Membrane Technique for Control of Expansive Clays

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Much northeastern Arizona highway is built on expansive clay. Changes in the moisture content of these clay subgrades cause volume changes that in turn cause excessive pavement deterioration and thus affect safety. During initial construction, a variety of experimental sections were built to test such stabilization methods as moisture and compaction control, chemical admixtures, electro-osmosis, overexcavation, ditch widening, underdrains, and membranes, alone or combined. Some methods were relatively successful when compared to the rapid deterioration of the untreated highways. These findings led to choosing impermeable rubber membranes to control moisture in the clay subgrades. The first trial of the technique at full contract scale was an 18-km (11-mile) overlay on I-40 completed in 1975. After the slopes were flattened for safety, the roadway prism under the asphalt concrete overlay and down the shoulder slopes was covered with the asphalt-rubber membrane. The control section was an adjacent overlay of the same design but with no membrane. In 1976, a 5-km (3-mile) overlay on US-89 with asphalt-rubber membranes and shoulder and ditch paving was constructed. This report presents the data on the three full-scale overlays and the success of the membrane.

Expansive clay is a major problem for the state of Arizona. Changes in moisture content in clay subgrades lead to volume changes great enough to cause serious deterioration of the pavement structure. The problem is most severe in the northeastern corner of the state, where 483 km (300 miles) of state highways are on the clays of the Chinle formation. The cost of simply maintaining these highways in safe condition, apart from repairing damage to the structural capacity of the roadway, is excessive.

In the early 1960s a variety of experimental techniques for controlling expansion began to be tried on new construction. Success varied from worse than none to very good. After analyzing all the various treatments, it became apparent that, to successfully control expansive clay subgrades, changes in moisture content must be kept to a minimum. The degree of success of each treatment seemed to depend on the extent to which it accomplished this.

In 1973, two test sections in cuts on a new two-lane highway at the south edge of the Petrified Forest had full-depth asphalt concrete pavement, and a third cut had a catalytically blown asphalt membrane on the clay subgrade under the normal pavement design of select material and asphalt concrete. Also, in all cuts the seal was carried across the ditches, which were paved with thinner asphalt concrete from the regular pavement out to 30 cm (1 ft) up the back slope. The apparent success of these tests led to an early trial of membranes for the newly arisen problem of treating the many deteriorating kilometers of highway on Chinle clay. Asphalt-rubber membrane was selected because of its waterproofing properties and ease of application. The asphalt-rubber membrane serves a threefold purpose: It reduces evapotranspiration of moisture from the subgrade; it prevents infiltration of moisture from surface runoff; and it prevents reflective cracking in the new overlay.

This report presents and discusses data on the first three projects built as trials of asphalt-rubber membranes. Two of these were 18-km (11-mile) overlay contracts on I-40, one built in 1975 with the membrane, the other adjacent and built in 1974 without it. Both were of similar design, including flattened slopes for safety. On the third project, located on US-89 north of Cameron, asphalt-rubber membranes were used in conjunction with shoulder and ditch paving. All three projects were monitored for changes in roughness, moisture content, and surface elevation and tested periodically with the Dynaflect. A short description of Chinle clay is followed by a review of the earlier field trials of the various other treatments used on it.

OCCURRENCE AND PROPERTIES

In northeastern Arizona the majority of the expansive soils are contained in the Chinle formation. Figure 1 illustrates the present exposure of the Chinle formation and 483 km (300 miles) of highways located on it.

The Chinle formation is predominantly clay, although there are some thin layers of sandstone, siltstone, and conglomerate. Where erosion is too rapid for vegetation to develop in a weathered surface layer, the clay erodes to the rounded hummocks and gullied slopes typical of clay deposits, but with massive layers of varying colors, as in the scenic Painted Desert. Beneath any weathered and softened surface layer, the in-place clay is typically strong and hard with a moisture content from 5 to 20 percent, dry densities from 1442 kg/m^3 to 1842 kg/m^3 (90 lb/ft^3 to 115 lb/ft^3), and textures and strengths that may cause it to be identified as sandstone or siltstone as often as shale or clay. Vigorous wet rubbing can reduce a sandy textured chip to resembling a clay-cemented sandstone; after thorough soaking 80 percent or more will pass a 75-μm (no. 200) sieve.

