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16. Abstract <p>This report presents the results of a laboratory study to evaluate the effectiveness of two proprietary materials, Paczyme and Reynolds Road Packer, for improving the compactability and strength of fine-grained soils.</p> <p>The testing program used to evaluate the materials was developed by FHWA and endorsed by the manufacturers prior to its initiation. The testing program was conducted on four fine-grained soils of three different clay mineralogies typical of those found in the mid-Atlantic States. The effects of Paczyme and Road Packer on (1) Atterberg limits; (2) the optimum moisture content and maximum dry density as determined by AASHTO Methods T 99 and T 180; (3) unconfined and triaxial compressive strength; (4) California Bearing Ratio (CBR); and (5) resistance R-Value and expansion pressure, were determined.</p> <p>Based on the results of the testing program it was concluded that neither Paczyme nor Road Packer produced sufficient alteration of soil properties to be of any practical utility. The ineffectiveness of the materials evaluated was attributed, in part, to the nature of the soils used -- all four were acidic. It has been postulated by researchers conducting a similar, but broader study, that acidic products such as Paczyme and Road Packer may only be effective with neutral or alkaline soils.</p>				13. Type of Report and Period Covered Final Report	
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CONTENTS

INTRODUCTION . . . . . 1

EXPERIMENTAL MATERIALS AND PROCEDURES . . . . . 1

    Soils . . . . . 1

    Compaction Aids . . . . . 3

    Soil-Chemical Mixture Preparation . . . . . 4

    Atterberg Limits . . . . . 6

    Moisture-Density Relationships . . . . . 6

    Unconfined and Triaxial Strength Tests . . . . . 7

    California Bearing Ratio . . . . . 8

    Resistance Value and Expansion Pressure . . . . . 9

DISCUSSION OF RESULTS . . . . . 10

    Atterberg Limits . . . . . 10

    Moisture-Density Relationships . . . . . 11

    Compressive Strength . . . . . 13

    California Bearing Ratio . . . . . 15

    Resistance Value and Expansion Pressure . . . . . 21

    Influence of Related On-Going Research on Interpretation  
    of Results . . . . . 21

SUMMARY AND CONCLUSIONS . . . . . 21

APPENDIX A - Laboratory Testing Program for Evaluation  
            of Paczyme . . . . . 24

APPENDIX B - Program for Treating Soil with Road Packer  
            and Testing Treated Soil . . . . . 26

## INTRODUCTION

The purpose of this study was to evaluate the effectiveness of Paczyme and Reynolds Road Packer for improving the compactability and strength of fine-grained soils.

This investigation was conducted as a part of the Federal Highway Administration's (FHWA) cooperative program with members of chemical industry to develop chemicals for soil improvement or stabilization. Industry's role in this program was to provide the major initiative and effort in the search for suitable new materials for soil improvement. The FHWA's role was to consult with and advise industry, further evaluate partly proven promising materials, and assist in implementing the practical use of materials shown to be effective. The selection of the two materials evaluated in this study was prompted by inquiries from FHWA field offices requesting information on which to base approval or disapproval of their use in Federally-aided construction projects.

Representatives of the Larutan Corporation, Anaheim, California, manufacturers of Paczyme, and the Zel Chemical Company, Portland, Oregon, manufacturers of Reynolds Road Packer, were invited to discuss their products with FHWA, and to submit samples for laboratory evaluation in a mutually acceptable testing program to be developed by FHWA. Based on these discussions, a testing program for each of the materials (Appendixes A and B) was developed by FHWA and approved by the manufacturers, and chemicals were submitted and tested in accordance with the mutually agreeable testing programs.

## EXPERIMENTAL MATERIALS AND PROCEDURES

### Soils

Evaluation of the two proprietary materials was based on the results of tests to determine their effects on four soils. Initially, only two soils, Keyport clay loam and Cecil clay were used. However, after reviewing the test results obtained using these two soils, it was decided to obtain samples of two less plastic soils, Mattapex and Readington silt loam, to further evaluate the effectiveness of Paczyme and Road Packer. Data on the physical, chemical and mineralogical properties of the soils are presented in table 1.

Prior to chemical treatment and testing, the soil samples obtained from the field were prepared in accordance with the method described in Report No. FHWA-RD-73-12, "Mechanical Method of Preparing Soil for Test." This method involves: (1) air drying of samples at 60°C(140°F) or less, and (2) breaking up soil aggregations by rubber-covered rollers.

All tests were performed on that portion of the soil samples passing the No. 10 sieve.

Table 1. Properties of soils

Property	Keyport clay loam	Cecil clay	Readington silt loam	Mattapex silt loam
Percentage passing:				
No. 10 sieve(2.0 mm)	100	100	100	100
No. 40 sieve(0.425 mm)	93	92	93	98
No. 200 sieve(0.075 mm)	59	78	82	87
Percentage finer than:				
0.050 mm	57	74	80	81
0.020 mm	52	61	71	64
0.005 mm	40	47	45	33
0.002 mm	34	41	33	18
0.001 mm	30	39	29	10
Liquid limit	46	56	29	32
Plastic limit	22	30	20	21
Plasticity index	24	26	9	11
Maximum dry density (AASHTO T 99), pcf(kg/m <sup>3</sup> )	110(1762)	99(1586)	114(1826)	112(1794)
Optimum moisture content (percent)	16	24	16	17
AASHTO classification	A-7-6(12)	A-7-5(22)	A-4(6)	A-6(9)
Cation exchange capacity, m.e./100 g.	21.5	6.0	-	-
Calcium content:				
percent	0.15	0.01	-	-
m.e./100 g.	4.0	0.3	-	-
pH	3.9	3.9	4.1	4.2
Major clay mineral	Montmorillonite	Kaolinite	Vermiculite	Vermiculite

## Compaction Aids

1. Paczyme - according to the manufacturer, Paczyme is "a blend of certain surfactants in a fermented base designed to reduce the surface tension of compaction water for better penetration without deleterious effect on the soil being treated." It has also been referred to by the manufacturer as a biocatalytic system containing enzymes. The basic patent covering the material indicates that it contains a fermenting agent from the group consisting of dry yeast and malt; sucrose; a wetting agent from the group consisting of polyethylene glycol of molecular weight between 300 to 1500, a polyoxyethylene fatty alcohol ether, sodium tetradecyl sulfate, and a polyoxyethylene partial fatty acid ester and an antibiotic -- a tetracycline.

The manufacturer indicates that "Paczyme is used in soil stabilization in the following ways:

"Paczyme increases the penetration of water into the soil, thereby achieving optimum moisture with less problems.

"Paczyme treatment decreases the amount of compactive effort required to achieve a given density in a field operation.

"Paczyme treatment increases the strength of many soils through a thixotropic action of the soil particles and by flocculation of the individual soil particles.

"Paczyme treatment can reduce the moisture content of over-wet soils by release of bound water and better drainage conditions, provided that there is an escape route for the 'released' water."

2. Reynolds Road Packer - Literature provided by the Zel Chemical Company indicates that Road Packer is:

"a water soluble hydrocarbon, derived from sulphonated petroleum. A soil conditioner, that lowers the di-pole moment of the oxygen hydrogen bond of the water molecule. A catalyst that induces ion-exchange, is not used up or absorbed by the soil particle, its action is continuous and perpetual in the presence of water.

