Construction and Initial Performance Evaluation
of Stabilized Phosphogypsum
Test Sites - La Porte, Texas

by

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for

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Pasadena, Texas

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We are sorry but some of the older reports or AS IS.

The pictures are of poor quality.
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INTRODUCTION

1.1 Background

Ever increasing highway construction costs coupled with a geographic shortage of good quality materials continually spurs interest in the search for alternate construction methods and materials. In many locations, such as in the Houston area, aggregate must be hauled several hundred miles thereby adding significant transportation charges to the cost of the material. One material currently existing in large quantities in the Houston area that could help relieve this problem is phosphogypsum (PG).

Phosphogypsum is a by-product of phosphoric acid production. For every ton of phosphoric acid produced, approximately 4.5 to 5.5 tons of phosphogypsum are generated (1). Consequently, approximately 25 million tons of this material presently exist in the Houston area, alone. In the state of Florida, over 334 million tons of phosphogypsum had been stockpiled as of 1980. Long term projections predict that over one billion tons will be stockpiled in the United States by the year 2000 (2).

Pumped in a slurry form to stockpiles, this material predominantly consists of calcium sulfate crystals which can exist in at least three forms; anhydrate (CaSO$_4$), hemihydrate (CaSO$_4$·1/2H$_2$O) and dihydrate (CaSO$_4$·2H$_2$O). This material has a grain size distribution similar to a sandy slit or silty sand and is very friable in nature.

During the past two and one-half years, the Texas Transportation Institute (TTI) has been involved in an ongoing research effort involving the development of cost effective utilization of phosphogypsum with the objective of evaluating the potential of PG
stabilized with either fly ash or portland cement for use in road bases and subbases. Research to date has utilized material from an inactive stockpile (Pile No. 2) and an active stockpile (Pile No. 3) at the Mobil Chemical Company (MCC), Pasadena, Texas plant. The bulk of the research activity has involved measuring the load bearing capability of stabilized phosphogypsum in terms of unconfined compressive strength. Several factors which have been shown to affect strength development are initial moisture content, compactive effort, curing conditions, stabilizer content and age. Three stabilizers have been investigated; portland cement, fly ash and reclaimed fly ash. Results of the laboratory phase of the study led to the conclusion that Pile No. 2 mixtures performed well enough to warrant a full scale evaluation (3,4).

The Texas Transportation Institute was contracted by Mobil Chemical Company to design and evaluate seven (7) full-scale city street test sections, five (5) utilizing stabilized phosphogypsum as a road base, and two (2) using crushed limestone for control comparisons. These experimental sections are located in the city of La Porte, Texas a community located approximately 20 miles east of Houston, Texas (see Figure 1). A copy of the proposal outlining the scope of the project, which was submitted to the city of La Porte, is enclosed in Appendix D.

The remainder of this report summarizes properties of the construction materials, the actual construction phase and the results from the post construction and six month performance evaluation of these test sections.
Figure 1. Geographic location of La Porte, Texas and the surrounding area.
1.2 Objective

The objective of this study was to evaluate the constructability and performance of full scale test sections of stabilized phosphogypsum base courses on city streets in La Porte, Texas.

1.3 Scope of Work

This report represents the construction details of two full scale test sites which utilized phosphogypsum from MCC's Pile No. 2. Each test site had two or more sections including a control section. In all, three sections contained portland cement stabilized phosphogypsum as a base layer. Two sections contained a base layer of fly ash stabilized phosphogypsum. All sections were surfaced with a two course asphalt surface treatment. Also included in this report are the results of the post-construction and six month performance evaluation. The activity includes analysis of field cores and deflection measurements using the Dynaflect. A final report addressing long term performance will be prepared at the end of a four year evaluation period.

1.4 Materials

1.4.1 Phosphogypsum

The phosphogypsum used in the five experimental sections was obtained from the surface of the north quadrant of MCC Pile No. 2. The pH of this material ranged from 5.4 to 5.7, well above the minimum of 3.0 specified. The material was gathered from the top of the pile,
loaded into trucks with a backhoe and hauled to the job site.
Appendix D contains a copy of the material specifications pertinent to phosphogypsum.

1.4.2 Fly Ash

The fly ash utilized both in the laboratory and field trials was supplied by the W. A. Parish power plant in Richmond, Texas. This ash exhibited the chemical make up and cementitious properties associated with high quality Class C fly ashes as specified in ASTM C-618 (5). The ash was tan in color, which often is a distinguishing property of fly ashes produced from sub-bituminous and lignite coals. Two one gallon samples were taken from each truck during application at the job site. Total calcium oxide (CaO) contents, as determined by the CaO heat evolution test (6), ranged from 22 to 25%, well above the specified minimum value of 15%. The fly ash was also checked for fineness in accordance with guidelines set forth in ASTM C-311 (5). Percentages coarser than the No. 325 sieve ranged from 10 to 18%, which were significantly below the specified maximum amount of 25% (see Appendix D).

1.4.3 Portland Cement

The portland cement was a commercial Type I cement meeting the requirements of ASTM C-150 (7). The bulk cement was purchased from General Portland Inc. of Houston, Texas. Record samples were collected by TTI during construction.
1.4.4 Crushed Limestone

The crushed limestone used as the base material in the control sections was provided by the City of La Porte, Texas. Current city specifications (see Appendix C) call for using a Type A, Grade 1 flexible base (crushed stone) as listed in Item 242 of the 1972 TDH Standard Specifications for Construction of Highways, Streets and Bridges (8). Sieve analysis of this material by TTI as shown in Table B1 revealed that specification was not met. However, since the City of La Porte had supplied this material which is typical of that used in similar city street construction projects, the city permitted this material to be used.

1.4.5 Wearing Course

The job specifications (see Appendix D) called for a wearing course consisting of two-course surface treatment of precoated aggregate as defined in the 1972 TDH Standard Specifications for Construction of Highways, Streets and Bridges under Item 305, Class A, Precoated, Type PE. Specifications called for Grade 2 material as the first course followed by an application of Grade 4. The precoated aggregate applied to the test sections of both sites did not meet either Grade 2 or Grade 4 specifications. The sieve analysis results are enclosed in Table B2 of Appendix B.
2.0 CONSTRUCTION OF FIELD TEST SITES

2.1 Test Site I

2.1.1 General

Test Site I, called "C" street, is an entrance road connecting Sens Road (26th St.) and the construction storage yard at the I.J. Kibodeaux Service Center (Figure 2). This site was designed to include one experimental section and a control section. Each test section contained six inches of lime stabilized subgrade, eight inches of base course material and a two course surface treatment. A typical pavement cross section is given in Appendix A. Also included in Appendix A are an "as built" plan view, construction equipment spreads, and a list of contractors and testing laboratories involved in construction.

A copy of the specification for the lime-stabilized subgrade is given in Appendix C. This specification required a final gradation requirement of 100% material passing the 1 3/4 inch sieve and at least 60% passing the No. 4 sieve along with a density requirement of 95% of laboratory density as determined by AASHTO T-99 (standard Proctor) (9). An independent testing laboratory retained by the city established lime percentages and the target plasticity index (PI) of 20. Preliminary site investigation in this area characterized the natural soil as a highly plastic clay with PI's ranging from 30 to 50. The lime slurry for subgrade stabilization was purchased from Chemlime Corporation of La Porte, Texas.

The city's specification (see Appendix C) for the crushed stone base course calls for "95 percent modified density, as determined by
Experimental Details

<table>
<thead>
<tr>
<th>Site</th>
<th>Section</th>
<th>Base Course Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>Crushed Limestone (Control)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10% PC Stabilized phosphogypsum</td>
</tr>
</tbody>
</table>

Figure 2. Experimental phosphogypsum test sections in La Porte, Texas. Site I.
the AASHTO Method T-99. This method is commonly known as standard Proctor compaction. Discussion with the city inspector concluded that the compactive effort of Method T-180 was intended. Consequently, this compactive effort was used as the standard. The dry density specification for the phosphogypsum base course was 97 percent of laboratory density as determined by AASHTO T-180 (see Appendix D).

The initial site preparation, ditch construction and construction of the subgrade was performed by the City of La Porte. This was accomplished between June 6, 1983 and June 15, 1983.

Subgrade construction began by removing debris that had been placed on the site for temporary disposal and the top soil. Ditches were then prepared with the excavated material used as fill for the subgrade (see Figure 3). Initial lime stabilization took place on June 6. Procedures included scarification of the surface, with scarifying tools mounted on maintainers, followed by application of the lime slurry (see Figure 4). Next the material was mixed thoroughly by several passes of a pulver mixer at a depth of approximately 6 inches. The material was watered, then compacted with a sheepfoot roller (see Figure 5) and followed by a pneumatic roller. This compaction sequence was performed twice. The surface was watered to keep the section from drying out during the curing period.

Second mixing of the lime stabilized subgrade took place on June 14. Again the material was scarified and then remixed. In this case, the material was mixed by a pulver mixer and a reclaimer. The reclaimer, which rotates so as to crush the material into the blade housing, made the first pass. The pulver mixer, which mixes by
Figure 3. Ditch and subgrade preparation on Test Site I.

Figure 4. Stabilization of clay subgrade at Test Site I with lime slurry.
Figure 5. Compaction of subgrade with sheepsfoot compactor at Test Site I.
rotating in the opposite direction to the reclaimer, followed behind the reclaimer and created a finer mix. A minimum of four coverages by each unit helped to insure proper pulverization and resulted in a material meeting the final gradation specifications. Due to compaction equipment limitations, the material was compacted in successive layers using a windrowing technique. Laboratory tests showed that the compacted subgrade met density specifications. All depth checks indicated lime at depths of at least 6 inches below the surface. Plasticity indices on the stabilized subgrade ranged from four to 14, meeting the specification.

The base material for each section was installed on July 18 and 19. Each is discussed in more detail in the following subsections. Field data concerning the base material at Site I are shown in Table 1.