In the laboratory, the properties of various samples varied widely and included nonplastic silts and fine sands, although a rocklike core of deceptive texture may have a liquid limit of 65, a plastic index (PI) of 38, and a T99 maximum density of 1522 kg/m^3 (95 lb/ft^3) at an optimum 32 percent moisture content. These clays are bentonitic, but the bentonite is disseminated. In other layers, a more clayey or shale-like appearance is found in a finely fissured structure with seams and nodules of pure bentonite.

CONTROL OF EXPANSIVE SOILS

Clay formations in the field are usually disturbed when the roadbed embankment and subgrades are constructed. This creates the worst possible case of maximum expansion. Historically, attempts have been made to control this expansion during original construction. Some of the experimental trials were

1. Overexcavation up to 1.5 m (5 ft) and replacement with granular materials and french drains;
2. Lime ponding, which involved spreading lime on Chinle clay subgrade and then ponding with water;
3. Lime post holes drilled to various depths into the clay on a grid pattern and then filled with lime slurry;
4. Lime treating the top 150 mm (6 in) of subgrade;
5. Ponding with potassium chloride solution;
6. Electro-osmosis using potassium chloride solution; and

7. Widening of cut ditches and paving shoulder slopes.

The success of the experimental trials varied enormously, from detrimental to very successful. A detailed account of the original construction features and overlay experiments is found elsewhere (1).

A very large portion of the 483 km (300 miles) of highways over the Chinle formation received little special treatment during original construction. After 10 or 12 years of service, excessive distortions had made it necessary to overlay some sections of these highways. Normally the distorted highway was surveyed to determine the amount of leveling needed to obtain a suitable riding surface with proper geometrics. Arizona uses a Missouri computer program that designs asphalt concrete overlays, in one or two lifts, to a smooth grade line and prints out superelevation, centerline profile grade, accumulated quantity and thickness of the top lift (binder course), accumulated quantity left and right of centerline for the leveling course, and thicknesses of the leveling course at various offset points. The program uses only the submitted existing roadway cross-section data, specified minimum thicknesses, desired superelevation transition data, and unit weight of asphalt concrete to compute grades and quantities. A detailed description is contained in Damgaard (2). The program came from Missouri, but alterations were made by Arizona and the name of the program became AZ-MO Overlay Program or just AZ-MO. By obtaining survey elevations across the highway (an elevation at centerline and each quarter point on the highway, five elevations) and at each even 7.6-m (25-ft) distance (station 0+00, 0+25, 0+50, 0+75, 0+100, etc.) it was possible to compute the amount of leveling needed before overlay.

The necessary overlaying of the distorted highway provided a good opportunity to try some method of treatment to improve overlay performance. Previous experience in Arizona and on US-180 and Colorado (3) showed that paved cut ditches and subgrade membranes have been successful in controlling volume changes of expansive clay subgrades. On I-40 two adjacent overlays were to be built over a highway badly distorted by the action of expansive clay. In order to determine whether the membrane sealing concept would work for an overlay, both projects were to be designed and built in the same manner but one would have a membrane seal across the pavement and down the slopes. The projects were designated as follows.

1. I-40-5 (38) County Line-Pinta: From milepost 307.2 to 318.8 eastbound (EB) and westbound (WB) or from station 0+00 to 613+00 EB and WB. This project was designed for an AZ-MO leveling plus a 31.8-mm (1.25-in) layer of asphalt concrete. In addition the slopes were flattened from 6:1 to 10:1. Likewise the cuts were laid back an additional 3.7 m (12 ft). Figure 2 shows the typical section for both fill and cut.

2. I-40-5 (44) Pinta-McCarroll: From milepost 318.8 to 330.6 EB and WB or station 613+00 to 1237 EB and WB. This project was designed and built like project I-40-5 (38) except the asphalt-rubber waterproofing membrane was placed over the pavement and 3.7 m (12 ft) down the shoulder slopes in both cut-and-fill sections. The membrane on the earth shoulder slopes was protected with 152.4 mm (6 in) of soil. Figure 2 depicts the typical section for a fill and cut on this project.

