS, THERMAL TREATMENT, AND TREATMENT WITH ADDITIVES FIND PRIMARY APPLICATION IN THE TREATMENT OF COHESIVE SOILS. ALTHOUGH BLASTING IS USUALLY THE FASTEST AND LEAST EXPENSIVE, COMPARED WITH VIBROFLOTATION AND COMPACTION PILES, THE RESULTS ARE THE LEAST CERTAIN. INSTALLATION OF STONE COLUMN PILES BY VIBROFLOTATION HAS EXTENDED THE RANGE OF APPLICATION OF THIS METHOD INTO COHESIVE SOILS. RECENTLY DEVELOPED CHEMICAL GROUTS ARE NOW APPROACHING THE IDEAL IN TERMS OF VISCOSITY AND CONTROL OF SETTING TIME. MIXED-IN-PLACE INTRUSION GROUTING APPEARS TO BE A PROMISING TECHNIQUE FOR CONSTRUCTION OF SOIL-CEMENT PILES IN PLACE. ADDITIVE STABILIZATION OF FOUNDATION SOILS FOR STRUCTURES IS USED MAINLY IN CONNECTION WITH GROUTING AND ELECTRO-OSMOSIS, WITH ADDITIONAL APPLICATION TO THE TREATMENT OF EXPANSIVE SOILS TO SHALLOW DEPTHS. /AUTHOR/

## DESCRIPTORS:

BLASTING  
COHESIONLESS SOIL  
COHESIVE SOILS  
ELECTROOSMOSIS  
FOUNDATIONS (SOILS)  
FOUNDATIONS (SOILS)  
GROUTING  
MIXED IN PLACE  
SOIL CEMENT  
SOIL STABILIZATION  
SOIL TREATMENT  
STATE OF THE ART STUDIES  
VIBROFLOTATION

233166 DA

**LIME STABILIZATION FOR PAVEMENT CONSTRUCTION**

Kelley, CM

New Mexico University; ./Proceedings 7th Paving Conference  
1969 pp 267-287, 1 FIG, 7 TAB, 20 REF

SUBFILE: HRIS

research conducted at the university of Illinois by dr. James I. Eades is reported. Scanning electron micrographs were made that show the formation and growth of the calcium silicate gel structure. Pictures can be made of fractures pieces of lime-treated soils without special preparation of the material. Experience is using lime (i.e., quicklime or hydrated lime) to stabilize (1) clays; (2) highly plastic swelling subgrade soils; and (3) wet, weak nonswelling subgrade soils is discussed. In the first case, 20 years experience in Texas is reported. It is noted that during the drought period 1951--1957 the lime-treated layer formed a moisture barrier and helped maintain a uniform moisture condition below the stabilized layer. For swelling soils the Texas highway department has developed a "potential vertical rise" index that accounts for soil type, moisture content, density, layer thickness, and surcharge load. Where the pvr exceeds 0.5 inch, measures must be taken to inhibit swelling action. Experiments in Texas and Utah utilizing lime stabilization for swelling soils are described briefly. In the last case, lime can be used to advantage in providing an impervious layer of stable material. However, it may be necessary to increase the lime-treated layer to as much as 12 inches to bridge the unstable soil below. Procedures for minimizing soil pumping are described. The range of improvement that can be expected for a variety of soils is indicated numerically in a table of CBR and k values. On the basis of laboratory and field experience AASHO structural numbers are proposed for bases, subbases, and subgrades. Cement, bituminous, and lime treatments for various traffic loads, subgrade supports, and paving materials are recommended in a set of tables. The benefits gained from use of hydrated lime in the western states, notably Arizona and Colorado, are discussed and tabulated.

**DESCRIPTORS:**

BITUMINOUS STABILIZATION

CEMENTS

CLAYS

COHESIONLESS SOIL

COHESIVE SOILS

FOUNDATIONS (SOILS)

