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THE PERFORMANCE OF CEMENT-STABILIZED PHOSPHOGYPSUM AS BASE STATE HIGHWAY 146, LA PORTE, TEXAS

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Technical Report Documentation Page

1. Report No. DHT-11	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Performance of Cement-Stabilized Phosphogypsum As Base State Highway 146, La Porte, Texas		5. Report Date October, 1988 6. Performing Organization Code
7. Author(s) Constance Wong and Michael K. Ho, P. E.		8. Performing Organization Report No. DHT-11
9. Performing Organization Name and Address State Department of Highways and Public Trans. Transportation Planning Division P.O. Box 5051 Austin, Texas 78763		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address State Department of Highways and Public Trans. 11th and Brazos Austin, Texas 78701		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

In 1983, Dr. William Ledbetter and Dr. Donald Saylak, along with Mobil Mining Co., approached the Texas Department of Highways and Public Transportation about using cement stabilized phosphogypsum as road base in an experimental test section. By February 1987, design work have begun and in May 1987, part of the base had been put down. In this paper, performance of 15 inches of phosphogypsum from Pile 2 at the Mobil plant, stabilized with Type II portland cement as road base, is documented.

17. Key Words Phosphogypsum gypsum stabilized phosphoric acid plasticity radioactive	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		65	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

THE PERFORMANCE OF CEMENT-STABILIZED PHOSPHOGYPSUM AS BASE STATE HIGHWAY 146, LA PORTE, TEXAS

By Constance Wong and Michael K. Ho, P.E.

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The Performance of Cement-Stabilized Phosphogypsum as Base

State Highway 146, La Porte, Texas

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Acknowledgements to those in the State Department of Highways and Public Transportation, District 12:

Joel Gonzales, Genoa Residency, for technical information;
Charles Frey, Genoa Resident Engineer, and Gaston Villalongin, Genoa Residency, for information, feedback and pictures;
Stanley Yin, District Laboratory, Assistant Engineer, for help with Dynaflect program and comments on paper;
Terry Martin, District Laboratory, for coring;
Jesse Sun, Central Design - D, for some graphics.

INTRODUCTION

Phosphogypsum is a solid waste by-product derived from wet process phosphoric acid reactions used in making fertilizers.[1] Mobil Chemical Company has been producing phosphogypsum since the end of World War II.[2] The wet process, which is most often employed, uses finely ground phosphate rock [$Ca_{10}F_2(PO_4)_6$] dissolved in phosphoric acid and subsequently reacted with sulfuric acid. Finally, the calcium sulfate is separated from phosphoric acid by filtration. The temperature of the reaction and concentration of phosphoric acid determines the dominating crystal type, which in turn pre-determines the amount of phosphoric acid left, the phosphogypsum properties, as well as the engineering properties.[3] Out of the three crystal forms (anhydrite, hemihydrate, dihydrate), the most common crystal type found is dihydrate[4]: $CaSO_4 \cdot 2H_2O$. The in-situ water content in phosphogypsum was found to range from 7% to 9% [5] and pH from 2 to 5.[6] Unlike clay, it is low in plasticity, but like clay, it can absorb water.[7] If dried above 104° F, chemically bound water is expelled, altering its chemical makeup and, consequently, its engineering properties.[8]

Phosphogypsum is known to be slightly radioactive. Radiation in Florida stockpiles averaged 0.78 disintegrations/second/gram and may be greater if finely graded.[9] Besides the radioactivity in its natural state, phosphogypsum may emit radioactive gas when mixed with construction acid, and the exposure, in terms of cancer risk, is like smoking one cigarette a month.[10]

From World War II through 1983, 25 million tons of phosphogypsum accumulated and have been piled in three stacks outside the Mobil plant in Houston, Texas.[11] In Florida, 334 million tons are already stockpiled, and the tonnage will increase to a billion by the year 2000.

United States' annual consumption of natural gypsum in 1979 was 22.5 million tons. The primary uses for gypsum include wallboard and cement retarder, while it serves in lesser capacities as a source of sulfur, a constituent of plaster and an agent in the reclamation of sodic soils.[12] As a cement retarder, gypsum controls early exothermic reactions of tricalcium aluminates in portland cement. Calcium aluminate hydrates and monosulfates are converted to ettringite in the presence of water and sulfate ions. This sulfate attack or delayed expansion, although primarily strengthening, can be destructive eventually due to the growth of ettringite crystals.[13] Phosphogypsum has not been used in the manufacturing of these products mainly because the supply of natural gypsum exceeds its demand.[14]

It is important to note phosphogypsum differs from fluorogypsum, also a solid waste by-product. At Dupont, the production of fluorogypsum stems from reacting fluorite, calcium fluoride, with sulfuric acid to yield calcium sulfate and hydrogen fluoride. Since the two gypsums were derived from different chemical processes, subtleties in chemical composition probably affect their performances as engineering materials. As an example of how chemistry affects performance, it was discovered that phosphogypsum from Pile 2, higher in pH relative to Pile 3, had greater unconfined compressive strength than phosphogypsum from Pile 3. The difference in strength of the phosphogypsum was attributed to the difference in pH. While the fluorogypsum is marketed as base, the hydrogen fluoride is marketed as a catalyst for petroleum processes, a fluoride source, a cleaning agent, an insecticide ingredient, fermentation arrestor and as an ingredient in numerous other products.

OVERVIEW

In 1983, Dr. William Ledbetter and Dr. Donald Saylak, along with Mobil Mining Company, approached the Texas Department of Highways and Public Transportation about using cement stabilized phosphogypsum as road base in an experimental test section. By February 1987, design work had begun and in May 1987, part of the base had been put down. In this paper, performance of 15 inches of phosphogypsum from Pile 2 at the Mobil plant, stabilized with Type II portland cement as road base, is documented. Figure 1 shows the location of State Highway 146 in La Porte, Texas, where the test base was put down. This material was placed on the northbound feeder road of State Highway 146 at different times and areas, as shown in Figures 2 and 3. Note that 9 percent cement stabilized phosphogypsum was placed from Station 424 + 02.5 to Station 442 + 28 and from Station 509 + 80 to Station 516 + 40. However, 6 percent cement with 80 percent phosphogypsum plus 20 percent sand was placed from Station 507 + 78 to Station 509 + 80. Thicknesses were 15 inches in all places, except for approximately the last 100 feet, which only saw 6 inches of base.

PRELIMINARY TESTING

Preliminary design criteria, including specifications and planned sections, are listed in Figures 4 to 8. Specification Item No. 2056 is listed by article number on Figures 4A, 4B, 4C and 4D, while planned sections occupy Figures 5 to 8. After preliminary considerations, testing of the material mixed with cement proceeded. Testing included determination of moisture-density curves and compressive strengths of samples. In the laboratory at Terra Mar Inc., the first curve, shown in Figure 9, was done at 6 percent cement plus phospho-

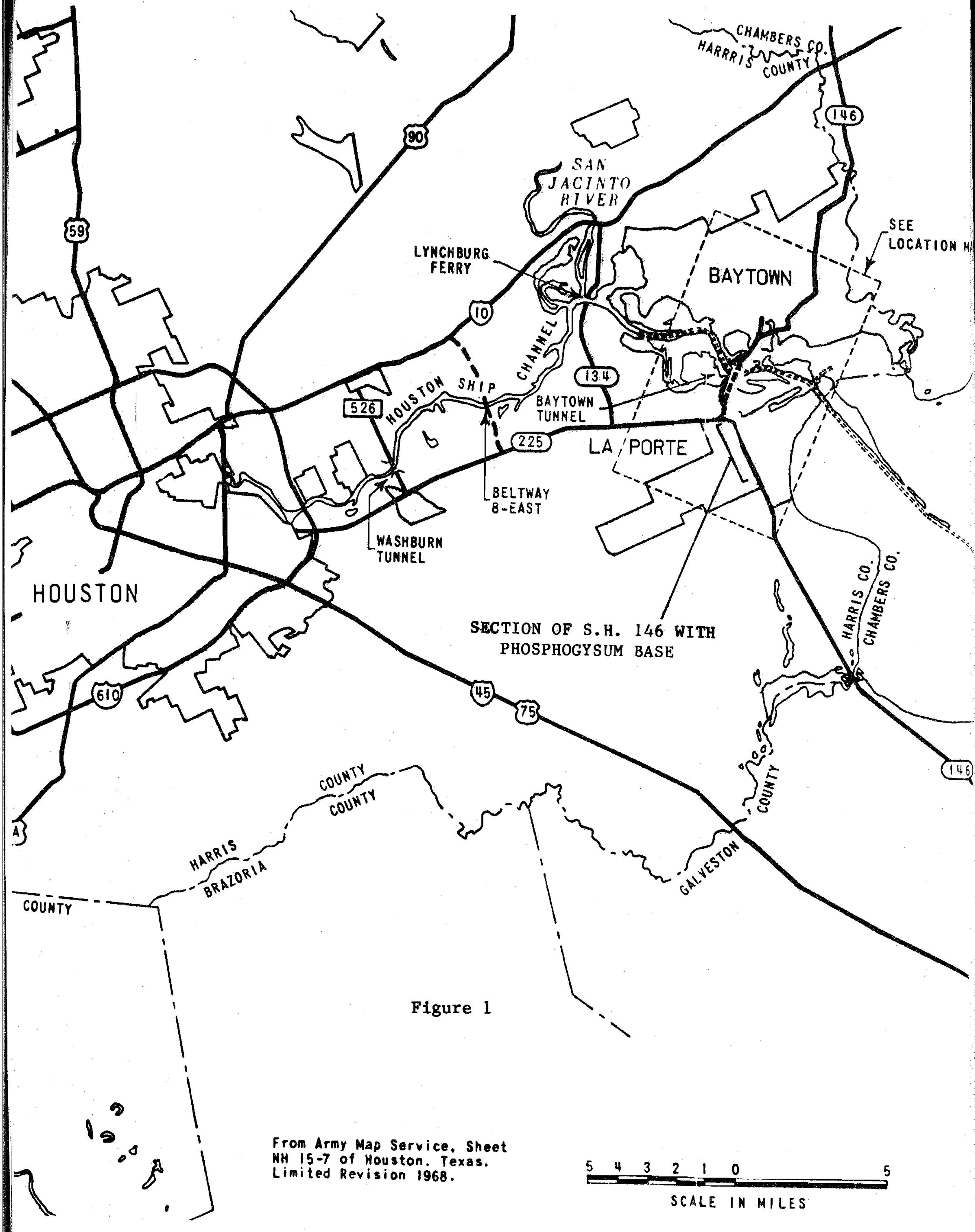
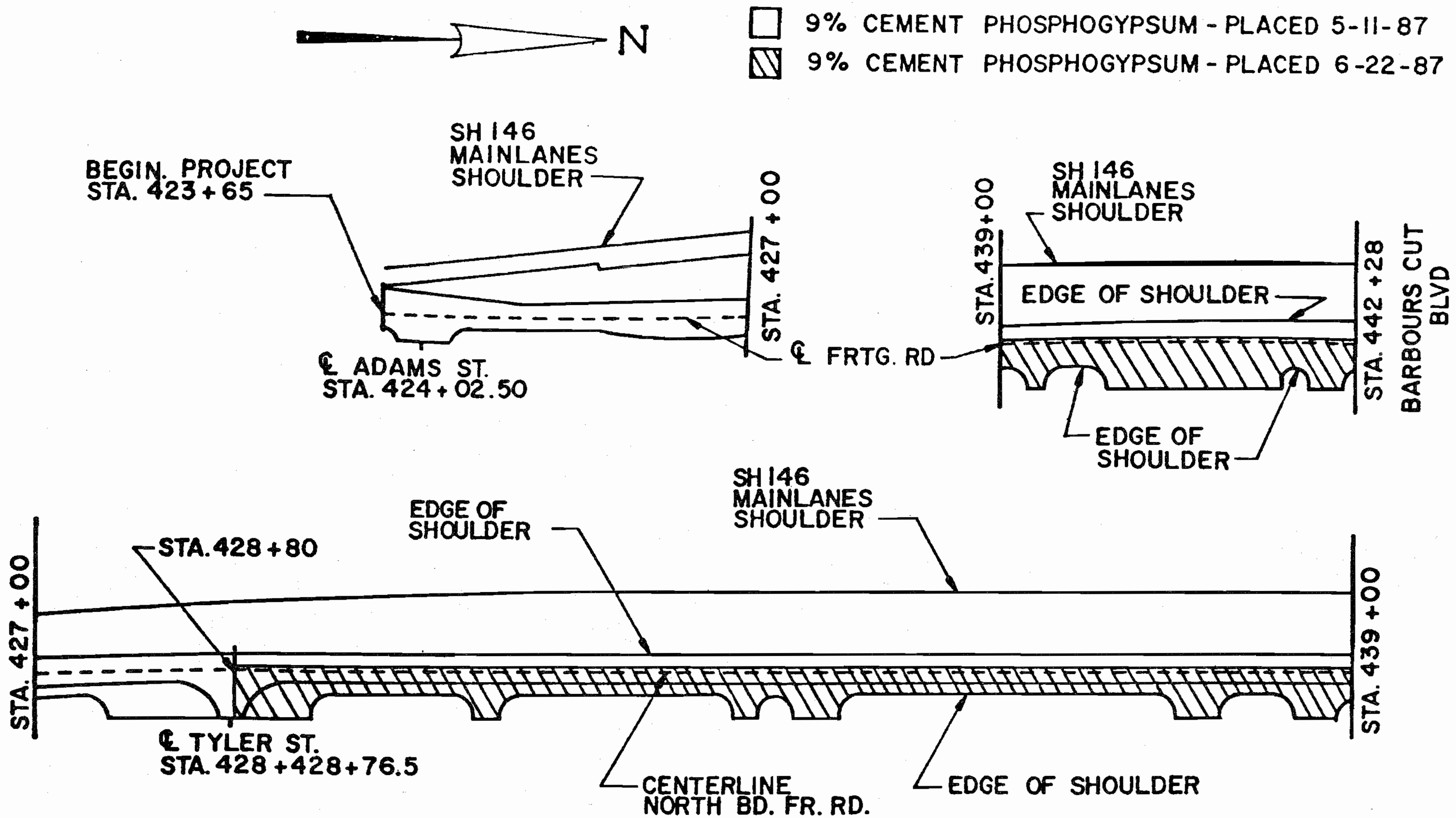
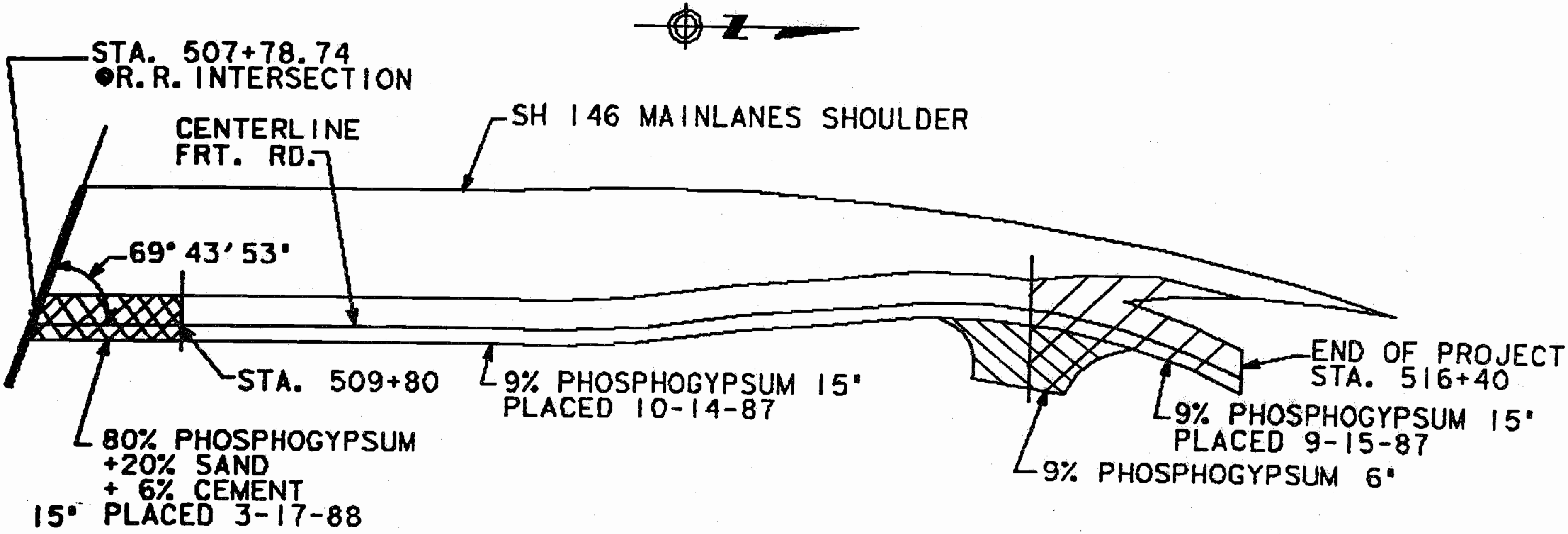

CHAMBERS CO.
HARRRIS COUNTY
146
90
SAN JACINTO RIVER
59
SEE LOCATION MA
LYNCHBURG FERRY
BAYTOWN
10
CHANNEL
134
526
HOUSTON SHIP
BAYTOWN TUNNEL
225
LA PORTE
BELTWAY 8-EAST
WASHBURN TUNNEL
HOUSTON
SECTION OF S.H. 146 WITH PHOSPHOGYSUM BASE
HARRIS CO.
CHAMBERS CO.
610
45
75
146
COUNTY
COUNTY
HARRIS
BRAZORIA
COUNTY
GALVESTON
COUNTY
From Army Map Service, Sheet NH 15-7 of Houston, Texas. Limited Revision 1968.
5 4 3 2 1 0 5
SCALE IN MILES

Figure 1



NORTH BOUND FRONTAGE ROAD - SH. 146

FIGURE 2



NORTH - BOUND FRONTAGE ROAD - SH. 146

FIGURE 3

Special Specification
Item 2056
Cement Stabilized Base (Gypsum Aggregate)

1. Description.

This Item shall consist of a base course composed of gypsum aggregate, portland cement and water, placed, then compacted, finished and shaped in accordance with the requirements of this specification and the plans as established by the engineer.

