Asphalt Membranes in Expressway Construction

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Envelope-type asphalt membranes have provided excellent stabilization of plastic earth fills for bridge abutments in urban expressway construction in Houston. Test fills have been observed over a 14-year period with excellent findings. The observations include detailed construction records of moisture-density conditions, followed by annual continuous core-drilling of fills and testing of cores for moisture content, density, and triaxial compressive strength. Test holes penetrated the entire depth of fill as well as the compacted subgrade below fills. For comparison, nearby soils of the same nature as the fills but not protected with the asphalt membranes have been sampled and similarly tested at intervals as found convenient.

Other observations have included the physical appearance of such fills, lateral movements in fills (or more properly, the lack of such movements), stability of the membranes under extreme drying conditions, and appearance of the membranes when exposed during subsequent stage construction. One of the most startling conclusions from these performance observations is that the membraned fills are in many cases more stable than concrete pavements placed on the fills.

The use of asphalt membranes in earth fills in expressway construction in Houston represents a major use of this type of design, having been used on 54 structures requiring 104 abutment fills of volume of over 400,000 cubic yards and treated with approximately 1,600,000 gal of grade OA-55 oil asphalt. It would be difficult to estimate the future demand for asphalt membranes in Houston's expressways as its use has been adopted as standard design for all fills except those having unusually low plastic properties.

Surface and buried types of asphalt membranes have also been used with good success, and these are discussed briefly with comments on general performance and design criteria.

Coverage of 1 gal per sq yd of grade OA-55 oil asphalt has been found to be sufficient to maintain a continuous membrane even under most adverse conditions and to maintain essentially constant moisture content, density, and compressive strength in the fills they envelop.

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• ASPHALT MEMBRANES have been extensively and successfully used in urban expressway construction in Houston. Figure 1 shows the three general types used—surface, buried, and envelope membranes. The last type is the most comprehensive and was used to stabilize medium to highly plastic clay soils known by past experience to be unsuitable for bridge abutment fills due to lateral and vertical seasonal movements. Expansion joints of only 1-in. width were provided between these fills and the bridge abutments. It was therefore imperative that soil movements be restricted to less than $\frac{1}{2}$ in. because some of the total joint opening would be reduced by seasonal expansion and contraction of concrete in the bridges themselves.

For these reasons it was decided to initiate a field research program of annual observations of soil conditions in several of such fills and supplementary observations at less frequent intervals of widths of joint openings at all bridge ends on the Gulf Freeway—a 50-mi length of urban and rural limited-access highway. It includes an approximately equal number of overpasses constructed on urban section with membrane protection and on rural section without protection.

CONSTRUCTION PROCEDURE

Figure 2 shows details of the envelope-type membranes used to completely "wrap-up" fills on urban type structures. The area to receive fill was first stripped of all organic vegetation, then compacted to 100 percent standard Proctor density (AASHO Method T99-38) at optimum moisture content to a depth of approximately 6 in. and then fine-graded to produce a smooth surface. OA-55 grade asphalt was then applied at rate of 1.0 gal per sq yd to the entire subgrade surface and for a distance of a few feet beyond the proposed toe of fill slopes. The fill core was then constructed in layers 6 to 8 in. thick to the same density requirements and the sides fine-graded to 1 on 1.5 slope. OA-55 asphalt was then applied to the fine-graded upper surface and side slopes at rate of 1.0 gal per sq yd in such a manner as to intersect and tie into the bottom membrane. Top soil previously stripped from the fill subgrade was then used to cover the side membranes and to flatten the side slopes to 1 on 4 or flatter; these slopes were then block-sodded to prevent erosion and to provide an architecturally pleasing outward appearance. The upper membranes were covered with an appropriate base course for the expressway pavement.

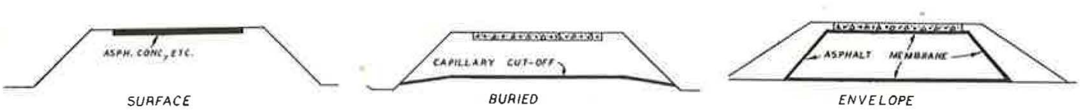

Figure 1. Functional types of membranes.

