PROJECT COMPLETION REPORT
OWRT PROJECT NO. A-059-ARIZ

DEVELOPMENT OF ASPHALT CUSHIONED PLASTIC AND PLASTIC REINFORCED ASPHALT MEMBRANES FOR SEEPAGE CONTROL

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ABSTRACT

This project was concerned with laboratory equipment development, laboratory testing, construction equipment development and field investigation of the APAC (Asphalt-Plastic-Asphalt-Chip-Coated) water seepage barrier.

The laboratory equipment that was designed and fabricated for the project included hydrostatic testing vessels, slope stability apparatus, and tensile testing grips.

Three testing methods were utilized and evaluated in the APAC investigation. The first test method evaluated the hydrostatic puncture resistance of the asphalt-polyethylene combination. This test confirmed the hypothesis that the asphalt effectively increases the puncture resistance of the APAC membrane over that of plain polyethylene. The second test investigated the slope stability of a protective APAC chip seal. It was found that a typical 3/8 in. (9.5 mm) cover aggregate remained stable on constructed slopes of 3:1 and 4:1 and that the 2:1 slope remained stable up to a surface temperature of 122°F (50°C). The third test method evaluated adhesive materials and indicated that Presstite mastic was the best suited adhesive for sealing polyethylene overlaps.

Subsequent field investigations resulted in equipment development that increased construction efficiency in the installation of the APAC membrane. Actual completed field installations were evaluated and further recommendations are included.

ACKNOWLEDGEMENTS

Special acknowledgement goes to R. K. Frobel, Civil Engineer and Research Associate at the Water Resources Research Center, who designed the laboratory testing equipment and accomplished the actual laboratory testing.

Special recognition is also given to D. Scheall for his work in the development of the jeep mounted plastic dispenser-roller.

Acknowledgement is also extended to W. D. Lichtenwalter and L. Gemson of the Civil Engineering Machine Shop for their work in fabricating the necessary laboratory equipment.

Acknowledgement is also extended to S. D. Resnick, Director of the Water Resources Research Center and secretary N. Svacha for her valuable contribution in preparation of data and manuscripts.

Recognition is due M. Henry and H. Cox of the Bureau of Indian Affairs as well as the vocational students from Baboquivari High School for their help in the field installations.

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INTRODUCTION

Plastic film is one of the many materials developed for use as a flexible membrane for lining canals, catchments and reservoirs. Asphalt, because of its waterproofing properties and low cost, has also been prominent among materials investigated for water harvesting and seepage control. C. B. Cluff, one of the principal investigators, has developed a new low cost impermeable barrier in the form of a flexible sandwich membrane composed of an asphalt emulsion, plastic sheeting and a protective chip-seal cover aggregate (Cluff et al, 1972) (Cluff, 1973). Prior to this study, the treatment, entitled "APAC" (Asphalt-Plastic-Asphalt-Chip-Coated), had been installed in two water harvesting catchments where it was working satisfactorily. It had not been used for seepage control although the potential had been recognized (Cluff, 1973). Sufficient laboratory investigation of this type of membrane was needed prior to the application of the APAC system to seepage control or for wide scale application to catchment construction.

Two possible uses of the asphalt in seepage control are: (1) an initial coat on the subgrade to serve as a cushion to minimize mechanical damage or (2) an initial coat on the subgrade plus a coating on top of the plastic. In (2) the plastic would, in effect, be acting as a reinforcement for the asphalt membrane, hence the term plastic reinforced asphalt membranes.

Extensive laboratory testing on flexible membrane linings has been accomplished by the U.S. Department of the Interior (Bureau of Reclamation, 1969). One of the Bureau's test procedures entitled "Hydrostatic Puncture Resistance," was chosen to evaluate the puncture resistance of the APAC membrane under hydrostatic pressure conditions. As there was no available testing apparatus for this test, part of the research effort was devoted to the design and fabrication of the hydrostatic test vessels and testing accessories.

An additional test utilized by the Bureau of Reclamation and adopted for APAC testing is that of bonded seam strength of polyethylene overlaps. Although a standard ASTM (American Society for Testing and Materials) test method was utilized, it was first necessary to design and fabricate special tensile testing grips for thin sheet testing. These adapters grip the polyethylene specimens for tensile testing of the bonded overlaps.

A third test procedure was utilized to evaluate the slope stability of a 3/8 in. (9.5 mm) aggregate cover material and investigate the maximum allowable slope that will retain the aggregate without excessive down slope creep. Slope stability, as used in this investigation, may be defined as the resistance of the cover aggregate to displacement on any given slope.

OBJECTIVES

The general objective of the research was to reduce costs of seepage control through the combined use of emulsified asphalt and inexpensive polyethylene sheeting.

The original specific objectives were:

1. To develop engineering specifications for:

   (a) Asphalt cushioned plastic membranes and
   (b) plastic reinforced asphalt membranes.

2. To develop an inexpensive dispenser-roller for applying plastic to an asphalt coated surface.

3. To make field tests of the above systems.

LABORATORY TESTING PROGRAM

The laboratory testing part of the study was conducted by R. K. Frobel, and the complete results are presented in his thesis (Frobel, 1975). A summary of that work is presented here.

The first of the three laboratory procedures consisted of hydrostatic puncture resistance testing and was chosen to evaluate the following APAC characteristics:

1. The cushioning effect of the asphalt when applied between the polyethylene sheeting and an aggregate subbase.

2. The relative effect of the top coat of asphalt on hydrostatic puncture resistance.

3. The hydrostatic puncture resistance of the total APAC membrane excluding the protective aggregate cover.

4. The hydrostatic puncture resistance of asphalt impregnated polypropylene.

5. The hydrostatic puncture resistance of a polypropylene-asphalt-polyethylene combination.

6. The relative effect of three different aggregate subbases on varying asphalt-polyethylene combinations.

Slope stability testing was designed and utilized to help determine the following APAC characteristics:

1. The effect of temperature and slope on the displacement of a 3/8 in. (9.5 mm) cover aggregate, using both polyethylene and polypropylene as a base.

2. The effect of the top coat asphalt quantity on slope displacement of a 3/8 in. (9.5 mm) cover aggregate.

A standardized ASTM testing procedure for seal strength of flexible barrier materials was used to evaluate the following APAC characteristics:

1. The relative shear and peel strength for three adhesive materials used in overlap bonding of the APAC membrane.

2. The effect of asphalt residue quantity on the overlap seal strength of polyethylene sheeting.

Thus, various combinations of asphalt emulsion and polyethylene or polypropylene were tested hydrostatically to examine the puncture resistance characteristics of the APAC membrane. In addition to this testing, overlap seal strength of the polyethylene was evaluated as well as slope stability of a typical aggregate cover material. It is anticipated that these laboratory results will be used in conjunction with the results of field investigations to formulate a set of specifications for the APAC treatment used as a water seepage barrier.

DESCRIPTIVE REPORT

LABORATORY EQUIPMENT DEVELOPMENT

Hydrostatic Testing Vessels. As indicated in the introduction, three test vessels were designed and fabricated for use in the hydrostatic testing of plastic reinforced asphalt membranes. Each vessel consists of a bottom assembly and a top assembly which are mated and joined securely. The bottom assembly of each vessel is fitted with a removable subgrade tray. The subgrade trays each contain a different gradation of aggregate to facilitate variation in subgrade texture. See Figure 1 for an unassembled view of one of the hydrostatic test vessels.

The top half of the test vessels are equipped with air pressure regulators and gages. Water is first allowed to cover the specimen to a depth of two inches. Air pressure is then applied to the water. The use of available building air pressure increases the maximum simulated head of water over that of available water pressure.

The three hydrostatic vessels were designed so that all three or any combination of the three individual units could be operated simultaneously. See Figure 2 for a series hookup of all three hydrostatic test vessels.

Aluminum Slope Assembly. An aluminum slope assembly was designed and fabricated for use in testing the slope stability of a cover aggregate. The slope assembly consists of a base and movable incline. The incline can be positioned at any desired slope for test purposes and can be positioned inside a glass front oven for accurate and undisturbed measurements of slope displacement. Figure 3 shows the slope assembly at an inclined position.

Tensile Testing Grips. The tensile testing grips were specially designed and fabricated for testing the overlap seal strength of various adhesive materials. The grips consisted of a spring loaded bar mounted on a frame and adapted for use in an Instrom Testing Machine (Figure 4). The testing grips applied an equally distributed load across the width of the test specimens.

