A DEMONSTRATION PROJECT:
ROLLER COMPACTED CONCRETE
UTILIZING PHOSPHOGYPSUM

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A DEMONSTRATION PROJECT

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FINAL REPORT

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The "Roller Compaction Concrete" (RCC) concept has found increasing favor as this technique has been demonstrated in this country. Until just recently equipment to continuously place a strip of RCC was not even manufactured in this country, but today a number of suppliers offer either domestic or foreign made equipment, and it is relatively simple to locate an experienced contractor to handle any size job.

While it is not possible to use large quantities of phosphogypsum in RCC, the approximately 15% that can be used results in a stronger concrete product. Since RCC requires a specific aggregate size graduation, it is possible that both the small size (helping to fill voids in the compacted mass) and the chemical reactivity of phosphogypsum contribute to this strength improvement.

Another advantage to using phosphogypsum in RCC is that the setting time of the mass is delayed and it can be worked for a longer period of time without adversely affecting the final properties of the RCC.

Considering the many demonstrated advantages of RCC it would appear that RCC with phosphogypsum would be an ideal construction material for central Florida roads, parking lots and storage areas. The improved properties that can be attributed to the phosphogypsum in RCC would seem to make this plentiful raw material a most desirable addition to RCC mix formulations.
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I. INTRODUCTION

Roller compacted concrete (RCC) is a relatively new technology in which a zero-slump portland cement concrete mixture is spread with concrete pavers and compacted with vibratory steel and rubber-tire rollers. Because of the ease and simplicity of this construction method, savings of one-third or more of the cost of conventional concrete pavement construction are possible for large projects.

Research on compacted concrete conducted by the University of Miami under the sponsorship of the Florida Institute of Phosphate Research has revealed that sufficient fines to fill the voids between aggregates is the key to the transformation of no slump concrete mix into a fully compacted mass. Phosphogypsum is a very fine material, which possesses good binding property under Compaction. The use of proper amounts of phosphogypsum in RCC lead to superior compaction and thus improves strength properties. Phosphogypsum also provides retardation and workability to the cement-based mixtures. Furthermore, laboratory studies have indicated that the durability of phosphogypsum-based concrete can be ensured when a proper combination of phosphogypsum and tricalcium aluminate (C₃A) content in cement is used in the mixtures.

The demonstration project consisted of driveways and parking areas located at the Florida Institute of Phosphate Research, Bartow, Florida. The project has successfully demonstrated the use of phosphogypsum in RCC pavement construction.

II. DESIGN OF THE DEMONSTRATION PROJECT

The demonstration project consisted of new driveways (including service drive) and parking areas as shown in Figure 1 and was constructed at the Florida Institute of Phosphate Research, Bartow, Florida, by the Peltz Construction Company in February of 1988. The area of pavement is approximately 2,000 sq. yd. Geometry and size of the project are not exactly ideal for RCC technology which is utilized at its best in large projects with simple geometry. However, the cost of the pavement, including site preparation and base construction was $18.00 per sq. yd.

MIX DESIGN

Economic considerations led to the use of locally mined limestone aggregate. For this reason, the target compressive strength was limited to 2,500 psi, which is on the low end of what is currently used for RCC pavement applications.
Proportions of the project's final mix constituents are reported in Table 1 and a detailed description of the mix constituents is given below:

1. **Portland Cement** A Type II portland cement with C_3A content of 7 percent was used. The cement was 14 percent, by dry weight, of the final mix.

2. **Phosphogypsum** The phosphogypsum was obtained from the USS AgriChemicals stockpile in Bartow, Florida and constituted 13 percent by dry weight of the final mix.

3. **Aggregate** Fine and coarse crushed limestone aggregate, with a maximum 7/8 in. particle size, were obtained from a Brooksville, Florida, quarry. This limestone rock, even if approved for use in road and bridge concrete construction, is of low quality.