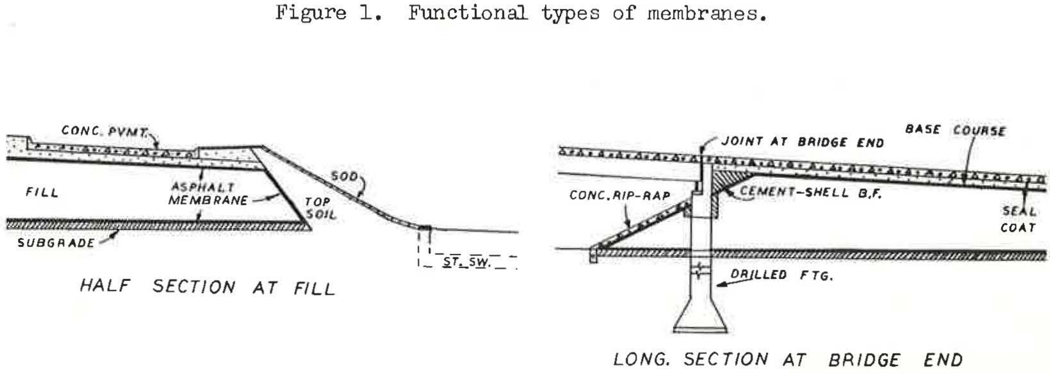

Figure 2. Typical embankment sections, Gulf Freeway.

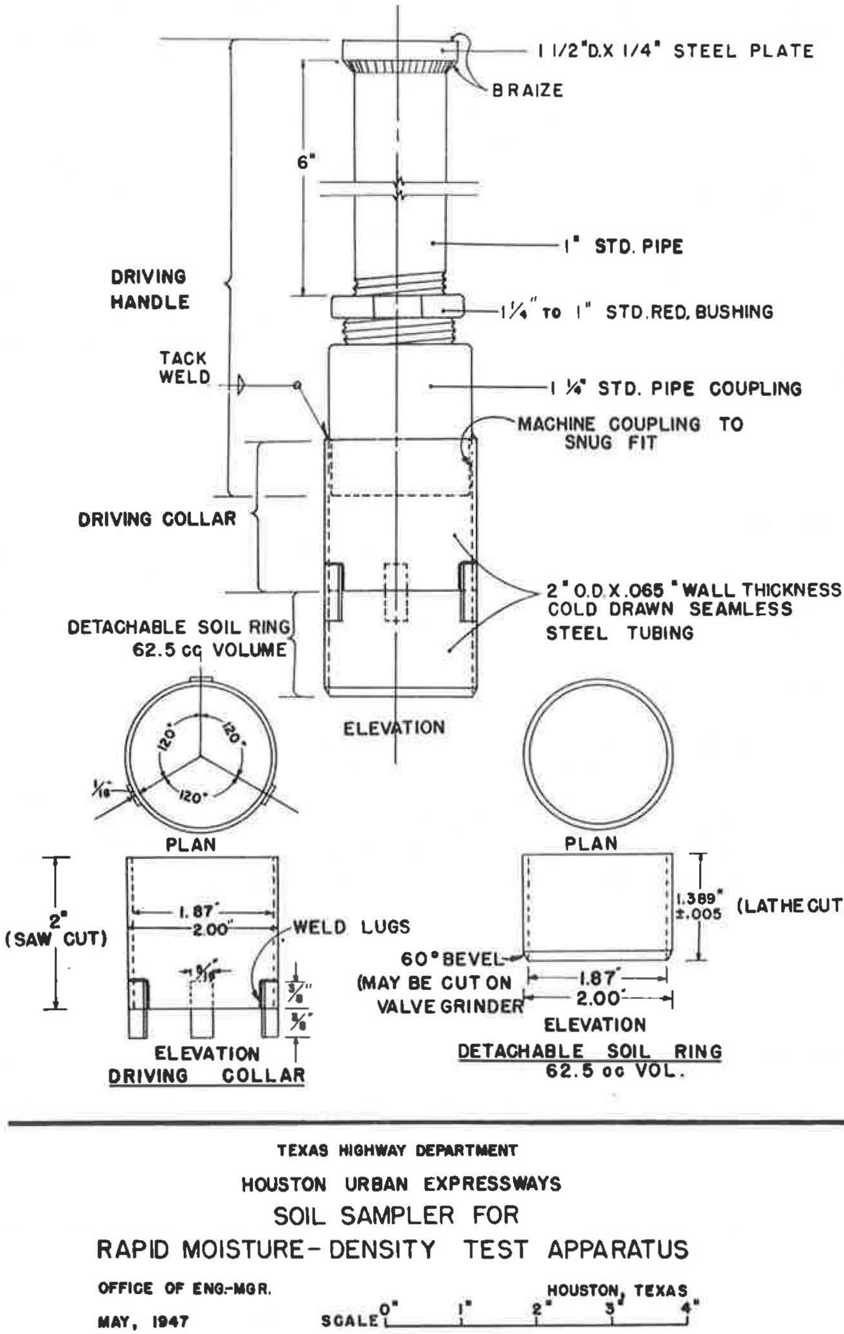

Figure 3. Ring density apparatus.

