Africa, Constructed in May 1965. CSIR, National Institute for Road Research, Pretoria, South Africa, Rept. RB/7/65, Oct. 1965.
5. J. A. Mabbutt. Report on Visit to Ovamboland, South West Africa, in Connection With Calcrete Problems, April 14 to 16, 1965. CSIR, National Institute for Road Research, Pretoria, South Africa, Rept. 1965.
6. Report of the Commission of Enquiry Into South West Africa Affairs (1962-1963), p. 15.
7. J. H. Mortimer. Summary of the Vegetation of Ovamboland and the Okavango Region. CSIR, National Institute for Road Research, Pretoria, South Africa.
8. Asphalt Pavement Design for National Roads, 1970. CSIR, National Institute for Road Research, Pretoria, South Africa, June 1971.
9. I. L. Jamieson and M. M. Hattingh. The Correlation of Chemical and Physical Properties of Bitumens With Their Road Performance. Proc., 5th Conference of the Australian Road Research Board, 1970.
10. C. P. Marais and I. L. Jamieson. The Performance of 80/100 Pen. Straight-Run and Air-Rectified Bitumens. Trans., South African Institute of Civil Engineers, Vol. 12, No. 9, Sept. 1970, pp. 203-210.
11. C. P. Marais. A New Technique to Control Compaction of Bitumen-Sand Mixes on the Road Using a Vane Shear Apparatus. Trans., South African Institute of Civil Engineers, Vol. 8, No. 3, March 1966, pp. 87-94.
12. R. H. Williamson and C. P. Marais. Pavement Temperatures in Southern Africa. Trans., South African Institute of Civil Engineers, Vol. 16, No. 8, Aug. 1975, pp. 203-214.
13. J. S. Gregg, G. L. Dehlen, and P. J. Rigden. On Properties, Behavior and Design of Bituminous-Stabilized Sand Bases. Proc., 2nd International Conference on the Structural Design of Asphalt Pavements, Ann Arbor, Mich., Aug. 1967, pp. 863-882.
14. C. R. Freeme and C. P. Marais. Traffic Load Associated With Cracking of Asphalt Pavements. Proc., 2nd Conference on Asphalt Pavements for Southern Africa, Durban, CSIR, Reprint 166, 1974, pp. 1-135 to 1-151.
15. L. Brown and P. Pell. Repeated Loading of Bituminous Materials. Proc., 2nd Conference on Asphalt Pavements for Southern Africa, Durban, CSIR, Reprint 166, 1974, pp. 3-28 to 3-50.

Publication of this paper sponsored by Committee on Soil-Bituminous Stabilization.

Ponding an Expansive Clay Cut: Evaluations and Zones of Activity

Malcolm L. Steinberg, Texas Department of Highways and Public Transportation

The use of ponding water on a clay subgrade of high swelling potential to cause soil heaves before pavement placement 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 definitive. 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.

Expansive soils are an international problem. They are also expensive problems, costing the United States more than $2.2 billion in 1973 (<u>1</u>). They have been studied extensively (<u>2</u>, <u>3</u>, <u>4</u>, <u>5</u>, <u>6</u>, <u>7</u>). In Texas, expansive clays extend in a corridor from the northern borders with Oklahoma and Arkansas almost to the Rio Grande River and Mexico in the south. They usually lie along the Wichita Falls, Dallas, Fort Worth, Austin, San Antonio line. The clays present fewer problems in the eastern areas of the state, where higher rainfall rates tend to keep subsoil moistures uniformly higher. In the areas west of San Antonio and Austin, the Balcones escarpment and the upland area contain more limestone and less expansive clay.

In 1968, the Texas Highway Department, now the State Department of Highways and Public Transportation, began planning improvements to US-90 west of San Antonio. This highway lays over an expansive clay area, and multiple control measures were considered. Ponding and the installation of a lime-treated moisture seal and an underdrain were chosen. The department, in cooperation with the Federal Highway Administration and the Center for Highway Research at the University of Texas, also decided to measure the effectiveness of these techniques, and to find the depths at which the movements of these clays and the moisture changes take place. The work was initially reported as part of the center's series on expansive clays (<u>8</u>).

SITE AND ITS GEOLOGY

US-90 is a transcontinental route. It passes through the San Antonio area where the movement of expansive clays has long been observed. This highway project, where the ponding was used, begins at I-410 on the southwest boundary of San Antonio and extends just beyond the city's outer loop (FM-1604).