There were two further overlay projects built with membranes. Project I-40-5 (45), also on I-40, was identical to I-40-5 (44) but lay approximately 40 km (25 miles) east and not adjacent to the control project. Project F 037-2-502 was built on US-89 over a very badly distorted highway. This project differed from the other overlay projects in several ways. First of all, in cut sections the membrane covered the entire roadway as well as the shoulder slopes and cut ditches. Second, 50.8 mm (2 in) of asphalt concrete were paved over the membrane for protection. Figure 3 depicts a cross-sectional view of this project.

The performance of the above four projects forms the basis of this report.

PROJECT CONSTRUCTION

The construction of all four overlay projects was essentially the same. First the leveling course was applied to the old pavement, and then the shoulder slopes were bladed and compacted to a uniform slope. Before the asphalt-rubber membrane was applied, the soil slopes were primed with a light shot of emulsion 0.36 L/m^2 (0.08 gal/yd^2). The asphalt-rubber mixture was applied to the slopes by using a special boot truck with a mast arm off the side of the truck. This allowed the truck to drive on the pavement while applying the membrane to the shoulder slopes. An Arizona Department of Transportation (DOT) report (4) presents details of the field construction of asphalt-rubber membranes.

The asphalt-rubber mixture used on all four projects was identical and consisted of 25 percent ground vulcanized rubber reacted with asphalt at high temperatures [177°C (350°F)]. This mixture is brought together in the boot truck and normally requires an hour for complete reaction to occur. This reaction time, however, depends on the temperature, rubber gradation and type, and the asphalt crude source. After complete reaction has occurred, the composition consists of a thick jellied material with good elastomeric properties.

The high viscosity of the asphalt-rubber composition is reduced with a small quantity of kerosene introduced into the mixture. This temporarily reduces viscosity and facilities application of the asphalt rubber. After not more than 2 h, the composition returns to its original high viscosity (5).

On the I-40 projects the asphalt rubber was applied at a rate of 3.4 L/m^2 (0.75 gal/yd^2) on the earthen shoulder slopes and 2.7 L/m^2 (0.60 gal/yd^2) on the leveled asphalt concrete. The asphalt rubber applied to the asphalt concrete was immediately covered with chips to provide a wearing surface and facilitate load transfer in the completed pavement. The membrane on the shoulders was protected with 15 cm (6 in) of soil. The spread rate on the US-89 project was 3.2 L/m^2 (0.70 gal/yd^2) on the leveled asphalt concrete. On this project chips were spread on the asphalt rubber used on the earth shoulder slopes as well as on the roadway. The application rate of the chips varied between 19.2 and 21.8 kg/m^2 (35 and 40 lb/yd^2). The membrane on the shoulders was protected with 5 cm (2 in) of asphalt concrete.

In Arizona, the asphalt-rubber mixture is paid for under a special item, AR-1000 (rubberized-membrane seal) and includes AR-1000 asphalt, granulated rubber, and kerosene and is calculated at the equivalency of 0.90 kg/hot L (7.5 lb/hot gal). The chips are paid for under a separate item. Both materials are paid for at the contract price for work completed in place. For asphalt-rubber projects undertaken in 1977, the cost per customary ton of asphalt rubber varied from \$311 to \$430. Using an average of these figures yields an average cost of asphalt rubber and chips in place of \$1.81/m^2 (\$1.50/yd^2).

PROJECT PERFORMANCE

The objectionable characteristics of the highways before

Figure 1. Map of northeastern Arizona.