"REYNOLDS ROAD PACKER solution is an organic solvent, initiating an oxidation plus a simultaneous reducing solution for the chemical preparation of the soil for physical compaction. It alters the organics, colloids, semi-soluble and insoluble constituents in the soils.

"By lowering the di-pole moments of the oxygen hydrogen bonds on the water molecule, ion-exchange takes place by supplying the hydrogen, hydroxyl ions, but most important, turning the hydrogen atom of the hydroxyl ion into a hydronium ion. This H (hydronium) ion can accept or lose either plus or minus charges at will, on demand for chemical soil changes. Chemical reaction is directed to cleaning, creating a more mineral soil, capable of absorbing plus electrical charges on one end, minus charges on the other end. Thru treatment, the soil particles align magnetically, compaction reduces the mass to zero air voids, with each particle having a higher coefficient of friction, the entire compacted mass has an extremely high coefficient of friction. The Zeta potential of soils is decreased by the log under proper compaction."

### Soil-Chemical Mixture Preparation

In a document, "Technical Information for Design and Use of Paczyme," prepared by the Larutan Corporation, it is recommended that "in general, AASHTO soils A-1, A-2 and A-3 will require the use of one gallon of Paczyme per 15 to 50 cubic yards of soil treated, depending on the subgroup and the properties desired. A-4 through A-7 soils can require the use of 1 gallon of Paczyme per 5 to 20 cubic yards of soils treated." To bracket the prescribed rates for the soils used in this study (AASHTO classifications A-4, A-6 and A-7), mixtures were prepared for testing at four rates of application: 1 gallon ( $.004 \text{ m}^3$ ) per 20 cubic yards ( $15.3 \text{ m}^3$ ), 1 gallon ( $.004 \text{ m}^3$ ) per 5 cubic yards ( $3.8 \text{ m}^3$ ), 1 gallon ( $.004 \text{ m}^3$ ) per 2.5 cubic yards ( $1.9 \text{ m}^3$ ), and mixtures for control specimens where tap water only was used in the mixture.

The Paczyme was added to the soil in the compaction water. An amount of a 1/100 stock solution of Paczyme was added to a given amount of air-dry soil to obtain the desired level of Paczyme treatment. For the preparation of specimens for testing, sufficient additional tap water was added to the mixture to bring it to the optimum moisture content as determined by AASHTO Method T 99. The soil-stabilizer mixture was then mixed in a counter-current mixer with muller wheel.

Literature provided by Zel Company presents the following guidelines: "Heavy clays, high organic content: Five gallons of Road Packer 2-3-5 per one thousand gallons of water applied in multiple, light sprinklings to cover 5,000 to 6,000 square feet.

"During treatment allow sufficient time between passes with tank truck so that soil does not become excessively wet or muddy.

"Following chemical treatment apply at least 3,000 gallons of water containing one gallon of Reynolds Road Packer 2-3-5 per 1,000 gallons of water to cover each 5,000 to 6,000 square feet, applied in multiple, light sprinklings over a period of two, three or more days to assure good penetration and to avoid runoff, puddling or excessive muddiness."

In addition, discussions with the manufacturer's representative indicated that after application of the Road Packer 2-3-5 solutions, sufficient water should be sprinkled on the surface so as to cause some water to drain from the bottom of the soil layer.

In order to fulfill the requirements for proper application of Road Packer described in the Zel Company literature and those conditions developed during discussions with their representative, the following procedure was used. One hundred and twenty pounds (55kg) of each of the air dry soils, passing the No. 10 sieve, were mixed in a counter-current mixer with sufficient tap water so as to bring the soils to a moisture content equal to about one-half their optimum moisture as determined by AASHTO T 99. The moist soil was then transferred to a truncated 55-gallon (0.22 m<sup>3</sup>) steel drum (that had been coated inside with asphalt to prevent corrosion by Road Packer) to a depth of about 10 inches (0.25 m) loose. The steel drum had a diameter of 21 inches (0.53 m) providing surface area of the soil of about 2.4 square feet (0.22 m<sup>2</sup>). A number of 1/16-inch (.16 mm) diameter holes were drilled in the bottom of the drum to permit drainage.

One-half gallon (0.002 m<sup>3</sup>) of 5/1000 Road Packer 2-3-5 solution was carefully sprinkled on the surface of the soil. (This amount of solution is equivalent to the rate of application recommended by the manufacturers.) After applying the half gallon (0.002 m<sup>3</sup>) of the 5/1000 solution, the drum, containing the loose soil, was covered with damp burlap and the treated soil permitted to cure for at least 24 hours. During the following several days the soil in the drum was repeatedly sprinkled with a 1/1000 solution of Road Packer 2-3-5 until a total volume of 2 gallons (0.008 m<sup>3</sup>) of 1/1000 solution had been applied.

The soil was sprinkled with an additional half gallon (0.002 m<sup>3</sup>) of tap water after completing the application of the 1/1000 Road Packer 2-3-5 solution in order to cause free drainage suggested by the manufacturer.

Each of the soils was retained in the steel drum for several days, after which it was removed and placed in an oven of 140°F (60°C) for simulated-air drying. After drying, the soil was repulverized to pass a No. 10 sieve and split into appropriate-sized batches for testing.

The above soil preparation procedure was again performed on each of the four soils except that tap water was substituted for the Road Packer solution.

### Atterberg Limits

The effects of Paczyme and Road Packer on the plasticity characteristics of the four soils were determined.

1. Paczyme - The "Design and Use Guide" prepared by the manufacturer indicate that for effective soil treatment the soil-water-Paczyme mixture must be permitted to "dry back" to about three-fourths of its optimum moisture content. In order to fulfill this requirement 50-gram portions of the minus No. 40 sieve fraction of each of the soils was treated with an appropriate amount of 1/100 Paczyme stock solution, to obtain the desired level of treatment, plus water to bring the mixture to its optimum moisture content. The mixture, prepared in an evaporating dish, was then covered with plastic wrap, placed in a humid cabinet and allowed to moist cure for 2 days. After curing, the mixture was removed from the cabinet, uncovered, and allowed to dry back to three-fourths of optimum moisture content. The mixture was then covered and returned to the moisture cabinet and stored overnight to permit redistribution of moisture. The following day the mixture was removed from the moist cabinet and the limits determined in the conventional manner.

2. Road Packer - The liquid and plastic limits of the raw soil and soils that had been treated with Road Packer were determined in the conventional manner, i.e., the tests were conducted on that portion of the Road Packer-treated and water-treated air-dry soils passing the No. 40 sieve.

### Moisture-Density Relationships

1. Paczyme - The standard compaction test (AASHTO T 99) was performed on the Cecil and Keyport soils containing each of the three rates of Paczyme -- 1 gallon (0.004 m<sup>3</sup>) of Paczyme per 20, 5.0 and 2.5 cubic yards (15.3, 3.8 and 1.9 m<sup>3</sup>) of soil. For the Mattapex and Readington soils four rates of Paczyme were used -- 1 gallon (0.004 m<sup>3</sup>) of Paczyme per 50, 20, 5 and 2.5 cubic yards (38.2, 15.3, 3.8 and 1.9 m<sup>3</sup>) of soil. A control test, using tap water only, was performed for each soil.