The area is a Pleistocene high-terrace deposit overlying the Taylor formation. In the ponding areas, this formation is a greenish-gray calcareous nodular clay that extends at least 6.1 m (20 ft) below the bottom of the proposed FM-1604 cut. About 1.5 m (5 ft) of the terrace gravel was left on the site at the east boundary of the ponded area.

X-ray diffraction analyses were made of two samples within the ponded area by the Bureau of Economic Geology at the University of Texas at Austin. A sample of clay from the base of the gravel at station 242+00 was 35 percent calcium montmorillonite, 50 percent illite, and 15 percent kaolinite and chlorite. A second sample, taken from a depth of 4.6 m (15 ft) at the other end of the site, was 30 percent calcium montmorillonite, 60 percent illite, and 10 percent kaolinite and chlorite.

SOIL PROPERTIES

A soil profile developed from area sampling is shown in Figure 1. The following data reflect samples taken from stations 170 to 258:

Property	Range	Avg
Liquid limit, %	46 to 109	69
Plastic limit, %	20 to 44	28
Shrinkage limit, %	7 to 19	14

PROJECT

The contract called for building a four-lane divided highway with frontage roads, grade separations at three locations, and span structures at Medio Creek. The grade separation of US-90 and FM-1604 involved the construction of an underpass as a part of a diamond interchange. Exploratory core drilling reaffirmed the presence of expansive clays, and by using McDowell's method of determining the potential vertical rise (PVR), the expected movement was calculated. The removal of 8.2 m (27 ft) of material in the excavation added rebound to the reactions of the expansive clay. The area to be ponded extended from station 245 to station 270 and covered the section up to 0.9 m (3 ft) on the backslope. Ponding was to be continued for a 30-d period. A moisture seal was to be placed by using 0.15 m (0.5 ft) of lime-stabilized subgrade.

Two other measures were added to minimize pavement distress. A strata of gravel removed as part of the interchange excavation was stockpiled and spread 0.45 m (1.5 ft) deep over the lime-stabilized moisture seal in the ponded area. Where some of the gravel remained at the east end in the finished subgrade section, 0.15-m (0.5-ft) diameter underdrains were placed beneath the centerlines of the outside main-lane ditches.

Instrumentation

Different types of devices were used to make the elevation and moisture measurements. Elevations were developed from rods embedded at depths of 0.6, 1.4, 3.2, and 5.8 m (2, 4.5, 10.5, and 19 ft) and read with a level rod. The elevation rods were 1.2-cm (0.5-in) galvanized water pipes with a 7.5-cm (3-in) auger plate welded on the bottom. The pipes were placed in 0.2-m (8-in) casings which were set in holes drilled 0.23 m (9 in) in diameter to depths of 0.5, 1.2, 3.1, and 5.6 m (1.5, 4, 10, and 18.5 ft) below subgrade. The space around and inside the 0.2-m (8-in) pipe was packed with automobile-chassis grease. The auger plate and the 1.2-cm (0.5-in) pipe were advanced 0.15 m (6 in) into the ground at the bottom of the grease-filled hole, with the top of the pipe extending about 0.5 m (1.5 ft) above the casings. The entire assembly was protected by a 1.2-m (4-ft) long section of 0.3-m (1-ft) clay pipe, which was capped (Figure 2). A variety of evolutionary measuring rods and nuclear access tubes were also set for moisture and density readings. More conventional moisture measurements were made by drilling samples with a rotary bit and conducting laboratory tests.

Contract Work

Work on the contract began on January 21, 1969. Excavation for the FM-1604 interchange began in June 1969 and initially included only the northern two-thirds of the cut. The rest remained so that traffic could use the existing pavement. Frontage roads were built to carry the future detour route. The first sets of elevation rods were placed before the ponding. They were located in the median area at stations 241, 245, 250, and 255. Each set consisted of four rods set at the different depths. The first readings were taken in December 1969.

The first group of 33 dikes were built the following February. They were spaced 15 m (50 ft) apart, usually at a 45° angle with the centerline following the contour line of the section. The dikes were usually 0.9 m (3 ft) high and 1.2 and 0.3 m (4 and 1 ft) thick at their base and top respectively. They were about 53 m (175 ft) wide and filled with water from a 244-m (800-ft) deep well with a pump.

Ponding began on March 3, 1970, and was completed by draining on April 7. Liming operations for the moisture seal were completed by May.