The first layer of each fill was compacted with bulldozers and other track-type equipment (in order not to puncture the asphalt membrane); subsequent layers were compacted with sheep's-foot rollers. Fine-grading of side slopes was done with motor graders to provide a smooth surface and included cutting of a small trench at the fill toes to expose the lower membrane temporarily until application of the side membranes; this was done to insure that the side membrane would tie in to the lower membrane at all points, thus resulting in a complete and continuous asphalt membrane envelope.

The soils in fills and fill subgrade varied from CL to CH unified soil classification with maximum and minimum limits approximately as follows: optimum moisture content, 23 to 28 percent; optimum dry density, 96 to 108 pcf; and plasticity index, 30 to 50 percent.

RESEARCH PROGRAM

Six representative abutments were selected as test fills. Moisture content and density of compacted subgrade and each layer of each fill were determined using Harris ring density apparatus (1). Figure 3 shows the field apparatus. Accurate records of these tests were maintained to serve as initial conditions for the proposed future observations. All available data on soil conditions in the vicinity of the tests fills were also assembled and reviewed to serve as initial conditions for untreated soil. After completion of construction, each test fill was cored to obtain undisturbed cores; these were tested to determine moisture content, density, and compressive strength. The latter tests were made with triaxial compressive test apparatus and the results were calculated to obtain compressive stress-strain curves.

At yearly intervals each fill was again core-drilled without use of drilling water; undisturbed cores were taken at approximately 2-ft intervals in each fill and in earth subgrade. These were tested to determine moisture content, density, and compressive strength as previously described. Average values of the test results for fill, subgrade, and the underlying natural soil were then compared with initial conditions and plotted against time in years. Figures 4 through 9 show such records over a period of 14 years to date. After 8 years, the time interval was lengthened to 5 years due to the consistency found in earth fill by yearly observations.

TEST RESULTS

Figures 4 through 9 show that moisture content, density, and shearing resistance of all fills and subgrades were essentially constant through 8 years of service. Conditions found at the last 5-yr observation were also essentially constant for all fills except East Approach Wayside (Fig. 7) which showed some unexplainable variations. This may be the result of a localized variation between test hole locations. Wide variations have been noted in soil conditions in nearby untreated soil, thereby definitely proving the efficiency of the envelope-type membranes.

It has been suggested that similar membranes be used with plastic soils to construct stable base courses for pavements (2) results of this investigation indicate such proposal to be entirely feasible and such construction of a permanently stable nature. These results also indicate that membrane thicknesses in excess 1.0 gal per sq yd are not required for soil conditions prevailing at the sites and the construction procedures used. This amount of coverage gives continuous membranes from $\frac{1}{16}$ to $\frac{1}{4}$ in. in thickness and has been found to be sufficient even under very adverse conditions, as discussed later.

STABILITY OF JOINT OPENINGS AT BRIDGE ABUTMENTS

The purpose of the envelope-type membranes was to provide stable fills for bridge abutments. The field and laboratory data obtained from the test fills seemed to indicate that excellent stability was being attained. However, it still remained to prove or disprove the effectiveness of the membranes in maintaining essentially open joints at bridge ends. It was therefore decided to examine after several years service the condition of 1 in. expansion joints at each bridge abutment, including the test fills and all other fills on the 50-mi length of the Gulf Freeway. An approximately equal number of fills with and without membranes are existing and were all constructed at approximately the same time (within a few years of each other). Observations were made in the spring of the year and on clear days when the air temperature was between 60 and

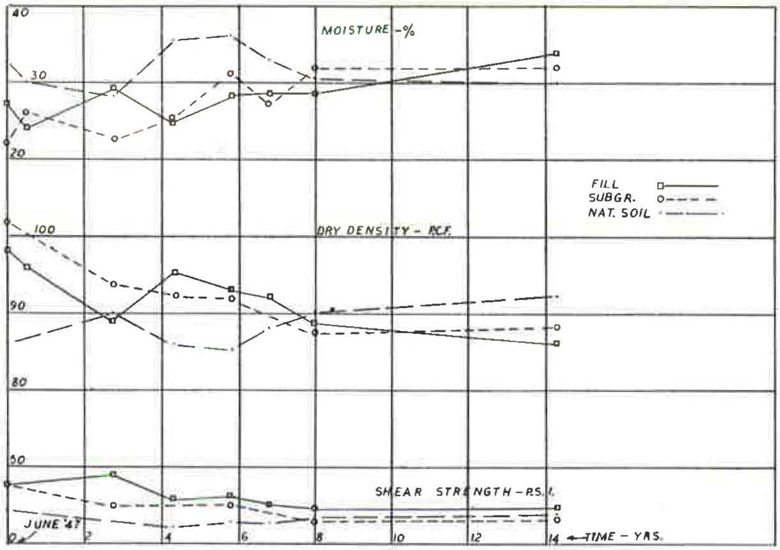

Figure 4. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, West Lombardy.