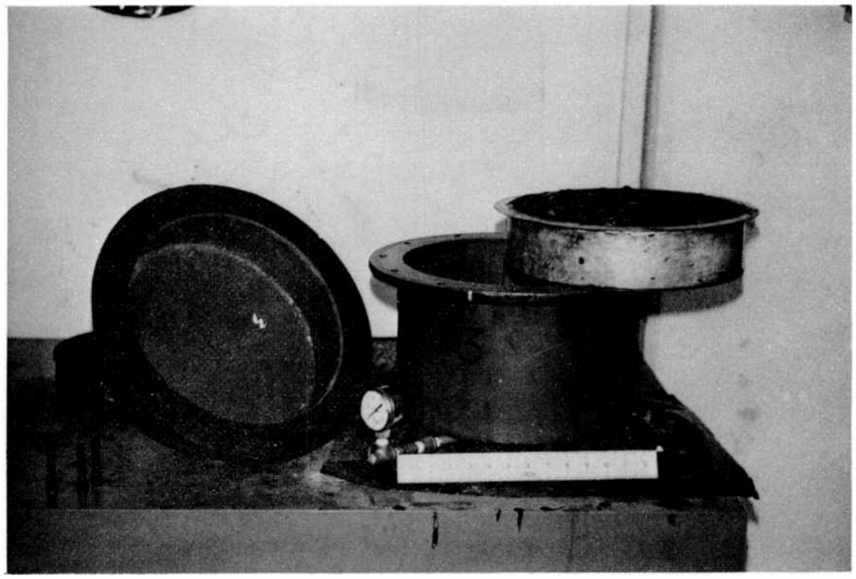

FIGURE 1. HYDROSTATIC TEST VESSEL - UNASSEMBLED

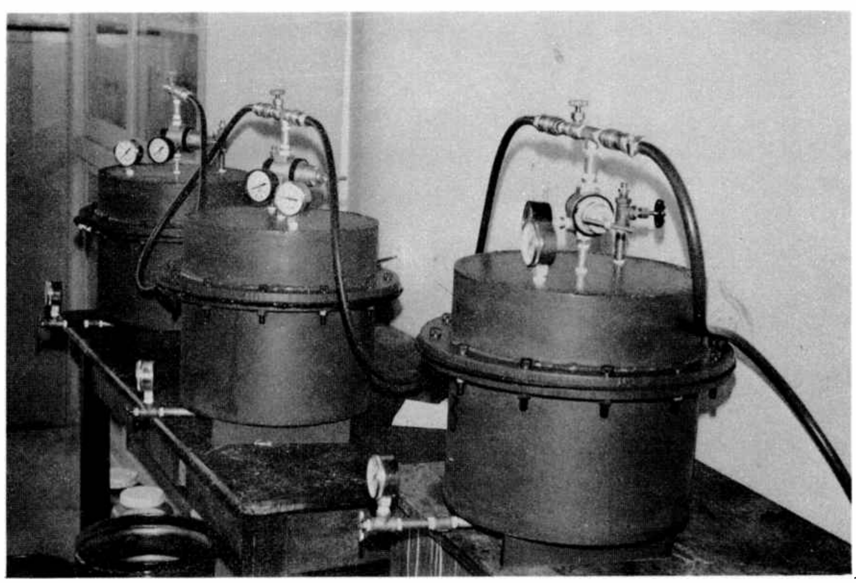

FIGURE 2. SERIES HOOK-UP OF HYDROSTATIC TEST VESSELS

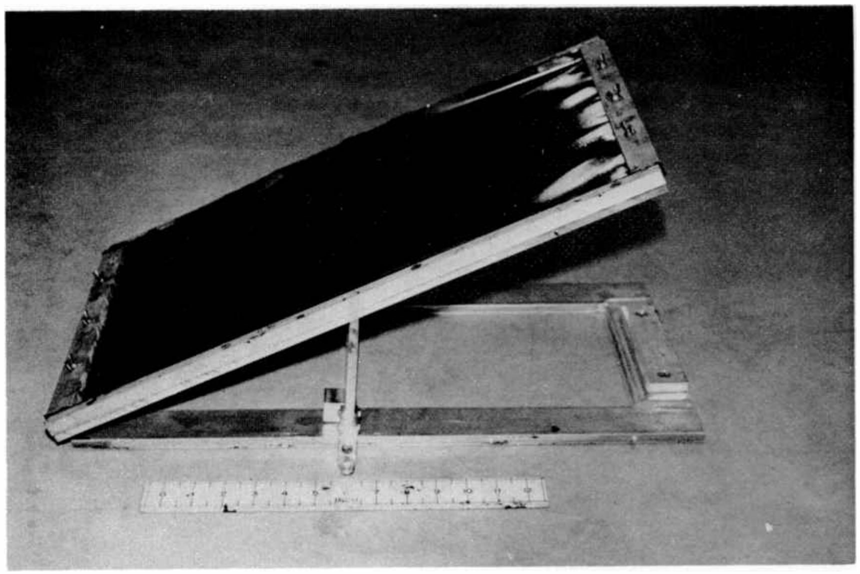

FIGURE 3. ALUMINUM SLOPE ASSEMBLY

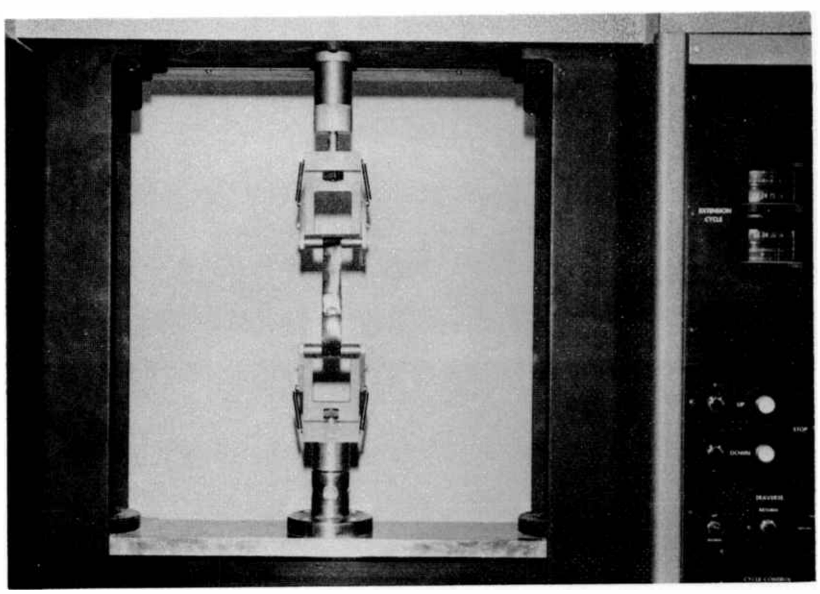

FIGURE 4. TENSILE TESTING GRIPS POSITIONED FOR TESTING OF OVERLAP SPECIMEN

SPECIMEN PREPARATION AND TESTING

Hydrostatic Puncture Resistance. Some of the samples tested hydrostatically consisted of the polyethylene sheeting without asphalt residue. These specimens represented control samples that were used for comparison with treated specimens. The plain polyethylene control samples were tested in triplicate to determine repeatability of the hydrostatic puncture resistance testing.

Each specimen, whether treated or untreated, was first cut to exactly 16 inches (407 mm) in diameter. The sample was then thoroughly inspected for flaws, holes and manufacturing defects. After inspection and acceptance for testing, each sample was appropriately marked with a specimen number and set aside for testing.

The samples to be treated with asphalt emulsion were placed in a mold assembly where the emulsion could be applied in accurately desired amounts. After applying the emulsion and recording the total weight, the specimens were placed in a forced draft oven and allowed to cure for 24 hours. After curing and cooling, the specimen was removed from the mold and set aside to be tested in the hydrostatic pressure vessel.

The specimen to be tested was placed over an aggregate subbase testing surface located in the bottom half of one of the three hydrostatic testing vessels. After careful positioning of the specimen, the top assembly of the pressure vessel was carefully aligned and placed over the bottom half. The flange bolts were then installed and torqued diametrically to 120 in-lb (13.5 N-m) to insure a water tight seal. After the bolts were torqued, the top of the vessel was charged with water. An initial pressure of 4 psi (2.76×10^4 N/m^2) was then applied to the test vessel and held for a minimum of four hours. Pressure was increased by 2 psi (1.38×10^4 N/m^2) every four hours thereafter until rupture of the specimen occurred.

Failure of the specimen was detected by a pressure gage at the base of the hydrostatic vessel. When rupture of the membrane occurred, pressure equalization between the bottom and top half of the vessel was indicated by a pressure reading in the bottom of the hydrostatic vessel.

After rupture of the membrane was evident, the failure pressure was recorded and the specimen was removed from the hydrostatic pressure vessel and visually inspected for type of puncture and its location.

Slope Stability of Cover Aggregate. Various combinations of asphalt residue quantity, surface inclination and temperature were utilized to test the relative slope stability of a common aggregate cover material. Polyethylene or polypropylene was used as the base upon which slope displacement was measured. The plastic was first positioned on the aluminum slope assembly and the desired quantity of asphalt emulsion was spread evenly on the surface. The aggregate cover material was immediately spread on the emulsion and the sample was allowed to cure. After curing, the sample was placed in a forced draft oven at a predetermined test temperature. Movement of the cover aggregate was measured from outside the oven through glass doors.

Several temperature ranges were chosen as variables to determine the effect of temperature and thus asphalt viscosity on the slope stability of the cover aggregate.

Overlap Seal Strength. Three types of adhesive materials were chosen for seal strength variability. The three types of adhesive materials tested were polyethylene tape, asphalt residue and mastic bead adhesive seal.* Samples were prepared in accordance with ASTM F88-73. Any obvious defect in the seal area of each specimen was recorded prior to testing.

Each overlap specimen was attached to the tension grips in an Instrom Testing Machine. The specimen was properly aligned between the clamps and sufficient slack was allowed so that the overlap seal was not stressed prior to loading. The specimen was loaded until failure occurred. The locations, type of breakage, and maximum load at failure were recorded.

LABORATORY TEST RESULTS AND DISCUSSION

The objectives of the laboratory study were to examine the hydrostatic puncture resistance characteristics, cover aggregate slope stability and overlap seal strength of the APAC water seepage barrier. The study consisted of devising the testing apparatus, procedures and determining the relative characteristics of the test results. The equipment development and testing procedures have been described in the preceding section. The overall evaluation and discussion of the test results are described in the following sections.

HYDROSTATIC PUNCTURE RESISTANCE

Graphical results of the hydrostatic puncture resistance tests are shown in Figures 5, 6 and 7. The aggregate subbases over which the specimens were tested consisted of three gradations. The aggregate gradations were the No. 8 to 1/2 in. (3.2 to 12.7 mm) aggregate for a fine texture, 1/2 to 3/4 in. (12.7 to 19.0 mm) for a medium texture and the 3/4 to 1-1/2 in. (19.0 to 38.1 mm) aggregate for a coarse subbase texture. It should be noted that the plain polyethylene samples are the control specimens. A minimum of three control samples of each polyethylene thickness was tested over each of the aggregate subbases. These results indicated that similar values could be obtained upon repeat testing over the same aggregate subbase. The average values for the control specimens are shown in Figures 5, 6 and 7. The subbase aggregate over which the individual specimens were tested is as indicated in the legend of each of the figures.

Figure 5 shows the puncture resistance comparison of plain polyethylene and polyethylene treated with asphalt residue on the bottom of the sheeting only. This comparison, in effect, is showing the hydrostatic puncture resistance results obtained by using the asphalt as a protective bottom coating for the polyethylene sheeting. The maximum test pressure was 28 psi (1.93×10^5 N/m^2) for 8 mil polyethylene treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt residue. This maximum test pressure was exhibited **over the fine aggregate subbase.**

*Prestite 579 Acoustical Sealant supplied by Interchemical Corporation, St. Louis, Missouri.