At the start of each compaction test the desired amount of Paczyme, sufficient to yield the proper concentration at the maximum dry density, was added to the batch of soil. The moisture content was increased for each point of the moisture-density curve by adding tap water.

In addition, the standard compaction test equipment was used to conduct compaction tests at the various rates of Paczyme treatment using less than the standard compactive effort. Series of tests using reduced compactive efforts of 15 and 20 blows per layer were conducted to determine if Paczyme treatment resulted in attainment of T 99 density with less than the standard compactive effort of 25 blows per layer.

2. Road Packer - Standard AASHTO T 99, Method A, and T 180, Method A, compaction tests were performed on the batches of soil and soil-Road Packer mixtures that were previously prepared.

### Unconfined and Triaxial Strength Tests

The effects of Paczyme and Road Packer on the shear strength parameters of the experimental soils were determined by conducting unconfined and triaxial shear tests on soil-stabilizer-water mixtures.

1. Paczyme - For the Cecil and Keyport soils, mixtures sufficient to provide 12 specimens were prepared for each rate of Paczyme (untreated and 1 gallon (.004 m<sup>3</sup>) per 20, 5.0 and 2.5 cubic yards (15.3, 3.8, and 1.9 m<sup>3</sup>) of soil) and compacted to AASHTO T 99 density at optimum moisture content using the Harvard miniature compaction apparatus.<sup>1/</sup> Immediately after compaction each of the specimens was removed from the mold, wrapped in plastic and stored in a moist atmosphere.

The 12 specimens for each rate of Paczyme additive and untreated soil were randomly divided into four groups of three specimens each. One group of three specimens was tested immediately for unconfined compressive strength; a second group of three was tested for unconfined compressive strength after 2 days of moist curing. The other six specimens were moist cured for 2 days, removed from the moisture cabinet and allowed to dry back to three-fourths of their original moisture content and moist cured for an additional 2 days to allow redistribution of moisture. Three of the dried-back specimens were tested for their unconfined compressive strength; the other three were tested in triaxial compression, one with 10 psi (70 kPa) confining pressure, one at 20 psi (140 kPa) and one at 40 psi (280 kPa) confining pressure with no drainage permitted.

The unconfined compressive strength of the Mattapex and Readington soils and for levels of Paczyme treatment of 1 gallon (0.004 m<sup>3</sup>) per 20.0, 5.0 and 2.5 cubic yards (15.3, 3.8 and 1.9 m<sup>3</sup>) of soil was determined using specimens prepared as described for the Cecil and Keyport soils. However, the unconfined compressive strength of uncured and moist cured specimens was not determined because the test results with Cecil and

<sup>1/</sup> Special Proceeding for Testing Soil and Rock Properties for Engineering Purposes, ASTM Special Technical Publication 479, 1970, pg. 101.

Keyport soils demonstrated that Paczyme treatment had no effect on strength for these curing conditions. Also, no triaxial strength tests were conducted with the Mattapex and Readington soils because Paczyme treatment did not alter the shear strength parameters of the Cecil and Keyport soils. However, the unconfined compressive strength of dried-back specimens, which had been compacted to AASHTO T 180 density, in addition to those compacted to AASHTO T 99 density, was measured to determine if increased density had any influence on the effectiveness of Paczyme treatment.

Road Packer - Specimens were compacted using the Harvard miniature compaction apparatus for unconfined compressive and triaxial strength determinations. Six specimens of each of the four soils, both Road Packer-treated and water-treated, were compacted to T 99 maximum density at optimum moisture content. Attempts to compact specimens of Cecil and Keyport soils to T 180 maximum density, using the Harvard apparatus, proved unsuccessful. Therefore, the six specimens for Cecil and Keyport soils were compacted using the maximum practical compactive effort of the Harvard equipment -- 10 layers, 35 tamps per layer, using 40-lb. (15-kg) spring pressure. The average resultant densities were 116 pcf (1858 kg/m<sup>3</sup>) instead of 123 pcf (1970 kg/m<sup>3</sup>) (maximum by T 180) for the Keyport soil, and 109 pcf (1746 kg/m<sup>3</sup>) instead of 112 pcf (1794 kg/m<sup>3</sup>) (maximum by T 180) for the Cecil soil.

Each set of six specimens was tested as follows: three specimens unconfined and one specimen at 10 psi (70 kPa) confining pressure, one at 20 psi (140 kPa) and the third at 40 psi (280 kPa) confining pressure.

Mohr envelopes were drawn and the angle of internal friction and cohesion determined for each of the soils at each of the two compactive efforts.

### California Bearing Ratio (CBR)

1. Paczyme - To measure the effects of Paczyme on CBR, two specimens of each soil, at each of the three rates of paczyme treatment, plus two control or zero-rate specimens, were compacted to AASHTO T 99 maximum density at optimum moisture content. Both specimens were moist cured for 2 days, dried back to three-fourths of their optimum moisture content and moist cured several additional days to allow for redistribution of the moisture throughout the dried-back specimens. After completion of the curing and drying back procedures one specimen was tested immediately and the other after 4 days of soaking. The CBR and percent of swell due to immersion for soaked specimens was determined.

2. Road Packer - The CBR was determined on specimens compacted to AASHTO T 99 and AASHTO T 180 maximum dry density at their respective optimum moisture contents. Three specimens of each of the four soils treated with Road Packer or with water were compacted to T 99 and T 180 density. One of the three specimens for each density was tested unsoaked, the second after 4 days of soaking by total immersion and the third after 4 days of wetting by capillary rise. Capillary wetting was obtained by placing the CBR mold, with perforated base plate, containing the compacted specimen into a tank of water about 4 inches deep. The base of the mold was slightly elevated above the bottom of the tank to permit free access of water to the bottom of the specimen.

After the various conditioning procedures were completed, the CBR and percent swell of the specimens were determined.

#### Resistance Value and Expansion Pressure

The effects of Paczyme and Road Packer treatment on the R-value and expansion pressure for only the Cecil and Keyport soils was determined in accordance with AASHTO T 190-66.

1. Paczyme - For each of the two soils, two specimens were compacted in the standard manner (AASHTO T 190-66) using the kneading compactor for each of the three rates of Paczyme treatment. After compaction, the exudation pressure was measured and the specimen was moist cured in the mold for 2 days. At the conclusion of the 2-day initial curing period all specimens were dried back to three-fourths of the optimum moisture content. Upon drying back to the proper moisture content the specimens were resealed with plastic food wrap and returned to the moist atmosphere to allow the moisture content to equilibrate in the dried-back specimen.

During drying back the soil in the mold shrank and pulled away from the inside walls of the mold, leaving a space between the soil and mold. In order to measure swell pressure, 200 ml. of water is normally added to the top of the specimen and the soil is permitted to swell for 16 hours, under a small surcharge load. The dried-back specimens, however, permitted the water to run off the surface and flow down the side of the soil specimen because of the gap between the soil and mold. To prevent the loss of moisture in this manner, the gap between the soil and the mold at the top of the specimen was sealed with modeling clay to prevent the loss of water, thereby permitting continuation of the test in the normal manner.