The rod readings and the moisture determinations indicated substantial increases in elevations of the rods set at shallow depths and considerable moisture variations and so the limits of the ponding were increased by 91.4 m (300 ft) to cover another area of anticipated significant potential swell and to expand the test sites.

The three new test sites in the ponded areas were in the portion of the interchange excavation about 30 m (100 ft) south of those in the median. The control sites were located in the median outside the ponded areas. The excavation on the south side of the interchange was completed in January 1971, a year after the first sections. Ponding began shortly afterward, with the first section completed in February. The placement of the lime and the stockpiled gravel was completed in July, and the construction work was completed on November 12, 1971. The originally estimated quantities of ponding were 36 900 m^3 (9 733 000 gal) covering 72 000 m^2 (88 981 yd^2). After the field change, the estimate was revised to 46 300 m^3 (12 200 000 gal) covering 88 000 m^2 (110 621 yd^2) at a bid price of 0.16¢/m^3 (0.0006¢/gal). The final quantity was 71 300 m^3 (18 831 000 gal) costing $11 298.60.

OBSERVATIONS

The readings of the moisture data began in April 1968 and those of the elevations in December 1969 and have continued semiannually. Some of the measuring locations have been lost, and others have been destroyed. Among these were the nuclear tubes. Whether their thin shells were unable to resist the extensive pressures or whether the upward movements of the soils covered them over is unknown. Only the pipes with the protective jackets remain identifiable today. A road surface inventory has given further indications of the effectiveness of the pondings. A series of profilometer readings have also been made, but an analysis of their relationship among the sections has not been completed.

Rod Readings

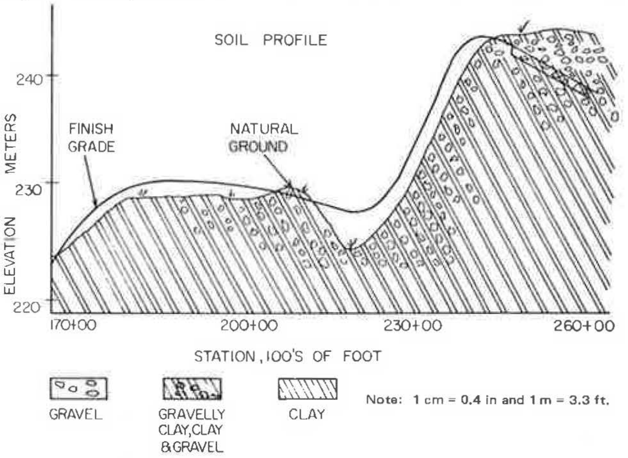
Generally, the ponding caused an upward movement in the elevation rods. This was most pronounced in those set 0.6 and 1.4 m (2 and 4.5 ft) deep, i.e., the shallower rods, and most clearly indicated in the rods set in the ponded median areas. With time, this movement was reflected to a lesser degree in the deeper set rods. No movements greater than 1 cm (0.4 in) were read in the rods set at the 5.8-m (19-ft) depth for more than 4 years. This is typically shown in the group at station 245 (Figure 3).

The control rods have also developed upward movements. At station 241, this did not occur until 2 years after the subgrade was shaped and the pavement placed (Figure 4). The movement was greatest in the elevation devices set at the shallowest depths, 0.6 and 1.4 m (2 and 4.5 ft). In the other control group at station 173, no movement was recorded until 1972. There, readings were greater and continue to show more movement from the 1.4 and 3.2-m (4.5 and 10.5-ft) rods than from the shallowest one at 0.6 m (2 ft).

The movements generally take place in a zone of activity, which was usually to a depth of 3.0 m (10 ft) on this project. Readings for the rods set in the areas of the 1971 pondings indicated less upward movement than those in the previous year's ponding, but the patterns were generally the same.