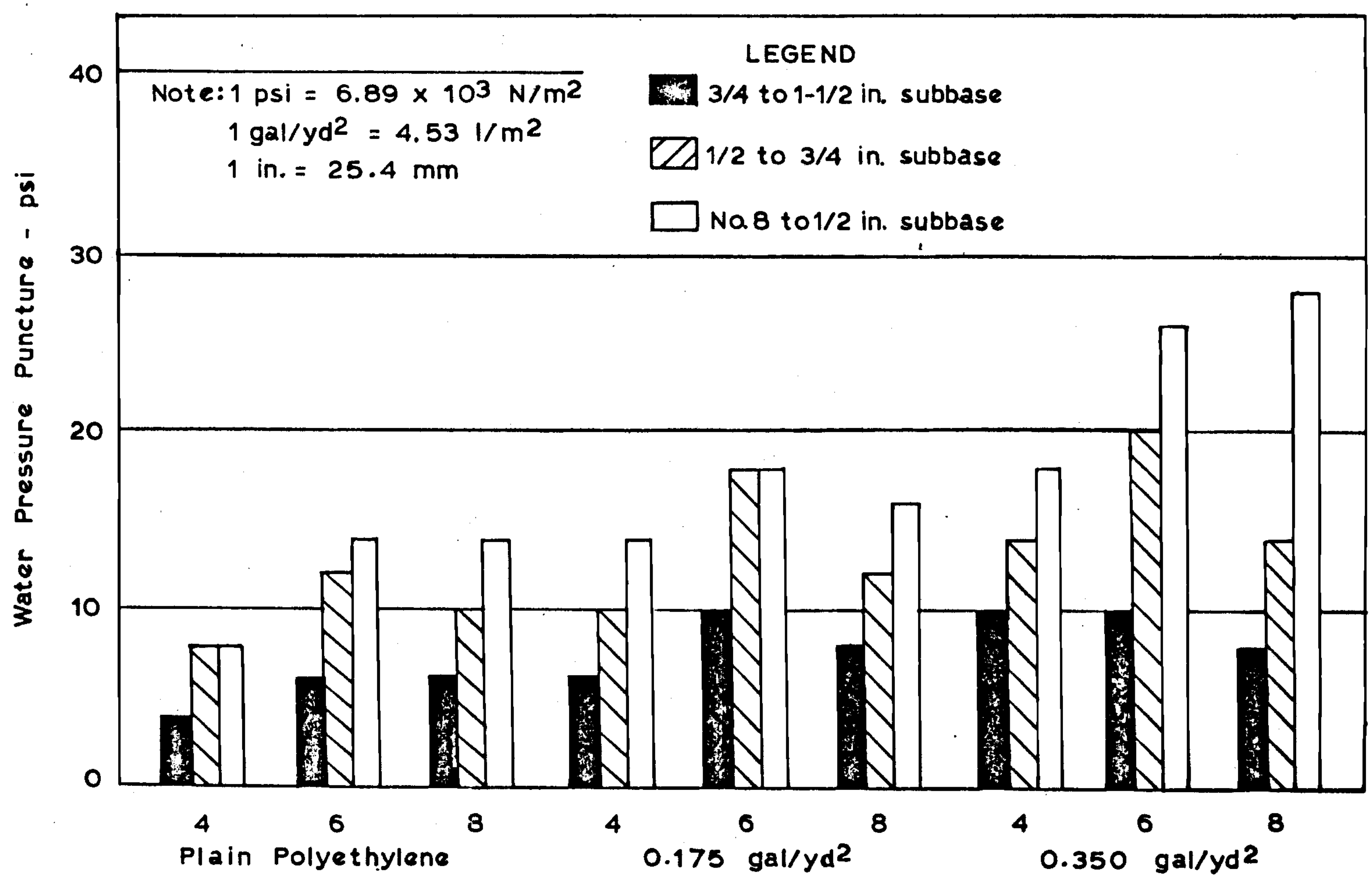

Fig. 5. Puncture Resistance Comparison of Different Mil Thicknesses of Plain Polyethylene and Polyethylene Treated with Asphalt Residue Quantities as Indicated--Bottom Application Only

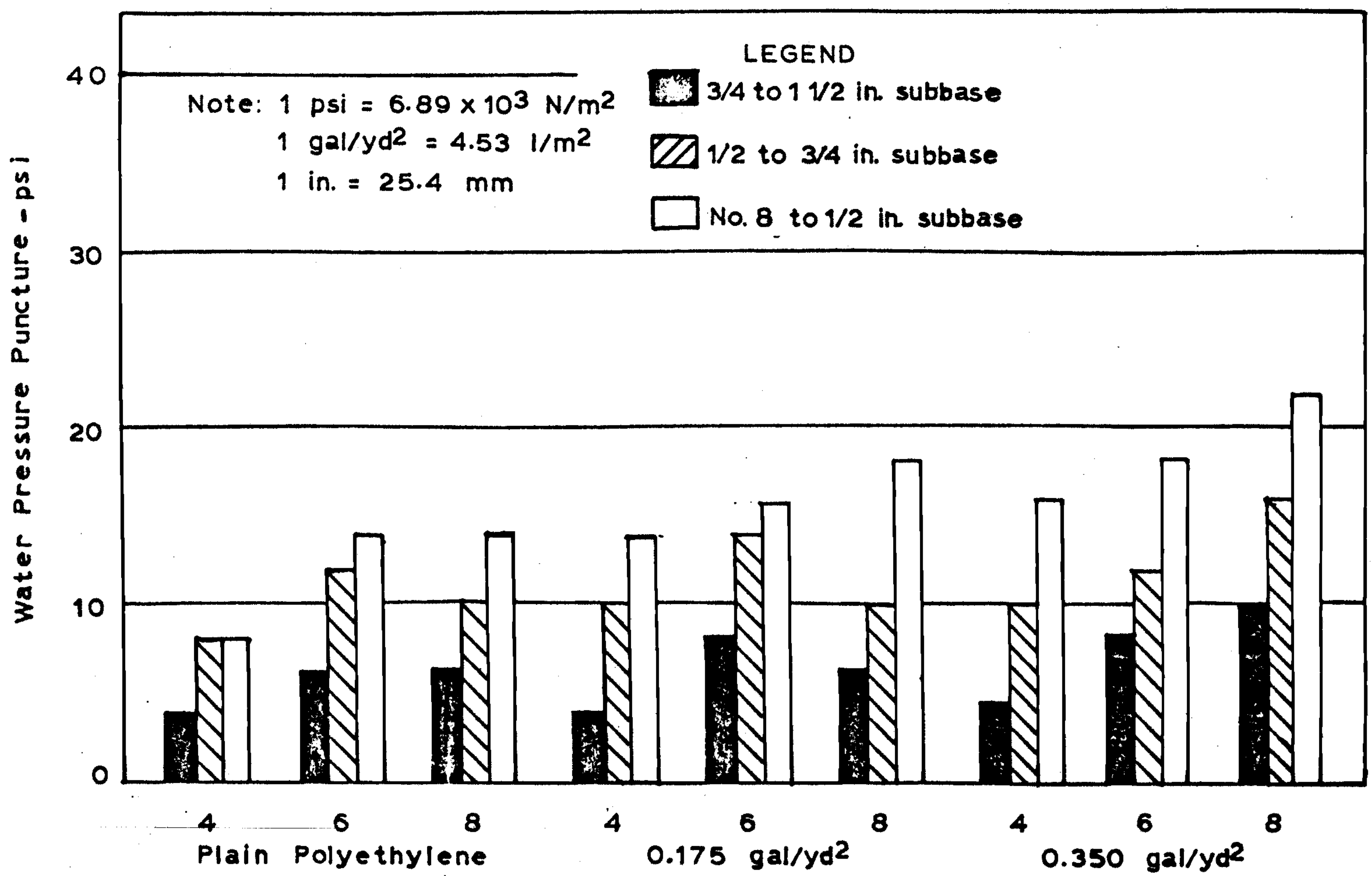

Fig. 6. Puncture Resistance Comparison of Different Mil Thicknesses of Plain Polyethylene and Polyethylene Treated with Asphalt Residue Quantities as Indicated--Top Application Only