2. Road Packer - The R-value and expansion pressure were determined for Road Packer-treated and water-treated Cecil and Keyport soils. The Zel Company representative requested that values be measured for specimens compacted using an effort greater than the standard used in AASHTO T 190-66. It was suggested that specimens be compacted using 1000 psi (7 MPa) tamping foot pressure, in addition to specimens compacted using the AASHTO standard 350 psi (2.45 MPa) foot pressure.

The standard procedure also requires that the compaction pressure be reduced to limit penetration of the tamping ram to 1/4 inch (6 mm). With the Keyport soil, the tamping foot pressures had to be reduced to 190 and 210 psi (1.33 and 1.47 MPa) for the water-treated and Road Packer-treated soils, respectively, to limit penetration of the ram. The Cecil soil had sufficient strength to permit using the 350 psi (2.45 MPa) foot pressure, as in the standard; 480 psi (3.36 MPa) was the maximum compaction pressure yielding less than one-fourth inch penetration and was used in lieu of the 1000 psi (7 MPa) requested by the Zel representative.

The R-value and expansion pressure were determined in the normal manner.

### DISCUSSION OF RESULTS

#### Atterberg Limits

The results of Atterberg limits tests on the experimental soils treated with Paczyme and Road Packer are presented in Tables 2 and 3 respectively. The modest differences between the limits of the treated and untreated soils are considered to result from differences in the individual batches of soil used for testing or experimental error and are not effects of chemical treatment. The results in table 2, for Paczyme treatment, indicate that drying back also had no effect on the limits.

Table 2. Effects of Paczyme on Atterberg limits

Soil	Rate of Paczyme: Cy. yd.soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	: Atterberg limits for curing procedure of			
		: None		: Dried back	
		: Liquid : limit	Plasticity index	: Liquid : limit	Plasticity index
		Percent	Percent	Percent	Percent
Keyport clay loam	0	45	23	46	24
	20.0(3950)	45	22	45	23
	5.0(980)	45	25	45	23
	2.5(490)	45	23	45	23
Cecil clay	0	62	30	61	29
	20.0(3950)	61	30	62	31
	5.0(980)	59	28	61	30
	2.5(490)	60	28	62	31
Readington silt loam	0	35	15	35	15
	20.0(3950)	35	15	35	15
	5.0(980)	34	14	35	15
	2.5(490)	34	14	34	14
Mattapex silt loam	0	31	11	31	10
	20.0(3950)	30	10	31	11
	5.0(980)	31	11	31	11
	2.5(490)	31	12	32	12

Table 3. Effects of Road Packer on Atterberg limits

Soil	Treatment	Liquid limit	Plasticity index
		Percent	Percent
Keyport clay loam	Water	46	24
	Road Packer	43	22
Cecil clay	Water	56	26
	Road Packer	55	25
Readington silt loam	Water	34	14
	Road Packer	36	16
Mattapex silt loam	Water	31	10
	Road Packer	28	10

#### Moisture-Density Relationships

Review of the results of the standard compaction tests, tables 4 and 5, indicate that Paczyme and Road Packer had no significant effect on the maximum dry density or the optimum moisture content of the four soils used in this study. In addition, Paczyme did not cause attainment of the maximum dry density with less than the standard compactive effort.

Review of the maximum dry densities recorded in Table 5 for the Road Packer- and water-treated soils shows that, in seven out of eight cases, the density for the Road Packer treated soil is slightly higher than for the water-treated soil. Although the maximum difference between treated and untreated soil is 2.5 pounds per cubic foot (pcf) (40 kg/m<sup>3</sup>), the effect of Road Packer treatment is not considered significant because it has been demonstrated that the standard deviation associated with the compaction test is about two pcf.<sup>2/</sup> Because differences of two pcf are normally observed on repetitive tests of the same soil, i.e., 95 percent of the maximum densities obtained for a given soil would be within 2.0 pcf (32 kg/m<sup>3</sup>) of the mean, an increase in density of at least 4.0 pcf (65 kg/m<sup>3</sup>) would be required to indicate that the chemical treatment had a significant effect on density.

<sup>2/</sup> Results of soil reference sample program on 14 soils. Program conducted by AASHTO Materials Reference Laboratory (unpublished).

Table 4. Effects of Paczyme on moisture-density relationships

Soil	Rate of Paczyme	Moisture & density for compactive effort (blows/layer) of					
		15		20		25	
		Maximum dry density	Optimum moisture content	Maximum dry density	Optimum moisture content	Maximum dry density	Optimum moisture content
	Cu.yd.soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	Pcf(kg/m <sup>3</sup> )	Percent	Pcf(kg/m <sup>3</sup> )	Percent	Pcf(kg/m <sup>3</sup> )	Percent
Keypoint clay loam	0	105.6(1692)	18.2	108.8(1743)	17.7	110.7(1773)	16.5
	20.0(3950)	106.0(1698)	19.2	108.8(1743)	17.5	110.0(1764)	16.4
	5.0(980)	106.2(1701)	18.9	107.8(1727)	17.3	110.8(1775)	16.6
	2.5(490)	106.0(1608)	18.0	108.2(1733)	17.1	110.0(1762)	17.0
Cecil clay	0	96.4(1544)	24.6	99.3(1591)	21.0	101.0(1618)	22.5
	20.0(3950)	97.1(1556)	24.2	98.4(1576)	22.6	100.0(1602)	22.5
	5.0(980)	96.4(1544)	24.0	99.0(1586)	23.2	100.7(1613)	22.3
	2.5(490)	96.6(1548)	24.0	98.5(1578)	22.8	101.0(1618)	22.0
Readington silt loam	0	110.2(1765)	16.8	113.0(1810)	16.0	113.7(1821)	15.3
	50.0(9860)	110.7(1773)	16.9	111.8(1791)	16.4	114.0(1826)	16.1
	20.0(3950)	110.6(1772)	17.0	111.8(1791)	16.2	113.6(1820)	15.8
	5.0(980)	110.8(1775)	17.2	112.4(1801)	16.1	113.6(1820)	15.8
	2.5(490)	110.6(1772)	17.1	111.9(1793)	16.5	114.4(1833)	15.8
Mattapex silt loam	0	108.5(1739)	17.8	110.8(1775)	17.3	112.1(1796)	16.8
	50.0(9860)	108.0(1730)	18.0	110.2(1765)	17.6	111.4(1785)	16.8
	20.0(3950)	108.2(1733)	18.0	110.6(1772)	17.4	111.6(1788)	17.0
	5.0(980)	108.2(1733)	17.8	109.6(1756)	17.6	112.2(1797)	17.0
	2.5(490)	107.4(1721)	18.4	109.4(1753)	17.4	111.8(1791)	17.0

Table 5. Effects of Road Packer on moisture-density relationships

Soil	Treatment	Compaction values by AASHTO T 99		Compaction values by AASHTO T 180	
		Maximum dry density	Optimum moisture content	Maximum dry density	Optimum moisture content
		Pcf(kg/m <sup>3</sup> )	Percent	Pcf(kg/m <sup>3</sup> )	Percent
Keyport clay loam	Water	109.6(1756)	16.0	122.3(1959)	12.0
	Road Packer	109.4(1753)	16.4	123.6(1980)	11.6
Cecil clay	Water	100.5(1610)	22.0	122.0(1794)	17.6
	Road Packer	102.9(1648)	21.0	122.2(1797)	17.0
Readington silt loam	Water	113.7(1821)	15.3	119.0(1906)	14.1
	Road Packer	114.2(1829)	15.1	121.1(1940)	13.2
Mattapex silt loam	Water	112.1(1796)	16.8	122.2(1958)	12.4
	Road Packer	113.0(1810)	15.8	123.6(1980)	12.7

Compressive Strength

The results of unconfined compressive strength tests for Paczyme and Road Packer treated soils and for untreated soils (control specimens) are presented in tables 6 and 7, respectively.