The wearing surface was a two course surface treatment. However, this two day application procedure was not initiated until April 17, 1984, almost a year later. The first treatment consisted of a prime coat of cutback asphalt (MC-30) applied at a rate of 0.25 gal/sy. A layer of AC-10 was applied the following day. The first course of precoated aggregate (30 cy) was then distributed and pressed into the surface with a pneumatic roller. A second application of AC-10 was covered by a 25 cy layer of precoated aggregate. The average application rate for the AC-10 was 0.24 gal/sy.

The post construction evaluation of this site was performed on July 29, 1983. On February 22, 1984 a six month performance evaluation was conducted.
<table>
<thead>
<tr>
<th>Test Section No.</th>
<th>Base Course Material (Design/Actual)</th>
<th>Date of Construction</th>
<th>Moisture Content (%)*,b,d</th>
<th>Field Dry Density b, (pcf)</th>
<th>Percent of Laboratory Dry Density c,d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crushed Limestone (Control)</td>
<td>7-18, 19-83</td>
<td>4.7</td>
<td>144.0</td>
<td>106</td>
</tr>
<tr>
<td>2</td>
<td>PC Stabilized Phosphogypsum (10/9.4%)</td>
<td>7-18, 19-83</td>
<td>15.3</td>
<td>97.8</td>
<td>97.2</td>
</tr>
</tbody>
</table>

*Percent of portland cement based on total dry weight of mixture.
*bAverage of at least four values.
*cLaboratory density determined by ASTM D 1557 (Modified Proctor).
*dFor the control section, applies to initial construction only.
2.1.2 Test Site I - Section 1, C St., (Crushed Limestone - Control)

The control section of crushed limestone was built to represent the type of street normally used in La Porte. Typical construction procedures were utilized. The material was hauled to the site in trailer dumps and spread over the 500 ft section by a maintainer. After spreading, the material was compacted by means of a sheepsfoot compactor and pneumatic roller. Excessive rainfall on the material made the addition of water unnecessary, and the high moisture content made optimum compaction difficult. However, density readings taken on the material at a later date showed that the section met density specifications.

As a result of hurricane Alicia (August, 1983) the city dumped debris adjacent to the control section for temporary storage. This excessive truck traffic caused a portion of the entire cross section of the limestone section to fail, necessitating reconstruction. During late January of 1984, base material in a portion of the roadway, beginning approximately 350 feet west of the east boundary and continuing westward approximately 110 feet, was removed and stockpiled. The subgrade was reshaped, restabilized with lime and tested for the required density. Once subgrade density requirements were satisfied, the stockpiled base material was placed on the subgrade, compacted and bladed. The net result of this reconstruction process is that the majority of the control section has received a substantial number of load applications while the reconstructed portion is effectively new. It must also be pointed out that the cement stabilized phosphogypsum section was kept almost free.
of traffic during the period from base construction to application of the surface course. The entire site was opened to all traffic on April 18, 1984.

The post-construction evaluation consisted of coring and deflection measurements. The material crumbled when coring was attempted. The Dynaflect applies a one thousand pound cyclic load to the pavement surface through a pair of force wheels spaced one foot apart. Five geophones measure the surface deflection at various points away from the force wheel. Geophone No. 1 is located halfway between the force wheels. Geophones No. 2 - 5 are located at one foot spacings from geophone 1 on an axis parallel to the force wheels passing directly between them. Figure 6 is a photograph of the Dynaflect.

TTI and other agencies typically use the Dynaflect for comparative pavement evaluations. One way to analyze Dynaflect data is by using two parameters, the "maximum deflection" and the "spreadability". The latter is the average deflection divided by the maximum. This value is usually presented as a percentage.

The set of curves in Figure 7 were developed by layered linear elastic computer programs for a base material which has a Modulus of Elasticity of 500,000 psi. More favorable values are achieved as one moves up and to the left on this plot. The point representing the C-Street section, as for all sections, is an average value representing at least six random measurements. The analysis of this material indicated an average maximum deflection of $26.8 \times 10^{-4}$ inches and an average spreadability of 64.9 percent. As can be seen from Figure 7, the representative value for the crushed limestone is
Figure 6. Taking deflection measurements with the Dynaflect.
Figure 7. Dynaflect dual parametric chart.
located between the lines representing 6 inch and 8 inch depths of base material with an elastic modulus of 500,000 psi. Interpolation to the nearest 0.5 inch yields a value of 6.5 inches. Since each of the pavement layers contribute to the surface deflection, the deflection of each cannot easily be quantified. It is, however, possible to relate the entire pavement section (i.e. 6 inch lime stabilized subgrade plus the 8 inch crushed limestone base) to an equivalent or effective thickness of 500,000 psi moduli base material. For example, it is possible to say that for this section, a material layer exists, above the natural subgrade, that is equivalent to a 6.5 inch layer of material having an elastic modulus of 500,000 psi. This provides a basis for comparison for sections of different mix designs and thicknesses.

A statistical analysis comparing six month performance of Site I to that measured during the post construction phase is given in Table 2. Those six month values marked with an asterisk are statistically significantly different from corresponding post construction measurements at a 95 percent confidence level ($\alpha = 0.05$). Again no cores were taken and only that portion of the control section not affected by the reconstruction operations was tested for deflection. The spreadability, 60.4 percent and maximum deflection, $26.5 \times 10^{-4}$ inches are plotted in Figure 7. The statistically significant drop in the ability of the base material to distribute load is reflected in the decreased spreadability measure. The effective thickness of this material dropped from 6.5 to 4 inches. This is the only section at either site that exhibited an apparent change in subgrade modulus. The decline of the performance level of this section was undoubtedly a
Table 2. Comparison of Dynaflect data for experimental test sections in La Porte, Texas - Site I.

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Test Section</th>
<th>Base Course Material</th>
<th>Post Const.</th>
<th>Six Months</th>
<th>Post Const.</th>
<th>Six Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>Crushed Limestone</td>
<td>Avg. = 26.8</td>
<td>26.5</td>
<td>64.9</td>
<td>60.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Control) n = 8</td>
<td>Std. Dev. = 5.7</td>
<td>3.1</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>10% PC Stabilized Phosphogypsum</td>
<td>Avg. = 18.9</td>
<td>19.9</td>
<td>73.5</td>
<td>71.2*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 2.4</td>
<td>2.8</td>
<td>1.8</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>n = 8</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*Spreadability = Average deflection/maximum deflection.

* Denotes a statistically significant difference from post construction value (α = 0.05).
result of the excessive traffic mentioned earlier coupled with the absence of a protective sealing surface treatment.

2.1.3 Test Site I - Section 2, C St., (10% Portland Cement Stabilized Phosphogypsum)

This 460 ft. long experimental test section, which completed Site I, consists of a base material of cement stabilized phosphogypsum. Phosphogypsum, hauled to the site in trailer dumps on July 18, 1983, was spread evenly with a maintainer with a minimum of effort. Stabilization took place the following day. Initially, the material was partially windrowed to each side to make ready for cement application. Successive passes of the transport truck equipped with a pressurized distributor helped to evenly distribute the 41 tons of cement. Pressures of about 10 psi caused a slight dusting problem with the cement (see Figure 8). Cement application was halted for about 20 minutes due to a clogged line in a transport truck. The operation was finally completed in approximately two hours. The windrowed material was bladed back out onto the roadway in preparation for the pulver mixing operation. After two complete coverages, an intimate mix was achieved. Excessive rainfall had made the phosphogypsum slightly wet of optimum. Therefore, no water was added to the mix. Compaction began with a sheepsfoot roller equipped with a vibratory capability. After five to six complete coverages, a 10 ton pneumatic roller was used to complete compaction and seal the surface. Nuclear total densities and laboratory moisture contents, shown in Table 1 indicate that density requirements were met. The section was immediately "blue-topped", cut to final grade and re-sealed with the
Figure 8. Dusting of portland cement at Test Site I.
pneumatic roller. Construction operations ended approximately six hours after cement application had begun.

Post construction Dynaflect readings are depicted in Figure 7. The average maximum deflection was $18.9 \times 10^{-4}$ inches with an average spreadability of 73.5 percent. The equivalent effective thickness for this section was 10 inches. Statistical analyses show that this section was significantly better than the control on the basis of both maximum deflection and spreadability ($\alpha = 0.05$).

Deflection data gathered during the six month evaluation (Figure 6) show a change in the load carrying capability of this section. While the average maximum deflection of $19.9 \times 10^{-4}$ inches was very close to the post construction value, the slight drop in spreadability, from 73.5 to 71.2 percent, was statistically significant. The effective thickness also dropped slightly to approximately 9 inches.

Cores were also taken from this section as part of the postconstruction evaluation activity. A total of five - 4 inch diameter cores were taken from the base material. These cores were wrapped in foil, coded and then wrapped in plastic before transporting to the laboratory. Laboratory treatment involved sawing the cores, followed by a total density determination. While some cores crumbled during the sawing operation, none of the cores tested in unconfined compression were less than 4.5 inches tall. Next the cores were capped and tested in unconfined compression. Moisture contents and pH were measured on the tested core material. Laboratory results generated for the cored materials are listed in Table 3. The unconfined compressive strength of the cores from this section ranged
Table 3. Results of laboratory analysis of stabilized phosphogypsum cores from Site I, La Porte, Texas - post construction evaluation, six months.

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Test Section</th>
<th>Base Course Material</th>
<th>Total Density (pcf)</th>
<th>Moisture Content (%)</th>
<th>Dry Density (pcf)</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Age at Testing</th>
<th>pH a</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>Crushed Limestone (Control)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10% PC Stabilized Phosphogypsum</td>
<td>108.4</td>
<td>13.6</td>
<td>95.4</td>
<td>230</td>
<td>17 days</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphogypsum</td>
<td>111.0</td>
<td>18.8</td>
<td>93.4</td>
<td>--- c</td>
<td>6 mths</td>
<td>9.6</td>
</tr>
</tbody>
</table>

aAverage of five values for post construction.

bAverage of two or more values for post construction.

cNo values obtained.

N/A - Cores crumbled during field coring procedures.
from 180 to 290 psi, with an average of 230 psi after 17 days. Core
dry densities average 95.4 pcf which is slightly less than those
obtained in the field measurements (97.8 pcf).

