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Subdrainage with a Sand Backfill as a Positive Influence on Pavement Performance

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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 m (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.

Swelling soils cause an estimated $4 billion a year in damages in the United States. More than half of this occurs in our transportation facilities: highways, railroads, airport runways, sidewalks, bikeways, and canals. Even this estimate is probably conservative.

The original $2 billion a year (1) estimated in 1973 reflected the lower side of industry estimates. Pavements damaged by these soils are usually repaired with asphalt products or other equally energy-intensive materials. As long as the price of a barrel of oil rises and other energy sources rise sympathetically, even extending cost increases makes the latest estimate lower than it actually should be.

What can be done about damaged transportation facilities? The roadways that represent half of the damages offer several possibilities. First, we can build them differently in the future and avoid expansive clay areas or remove a significant amount of it, treat it deeply with lime, pond it, or seal off the zones of activity with asphalt, lime, or fabric. All are worthy suggestions. However, some of these concepts do not adapt well to the existing roadway, runway, sidewalk, bikeway, or canal. Their remedy is the asphalt patch, asphalt level-ups, or total replacement.

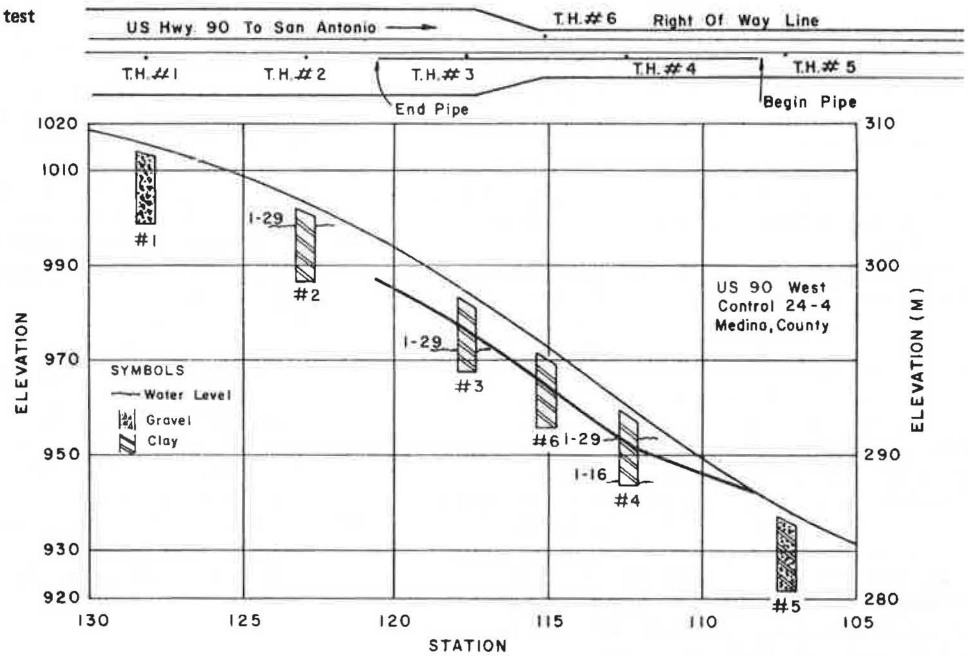


Figure 1. The US-90 site and test holes.

Figure 2. Typical section showing underdrain and backfill.

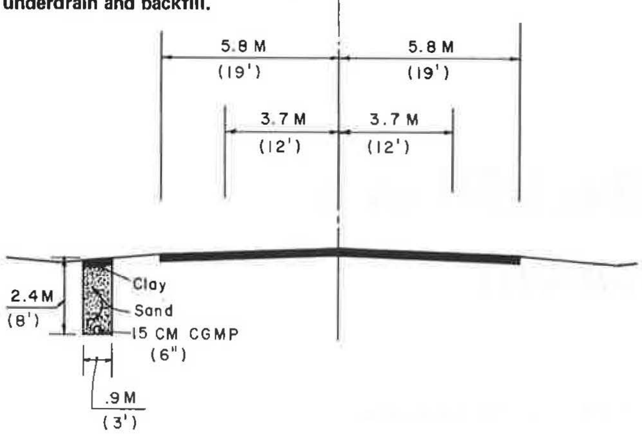
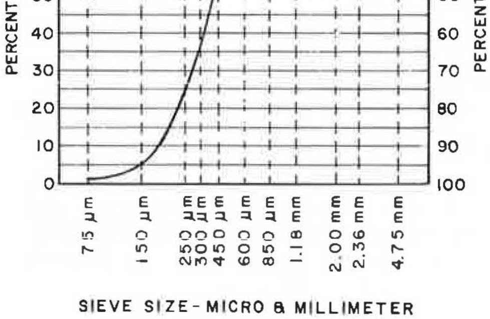


Figure 3. Sand-backfill gradation curve.