HYDRATED LIME

LIME

MOISTURE CONDITIONS

PAVEMENT DESIGN

QUICKLIMES

STABILIZERS

SUBGRADES

SWELLING SOILS

233457 DA

**EXPANSIVE SOILS AND CALIFORNIA HIGHWAYS (RESEARCH FINDINGS)**

Workshop Proceedings; .Smith, RE

VOL. 1 .May 1973 pp 255-74 3 Fig 1 Tab 1 Ref 1973

SUBFILE: HRIS

This research was prompted by several specific locations in California of distress identified as being caused by expansive soils. In particular, the dramatic emergence of severe localized cracking and joint separation on portions of newly constructed roads through the Sacramento valley served as impetus to investigate the problem. The objectives of the research were: (1) to define the extent of the problem; (2) evaluate the effectiveness (and shortcomings) of present procedures; and (3) find improved means (empirical or rational) of identifying soils with distress causing potential. In formulating an approach for the expansive soil problem and California highways, the research work plan was divided into two general phases. The first phase was intended to define the problem further. First, an inventory of locations of expansive soil type pavement distress was obtained. From those, a large representative sample (50-100) was selected for a field survey of pavement condition at these sites. Also, the riding condition of the roadway in the vicinity of the reported distress was evaluated using a PCA roadmeter. The objective was to determine, if possible, the effect of the expansive soils on riding quality of the roadway. Concurrently, the project records (and other publicly available data) were evaluated to see if information which could be utilized to minimize or prevent the problem was being overlooked or not utilized to the best advantage. The second or analytical phase involved an intensive analysis of approximately 25 locations selected from the initial field survey. Those were representative of the range of distress observed, as well as geographically distributed. This portion of the investigation included taking soil samples through the roadway, and an intensive "shotgun" program of laboratory testing. The data were analyzed to determine the relationship, if any, between these factors and the observed distress. The following conclusions were reached: (1) expansive soil type distress in California is prevalent enough to be classed as a significant problem. (2) the problem is highly localized. Potential problem sites are apt to be missed by "random sampling" type foundation investigations, as conducted for routine structural design purposes. (3) soils having more than 40 percent passing the no. 200 sieve, or more than 10 percent of clay sized fraction (less than 1.0 micron) have a high potential for causing distress. Other parameters having useful associations are clay mineral identification, atterberg limits, linear expansion and shrinkage, and internal surface area. (4) the U.S. Department of agricultural soils bulletins should be researched when evaluating a roadway location for expansive soils.

**DESCRIPTORS:**CLAY MINERALS  
ENCAPSULATIONEXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

233455 DA

**WORKSHOP INTRODUCTION**

Workshop Proceedings; .Smith, PC

VOL. 1 .May 1973 pp 11-5 9 Ref 1973

SUBFILE: HRIS

Introductory remarks are made concerning the workshop on expansive clays and shales. It is pointed out that the areas of the United States having the trouble-making clays and shales are principally west of the Mississippi river, where specific climatic and natural environmental conditions cause the clays and shales to provide very poor performance as foundations for structures. Consequently, the workshop attendees are principally from those states. The author anticipates that the workshop presentations and discussions will show that some treatment and design methods have been adopted in one or more states and should be implemented in other states, and that a clear picture of further needs for research and experimentation will be obtained.

**DESCRIPTORS:**CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FOUNDATIONS (SOILS)  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

236852 DA

**DESIGN CONSIDERATIONS FOR DEEP RETAINED EXCAVATIONS IN OVER-CONSOLIDATED SEATTLE CLAYS**

Workshop Proceedings; .Strazer, RJ; Wilson, SD; Bestwick, LK  
VOL. 2 .May 1973 pp 96-122 12 Fig 14 Ref 1973

SUBFILE: HRIS

The hard clays found in many parts of the Seattle area have presented major problems to highway engineers in the past 10 years. During this period interstate freeways, state highways and other local construction projects have required deep excavations and structures located within the clay strata. It was the construction of interstate 5 through downtown Seattle that created the most serious problems and resulted in a unique retaining wall system. The unstable slopes on this project alerted design engineers to the potential hazards of deep excavations in the hard clays. This paper discusses the origin and physical characteristics of the clays and illustrates how these characteristics are considered in the design of deep retained excavations.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MECHANICS (EARTH MASS)  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

and red tropical soils are discussed in a consideration of concretionary soils. Stresses and strains in soils, foundations and earthworks are covered. Papers are also presented on roads and slope erosion, design, strengthening and observation of road pavements, and on the effects of climate.