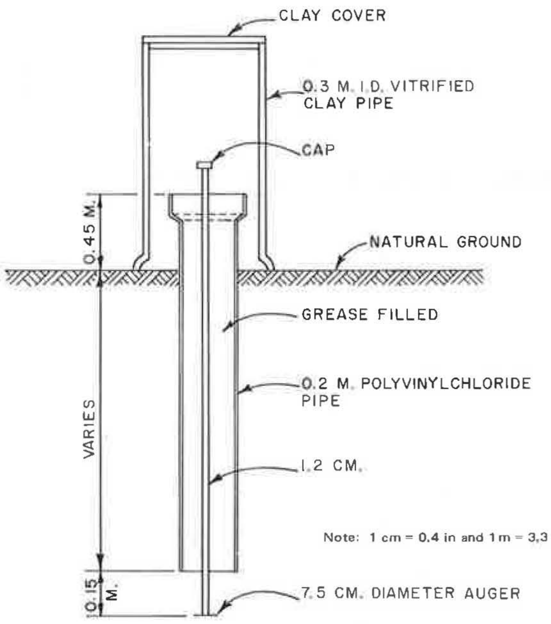
In mid 1974, a pronounced change occurred in most readings. The direct reading indicated that the deepest rod had a decreased elevation. Either the movement had suddenly reversed itself or the bench marks were more affected by the clays than was the 5.8-m (19-ft) rod, which was insulated from movement by the grease. When the grades were adjusted so that the deepest rod reading reflected no change, the pattern of increased upward movement tended to be fairly uniform. (Anticipation of this problem of the movement of the standard bench marks was the reason why the program of calculating the adjusted reading was followed from the beginning of the project.)

Figure 1. Soil profile.



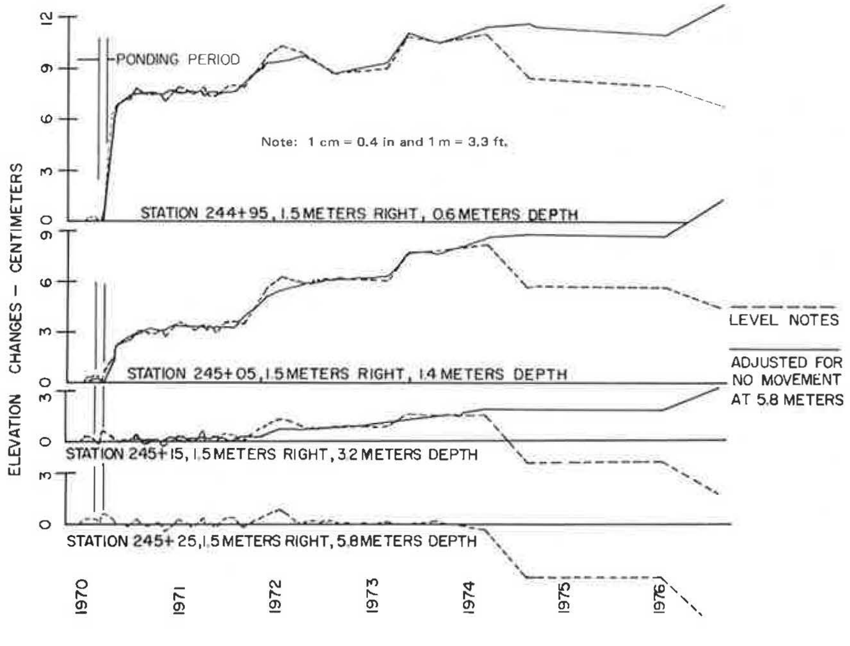
Note: 1 cm = 0.4 in and 1 m = 3.3 ft.

Figure 2. Elevation-rod device.



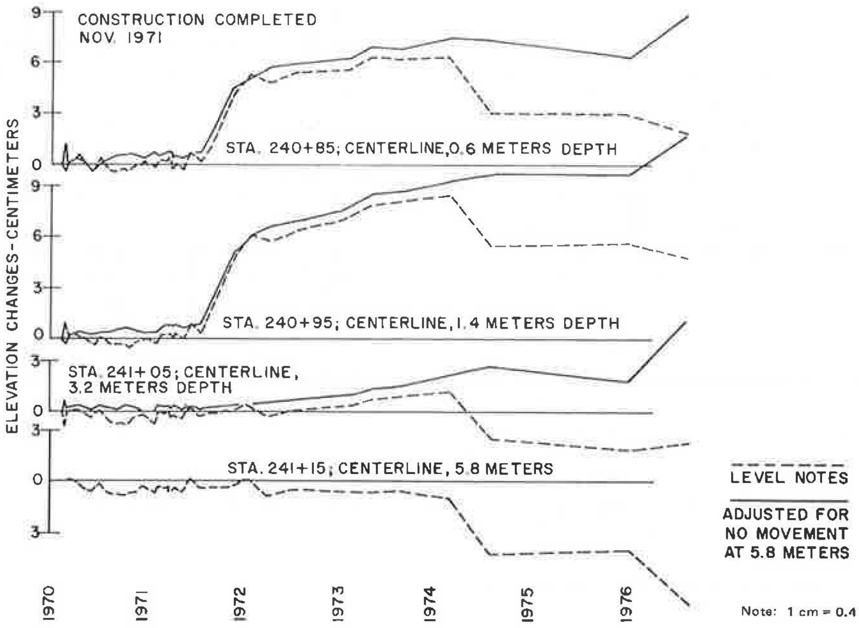
Note: 1 cm = 0.4 in and 1 m = 3.3 ft.