Engineers around the world have made studies of the swelling-soils and expansive-clay problem; a small sampling offers a broad bibliography (2, 3, 4, 5). The Texas State Department of Highways and Public Transportation is among this group that has been involved in searching for solutions to the swelling-soils problems for decades. The need to stabilize moisture variations has been a key element of this search for a solution to swelling-soils movements.

Underdrains have played a significant role in this effort to reduce the wide variations in moisture content. Their depth of placement and backfill material have also received international attention (6, 7, 8, 9, 10, 11, 12). This began with Terzaghi's analysis in the 1920s. Underdrains have been used extensively in many Texas projects. In the San Antonio area, an earlier study revealed an inconsistent record of results of varying success (13).

A previous project emphasized the importance of placing the underdrains at a maximum feasible depth. The ponding study on US-90 West in San Antonio noted the importance of a zone of activity (14). From the finished surface to a depth of 3 m (10 ft) moisture contents ranged from 5-35 percent. Below 3 m the changes were generally from 25 to 30 percent moisture, a fifth or sixth of those occurring in the zone of activity. Elevation rods founded in the zone of activity did the most moving too. This confirmed other studies' conclusions that underdrains must be placed close to the zone's lower level.

Israeli engineers have offered a possible solution for minimizing pavement movements over expansive clays. They examined an airfield runway where one pavement edge moved four times as much as the other, which was relatively stable. The earlier builders of the runway installed a sand-backfilled underdrain along the side that remained stable but not along the other. Expansive clays were moving the pavement, but the underdrained side was substantially stable.

Their laboratory tests suggested that the reservoir created in the sand backfill could stabilize the clay's moisture content. It would allow moisture to move from the sand in time of need and return to it in surplus situations. The underdrain removes the excess moisture the sand cannot handle.

The plan for this study was developed to duplicate in Texas the success of the Israelis' observations. Seco Hill is in Medina County, west of D'Hanis, Hondo, and San Antonio. San Antonio, in the south central part of the state is 80 km (50 miles) east of the site. As US-90 climbs Seco Hill, its gradient breaks through a strata of limestone and enters a clay formation. The clay is very expansive, as evidenced by the waves in the road surface. Over the years this section has claimed many tons of asphalt concrete level-up. It was so troublesome that, after many years of level-ups, holes were drilled 1.5 m (5 ft) deep, 45 cm (18 in) in diameter and on 1.5-m (5-ft) centers, each filled with a sack of lime, water, and backfill base. This did not stop the movement.

Table 1. Crown point movements.

	Movement (cm)				
Station	At 5.8 m	At 3.7 m	At Centerline	At 3.7 m	At 5.8 m
108+40 (end drain)	+3.0	+2.7	+2.1	-0.3	+0.3
109+00	+0.6	+0.9	+2.1	+1.8	+2.7
110+00	+3.9	+4.6	+7.0	+7.6	+6.7
111+00	+1.5	+1.5	+1.8	+1.8	+2.1
112+00	0	+0.3	+0.6	0	-0.3
113+00	-0.6	-0.9	0	+0.9	+0.6
114+00	+0.6	+0.9	+3.6	+3.3	+2.7
115+00	+1.5	-0.6	-0.3	-0.3	-0.3
116+00	+1.2	+0.6	-2.2	+0.9	+0.9
117+00	-0.3	0	-0.6	+1.8	+1.8
118+00	-1.5	-0.9	+2.4	+4.3	+0.6
119+00	-0.9	-0.3	+0.3	+1.2	+2.1
120+00	-0.6	-0.6	0	+0.3	+0.9
121+00 (end drain)	-0.3	0	+0.3	+0.6	+0.9
122+00	-3.4	-3.4	-3.4	-1.5	-3.0
123+00	-2.7	-3.4	-3.0	-3.4	-3.0
124+00	-2.1	+2.4	-0.3	-2.7	-2.4
125+00	-2.7	-2.7	-2.7	-3.0	-3.0
Average movement 108+40 121+00	+0.57	+0.58	+1.22	+1.71	+1.55

Note: 1 cm = 0.39 in; 1 m = 3.3 ft.