Review of the results in table 6 indicate that apparently significant differences in strength resulted at various levels of Paczyme treatment. In order to determine the significance of the differences in strength, analysis of variance (ANOVA) tests were performed on the data obtained for each soil-compactive effort-curing procedure combination, i.e., the only source of variation tested for was the rate of Paczyme. These analyses indicated that the rate of Paczyme had a significant effect on the strength specimens of Keyport soil compacted to T 99 density and cured by drying back, of Mattapex soil compacted to T 99 density and moist cured 2 days, and of Readington soil compacted to T 180 density and cured using the drying back procedure. ANOVA performed on the data for all other soil-compactive effort-curing combinations indicated that the rate of Paczyme had no effect on strength.

In order to determine if the significant differences detected by the ANOVA between the average strengths for the various rates of treatment, another statistic -- the Least Significant Difference (LSD)<sup>3/</sup> was calculated for these three sets of observations. This statistic was required because the ANOVA indicates whether or not there are significant differences among the rates of Paczyme treatment; it does not indicate which values differ significantly. The LSD for the Keyport soil (compacted to T 99 density and cured by drying back) was 7 psi (49 kPa), indicating that the 7 psi (49 kPa) difference in strength between the untreated soil and the average of the specimens treated at the 1 gallon (.004 m<sup>3</sup>) per 2.5 cubic yards (1.9 m<sup>3</sup>) is statistically significant. The

<sup>3/</sup> LSD=t<sub>.05</sub>,

$$\sqrt{\frac{\text{error mean square} \times 2}{\text{number of replicates}}}$$

Table 6. Effects of Paczyme on unconfined compressive strength

Soil	Rate of Paczyme	Unconfined compressive strength				
		No Curing	2 Days moist		Dried back	
		T 99	T 99	T 180	T 99	T 180
	Cu.yd.soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	Psi (kPa)	Psi(kPa)	Psi(kPa)	Psi(kPa)	Psi(kPa)
Keyport clay loam	0	57(399)	61(427)	-	186(1092)*	-
	20.0(3950)	58(406)	60(420)	-	175(1225)	-
	5.0(980)	59(413)	59(413)	-	175(1225)	-
	2.5(490)	59(413)	61(427)	-	193(3151)	-
Cecil clay	0	71(497)	72(504)	-	275(1925)	-
	20.0(3950)	73(511)	73(511)	-	279(1953)	-
	5.0(980)	75(525)	75(525)	-	283(1981)	-
	2.5(490)	68(476)	71(497)	-	275(1925)	-
14 Readington silt loam	0	-	73(511)	90(630)	171(1197)	336(2352)*
	20.0(3950)	-	73(511)	98(686)	213(1491)	333(2331)
	5.0(980)	-	81(567)	85(595)	221(1547)	356(2492)
	2.5(490)	-	67(469)	86(602)	184(1288)	312(2184)
Mattapex silt loam	0	-	76(532)*	152(1054)	233(1631)	219(1533)
	20.0(3950)	-	66(462)	148(1036)	231(1617)	248(1736)
	5.0(980)	-	84(588)	149(1043)	221(1547)	241(1687)
	2.5(490)	-	92(644)	153(1071)	227(1589)	243(1701)

\*Analysis of variance indicates significant effect of rate on strength

LSD for the Readington soil (T 180 density, dried back) was 29 psi (203 kPa), indicating that the 20 psi (140 kPa) difference between the untreated soil, the highest strength value for the Paczyme treated soil, is not significant. For the Mattapex soil (T 99 density, moist cured) the LSD value is 10 psi (70 kPa), indicating that the untreated soil and the 1 gallon (.004 m ) per 5.0 and 2.5 cubic yards (3.2 and 1.9 m ) are both significant.

Review of the data presented in table 7 indicates that Road Packer treatment of the four experimental soils also had some significant effect on the unconfined compressive strength. Although statistical analysis (t-test) of the data indicate that the average strength for the treated and untreated soils is different, in three out of the six cases where differences occurred the strength of the Road Packer-treated soil specimens was lower than for specimens of the untreated soil.

Review of the moisture content and density data presented in table 7 indicates that the observed differences in strength are not attributable to differences in density between sets of specimens. In summary, the results of the unconfined compressive strength tests to evaluate the effectiveness of Road Packer are inconclusive.

The results of triaxial compression tests for Cecil and Keyport soils treated with Paczyme are presented in table 8. The data presented were derived by drawing Mohr strength envelopes and graphically measuring the angle of internal friction and cohesion values. The four strength envelopes for the Cecil soil were almost colinear, indicating that Paczyme had no effect on the shear strength of that soil. The results for the Keyport soil indicate that Paczyme applied at the 1 gallon (.004 m ) per 2.5 cubic yards (1.19 m ) rate provided an increase in strength for that soil as evidenced by the fact that the angle of internal friction was 30 degrees higher than for the untreated soil. However, a substantial decrease in the cohesion was also recorded.

Triaxial test results for the four experimental soils treated with Road Packer are presented in table 9. These data indicate that Road Packer had no significant effect on the shear strength of the four soils tested.

During the conduct of the unconfined compressive strength tests, stress-strain curves were also developed. Although the curves are not presented, they indicate that neither Paczyme nor Road Packer had any effect on the slope of the stress-strain curve or the percent of strain at failure.

#### California Bearing Ratio (CBR)

In order to evaluate the effects of Road Packer and Paczyme on the CBR value of the experimental soils, an attempt was made to obtain an estimate of the precision of the CBR test method. The precision of the test method is required to determine if differences between the values recorded in tables 10 and 11 for treated and untreated soils could be attributed to experimental error, inherent in the method, or to chemical treatment.