Figure 3. Vertical movement at station 245.



Note: 1 cm = 0.4 in and 1 m = 3.3 ft.

Figure 4. Vertical movement at station 241.



Note: 1 cm = 0.4 in and 1 m = 3.3 ft.

Figure 5. Vertical movements: calculated and observed.

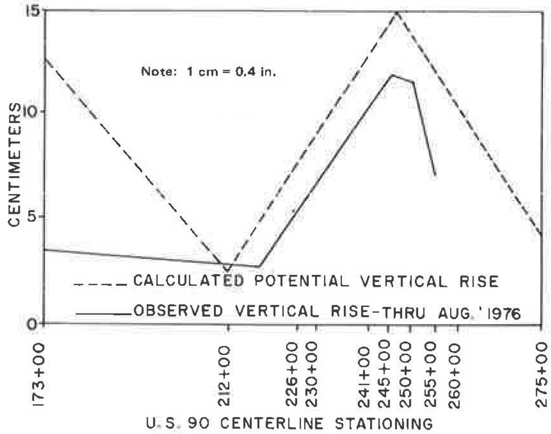
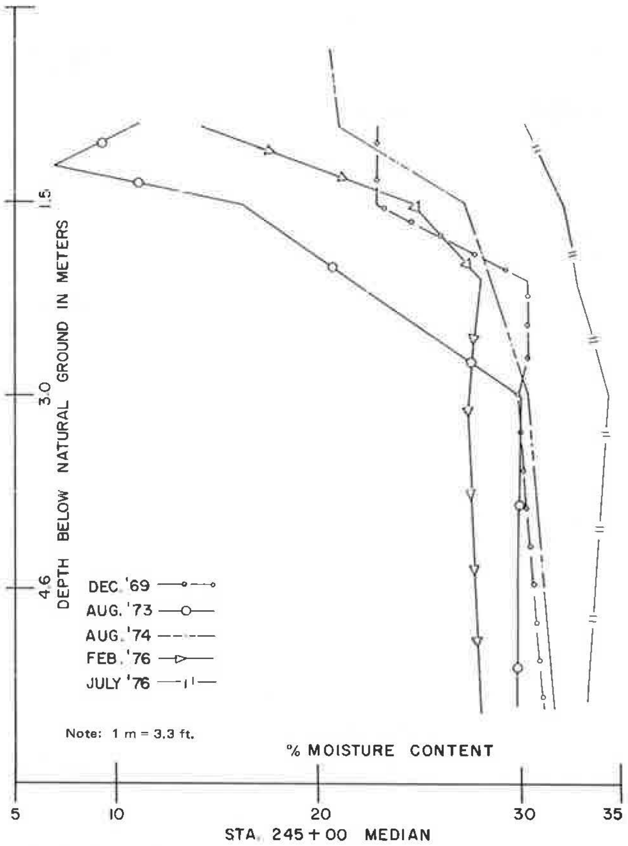


Figure 6. Moisture changes at station 245 (centerline).



Calculated Versus Observed Readings

On none of the rods has the actual maximum reading yet reached the calculated PVR. The movements seem to be approaching the calculated values if the adjustment to the 5.8-m (19-ft) rod is used. The rods in the stations 245 to 255 medians are now showing maximum upward movement close to the predicted PVR. The readings at station 173 have not come within that range, nor have the ones 30 m (100 ft) to the left of the centerline (Figure 5).

Moisture Contents and Depth

These readings cover a 9-year period. To avoid variations due to testing modes, they were all taken by the method of laboratory tests of drilled samples. They reflect a zone-of-activity pattern in which there is considerable change in the moistures (usually) down to 3 m (10 ft). They range from a low of close to 5 to a high of almost 35 percent (Figure 6). This was true for both the ponded and the unponded areas and as likely to occur in 1976 as in 1969. Below 3 m (10 ft), the samples showed much less variation. The range at that depth seemed to be from 24 to 28 percent at one site to 28 to 34 percent at others. Instead of the 30 percent moisture-content variations in the zone of activity, these deeper readings reflect changes of one-third that or less. Moisture changes seem to relate to elevation changes. Both have their maximums in the zone of activity.