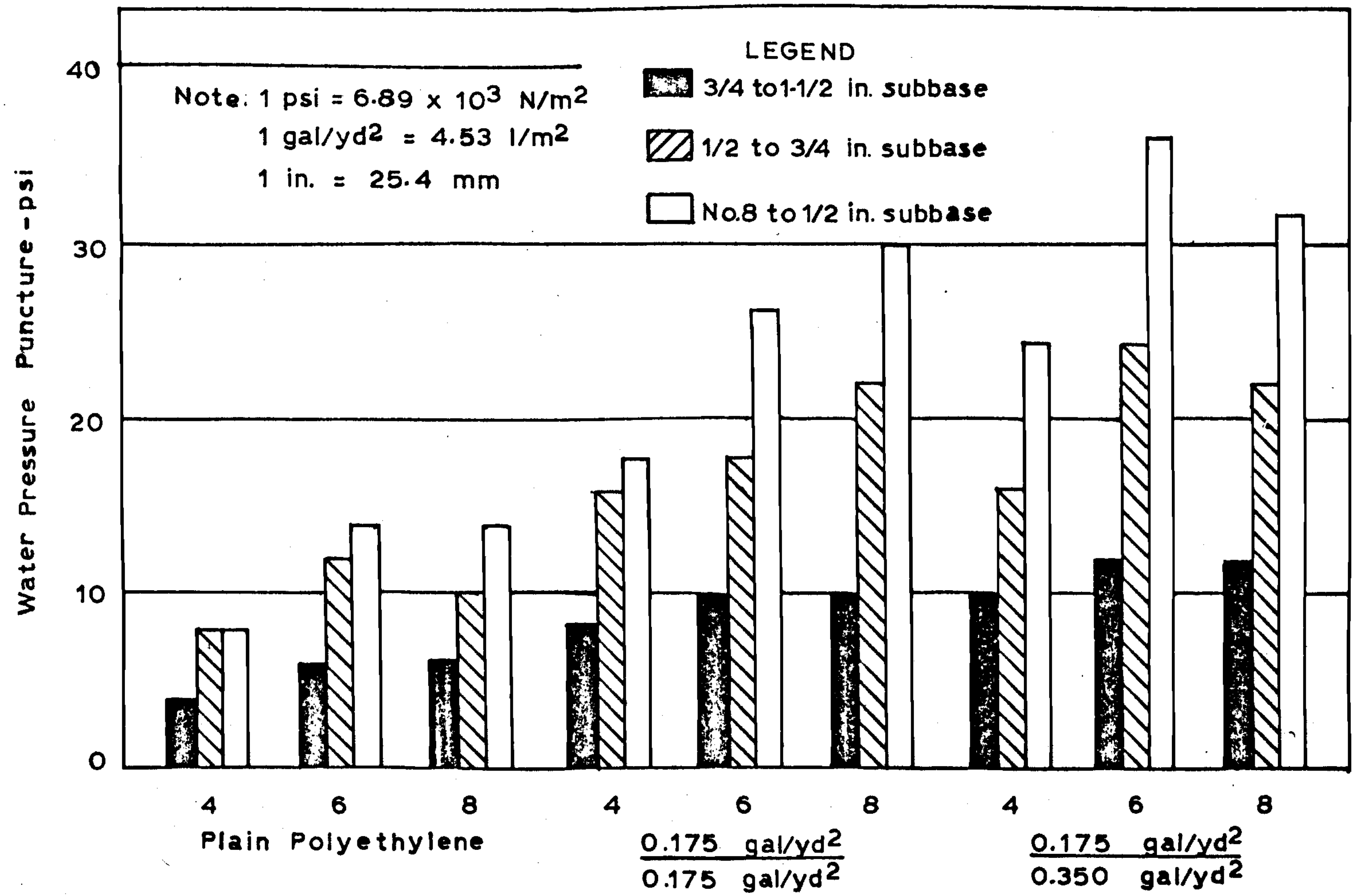

Fig. 7. Puncture Resistance Comparison of Different Mil Thicknesses of Plain Polyethylene and Polyethylene Treated Top and Bottom with Asphalt Residue Quantities as Indicated

The test results in Figure 5 show a definite increase in puncture resistance for the polyethylene treated with asphalt over that of plain polyethylene. The results also indicate an increase in puncture resistance with an increase in asphalt spread quantity. The increases in puncture resisstance are particularly noticeable with samples tested over the No. 8 to 1/2 in. (3.2 to 12.7 mm) subbase. The asphalt effectively protects the polyethylene from hydrostatic puncture by coating the aggregate subbase and filling in voids. This confirms visual observations in the field that trucks could be driven over asphalt cushioned polyethylene with minimal damage (Cluff, 1973).

Figure 6 shows the puncture resistance comparison of plain polyethylene and polyethylene treated with asphalt residue on the top of the sheeting. The maximum test pressure in this case was 22 psi (1.52×10^5 N/m^2) for 8 mil polyethylene treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt residue. This specimen failed over the fine aggregate subbase.

The test results represented in Figure 6 indicate that an increase in asphalt spread quantity increases the puncture resistance of the polyethylene sheeting. Whereas the asphalt was previously tested for its cushioning effect, it is now acting as a top coat only. Observations during this phase of hydrostatic testing indicate that the asphalt has good adhesion characteristics to the polyethylene. The asphalt forms an additional skin thickness on the polyethylene which helps increase puncture resistance of the total membrane. While testing the asphalt on top of the sheeting, the asphalt was observed to flow significantly under pressure. If a slight puncture through the polyethylene did occur, the asphalt residue flowed into the hole thus sealing off the puncture.

Figure 7 compares plain polyethylene sheeting with polyethylene treated with asphalt residue on both the bottom and the top surfaces of the sheeting. This configuration approximates the actual APAC membrane system with the exception of the protective aggregate cover material. The asphalt residue application quantities are shown as fractions in Figure 7. The numerator indicates the quantity of asphalt residue on the top and the denominator indicates the quantity of asphalt residue on the bottom of the sheeting. The various combinations tested indicate a definite increase in puncture resistance when the polyethylene and asphalt were combined as in the APAC membrane. It should be noted that when the asphalt quantity on the bottom of the membrane is increased the puncture resistance of the membrane is increased as well. This is primarily due to the cushioning effect of the asphalt on the aggregate subbase. The top coat of asphalt residue was again observed to flow under pressure and partially seal any occurring punctures.

The three aggregate gradations used as subbases in the hydrostatic testing indicate that as the subbase aggregate particle size increases, the relative puncture resistance of the APAC membrane decreases significantly. The 3/4 to 1-1/2 in. (19.0 to 38.1 mm) aggregate subbase was found to be an extreme subbase condition whereas the No. 8 to 1/2 in. (3.2 to 12.7 mm) aggregate subbase could approximate actual graded site conditions.

The maximum hydrostatic test pressure attained for polyethylene combinations was 36 psi (2.48×10^5 N/m^2) or an equivalent depth of 83 feet (25.3 m) of water. The test specimen that failed under this pressure consisted of 6 mil polyethylene with asphalt residue applied to the top and bottom surfaces of the sheeting. The asphalt residue quantity applied to the bottom surface was 0.350 gal/yd^2 (1.590 L/m^2) and that applied to the top surface was 0.175 gal/yd^2 (0.794 L/m^2). This particular test specimen configuration approximates the polyethylene reinforced APAC membrane with the exception of the cover aggregate. It should be noted that polypropylene used as a membrane reinforcement provides very minimal seepage control. This is primarily due to the woven structure of the sheeting. Polypropylene is, however, a strong reinforcement. The strongest APAC liner tested for use as a reservoir membrane consists of the combination of 4 mil polyethylene and 10 mil polypropylene. The polypropylene is used as the bottom reinforcement for protection from rough subgrade whereas the polyethylene is used strictly for seepage control. The two are sandwiched together with asphalt emulsion and provide a remarkably strong membrane. The polypropylene-polyethylene combination (APAPAC) did not fail under hydrostatic test and held under the maximum test pressure of 85 psi (5.85 x 10^5 N/m^2) or an equivalent of 196 feet (61.6 m) of water.

The maximum test pressures obtained from laboratory testing should not be interpreted as the exact depth to which a reservoir could be constructed. They can be used to indicate the relative strength of various combinations of asphalt, polyethylene, and polypropylene.

SLOPE STABILITY TESTING

As indicated in the introduction, an attempt would be made to determine the slope stability characteristics of a 3/8 in. (9.5 mm) cover aggregate. Graphical results for slope displacement of this particular cover aggregate when tested over a polyethylene base are shown in Figures 8, 9 and 10. A slope displacement of 10.0 mm was arbitrarily chosen to indicate the failure displacement of the aggregate. This failure displacement approximates the maximum diameter of the cover aggregate.

Figure 8 shows slope displacement plotted with time at a test temperature of 122^oF (50^oC). Each slope tested was treated with one of two quantities of asphalt residue as indicated in the legend of the figures. It should be noted in Figure 8 that there was no slope displacement for the 2:1 slope treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt residue. Also, slope displacement was not detected for the 3:1 or the 4:1 slope specimens when tested at 122^oF (50^oC). The 2:1 slope specimen treated with 0.175 gal/yd^2 (0.794 L/m^2) asphalt residue did not fail within the time span of testing. According to the established failure criteria, both 1.5:1 slope specimens failed. The 1.5:1 slope treated with 0.175 gal/yd^2 (0.794 L/m^2) residue shows a slight upward deflection of the slope displacement line as plotted graphically. This slope also failed within one hour whereas the other 1.5:1 slope treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt failed in three hours. These results indicate that, with an increase in asphalt residue surface quantity, there is a subsequent decrease in relative slope displacement of the embedded cover aggregate. This characteristic can be attributed to the increase in asphalt residue film thickness. If the asphalt emulsion is applied heavier, the asphalt residue film remains higher on the aggregate after setting thus increasing the bond between adjacent aggregate surfaces. This increase in bonding produced a decrease in total displacement of the cover aggregate. Figure 9 and Figure 10 also indicate a decrease in aggregate displacement with an increase in asphalt residue thickness.

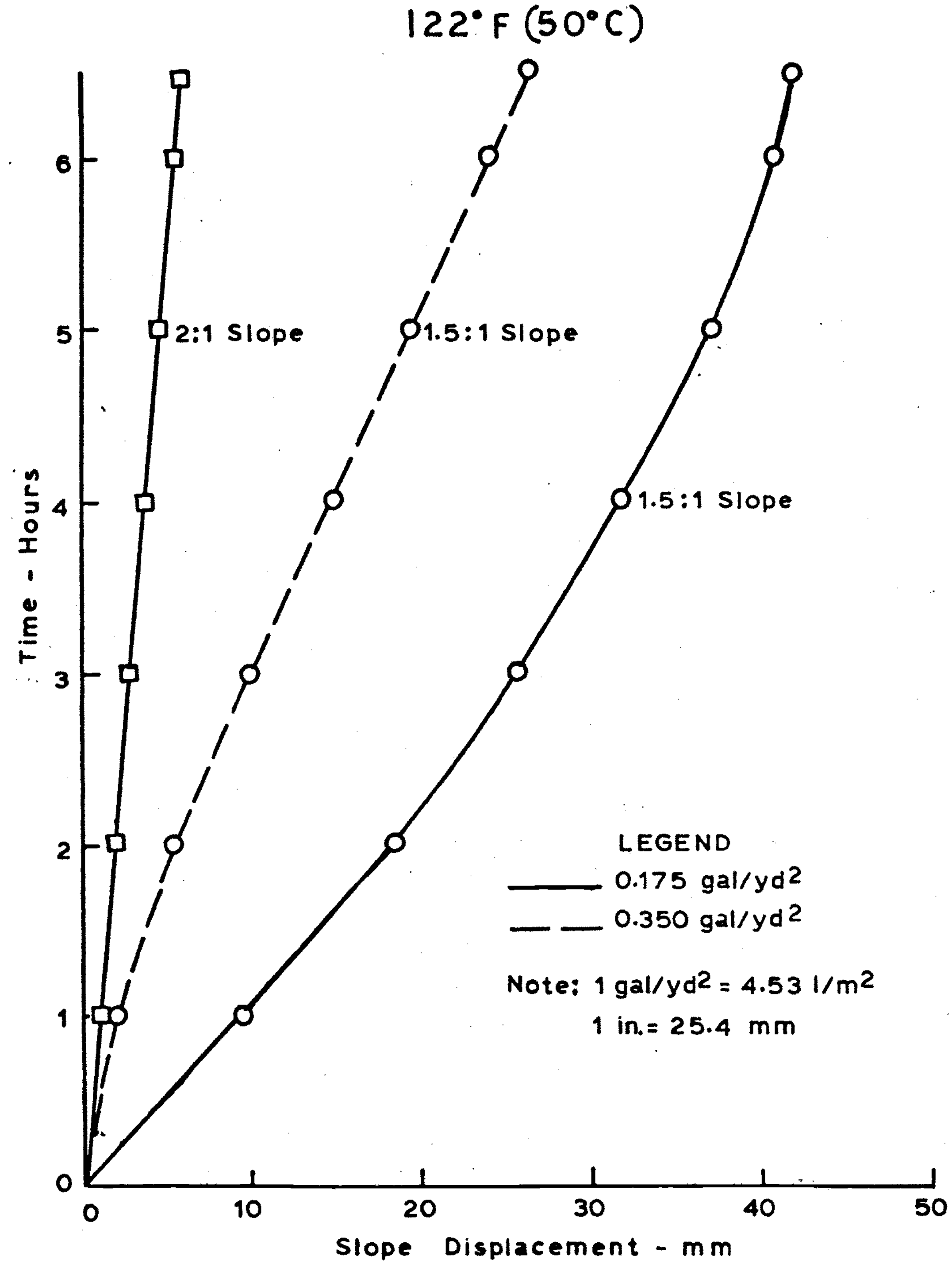

Fig. 8. Effect of Temperature and Slope on the Displacement of a 3/8 in. Cover Aggregate Tested at 122^{o}F (50^{o}C) - Polyethylene Base