Table 7. Effects of Road Packer on unconfined compressive strength

Soil	Treatment	:Specimens at T 99 target density			:Specimens at T 180 target density		
		: Density	: Moisture	: Strength	: Density	: Moisture	: Strength
		: Pcf(kg/m <sup>3</sup> )	: Percent	: Psi(kPa)	: Pcf(kg/m <sup>3</sup> )	: Percent	: Psi(kPa)
Keyport clay loam	Water	112.2(1797)	16.2	63(441)	117.9(1889)	17.3	46(322)*
	Road Packer	111.3(1783)	16.9	59(413)	114.0(1826)	17.2	54(378)
Cecil clay	Water	101.5(1626)	21.6	50(420)*	109.0(1746)	21.2	65(455)
	Road Packer	103.4(1656)	20.7	55(385)	109.4(1753)	20.9	59(413)
Mattapex silt loam	Water	112.1(1796)	16.8	48(336)*	122.2(1958)	12.4	106(742)*
	Road Packer	113.0(1810)	15.8	62(434)	123.6(1980)	12.7	121(847)
Readington silt loam	Water	113.7(1821)	15.3	59(413)*	119.0(1906)	14.1	72(504)
	Road Packer	114.2(1829)	15.1	46(322)	121.1(1940)	13.2	71(497)

\*Statistical analysis (student's t-test) indicates that there is a difference in average strength

Table 8. Effect of Paczyme on shear strength parameters

Soil	Rate of Paczyme	Density	Moisture content at time of test	Cohesion	Angle of internal friction
	Cy. yd. soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	Pcf(kg/m <sup>3</sup> )	Percent	Psi(kPa)	Degrees
Keyport clay loam	0	110.2(1765)	13.6	83(581)	6.8
	20.0(3950)	110.6(1772)	13.3	62(434)	19.8
	5.0(980)	110.7(1773)	13.3	65(455)	18.8
	2.5(490)	110.4(1769)	12.7	48(336)	36.5
Cecil clay	0	100.8(1615)	16.2	85(595)	27.9
	20.0(3950)	101.9(1632)	16.2	92(644)	23.8
	5.0(980)	102.2(1637)	16.3	90(630)	25.6
	2.5(490)	100.7(1613)	16.2	88(616)	25.2

Table 9. Effects of Road Packer on shear strength parameters

Soil	Treatment	Specimens prepared at AASHTO T 99		Specimens prepared at AASHTO T 180	
		Cohesion	Angle of internal friction	Cohesion	Angle of internal friction
		Psi(kPa)	Degrees	Psi(kPa)	Degrees
Keyport clay loam	Water	26(182)	9.5	16(112)	11.9
	Road Packer	23(161)	9.5	16(112)	17.6
Cecil clay	Water	20(140)	14.5	20(140)	17.6
	Road Packer	14( 98)	25.6	18(126)	18.5
Readington silt loam	Water	15(105)	36.2	16(112)	41.7
	Road Packer	13( 91)	36.5	18(126)	35.5
Mattapex silt loam	Water	16(112)	25.5	28(196)	33.0
	Road Packer	18(126)	29.0	28(196)	36.5

Table 10. Effects of Paczyme on California Bearing Ratio

Soil	Rate of Paczyme	Soaked			Unsoaked	
		Drying shrinkage	Swell	CBR	Drying shrinkage	CBR
	Cu.yd.soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	Percent	Percent	Percent	Percent	Percent
Keyport clay loam	0	1.36	2.69	6.4	1.52	51.7
	20.0(3950)	2.10	2.15	7.4	1.42	54.6
	5.0(980)	2.20	2.25	7.3	0.87	67.8
	2.5(490)	1.23	3.36	6.3	0.84	55.7
Cecil clay	0	1.77	2.46	8.0	3.12	79.0
	20.0(3950)	1.52	2.61	8.1	1.80	78.2
	5.0(980)	1.52	3.53	6.6	1.61	88.3
	2.5(490)	2.20	2.79	7.2	1.84	65.5
Readington silt loam	0	-	0.15	10.0	-	32.5
	20.0(3950)	-	0.20	11.5	-	34.0
	5.0(980)	-	0.21	14.0	-	41.0
	2.5(490)	-	0.26	15.0	-	36.0
Mattapex	0	-	-	-	-	41.0
	20.0(3950)	-	0.49	5.5	-	42.0
	5.0(980)	-	0.08	5.5	-	40.0
	2.5(490)	-	0.69	6.0	-	43.5

The American Society for Testing and Materials (ASTM) has developed Precision Statements for many of their Standard Methods of Test and a Standard Recommended Practice for Preparing Precision Statements for Test Methods for Construction Materials (Designation C670-75). However, a Precision Statement for the CBR test (ASTM Designation D1883-73, "Bearing Ratio of Laboratory-Compacted Soils") has not yet been prepared. The fundamental statistic of precision used by ASTM is the standard deviation or "one-sigma limit." In order to provide some measure of the "precision" of the test method, as performed in the FHWA Laboratory, seven repetitions of the test were conducted with the Keyport soil compacted to each of the AASHTO T 99 and T 180 densities and the resultant standard deviations calculated. The standard deviation for specimens using the T 99 effort was 1.4 while that for the T 180 effort was 4.8. Although the standard deviations obtained in the FHWA Laboratory are not adequate to serve as a "reliable estimate of the true precision" as defined by ASTM, they are the only data available to assist in the interpretation of the CBR test results. ASTM has selected the "difference two-sigma limit ( $D2S = (1S) \times 2\sqrt{2}$ )" as an appropriate index of precision for ASTM methods. The (D2S) index indicates the difference between two results on test portions of the same material that would be equaled or exceeded in the long run in only 1 case in 20 in the normal and correct operation of the method. In addition, ASTM indicates that "if the standard deviation is essentially proportional to the average of the property in question (i.e., the coefficient of variation is essentially constant) then the "one-sigma limit in percent (1S%)" and "difference two-sigma limit in percent (D2S%)" shall be given. The coefficient of variation for specimens compacted to AASHTO T 99 density is  $\frac{1.4}{17.9} = .078$ ; while the coefficient of variation for

specimens compacted to AASHTO T 180 density is  $\frac{4.8}{73.3} = .065$ . Because the coefficient of variation is essentially constant (.078 and .065) for the two levels of CBR the use of 1S% and D2S% to help interpret the CBR test results is deemed appropriate. For the FHWA Laboratory, 1S%  $\cong .07 \times 100 \cong 7$  percent, the D2S%  $\cong (7.0 \times 2\sqrt{2}) \times 100 \cong 19.8 \cong 20$  percent. The D2S% statistic indicates that the CBR values for the treated and untreated soil materials would have to differ by more than 20 percent in order to indicate that chemical treatment had an effect on the CBR test results.

Applying the criteria that the CBR of the chemically treated soil must be 20 percent higher than for the untreated soil to the results presented in table 10 indicates that Paczyme increased the CBR of only one soil -- Keyport clay loam -- when applied at a rate of 1 gallon of Paczyme for 5 cubic yards of soil. Paczyme was ineffective for increasing the CBR of the other three soils at the three rates of application used in this study. Similarly, using the criteria that a 20 percent increase in CBR must be observed to indicate a "real" effect of chemical treatment to the CBR results for Road Packer treatment of the four experimental soils presented in table 11, indicates that Road Packer effectively increased the CBR value for the Keyport and Readington soils when compacted to T 180 density. For the Cecil and Mattapex soils compacted to T 180 density significant decreases in CBR were observed. However, these effects were eliminated by soaking, indicating that Road Packer affords no protection against the detrimental effects of moisture. The lack of protection against moisture effects is further demonstrated by the observation that Road Packer had very little influence on the amount of swell recorded.