2. Materials.

(A) Gypsum Aggregate. Gypsum Aggregate shall be predominantly a calcium sulfate, free of injurious or hazardous products and free of organic material or other foreign matter. The source shall be approved by the engineer prior to use. The gypsum aggregate, when tested according to Test Method *Tex-110-E* shall meet the following requirements:

Square Sieve	Percent Retained
1-3/4"	0-10
No. 4	0-75
No. 60	0-85

(B) Portland Cement. Cement shall be Type II portland cement conforming to the item, "hydraulic cement."

(C) Water. Water shall meet the requirements of water for the item, "concrete pavement."

3. Proportioning of mixes.

Cement stabilized base mixture shall be proportioned as set out below.

(A) Strength Design. The mix will be designed with the intention of producing a *minimum average compressive strength of 200 pounds per square inch at the age of seven days using unconfined compression testing procedures* unless otherwise specified on the plans. Cement stabilized base specimens shall be *prepared, cured and tested as outlined in the Test Method Tex-120-E*. The *cement content shall not be less than 4.5% of the dry weight of the cement base material mixture*. The *cement content added at the plant should be approximately one percent more than that required to obtain the minimum strength required in the laboratory*.

(B) Test Specimens. The strength of the mix will be checked by tests of the mix as placed on the roadway. A *minimum of three test specimens shall be made for each 1000 tons of material* or fraction thereof placed each day. For these tests, the material will be *sampled prior to compaction*. The material will *not be acceptable if the average compressive strength of these specimens is less than 200 psi when tested as outlined in the Test Method Tex-120-E. No individual compressive strength below 170 psi will be acceptable*. It will be the responsibility of the contractor to sample and test the material as described previously. The testing shall be performed as approved by the engineer by a commercial testing company under a contract to the state.

4. Construction Methods.

(A) General. It is the primary requirement of this specification to secure a completed base course of gypsum aggregate, stabilized with cement as necessary, uniformly compacted to the specified density with no loose or poorly compacted areas, with uniform moisture content, well bound throughout its full depth and with a surface finish suitable for placing a surface course. It shall be the responsibility of the contractor to regulate the sequence of work, maintaining the work, and rework the courses as necessary to meet the requirements of this specification.

(B) Preparation of Subgrade. The roadbed shall be excavated and shaped in conformity with the typical sections shown on the plans to the lines and grades established by the

(Authors' italics)

engineer. All unstable or otherwise objectionable material or roots shall be removed from the subgrade and replaced with approved material. All holes, ruts and depressions shall be filled with approved material and, if required, the subgrade shall be thoroughly wetted with water and reshaped and rolled to the extent directed in order to place the subgrade in an acceptable condition to receive the base material. The surface of the subgrade shall be finished to lines and grades as established and shall be in conformity with the typical sections shown on the plans. A subgrade planer may be used. Any deviation in excess of one-half inch in cross section and in length of 16 feet measured longitudinally shall be corrected by loosening, adding or removing material, reshaping and compacting by sprinkling and rolling. Sufficient sub-grade shall be prepared in advance to insure satisfactory prosecution of the work. Material excavated in preparation of the subgrade shall be utilized in the construction of adjacent shoulders and slopes or otherwise disposed of as directed, by the engineer. Excavation and embankment required for preparation of subgrade will be measured and paid for under the special specification items "excavation" and "embankment" respectively.

(C) Mixing. The cement, base material and water shall be thoroughly mixed in an approved processing plant. The mixer shall be a stationary pug mill. Batch or continuous type mixers which will produce a uniform material will be allowed. The plant shall be equipped with feeding and metering devices which will add the base material, cement and water into the mixer in the specified quantities. Regardless of the type of mixer employed, the resulting mixture shall be homogeneous and uniform in appearance, and shall meet the following requirements when tested from the roadway in the roadway condition by Test Method *Tex-101-E*, Part 3:

	Percent
Minimum Passing 1-3/4" Sieve	100
Minimum Passing 3/4" Sieve	85

(D) Placing. The cement stabilized base shall be placed in uniform layers on the prepared subgrade to produce the depth specified on the plans. The depth of layers shall be as approved by the engineer. To insure homogeneous distribution of the base material in each layer, the material shall be placed using an approved spreader. The spreading operations shall be done in such a manner as to eliminate nests or pockets of material of nonuniform gradation resulting from segregation in the hauling or dumping operations and in such a manner as to eliminate planes of weakness.

Cement stabilized base shall not be placed when the air temperature is below 40° F and is falling, but may be placed when the air temperature is above 35° F, and is rising, the temperature being taken in the shade and away from artificial heat and with further provision that cement stabilized base shall be mixed or placed only when weather conditions in the opinion of the engineer are suitable for such work.

(E) Construction Joints. If a road section is not completed at the end of a construction day, a straight transverse construction joint shall be formed by cutting back into the completed work to form a vertical face. The base course shall be constructed and finished full width each day without longitudinal joints.

(F) Compaction. Unless shown otherwise on the plans, the cement stabilized base *shall be compacted to a density of not less than 95 percent of compaction ratio density, Test Method Tex-114-E* and *shall be checked in the field by Test Method Tex-115-E*. The *moisture content of the mixture during compaction operations shall be maintained within a range from optimum percentage to two percentage points above or 3.5 percentage points below the optimum percentage or within the range directed by the engineer.* All moisture contents should be determined based on a constant dry weight achieved at 104° F. If the obtained density does not satisfy requirements, the contractor shall make adjustments in roller weight, lift thickness or material moisture level or replace the material in question. The material shall not be compacted until the necessary shape and thickness has been achieved by grading. When additional lifts are necessary, the existing layer shall be lightly sprinkled prior to placing the additional courses.

(Authors' italics)

(G) Finishing. After the final course of cement stabilized base, except the top mulch, is compacted, the surface shall be finished to grade and section by blading and shall be sealed with approved pneumatic tire or flat wheel rollers. When directed by the engineer, surface finishing methods may be varied from this procedure provided a dense uniform surface is produced and further provided that the construction of compaction planes is avoided. Unless otherwise shown on plans, (1) not more than 60 minutes shall elapse between the start of mixing and the time of starting the compaction of the cement treated mixture of the prepared subgrade, (2) any mixture of aggregate, cement, and water that has not been compacted shall not be left undisturbed for more than 30 minutes, and (3) all finishing operations shall be completed within a period of five (5) hours after cement is added to the base material.

(H) Curing. Immediately after the cement stabilized base has been brought to line and grade, an asphaltic membrane shall be placed on the cement stabilized base to prevent evaporation of water and provide curing. The asphalt used for curing shall be of the type and grade shown on the plans or as approved by the engineer and shall be applied at the rate of approximately 0.1 gallon per square yard unless the plans require otherwise, asphalt shall meet the requirements of the item, "asphalts, oils and emulsions."

(I) Traffic. The cement stabilized base shall be *opened to traffic* as specified on the plans or as directed by the engineer, *but in no case before being cured at least three days.*

5. Maintenance.

The contractor will be required within the limits of his contract to maintain the cement stabilized base in good condition until all work has been completed and accepted. Maintenance shall include immediate repair of any defects that may occur. This work shall be done by the contractor at his entire expense and shall be repeated as often as may be necessary to keep the area continuously intact. Repairs to cement stabilized base shall be effected by replacing the base for its full depth rather than by adding a thin layer of cement stabilized material to the layer of base in need of repair.

6. Penalty for Deficient Base Thickness.

It is the intent of this specification that the cement stabilized base be constructed in strict conformity with the thickness and typical sections shown on the plans. Where any such base is found not so constructed, the following rules relative to adjustment of payment for acceptable stabilized base and to replacement of faulty stabilized base shall govern.

(1) Base thickness. The cement stabilized base will be measured for thickness by the department prior to final acceptance. The thickness of the base will be determined by measurement of the base in a finished grade condition.

For the purpose of etablishing an adjusted unit price for cement stabilized base, units to be considered separately are defined as 1000 lineal feet of base in each traffic lane starting at the end of the base bearing the smaller station number. The last unit in each lane shall be 1000 feet plus the fractional part of 1000 feet remaining. Lane width shall be considered as the width between longitudinal construction joints or between the longitudinal construction joint and the edge of the cement stabilized base. For widening, the width shall be considered as the average width placed of the widened section that is deficient in thickness. One measurement will be taken at random by the department in each unit. When the measurement from a unit it not deficient more than *0.5 inch from the plan thickness, full payment will be made.* When such measurement is deficient *more than 0.5 inch and not more than 1.5 inches from the plan thickness, two additional measurements at intervals not less than 300 feet will be taken and used in the average thickness for that unit.* An adjusted unit price as provided in subarticle (2) will be paid for the unit represented.

Other areas such as intersections, entrances, crossovers, ramps, etc., will be considered as one unit, and the thickness of each unit will be determined separately. Small irregular unit areas may be included as part of another unit. At such points as the engineer may select in each unit, *one measurement will be taken for each 1000 square yards of cement stabilized base,* or fraction thereof, in the unit. If the measurement so taken is not deficient more than 0.5 inch from the plan thickness, full payment will be made. If the

(Authors' italics)

base is deficient in thickness by more than 0.5 inch but not more than 1.5 inches from the plan thickness, two additional measurements will be taken from the area represented and the average of the three measurements determined. If this average measurement is not deficient more than 0.5 inch from the plan thickness, full payment will be made. If the average thickness is deficient more than 0.5 inch but not more than 1.5 inches from the plan thickness, an adjusted unit price as provided in subarticle (2) will be paid for the area represented.

In calculating the average thickness of the cement stabilized base, measurements which are in excess of the specified thickness by more than 0.2 inch will be considered as the specified thickness plus 0.2 inch, and *measurements which are less than the specified thickness by more than 1.5 inches will not be included in the average.*

When any measurement is less than the specified thickness by *more than 1.5 inches,* the actual thickness of the cement stabilized base in this area will be determined by *taking additional measurements at 10-foot intervals parallel to the center line in each direction from the affected location until in each direction a thickness is found which is not deficient by more than 1.5 inches.* Areas found deficient in thickness by more than 1.5 inches shall be evaluated by the engineer and, if in his judgement the deficient areas warrant removal, they shall be removed and replaced with stabilized base of the thickness shown on the plans.

Exploratory measurements for deficient thickness will not be used in averages for adjusted unit price.

(2) Price adjustments. Where the average thickness of cement stabilized base is deficient in thickness by more than 0.5 inch, but not more than 1.50 inches, payment will be made at an adjusted price a specified in the following table.

Cement Stabilized Base Deficiency

Deficiency in Thickness Inches	Proportional Part of Contract Price Allowed
0.00 thru 0.50	100 percent
0.51 thru 0.75	80 percent
0.76 thru 1.00	70 percent
1.01 thru 1.25	60 percent
1.26 thru 1.50	50 percent

When the thickness of cement stabilized base is deficient by more than 1.50 inches and the judgment of the engineer is that the area of such deficiency should not be removed and replaced, there will be no payment for the area retained.

(3) No additional payment over the contract unit price will be made for any cement stabilized base of a thickness exceeding that required by the plans.

7. Measurement.

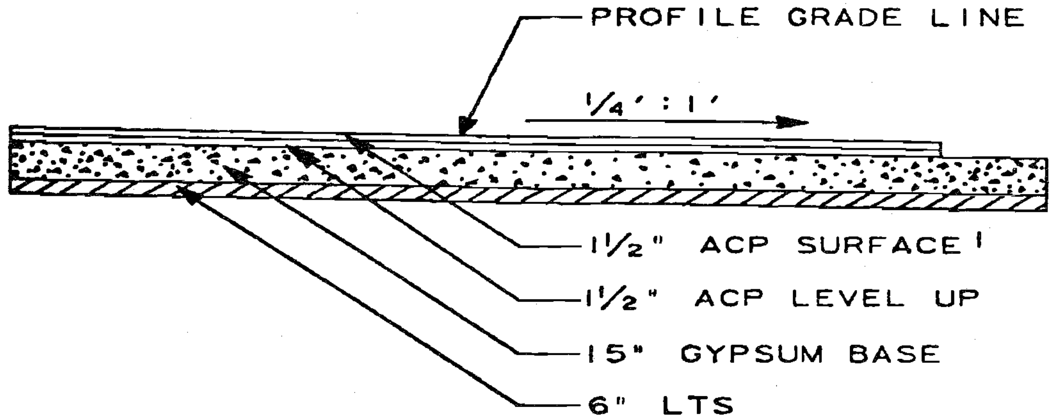
Work and acceptable materials as prescribed by this item will be measured for payment by the square yard of completed and accepted work.

8. Payment.

The work performed and materials furnished as prescribed by this item and measured as provided under "Measurement" above will be paid for at the unit prices bid per square yard for "cement stabilized base (gypsum aggregate)(density control)" of the depth specified.

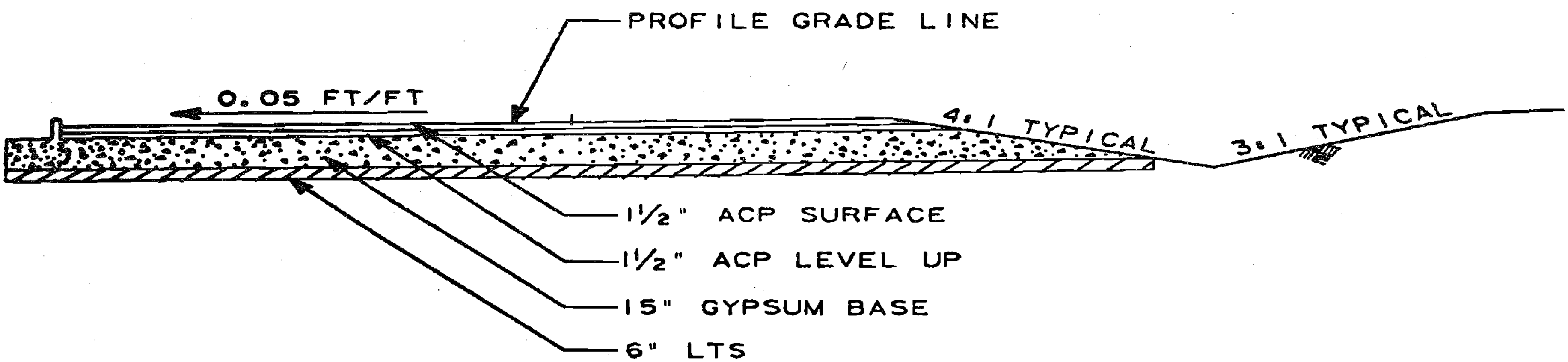
The unit prices bid will be full compensation for securing and furnishing all materials; including all royalty, freight and storage involved; for all processing, crushing and loading; for all hauling, delivering, stockpiling, placing, spreading, blading, mixing, stripping, dragging, finishing, curing and maintaining; for all fine grading; for wetting and compacting and all manipulation, labor, tools, and incidentals necessary to complete the work.