Cores taken during the six month evaluation phase were subjected
to the same testing sequence as mentioned earlier. Excessive cooling
water used during the coring operation had a deleterious effect on the
cores. This problem was more evident during the six month coring than
during the post construction phase. While the five cores could be
analyzed for density, moisture content and pH, no cores could be
preserved for compressive strength testing. Alternate coring
procedures should minimize this problem in the future.

2.2 Test Site II

2.2.1 General

Test Site II is located in the Lomax subdivision of La Porte,
Texas. It is a predominantly residential area located immediately
south of State Highway 225. This site consists of two streets; namely
Deaf Smith and Santa Anna (see Figure 8). Five sections (four
stabilized phosphogypsum and one control) were constructed at this
site. The cross section of each section are similar in depth and
width as those for Site I. An "as built" plan view and construction
equipment spreads are given in Appendix A. The same specifications as
discussed for Site I also apply for Site II. Preliminary site
investigation, design lime percentages and target PI's (20) were again
established an independent testing laboratory. This same laboratory
served as the testing lab of record for the subgrade. Complementary
Experimental Details

<table>
<thead>
<tr>
<th>Site</th>
<th>Section</th>
<th>Base Course Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>1</td>
<td>25% FA Stabilized Phosphogypsum</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15% FA Stabilized Phosphogypsum</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5% PC Stabilized Phosphogypsum</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Crushed Limestone (Control)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.5% PC Stabilized Phosphogypsum</td>
</tr>
</tbody>
</table>

Figure 9. Experimental phosphogypsum test sections in La Porte, Texas. Site II.
data were collected by another independent laboratory and TTI. Lime slurry from Chemlime was used to stabilize the subgrade.

The lime-stabilized subgrades for Deaf Smith and Santa Anna were prepared during June 1 to 13, 1983. PI's for the natural subgrade in this area ranged from 17 to 49. Since these streets were reconstruction projects, efforts were made to remove all base material, which was predominantly limestone and shell, from each street. Later evaluation showed that variable amounts of limestone remained in the subgrade of Santa Anna, especially in the south half of the street. Consequently, samples for optimum density determination were taken from two areas on the subgrade. In one instance, the contractor blended limestone that was used as the new base material into the subgrade in an effort to "dry up" the area. This area included the south bound lane of Santa Anna extending from approximately 100 feet south of Deaf Smith to the Bois D'Arc intersection. Construction of the north end of Santa Anna was plagued by the development of low areas in the subgrade and poor densities. Ultimately, extra material from the Deaf Smith subgrade was hauled to Santa Anna site and compacted into the low areas. This corrective action solved both problems.

Construction methods were similar for each subgrade. After initial preparation and shaping, the raw subgrade was scarified in preparation for lime application. Mixing of the lime slurry was accomplished by means of a reclaimer and a pulver mixer. Water was then added to the mixed material and the entire two-pass operation was repeated. Compaction was accomplished with a sheepsfoot compacter followed by a pneumatic roller. After densification was completed,
the surface was lightly sprinkled with water. Efforts were made to keep the surface moist during the initial four to five day curing period. Final mixing operations took place on June 7, 1983, on Santa Anna and June 13, 1983, on Deaf Smith. Generally, the same construction sequence was used as in initial mixing. Laboratory results showed that gradation and density specifications were met. PI values for the lime-stabilized subgrade ranged from 5 to 9 on Deaf Smith and 1 to 6 on Santa Anna, thereby also meeting specifications. Construction of the base course proceeded without any problems. Construction details for each will be discussed in the following subsections. Field data concerning base construction is given in Table 4.

The two course surface treatment was applied on July 19 and 20, 1983. The first treatment consisted of a prime coat of cutback asphalt (MC-30) applied at a rate of 0.13 gal/sy. Inspection revealed a penetration of 1/4 to 3/8 inch into the base material. Next a layer of AC-10 was applied at the rate of 0.30 gal/sy. The first course of precoated aggregate was then distributed over the surface and pressed into the surface with a pneumatic roller. A second application of AC-10 followed (0.25 gal/sy) and was covered by the second layer of precoated aggregate. This aggregate was rolled into the surface thereby completing the surface treatment. The post construction evaluation for this site was performed on July 29, 1983. The six month evaluation took place on February 22, 1984.
Table 4. Field data for base material of Test Site II.

<table>
<thead>
<tr>
<th>Test Section No.</th>
<th>Base Course Material (Design/Actual)</th>
<th>Date of Construction</th>
<th>Moisture Content (%)&lt;sup&gt;a,b&lt;/sup&gt;</th>
<th>Field Dry Density (pcf)</th>
<th>Percent of Laboratory Dry Density&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FA Stabilized Phosphogypsum (25/21.1)</td>
<td>6-23-83</td>
<td>13.3</td>
<td>96.1</td>
<td>90.7</td>
</tr>
<tr>
<td>2</td>
<td>FA Stabilized Phosphogypsum (15/13.0)</td>
<td>6-24-83</td>
<td>13.9</td>
<td>100.7</td>
<td>95.9</td>
</tr>
<tr>
<td>3</td>
<td>PC Stabilized Phosphogypsum (5/4.9)</td>
<td>6-24-83</td>
<td>14.6</td>
<td>93.8</td>
<td>91.9</td>
</tr>
<tr>
<td>4</td>
<td>Crushed Limestone (Control)</td>
<td>6-22-83</td>
<td>4.0</td>
<td>137.5</td>
<td>101.8</td>
</tr>
<tr>
<td>5</td>
<td>PC Stabilized Phosphogypsum (7.5/6.9)</td>
<td>6-25-83</td>
<td>11.9</td>
<td>98.7</td>
<td>96.8</td>
</tr>
</tbody>
</table>

<sup>a</sup>Based on total dry weight of mixture.

<sup>b</sup>Average of at least four values.

<sup>c</sup>Laboratory density determined by ASTM D 1557 (Modified Proctor).
2.2.2 Test Site II - Section 1, Deaf Smith, St., (25% Fly Ash Stabilized Phosphogypsum)

Construction of this 675 ft. long section began on June 22, 1983. Phosphogypsum was hauled to the site, spread evenly with a maintainer, compacted initially with a sheepsfoot, and then compacted with a pneumatic roller. Fly ash distribution began early the following day. Again transport trucks, carrying up to 25 tons of fly ash, applied the fly ash through pneumatic discharge. Dusting problems were encountered primarily in those trucks with distributors approximately 2.5 feet or more from the ground. Trucks with rubber nozzles on the discharge outlets resulted in only a 3-4 inch drop to the ground and consequently less dusting. Figure 10 illustrates the dusting which occurred during fly ash distribution.

Due to the high amount of fly ash deposited (145 tons) and to the warm temperature of the fly ash, substantial amounts of water (about 5500 gallons) had to be added. Later results showed that this was still not enough to create optimum moisture conditions. Consequently, the compaction specification was not met for this section (see Table 4).

Dynaflect results are plotted in Figure 7 which, for the post construction evaluation, reveal an average maximum deflection of $16.7 \times 10^{-4}$ inches and an average spreadability of 61.3 percent. These measurements translate into an equivalent effective thickness of 7.0 inches. Statistical analyses reveal that the average maximum deflection of this material statistically was significantly less than that of the control section ($\alpha = 0.05$) (Site II, Section 4). The six month evaluation showed that this section had not significantly
Without nozzels and excessive discharge pressure.

With nozzels and lower discharge pressure.

Figure 10. Dusting of fly ash at Test Site II.
changed (see Table 5). An average maximum deflection of $17.7 \times 10^{-4}$ inches and average spreadability of 59.8 percent were determined. The effective thickness again dropped only slightly to just above 6 inches.

In the post construction phase, only two of the five cores were suitable for compressive strength testing. These two cores had strengths of 650 and 720 psi yielding an average of 680 psi after 43 days (see Table 6). Dry densities from the cores (93.4 pcf) were slightly lower than field measurements (96.1 pcf). None of the five cores taken from this site during the six month evaluation could be saved for strength evaluation. Again this was primarily due to problems in the coring operation discussed earlier. The higher moisture contents of the cores (Table 6) support this theory.

2.2.3 Test Site II - Section 2, Deaf Smith St., (15% Fly Ash Stabilized Phosphogypsum)

The 625 ft. long base layer for this section was constructed on June 24, 1983. Fly ash application began about 8:40 am, immediately following a substantial rain storm. Drainage was adequate to remove most of the water from the surface. Again dusting problems arose but were somewhat minimized by using a lower discharge pressure of 7 psi. Mixing of the 85 tons of fly ash with pulver mixers began at 10 AM. About 2500 gallons of water were added to the material and mixed thoroughly with pulver mixers. The compaction sequence consisted of eight to 10 coverages by the sheepsfoot roller, followed by blading, compaction by pneumatic rolling and vibratory compaction with a smooth wheel roller. Use of the smooth wheel roller had to be discontinued
<table>
<thead>
<tr>
<th>Test Site</th>
<th>Test Section</th>
<th>Base Course Material</th>
<th>Maximum Deflection (x $10^{-4}$ inches)</th>
<th>Spreadability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>1</td>
<td>25% FA Stabilized Phosphogypsum</td>
<td>Avg. = 16.7</td>
<td>61.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 2.0</td>
<td>n = 8</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15% FA Stabilized Phosphogypsum</td>
<td>Avg. = 18.7</td>
<td>59.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 9.7</td>
<td>n = 9</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5% PC Stabilized Phosphogypsum</td>
<td>Avg. = 15.7</td>
<td>66.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 1.8</td>
<td>n = 8</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Crushed Limestone (Control)</td>
<td>Avg. = 21.8</td>
<td>60.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 3.8</td>
<td>n = 9</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.5% PC Stabilized Phosphogypsum</td>
<td>Avg. = 13.8</td>
<td>66.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev. = 1.3</td>
<td>n = 9</td>
<td>8.3</td>
</tr>
</tbody>
</table>

*aSpreadability = Average Deflection/maximum deflection.*

*Denotes a statistically significant difference from post construction value ($\alpha = 0.05$).
Table 6. Results of laboratory analysis of stabilized phosphogypsum cores from Site II in La Porte, Texas - post construction, six months.