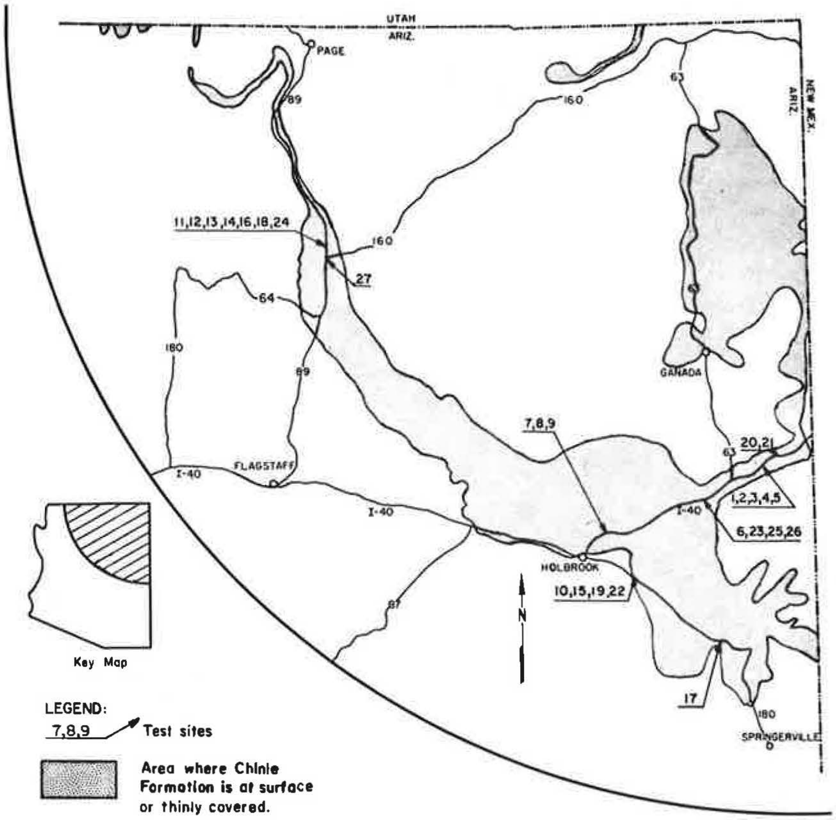


Figure 2. I-40 typical sections.

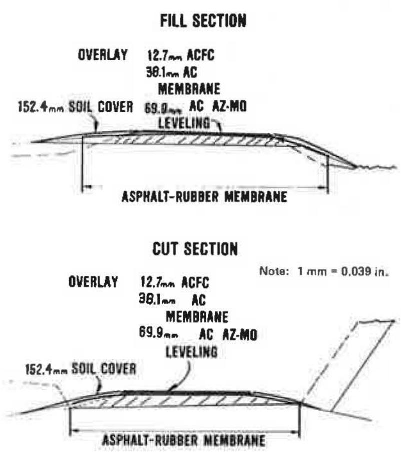
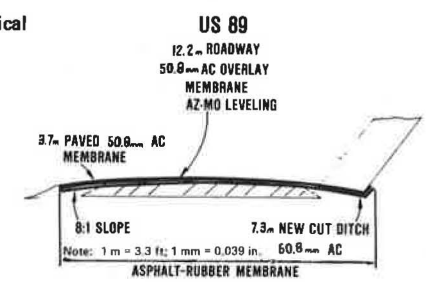


Figure 3. US-89 typical sections.



overlay included pavement distortion, cracking, and excessive maintenance. The picture in Figure 4 shows the typical condition of a highway before overlay. Visual observations of the projects were sufficient to indicate the nature and extent of the distress, but the following measurements indicated the severity of the problem:

Figure 4. Highway condition before overlay.

1. Ride, or the roughness as measured by Mays ride meter (6);
2. Percentage of cracking as measured by the Arizona DOT percent cracking index (7);
3. Centerline profile change from plans as determined by comparing the plans elevation to actual elevation and computing the variance; and
4. Change in subgrade moisture as measured by the nuclear depth moisture probe (8).

In addition to this continuous field monitoring, the Arizona DOT collected samples from selected locations. Samples included drive samples for in-place density and moisture determination and auger samples for disturbed percentage of swell and expansive pressure measurements. In addition, the U.S. Army Engineer Waterways Experiment Station took undisturbed Dennison samples from the same location as part of a national project (9). Table 1 contains results of tests by the Arizona DOT.

In general the following observations can be drawn from the test results. Moisture content of the fills was

Table 1. Test results from field samples.