(Authors' italics)



STA. 423+65 TO STA. 424+47.84

PROPOSED TYPICAL SECTION



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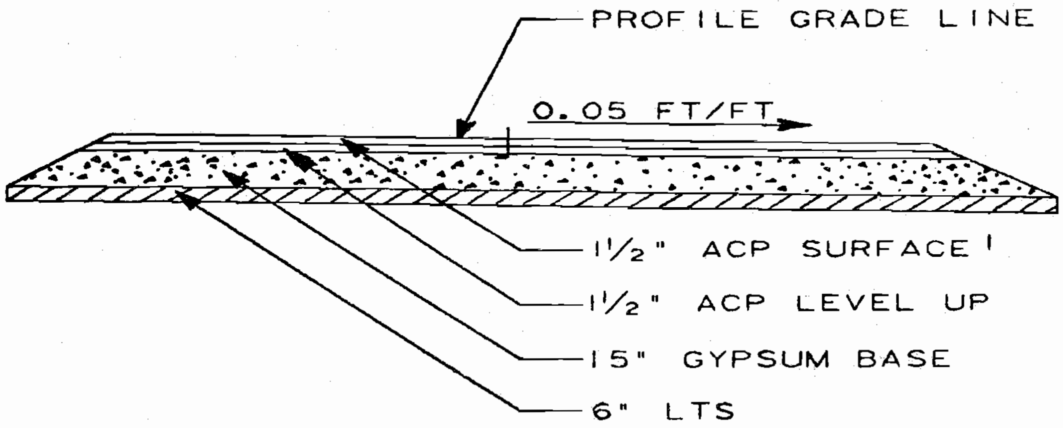
PROPOSED FULL SUPERELEVATED SECTION

FIGURE 5



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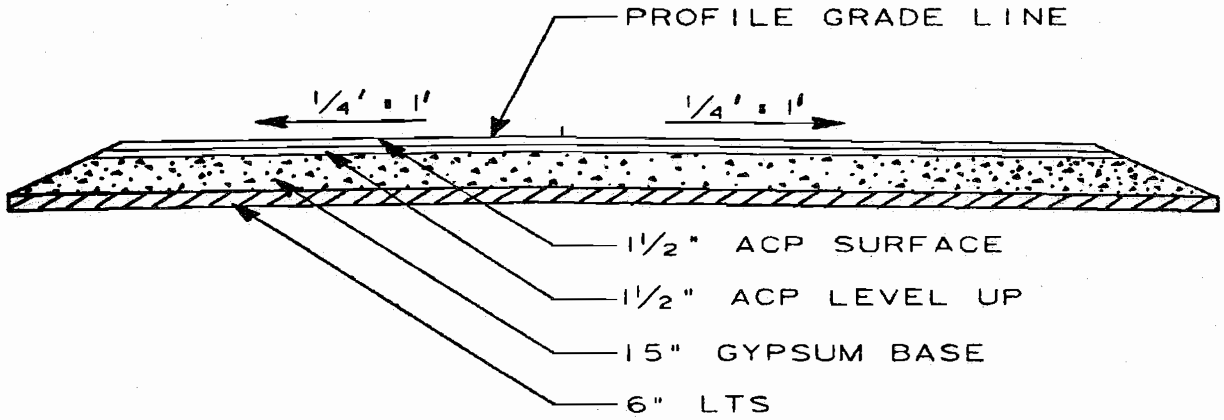
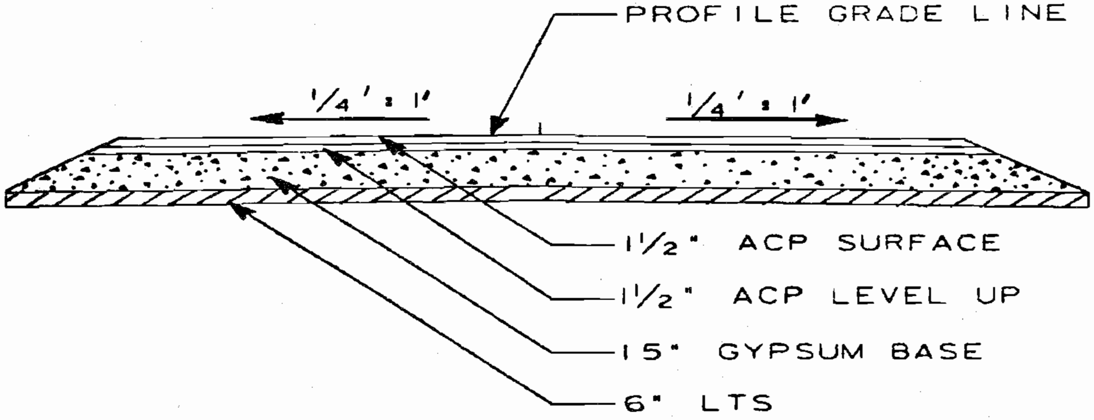


STA. 429+02.35 TO STA. 442+28

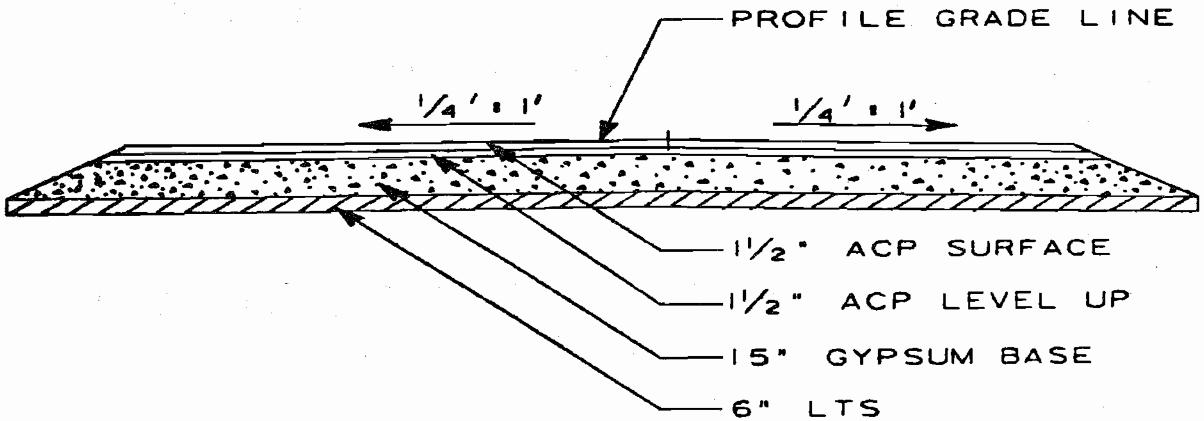
PROPOSED TYPICAL SECTION

FIGURE 6



STA. 509+80 TO STA. 511+00

PROPOSED TYPICAL SECTION



STA. 511+00 TO STA. 514+25

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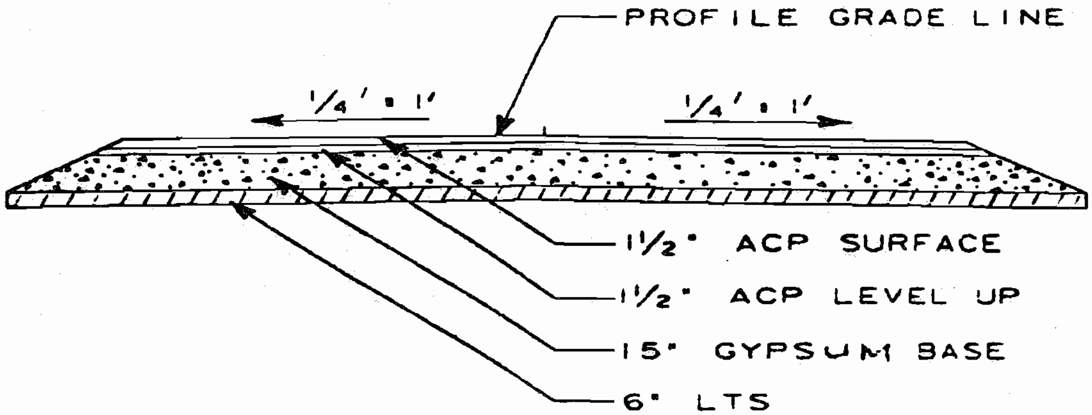


STA. 516+20 TO STA. 516+40

NOTE:
SLOPE VARIES WITHIN LIMITS OF SUPERELEVATION TRANSITION.

PROPOSED TYPICAL SECTION

FIGURE 8

gypsum and yielded an optimum moisture content of 12.2 percent and maximum dry density of 93.5 pcf. From this information, an equation was used to approximate the optimum moisture content of 9 percent cement-stabilized phosphogypsum. After the optimum moisture content was approximated to be 13 percent, a moisture-density curve (Figure 10) was run which yielded an actual optimum moisture content of 13.6 percent and maximum dry density of 96.4 pcf. Figure 11 shows phosphogypsum samples with 4 percent, 6 percent, 7 percent, 8 percent and 9 percent cement were molded up using Tex-120-E and yielded average unconfined compressive strengths of 113 psi, 142 psi, 168 psi, 208 psi and 249 psi, respectively. The 9 percent cement-stabilized phosphogypsum was chosen, since strengths were well above the minimum compressive strength of 200 psi. Additional engineering properties from research done before can be found in Figure 12.

JOB CONTROL TESTING

Job control testing, in the form of unconfined compression testing, was done to insure the base reached proper strengths of 200 psi after 7 days of moist curing. 9 percent cement-stabilized phosphogypsum samples were taken from the field on the placement dates and compacted in the laboratory, as required by the specification. The 7-day compressive strengths, listed in Figure 13, averaged 237.7 psi. Other averages for 8, 14, 17, 22, 23 and 28 days (Figure 14) are 276, 420, 276, 308, 411 and 485 psi, respectively. All these samples came from locations within Station 424 + 02.5 (Adams St.) to Station 422 + 28 (Barbours Cut) and Station 509 + 80 to Station 516 + 40.

MAXIMUM DENSITY/OPTIMUM MOISTURE TEST REPORT

TO State Dept. of Hwy. & Public Transportation
7721 Washington
Houston, TX 77007

Attn: Charles A. Frey

DATE 2/17/87

Project #CD389-12-57
Control #389-12-57

PROJECT Texas Highway 146

TEST DATA

TYPE OF MATERIAL 6% Cement Stabilized Phospho-Gypsum

SAMPLE LOCATION Mobil Phospho-Gypsum Plant - Stockpile #2

MAXIMUM DRY DENSITY 93.5 lbs/ft^3

LIQUID LIMIT N/A %

OPTIMUM MOISTURE CONTENT 12.2 %

PLASTICITY INDEX N/A

METHOD OF TEST:

/X/ TEX-114-E

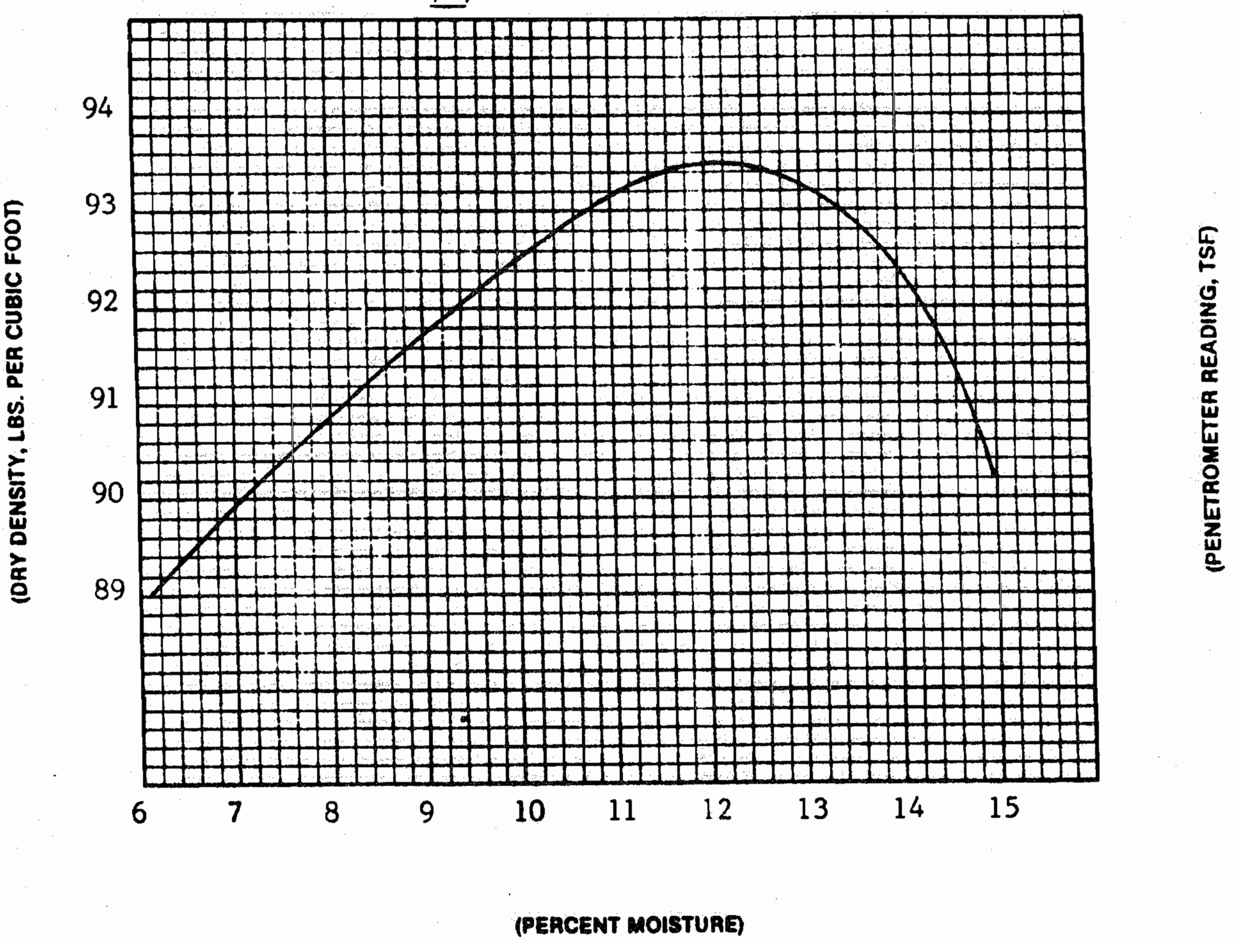


Figure 9

TEST DATA

TYPE OF MATERIAL Phospho-Gypsum w/9% Cement

SAMPLE LOCATION Mobil Stockpile #2

MAXIMUM DRY DENSITY 96.4 lbs/ft^3

LIQUID LIMIT NP %

OPTIMUM MOISTURE CONTENT 13.6 %

PLASTICITY INDEX

METHOD OF TEST: THD-114E

☐ MODIFIED ASTM, D-1557

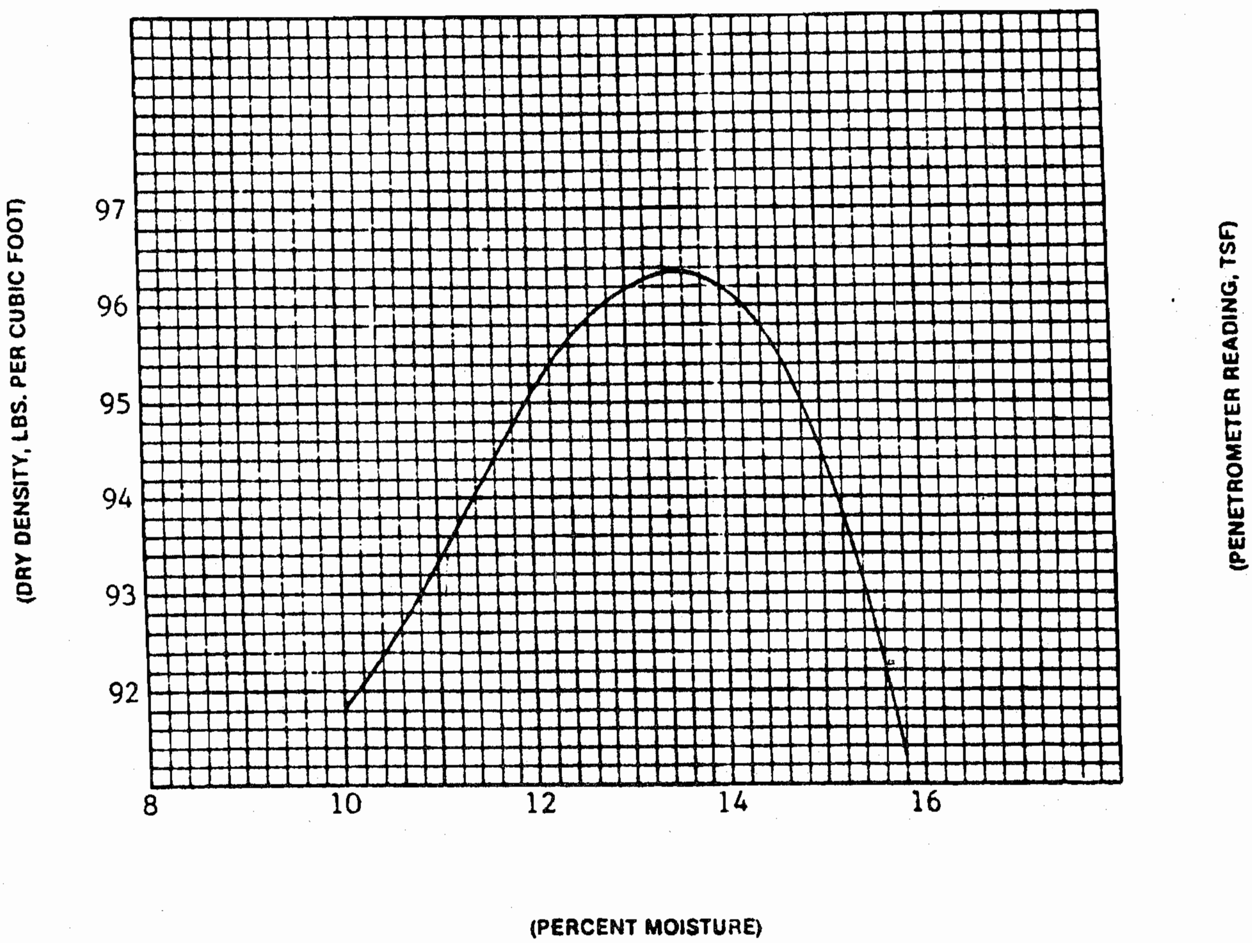


Figure 10

STRENGTH DATA FOR 7 DAYS IN THE LABORATORY

Cement Stabilized Phosphogypsum

Cement %	Average Unconfined Compressive Strength (psi)
4	113
6	142
7	168
8	208
9	249

Figure 11

GENERAL ENGINEERING PROPERTIES

Plastic Index: 1 [15] Plastic Limit: 7% and Liquid Limit: 8% [16]

For compacted samples, void ratio[17] and permeability[18] are low.

For cement stabilized phosphogypsum, pore water pressures are negative at failure indicating water was expelled and samples expanded upon loading.[19]

For saturated phosphogypsum, it acts as a viscous fluid when its yield stress is exceeded, instead of exhibiting classical slope stability failure.[20]

Cement stabilized phosphogypsum has shown to have volumetric swell ranging from 0.5% to 2.2%, depending on curing time and conditions.[21]

Phosphogypsum from pile 1 has an effective angle of internal friction of 28 to 40 degrees and an effective cohesion of 4 to 30 psi.[22]

Phosphogypsum from pile 2 has unconfined compressive strength at 3 days for samples compacted at 14% moisture and 106 pcf of 35 psi.[23]

The following have been shown to significantly increase unconfined compressive strength:

1. Addition of fly ash[24]
2. Addition of cement up to 10%[25]
3. Increase in curing time of fly ash stabilized phosphogypsum[26]
4. Increase in compactive effort energy[27]
5. Increase in pH: strengths of samples from pile 2 (pH = 5) were higher than strengths of samples from pile 3 (pH = 3)[28]

Figure 12

STRENGTH DATA FOR 7 DAYS FROM THE FIELD

9% CEMENT STABILIZED PHOSPHOGYPSUM

Date	Station	Unconfined Compressive Strength (psi)
05-11-87	432 + 00 to 437 + 00	268.0
		308.6
		303.7
		225.3
		209.3
		249.1
05-12-87	423 + 65 to 425 + 35	245.6
		242.8
		240.0
05-12-87	425 + 35 to 427 + 00	259.6
		200.8
		209.9
05-15-87	427 + 00 to 432 + 00	264.1
		244.3
		250.1
06-29-87	636 + 00	202.0
		206.0
		215.0
06-29-87	637 + 00	210.0
		219.0
		239.0
06-30-87	431 + 50	211.0
		207.0
		226.0
06-30-87	432 + 75	206.0
		206.0
		225.0
09-15-87	515 + 90	263.0
		204.0
		218.0
09-22-87	515 + 40	259.0
		273.0
		375.0
10-22-87	514 + 30 ctln	177.0
	" 1' left ctln	334.0
	" 1' rt ctln	160.0
		AVE. = 327.7 psi

Figure 13

STRENGTH DATA FOR 8-28 DAYS FROM THE FIELD

9% CEMENT STABILIZED PHOSPHOGYPSUM

Date	Station	Unconfined Compressive Strength (psi)
8 days		
10-22-87	511 + 25 5' rt ctln	223.0
	" 6' rt ctln	313.0
	" 7' rt ctln	294.0
		AVE. = 276.7
14 days		486.0
09-29-87	515 + 40 27' rt ctln	446.0
		328.0
		AVE. = 420.0
17 days		
07-10-87	436 + 50 10' rt ctln	281.0
	" "	322.0
	" 6' rt ctln	220.0
	" "	192.0
	" 3' rt ctln	334.0
	" "	295.0
	429 + 00 12' rt ctln	214.0
	439 + 00 12' rt ctln	288.0
	" "	346.0
		AVE. = 276.9
22 days		
06-08-87	515 + 40 30' rt ctln	428.0
	515 + 42 "	343.0
	515 + 46 "	155.0
		AVE. = 308.7
23 days		
06-08-87	425 + 25 to 430 + 00	453.0
		373.0
		556.0
		380.0
		320.0
		386.0
		465.0
		359.0
		AVE. = 411.5
28 days		
10-13-87	515 + 40 28' rt ctln	480.0
		473.0
		503.0
		AVE. = 485.33

Figure 14

Due to the severe cracking of the base from Adams Street to Barbours Cut, a field change was made at the request of the producer for the section from Station 507 + 78 (railroad) to Station 509 + 80, and 6 percent cement-stabilized phosphogypsum was placed there. Road cores were taken, but had lower strengths (displayed in Figure 15) of 61, 153, and 191 psi for 7, 14 and 21 days, respectively. Much difficulty was encountered in obtaining intact road cores and in capping the specimens for compressive strength testing. The rotary movement of the drilling barrel and the water used for lubricating the barrel disturbed the road cores. Often, they came out laminated or crumbled, as Picture A shows. In Picture B, laminations seem to pre-exist in the base.

Due to low compressive strengths of the 6 percent cement-stabilized phosphogypsum, it was replaced at the request of the producer, by a blend of 6 percent cement with 80 percent phosphogypsum and 20 percent sand. According to Figure 16, moisture optimized at 11.3 percent and dry density maximized at 103.5 pcf for the blend. In Figure 17, the blend averaged 225 psi for 7 days at 6 percent cement, while 7 percent, 8 percent and 9 percent cement-stabilized blend samples had strengths of 290, 345, and 405 psi at 7 days. In the end, only the 6 percent cement blend was used, since it met minimum strength requirements. Also, a layer of fabric underseal was used to cover all of the cement-stabilized phosphogypsum in order to prevent cracking in the upper asphalt pavement.

RESULTS OF MOISTURE AND DENSITY READINGS FROM THE FIELD

Moisture contents for 9 percent cement stabilized phosphogypsum field samples are shown in Figure 18. Readings from the speedy moisture meter averaged 13.6 percent, while oven dried samples averaged 14.7 percent. Overall moisture content, regardless of method, was 14.2 percent.

UNCONFINED COMPRESSIVE STRENGTHS

6% CEMENT STABILIZED PHOSPHOGYPSUM ROAD BASE CORES

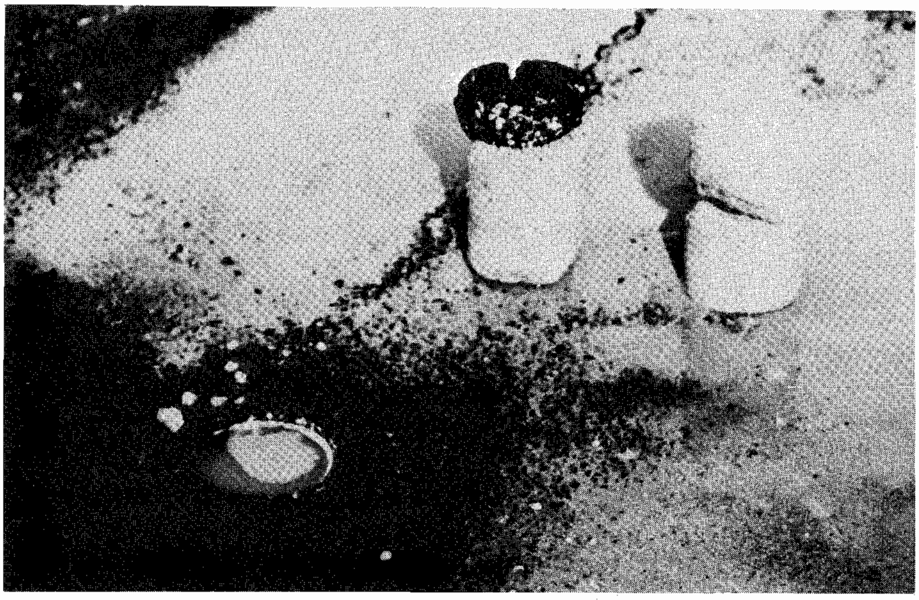
Station	Age (days)	Date Cored and Broken	Compressive Strength (psi)
507+95 6.5' Rt. CT.	7	01-28-88	*60.7
508+95 CT.	14	02-04-88	**152.7
508+24 CT.	21	02-11-88	***190.8

* Only one core out of 6 holes drilled was recovered.

** Only one core out of 9 holes drilled was recovered.

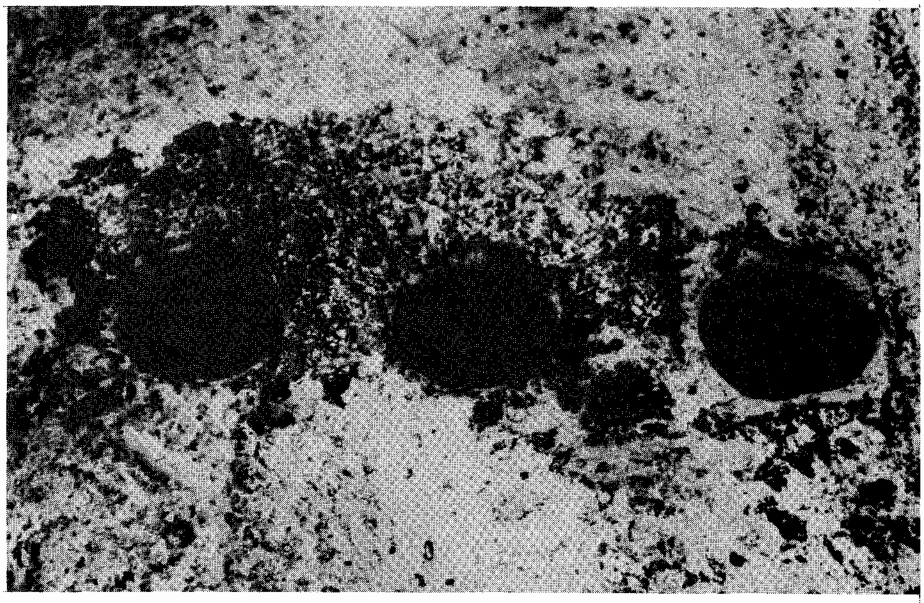
*** Only one core out of 5 holes drilled was recovered.

Figure 15



A

Fragmented cores of 9% cement stabilized phosphogypsum.



B

In-situ laminations in 9% cement stabilized phosphogypsum.

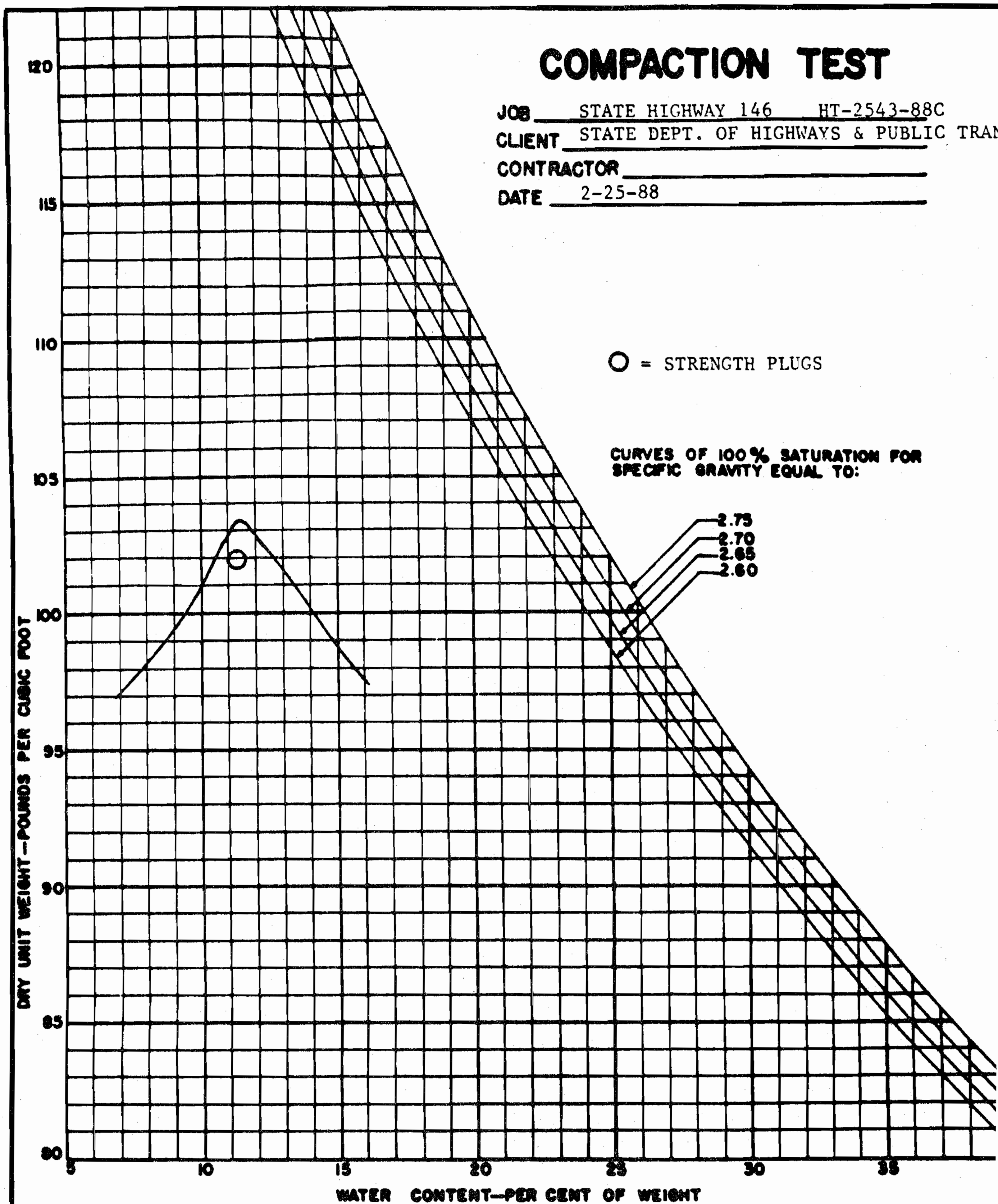
COMPACTION TEST

JOB STATE HIGHWAY 146 HT-2543-88C

CLIENT STATE DEPT. OF HIGHWAYS & PUBLIC TRAN

CONTRACTOR

DATE 2-25-88



MOISTURE DENSITY RELATION	METHOD OF TEST	MAX. DRY DENSITY PCF	OPTIMUM MOISTURE CONTENT %	SOIL DESCRIPTION OR CLASSIFICATION AND SAMPLE LOCATION
1	TEX 113 E	103.5	11.3%	LAB NO. 3143 6% CEMENT STABILIZED GYPSUM SAND Figure 16

7 DAYS UNCONFINED COMPRESSIVE STRENGTHS

CEMENT STABILIZED 20% SAND
+ 80% PHOSPHOGYPSUM BLEND

Cement Percent	Average Compressive Strength (psi)
6	225
7	290
8	345
9	405

Figure 17

MOISTURE CONTENTS

Optimum moisture for 9% cement stabilized phosphogypsum is 13.6%.