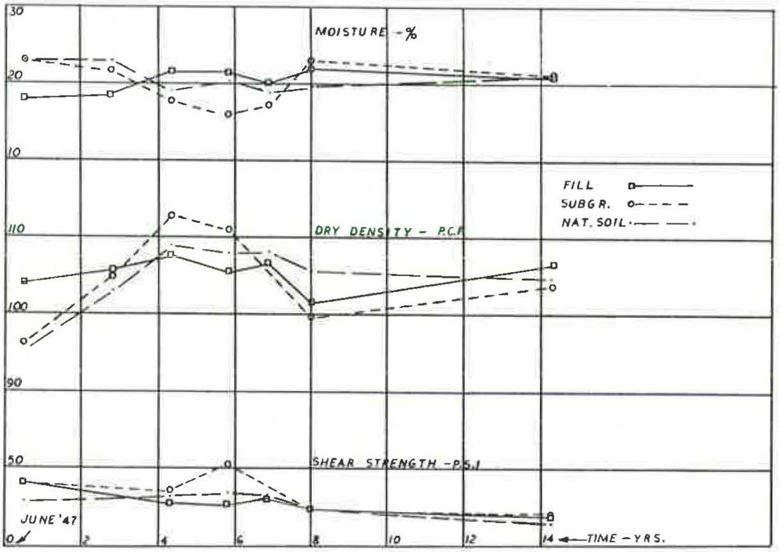

Figure 5. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, West Calhoun.

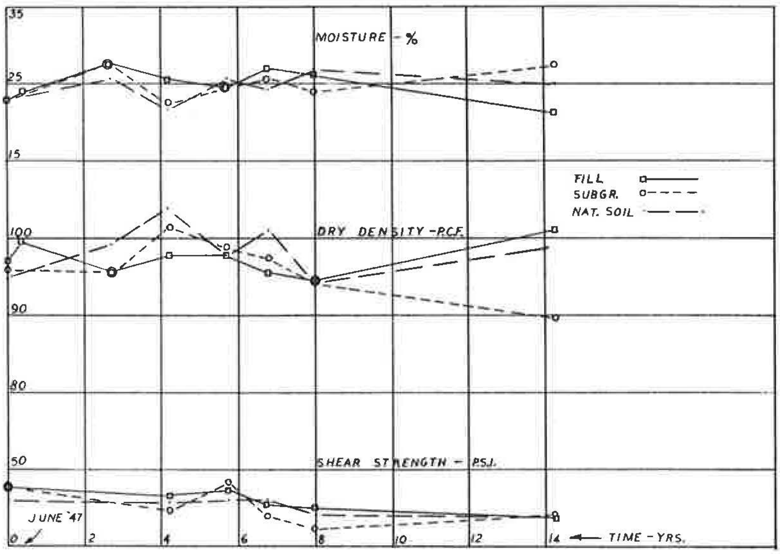

Figure 6. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, East Calhoun.

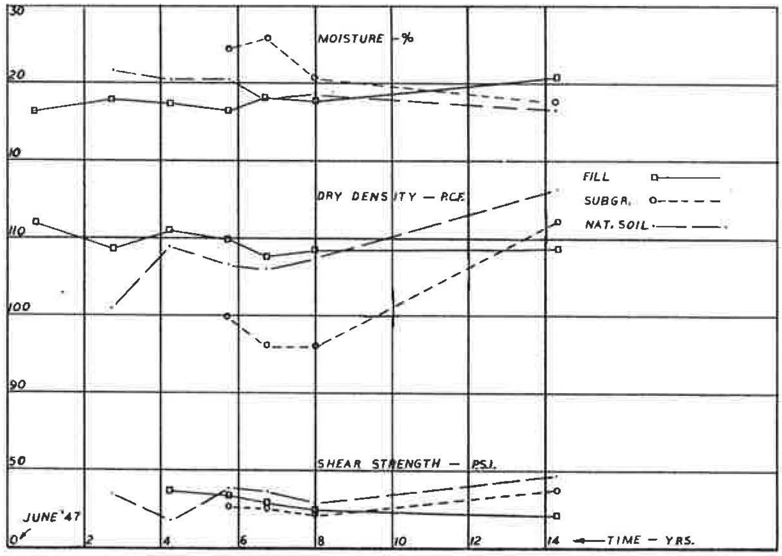

Figure 7. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, East Wayside.