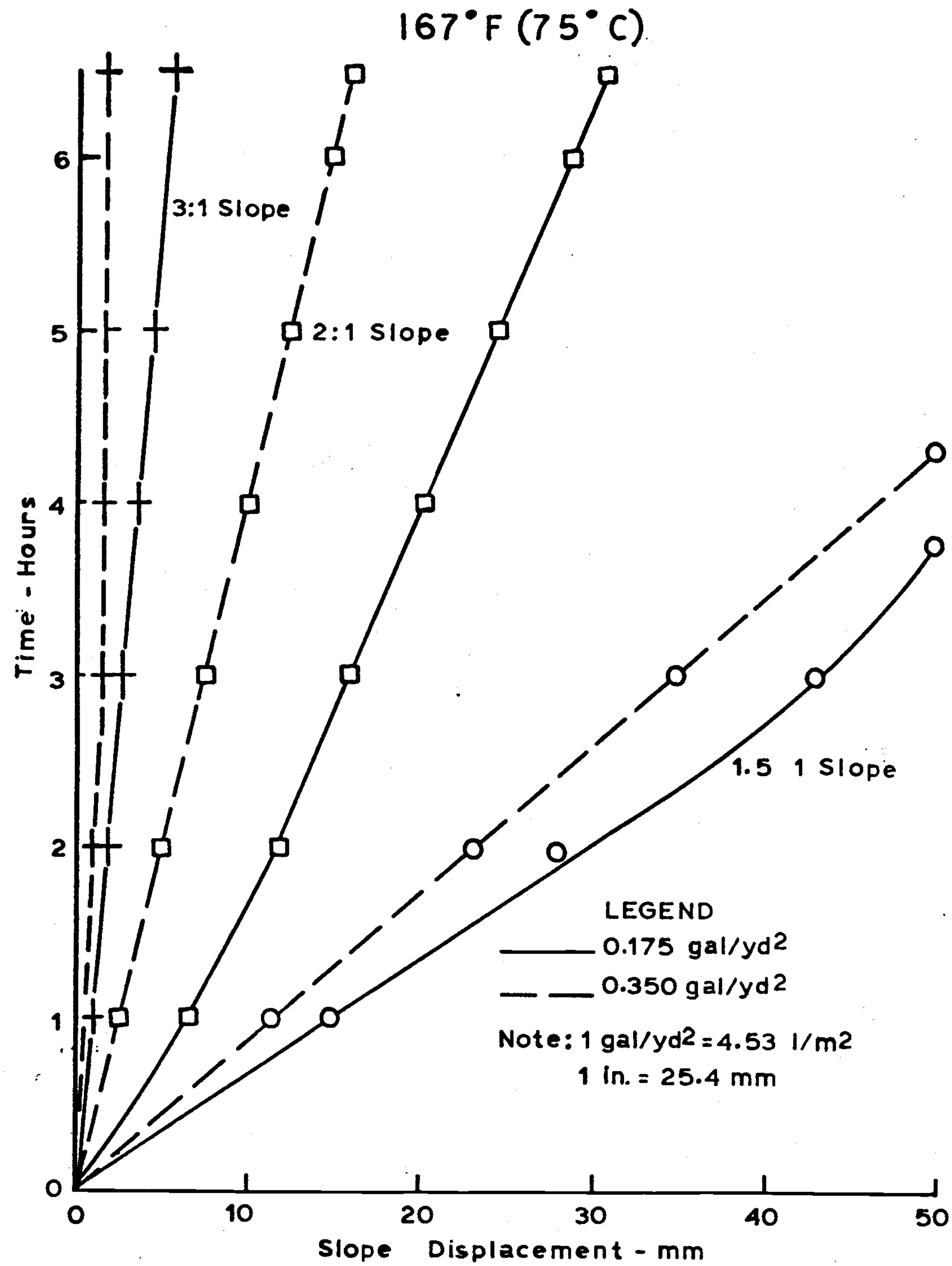

Fig. 9. Effect of Temperature and Slope on the Displacement of a 3/8 in. Cover Aggregate Tested at 167°F (75°C) - Polyethylene Base

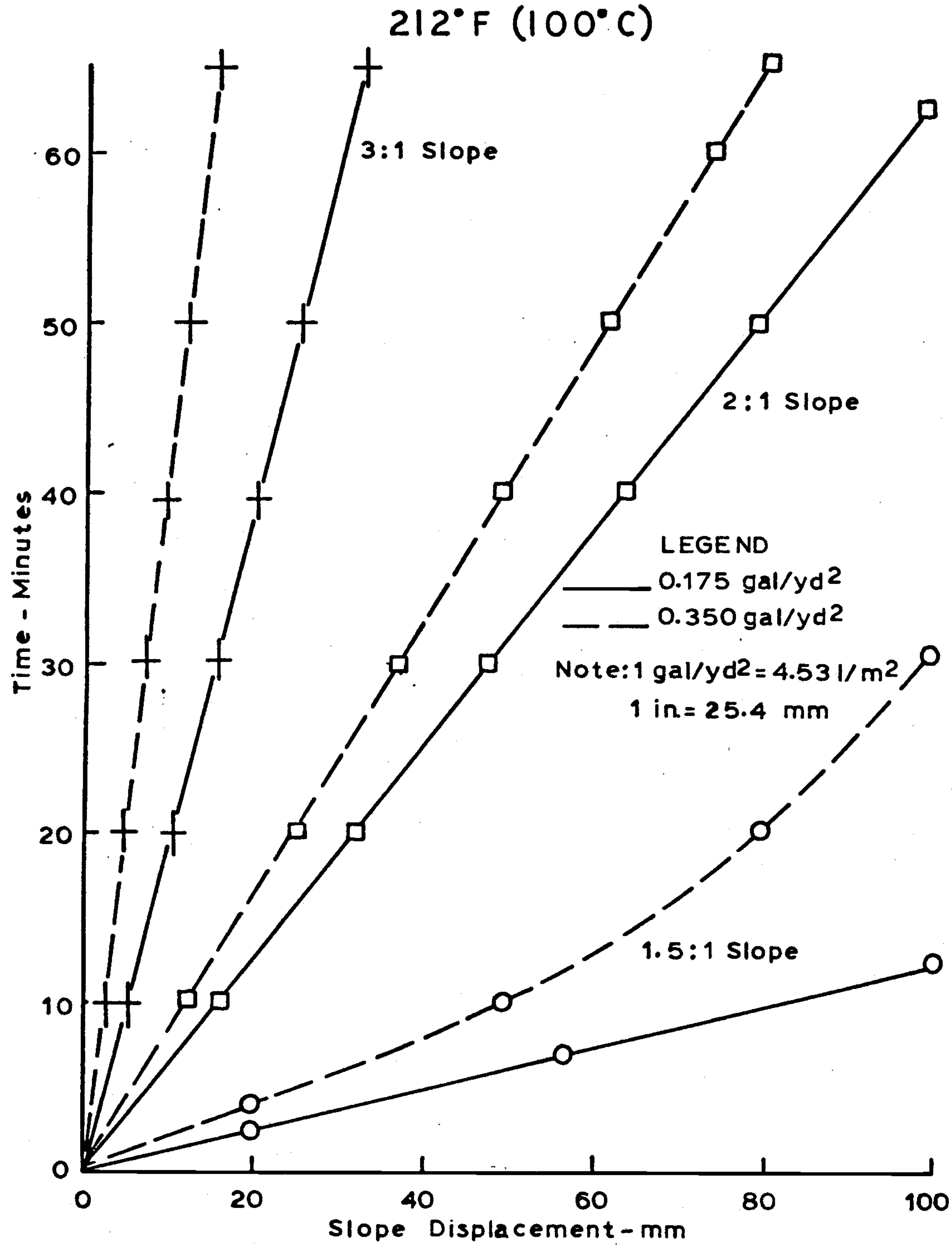

Fig. 10. Effect of Temperature and Slope on the Displacement of a 3/8 in. Cover Aggregate Tested at 212°F (100°C) - Polyethylene Base

The resultant graphs for slope stability all show at least one slope displacement line that indicates a slight upward deflection. This upward deflection is due to a decrease in aggregate displacement with time and might be attributed to one of two characteristics. First, slope displacement may become less with time due to the aging characteristics of the asphalt residue. This aging of the residue results in an increase in residue viscosity (Jimenez, 1970) which may characteristically result in a decrease in cover aggregate movement on the slope. Second, the aggregate may tend to bind together as it moves down the slope causing a decrease in movement with time.