Speedy %	Change from Optimum	Oven Dried %	Change from Optimum
13.3	- 0.3	14.1	+0.5
13.7	+0.1	14.4	+0.8
14.8	+1.2	17.1	+3.5
14.5	+0.9	16.3	+2.7
14.0	+0.4	15.1	+1.5
13.8	+0.2	14.9	+1.3
12.7	- 0.9	13.4	- 0.2
13.0	- 0.6	13.6	0.0
13.2	- 0.4	14.0	+0.4
13.6	0.0	14.1	+0.5
13.0	- 0.6	13.2	- 0.4
14.1	+0.5	15.6	+2.0
14.6	+1.0	16.4	+2.8
13.8	+0.2	14.9	+1.3
11.4	- 2.2	12.1	- 1.5
12.8	- 0.8	13.0	- 0.6
12.4	- 1.2	13.2	- 0.4
14.0	+0.4	14.2	+0.6
13.0	- 0.6	13.9	+0.3
12.8	- 0.8	14.2	+0.6
14.8	+1.2	14.5	+0.9
12.4	- 1.2	13.4	- 0.2
13.4	- 0.2	13.1	- 0.5
13.6	0.0	15.0	+1.4
13.2	- 0.4	14.9	+1.3
13.6	0.0	14.5	+0.9
13.8	+0.2	14.2	+0.6
12.4	- 1.2	14.5	+0.9
13.2	- 0.4	14.5	+0.9
14.6	+1.0	15.1	+1.5
13.2	- 0.4	14.9	+1.3
13.2	- 0.4	14.7	+1.1
13.2	- 0.4	14.3	+0.7
13.6	0.0	15.0	+1.4
13.4	- 0.2	14.9	+1.3
13.6	0.0	14.7	+1.1
13.9	+0.3	15.4	+1.8
14.1	+0.5	14.6	+1.0
13.2	- 0.4	12.6	- 1.0
14.8	+1.2	15.3	+1.7
14.0	+0.4	14.7	+1.1
14.4	+0.8	14.2	+0.6
12.6	- 1.0	15.3	+1.7
12.8	- 0.8	14.5	+0.9
13.6	0.0	15.3	+1.7
Average Speedy Moisture %: 13.6%		Average Oven Dried Moisture %: 14.7%	
Overall Average Moisture %: 14.2%			

Figure 18

Another list, Figure 19, shows data from taking densities with either a volumeter or nuclear gauge for 9 percent cement-stabilized phosphogypsum. The average moisture content of 20.4 percent was 7 points above the optimum moisture of 13.6 percent, probably due to heavy rains or excess water used in compaction. Average dry density of 88.8 pcf was below maximum dry density of 96.4 pcf. The percentage of compaction of 92 percent was a few percentage points below specified minimum percent compaction.

For the phosphogypsum-sand blend, moisture contents were above optimum moisture and dry densities below maximum dry density, as shown in Figure 20. Average percent compaction was 5 points below minimum.

Figure 21 shows that 64 percent of the 9 percent cement-stabilized phosphogypsum densities made the specified minimum compaction of 95%. Most of the densities were just below the maximum dry density of 96.4 pcf, as shown in Figure 22. In Figure 23, the distribution of moisture contents peaked around 13.8 percent, using data from Figure 18.

POST CONSTRUCTION, NON-DESTRUCTIVE TESTING

The dynaflect was used to procure data characterizing the deflection response of the pavement to load. Responses to 5 geophones spaced 1 foot apart were recorded as the rig stopped along the 3 sections. At least 10 stops were made per section. Data were put into a program called "Dynaflect Stiffness Coefficient Program" which reduced the data and generated averages, surface curvature indices, stiffness coefficients for subgrade, stiffness coefficients for

DENSITIES AND PERCENT COMPACTION FOR 9% CEMENT STABILIZED PHOSPHOGYPSUM

OPTIMUM MOISTURE %: 13.6%
MAXIMUM DRY DENSITY: 96.4 PCF

Method	Moisture %	Dry Density (pcf)	Percent Compaction	Spec. Minimum % Compaction
Volumeter	15.5	93.9	97.4	95
Nuclear	15.0	95.8	99.4	95
Volumeter	13.6	94.3	97.8	95
Volumeter	15.5	93.2	96.6	95
Nuclear	15.5	96.9	100.5	95
Nuclear	15.5	95.2	98.8	95
Volumeter	15.5	93.2	96.6	95
Nuclear	14.9	92.5	96.0	95
Nuclear	17.5	92.5	96.0	95
Nuclear	15.5	94.4	97.9	95
Nuclear	17.2	92.8	96.3	95
Nuclear	12.6	94.8	98.3	95
Volumeter	22.0	85.0	88.2	95
Volumeter	32.4	76.0	78.8	95
Volumeter	22.0	85.0	88.2	95
Nuclear	32.4	76.0	78.9	95
Nuclear	38.0	76.6	79.0	95
Nuclear	31.7	80.3	83.0	95
Nuclear	33.4	80.2	83.2	95
Nuclear	14.3	93.5	97.0	95
Nuclear	14.6	93.3	96.8	95
Nuclear	16.2	92.0	95.4	95
Nuclear	17.3	91.1	94.5	95
Nuclear	31.9	77.0	79.8	95
Nuclear	19.5	85.6	88.8	95

Maximum:	38.0	96.9	100.5
Minimum:	12.6	76.0	78.8
Average:	20.4	88.8	92.1

Figure 19

DENSITIES AND PERCENT COMPACTION FOR 6% CEMENT + 20% SAND + 80% PHOSPHOGYPSUM

OPTIMUM MOISTURE: 11.3%
MAXIMUM DRY DENSITY: 103.5 PCF

Method	Moisture %	Dry Density (pcf)	Compaction %	Min. Spec. Compact. %
Nuclear	24.9	89.9	88.7	95
"	24.8	90.4	89.2	95
"	20.8	93.4	92.0	95
"	23.2	91.6	90.0	95
	Ave: 23.4	91.3	89.9	
	Max: 24.9	93.4	92.0	
	Min: 20.8	89.9	88.7	

Figure 20

9% CEMENT STABILIZED PHOSPHOGYPSUM

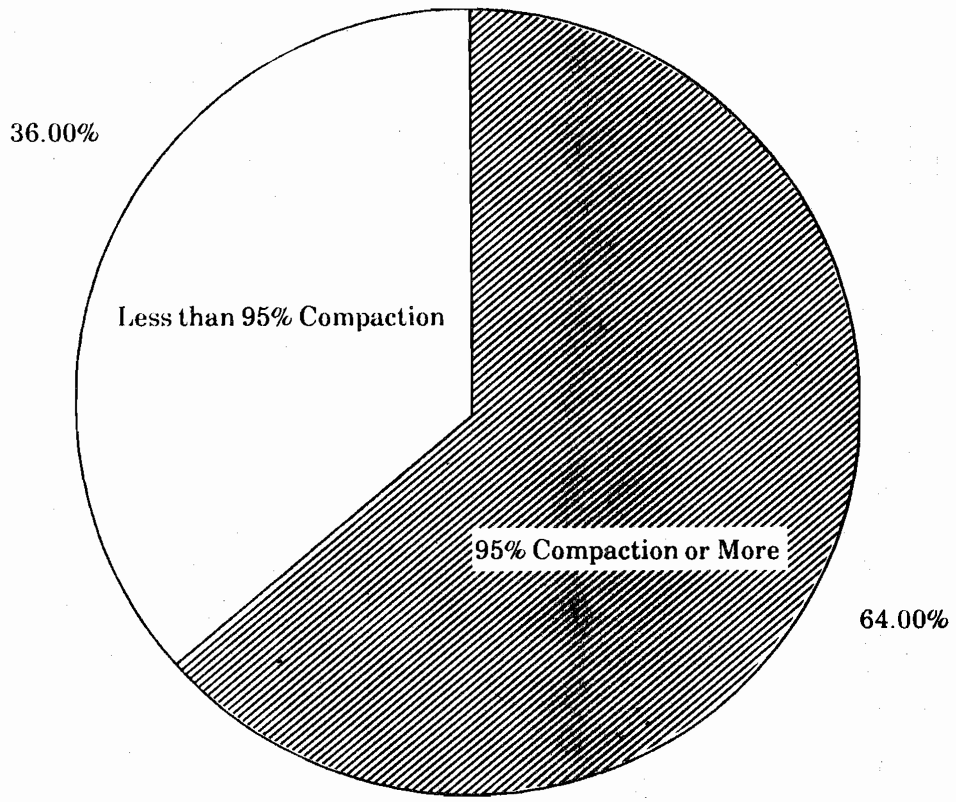


Figure 21

9% CEMENT STABILIZED PHOSPHOGYPSUM BASE

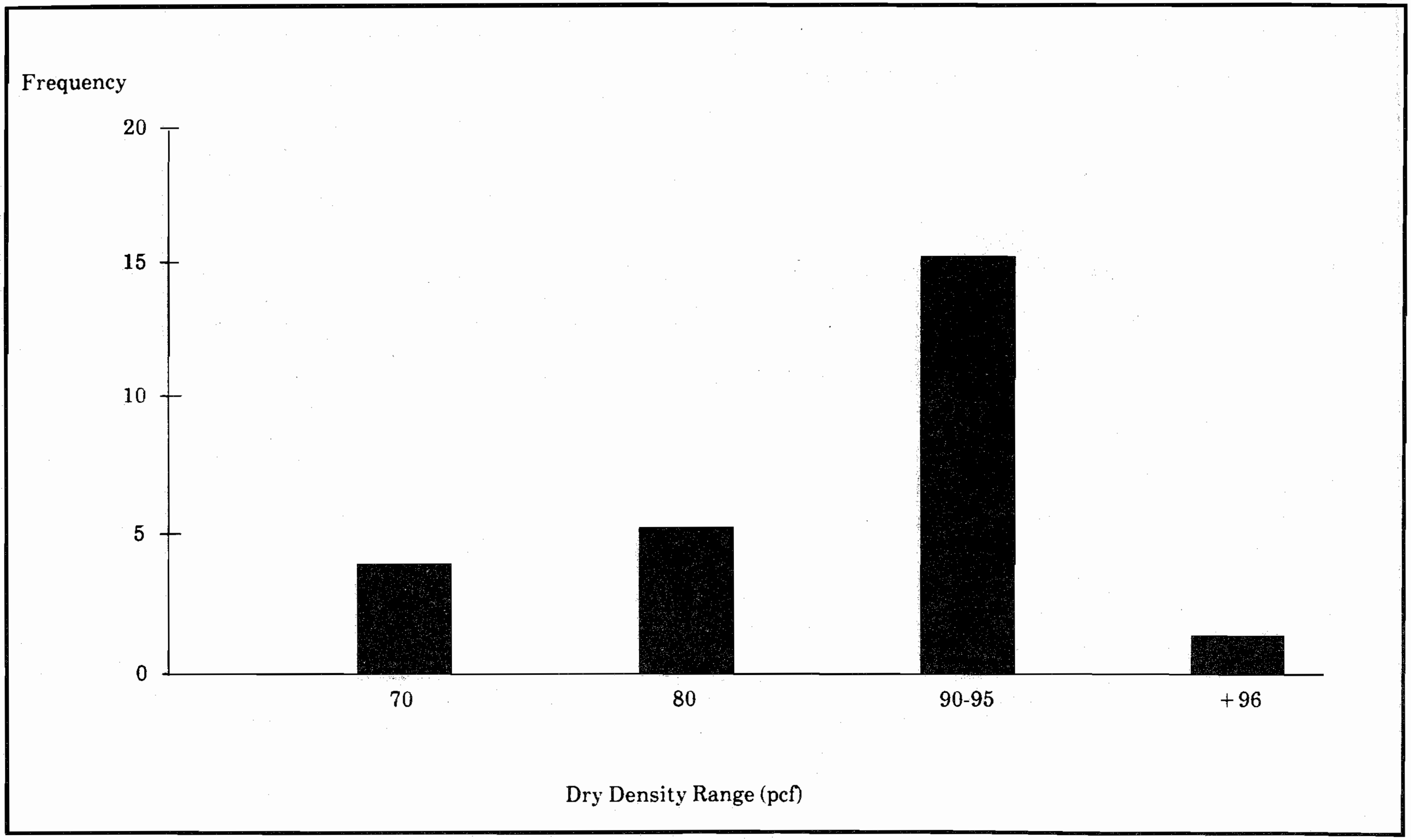


Figure 22

9% CEMENT STABILIZED PHOSPHOGYPSUM

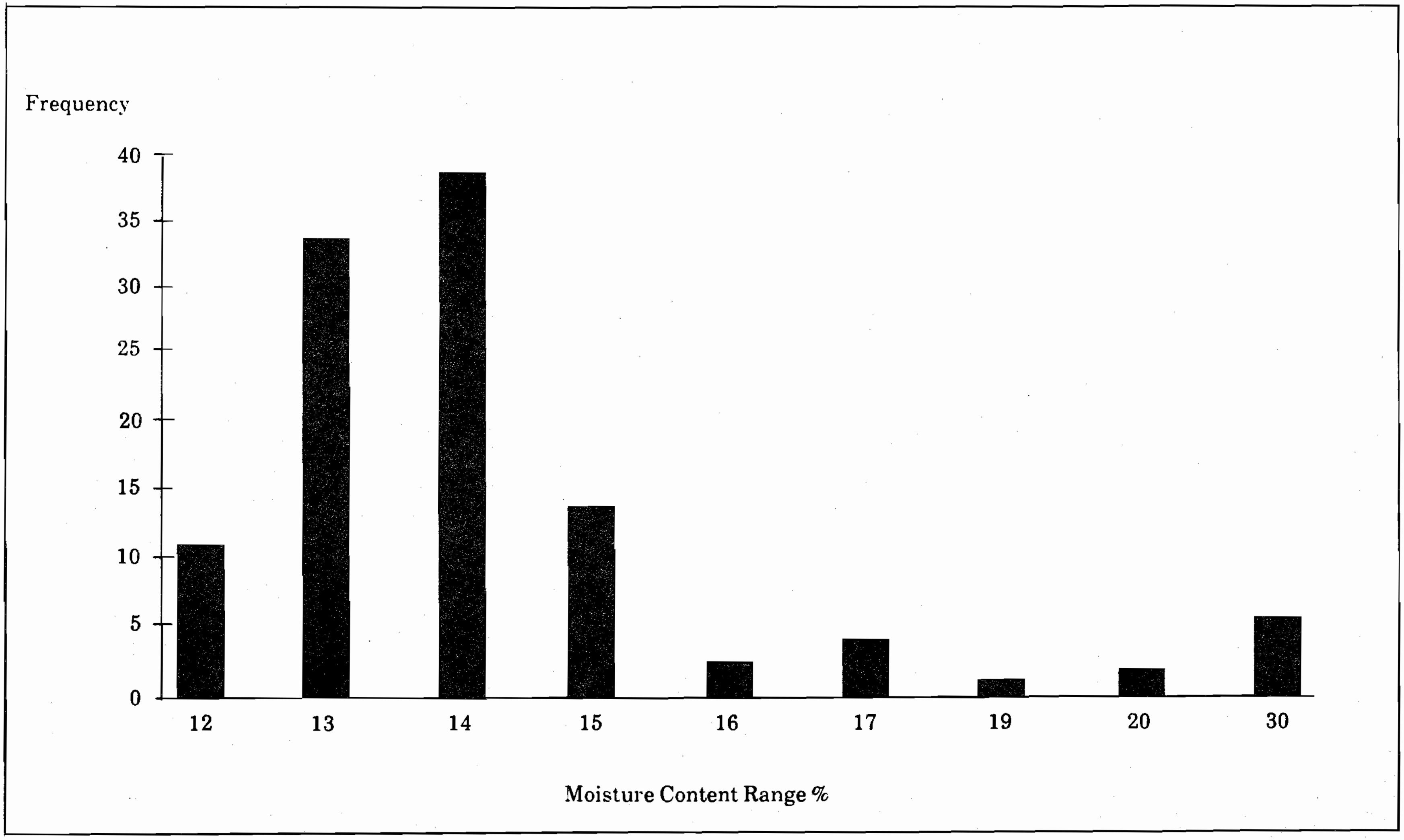


Figure 23

pavement and base, and standard deviations. These are shown in Figures 24, 25, and 26.