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Test Section</th>
<th>Base Course Material</th>
<th>Total Density&lt;sup&gt;a&lt;/sup&gt; (pcf)</th>
<th>Moisture Content&lt;sup&gt;a&lt;/sup&gt; (%)</th>
<th>Dry Density&lt;sup&gt;a&lt;/sup&gt; (pcf)</th>
<th>Unconfined Compressive Strength&lt;sup&gt;b&lt;/sup&gt; (psi)</th>
<th>Age at Testing</th>
<th>pH&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>1</td>
<td>25% Fly Ash</td>
<td>108.8</td>
<td>16.5</td>
<td>93.4</td>
<td>680</td>
<td>43 days</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>110.2</td>
<td>19.1</td>
<td>92.5</td>
<td>-</td>
<td>≈6 mths</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15% Fly Ash</td>
<td>113.0</td>
<td>13.4</td>
<td>99.6</td>
<td>260</td>
<td>42 days</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>110.0</td>
<td>14.7</td>
<td>95.9</td>
<td>550</td>
<td>≈6 mths</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5% Portland Cement</td>
<td>108.4</td>
<td>15.5</td>
<td>93.8</td>
<td>270</td>
<td>42 days</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>107.4</td>
<td>19.5</td>
<td>89.9</td>
<td>280</td>
<td>≈6 mths</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>CLS (Control)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.5% Portland Cement</td>
<td>109.0</td>
<td>13.5</td>
<td>96.0</td>
<td>340</td>
<td>41 days</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>109.2</td>
<td>13.3</td>
<td>96.4</td>
<td>450</td>
<td>≈6 mths</td>
<td>10.6</td>
</tr>
</tbody>
</table>

<sup>a</sup>Average of 5 values.

<sup>b</sup>Average of 2 or more values.

NA - Cores crumbled during field coring procedures.

<sup>c</sup>Represents only one core.
because of excessive amounts of material adhering to the surface of
the drum. Field density measurements show that only 95.9 percent of
optimum density conditions was achieved (see Table 4).

Dynaflect data from the post construction phase show that an
average maximum deflection of $16.7 \times 10^{-4}$ inches and an average
spreadability of 65.5 percent were obtained. The equivalent depth for
this section was 8.0 inches. Statistical analyses showed that the
average spreadability and average maximum deflection of this section
were significantly more favorable than those of the control section
(Site II, Section 4). Deflection data collected in January showed no
significant change in the maximum deflection. The spreadability did
lessen slightly with the net result of reducing the effective
thickness to approximately 7 inches.

Dry densities of the post construction cores, as shown in Table
6, and those determined in the field compare closely (99.6 vs. 100.7
pcf respectively). Average compressive strength of these cores was
260 psi after 42 days. The one core tested during the six month
evaluation had a compressive strength of 550 psi. Although this is
only one value, it does suggest an strength increase over the post
construction data.

2.2.4 Test Site II - Section 3, Deaf Smith St., (5% Portland Cement
Stabilized Phosphogypsum)

This 625 foot section, built on June 24, was the first
cement-stabilized section constructed. Dusting of the cement was
still a problem, but only minimal compared to that encountered with
the fly ash. Mixing of the 28 tons of cement began at 1:20 PM. The
mixing and compaction sequence was the same as that used in Section 2, with the exception that this section was not compacted with a smooth steel wheel roller. Density measurements showed that only 91.9 percent of optimum compaction was achieved. However, due to the time limitations involved with portland cement, the section was blue-topped, cut to final grade and rolled with the pneumatic roller. Construction was completed by 5 PM.

Post construction Dynaflect readings for this section produced an average maximum deflection of $15.5 \times 10^{-4}$ inches and an average spreadability of 62.2 percent (see Figure 7). The equivalent depth for this section was 7.0 inches. Statistical analysis shows that the maximum deflection for this section was significantly lower than that for the control section. Based on Dynaflect readings, there was no significant change in deflection or load distribution capability for this section after six months in service. At that time, the average maximum deflection was $14.8 \times 10^{-4}$ inches with an average spreadability of 63.5 percent. The effective thickness did increase slightly to about 7.5 inches. Post construction core data suggest an average compressive strength (270 psi) was almost equivalent to that developed in the 15% fly ash section (260 psi). Average core densities and field densities were identical at 93.8 pcf. The six month core data showed higher moisture contents and approximately the same compressive strength (280 psi).
2.2.5 Test Site II - Section 4, Santa Anna St., (Crushed Limestone - Control)

This control section was built for the purposes of establishing a "typical" level of performance. The section extends from the intersection of Bois D'Arc to approximately 140 feet north of Deaf Smith and from the end of Section 3 on Deaf Smith east to Santa Anna (approximately 145 feet).

Base material was installed on June 22, 1983, using typical construction procedures. The material was bladed into place, watered and then compacted by sheepsfoot and pneumatic compactors. Dry density specifications of 131.1 pcf were met. No problems were encountered.

Dynaflect readings taken in the post construction evaluation for this section consisted of an average maximum deflection of 21.8 x 10^{-4} inches with an average spreadability of 60.2 percent. Equivalent depth of a 500,000 psi modulus material was 6.0 inches. After approximately six months, the maximum deflection decreased slightly but significantly, resulting in an increase in effective thickness to about 7 inches. No cores were taken from this section.

2.2.6 Test Site II - Section 5, Santa Anna St., (7.5 Portland Cement Stabilized Phosphogypsum)

This 720 foot section spans from the end of the crushed limestone section north to Houston Drive and was constructed on June 25, 1983. Application of cement from the transport trucks began at 7:30 AM with only slight dusting problems. A uniform distribution of the 42 tons of cement was achieved except at the extreme north end of the section.
To correct the problem, the material was remixed by a pulver mixer and then rebladed evenly across the street. The entire base material was mixed using a minimum of four passes of a pulver mixer. The problem material at the north end of the section received an additional two passes. In order to help insure compaction, six to eight coverages of the entire section were made by the sheepsfoot compactor. At this point the material looked and felt too dry. Therefore, approximately 600 gallons of water were added to the section. This was followed by another four coverages by the sheepsfoot roller at which time the compactor was making 0.5 - 1 inch indentations (see Figure 11) and "walked out." The section was then blue topped, cut to final grade and sealed with a pneumatic roller. These operations were then hampered by a massive downpour of rain. As a result, some of the edges of the base experienced some washing, especially at the north end. One resident on the street created a rut in the soaked material by turning into his driveway. Several days later, the material had set and the rut remained (see Figure 12). Density measurements showed that 96.8 percent of optimum density was achieved.

Average maximum deflection and spreadability values generated from Dynaflect measurements during post construction evaluation were $13.8 \times 10^{-4}$ inches and 66.1 percent, respectively (see Figure 7). Equivalent thickness for this section was 8.0 inches. Favorable statistical comparisons for each value exist, meaning that the lesser maximum deflection and the higher spreadability were significantly different than that of the control section. After about six months in service, no significant change in performance was noted. The average
Figure 11. Sheepsfoot compaction of cement stabilized phosphogypsum at Test Site II.

Figure 12. Wheel rut preserved in hardened cement stabilized phosphogypsum.
maximum deflection was $13.3 \times 10^{-4}$ inches with an average spreadability of 66.4 percent. The effective thickness remained 8.0 inches.

Dry density for the post construction cores averaged 96.0 pcf as compared to an average of 98.7 pcf for the field readings. Mean compressive strength of the cores was 340 psi after 41 days of aging. Although this section was installed in the worst weather conditions, it appears to be best in service section to date. This can be validated by its visual appearance, performance and increase in average compressive strength to 450 psi in six months. Each strength is an average representative of four cores.

2.3 Construction Problems

One of the objectives of this project was to define unusual or anomalous construction problems, if any, that may be created due to the use of phosphogypsum. The only problems which were encountered on the job were dusting during fly ash and portland cement application, measurement of total density and moisture content of the stabilized-phosphogypsum mixture in the field and coring of the stabilized material. Only the latter two could be considered to be inherent to the use of phosphogypsum.

Field density measurements involved use of a Troxler nuclear density gauge. Total density readings given by the gauge can be affected by the composition of the material (10). Testing by TTI has shown that only minimal variations in total density of the order of 0-1 pcf in excess of typical scatter in the gauge were found for phosphogypsum. These variations were found to be more prevalent with
the gauge operating in the "FAST" counting mode. Smaller errors and more repeatable data were generated when using SLOW and NORMAL counting modes.

Moisture contents are used in conjunction with total density to calculate dry density, which is the basis for almost all density specifications. Nuclear moisture readings measure the amount of hydrogen in the soil and thus can also be affected by materials having hydrogen concentrations well out of the typical range of most construction materials. This is the case of the hydrogen present in the structural water of dihydrate phosphogypsum (CaSO$_4$•2H$_2$O).

Moisture contents of oven dried (40$^\circ$C) phosphogypsum in the range of 15% were found to give nuclear moisture readings ranging from 31.1 to 40.4 percent. Usually these values can be calibrated by using an appropriate "K-factor" (10). Once established, this factor can be input in the gauge providing a moisture correction in the field. Research by TTI has been aimed at establishing this K-factor for both neat phosphogypsum and stabilized phosphogypsum mixtures. Data presented in Table 7 indicates more data scatter associated with the FAST counting mode. The least data scatter was experienced with the SLOW setting. However, since this is a relatively long counting (four min.) operation, it may not be practical in the field.

Potential field problems with the use of a nuclear density gauge will be minimal in that field moisture contents can eventually be estimated by eye. Another alternate method of obtaining optimum moisture content in the field is to base field density measurements on total density. Field mixed material can easily be compacted according to standard procedures with portable laboratory equipment located at
Table 7. Summary of oven-dry moisture content calibration with the percent moisture reading by nuclear density gauge.