The surrounding land has flat valleys and gently rolling hills. Medina County's major enterprises are farming and ranching. Vegetation is varied; crops are usually feedgrains. Much land is in pasture and the livestock industry is important, but there is much brush land with mesquite, huisache, oak, pecan, and some cottonwood. The climate is subtropical. Temperature averages for 30 years indicate a daily mean in the 30-35°C range (90°s F) between June and September. Wintertime averages are in the 15-20°C range (60°s F). The average annual rainfall is 71.2 cm (28.5 in). Usually heavier rainfalls occur between April and June, and during September and October. Summers tend to be hot and dry.

Soil types in the Seco Hill area are generally clays in valleys and gravelly to rocky mixtures on the hills. The Knippa Mercedes and Monteola clay series have light to very high shrink-swell potentials. The Monteola has CH and A 7-6 unified and AASHTO classifications, respectively, with plasticity indices in the 35-45 range. The Olmos Yologo series are generally gravelly loams with moderate to low activity (15). Beneath these surface soils are cretaceous formations generally in the Gulf series.

PROCEDURE

It was decided to evaluate the effectiveness of the sand-backfilled deep underdrain in minimizing pavement movement over a swelling clay. The underdrain would be placed along the south edge of the pavement edge in the clay subgrade area. No underdrain would be placed along the north edge.

A portable rig drilled six test holes on the east slope of Seco Hill on January 16, 1974. Five were in the highway's south ditch line, one in the north line. The holes were 20 cm (8 in) in diameter and 6 m (20 ft) deep. Test hole 1 near the crest of the hill (station 128) showed only gravel. Test holes 2, 3, and 4 in the south ditch line indicated only clay, as did hole 6 in the north ditch line. The hole near the bottom of the hill, hole 5, had a clayey gravel. All but test hole 4, which showed a trace of water, were dry when drilled. By January

Figure 4. Crown movements at site.

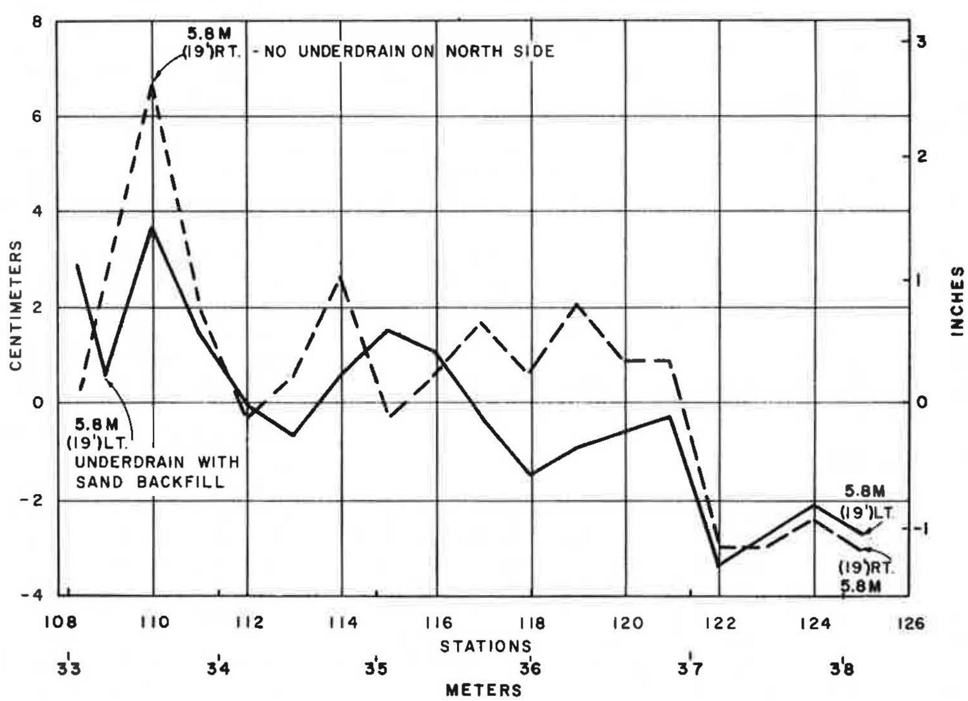
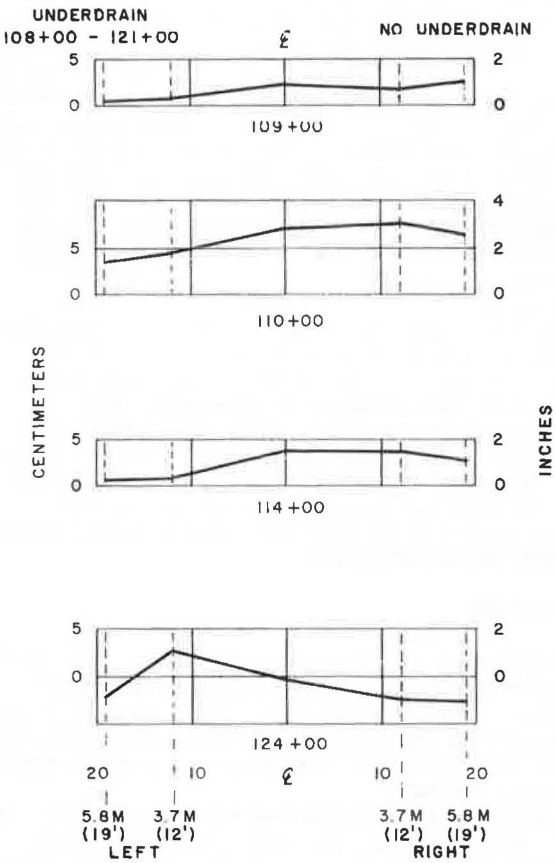