The oldest section, from Station 424 + 02.5 to 442 + 28, had the largest standard deviation in the SCI (0.048), while the other 2 sections had standard deviations of 0.030 for the blend and 0.032 for the other 9 percent cement-stabilized phosphogypsum section. The standard deviations of SCI may indicate the first section has more varied responses to loading than the other 2 sections, which have a more uniform response to loading. The stiffness coefficients of pavements (AP2), 0.76, 0.87, and 0.89, shown in Figures 24, 25, and 26 respectively are in the lower limit of cement-stabilized base. The stiffness coefficients of pavement (AP2) with cement-stabilized base are normally in the range of 0.8 to 1.2.

In Figure 27, deflection data shows that the subgrade response is mostly stable, except from Station 439 + 02.5 to Station 442 + 77.5. The 9 percent cement-stabilized phosphogypsum base shows deflection increases at Stations 427 + 02.5, 433 + 02.5 and 440 + 52.5. The blend base exhibits deflection increase at Station 509 + 80.7, but its subgrade response seems uniform, according to Figure 28. Figure 29 depicts subgrade and base exhibiting deflection increases at Stations 512 + 44.7, 514 + 42.7 and 516 + 40.7. In Figure 30, the blend base displays less deflection than the two sections of 9 percent cement-stabilized phosphogypsum for each sensor.

DISCUSSION OF PERFORMANCE

Several aspects of the use of cement-stabilized phosphogypsum as base should be addressed here. The following problems were encountered during

TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

STCOEF	STIFFNESS COEFFICIENT - 227002	VER 2.0 MAY 83

DISTRICT 12 - DESIGN SECTION

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
12	HARRIS	0389	12		SH 146	05-09-88	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SCI	AS2	AP2	REMARKS
0.00	0.980	0.810	0.710	0.610	0.550	0.170	0.22	0.61	ADAMS ST.
150.0	0.870	0.770	0.650	0.560	0.500	0.100	0.21	0.74	150 FT. FROM 0.00
300.0	1.130	0.960	0.710	0.690	0.570	0.170	0.21	0.64	
450.0	1.050	0.910	0.770	0.660	0.580	0.140	0.21	0.69	
600.0	0.800	0.720	0.650	0.570	0.520	0.080	0.21	0.80	
750.0	0.860	0.780	0.680	0.590	0.520	0.080	0.20	0.82	
900.0	1.090	0.880	0.740	0.610	0.540	0.210	0.22	0.57	
1050.0	0.950	0.840	0.720	0.600	0.550	0.110	0.21	0.74	
1200.0	0.970	0.820	0.720	0.600	0.530	0.150	0.22	0.64	
1350.0	1.030	0.900	0.780	0.650	0.580	0.130	0.21	0.70	
1500.0	0.880	0.750	0.680	0.580	0.510	0.130	0.22	0.66	
1650.0	1.180	1.100	1.020	1.000	0.990	0.080	0.18	0.93	
1800.0	1.150	1.130	1.000	0.960	0.920	0.020	0.15	1.38	
1950.0	0.810	0.690	0.530	0.470	0.360	0.120	0.22	0.67	BARBOURS CUT
AVERAGES	0.982	0.861	0.740	0.650	0.587	0.121	0.21	0.76	
STANDARD DEVIATION						0.048	0.02	0.20	

NUMBER OF POINTS IN AVERAGE = 14

W1-5 DEFLECTIONS AT GEOPHONES 1, 2, 3, 4, & 5
SCI SURFACE CURVATURE INDEX (W1 MINUS W2)
AS2 STIFFNESS COEFFICIENT OF THE SUBGRADE
AP2 STIFFNESS COEFFICIENT OF THE PAVEMENT

Figure 24

TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

STCOEF — STIFFNESS COEFFICIENT - 227002 — VER 2.0 MAY 83

DISTRICT 12 - DESIGN SECTION

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
12	HARRIS	0389	12		SH146	05-09-88	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SC1	AS2	AP2	REMARKS
0.000	0.660	0.600	0.530	0.450	0.410	0.060	0.21	0.84	FFW FT NO OF RR
20.00	0.660	0.570	0.500	0.430	0.390	0.090	0.23	0.71	20' FROM 1ST RDG.
40.00	0.600	0.530	0.480	0.410	0.370	0.070	0.22	0.76	
60.00	0.570	0.510	0.460	0.400	0.360	0.060	0.22	0.80	
80.00	0.560	0.510	0.460	0.400	0.360	0.050	0.22	0.86	
100.0	0.660	0.620	0.560	0.490	0.450	0.040	0.19	1.00	
120.0	0.660	0.640	0.580	0.510	0.460	0.020	0.18	1.25	
140.0	0.640	0.580	0.510	0.440	0.400	0.060	0.21	0.83	
160.0	0.730	0.670	0.590	0.510	0.450	0.060	0.20	0.88	
180.0	0.730	0.670	0.600	0.510	0.450	0.060	0.20	0.88	
200.0	1.160	1.020	0.670	0.500	0.430	0.140	0.20	0.71	
AVERAGES	0.0.694	0.629	0.540	0.459	0.417	0.065	0.21	0.87	
STANDARD DEVIATION						0.030	0.02	0.15	

NUMBER OF POINTS IN AVERAGE = 11

W1-5 DEFLECTIONS AT GEOPHONES 1, 2, 3, 4, & 5
SCI SURFACE CURVATURE INDEX (W1 MINUS W2)
AS2 STIFFNESS COEFFICIENT OF THE SUBGRADE
AP2 STIFFNESS COEFFICIENT OF THE PAVEMENT

Figure 25

TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION		
STCOEF	STIFFNESS COEFFICIENT - 227002	VER 2.0 MAY 83
	DISTRICT 12 - DESIGN SECTION	

DIST.	COUNTY	CONT.	SECT.	PPSN	HIGHWAY	DATE	DYNAFLECT
12	HARRIS	0389	12		SH146	05-09-88	48

DYNAFLECT DATA

ODOMETER	W1	W2	W3	W4	W5	SC1	AS2	AP2	REMARKS
0.000	0.850	0.740	0.610	0.510	0.450	0.110	0.21	0.71	
66.00	0.780	0.690	0.580	0.490	0.430	0.090	0.21	0.75	66' FROM 1ST RDG.
132.0	0.880	0.790	0.670	0.560	0.500	0.090	0.20	0.78	
198.0	0.950	0.890	0.790	0.690	0.610	0.060	0.18	0.97	
264.0	0.690	0.650	0.590	0.510	0.470	0.040	0.19	1.02	
330.0	0.800	0.770	0.720	0.650	0.600	0.030	0.17	1.17	
396.0	0.990	0.980	0.840	0.730	0.650	0.060	0.18	0.99	
462.0	0.780	0.680	0.600	0.510	0.470	0.100	0.22	0.72	
528.0	0.580	0.550	0.500	0.440	0.410	0.030	0.19	1.07	
594.0	0.970	0.860	0.730	0.610	0.570	0.110	0.20	0.74	
AVERAGES	0.827	0.755	0.663	0.570	0.516	0.072	0.20	0.89	
STANDARD DEVIATION						0.032	0.02	0.17	

NUMBER OF POINTS IN AVERAGE = 10

W1-5 DEFLECTIONS AT GEOPHONES 1, 2, 3, 4, & 5
SCI SURFACE CURVATURE INDEX (W1 MINUS W2)
AS2 STIFFNESS COEFFICIENT OF THE SUBGRADE
AP2 STIFFNESS COEFFICIENT OF THE PAVEMENT

Figure 26

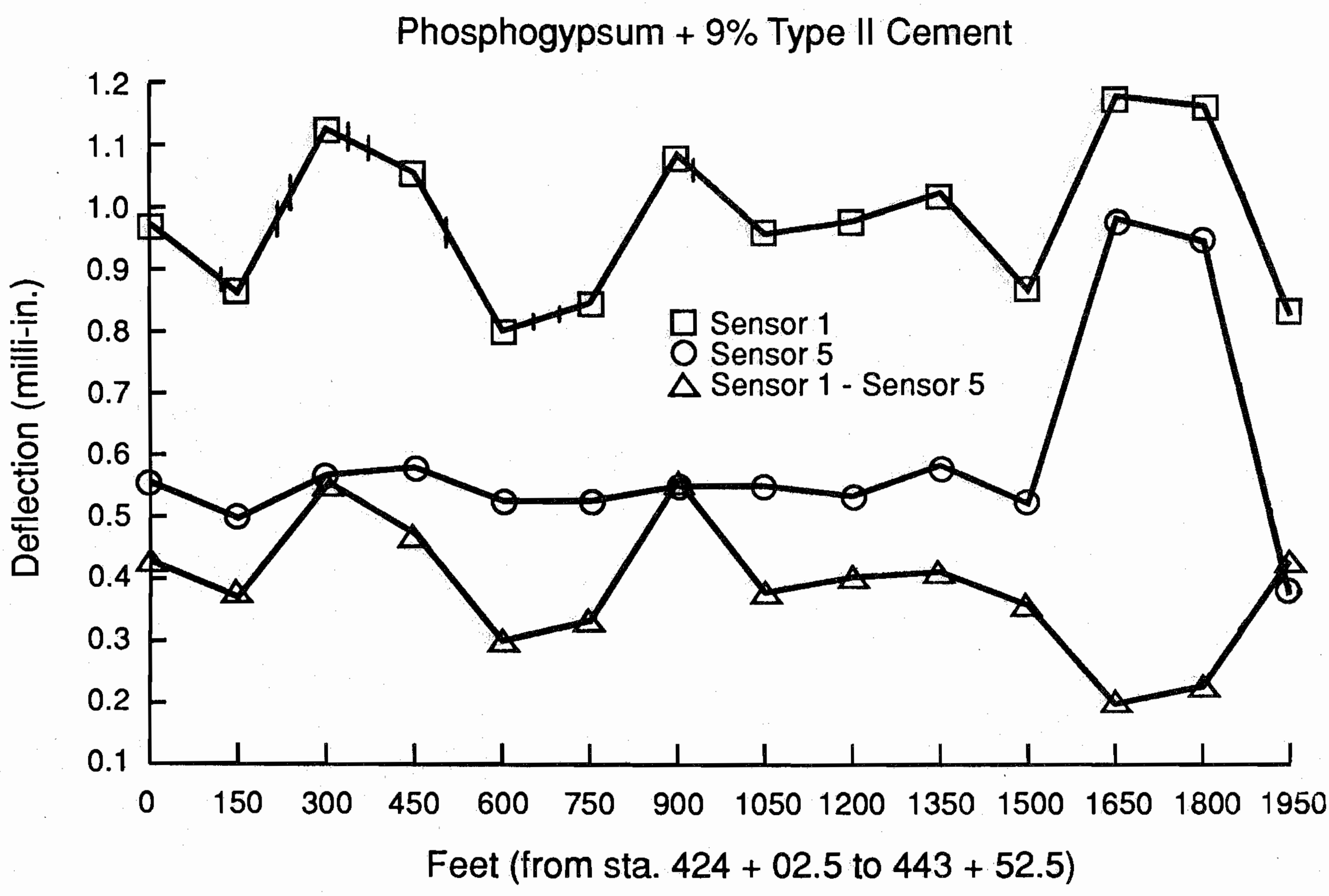

Phosphogypsum + 9% Type II Cement
Deflection (milli-in.)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800
1950
Feet (from sta. 424 + 02.5 to 443 + 52.5)
Sensor 1
Sensor 5
Sensor 1 - Sensor 5

FIGURE 27

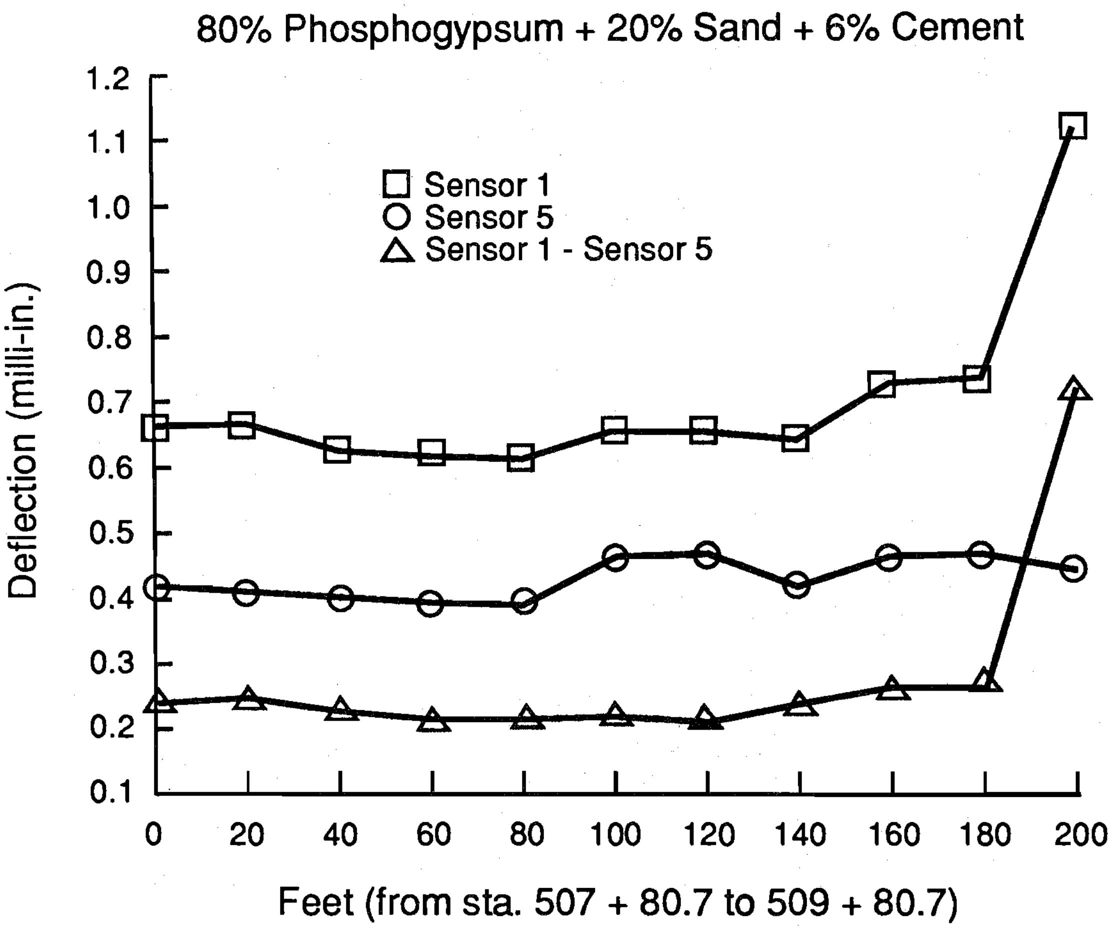

80% Phosphogypsum + 20% Sand + 6% Cement
Sensor 1
Sensor 5
Sensor 1 - Sensor 5
Deflection (milli-in.)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140
160
180
200
Feet (from sta. 507 + 80.7 to 509 + 80.7)