Figure 9 represents the slope displacement of the 3/8 in. (9.5 mm) cover aggregate plotted with time at a test temperature of 167°F (75°C). This temperature approximates the maximum pavement temperature in the Southwest during the summer months (Rumney, 1970). It should be noted that there was no slope displacement recorded for the 4:1 slope and only minimal displacement for the 3:1 slope specimens. Using the failure criteria of 10.0 mm maximum displacement, neither 3:1 slope specimen failed within the time span of testing. The 3:1 slope treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt residue indicated no further movement after three hours of testing. This particular slope would be very stable at the maximum pavement temperature of 167°F (75°C). The 2:1 slope treated with 0.350 gal/yd^2 (1.590 L/m^2) asphalt residue indicates failure after four hours of testing whereas the same slope treated with 0.175 gal/yd^2 (0.794 L/m^2) residue failed in 1.7 hours. This is attributed to the increase in asphalt residue quantity as described previously. The 2:1 slope treated with 0.350 gal/yd^2 (1.690 L/m^2) residue would be moderately stable provided the surface temperature did not exceed 167°F (75°C). The 1.5:1 slope specimens treated with either quantity of asphalt residue showed very unstable characteristics. Both failed within one hour of testing and both indicated excessive movement of cover aggregate.

The results for the maximum test temperature of 212°F (100°C) are shown in Figure 10. It should be noted that the time of displacement is recorded in minutes and that displacement of the cover aggregate is excessive. The 4:1 slope indicated no displacement of the 3/8 in. (9.5 mm) cover aggregate when tested at 212°F (100°C). All other slope specimens tested at this temperature failed to meet the minimum displacement criteria of 10.0 mm and all failed within one hour of test time.

Although this particular test temperature may never be encountered in the field, the results show that for an increase in temperature, the relative viscosity of the asphalt residue decreases significantly. The effect of temperature is comparable to the effect of asphalt residue viscosity on relative slope displacement. As the relative viscosity decreases, the downslope displacement of the cover aggregate increases considerably. Although the test temperature was extreme, the slopes treated with a greater quantity of asphalt residue consistently indicated less displacement with time.

Polypropylene was also tested as the base plastic in slope stability testing. Graphical results for slope displacement of the 3/8 in. (9.5 mm) cover aggregate when tested over a polypropylene base are shown in Figures 11 and 12. It should be noted that there was negligible slope displacement for slopes tested at 122°F (50°C).

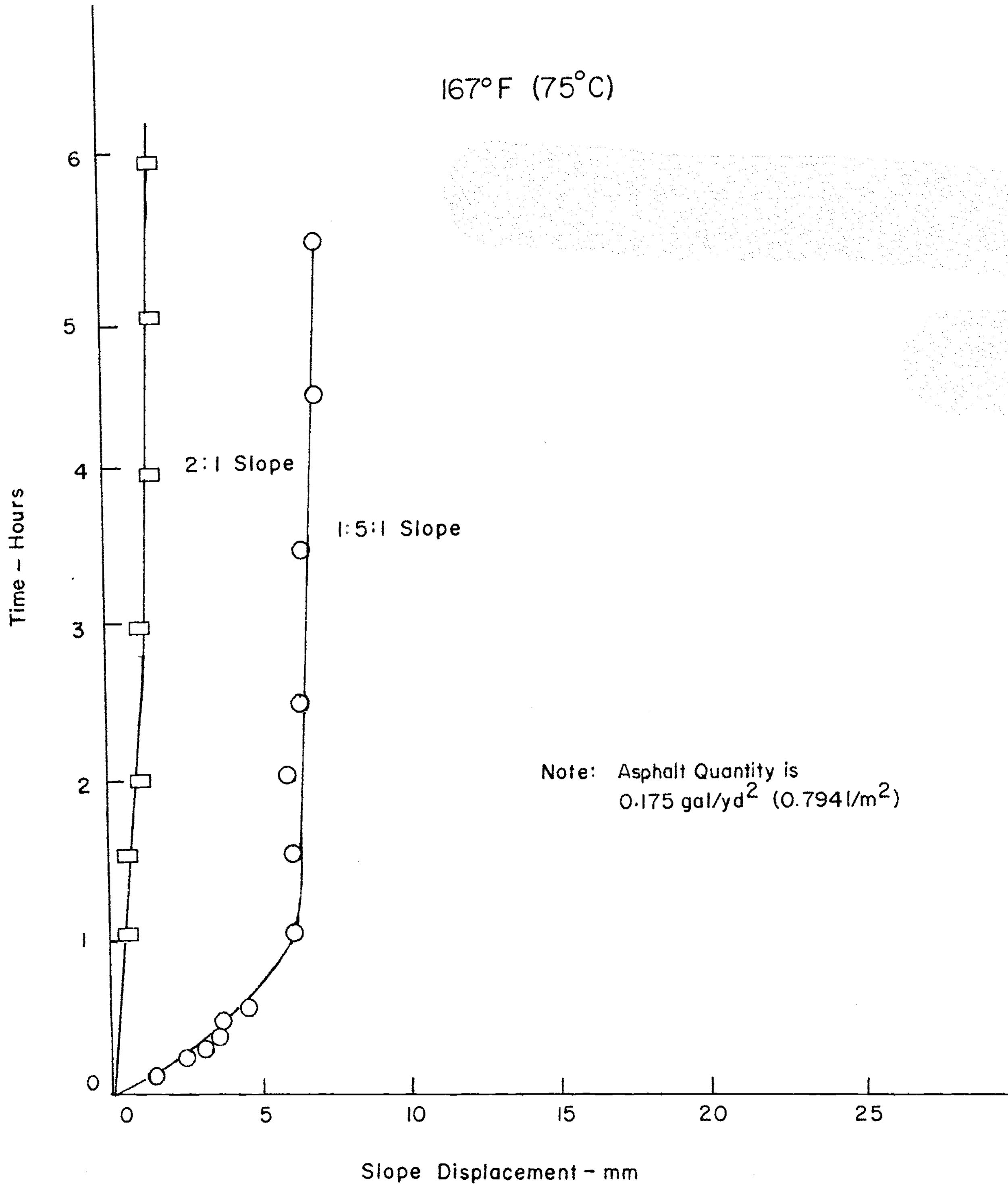

Figure 11. Effect of Temperature and Slope on the Displacement of a 3/8" Cover Aggregate Tested at 167°F (75°C) - Polypropylene Base

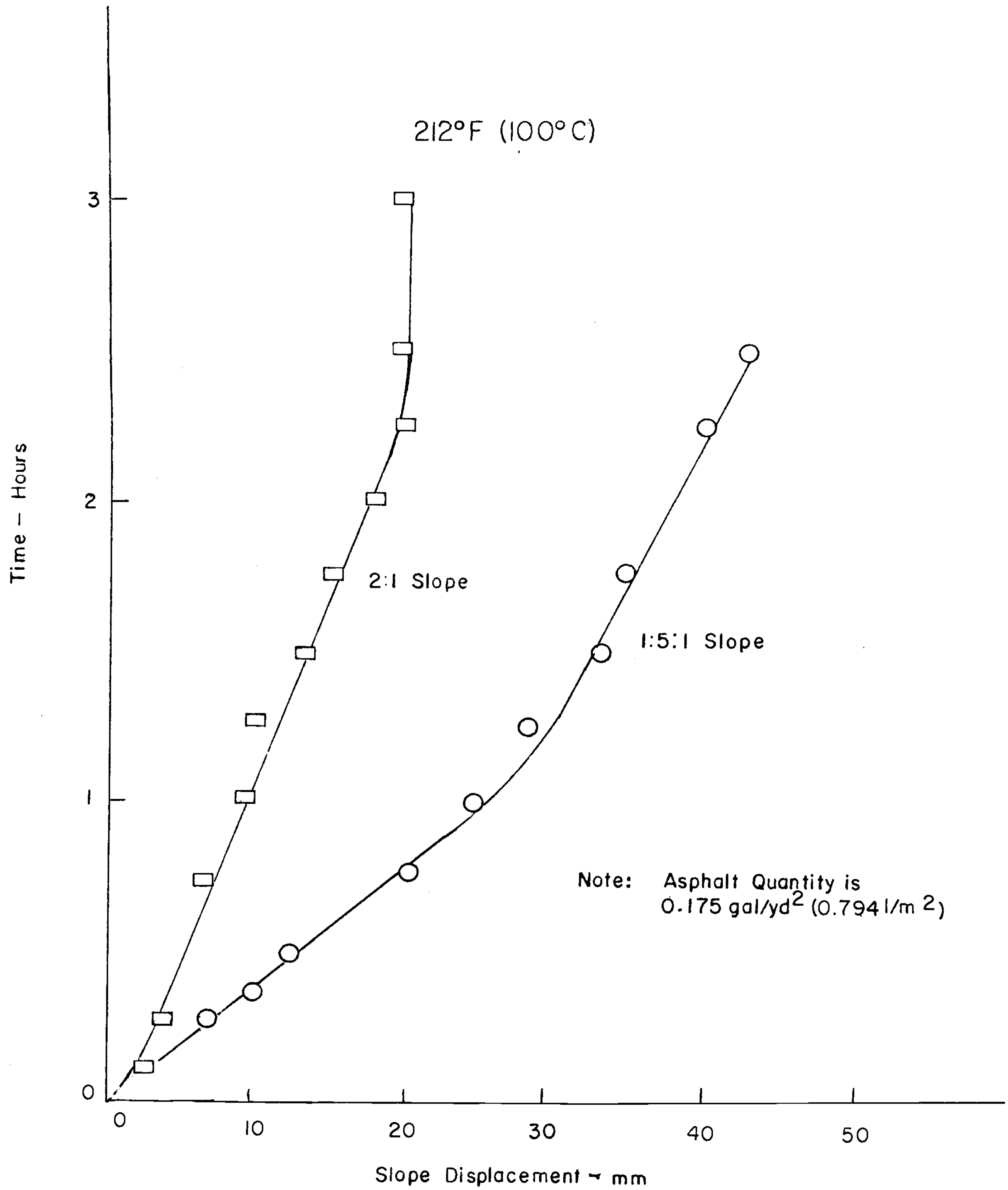

Figure 12. Effect of Temperature and Slope on the Displacement of a 3/8" Cover Aggregate Tested at 212°F (100°C) - Polypropylene Base

Figure 11 shows slope displacement plotted with time at a test temperature of 167°F (76°C). There was no slope displacement for the 3:1 or 4:1 slopes. It should be noted that the 1.5:1 and 2:1 slopes did not fail according to the 10.0 mm failure criteria. The 2:1 slope had only minimal aggregate displacement.