Figure 5. Typical cross-sectional movements.



24, 1974, three holes in the south ditch line showed significant amounts of water. Two were filled almost to the top of the hole, while the third was half full (Figure 1).

Atterburg limit tests at two sample sites showed the liquid limits to be from 65 to 67 and plasticity indices from 40 to 42. This would confirm these clays as potentially high-swelling soils according to the Waterways Experiment Station's studies (16, p. 38).

A trench about 2.4 m (8 ft) deep, 0.9 m (3 ft) wide, and 381 m (1250 ft) long was excavated by state maintenance forces along the south ditch line. The water-bearing stratum was uncovered. The 15-cm (6-in) corrugated metal pipe underdrain was placed in the trench (Figure 2). It was backfilled with a fine sand (Figure 3).

Elevations were taken with a level and rod at the centerline and on either side at 3.7 m (12 ft) and 5.8 m (19 ft), the crown points of the roadway. These elevations were taken on the pavement opposite the pipe outfall at station 108+42, and at the pavement stations from 109+00 to 125+00. Readings were taken on September 26, 1975, October 14, 1976, and July 20, 1977.

OBSERVATIONS

The changes in elevation between 1975 and 1977, three years of measurement, indicate least movement closest to the sand-backfilled underdrain. Movements at the stations have been generally uniform. The average changes, calculated between the readings in 1975 and 1977, are shown in Table 1. These average movements were three times greater on the non-underdrained side than on the underdrained side. Average movement at the centerline was twice that of the underdrained side. Changes between stations have been less regular. Larger upward movement generally took place farther away from the underdrain (Figure 4).

Elevations were taken farther up the hill beyond the underdrain at the same distances from the roadway centerline. There the average changes from left to right were 2.72 cm (1.07 in), 1.77 cm (0.7 in), 2.35 cm (0.93 in), 1.90 cm (0.75 in), and 2.85 cm (1.2 in), respectively. They ranged from three to five times greater than those on the underdrained crown. All were downward movements as compared to the upward clay section changes. Possibly the water's being removed resulted in this difference. It is also noted that the underdrains may have affected movement all across the road (Figure 5). Its crown movements were usually less than those beyond the drains.

CONCLUSION

Of the $4 billion dollars' damage a year that expansive clays have caused and continue to cause, more than half was to transportation facilities. This has been the subject of a considerable number of studies over the years.

The result of this study indicates that movements caused by expansive clays can be substantially reduced after structure placement. The sand-backfilled underdrain placed deeply in the zone of activity has resulted in pavement movements that are only a third of those along the unprotected pavement edge. Even the unprotected edge had less than half the movement of the adjacent pavement section without the underdrain.

These results confirm prior Israeli investigations, where a deep sand-backfilled underdrain along one runway crown resulted in one-quarter of the movement that the unprotected crown experienced. Subsequent laboratory tests indicated that the sand acted as a moisture reservoir for the clay. Excess moisture passed from the clay to the sand, and, when the clay needed the moisture, it was drawn from the sand. The change in the clay's moisture content was thus minimized, which significantly reduced movement of the clays.

These field tests substantiate the earlier studies. They put together vital data from previous observations. Expansive clays can be partially controlled by an underdrain set deeply in the zone of activity with a sand backfill that can significantly reduce the expansive clay's movements.