4. **Water** No water was added to the mix ingredients during mixing. The reported content of 8.5 percent by dry weight resulted from natural moisture of both phosphogypsum and aggregates. The mix optimum moisture content according to the Modified Proctor Method (ASTM D1557) was 8.0 percent.

<table>
<thead>
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<th>Table 1: Field Mix Proportions</th>
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<tr>
<td>Constituents</td>
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<td></td>
</tr>
<tr>
<td>Type II Cement</td>
</tr>
<tr>
<td>Phosphogypsum</td>
</tr>
<tr>
<td>Fine and Coarse Aggregate</td>
</tr>
<tr>
<td>Total Water</td>
</tr>
<tr>
<td>Free Water</td>
</tr>
</tbody>
</table>

5. **Design Mix** Phosphogypsum, cement and aggregate were initially blended together to obtain the combined grading as shown by the dashed line of Figure 2. A trial strip was laid using this gradation, but it was found unsuitable for the lack of intermediate size particles. The correction was made, and the final gradation, as shown by the solid line of Figure 2, was arrived at. The
Figure 2: Combined Phosphogypsum and Aggregate Grading
adopted particle size distribution, as seen in Figure 2, is well inside the grading limits of the combined aggregate Proposed by the Corps of Engineers Guide Specification.

PAVEMENT THICKNESS DESIGN

The pavement was designed according to the U.S. Army Corps of Engineers documents ETL 1110-141 which is specifically devoted to RCC design. Calculations herein presented are based on field concrete strength.

Pavement thickness is determined as a function of the following three parameters:

1. **Flexural Strength** ($f_c$) This property can be derived from the compressive strength according to the following formula:

   $$ f_r = C (f_c)^{0.5} $$

   Where: $C$ = Constant between 9.4 and 10.8. The value of 9 was used for design.

   $$ f_{c} = 28 \text{ day compressive strength} $$

   Data on field cores, as reported in Table 2, indicates that compressive strength varied between 2176 psi for the 2.7 x 5.4 in. core and adjusted 2856 psi for the 4 x 4.5 in. core (correction coefficient of 0.9 for a length to diameter ratio of 1.125 as suggested in ASTM C42). In order to check the design, a lower bound flexural strength becomes 420 psi. resulting Modulus of Subgrade Reaction ($k$) The suggested $k$ value for a silty sand subgrade is 200 pci in accordance with the document TM5-822-6, Department of the Army Washington, D. C.. The contribution of the 7 in. thick phosphogypsum stabilized base course is considered equivalent to a 4 in. cement stabilized base. The final value of $k$ is therefore 220 pci.

2. **Modulus of Subgrade Reaction** ($k$) The suggested $k$ value for a silty sand subgrade is 200 pci in accordance with the document TM5-822-6, Department of the Army Washington, D. C.. The contribution of the 7 in. thick phosphogypsum stabilized base course is considered equivalent to a 4 in. cement stabilized base. The final value of $k$ is therefore 220 pci.

3. **Design Index (DI)** Considering that the purpose of the parking lot is to accommodate administrative vehicles with traffic composed primarily of passenger cars pickup trucks, and not more than 1 percent 2-axle trucks, the traffic category is I and the design index is 1 according to the documents TM 5-822-6.
Table 2: Properties of Field and Laboratory Mixes

<table>
<thead>
<tr>
<th>Mix</th>
<th>Initial Moisture Content (%)</th>
<th>Initial Dry-Density (lb/cu ft)</th>
<th>Compressive Strength A (psi)</th>
<th>Compressive Strength B (psi)</th>
<th>90-day Modulus of Elasticity A (psi)</th>
<th>90-day Modulus of Elasticity B ($10^6$ psi)</th>
<th>Split-Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field</td>
<td>8.5</td>
<td>131.1</td>
<td>2176</td>
<td>3174</td>
<td>2426</td>
<td>2.26</td>
<td>318</td>
</tr>
<tr>
<td>Lab</td>
<td>8.0</td>
<td>132.7</td>
<td>--</td>
<td>2767</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ref/Lab</td>
<td>8.0</td>
<td>132.3</td>
<td>--</td>
<td>3024</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* Ref/Lab= No Phosphogypsum
** A= 2.7 x 5.4 in. cylinder
*** B= 4.0 x 4.5 in. cylinder
According to the design chart as presented in the document ETL 1110-1-141, the required pavement thickness (using \( f_r = 420 \) psi, \( k = 220 \) pci and DI = 1) is 5.4 in., which is smaller than the provided pavement thickness of 6.0 in.