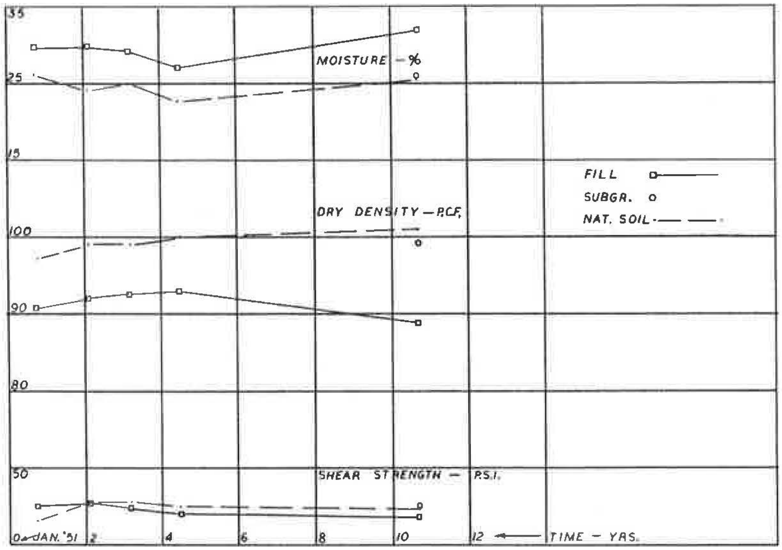

Figure 8. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, East Sims.

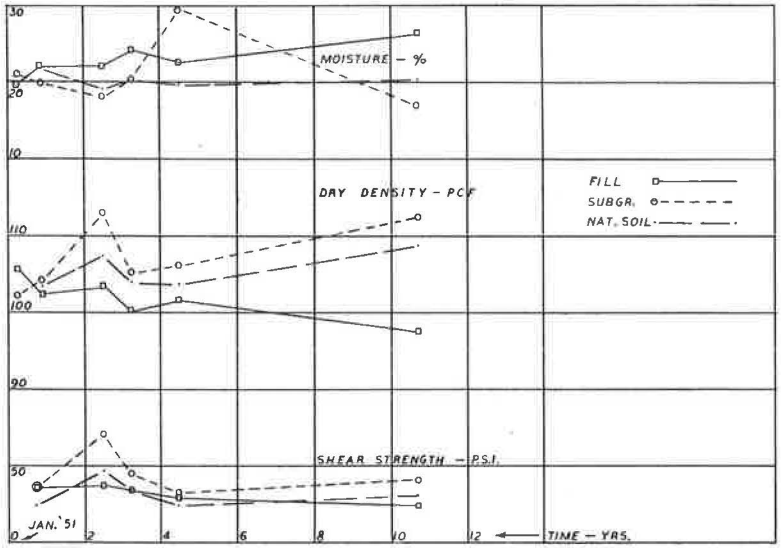

Figure 9. Moisture, dry density, and shear strength of fill, subgrade, and natural soil vs time, West Sims.

80 F, so as to eliminate as nearly as possible the effect of concrete expansion in the bridges themselves and in the adjoining concrete pavement slabs. Table 1 summarizes the conditions found in 1956 (maximum of 8 years after construction). Tables 2 and 3 summarize the conditions found in 1962 (maximum of 14 years after construction). These figures show excellent performance of the membraned fills, and poor to mediocre performance in the majority of the fills constructed without membranes.

OTHER OBSERVATIONS

A striking demonstration of the efficiency of such membranes was provided late in the summer of 1952 by what at first appeared to be a failure in one of the 4-year-old

TABLE 1

BRIDGE ABUTMENT SURVEY, APRIL 19, 1955, US 75, GULF FREEWAY[a]