The zone of activity should be carefully considered in locating the underdrain deep enough to help minimize movement. The sand backfill may offer additional assistance in stabilizing moisture variations in the expansive clays.

Although some may feel that swelling clays cannot be controlled, others recognize that identification before construction can minimize destructive results from these soils. Replacement, chemical admixtures (most frequently with lime), horizontal and vertical moisture barriers, and ponding all afford opportunities to reduce the movement before construction. This study provides additional indications that these movements can also be minimized after the structure has been placed.

Reducing movements of expansive soils, which frequently requires energy-intensive remedies that use deep underdrains with sand backfill, may significantly help conserve energy.

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Addendum

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[This is the author's closure to the discussion of the paper Sand Drain Theory and Practice, which was published in Transportation Research Record 678. The reference and equation numbers that follow refer to those in the paper. The paper and discussion can be found on pages 22-36 of Transportation Research Record 678.]

The discussion prepared by R. D. Holtz is appreciated and reflects a degree of effort commensurate with the importance of the subject. It is difficult to justify any controversy relating to the use of the term nondisplacement as a descriptive word for sand drains installed where the cavity is formed by excavation techniques. The nondisplacement characteristic is certainly as approachable as the undisturbed characteristic is approachable in the taking of undisturbed samples, yet I am certain that there is no need to think twice about the practical validity of obtaining undisturbed samples. As a matter of record, Olson has shown that sand drain installations can outperform predictions made from data obtained from the best undisturbed samples (10, p. 101), which suggests that such terms should be considered as adjectives to differentiate between available techniques and not as absolutes.

The omission in the paper of Japanese and European improvements in the type of wick available for use with the Kjellman type of installation does not in any way denigrate the importance of such materials; however, the paper relates to the description of methods of installation. The installations fall into the categories presented: either displacement or nondisplacement techniques.

The paper attempts to broaden the method of sand drain design to the extent that previous publications may not have included all factors involved in the evaluation of installation techniques. To this end, an attempt was made to extend the available theory by providing additional equations that may be useful to the designer, particularly to avoid trial and error procedures, which are normally necessary. Equation 9 is an example, and its derivation is presented:

$$t_p = (T_h D_e^2)/c_h \tag{4}$$

by transposing and substituting $D_c/E_w^{1/2}$ (5, p. 94) for D_e, Equation 4a results, where D_c = the diameter of sand drain influence as constructed:

$$(D_c/E_w^{1/2})^2 T_h = t_p c_h \tag{4a}$$

Substituting from Equation 6 for T_h, and transposing the term $0.8u_h^{2.5}$, it is found that:

$$(D_o/E_w^{1/2})^2 \log_{10}(n/2) = t_p c_h / 0.8u_h^{2.5} \quad (9a)$$

and

$$n = D_c/E_w^{1/2} d_w$$

Equation 9 results from Equation 9a by taking the square root of both sides of the equation, where $M = (t_p c_h/0.8u_h^{2.5})^{1/2}$. Inasmuch as t_p, c_h, and u_h are fixed for any specific design problem, M is a constant that can be used to establish equivalent designs where D_o, E_w, and n can be variables.

I will gladly provide derivations of other equations to those who request the information. Derivations were not provided in the text due to the length of the paper and space limitations imposed.

The vibroflotation Dutch jet-bailer method has been practiced in a manner that is inconsistent with nondisplacement procedures, just as much as the auger method has been similarly misused. There is no tool that can be indiscriminately and uncontrollably raised and lowered, be it a jet or an auger, that will not result in undue subsoil displacement. On the other hand, both tools can be carefully controlled so as to avoid displacement. Holtz suggests that to impose controls on the vibroflotation Dutch jet-bailer method would make its use more costly. I have observed the vibroflotation system in operation on projects where the equipment was used without any plunging of the apparatus allowed. The designer must answer for himself whether or not the risks associated with uncontrolled use of cavity forming apparatus is desirable and consistent with design assumptions, and if it is then perhaps it should be allowed. A number of failures or sharp deviations from design performance have occurred on projects where jetting methods have been used, and this could be related to such lack of controls. Unfortunately, Holtz may not be aware of these since, to the best of my knowledge, they have not as yet been reported in the literature. To avoid the unexpected failure of otherwise sound sand drain designs, close field controls are required for all methods.

We can appreciate the effort presented by Holtz in his discussion. It now remains for the geotechnical practitioner to fully document designs and field performance that, we hope, will provide the profession with the practical results necessary to the making of future judgments as to the performance of various sand drain installation techniques.