Table 11. Effects of Road Packer on California Bearing Ratio

Soil	Treatment	Specimens prepared at AASHTO T 99						Specimens Prepared at AASHTO T 180					
		Unsoaked		Capillary		Soaked		Unsoaked		Capillary		Soaked	
		CBR	Swell	CBR	Swell	CBR	Swell	CBR	Swell	CBR	Swell	CBR	Swell
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	
Keyport clay loam	Water	17.9	-	19.4	0.23	8.1	1.15	73.3	-	85.2	0.08	3.9	5.35
	Road Packer	17.7	-	17.8	0.28	3.9	1.23	97.2	-	102.5	0.05	3.7	4.66
Cecil clay	Water	17.2	-	15.5	0.21	10.1	0.72	87.0	-	59.8	0.66	4.8	4.10
	Road Packer	16.9	-	16.7	0.18	12.1	0.52	72.7	-	57.1	0.52	6.5	3.15
Readington silt loam	Water	17.0	-	9.5	0.08	9.0	0.33	14.0	-	16.0	0.00	11.0	0.52
	Road Packer	8.5	-	11.0	0.03	7.9	0.46	31.0	-	20.5	0.05	14.0	0.44
Mattapex silt loam	Water	7.8	-	8.5	0	7.0	0.42	86.0	-	78.0	0.23	19.0	1.85
	Road Packer	15.0	-	10.0	0.05	5.5	0.42	47.0	-	40.0	0.08	14.0	1.01

## Resistance Value and Expansion Pressure

Results of resistance R-value and expansion pressure of Keyport and Cecil soils treated with Paczyme and Road Packer are presented in tables 12 and 13. The only deviation from the standard procedure (AASHTO Method T 190) was that a pair of specimens using Cecil soil (one Road Packer treated and one water-treated) were compacted using 480 psi (3360 kPa) tamping foot pressure, in addition to a pair using the standard 350 psi (2450 kPa).

The data indicate that neither Paczyme nor Road Packer afforded any appreciable effect on the R-value or expansion pressure of the two soils. The treatments resulted in a very slight increase in R-value which perhaps can best be interpreted by use of pavement design charts developed for California. The pavement design charts indicate that use of Paczyme or Road Packer would afford a savings of 2 inches or less of travel if the subgrade soils were treated with either of the materials.

## Influence of Related On-Going Research on Interpretation of Results

Researchers at Iowa State University are conducting a comprehensive evaluation of chemical compaction aids for fine-grained soils; their preliminary findings have some bearing on the results of this study.

Results of the Iowa State University pilot laboratory study, (made subsequent to the tests in the study) indicate that the effects of compaction aids on maximum density are not evident when the compaction test is conducted in the normal manner, i.e., moisture-density (M-D) specimens are produced by breaking up the previously molded specimen of the M-D run, adding additional chemical and/or water, remixing and recompacting. They indicate that when a freshly-mixed soil-water, or soil-chemical concentration specimen was prepared for each point on the M-D curve, significantly different curves were produced. The effects of Paczyme and Road Packer on maximum density might not have been observed in the FHWA study because the compaction tests were run in the normal manner.

Results of the Iowa State University study have also led to the hypothesis that acidic compaction aids might not be effective with acidic soils. Because Paczyme and Road Packer are extremely acidic, pH 3.3 and 1.5, respectively, they may not have been effective with the acidic soils used in the FHWA investigations.

## SUMMARY AND CONCLUSIONS

The effects of two proprietary materials, Paczyme and Road Packer, on the moisture-density relationships, Atterberg limits, unconfined and triaxial compressive strength, CBR and resistance R-value of four soils were evaluated in the laboratory. The soils were treated with the pro-

Table 12. Effects of Paczyme on R-value and expansion pressure

Soil	Rate of Paczyme	Expansion pressure at 300 psi exudation pressure	R-value at 300 psi exudation pressure
	Cu.yds.soil/gal. (m <sup>3</sup> soil/m <sup>3</sup> ) Paczyme	Psi (kPa)	
Keyport clay loam	0	0.9 (6.3)	29
	20.0(3950)	1.0 (7.0)	36
	5.0(980)	0.8 (5.6)	37
	2.5(490)	1.4 (9.8)	25
Cecil clay	0	6.0 (42)	48
	20.0(3950)	4.8 (33.6)	48
	5.0(980)	5.0 (35.0)	48
	2.5(490)	4.7 (32.9)	54

Table 13. Effects of Road Packer on R-value and expansion pressure

Soil	Treatment	Tamping foot pressure	Expansion pressure at 300 psi exudation pressure	R-value at 300 psi exudation pressure
		Psi (kPa)	Psi (kPa)	
Keyport clay loam	Water	190(1330)	0.5(3.5)	13
	Road Packer	210(1470)	0.15(1.05)	13
Cecil clay	Water	350(2450)	0.4(2.8)	29
	Road Packer	350(2450)	3.2(22.4)	36
	Water	480(3360)	3.0(21)	36
	Road Packer	480(3360)	2.8(19.6)	32

prietary materials at rates of application and in such a manner as to conform to the instructions provided by the manufacturers. The type of tests and the manner in which they were performed were mutually acceptable to the manufacturer and the FHWA.

The results of this investigation indicate that neither Paczyme nor Road Packer significantly improved the engineering characteristics of the four soils tested.

Based on the results of the laboratory tests conducted using four fine-grained soils the following conclusions are warranted:

1. Neither Paczyme nor Road Packer had any significant effect on the optimum moisture content or maximum dry density as determined by AASHTO Methods T 99 and T 180.
2. Paczyme treatment did not cause attainment of maximum T 99 density by using less than the standard compactive effort.
3. Although statistical analyses demonstrated that Paczyme and Road Packer increased the unconfined compressive strength for some of the soils under certain conditions of density and curing, the magnitude of the strength increase is deemed too small to be of any practical utility.
4. The increases in strength detected in the unconfined compressive strength test were not confirmed by triaxial tests, i.e., the strength envelopes for the raw soils and Paczyme and Road Packer treated soils were almost colinear.
5. Neither Paczyme nor Road Packer had any effect on the slope of the stress-strain curve or the percent of strain recorded at failure.
6. Paczyme had no effect on the CBR value for the four soils. Road Packer, however, significantly increased the CBR of the Keyport and Readington soils when compacted to AASHTO T 180 density.
7. Neither of the products had any effect on the ability of the soils to resist the detrimental effects of water, i.e., soaked CBR values were much lower than for unsoaked values regardless of whether the soil was treated or untreated.
8. Treatment with either of the products had little effect on the R-value or expansion pressure of the four experimental soils.

## APPENDIX A

A copy of the testing program described below was submitted to the Larutan Corporation, manufacturers of Paczyme, for their review and comment. The evaluation testing program was acceptable in total to the Larutan Corporation. Detailed information concerning soil-water-Paczyme mixture and specimen preparation and the conduct of the various tests are available from the Materials Division, Office of Research, FHWA.

### Laboratory Testing Program for Evaluation of Paczyme

#### Unconfined Compressive Strength (UCS)

Prepare specimens at AASHTO T 99 optimum moisture-maximum density; using water alone and water plus appropriate rates of Paczyme. Determine UCS of some specimens immediately and of others after 2-day moist cure; moist cure others 2 days, then dry back slowly to appropriate intermediate moisture content (perhaps 3/4 of original moisture content); test for strength.