<table>
<thead>
<tr>
<th>Mix Design</th>
<th>K-Factor = ( \frac{%M(\text{True}) - %M(\text{Gauge})}{%M(\text{Gauge}) + 100} ) x 1000</th>
<th>( \text{Counting Speed} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Slow (4 min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal (1 min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fast (.25 min)</td>
</tr>
<tr>
<td>100% Phosphogypsum</td>
<td>Avg. = -148, Std. Dev. = 1.51, n = 8</td>
<td>-152, 6.9, 20</td>
</tr>
<tr>
<td>15% Fly Ash/85% Phosphogypsum</td>
<td>Avg. = -103, Std. Dev. = 2.7, n = 10</td>
<td>-103, 5.0, 20</td>
</tr>
<tr>
<td>5% Portland Cement/95% Phosphogypsum</td>
<td>Avg. = ----, Std. Dev. = ----, n = ----</td>
<td>-146, 10.9, 20</td>
</tr>
<tr>
<td>10% Portland Cement/90% Phosphogypsum</td>
<td>Avg. = ----, Std. Dev. = ----, n = ----</td>
<td>-143, 3.4, 20</td>
</tr>
</tbody>
</table>

K-Factor = \( \frac{\%M(\text{True}) - \%M(\text{Gauge})}{\%M(\text{Gauge}) + 100} \)

41
the jobsite. Addition of successive amounts of water to the original mix will result in several total density values that can be plotted on a master moisture density curve. Once the relative position of the insitu material is established on the curve, simple calculations can dictate the amount of water to be added in the field to achieve optimum conditions. This procedure was successfully demonstrated in the construction of Section 2 of Site I.

The coring problem was due to excessive water used in the coring operation combined with the destructive action of the core. This could probably be minimized by using an alternate technique in which the water is replaced by compressed air as the lubricant. Current plans include the investigation of the feasibility of this method in the one year evaluation period.
3.0 Conclusions and Recommendations

3.1 General

The phosphogypsum test sections of La Porte represent one of the first, if not the first, supervised and fully documented construction project with this new by-product material. Five experimental sections containing a portland cement or fly ash stabilized base course were constructed, with minimal difficulty, using typical construction equipment, practices and procedures. A four year performance evaluation, presently underway, will monitor the performance of these sections as they are subjected to traffic and exposed to the environment. The initial construction and two phases of evaluation, post-construction and six months, have been completed. The following conclusions and recommendations concerning the specific materials utilized are warranted at this time. Generalizations beyond the specific conditions involved in this study should not be drawn.

3.2 Conclusions

1. Base courses for city streets were successfully constructed using phosphogypsum stabilized with either portland cement or fly ash.

2. The only construction problems encountered were dusting during placement of the dry portland cement or fly ash and some data scatter in using nuclear density quality control techniques. These problems can easily be overcome.
3. Post construction and six month evaluations reveal all the stabilized phosphogypsum base course test sections are performing as well as or better than, the crushed limestone control sections. This is very significant since all the sections were subjected to severe weather (a hurricane) shortly after being constructed and one test section remained uncovered for about a year.
4.0 REFERENCES


Appendix A. Planviews, pavement cross sections, construction equipment spreads, contractors and testing laboratories.

Figure A1. Plan view of experimental phosphogypsum test sections in La Porte, Texas - Site I.
Figure A2. Plan view of experimental phosphogypsum test sections in La Porte, Texas - Site II.
Figure A3. Typical cross section for Test Site I and II - La Porte, Texas.
Table A1. Equipment spread for Test Site I.

Subgrade (City of La Porte)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number Used</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor Mounted Pulver Mixer</td>
<td>2</td>
<td>Rex</td>
</tr>
<tr>
<td>Reclaimer*</td>
<td>1</td>
<td>Ray Go</td>
</tr>
<tr>
<td>Maintainer</td>
<td>2</td>
<td>Galion</td>
</tr>
<tr>
<td>Pneumatic Roller</td>
<td>1</td>
<td>Tampo</td>
</tr>
<tr>
<td>Sheepsfoot Compactor</td>
<td>1</td>
<td>----</td>
</tr>
<tr>
<td>(towed behind tractor)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Base (BWF General Contractors Inc.)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number Used</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulver Mixer</td>
<td>1</td>
<td>Ray Go</td>
</tr>
<tr>
<td>Maintainer</td>
<td>2</td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Sheepsfoot Roller</td>
<td>1</td>
<td>Ingersoll-Rand</td>
</tr>
<tr>
<td>Pneumatic Roller</td>
<td>1</td>
<td>Hyster</td>
</tr>
</tbody>
</table>

*On loan from BWF.
Table A2. Equipment spread for Test Site II.

Subgrade (McKey Construction Co.)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number Used</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintainer</td>
<td>2</td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Pulver Mixer</td>
<td>2</td>
<td>Bros</td>
</tr>
<tr>
<td>Pneumatic Roller</td>
<td>2</td>
<td>Caterpillar, Ingram</td>
</tr>
<tr>
<td>Sheepsfoot Compactor</td>
<td>1</td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Front End Loader</td>
<td>1</td>
<td>John Deere</td>
</tr>
<tr>
<td>Water Truck</td>
<td>1</td>
<td>----</td>
</tr>
<tr>
<td>Smooth Wheel Roller</td>
<td>1</td>
<td>Bros</td>
</tr>
</tbody>
</table>

Base (BWF General Contractors Inc.)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number Used</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulver Mixer</td>
<td>2</td>
<td>Ray Go</td>
</tr>
<tr>
<td>Maintainer</td>
<td>1</td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Sheepsfoot Roller</td>
<td>1</td>
<td>Ingersoll-Rand</td>
</tr>
<tr>
<td>Pneumatic Roller</td>
<td>1</td>
<td>Hyster</td>
</tr>
<tr>
<td>Smooth Wheel Roller</td>
<td>1</td>
<td>Ingersoll-Rand</td>
</tr>
<tr>
<td>Water Truck</td>
<td>1</td>
<td>----</td>
</tr>
</tbody>
</table>
Table A3. Contractors involved with construction of experimental phosphogypsum test sections in La Porte.

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Pavement Component</th>
<th>Contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Subgrade</td>
<td>City of La Porte</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>BWF General Contractors, Inc.</td>
</tr>
<tr>
<td></td>
<td>Two Course</td>
<td></td>
</tr>
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<td></td>
<td>Surface Treatment</td>
<td>City of La Porte</td>
</tr>
<tr>
<td>II</td>
<td>Subgrade</td>
<td>McKey Construction Equipment Inc.</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>BWF General Contractors, Inc.</td>
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<tr>
<td></td>
<td>Two Course</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface Treatment</td>
<td>City of La Porte</td>
</tr>
<tr>
<td>Test Site</td>
<td>Pavement Component</td>
<td>Laboratory/Agency</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>aCoastal Testing Laboratories, Inc.</td>
</tr>
<tr>
<td>I &amp; II</td>
<td></td>
<td>MRA/Materials Engineers, Inc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Texas Transportation Institute</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>MRA/Materials Engineers, Inc.</td>
</tr>
<tr>
<td></td>
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<td>Texas Transportation Institute</td>
</tr>
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<td></td>
<td>Two Course Surface Treatment</td>
<td>Coastal Testing Laboratories, Inc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MRA/Materials Engineers, Inc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Texas Transportation Institute</td>
</tr>
</tbody>
</table>

\(^a\)Independent testing laboratory of record. Retained by the City of La Porte.
Appendix B. Material Properties

<table>
<thead>
<tr>
<th>Sieve Size (in)</th>
<th>Specification Limits</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 3/4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>5-25</td>
<td>13.4</td>
</tr>
<tr>
<td>1/2</td>
<td>30-50</td>
<td>36.3</td>
</tr>
<tr>
<td>No. 4</td>
<td>45-65</td>
<td>64.2</td>
</tr>
<tr>
<td>No. 40</td>
<td>70-80</td>
<td>88.2</td>
</tr>
</tbody>
</table>

Table B1. Sieve analysis on crushed limestone used in control sections in La Porte. 1972 TDH Standard Specifications
Item 242, Type A; Grade 1
Table B2. Sieve analysis of precoated aggregate used for surface treatment. 1972 Standard Specifications

**First Course. Item 305, Class A, Precoated, Type PE, Grade 2**

<table>
<thead>
<tr>
<th>Sieve Size (in)</th>
<th>Specification Limits</th>
<th>Site I Actual</th>
<th>Site II Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5/8</td>
<td>0-5</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>1/2</td>
<td>85-100</td>
<td>49</td>
<td>20</td>
</tr>
<tr>
<td>3/8</td>
<td>95-100</td>
<td>88</td>
<td>72</td>
</tr>
<tr>
<td>No. 10</td>
<td>99-100</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

**Second Course. Item 305, Class A, Precoated, Type PE, Grade 4**

<table>
<thead>
<tr>
<th>Sieve Size (in)</th>
<th>Specification Limits</th>
<th>Site I Actual</th>
<th>Site II Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3/8</td>
<td>0-5</td>
<td>45</td>
<td>41</td>
</tr>
<tr>
<td>1/4</td>
<td>95-100</td>
<td>88</td>
<td>86</td>
</tr>
<tr>
<td>No. 10</td>
<td>99-100</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>
Appendix C. City of La Porte Specifications.

LIME STABILIZATION

ART NO.
1. Description
2. Materials
3. Equipment
4. Construction Methods
5. Finishing, Curing and Preparation for Surfacing
6. Laboratory Services
1. **Description:** This item shall consist of treating the subbase by the pulverizing, addition of lime, mixing and compacting the mixed material to the required density. This item applies to natural ground or embankment, and shall be constructed as specified herein and in conformity with the typical sections, lines and grades as shown on the plans or as established by the Engineer.

2. **Materials:** (1) The lime shall meet the following requirements for "Hydrated Lime and Lime Slurry", Type A Hydrated Lime:

Type A, Hydrated Lime, shall consist of a dry powder obtained by treating quicklime with enough water to satisfy its chemical affinity for water under the conditions of its hydration. This material is to consist essentially of calcium hydroxide or a mixture of calcium hydroxide and a small allowable percentage of calcium oxide, magnesium oxide and magnesium hydroxide.

When sampled and tested according to prescribed Texas Highway Department procedure, hydrated lime shall conform to the following requirements as to chemical composition:

- Hydrate alkalinity, percent by weight of Ca (OH)2
- Unhydrated lime content, percent by weight CaO
- "Free Water" content, percent by weight H2O

The percent by weight of residue retained shall conform to the following requirements:

- Residue retained on a No. 6 (3360-micron) sieve
- Residue retained on a No. 10 (2000-micron) sieve
- Residue retained on a No. 30 (590-micron) sieve

Specifications for Type A applies specifically to the normal hydrate of lime made from "high-calcium" type limestone. Hydrated Lime for stabilization purposes shall be applied, as provided in the governing specifications, as a dry powder or mixed with the water to form a slurry.