Project	Section	Depth (m)	Moisture (%)	Dry Density (kg/m³)	Swell (%)	PI	Percent Passing 75 μm Sieve
I-40-5(38)	Fill	0.6	11.1	1980	0.20	2	25
		1.2	10.0	1730	1.25	5	31
		1.8	13.4	1759	1.23	5	43
		2.4	17.4	1754	0.07	2	31
		3.0	14.1	1655	-	-	-
	Cut	0.6	11.3	1704	0.03	4	23
		1.2	11.6	1842	1.86	14	37
		1.8	6.2	1855	0.10	3	21
		2.4	10.0	1865	4.25	16	58
		3.0	13.5	1754	-	-	-
I-40-5(44)	Fill	0.6	7.7	1842	0.00	NP	20
		1.2	15.5	1671	0.11	2	31
		1.8	23.0	1544	0.88	8	43
		2.4	22.6	1509	10.19	30	62
		3.0	22.3	1366	-	-	-
	Cut	0.6	7.3	1671	0.20	3	30
		1.2	17.9	1857	2.49	16	57
		1.8	11.1	1663	0.41	10	47
		2.4	12.4	1849	3.57	16	63
		3.0	14.3	1549	-	-	-

Note: 1 m = 3.3 ft; 1 kg/m³ = 0.062 lb/ft³; 75 μm sieve = no. 200 sieve.

Table 2. Mays ride roughness history before overlay.

Project	Rate of Roughness Increase per Year	Years to Objectionable Ride
I-40-5(38)	15	14
I-40-5(44)	16	14
I-40-5(45)	18	12
F 037-2(7)	15	15

Table 3. Predicted ride roughness after overlay.

Project	Annual Rate of Roughness Increase	Predicted Years to Objectionable Ride
No membrane		
I-40-5(38)	14	16
With membrane		
I-40-5(44)	6	36
I-40-5(45)	6	36
F 037-2(7)	6	26

Table 4. Analysis of evaluation differences.

Project	Section	Largest Heave (mm)	Average Heave Plus Settle	Variance of Elevation
I-40-5(38)	Fill	55.9	-0.91	0.001 07
Untreated	Cut to fill	50.8	10.52	0.001 14
	Cut	12.7	1.07	0.000 27
I-40-5(44)	Fill	15.2	0.66	0.000 10
Treated	Cut to fill	10.2	-0.66	0.000 34
	Cut	35.6	-0.51	0.000 45

Note: 1 mm = 0.039 in.

greater than the cuts for the same depth from the surface. Dry densities in the cut were higher than in the fills for the same depth from the surface, and the percentage of swell and expansive pressure were directly related and increased in parallel fashion. Depending on the location, the swelling layer could be as deep as 3.0 m (10 ft) below the surface of the pavement or as shallow as the top of subgrade. However, even deep formations could exert a change in elevation.

With the above in mind the following will detail the analysis of project performance.

ANALYSIS OF PERFORMANCE DATA

Pavement smoothness or ride quality is a very important consideration when examining project performance. Tables 2 and 3 show the project ride history for the four projects under study. The following observations can be determined.

1. It took 10-12 years for the originally constructed pavement to reach an unacceptable level of roughness and maintenance.
2. Since overlaying, the control project is increasing in roughness at such a rate that it will take approximately 16 years to reach the objectionable level of roughness.
3. Since overlaying, the treated projects are increasing in roughness at a rate such that it will take 33 years to reach the objectionable level of roughness.

At present the rate of increase in objectionable ride characteristics is so small that estimates even longer than 20 years are predicted. However, these values seem a little too optimistic. The treated sections seem to be increasing in roughness at a rate no more than half as fast as the untreated sections. In other words, the treated sections should last twice as long.

CRACKING

Before overlaying, all projects had a level of cracking of 10 percent or more. At present the treated projects show no cracking, whereas the untreated have shrinkage cracks on the order of 1 percent cracking.