FIGURE 28

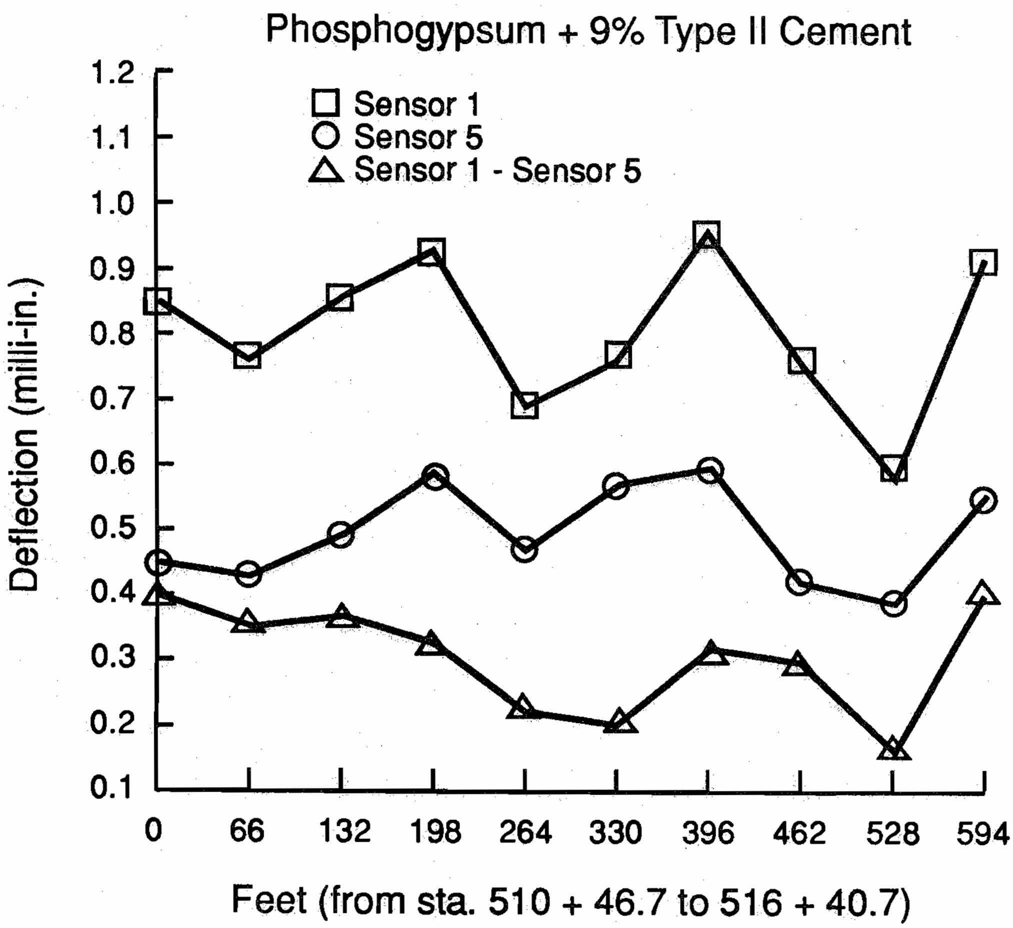

Phosphogypsum + 9% Type II Cement
Sensor 1
Sensor 5
Sensor 1 - Sensor 5
Deflection (milli-in.)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
66
132
198
264
330
396
462
528
594
Feet (from sta. 510 + 46.7 to 516 + 40.7)

FIGURE 29

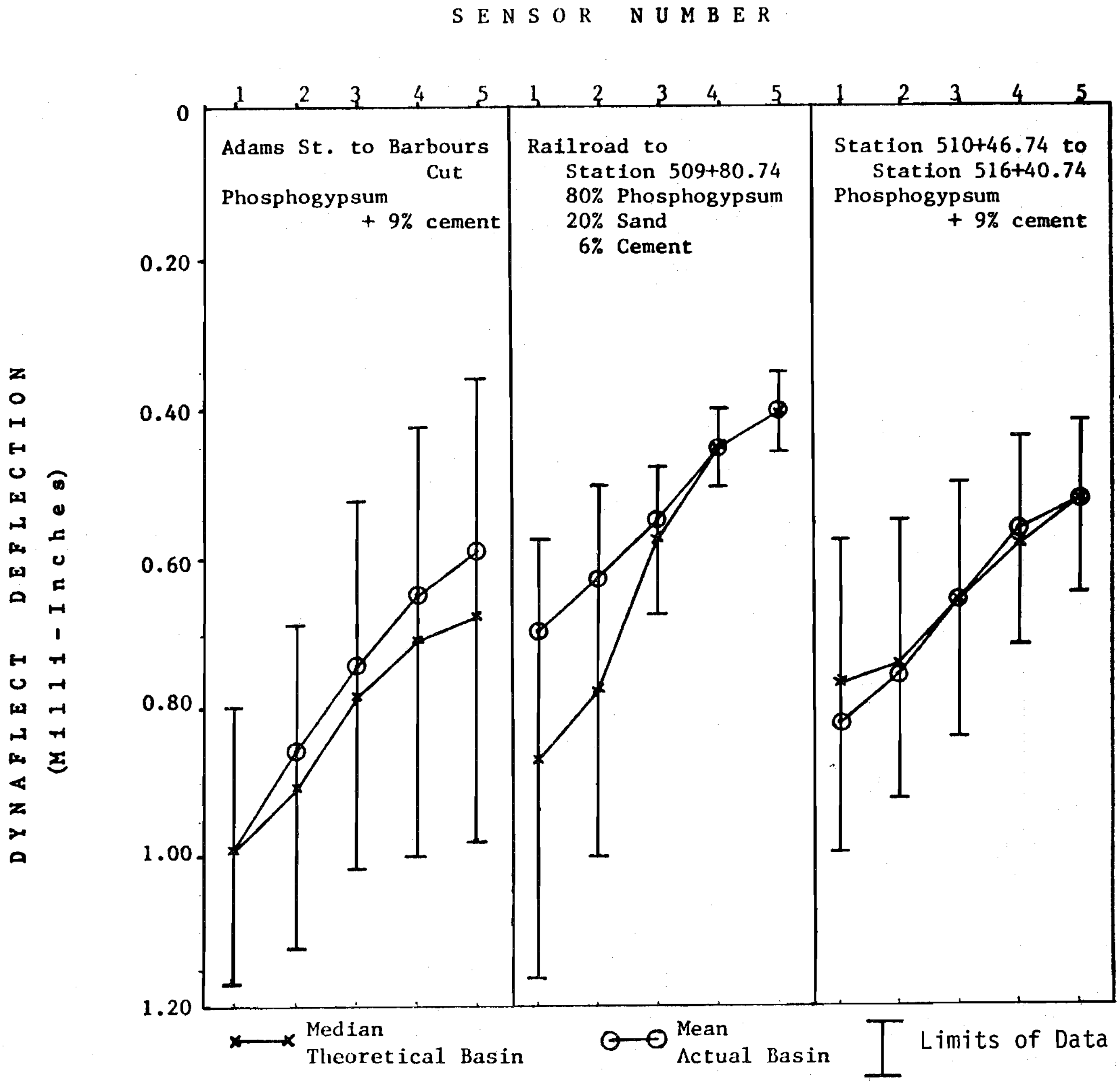

SENSOR NUMBER
DYNAFLECT DEFLECTION
(Mili-Inches)
0
0.20
0.40
0.60
0.80
1.00
1.20
1 2 3 4 5
Adams St. to Barbours Cut
Phosphogypsum + 9% cement
Railroad to Station 509+80.74
80% Phosphogypsum
20% Sand
6% Cement
Station 510+46.74 to Station 516+40.74
Phosphogypsum + 9% cement
Median Theoretical Basin
Mean Actual Basin
Limits of Data

FIGURE 30

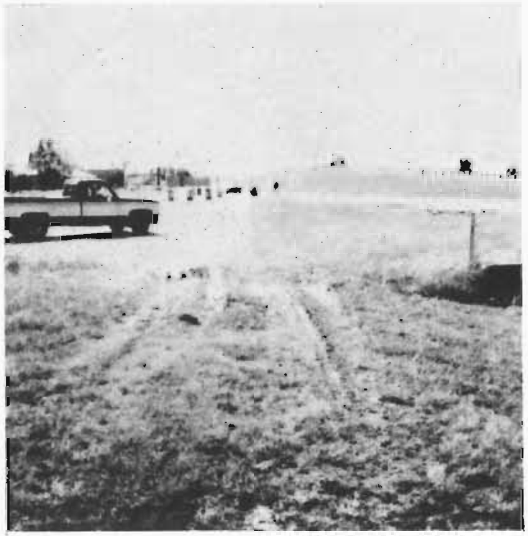
and after construction:

1) early cracking of the base top and asphaltic concrete pavement;
2) dissolution of the phosphogypsum;
3) possible false moisture readings from the nuclear gauge; and
4) significant percentage of nuclear density readings not meeting specified minimum compaction.

1) EARLY CRACKING OF BASE TOP AND ASPHALTIC CONCRETE PAVEMENT

At least 122 days after placement of the cement-stabilized base, cracking of the base and flexible pavement were found on the section from Adams St. to Barbours Cut. To start with, Pictures C and D show the location of the frontage road before it was built. After construction of the 15-inch phosphogypsum base and 1 1/2-inch asphaltic concrete pavement, pictures looking north were taken at 122 and 183 days. The beginnings of alligator cracking were observed in Pictures E to I. Also, Pictures J to M show transverse cracks. Longitudinal cracks are seen in Pictures N and O.

The cause of cracking may be due to a variety of reasons including improper design, weak base or subgrade, joint cracks, reflection cracks; and volume changes in base, pavement, or subgrade.[29] One factor that may be significant in this case is the cement content. Pictures P, Q, and R show that these intersection cracks originated in the top of the base and migrated through the asphaltic concrete pavement. Three sets of intersecting cracks were cored. Figure 31 shows their compressive strengths at 183 days, which ranged from 424 psi to 602 psi. The high cement content, along with excess moisture, may have caused the cracking: "The hydration reaction of cement is accompanied by the evolution



SH 146 feeder location looking south, between Spencer Hwy and Tyler Street (11-16-83).

C

SH 146 feeder location looking north (11-16-83).

D

E

Picture taken at 122 days of alligator cracks. Taken on Oct. 23. 1987 on west lane of SH 146 feeder looking north.

Alligator cracks on lane under traffic at 122 days (10-23-87). Station 431+50 to 433+50 Lf. CT.

F

G

Alligator crack close-up taken Oct. 23, 1987 at 122 days.

H

I

Close-up of alligator crack in area not under traffic. Taken at 122 days (10/23/87).
Station 426+53, offset 3' Lf. CT.

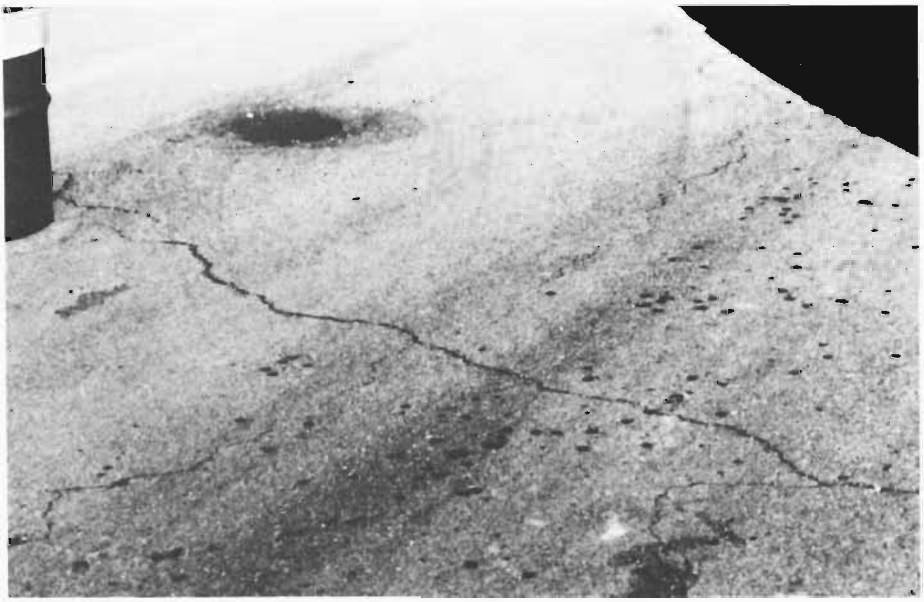
Cracks are developing randomly on this lane under traffic (10/23/87).
Station 428+10, offset 13' Lf.CT.

Area not under traffic pictured at 122 days on 10-23-87 showing intersecting cracks. Station 426+73, offset 3' Lf.CT.

J

Transverse cracks are shown in this are under traffic on 10-23-87. Station 429+50, offset 2-3' Lf.CT.

K



L

Transverse crack pictured at 183 days on Dec. 23, 1987.

M

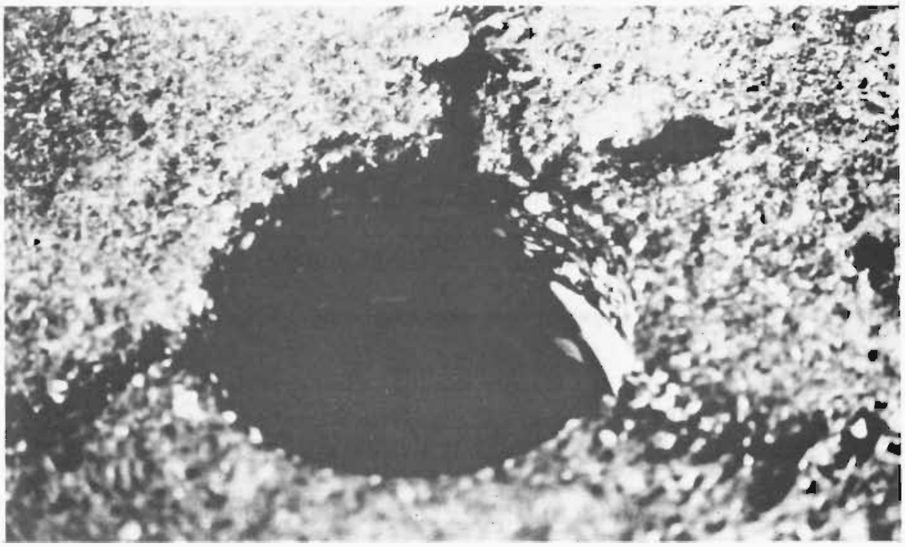
Close-up of transverse crack taken at 183 days on Dec. 23, 1987.