Figure 12 represents the slope displacement of the 3/8 in. (9.5 mm) cover aggregate plotted with time at a test temperature of 212°F (100°C). Here again, there was no slope displacement recorded for the 3:1 slope or the 4:1 slope. Although the 1.5:1 and 2:1 slopes did fail, their overall displacement was far less than the same slopes using polyethylene as a base. This can be attributed to the woven texture of the polypropylene which provides an excellent friction surface thus reducing slope displacement.

OVERLAP SEAL STRENGTH

The overlap seal strength of three adhesive sealants was determined in accordance with ASTM F 88-73 (Seal Strength of Flexible Barrier Materials).

A minimum of five specimens were tested for each overlap seal test. The maximum load applied to the specimens at breakage was recorded and the average of the five values was reported. The highest recorded shear strength was 13.9 psi (9.58×10^4 N/m^2) for polyethylene tape adhesive seal. The polyethylene tape also had the highest recorded peel strength of 8.2 lb/in. (1.40×10^3 N/m). These results indicate that polyethylene tape was the strongest of the three adhesive seals tested.

Asphalt residue when used as an adhesive indicates relatively good shear strength but exhibits no peel strength. It should be noted here that specimens treated with asphalt emulsion and allowed to cure before testing showed no shear or peel strength. This characteristic may be due to the fact that the water in the emulsion was unable to evaporate through the polyethylene overlap. For this reason, asphalt residue was first obtained by evaporation and then used to fabricate the test specimens.

The mastic bead adhesive seal exhibited the lowest shear and peel strength. Test observations, however, indicate that the shear and peel failure was within the mastic material and not at the polyethylene surface. The adhesion characteristics of the mastic bead to the polyethylene sheeting were much better than either the polyethylene tape or the asphalt residue. Whereas the polyethylene tape and asphalt residue separated from the polyethylene in peel, the mastic bead adhesive did not.

DEVELOPMENT OF THE PLASTIC DISPENSER-ROLLER AND FIELD TESTS

One of the biggest advantages the APAC method has over other techniques is that it is well adapted to being installed using conventional asphalt dispensing equipment. An asphalt boot truck, a loader and dump truck equipped with a gravel spreader are essential in reducing the time of installation. The first one-half acre APAC field installation was completed in four hours using the above equipment (Cluff, 1973). The drivers of the asphalt distributor truck and the gravel truck were experienced. The rest of the crew was composed mainly of inexperienced high school students.

In constructing the APAC catchment the asphalt boot truck first rolls over the area spraying the initial coat of asphalt. This is immediately followed with a sheet of plastic. The plastic is then rolled lightly to hold it in place until the boot truck can drive over it and apply the top coating of asphalt. This is followed immediately with a layer of aggregate chips which are applied in the conventional way with the dump truck being driven backwards. The truck, therefore, is driving on top of the chips.

The initial coat of asphalt provides sufficient protection as to allow equipment to be driven on the plastic with minimal drainage to the plastic sheeting. This is especially important since most catchments are installed using four mil black polyethylene plastic. This cushion effect of the asphalt was also demonstrated in the laboratory as reported earlier in the report.

Observations during the first two catchment installations indicated that the slowest part of the construction process was in unrolling the plastic by hand. Time consuming hand labor was involved in keeping the plastic sheeting tight and in alignment during installation.

In order to reduce construction time, the plastic dispenser-roller shown in Figures 13 and 14 was developed. The roller is composed of used deflated rubber tires placed side by side on three sections of lightweight steel pipe. Each section can float independently to follow the contour of the finished grade. The dispenser was first used in December 1974 to install a one-half acre catchment on the Papago Reservation in Sells, Arizona. The catchment is one of three treatments on an experimental jojoba water harvesting agrisystem. The agrisystem is being constructed in cooperation with the Vocational Department at Baboquivari High School, the Papago Tribe, the Bureau of Indian Affairs and the Office of Arid Lands Studies.

Figure 15 shows the chipping of a previously installed strip of catchment. The figure also shows the next strip of plastic in place awaiting asphalt, with the untreated portion to the left. Figure 16 shows the completed catchment.

The plastic dispenser-roller worked satisfactorily except for the method of raising and lowering the unit for turning. It was found that the unit would lay the 12-foot wide plastic sheet at about a 4 to 6 mile per hour speed. This effected a considerable saving of time and reduction in the number of workers needed for installation. An approximate cost analysis of the APAC catchment at Sells is given in Table 1.

In addition to the Sells catchment, an additional 1/2-acre APAC catchment near Camp Verde, Arizona was constructed in cooperation with Oscar Walls, a local rancher. The Camp Verde installation was made using hand labor for both the installation of the plastic and for covering the plastic with chips. The latter operation was aided with the use of a front end loader and pick-up truck. This installation was made without the use of an experienced asphalt truck operator. It should be noted here that the area was remote and relatively inaccessible by conventional equipment. It required 16 hours to complete the catchment and indicated the advantages in utilizing the right type of equipment. An experienced asphalt boot truck operator is also essential for efficient construction operation.

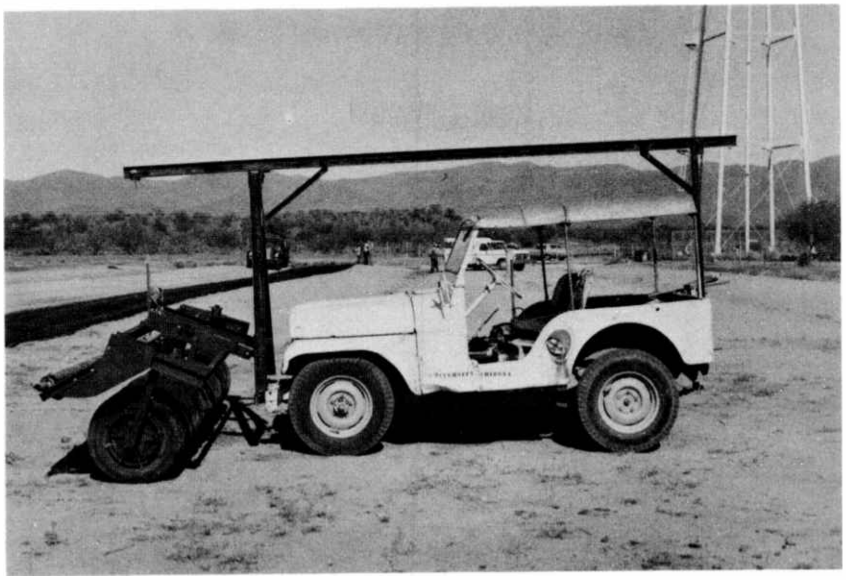

FIGURE 13. SIDE VIEW OF JEEP MOUNTED PLASTIC DISPENSER ROLLER

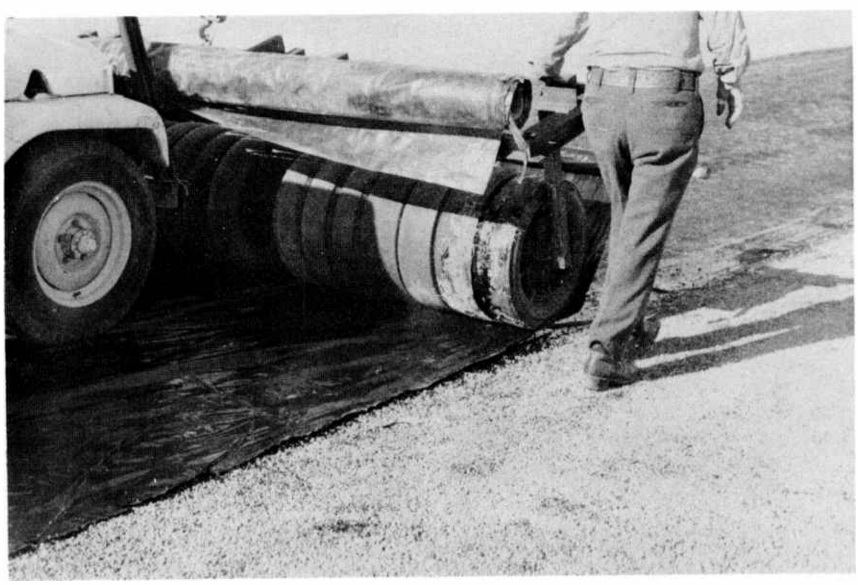

FIGURE 14. JEEP-MOUNTED PLASTIC DISPENSER-ROLLER IN OPERATION

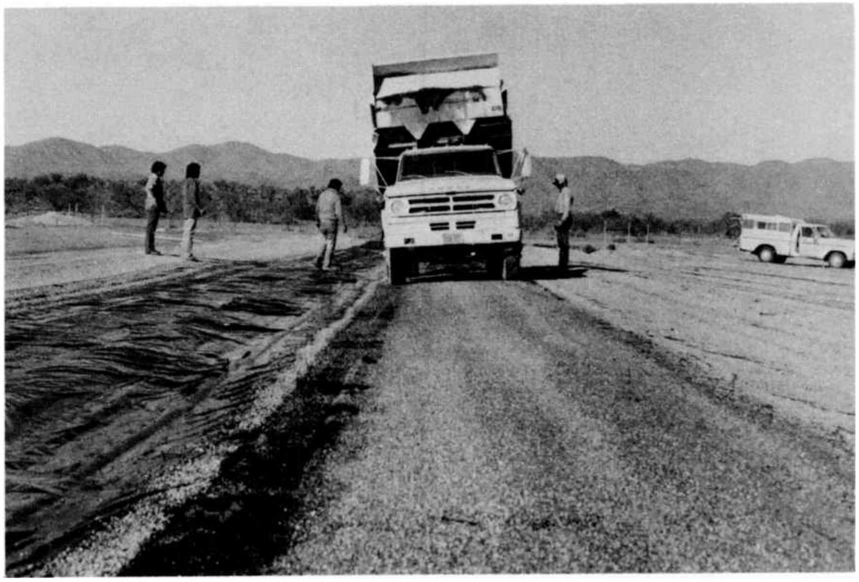

FIGURE 15. CONSTRUCTION OF APAC CATCHMENT IN PROGRESS AT SELLS, ARIZONA

FIGURE 16. COMPLETED APAC CATCHMENT AT SELLS, ARIZONA

TABLE 1.