**DESCRIPTORS:**

CLAYS  
COLLAPSE  
CONCRETIONARY MATERIAL  
EARTH DAMS  
EXPANSIVE SOILS  
FERRICRETES  
FOUNDATION ENGINEERING  
LATERITES  
MECHANICS (EARTH MASS)  
ROCK FILLS  
SANDS  
SOIL MECHANICS  
SOIL PROPERTIES  
SOIL SCIENCE  
SOIL STABILIZATION  
TROPICS  
UNSTABLE SOIL

236786 DA

**SOIL MECHANICS AND FOUNDATION ENGINEERING**

Soil Mech & Fdn Eng Proc /South Africa/ VOL. 1 .Aug 1971  
282 pp Figs Tabs Refs 1971

SUBFILE: HRIS

The papers presented in this publication stress problems relating to tropical and subtropical soils, and the derivative geotechnical considerations. Matters concerning laterites, collapsing soils, stabilization of sandy and similar soils, as well as material work on regional development are some of the subjects covered. Attention is paid to the field of earth dams and rockfill. The papers presented on unstable soils, discuss such aspects as the engineering properties of expansive soils, clay-containing soils, collapsing soils and African tropical black clay soils. Ferricretes, laterites, marine nonclastics

238143 DA

**LATERAL SWELLING PRESSURES IN COMPACTED OKLAHOMA COHESIVE SOILS**

Snethen, DR; Haliburton, TA

Highway Research Record, Hwy Res Board N429 Abridgment pp 26-8 2 Fig 6 Ref 1973

SUBFILE: HRIS

the objective was to develop instrumentation to measure lateral swelling pressure of compacted soils and the relative magnitudes of 2 cohesive soils of moderate to high plasticity and swell potential, as influenced by initial moisture content, dry density, compaction mode and energy, and lateral swell. A device consisting of a pressure transducer and strip-chart recorder is constructed out of lucite. This was used with compacted samples surrounded by filter paper and a rubber membrane to take in water and develop swelling pressure until it stabilizes at A maximum value. The influences of initial moisture content, dry density, and compacted soil structure on lateral swelling pressure were found to be highly interrelated for samples compacted at a specific level.

**DESCRIPTORS:**

COHESIVE SOILS  
 DRY DENSITY /SOILS/  
 LATERAL MOVEMENT  
 MOISTURE CONTENT  
 PLASTICS  
 SOIL COMPACTION  
 SOIL PLASTICITY  
 SOIL SCIENCE  
 SOIL STRUCTURE  
 SWELLING SOILS  
 TRANSDUCERS

237907 DA

**SUBGRADE MOISTURE VARIATIONS: EVALUATION OF COLLECTED DATA 1966-1968**

Shaw, LK; Haliburton, TA

Oklahoma State University /School of Civil Engineering  
 Jun 1970 Interim Rept NO 8, 99 PP. 37 FIG, 15 REF, 2 APP  
 SUBFILE: HRIS

A SIX-YEAR SUBGRADE MOISTURE VARIATIONS PROJECT IS BEING CONDUCTED IN OKLAHOMA TO : (1) REVIEW PREVIOUS WORK ON SUBGRADE MOISTURE BEHAVIOR BY THIS PROJECT AND BY OTHER AGENCIES, (2) RELATE MEASURED SUBSURFACE MOISTURE CONDITIONS TO SOIL, CLIMATE AND PAVEMENT, AND (3) DISCUSS OBTAINED RELATIONSHIPS AS THEY APPLY TO OKLAHOMA HIGHWAY DESIGN. FIFTY FIELD RESEARCH SITES WERE INSTALLED THROUGHOUT THE CENTRAL AND NORTH CENTRAL/ NORTH EASTERN PARTS OF OKLAHOMA. THE SITES WERE LOCATED ON HIGHWAYS OF VARIOUS AGE, CONDITION RATINGS, CROSS-SECTION, AND PAVEMENT TYPE. PROCEDURES USED TO COLLECT RESEARCH DATA AT THE 50 FIELD RESEARCH SITES ON EXISTING PAVEMENT FOR A 3-YEAR PERIOD ARE DESCRIBED. PROCEDURES USED