(2) **Sampling and Testing:** The sampling and testing of lime slurry shall be as determined by Test Method Tex-600-J, Lime Testing Procedure" as outlined by the Texas Highway Department.

(3) The percent of lime to be used for the treated subbase will be determined by preliminary tests performed in accordance with Test Method Tex-121-E as outlines by the Texas Highway Department.
3. **Equipment:** (1) The machinery, tools and equipment necessary for proper prosecution of this work shall be on the project and approved by the Engineer prior to the beginning of construction operations.

All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

(2) Hydrated lime shall be stored and handled in closed weatherproof containers until immediately before distribution on the subgrade. If storage bins are used they shall be completely enclosed. Hydrated lime in bars shall be stored in weatherproof buildings with adequate protection from ground dampness.

(3) If lime is furnished in trucks, each truck shall have the weight of lime certified on public scales approved by the Engineer.

(4) If lime is furnished in bags, each bag shall bear the manufacturer's certified weight. Bags varying more than 5 percent from that weight may be rejected and the average weight of bags in any shipment, as shown by weighing 50 bags taken at random, shall not be less than the manufacturer's certified weight.

4. **Construction Methods:** (1) General: It is the primary requirement of this specification to secure a complete course of treated material containing a uniform lime mixture, free from loose or segregated areas, of uniform density and moisture content, well bound for its full depth and with a smooth surface suitable for placing subsequent courses. It shall be the responsibility of the Contractor to regulate the sequence of his work, to use the proper amount of lime, maintain the work and rework the courses as necessary to meet the above requirements.

Prior to beginning any lime treatment, the roadbed shall be constructed and shaped to conform to the typical sections, lines and grades as shown on the plans or as established by the Engineer. The material to be treated shall then be excavated to the secondary grade (proposed bottom of the lime treatment) and removed or windrowed to expose the secondary grade. Any wet or unstable materials below the secondary grade shall be corrected as directed by the Engineer, by scarifying, adding lime, and compacting until it is of uniform stability. The excavated material shall then be spread to the desired cross section.

If the Contractor elects to use a cutting and pulverizing machine that will remove the subgrade material accurately to the secondary grade and pulverize the material at the same time, he will not be required to expose the secondary grade nor windrow the material, however the Contractor shall be required to roll the subgrade, as directed by the Engineer, before using the pulverizing machine and correct any soft areas that this rolling may reveal. This method will be permitted only where a machine is provided which will insure that the material is cut uniformly to the proper depth and which has cutters that will plane the secondary grade to a smooth surface over the entire width of the cut. The machine shall be of such design that a visible indication is given at all times that the machine is cutting to the proper depth.
(2) Application: Lime shall be spread only on that area where the first mixing operations can be completed during the same working day.

The application and mixing of lime with the material shall be accomplished by the methods hereinafter described as "Dry Placing" or "Slurry Placing". When Type A, Hydrated Lime is specified, the Contractor may use either method.

(a) Dry Placing: The lime shall be spread by an approved screw type spreader box or by bag distribution at the rate shown on the plans or as directed by the Engineer.

The lime shall be distributed at a uniform rate and in such manner as to reduce the scattering of lime by the wind to a minimum. Lime shall not be applied when wind conditions, in the opinion of the Engineer, are such that blowing lime becomes objectionable to traffic and adjacent property owners. A motor grader shall not be used to spread lime.

The material shall be sprinkled as directed by the Engineer, until the proper moisture content has been secured.

(b) Slurry Placing: The lime shall be mixed with water in trucks with approved distributors and applied as a thin water suspension or slurry. Type B, Commercial Lime Slurry, shall be applied with a lime percentage not less than that applicable for the grade used. The distribution of lime at the rates shown on the plans or as directed by the Engineer shall be attained by successive passes over a measured section of roadway until the proper moisture and lime content has been secured. The distributor truck shall be equipped with an agitator which will keep the lime and water in a uniform mixture.

(3) Mixing: The mixing procedure shall be the same for "Dry Placing" or "Slurry Placing" as herein after described.

(a) First Mixing: The material and lime shall be thoroughly mixed by approved road mixers or other approved equipment, and the mixing continued until, in the opinion of the Engineer, a homogeneous, friable mixture of material and lime is obtained, free from all clods or lumps. Materials containing plastic clays or other material which will not readily mix with lime shall be mixed as thoroughly as possible at the time of the lime application, brought to the proper moisture content and left to cure 1 to 4 days as directed by the Engineer. During the curing period the material shall be kept moist as directed.

(b) Final Mixing: After the required curing time, the material shall be uniformly mixed by approved methods. If the soil binder-lime mixture contains clods, they shall be reduced in size by raking, blading, discing, harrowing, scarifying, or the use of other approved pulverization methods so that when all nonslaking aggregates retained on the No. 4 sieve are removed the remainder of the material shall meet the following requirements when tested dry by laboratory sieves:

Minimum Passing 1 3/4" sieve ............... 100%
Minimum Passing No. 4 sieve ............... 60%
During the interval of time between application and mixing, hydrated lime that has not been exposed to the open air for a period of 6 hours or more or to excessive loss due to washing or blowing will not be accepted for payment.

(4) Compaction: Compaction of the mixture shall begin immediately after final mixing and in no case later than 3 calendar days after final mixing, unless approval is obtained from the Engineer. The material shall be aerated or sprinkled as necessary to provide the optimum moisture. Compaction shall begin at the bottom and shall continue until the entire depth of mixture is uniformly compacted by the method of compaction hereinafter specified as the "Density Control" method as indicated on the plans.

If the total thickness of the material to be treated cannot be mixed in one operation, the previously mixed material shall be bladed to a windrow just beyond the area to be treated and the next layer mixed with lime as specified in Section (3). The first layer of the treated material shall be compacted in such a manner that the treated material will not be mixed with the underlying material.

When the "Density Control" method of compaction is indicated on the plans the following provisions shall apply:

The course shall be sprinkled as required and compacted to the extent necessary to provide the density specified below as determined by the compaction ratio method.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>DENSITY, PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subbase under base courses</td>
<td>95%</td>
</tr>
<tr>
<td>Subbase under Concrete Paving</td>
<td>98%</td>
</tr>
</tbody>
</table>

The testing shall be as outlined in Test Method Tex-114-E as outlined by the Texas Highway Department or other approved methods. In addition to the requirements specified for density, the full depth of the material shown on the plans shall be compacted to the extent necessary to remain firm and stable under construction equipment. After each section is completed, tests as necessary will be made by the Engineer. If the material fails to meet the density requirements, it shall be reworked as necessary to meet these requirements. Throughout this entire operation the shape of the course shall be maintained by blading and the surface upon completion shall be smooth and uniform in conformity with the typical section shown on the plans and to the established lines and grades. Should the material due to any reason or cause, lose the required stability, density and finish before the next course is placed or the work is accepted, it shall be recompacted and refinished at the sole expense of the Contractor.

5. **Finishing, Curing and Preparation for Surfacing:** After the final layer or course of the lime treated subbase has been compacted, it shall be brought to the required lines and grades in accordance with the typical sections. The completed section shall then be finished by rolling as directed with a pneumatic or other suitable roller sufficiently light to prevent hair cracking. The completed section shall be moist-cured for a minimum of 7 days before further courses are added or any traffic is permitted, unless otherwise directed by the Engineer. In cases where subbase sets up sufficiently to prevent objectionable damage from traffic,
such layers may be opened to traffic 2 days after compaction.

6. **Laboratory Services:** The services of a testing laboratory will be required under this item of work and shall be paid for by the Contractor. Selection of the laboratory will be made by the Contractor with the approval of the Engineer. The laboratory shall make preliminary tests to determine the percentage of lime necessary to obtain stability and compaction, compaction tests, tests of the lime to determine compliance with these specifications, sieve tests, residual lime content tests, and such other tests as the Engineer deems necessary to meet these specifications.
1. Description
2. Materials
3. Construction Methods
4. Tests
CRUSHED STONE BASE COURSE

1. Description: This item of work shall consist of the construction of a base course of crushed limestone, wetted and compacted, to be placed on a prepared subgrade in accordance with these specifications, and in conformity with dimensions and sections shown on the plans, and to the lines and grades as shown or as established by the Engineer.

2. Materials: The materials shall be crushed or uncrushed as necessary to meet the requirements, hereafter specified and shall consist of durable course aggregate mixed with approved binding materials. The material source shall be approved by the Engineer.

   a. Type: Materials shall be Type A, conforming to Texas Highway Department Standard Specification, Item 242.

   b. Grade: Material shall be Grade I, conforming to Texas Highway Department Standard Specification, Item 242.

   c. Water: The water used shall be clean, clear, and free from oil, acids, alkali, or vegetable matter, at the time it is mixed with the dry ingredients. Any source of water must be approved by the Engineer before the water is used.

3. Construction Methods:

   a. General: Before any of the material is delivered to the job, the subgrade shall be finished by the Contractor and approved by the Engineer.

   b. Spreading: Material dumped on the subgrade shall be spread and shaped the same day. The material shall be sprinkled, if necessary and shall then be bladed, dragged, and shaped to conform to the typical section shown on the plans. All areas and "nest" of segregated course or fine material shall be corrected, or removed and replaced with well graded material.

   c. Compaction: After the material has been spread and shaped, it shall be sprinkled, if necessary, and rolled and compacted. The rolling shall continue until the base material has been compacted to not less than 95 per cent modified density, as determined by the AASHO Method T-99, or the latest revision thereof for course graded materials. During compaction operations, the shape of the course shall be maintained by blading. Rolling and blading shall be done alternately, as required or as directed, to obtain a smooth, even and uniform compacted base. The rollers shall be of sufficient weight to obtain the required density. In the areas that are inaccessible to rollers, the material shall be compacted with mechanical tamps.