Fill Type	Structure	Height (ft)		Structure Length (ft)	Condition of Expansion Joints in Bridge
		Fill	Cut		
Membraned	Velasco-IGNRR	10		958	Fully open
	Scott St.	10		676	Very slight closure
	Cullen Blvd.	9		704	Fully open
	Calhoun Rd.-HB&TRR	10		1,192	Fully open
	Lombardy St.-HB&TRR	10		1,208	Approx. 1-in. closure at each end
	Telephone Road	11		366½	Closed due to 1-in. movement of pavement slabs into bridge
	Wayside Drive	8	4	292	Fully open
	Bray's Bayou	2-17		370	Fully open
	Grigg's Rd.	10-11		1,115½	Fully open except possibly some closure on south end
	Woodridge St.	9	3	295	Fully open
	Str. 12 (Reveille)	12	3	200	Fully open; anchor bolts on rocker arms too tight
	Str. 13 (Reveille)	13	4	165	Fully open; anchor bolts on rocker arms too tight
	Park Place Rotary	10		710	Fully open
	Sims Bayou	0-14		223	Fully open
Plain	Howard Street	12		184	Fully closed
	Garden Villas	20		181.6	Fully closed
	Ellington Field	19		231½	Fully open
	Clear Creek	16		451½	Some closing, not serious
	FM 518	17		181½	Some closing, not serious
	Dickinson Bayou	13½		290½	Fully open
	Camp Wallace	16		182	Fully open
	FM 1765 (St. 348 Ext)	17		181.9	Fully closed
	FM 519	15		181.9	Fully closed
	Rt. Lane at Galv. "Y"	20		244½	Some closure on north end

[a]Weather: clear and mild; temperature, 70 to 80 F.

TABLE 2

BRIDGE ABUTMENT SURVEY, MAY 3, 1962, US 75, GULF FREEWAY

Fill Type	Structure	Height (ft)		Structure Length (ft)	Condition of Expansion Joints at Bridge Ends
		Fill	Cut		
Membraned	Velasco-IGNRR	10		958	Fully open, except at pavement ends joint closed completely
	Scott St.	10		676	Open 7/8 in., except at pavement ends joint closed 1/2 to 3/4 in.
	Cullen Blvd.	9		704	Open 1/2 in.
	Calhoun Rd-HB&TRR	10		1,192	Fully open, except at pavement ends joint closed 3/4 in.
	Lombardy St.-HB&TRR	10		1,208	Open 1/2 in. on right, closed on left
	Telephone Rd.	11		336.5	Fully open, except at pavement ends joint closed completely
	Wayside Drive	8	1/3	292	Open 5/8 to 7/8 in., except at pavement ends joint closed completely
	Bray's Bayou	2-17		370	Open 1/4 in., except at pavement ends joint closed completely
	Griggs Road	10-11		1,115.5	Open 3/4 to 1 in., except at pavement ends joint completely closed
	Woodridge St.	9	1/4	295	Fully closed
	Str. 12 (Reveille)	12	3	200	Completely open
	Str. 13 (Reveille)	13	4	165	Almost completely closed at pavement ends, joint varies from open to closed
	Park Place Rotary	10		710	Completely open except at pavement ends joint completely closed and 1/2-in. differential uplift evident
	Sims Bayou	0-14		223	Open 7/8 in. same closure at pavement ends
Plain	Howard St.	12		184	Completely closed, distress
	Garden Villas	20		181.6	Completely open, except partially closed at pavement ends
	Ellington Field	19		231.5	Completely open
	Clear Creek	16		451.5	Completely closed, distress
	FM 518	17		181.5	Completely open, except 1/2 closed at pavement ends
	Dickinson Bayou	13.5		290.5	Completely closed
	Camp Wallace	16		182	Completely open
	FM 1765	17		181.9	Completely closed
	FM 519	15		181.9	Completely closed
	Rt. Lane at Galv. "Y"	20		244.5	Completely closed

TABLE 3

BRIDGE ABUTMENT SURVEY, MAY 3, 1962, US 75, GULF FREEWAY, SUMMARY OF ABUTMENT JOINTS IN FILLS

Fill Type	Fill No.	Condition of Joint	% of Total[a]
Membraned	2	Completely or almost completely closed	14
	5	Partially closed	36
	7	Completely or almost completely open	50
Total	14		100
Plain	6	Completely or almost completely closed	60
	0	Partially closed	0
	4	Completely or almost completely open	40
Total	10		100

[a]Of each type.

membraned fills, but which on further examination proved to be limited to the soil above the upper asphalt membrane. During a long dry season, a crack of up to 12-in. width and 80 ft in length opened near the crown of this fill. Figure 10 shows a man standing in this crack; his feet are resting on the upper membrane where the crack stopped. The crack was cleaned out in several places and the membrane found to be intact in all cases and showing numerous shiny surfaces. Figure 11 shows one such test pit with the membrane cut and peeled back to allow drilling of a test hole. The exposed surface of the fill was intact and showed even the marks of the grader blade used in fine grading of slopes.

Tests of samples from this test hole and from others in the clay above the membrane showed conditions as summarized in Figure 12. Shrinkage cracks developing in the clay above the upper membrane had become so numerous that the weight of the laterally unsupported prisms of soil produced sliding forces greater than the shearing resistance of the warm asphalt membrane, and these soil prisms accordingly slid downhill and closed together in much the same manner as stacking a deck of playing cards. The clay fill under the membrane was in essentially the same condition as constructed (25 to 28 percent moisture) and did not show even small cracks; the clay above the membrane varied from hard and dry to soft and wet in consistency with moisture contents varying from 7 to 35 percent.