MOISTURE BEHAVIOR AND RELATED FACTORS ARE PRESENTED. EFFECTS OF SUBGRADE MOISTURE ON VARIOUS HIGHWAY DESIGNS ARE DESCRIBED. TWO MODES OF SUBGRADE MOISTURE BEHAVIOR OCCUR IN OKLAHOMA: SUBGRADE MOISTURE ACCUMULATION AND SUBGRADE MOISTURE VARIATION. DATA STUDIED AND EVALUATED INDICATE THE FOLLOWING CONCLUSIONS: (1) SUBGRADE MOISTURE ACCUMULATION OCCURRED AFTER HIGHWAY CONSTRUCTION AND/OR OVER LONG PERIODS OF DROUGHT, (2) SUBGRADE MOISTURE VARIATIONS ARE EITHER PRECIPITATION OR WATER TABLE-DEPENDENT, (3) HIGHWAY PAVEMENT RATINGS ARE EVIDENT IN IMPERVIOUS PAVEMENTS WITH WIDE SHOULDERS, IMPERVIOUS AND INFLEXIBLE BASE MATERIAL, AND GRADE OR CUT SECTION, (4) HIGHWAYS WITH WIDE SHOULDERS EXHIBITED MORE NEARLY CONSTANT MOISTURE CONDITIONS AND REDUCED MOISTURE CONTENT INCREASE-DECREASE BENEATH THE PAVEMENT WHILE MOISTURE CONDITIONS BENEATH SHOULDERS VARIED SOMEWHAT MORE, (5) SUBGRADE MOISTURE CONTENTS WERE FOUND TO FLUCTUATE SEVERELY BENEATH SHOULDERS IN FILL AND TRANSITION SECTIONS, BUT FLUCTUATE LESS IN GRADE OR CUT SECTIONS, (6) WET-DRY INTERFACE BEHAVIOR SEEMS TO BE THE CAUSE OF LONGITUDINAL CRACKING IN SHOULDERS, (7) SUBGRADE SOILS ENCOUNTERED WERE FOUND TO BE EXPANSIVE, (8) LATERAL AND VERTICAL SWELLING OF EXPANSIVE OKLAHOMA SUBGRADES WERE FOUND TO CAUSE MOST DAMAGE TO SOIL-CEMENT BASE MATERIAL AND TO PAVEMENTS WITHOUT BASE MATERIAL, AND (9) FLEXIBLE, IMPERVIOUS BASE MATERIALS SUCH AS STABILIZED AGGREGATE BASE COURSES OR SAND-ASPHALT BASE COURSES, REDUCED INFILTRATION AND RESISTED CRACKING BETTER THAN SAND CUSHION OR SAND-CEMENT BASE MATERIALS.

**DESCRIPTORS:**

CLIMATE  
 EXPANSIVE SOILS  
 FIELD STUDIES  
 FOUNDATIONS (SOILS)  
 HIGHWAY DESIGN  
 IMPERVIOUS MATERIALS  
 LONGITUDINAL CRACKING  
 MOISTURE CONDITIONS  
 PRECIPITATION  
 SHOULDERS  
 SOIL SCIENCE  
 SOILS  
 STABILIZED BASE COURSES /MATERIALS/  
 SUBGRADE MOISTURE  
 SWELLING  
 WATER TABLES

238257 DA

**EXPANSIVE SOILS AND HOUSING DEVELOPMENT**

Workshop Proceedings; .Jones, DE

VOL. 1 .May 1973 pp 16-43 6 Fig 4 Ref 1973

SUBFILE: HRIS

The American society of civil engineers has formed A research council on the expansive behavior of earth materials, popularly known as the expansive soils research council, to seek improved ways to avoid damages from shrinking or swelling soil volume changes. The council has brought together professional persons representing a variety of interests to overview the state of the expansive soils art, identify priority research needs, stimulate and coordinate research, and transfer research findings into practice. The council conservatively has estimated damages attributable to expansive soil movements; these estimates add up to a total estimated average annual loss of 2,255,000,000 dollars. These damage estimates are shocking, particularly because actual damages may be as much as twice those indicated. Damages from expansive soil movements are widely unrecognized and are almost completely unreported. Damages to public facilities are well over half of the estimated damages. Expansive soil damages now exceed the combined average annual damages from floods, hurricanes, earthquakes and tornados. They have grown without public attention and with only limited professional recognition and attention. The problem developed in similar ways in housing, highway, and other construction activities. An understanding of the problem's development may provide clues to necessary dimensions in its solution. Therefore, this report addresses itself to a discussion of the problem development and identification. The importance of environmental factors and soil moisture control are considered, as well as the effects of loading and the ability to make predictive insights.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

**ACTIVITIES OF THE A.S.C.E. RESEARCH COUNCIL ON THE BEHAVIOR OF EXPANSIVE EARTH MATERIALS**

Workshop Proceedings; .Holtz, WG

VOL. 2 .May 1973 pp 190-9 1973

SUBFILE: HRIS

The purpose of this paper is to acquaint the reader with the a.s.c.e. Research council on the behavior of expansive earth materials, and to discuss the reason for its' formation, current activities, research needs, and coordination functions. The council now consists of 22 members, all of whom have had significant experience with expansive earth materials. The council has recommended two research proposals as being important and timely. The first is to prepare and publish a comprehensive monograph on the present state of the engineering art with respect to the nature and properties of expansive earth materials, how to recognize them, how to prevent damages through treatment or structure design and how best to repair or reduce damages once they have begun. The second project has to do with the expansion of soils containing sodium sulphate.