   Where the compacted material fails to meet the specified density, the compaction methods shall be altered, as necessary, to obtain the required density. The finished base course shall be kept in a moist condition and at the specified density until the prime coat is placed thereon.
4. **Test:**

a. **Surface:** After the course is completely compacted, the surface shall be tested for smoothness and accuracy of grade and crown. If any areas are found to be deficient in smoothness and accuracy of grade and crown, such areas shall be scarified, reshaped, and recompacted until the required smoothness and accuracy is obtained. The finished surface shall not vary more than 3/8" from a 16' straight edge placed on the surface parallel to the centerline and moved sideways across the course. Each trip of the straight edge across the base course, shall overlap the previous trip by 1/4 its length.

b. **Thickness:** The thickness of the completed base course shall be determined by depth test or cores taken at locations designated by the Engineer. There shall be a minimum of one (1) test hole for every 500 square yards of base course. Where the base has a thickness deficiency of more than one-half inch (\(\frac{1}{2}\)"), the Contractor shall take up the material and reconstruct the base to the correct thickness and in accordance with these specifications. The Contractor shall replace at his expense, the base material that was removed for the test purposes.
TWO COURSE ASPHALT SURFACE TREATMENT

1. DESCRIPTION

2. MATERIALS

3. CONSTRUCTION METHODS
TWO COURSE ASPHALT SURFACE TREATMENT

1. DESCRIPTION: This item shall consist of a wearing surface composed of two applications of liquid asphalt covered with aggregate, both courses consisting of precoated limestone rock asphalt aggregate. This item shall conform in all respects to Item 322 of the Standard Specifications for Construction of Highways, Streets and Bridges, 1972 edition as adopted by the Texas Department of Highways and Public Transportation.

2. MATERIALS:

   a. Oil Asphalt: This material shall conform in all respects to Item 300 of the Standard Specifications for Construction of Highways, Streets and Bridges, as above. Oil asphalt shall be Type OA, Grade 175.

   b. Aggregate: Both courses shall consist of sound and durable particles of precoated limestone rock asphalt aggregate conforming in all respects to Item 305, Class A, of the Standard Specifications, as above. Aggregate shall be Type PE, and the first course shall be Grade 2, and second course shall be Grade 4.

   c. Flux Oil: The fluxing material to be used shall conform in all respects to Item 300 of the Standard Specifications, as above.

   d. Prime Coat: The prime coat asphaltic material shall conform in all respects to Item 300, of the Standard Specifications, as above, and shall be cut back asphalt Grade MC-1.

3. CONSTRUCTION METHODS: The prime coat and asphalt shall be placed only when the weather conditions, in the opinion of the Engineer, are suitable.

   a. Prime Coat: When the base course is satisfactory to receive the prime coat, in the opinion of the Engineer, the surface shall be cleaned by sweeping or other approved methods. The asphaltic material shall be applied to the cleaned base by an approved type of self-propelled pressure distributor so operated as to distribute the material at a rate of 0.20 to 0.30 gallons per square yard of surface, evenly and smoothly under a pressure necessary for proper distribution. No traffic, hauling, or placement of surface shall be permitted over the freshly applied prime coat until it is sufficiently cured.
b. Asphalt and Aggregate: The asphalt and aggregate shall be applied at the approximate rate within the limits of the following schedule as directed by the Engineer:

<table>
<thead>
<tr>
<th>Gallons of Asphalt Per Sq. Yard</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Course</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>Second Course</td>
<td>0.12</td>
<td>0.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First Course</td>
<td>1:90</td>
<td>1:80</td>
</tr>
<tr>
<td>Second Course</td>
<td>1:105</td>
<td>1:95</td>
</tr>
</tbody>
</table>

c. Rolling: This item shall conform in all respects to Item 210 and/or Item 213, of the Standard Specifications as in Paragraph 1 above.

After the work has been completed as specified above, there should be a slight excess of aggregate on the surface. The Contractor shall be responsible for the maintenance of the surface and the distribution of the excess aggregate until the work is accepted by the Owner.
A PROPOSAL

FOR

EXPERIMENTAL TEST SITES USING PHOSPHOGYPSUM BASE

Submitted to:

The City of LaPorte, Texas

Submitted by:

Pasadena Chemical Corporation
A Wholly-Owned Subsidiary
of
Mobil Oil Corporation
P. O. Box 3447
Pasadena, Texas 77501

February 9, 1983
TITLE

EXPERIMENTAL TEST SITES USING PHOSPHOGYPSUM BASE

PURPOSE

To design and construct experimental test sites on city streets in LaPorte, Texas to demonstrate the effectiveness of and cost savings through the use of phosphogypsum as a base course in city streets.

SCOPE

Pasadena Chemical Corporation (PCC) proposes to provide the City of LaPorte, Texas a constructed base layer of phosphogypsum on the following three city street sites:

- West C Street-Service Center fence to 26th Street: 960 ft
- Deaf Smith Street-Houston Drive to Santa Anna: 2135 ft
- Santa Anna Street-Houston Drive to Bois D' Arc: 1116 ft

TOTAL: 4211 ft

PCC will provide, at no cost to the City of LaPorte, a base layer of phosphogypsum which equals or exceeds the presently used city street design employing 6 inches of crushed limestone base. This base layer will be placed on a stabilized subgrade provided by the City of LaPorte. The City of LaPorte will also provide a two course surface treatment.

PCC will engage the services of the Texas Transportation Institute (TTI) to assist in the design of the base layer, monitor construction, evaluate the test sites for a period of three years and prepare appropriate reports summarizing the results.
BACKGROUND

Mobil's subsidiary, Pasadena Chemical Corporation (PCC), produces phosphogypsum as a byproduct from the production of fertilizer at its Pasadena, Texas, facility. Phosphogypsum is predominantly calcium sulfate dihydrate. PCC has engaged the services of the Texas Transportation Institute (TTI) to assist it in a comprehensive research program to develop uses for phosphogypsum in road construction. TTI has been determining the technical feasibility of utilizing the phosphogypsum as a base layer in a highway or street pavement structure. A report summarizing the results to date is included in Appendix A to this proposal. The results by TTI conclude that phosphogypsum will provide a high quality base layer in a pavement structure, provided it is stabilized with a fly ash binder and properly constructed. This finding is especially significant because TTI is a nationally recognized research agency of the Texas A&M University System and is the research agency for such entities as the Texas Department of Highways and Public Transportation. TTI has extensive expertise and experience in all facets of transportation, including pavement materials evaluation. Dr. W. B. Ledbetter, P. E., of TTI has recommended the phosphogypsum be evaluated in a full-scale test site with several test sections.

Phosphogypsum presents no unfavorable environmental effects from use in a pavement structure. PCC has conducted extensive environmental investigations of the phosphogypsum, engaging several laboratories and agencies to fully investigate all known environmental considerations involving its phosphogypsum inventory and its use. Based on extensive testing, the Texas Department of Water Resources has classified the phosphogypsum as a
Class II material. As such, the Texas Department of Water Resources places no restrictions upon the sales and use of this material. Like most natural minerals, phosphate rock contains a small quantity of radioactive materials. A fraction of these materials are precipitated with the phosphogypsum. Studies conducted by the Office of Radiological Safety, Texas A&M University, show a high degree of uniformity throughout the phosphogypsum inventory with overall measurements of a low order of magnitude sufficient to support PCC's application for a license to sell phosphogypsum for a broad range of non-domiciliary construction applications. This license, which has been drafted, is now in the final stages of review by the Bureau of Radiation Control, Texas Department of Health, and is expected to issue within the next 30 days. This proposed test program is consistent with and falls within those usages listed in the license draft. Documents relating to these actions are attached as Appendix B.

PROPOSED WORK

The work is divided into the following tasks:

TASK 1. Subgrade Preparation. The City of LaPorte will shape and provide the required drainage for the sites to the current city standards. The city will also remove any existing base and surfacing, then stabilize 6 to 8 inches of the existing subgrade with lime in accordance with current city standards.

TASK 2. Base Construction. PCC will engage the services of a general contractor (suitable to the city) who will construct, at no charge to the city, the base layer on the three city streets enumerated in the SCOPE.
Two test sections will be designated as "control" and constructed using crushed limestone base (CLB). The CLB for these two control sections, each approximately 600 ft. long, will be furnished to the site by the City of LaPorte at no cost to PCC. The contractor will place, compact, and shape the CLB control sections in accordance with current city specifications at no cost to the city. The remainder of the experimental sites will be constructed by the contractor, at no cost to the city, using the PCC phosphogypsum produced by the Pasadena Chemical Corporation at Pasadena, Texas. Several test sections utilizing phosphogypsum with differing amounts and perhaps types of stabilizing agents will be constructed by the contractor, at no cost to the city, for the purpose of determining the most cost effective combination of materials and construction procedures. The specific lengths and designs of the individual test sections will be determined in cooperation with the Director of Public Works for LaPorte. All test sections will be constructed in accordance with current city standards and the specification given in Appendix C.

**TASK 3. Surface Treatment Construction.** The City of LaPorte will provide a two course surface treatment on the completed base layer, constructed in accordance with the city's current standards. The aggregate used for the first course shall be Grade 2 and the aggregate used for the second course shall be Grade 4 as described in the City of LaPorte's current specification for Two Course Surface Treatment.

**TASK 4. Construction Evaluation.** PCC will engage the services of Texas Transportation Institute (TTI) to monitor the construction of the
subgrade, base, and surface courses, and to evaluate the test sites for a period of three years. Under the direction of W. B. Ledbetter, P. E., TTI will prepare two reports on the experimental test sites; one shortly after completion of the construction and the second after the three-year in-service period. PCC will furnish this evaluation and the reports to the City of LaPorte at no cost to the city.