It was concluded from these observations that the 1.0-gal per sq yd coverage

Figure 10. Construction engineer in crack, Str. 13, summer 1952.

Figure 11. Crack and test pit, membrane peeled back from embankment, Str. 13, summer 1952.

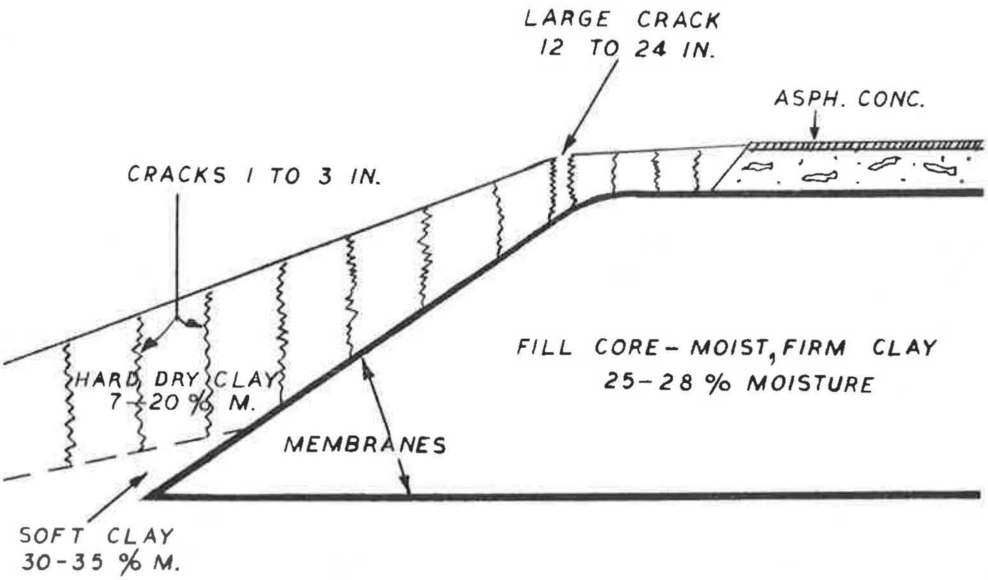

Figure 12. Cross-section near bridge end, Str. 13, summer 1952.

of OA-55 asphalt is sufficient to maintain a continuously stable membrane under adverse conditions, and that such membranes will effectively and permanently stabilize the most plastic soils encountered in the Houston area. Also, there is no reason to believe that such membranes will perform any less efficiently in highly plastic than in moderately plastic soils.

Much of the expressway work in Houston is necessarily accomplished by stage construction. On many such projects built initially several years ago, the original construction has been recently tied into for expansion of these facilities and it has been necessary to make excavations into and through membraned fills. This has afforded opportunities to examine visually the membranes and the protected portions of such fills. In all such cases, the membranes have been found to be intact and the fills in excellent condition; in most cases each individual layer of fill is easily discernible.

SURFACE- AND BURIED-TYPE MEMBRANES

Figures 1 and 2 show that only the envelope-type membranes can afford complete and permanent stabilization of the contained soil. However, the high degree of insurance afforded by envelope membranes is not necessary in all phases of expressway construction, and further examination of Figure 2 shows some examples of buried- and surface-type membranes incorporated in the Gulf Freeway construction. Other arrangements of buried and surface types have been used in other road and street projects to inhibit or prevent edge failures (2, 3). Experience with such single-layer membranes justifies the following conclusions:

1. Single-layer membranes prevent capillary migration of moisture upward through the membrane.
2. Similarly, such membranes prevent passage of surface runoff downward through the membrane.
3. Shrinkage forces during dry seasons stop at the membrane, except at and beyond membrane edges. Hence, the effect of any single-layer membrane placed in the vicinity of pavement edges is to move the edge of the zone of seasonal moisture fluctuation from the pavement edge to the outside edge of the membrane.
4. Shrinkage forces will migrate downward and inward from the membranes outer edge on an angle of up to 45°.