Observations from the second ponded group, those set about 30 m (100 ft) from the median and first recorded in

Figure 7. Moisture changes at station 245 (30 m left of centerline).

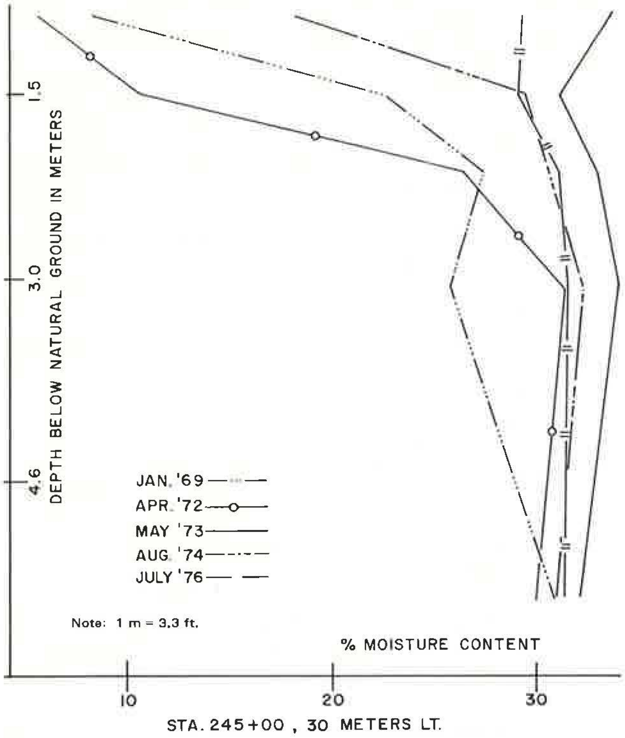
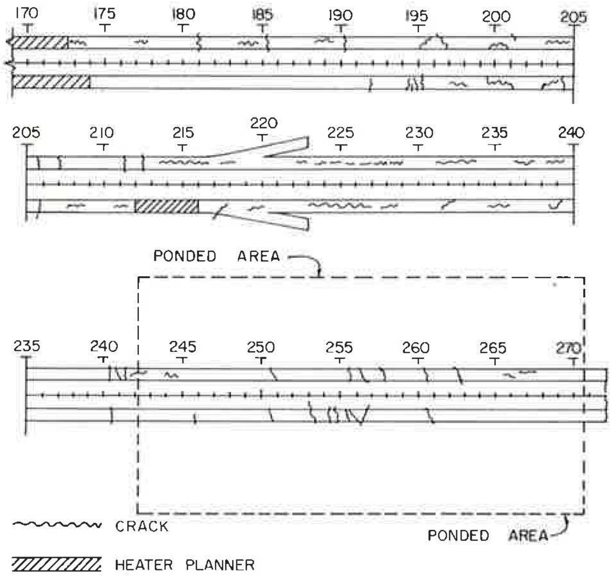


Figure 8. Road inventory.



1969 indicate that they have less moisture variation below 3 m (10 ft) (Figure 7). Whether this diminished range of change is due to differences in the material has not been clarified. The soil profiles do reflect some variations. Other possible reasons are closeness to the slopes of the 6-m (20-ft) deep excavation and the fact that these latter sites were ponded shortly after excavation. However, the pattern is generally the same. Major moisture changes take place near the surface in the zone of activity, and the changes at the lower depths are relatively minimal.

The effect of ponding on these moisture contents was not clearly observed. This was due in part to the delay in testing that required moving heavy drilling equipment into the site. Nuclear measurements would have avoided this, but the loss of the tubes prevented them.

Road Conditions

A road inventory has been made through the test area in the last 2 years. The ponded area has shown less need for major repairs and less major cracking. Heater-planner work areas that indicate the need to reduce a significant swell in the roadway surface have been required only in nonponded areas.

Though cracking has occurred on roadway surfaces over the ponded subgrades, it has not been of a prolonged nature. The cracks that have occurred there are relatively short and usually transverse. The nonponded areas of the test section show more prolonged cracking, both longitudinal and transverse, and require heater-planner repair work. Recent records show the pattern that began to evolve in the first examination (Figure 8).