N

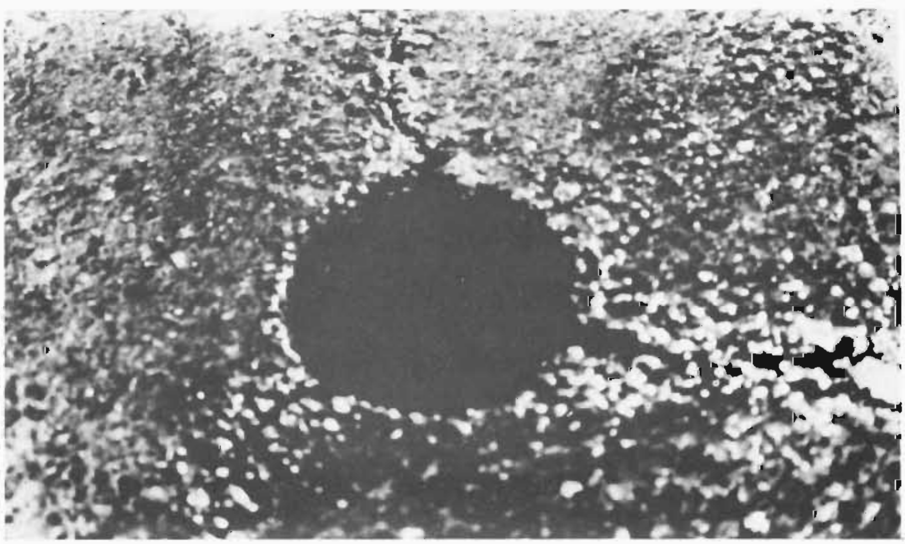
Note longitudinal cracks in wheelpath and center of lane; picture taken at 183 days on Dec. 23, 1987.

Longitudinal crack semi-parallel to centerline developed in area under local traffic with light to medium loads. Picture taken at 122 days on 10-23-87. Station 425+58, offset 6' Lf.CT.

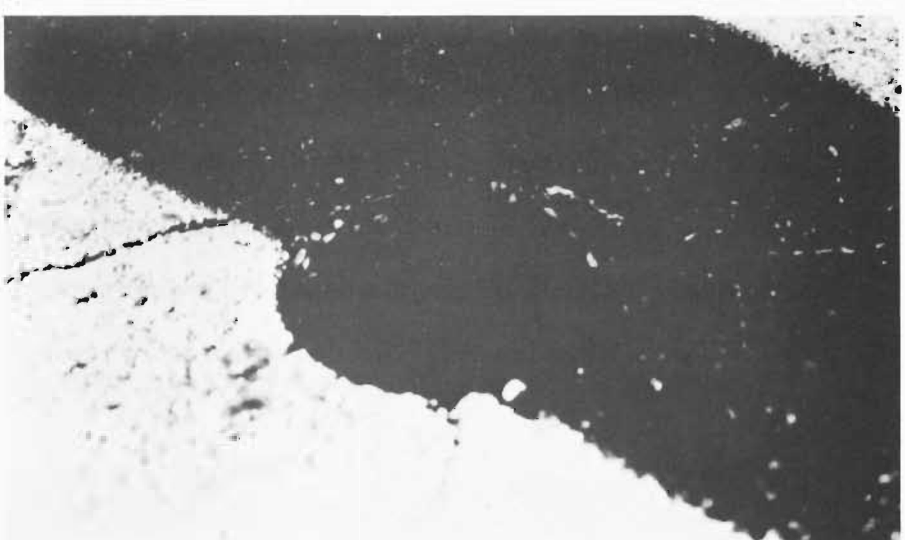
0



P



Q



R

These three pictures were taken at 183 days in the vicinity of Station 427+19 to 431+51. They show 3 intersecting cracks extending through 1½" hot mix and 1" of the top of the 9% cement stabilized phosphogypsum.

STATE DEPARTMENT OF
HIGHWAYS AND PUBLIC TRANSPORTATION

GENERAL TEST REPORT

Contract/Reqn. No. ______ Control 389-12-87 No. ______
Engineer C. A. Frey Project ______ Hwy. SH 146
Contractor S.H.B. Builders District 12 County Harris

Laboratory No. ______
Date Sampled cored 11-6-87 Date Received ______ Date Reported 12-23-87
Material 9% cement stabilized phosphogypsum Code ______
Producer ______ Code ______
Identification Marks ______ Spec. Item 2056
Sampled From Road Base Cores Quantity ______ Units ______

Core	Station	Date Placed	Date Tested	Age	Unconfined Compressive Strength
*1	431+51 10'Left of ctr.ln	05-12-87	12-23-87	183 days	423.5 p.s.i.
*2	431+45 10'Left of ctr.ln	05-12-87	12-23-87	183 days	466.6 p.s.i.
*3	427+19 1'Right of ct.ln	05-12-87	12-23-87	183 days	601.5 p.s.i.

* All holes were drilled at the intersection of cracks in the hotmix and exhibited cracking 1 inch into the phosphogypsum base.

Samples 2 and 3 had horizontal cracks near cap before breaking but after capping.

Figure 31

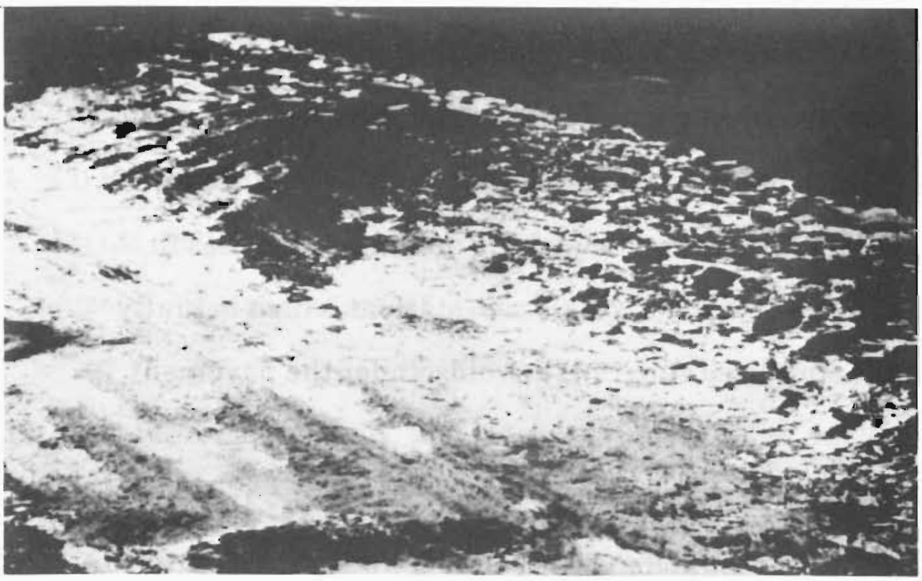
of heat which causes temperature rise in concrete. In mass concrete, the differential in temperature between the surface and the interior of the concrete structure will produce thermal gradients which may result in concrete stresses exceeding the tensile strength of the concrete at early ages."[30]

About half of the locations of the cracks in these pictures coincide with increases in deflection. The lines in Figure 27 that intersect Sensor 1 Line are locations of cracks. Not all surficial cracks may extend into the base, but they probably could. From the coincidences of cracks with deflections, it may be assumed that deflections were caused by the cracks in pavement or base. For those cracks not incidental to increases in deflections, they may not have been directly in the path that the dynaflect rig took. Deflection increases can manifest in some physical way, such as voids, weak spots, excessive moisture or anisotropies. An example of deflection data matching actual weaknesses in pavement is given in Reference 31. Peaks correlate to stations which actually have water underneath the stabilized subgrade or voids under the pavement.

2) DISSOLUTION OF PHOSPHOGYPSUM

Cement-stabilized phosphogypsum may wash out during a rain if exposed through cracks in the asphaltic concrete pavement. As Pictures S, T, and U suggest, phosphogypsum may have leached out from the holes drilled that were not immediately filled or from the side of the section. Phosphogypsum's tendency to dissolve has been encountered in previous research: "'The phosphogypsum produces a crystal matrix as it takes on water and . . . this matrix is somewhat water soluble."[32] Also in Pictures V, W, and X, phosphogypsum con-

S



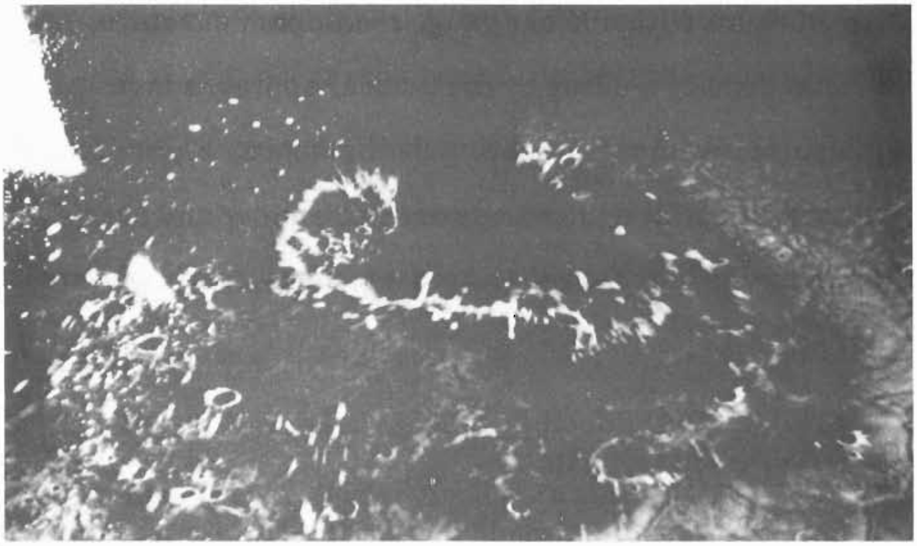
T

U

These three pictures show 9% cement stabilized phosphogypsum washed out from some where, either the sides of the section (from Station 509+80 to 516+40) or drilled holes. The residue lies on top of the asphalt; no hot mix has been placed yet. This was taken at 9 days after compaction on 10-14-87. Tire tracks are evidence some traffic came through by this time.

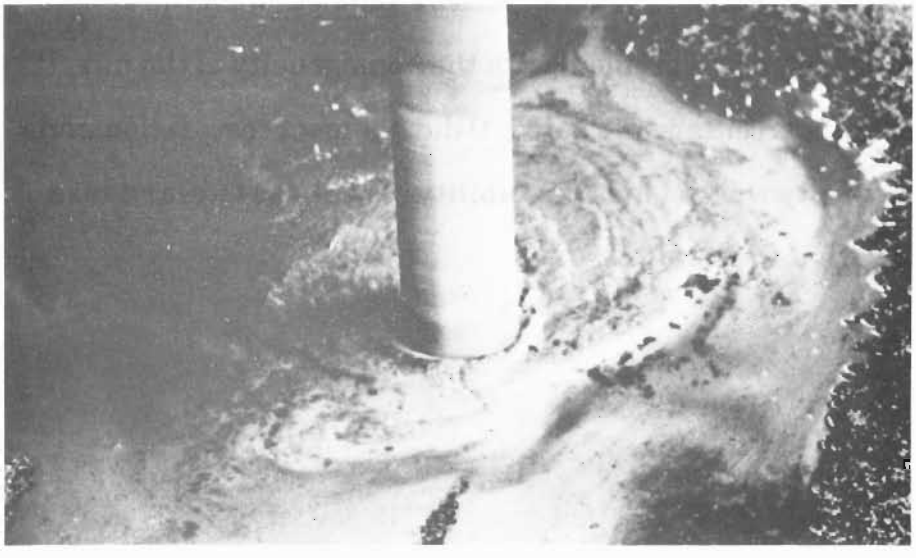
V

All 3 pictures were taken on Dec. 23, 1987 at 183 days from compaction.



W

Pictures V & W show phosphogypsum dissolving into the water as the auger drills into 9% cement stabilized phosphogypsum.



X

Picture X shows a brown solution, dissolved subgrade, and a white solution of phosphogypsum. Auger is being lifted from hole.

temporaneously dissolved in lubricating water as the drilling barrel rotated. Stricter timing for sealing and covering the phosphogypsum with asphaltic concrete pavement must be met so that additional moisture will not seep in or so that moisture will not evaporate out. Excess water may cause the base to swell or shrink and cause the material's strength to decrease.

3) FALSE MOISTURE READINGS

This problem was discovered in an earlier (1983) test section in La Porte. In that report it was found that, "The presence of hydrogen ions in the phosphogypsum material causes problems with nuclear gauge readings of moisture. Consequently, only the total density reading by the nuclear approach is reliable."[33] Some of the moisture readings from the nuclear gauge on Figure 19 seem to be elevated. Other methods like the speedy moisture meter and oven drying probably should be used in order to get an accurate measure of moisture in phosphogypsum samples.

4) SPECIFIED MINIMUM COMPACTION

Only 64 percent of the density readings made the specified minimum compaction of 95 percent. Perhaps the low ratio signifies a problem with the actual compaction of phosphogypsum or a problem with the homogeneity of the mix. It appears that a significant percentage (36 percent) did not meet compaction and, therefore, maximum density was not met. The ability of the base to bear a load is directly associated with its density.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

1) After years of experience in dealing with phosphogypsum ($CaSO_4$), it appears that phosphogypsum is not a uniform or homogenous material. It is quite difficult to control its quality or its performance as an engineering material.

2) Based on results of the dynaflect and compression tests, we can say that, if phosphogypsum is to be used in highway construction as base material, it must be blended with other aggregates in order to increase its strength. Also, fly ash or other stabilizing agents should be considered to reduce cracking due to shrinkage.

3) Investigation should be conducted to find the proper compaction equipment to achieve specified minimum compaction.

4) Because of the uncertainty of the impact and effects of phosphogypsum on the natural environment and public health, further use of this material should be restricted until such time as this material is endorsed by the Environmental Protection Agency.

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3. Gregory, "Preliminary Experience...," p. 1.

4. Gregory, "Laboratory Experience...," p. 10.

5. Dallas N. Little and Stanley Yin, "Determination of Effective Strength Parameters ϕ' and c' for Mobile Phosphogypsum," Texas Transportation Institute, Texas A & M University, College Station, April 1985, p. 16.

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7. Little and Yin, "Determination of Effective...," p. 5.

8. Gergory, "Preliminary Experience...," p. 6.

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10. William Pacx and Brenda Sapino, "City of Houston Testing Controversial Road Base," Houston Post, May 7, 1987.

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12. Gregory, "Preliminary Experience...," p. 1, 2.

13. Dallas N. Little and William W. Crockford, "Stabilization of Calcium Sulfate," Texas Transportation Institute, Texas A & M University, College Station, May 6, 1987, p. 5.

14. Gregory, "Laboratory Investigation...," p. 3.

15. Little and Yin, "Determination of Effective...," p. 16.

16. Ibid, p. 23.

17. Ibid, p. 48.

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18. Correspondence to Mobil Mining and Minerals Company from Woodward-Clyde Consultants, "Results of Permeability Tests, Gypsum Aggregate Project, WCC File: 87H252C," Houston, Texas, August 13, 1987, p. 5.

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20. Jey K. Jeyapalan, et al, "Investigation of Flow Failures of Tailings Dams," Vol. 109, No. 2, Journal of Geotechnical Engineering, A.S.C.E., February 1983.

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22. Little and Yin, "Determination of Effective. . .," p. 28.

23. Gregory, "Preliminary Experience. . .," p. 9.

24. Little and Yin, "Determination of Effective. . .," p. 44.

25. Correspondence to Mobil Mining and Minerals and Company from McBride-Ratcliff and Associates, Inc., "Report for Testing Services, Cement-Gypsum Evaluation, MRA File No. 83-714," Houston, Texas, September 1, 1983, Figures 5 and 6.

26. Gregory, "Laboratory Investigation. . .," p. 21.

27. McBride-Ratcliff and Associates, Inc., "Report for Testing Services, Cement-Gypsum Evaluation, MRA File No. 83-174," p. 16.

28. Gregory, "Preliminary Experience. . .," p. 14.

29. J.A. Epps, et al, "Roadway Maintenance Evaluation–User's Manual," Texas Transportation Institute, Texas A & M University, College Station, September 1974, p. 10.

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31. David Fred Martinez, "Pavement Investigation at the Southeast Parking Area Located at Big "H" Auto Auction Facility, West Road, Houston, Texas," Southwest Laboratories, April 19, 1988, p. 14, 27, 33, 77.

32. Little and Yin, "Determination of Effective. . .," p. 22.

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