III. CONSTRUCTION

BASE COURSE

The base course was built by spreading 5 in. of loose phosphogypsum on the existing soil; mixing it with the on-site subgrade material to a 14" loose mixture; and compacting with a steel-wheel roller.

BLENDING AND MIXING

A power screen as shown in Figure 3 was used to break up phosphogypsum lumps. The fine particles were then fed through the pug mill mixer as shown in Figure 4, and blended with fine and coarse aggregates to avoid re-lumping. The combined aggregate was stockpiled at the side of the mixing plant until the time of mixing with cement. Moisture content of the combined aggregate was such that no water had to be added during mixing. Pre-blending provided a uniform moisture distribution and did not cause aggregate segregation.

PAVING AND CURING

The mix was loaded to the dump truck as shown in Figure 5 and hauled to the construction site, located less than two miles from the plant. The mix was dumped into a heavy duty, double tamping screened paver as shown in Figure 6. The paving operation is shown in Figures 7 and 8. Shear cracks appeared on the surface following the paving operation as shown in Figure 9, which were closed immediately by using a rubber tire roller. Tire marks as shown in Figure 10, were then made smooth by a steel-wheel roller. After the completion of the paving operation, pavement lateral edges were sloped and consolidated with a plate type hand compactor. The pavement as completed is shown in Figure 11. A coat of chemical sealer was spread on the pavement surface to maintain sufficient moisture content in the mixture for the hydration of cement. Construction started at mid afternoon, was interrupted in the early evening and was completed the morning after. Due to set retarding effect of phosphogypsum, it was evident by visual inspection that continuity was ensured at the construction joints. No contraction joint was provided.
IV. FIELD MONITORING

Three weeks after construction samples were cored from the pavement as shown in Figure 12. Cores showed that no segregation had occurred during hauling and placement.

A careful inspection of the paved surface three months after construction indicated that no cracks had developed and that good quality surface conditions extended throughout the project.

STRENGTH CHARACTERISTICS

Mechanical properties of field collected samples are presented in Table 2. The 28-day compressive strength of 4 x 4.5 in. cylinders is compared with results obtained from laboratory specimens fabricated according to the Modified Proctor Method. The first group (Lab) was made with an identical mix, whereas the second group (Lab/Ref) did not contain phosphogypsum. It can be seen that field cores have superior compressive strength. Observation of the compression failure mode consistently showed crushing of the limestone aggregates produced in Central Florida. Split-tensile strength and modulus of elasticity have values within expected ranges for the given compressive strength.

Data obtained from a previously built phosphogypsum-based RCC ramp at the University of Miami indicated an average compressive strength, of 2.7 x 5.4 in. cores taken at 2 years, was 3532 psi. In this application, cement and phosphogypsum contents were 10 and 20 percent by dry weight, respectively. Higher strength results were a consequence of the use of good quality limestone aggregate produced in South Florida.

STRENGTH DEVELOPMENT

The field observation that continuity at the construction joints was ensured by the retarded setting of the mix, is further confirmed by data presented in Table 3. Specimens were fabricated according to the Modified Proctor Method, making use of good quality limestone aggregate. After 18 hours from mixing, specimens 13-14 (i.e. 13 percent cement and 14 percent phosphogypsum) possess very low compressive strength as compared to that of the reference specimens 13-0 (i.e. 13 percent cement and no phosphogypsum). The strength of specimens C13-14 at 18 hours is equivalent to that of the reference specimens 13-0 at 4 hours. After 74 hours from mixing the difference in strength between specimens 13-14 and specimens C13-0 is in the order of 15%.
ABRASION

Field cores were subjected to abrasion tests according to the ball bearing method (ASTM C779, Procedure C) at age 28-day. The top 3 in. portion of field cores was saw-cut and both top (pavement surface) and bottom (saw-cut) surfaces were tested under wear with average results shown in Figure 13. It is evident that the abrasion resistance of the exposed top surface, composed of a thin layer of fine particles, is better than that of the saw-cut surface, which is mainly composed of coarse aggregate.