An attempt to relate some of these observations of roadway conditions to the elevation-rod movements showed that the greatest amount of pavement repair work and apparent distress was between stations 170 and 175, but that these sections had little rod movement compared to those from stations 242 to 255. However, the sections over the ponded areas had also made use of the select material of low plasticity index, which contributed to those pavements relative lack of distress.

The results of other ponding projects (8, 9) confirm the effectiveness of ponding in reducing pavement maintenance work. Roadway sections that are above ponded subgrades tend to have less pavement distress. In tests in Mississippi, the introduction of moisture by drilling reverse drains to put the water deeper into the clays indicated considerable benefits to the pavements in terms of low maintenance requirements.

Rainfall and Rod Readings

A pattern of upward elevation changes following rainfall is being examined by comparing plots of the rod readings to rainfall records from the U.S. National Weather Service at San Antonio International Airport, 32 km (20 miles) northwest of the project. Rains in this area are irregular with dry and wet periods, and those recorded at the airport are not necessarily the same as those at the site. With all of these limiting factors, the pattern is clouded. Surface cracking caused by an extended dry spell tends to allow rainfall to enter these openings, and the upward movements in the shallower rods can be attributed to these rains.

CONCLUSIONS

Ponding apparently caused the upward movement of elevation rods set at shallow depths. The movements continued in these clay soils after the ponding and in the nonponded areas. In the nonponded areas, the movements took place only after the pavement had been placed.

The moisture changes were greatest at the shallower depths. At depths below 3 m (10 ft), there was considerably less variation. The greatest rod movement generally took place in those set less than 3 m (10 ft) deep. This was also the area of maximum moisture change, the zone of activity.

In this area, pavement maintenance problems are occurring more frequently outside the ponded area. Problems in the ponded areas are less frequent and less serious than those outside. Ponding appears to have contributed to the reduction of these problems. This confirms the reports of other engineers in other places. It appears that if the zone of activity could be isolated from moisture changes that affect its movements, then many maintenance problems might be avoided.

ACKNOWLEDGMENTS

The work in this study was performed cooperatively by personnel of the Texas State Department of Highways and Public Transportation, the Center for Highway Research of the University of Texas, and the Federal Highway Administration.

The contents of this report reflect my view, and I am responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of any agencies or institutions mentioned.

Special note is made of the assistance of the late Gordon Watt, of Saskatchewan, Canada, who contributed a great deal in the first several years of this research.

The interest of all the agencies and their personnel involved is gratefully acknowledged.

REFERENCES

1. D. E. Jones and W. G. Holtz. Expansive Soils: The Hidden Disaster. ASCE, Civil Engineering, Vol. 43, No. 8, Aug. 1973, p. 49
2. G. E. Blight and J. A. DeWet. The Acceleration of Heave by Flooding. In Moisture Equilibria and Moisture Changes in Soils Beneath Covered Areas: A Symposium in Print, Butterworth, 1965.
3. G. M. Kassiff, M. Livneh, and G. Wiseman. Pavements on Expansive Clays. Jerusalem Academic Press, 1969.
4. T. A. Haliburton. Preliminary Planning. Interim Rept. 1, Subgrade Moisture Variations, School of Civil Engineering, Oklahoma State Univ., 1966.
5. C. O'Bannon and F. Mancini. Field Stabilization of Chinle Clay by Electroosmosis and Base Exchange of Ions. Arizona State Univ.; Arizona Department of Transportation; Federal Highway Administration, Rept. FHWA-A2-RD-13 (145), 1975.
6. D. R. Snethen and others. A Review of Engineering Experiences With Expansive Soils in Highway Subgrades. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.; Federal Highway Administration, Interim Rept., 1975.
7. M. L. Steinberg. Interceptor Drains in Heavy Clay Soils. Proc., ASCE, Transportation Engineering Journal, Vol. 96, No. TE 1, Feb. 1970, pp. 1-10.
8. R. Lytton and others. Study of Expansive Clays in Roadway Structural Systems. Center for Highway Research, Univ. of Texas, Austin, Repts. 118 1-8, 1969 to 1974.
9. P. T. C. Teng, R. M. Mattox, and M. B. Clisby. A Study of Active Clays as Related to Highway Design. Research and Development Division, Mississippi Highway Department, 1972.

Publication of this paper sponsored by Committee on Lime and Lime-Fly Ash Stabilization.