**DESCRIPTORS:**

CLAY MINERALS  
ENCAPSULATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
GEOLOGY /SOILS/  
HIGHWAY CONSTRUCTION  
HIGHWAY DESIGN  
MEMBRANES  
PAVEMENT SUBGRADES  
SHALES  
SOIL LIME MIXTURES  
SOIL SCIENCE  
SOIL STABILIZATION  
SOIL STRUCTURE  
SWELL TEST  
SWELLING INDEX  
SWELLING SOILS

238202 DA

263863 DA

**THE DEFORMATION OF ROADS RESULTING FROM MOISTURE CHANGES IN EXPANSIVE SOILS IN SOUTH AFRICA**

Williams, AAB

Commonwealth Scientific Industrial Research Org; .314 Albert Street; East Melbourne; Victoria; Australia

South African Council of Science

pp 143-155 15 Fig. 2 Tab. 11 Ref. 1965

REPORT NO.: TA7109 A82;

SUBFILE: HRIS

The effects of moisture changes in deep, active clay subgrades are reflected in the general deformation of roads which can develop and in the bumps which arise at pipe culverts in parts of South Africa. A deformation of 0.4 in. over 20 ft. is often found on sections of road about five years after new construction, and this constitutes an engineering problem if high standards are to be maintained for fast travel. The records of movement, obtained from several field sites during about seven years of precise level observations, are reviewed and the results are given of laboratory tests on a typical clay, residual from the weathering of Eccra Shale. The prediction of heave is mentioned and examples are given of the effects of change in the level of the water table, or of change in the thickness of cover. Remedial measures suggested for reducing the deformation include lime stabilization of the top layer of an active clay subgrade, additional cover thickness, and pre-wetting, not only of culvert sites, but also of the road formation by "fallowing" before construction in order to conserve moisture from rainfall. One of the most outstanding remaining problems appears to be the prediction of the rate of heave under various conditions, having in mind the diffusion of moisture through partially saturated and fissured material.

/Author/

## DESCRIPTORS:

CLAYS  
DEFORMATION  
EXPANSIVE CLAYS  
EXPANSIVE SOILS  
FIELD OBSERVATION  
HEAVE  
LABORATORY TESTS  
LIME  
MOISTURE CONDITIONS  
PIPE CULVERTS  
PREDICTIONS  
REMEDIES  
ROADS  
SOIL SCIENCE  
STABILIZATION  
SUBGRADES

263865 DA

**A REVIEW OF LITERATURE ON SWELLING SOILS**

Colorado Division of Highways; 4201 East Arkansas Avenue;  
Denver; Colorado; 80222  
pp 1-65 178 Ref. 1964

SUBFILE: HRIS

This report, which is based on review of selected literature available to the authors and deemed pertinent to the study of expansive clays, may be briefly summarized as follows: High volume change clays have been encountered in many parts of the world and frequently have caused severe damage to structures. Differential movement of these soils may be due to shrinkage swelling, or cyclic volume changes. Of these, swelling is the most detrimental. Swelling of soil may result from any combination of increase in the availability of water, alteration of clay so that its thirst for water is increased, and reduction of the applied load on the clay. Because of their electrical colloidal nature, clay particles have a great attraction for water. The osmotic imbibition of water by clay minerals combined with relaxation of effective stress provides the principle mechanism involved in the swelling of soils. Identification of high volume change soils can be accomplished by methods of mineralogical identification or by methods based on volume change characteristics of the soil. In a complete study of high volume change soils both types of studies should be made. For many laboratories, however, some of the specialized mineral identification methods, such as X-ray diffraction or differential thermal analysis, may prove to be too complicated and expensive, and identification may have to be based entirely on the simpler and more practical tests of volume change characteristics. The quantitative prediction of potential volume change of a clay is essential to solution of the engineering problems arising from volume change. The use of the consolidometer, which has proved the most satisfactory means of prediction of potential volume change, still needs further study. Reduction of the detrimental effects of swelling soils has been the object of numerous research studies. Probably the most satisfactory single remedial procedure in use has been the removal of the expansive soil and its replacement with stable material, but surcharge loads, prevention of ingress of water, prewetting, and chemical stabilization all have had some success in reducing detrimental swell. It is evident that investigation into all aspects of swelling soils has been extensive in many parts of the world as is indicated by the extent and diversity of published literature. It is also evident that some aspects of the swelling soil problem have been solved reasonably satisfactorily from the point of view of the engineer, some aspects are moderately understood, and some aspects will bear further research. From the point of point of view of the engineer, clay mineralogy, the behavior of water in a clay system, and the mechanisms leading to the swelling of a soil are basically understood. However, the interdependence of the several factors upon which a particular behavioral relationship depends is not always clear. An example of this is the disagreement noted in this review over the effects of