COST ANALYSIS OF 20,000 FT^2
CATCHMENT INSTALLATION AT SELLS, ARIZONA

Layout	1 hour @ $10.00	$ 10.00	
			$ 10.00
Grading			
Equipment	2 hours @ $25.00	50.00	
			50.00
Labor			
Technician	2 hours @ $6.00	12.00	
Common	6 hours @ $2.00	12.00	
			24.00
Lining			
Materials			
Polyethylene	21,000 ft^2 @ $0.03	630.00	
Asphalt	1,500 gal. @ $0.32	480.00	
Chips	22 yds^3 @ $8.00 (delivered to site)	176.00	1,286.00
Equipment			
Asphalt Distributing truck	4 hours @ $25.00	100.00	
Dump Truck	4 hours @ $20.00	80.00	
			180.00
Labor			
Supervisory	4 hours @ $6.00	24.00	
Common	32 hours @ $2.00	64.00	
			88.00
		GRAND TOTAL	$1,638.00

The first field installation of an APAC membrane for use in seepage control was made on a 170,000 gallon reservoir in July, 1974. The reservoir dimensions were 67 ft. x 67 ft. x 6 ft. in depth, with side slopes of 1.5:1. Thirteen foot widths of Exxon polypropylene matting was used in the membrane installation. The installation was made in a six hour period using vocational high school student labor. A cost analysis of the installation is given in Table 2.

Unfortunately, the lining when first installed had a seepage loss of approximately 8 inches per day. This dropped significantly with time as sodium rich clays from Catchment No. 1 (a compacted earth sodium treated catchment) accumulated in the reservoir. Subsequent laboratory tests confirmed that the polypropylene was not made impervious by the field applied quantities of asphalt. Also, sufficient care was not taken with the overlaps. Observations indicated that aggregate chips from the coating operation did infiltrate under the seams. The aggregate was also observed to slip down the steep slopes as the surface temperature of equivalent asphalt viscosity approached 160°F (71°C).

A second attempt at lining the reservoir was made in May 1975. This time a combined treatment of asphalt, polypropylene matting, asphalt, 8 mil black polyethylene, asphalt and chips was installed. Seams in the polypropylene were made using asphalt between clean overlapped sheets. The overlapping seams of the polyethylene were sealed with Presstite, a beaded mastic adhesive described earlier in the laboratory section of this report. Some difficulty was encountered in getting the chips to stay on the 1.5:1 slopes.

The original design procedure called for the binding of the aggregate cover with a commercial epoxy resin rock binder before temperatures became critical. If the rocks were held together, they would be self supporting and not dependent on the asphalt to be held in place. The weather cooperated for a short time and temperatures remained below the critical point. However, due to scheduling problems the coating of the chips on the side slopes with rock binder did not commence until approximately a week later. Temperatures had become critical, the asphalt between the polypropylene and polyethylene lost its adhesive properties putting the full weight of the rocks on the polyethylene. The polyethylene failed at about the mid point along two slopes. Excessive slippage of both the rock and the ruptured plastic was noted.

An attempt was made to salvage the lining by coating the slopes with wire reinforced mortar. This technique of protecting plastic on slopes has been successfully tested in the past (Cluff, 1973). However, this technique is more expensive than using the rock binder.

CONCLUDING REMARKS

LABORATORY TESTS

The physical characteristics investigated were:

(1) the hydrostatic puncture resistance of asphalt-plastic combinations,

TABLE 2.

COST ANALYSIS OF 170,000 GALLON TANK
AT SELLS, ARIZONA

Layout	3 hours @ $10.00	$30.00	
			$ 30.00
Excavation			
Equipment	D-8 Dozer, 12 hours @ $25.00	300.00	
			300.00
Labor			
Technician	12 hours @ $6.00	72.00	
Common	144 hours @ $2.00	288.00	
			360.00
Lining			
Materials			
Polypropylene Matting	5,000 ft^2 @ $0.06	300.00	
Asphalt	787 gal. @ $0.32	250.00	
Chips	8 yds^3 @ $8.00 (delivered to site)	64.00	
			614.00
Equipment			
Asphalt Distributing Truck	6 hours @ $25.00	150.00	
Loader	6 hours @ $20.00	120.00	
			270.00
Labor			
Supervisory	8 hours @ $6.00	48.00	
Common	64 hours @ $2.00	128.00	
			176.00
		GRAND TOTAL	$1,750.00

(2) slope stability of a cover aggregate, and
(3) overlap seal strength of three available adhesives.

Hydrostatic puncture resistance testing uncovered some interesting characteristics of asphalt-plastic combinations. The asphalt does provide an excellent protective base for the polyethylene when applied over an aggregate subbase. It was found that a heavier tack coat of asphalt provides more protection against puncture. The top coating of asphalt does aid in puncture resistance simply by providing an additional skin thickness. The asphalt also readily flows under pressure, thus partially sealing any occurring punctures.

Test results indicate that the use of the asphalt with the polyethylene in the APAC membrane does increase puncture resistance by a factor of three over that of plain polyethylene. Although the test results show that the APAC membrane has superior puncture resistance, the subbase over which the APAC treatment is applied should be of relatively fine aggregate gradation. All large irregularities in the subgrade should be removed and, if necessary, a cushion layer of fine soil should be applied and compacted. These precautions are not as important when constructing a water harvesting catchment where negligible water pressures are encountered. It is important, however, to consider the subgrade when constructing a reservoir for the containment of water. Test results indicated that polypropylene used as the membrane reinforcement provided little seepage control if used as a reservoir lining. If, however, the polypropylene and polyethylene are used together as a reservoir lining, the combination provides the strongest and toughest membrane.

The slope stability tests indicated that the 3/8 in. (9.5 mm) cover aggregate was relatively stable on the 4:1 and 3:1 slopes. The aggregate on the 2:1 slope over the polyethylene base showed only slight displacement at the lower test temperature. It can be concluded that the 2:1 slope can be constructed over the polyethylene base if it is found that the surface temperature or equivalent asphalt viscosity does not exceed 122°F (50°C). A 1.5:1 or steeper slope should never be utilized with a single aggregate layer as tested in conjunction with the APAC treatment. It should be noted that polypropylene, when used as the plastic reinforcement, greatly reduces slope displacement of cover aggregate on steep slopes. Polypropylene should, therefore, be used as a base for asphalt and cover aggregate if steep slopes are anticipated.

The test results indicate that a heavier spread quantity of asphalt increases the slope stability of an embedded aggregate cover material. A heavier spread quantity, however, is not always possible to apply in a single application to relatively steep slopes due to the low viscosity of the applied asphalt emulsion.

Overlap seal strength test results indicated that the polyethylene tape was the strongest of the three adhesives tested. The Presstite mastic bead adhesive, however, exhibited the best adhesion characteristics. An ideal overlap seal could be a combination of the Presstite adhesive sealant and the polyethylene tape.

The asphalt residue formed a relatively good seal but exhibited no peel strength. A smaller spread quantity of asphalt residue will obtain the strongest overlap seal. It should be noted that asphalt emulsion as applied in the field will require a considerable length of time to form a cured residue if covered by an overlap of polyethylene. The overlap seal will be relatively weak until the emulsion has cured to an asphalt residue.

In summary, it was found that for the particular asphalt-plastic combinations used in this study, the APAC membrane does provide hydrostatic puncture resistance if used as a reservoir lining. Also, 3/8 in. (9.5 mm) cover aggregate remains stable on slopes of 4:1 and 3:1 up to and including maximum surface temperatures in the Southwest. The aggregate on a 2:1 APAC slope remains stable if the surface temperature or equivalent asphalt viscosity does not exceed 122°F (50°C). If steep slopes are anticipated, polypropylene should be used as the base for asphalt and cover aggregate. APAC test results also indicate that a greater asphalt quantity used as a top coat reduces downslope movement of embedded aggregate.

It was found that the Presstite adhesive sealant provides the best adhesion to the polyethylene. If used in conjunction with the polyethylene tape, the Presstite sealant should form an adequate overlap bond. It should be noted that this combined overlap seal method must be applied prior to the final top coat of asphalt and aggregate.

FIELD TESTS AND EQUIPMENT DEVELOPMENT

The development of the jeep mounted plastic dispenser-roller resulted in increased construction efficiency in the installation of the one-half acre catchment at Sells, Arizona. Only minor modifications need to be made to the model developed.

An APAC catchment installation near Camp Verde, Arizona demonstrated the importance of using the right equipment and trained personnel in order to take advantage of inherent difficulties in installing the APAC system. However, the installation also showed that the APAC catchment can be installed, if necessary, using primarily hand labor. There has been sufficient installation experience with the APAC system to project costs to a large scale system with a fair degree of accuracy.

The first field installation of the APAC system for seepage control was made, due to prior commitments before the laboratory results were available. The second installation at the same site of an asphalt polypropylene, asphalt, polyethylene asphalt chip (APAPAC) system was not successful due to the relatively steep slopes of the reservoir sides. This was the only difficulty encountered in field installation of this technique. The APAPAC system is more expensive than the APAC system but hydrostatic laboratory testing indicates that it is a preferred treatment particularly for deeper reservoirs.

RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Although this investigation has exposed some particularly desirable properties of the APAC membrane, further research is needed before conclusive specifications can be compiled and published. Some of the additional research needed for the APAC treatment is as follows:

The puncture resistance of the APAC membrane should be evaluated when protectively covered by different aggregate gradations as well as a layer of fine granular soil.

More slope stability testing is needed to evaluate finer aggregate cover materials such as sand. The use of multiple layers of asphalt and cover aggregate on steep slopes could also be investigated.

The various overlap bonding techniques must be evaluated as to efficiency in seepage control. This phase of testing can be accomplished by utilizing the hydrostatic test vessels or field test pits. Finally, additional adhesives should be evaluated for use in conjunction with polyethylene sheeting.

Additional field installations of the APAC system for seepage control need to be made and evaluated. These installations should be on a small scale until the system is further proven.

Additional tests are needed to develop an inexpensive method of stabilizing cover on steep side slopes. In practice, steep side slopes (greater than 2:1) on reservoirs should be avoided where site conditions permit.

Further observation of the weathering of existing APAC catchments is needed before accurate costs of producing water using this system can be made.

Although additional laboratory investigation and field work is needed, it is evident that the joint use of asphalt and plastic has considerable potential as a water seepage barrier. A comparison of laboratory test results and field data will be needed before a set of specifications on APAC can be compiled and published.

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