The above procedure evaluates any thixotropic hardening. The guide (page 3) claims that drying back is necessary. The procedure also determines whether the effect of drying is different for water + Paczyme specimens than it is for specimens treated with water only.

#### CBR, R-Value and Triaxial Tests

The design and use guide states that for these three tests, specimens must have an "air-cure period" - i.e., a drying back from the moisture content at which the specimens are compacted. Otherwise, no benefit is claimed. Prepare test specimens with water alone and others with water plus Paczyme, and after about 2 days of moist curing each specimen must be dried back to a suitable moisture content -- possibly to about 3/4 of that at which the specimen was compacted. Wrap, equilibrate and then test. Include measurement of swell in CBR and R-Value tests.

#### Plasticity

The guide indicates little or no effect on plasticity. Larutan's data, however, indicate some increase in plasticity due to Paczyme treatment. We should therefore perform plasticity tests at appropriate rates of Paczyme. Include normal liquid addition as well as drying back some after addition, then rewetting.

### Permeability and Capillarity

The guide indicates that Paczyme reduces permeability and increases capillarity. As these effects should depend on increased density, there should be no need to study them separately.

NOTE: If the capillarity of a soil increases, frost susceptibility may increase.

### Penetration of Water

In the design and use guide the claim is made that Paczyme increases the penetration of water into the soil. In the field this could be significant in watering operations for achieving optimum moisture content. To determine the effect of Paczyme on penetration, prepare a glass cylinder having a diameter of about 2 inches, let top open but fasten screen and gauze to bottom to retain soil, fill to depth of about 2 feet with dry pulverized experimental soil, cover soil surface with sand to prevent puddling, add at appropriate rate sufficient water or Paczyme-water solution to wet soil to a depth of about 1 foot. Note time to attain greatest depth of penetration and measure this depth. Then note time and add sufficient solution to cause liquid to drip from the bottom of the specimen, catch the percolate. Note time first percolate emerges and the amount of percolate obtained. If desired, apply further increments of water, note times of application and end of percolation and measure percolate.

If desired, the same experiment can be performed using soil pre-moistened to about half of optimum-moisture content. With dry as well as moist soil, care should be taken to have the soil depth at start be the same for replicated specimens.

### Paczyme-soil-cement

Increased unconfined compressive strength is claimed, a drying-back being required. Appropriate soil-cement specimens should be prepared at cement requirement percentage and at a lower percentage, using water alone and water + Paczyme. After 2 days of moist curing some specimens should be air-cured (dried back) for 2 days, returned to moist curing for the remaining 3 days and then tested. Other duplicate specimens should be moist cured throughout the 7-day period and then tested.

### Optimum Moisture-Maximum Density-Compactive Effort

The design and use guide claims that Paczyme reduces the amount of compactive effort required to achieve a given density. Perform standard AASHTO T 99 optimum moisture-maximum density tests using water alone and water plus appropriate rates of Paczyme. Make identical series of tests using two or more reduced compactive efforts.

## APPENDIX B

A copy of the testing program described below was submitted to the Zel Chemical Company, manufacturers of Road Packer, for their review and comments. Zel's only comment was that they would prefer that air-dry soil be brought to optimum moisture content by sprinkling with a 5/1000 solution of Road Packer. FHWA maintained that very few soils in the field would be in the air-dry condition and require the addition of an amount of water or Road Packer solution equal to the optimum moisture content. As a compromise, the air-dry soil was mixed with an amount of tap water sufficient to bring to about one-half the optimum moisture content prior to sprinkling with the Road Packer solution.

### Program for Treating Soil with Road Packer and Testing the Treated Soil

Soil for treatment should be moderately or highly plastic (maximum PI of 60), air-dry, pulverized to pass the No. 4 sieve. Treatment of the soil should be performed in the laboratory at normal laboratory temperature and humidity. Soil should be placed loose to a depth of 6 to 12 inches in a bucket-like or box-like plastic container having a perforated bottom to provide for free drainage of percolating liquid. A cloth or equivalent filter pad on the upper surface of the perforated bottom prevents the soil from being lost through the perforations. The loose soil in the plastic container is brought to about optimum moisture content (AASHTO T 99) by a series of light sprinklings with water. Then, to the surface of the moistened soil, a solution of Road Packer 2-3-5 in water (5 gallons of Road Packer to 1000 gallons of water) is applied in a series of light sprinklings, in the amount recommended in the Zel Chemical Company's leaflet (1 gallon of solution per 5 to 6 square feet of soil surface).

The amount of solution applied in a single sprinkling will depend on the soil's ability to absorb the solution; whereas in field application the solution is normally applied slowly enough that runoff does not occur, in the laboratory the solution may briefly cover the soil surface so long as all of the solution finally penetrates the soil and none is lost by overflowing.

The time required for the sprinkling application of the 5 to 1000 solution may vary from a few minutes to several hours. When the application is complete, the soil is allowed to cure in the container for not less than 24 hours in the same laboratory conditions - undisturbed, lightly covered with cloth to minimize evaporation, but not made air-tight. At the end of the curing period, the surface of the soil is lightly scarified to a depth of 1/2 to 1 inch and a second solution of Road Packer (1 gallon of Road Packer 2-3-5 to 1000 gallons of water) is applied to the scarified surface in a series of light sprinklings. The total volume of second (1 to 1000) solution to be applied will be at least three times that

of the first (5 to 1000) solution. The amount of the second solution in a given sprinkling will depend on the soil's ability to absorb the solution; whereas, in field application the solution is normally applied slowly over a 2-day or longer period to ensure that runoff does not occur, in the laboratory the solution may briefly cover the soil surface so long as all of the solution finally penetrates the soil and none is lost by overflowing. The time required for the series of sprinklings of the second solution may vary from a few minutes to several hours.

Following the series of sprinklings of the second solution, the treated soil is permitted to remain in the container until drainage of liquid ceases, and is then removed and spread over a suitable surface for air-drying, or placed in an oven equipped for fan-driven air circulation and dried at 140°F. The drying operation will be continued until the moisture content is reduced to optimum (AASHTO T 99) or lower; it can be continued until the soil is fully air-dry or 140°F oven-dry. The dried or partially dried, treated soil is pulverized to pass a No. 4 sieve and stored in a suitable container, from which representative portions are removed for the preparation of test specimens; this soil will be referred to as the Road Packer-treated soil. Some of the treated soil may be further pulverized to pass a No. 40 sieve to provide material for plasticity tests.

A duplicate sample of the untreated soil will be subjected to the same operations and treatments as described above, except that all of the liquid employed will be ordinary tap water. The resulting soil material will be referred to as water-treated soil.

The treated (both Road Packer-treated and water-treated) soil will be subjected to tests for plasticity, optimum moisture-maximum density (AASHTO T 99 and T 180), grain size distribution, shrinkage limit, volume change (AASHTO T 116). The following strength tests will be performed:

1. Triaxial compressive strength
2. Unconfined compressive strength
3. CBR, regular and modified to provide increased compactive effort and wetting by capillary rise rather than by immersion.
4. R-value, regular with specimens prepared at 350 psi foot pressure, and modified to provide 1000 psi foot pressure.