the combination of stress history and climatic history on the subsequent swelling of a soil. In regard to identification of swelling soils for engineering purposes, the qualitative aspect appears essentially solved, utilizing classification test data as done by Seed, Woodward, and Lundgren. In research work more complex methods are applicable. The problem of quantitative prediction of swell has not been solved as successfully, but it appears that further investigation into the use of the consolidometer test will be profitable. In this regard the double oedometer test appears to hold promise. The control of swelling of expansive soils appears to be the largest problem yet to be solved satisfactorily. Control of compacted swelling soils apparently is best achieved by moisture and density management, though further work seems necessary. Numerous methods of control of swell of undisturbed soils are reported in the literature, but the efficacy of any method or group of methods in a particular instance is often speculative until attempted. This is

## DESCRIPTORS:

COLLOIDS  
CONSOLIDOMETER  
DENSITY  
ENGINEERING  
EXPANDED CLAY AGGREGATES  
EXPLORATION CLASSIFICATION (SOILS)  
HIGHWAY CONSTRUCTION  
LOADS  
MINERALS  
OEDOMETERS  
OSMOSIS  
PREDICTIONS  
REVIEWS  
SOIL COMPACTION  
STABILIZATION  
SURCHARGE  
SWELLING SOILS  
VOLUME CHANGES  
WATER  
WETTING

301592 DA

**SUBDRAINAGE WITH A SAND BACKFILL AS A POSITIVE INFLUENCE ON PAVEMENT PERFORMANCE**

Steinberg, ML

Transportation Research Board

Texas State Department of Highways &amp; Public Transp

Transportation Research Record N705 1979 pp 71-75 5 Fig. 1

Tab. Refs.

AVAILABLE FROM: Transportation Research Board Publications  
Office 2101 Constitution Avenue, NW Washington D.C. 20418

SUBFILE: HRIS

Expansive soils are an estimated \$4 billion-a-year problem in the United States. They cause severe distortion in many human works, including highways. Subdrainage has been used extensively in attempts to intercept or remove excess moisture from expansive clays. Minimizing moisture change is seen as a way of reducing surface distortion and improving pavement performance. Underdrains have been used on many highways to remove excess subsurface water, and one Texas study revealed that their use in expansive soils results in a mixed pattern. The effectiveness of deep underdrains with sand backfill is now being examined. The sand is used to provide a moisture reservoir and stabilizer for the expansive clay and the underdrain will remove the moisture the sand cannot hold. A field test of an Israeli experiment is being conducted on a roadway section, which has resisted considerable previous attention, on US-90 west of D'Hanis and Hondo, Texas. This section cuts through a limestone crust into a clay and has had repeated level-up courses of asphalt. Lime had been placed in holes 45 cm (18 in) in diameter, 1.5 m (5 ft) deep, and on centers. In this test 381 m (1250 ft) of 15.24-cm (6-in) slotted underdrain pipe was placed 2.4 (8 ft) deep; the sand backfill was placed along the south roadway crown line. Observations indicate that maximum movements are taking place on the nonunderdrained side in 9 of the 12 sections and are averaging three times the movement on the underdrained side. Expansive soil movement under existing pavements probably can be reduced by sand-backfilled underdrains. /Authors/ This paper appeared in Transportation Research Record No. 705, Subdrainage and Soil Moisture.

**DESCRIPTORS:**

BACKFILLS  
EFFECTIVENESS  
EXPANSIVE CLAYS  
HIGHWAY PAVEMENTS  
MECHANICS (EARTH MASS)  
MOISTURE CONTROL  
PAVEMENT PERFORMANCE  
SANDS  
SUBDRAINS  
UNDERDRAINS