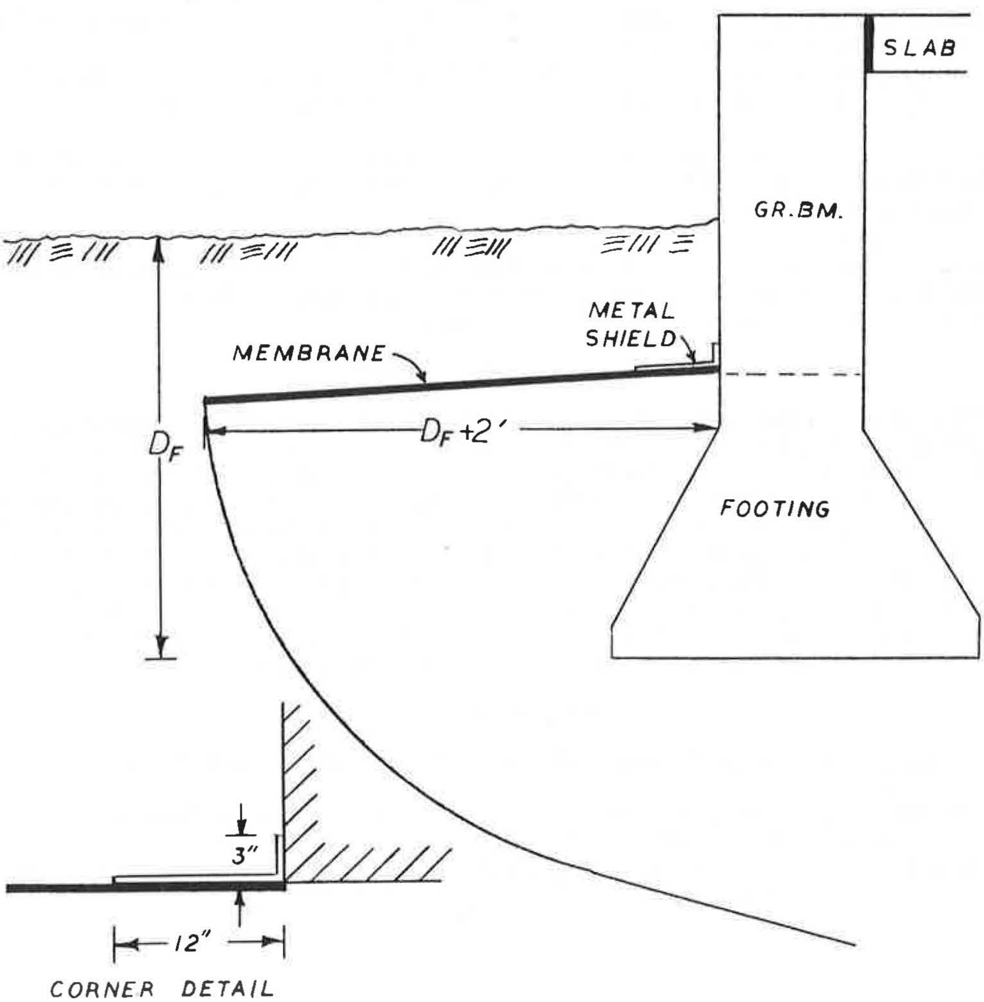

Figure 13. Example of single buried type of asphalt membrane.

5. The zone of effective moisture stabilization afforded by any single-layer membrane is therefore limited to an approximately cylindrical volume contained in vertical section within a quarter circle having center at inner membrane edge and radius equal to the membrane width, as shown in Figure 13.

6. Single-layer membranes are therefore influenced by soil and climatic conditions and the degree of stabilization required or desired. Their design is therefore necessarily predicated on individual requirements and soil conditions in each case. In some cases, for example, the membrane may consist of a small percentage of emulsion or cut-back asphalt mixed with a 4- to 6-layer of soil or base material; in other cases, it may consist of a seal coat over a relatively pervious base course. Other variations are evident.

SUMMARY OF FINDINGS

1. Envelope membranes such as employed in Gulf Freeway abutment fills afford complete and permanent stabilization of plastic soils.
2. Coverage of 1.0 gal per sq yd of OA-55 asphalt is sufficient to provide continuously permanent membranes even under adverse conditions of use.
3. The preceding conclusions are based on observations of moisture content, density, and compressive strength in test fills over a period of 14 years.
4. These findings and conclusions are further confirmed by outward stability as evidenced by observations of expansion joint openings at bridges having membraned and unmembraned abutment fills after 10 to 14 years of service.
5. There is some evidence to the effect that the test fills are consolidating and gaining strength very slowly under the effect of their own weight at constant moisture content.
6. Single-layer membranes (surface and buried types) afford a lesser degree of stabilization, and have a definite range of applicability in expressway and other highway construction.
7. Design criteria have been established and are given in the preceding section (conclusion 5 and Fig. 13) for single-layer membranes, whereby the designer may establish membrane types, widths, and thicknesses consistent with economic considerations and soil conditions in each individual case.

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