**TASK 5. Laboratory Tests.** The City of LaPorte will engage an independent testing laboratory at no cost to PCC to perform the standard tests required for city streets, to include subgrade stabilization, all base stabilization with the phosphogypsum as enumerated in Appendix C of this proposal, the crushed limestone, and the two course surface treatment. Copies of all data and reports from the laboratory will be furnished as follows:

One Copy

H. H. King
Pasadena Chemical Corporation
P. O. Box 3447
Pasadena, Texas 77501

One Copy

Contractor

Two Copies

W. B. Ledbetter, P. E.
Texas Transportation Institute
Texas A&M University
College Station, Texas 77843
WARRANTIES

Pasadena Chemical Corporation (PCC) warrants all designs utilizing the phosphogypsum for the base layer in these experimental test sites will be sound and durable and are expected to perform as well as the crushed limestone base control sections. If, during the test period, any experimental areas should fail, in the judgment of TTI, to perform as well as the control sections due to inadequate performance of the phosphogypsum base, PCC will remove the phosphogypsum from those failed areas and restore the lime stabilized subgrade as necessary to meet current LaPorte standards; all at no cost to the City of LaPorte.

TIME SCHEDULE

PCC will commence construction of the base layers within 30 days after the city completes the lime stabilized subgrade and will diligently prosecute the construction of the base layer as quickly as possible consistent with good construction practices.
GYPSUM BYPRODUCT BASE

1. **Description:**
This item of work shall consist of a base course composed of gypsum byproduct produced by the Pasadena Chemical Corporation's plant in Pasadena, Texas; placed and mixed if necessary with either fly ash or portland cement; then compacted, finished and shaped in accordance with the requirements of this specification and the standard requirements of the City of LaPorte.

2. **Materials:**
The materials shall be crushed or uncrushed as necessary to meet the requirements hereinafter specified and shall consist of a durable base material. All materials shall be approved in advance of use by W. B. Ledbetter of the Texas Transportation Institute.

   (1). **Gypsum Byproduct.** The gypsum byproduct shall be predominantly a Calcium Sulfate as produced by Pasadena Chemical Corporation, free of injurious or hazardous products. The pH of the material, when tested in accordance with the following procedures, shall not be less than 3.0:

   1. Calibrate the pH meter with at least two standardized buffered solutions.

   2. Crush the gypsum byproduct to 100 percent passing the number 10 mesh sieve.

   3. Mix thoroughly the byproduct gypsum, dried to a constant weight at 104 F, with distilled water on a 1:1 ratio of grams to milliliters.
4. Make three separate pH determinations and report the result as the average of the three determinations.

It is the intent of this specification to provide that the gypsum byproduct will have an average 28 day unconfined compressive strength of at least 200 psi, when molded in the laboratory in accordance with AASHTO T-180, Method C and sealed in plastic bags at room temperature with the time of test. In addition, it is the intent of this specification to provide that the gypsum byproduct, when sampled and tested in accordance with ASTM D-3668, will have an average 96 hour soaked CBR value of at least 80. Specific certificates will be obtained by the Contractor as required in the current City of LaPorte Special Conditions to city street construction Contracts. Any fly ash and portland cement to be used in conjunction with the gypsum byproduct in order to meet these strength requirements will be tested in accordance with this specification and the appropriate certificates obtained. Use of gypsum byproduct at any location other than that location which has been approved will not be permitted.

(2). Fly Ash. Fly ash shall meet ASTM Specification C593. In addition, the fly ash shall meet the following requirements:

(a). The fly ash shall have a minimum Calcium Oxide content of 15.0 percent, on a dry weight basis.

(b). The fly ash shall have a maximum of 25.0 percent larger (coarser) than the number 325 mesh sieve.

(c). The fly ash shall meet the uniformity requirements of ASTM Specification C-618.
(3). **Portland Cement.** Portland cement shall be Type I and meet the requirements of ASTM C-150.

(4). **Water.** The water used shall be clean, clear, and free from oil, acids, alkali, or vegetable matter, at the time it is mixed with the dry ingredients. Any source of water must be approved by the Engineer before the water is used.

(5). **Laboratory Services.** The services of a testing laboratory will be required under this item of work and shall be paid for by the City of LaPorte. The laboratory shall make field density tests as described hereinafter. Test results will be submitted as follows:

- One Copy to Owner
- One Copy to H. H. King
  Pasadena Chemical Corporation
  P. O. Box 3447
  Pasadena, Texas 77501
- One Copy to Contractor
- Two Copies to W. B. Ledbetter, P.E.
  Texas Transportation Institute
  Texas A&M University
  College Station, TX 77843
3. **Equipment:**

(1) The machinery, tools, and equipment necessary for proper prosecution of the work shall be on the project and approved by the City of LaPorte prior to the beginning of the construction operations. All machinery, tools, and equipment shall be maintained in a satisfactory and workmanlike manner.

(2) Fly ash and portland cement shall be stored and handled in closed weatherproof containers until immediately before distribution to the road. If storage bins are used, they shall be completely enclosed. Fly ash in bags shall be stored in weatherproof buildings with adequate protection from ground dampness.

(3) If fly ash or portland cement is furnished in trucks, each truck shall have the weight of fly ash or portland cement certified on public scales or the Contractor shall place a set of standard platform truck scales or hopper scales at a location approved by the Engineer.

(4) If fly ash or portland cement is furnished in bags, each bag shall bear the manufacturer's certified weight. Bags varying by more than 5 percent from that weight may be rejected, and the average weight of bags in any shipment, as shown by weighing 50 bags taken at random, shall not be less than the manufacturer's certified weight.

4. **Construction Methods:**

(1) General. It is the primary requirement of this specification to secure a completed base course of gypsum byproduct, stabilized with fly ash or portland cement if 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, to use the proper amount of fly ash or portland cement, if needed, maintain the work, and rework the courses as necessary to meet the requirements of this specification.

Before any material is delivered to the job site, the subgrade shall be finished by the city in accordance with their current standards.

(2) Placing and Mixing Gypsum Byproduct Base.

A. If fly ash or portland cement is used, the base material may either be field mixed at the job or plant mixed at the source of the gypsum byproduct in an approved mixing plant. Using either method, the control of the mixing shall be of such accuracy that the proportions of the materials in the mixture based on total dry weight will be maintained within the following tolerances:

fly ash................+ 4.0 percent by weight
portland cement......+ 4.0 percent by weight

a) Field Mixing With Fly Ash or Portland Cement. The gypsum byproduct shall be deposited full width directly on the prepared subgrade and shaped in layers of not less than 4 inches nor more than 10 inches (compacted) in thickness. The fly ash or portland cement shall be spread full width only on that area where the mixing and compacting can be completed within a four hour period. The fly ash or portland cement shall be spread by an approved spreader or by bag distribution at the rates determined by the Texas Transportation Institute. The fly ash or portland cement shall be applied dry and distributed at a uniform rate and in such manner as to reduce to a minimum the scattering of fly ash or portland cement by wind. A motor grader shall not be used to spread the fly ash.
The materials shall be sprinkled with water, as necessary, to reach the proper moisture content. However, initial mixing of the gypsum byproduct and stabilizer will be accomplished dry or with a minimum of water to prevent fly ash or portland cement balls.

The raw materials shall be thoroughly mixed by approved road mixers or other approved equipment, and the mixing and sprinkling continued until a homogeneous mixture is obtained containing an intimate blend of gypsum byproduct and stabilizer. The mixture shall be constructed in layers not less than 4 inches nor more than 10 inches (compacted) in thickness. Where more than one layer is to be placed, the previous layer shall be maintained in a moistened condition until the succeeding layer is placed. Succeeding layers shall not be placed until the previous layer has been tested for density and approved by the Texas Transportation Institute.

b) Plant Mixing with Fly Ash or Portland Cement. Plant mixing of the gypsum byproduct and stabilizer will be accomplished in an approved mixer. The mixture shall be a homogeneous, uniform and intimate blend of the materials and the proper amount of water. Only that amount of material will be mixed and placed directly on the prepared subgrade, full width, that can be compacted to the specified density within a four hour period from the time of initial mixing. The mixture shall be constructed in layers not less than 4 inches nor more than 10 inches (compacted) in thickness. Where the mixture must be placed in more than one layer, the previous layer shall be maintained in a moistened condition until the succeeding layer is placed. Succeeding layers shall not be placed until the previous layer has been tested for density and approved.
(3) **Compaction.** The base course material shall be compacted to at least 97% of maximum density. The maximum density will be determined in accordance with AASHTO T-180, Method A.

The density of each layer of compacted base course will be determined by the testing laboratory for compliance with these specifications in accordance with the following test methods: AASHTO Method T-238, AASHTO T-239, AASHTO T-191, or other methods approved by the Texas Transportation Institute. If these tests indicate the layer does not comply with the density requirements, the condition shall be corrected or the material replaced to meet these specifications.

In constructing the top layer, the grade shall be kept at sufficient height so that the top surface, when compacted, will be at or slightly above grade, rather than below grade. Finish grading shall be accomplished by removing excess material followed by recompaction by rolling.

(4). **Curing.** When gypsum byproduct and stabilizer are used, the surface shall be kept continuously moist until the bituminous prime coat is applied. The Contractor shall protect the bituminous prime coat from being picked up from traffic.

(5). **Construction Joints and Maintenance.** If a street section is not completed at the end of each day's construction, a straight transverse construction joint shall be formed by cutting back into the completed work to form a vertical face. Damage to completed work shall be avoided. The base course shall be constructed and finished full width each day without longitudinal joints.
5. Test:

(1). Surface. After the base course is completely compacted and finished to grade, the surface shall be tested for smoothness and accuracy of grade and crown. If any areas are found to be deficient in smoothness or accuracy of grade and crown, such areas shall be brought to the required smoothness and accuracy of grade and crown in a manner approved by the City of LaPorte. The finished surface shall not vary more than 3/8 inch from a 16 foot straight edge placed on the surface parallel to the centerline and moved sideways across the course. Each trip of the straightedge across the base course shall overlap the previous trip by 1/2 its length.

(2). Thickness. The thickness of the completed base course shall be determined by depth test or cores taken at locations designated by the Texas Transportation Institute. There shall be a minimum of one (1) test hole for every 400 square yards of base course. Where the base course has a thickness deficiency of more than one-half (1/2) inch, the Contractor shall place at his expense a layer of approved hot-mixed asphaltic concrete with a minimum thickness of at least one-half (1/2) inch throughout the deficient area. The final crown and grade of the surface of the hot-mixed asphaltic concrete shall conform to this specification. The Contractor shall replace at his own expense, the base material that was removed for the test purposes.