CHANGES IN ELEVATION

Three elevation test grids 91.4 m (300 ft) long were established after overlay construction on the adjacent treated and untreated projects, I-40-5 (44) and I-40-5 (38), respectively. Test grids on 91.4 m (301.6 ft) of highway 116 m (382.8 ft) wide represented a 1.5-m (5-ft) fill, a cut-to-fill transition, and a cut section. There were 217 survey points per location. Table 4 shows results of measurements for the overlay new and 2.5 years old. The larger the variance is, the more total distortion will take place. From this information we can say that none of the test sections are showing excessive heaves at this time, although the untreated sections are showing larger heaves, and that the overall variance would indicate that the membrane is working particularly well in the fills and the cut-to-fill transitions.

MOISTURE

Since construction of the overlays, the percentage of moisture has been monitored with nuclear depth mois-

Figure 5. Weight percentage moisture changes with time.

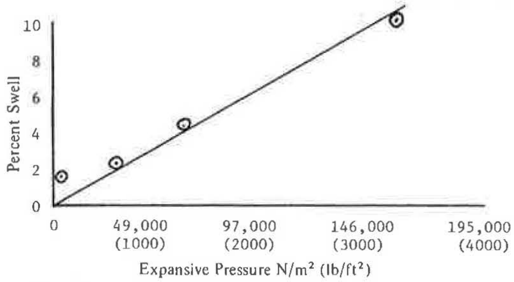


Table 5. Moisture change with depth for locations of travel lane tubes.

Section	Depth Below Asphalt Concrete Surface (m)	No Membrane I-40-5(38) Average Moisture (%)	Variance	With Membrane I-40-5(44) Average Moisture (%)	Variance
Fill	0.6	11.4	0.3	10.6	0.1
	1.2	11.2	0.5	11.2	0.1
	1.8	15.4	1.0	23.9	0.1
	2.4	13.0	0.3	21.8	0.1
	3.0	8.6	0.5	21.5	0.3
Cut	0.6	12.4	0.4	7.3	1.0
	1.2	9.9	0.2	18.6	0.2
	1.8	14.1	1.8	12.5	0.5
	2.4	9.0	3.6	12.2	0.1

Note: 1 m = 3.3 ft.
[a]This variance is unique because no wetting and drying takes place; rather, the soil has continued to become wetter with time.

ture equipment. Figure 5 shows a typical moisture plot for a cut-and-fill section. Table 5 gives the moisture values and variance for comparable cut-and-fill locations on project I-40-3 (38) and I-40-5 (44). The following observations can be drawn.

The membrane sections in cut and fill show less moisture variance over time than the untreated control sections for all depths except the 0.6-m (2-ft) treated cut. This location is the depth at which the moisture has continued to increase with time, which represents a redistribution of moisture. The cut-and-fill sections with and without treatment do not appear to be becoming consistently wetter or drier, but rather appear to be oscillating about the mean.

CONCLUSIONS

Field observations plus objective measurements now indicate that the membrane treatment over the badly distorted highway has improved the overlay performance. This improvement, obviously, is attributable to the membrane's ability to seal out moisture. Although some moisture redistribution is taking place, the significant observation is that less moisture fluctuation (dry to wet to dry) is taking place under the membrane. In addition and as predicted in an earlier report on reflective cracking (10), the membrane is preventing cracking, which also prevents moisture from entering the expansive soil.

Arizona's experience with asphalt concrete overlays with some form of membrane treatment to prevent cracking, plus shoulder and ditch paving, has led to the following conclusions.

1. Such treatment will prevent reflective cracking, as predicted in an earlier report (10).
2. Shoulder and ditch membrane treatments (asphalt rubber, paved shoulders and ditches, or any other suitable waterproofing membrane layer) can and will improve the long-term ride performance of a highway over an expansive soil.
3. If ride is improved and cracking severity is reduced, maintenance costs will undoubtedly fall.

Such positive conclusions from all the accumulated information have led Arizona to implement the membrane process of control on an operational basis for all expansive soil subgrades.

ACKNOWLEDGMENT

The contents of this report reflect our views, and we only are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the views or policies of the Arizona DOT or of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names that may appear here are cited only because they are considered essential to the objectives of the report. The United States government, the state of Arizona, and the Transportation Research Board do not endorse products or manufacturers.

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