A comparison between wear resistance of field cores and concrete samples of similar composition (i.e., 10-15 = 10 percent cement and 15 percent phosphogypsum, and 15-15 = 15 percent cement and 15 percent phosphogypsum), but with different limestone aggregate is given in Figure 14. It is evident that the quality of the aggregate affects abrasion performance.

SHRINKAGE COMPENSATION

The pavement was inspected three months after construction. No natural joint had yet opened and no crack was observed. A possible reason for this performance may be in the reduced drying shrinkage of a matrix containing phosphogypsum. In Figure 15, the length change of specimens tested according to ASTM C806 indicates that addition of 10 percent phosphogypsum reduces the drying shrinkage of mortar with 10 and 15 percent cement. The cement used in these specimens contained 8.8 percent C3A.

DYNAFLECT TESTING

The dynaflect was used for the non destructive measurement of dynamic deflections on June 27, 1988. It consists of a dynamic force generator, sensor assembly and digital control device mounted on a relatively lightweight (2,000 pound) two-
Figure 13: Abrasion Test Results
Figure 14: Comparative Abrasion Resistance
Figure 15: Mortar Bar Length Change
wheel trailer. Two counter rotating steel weights provide a 1,000 pound dynamic force to the pavement surface through a pair of rigid wheels. Deflections along the pavement surface away from the rigid wheels are measured by five geophones spaced at one foot intervals as shown in Figure 16. Electrical signals from each geophone are amplified and recorded as deflection in milli-inches. The dynaflect tests were conducted by personnel of the Florida Department of Transportation.

Dynaflect testing performed on the RCC project consisted of 21 test sites along the center of the driveway at the cold joint of the pavement and of 5 test sites along the center of the parking area as shown in Figure 17. Figure 18 shows the measured deflections at the five geophones with the nearest geophone measuring the maximum deflection.

RADIATION MONITORING

A gamma radiation survey on the RCC pavement was conducted under the supervision of Dr. Gordon Nifong, Research Director of Environmental Services, Florida Institute of Phosphate Research. A summary of the survey as conducted is as follows:

<table>
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<tr>
<th>LOCATION</th>
<th>GAMMA READINGS (micro-R/hr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCC Pavement</td>
<td>11.4</td>
</tr>
<tr>
<td>Asphalt Pavement</td>
<td>24.1</td>
</tr>
<tr>
<td>Non-Paved Surfaces</td>
<td>15.0</td>
</tr>
<tr>
<td>Laboratories (indoor)</td>
<td>7.9</td>
</tr>
</tbody>
</table>

The external gamma radiation over the new RCC pavement is about 50% lower than that over the old asphalt pavement. The level over the new lot is also less than that over the original ground cover. As a point of reference, the HRS guide for indoor residential gamma is 20 micro-R/hr.

V. CONCLUSIONS

This demonstration project indicates that phosphogypsum based RCC is suitable for the construction of parking facilities. The advantage of using phosphogypsum in RCC pavement are described as follows:

1. Phosphogypsum provides additional fines for better compactability and surface finish without impairing long term durability.
2. It compensates for some of the dry shrinkage to limit the extent of cracking.
DYNAFLECT MEASURING ARRAY

Figure 16
Figure 17: Mile Posts for Dynaflect Deflection Testing
Figure 18. MILE POST

FLORIDA DOT BUREAU OF MATERIALS & RESEARCH
DYNAFLECT DEFLECTIONS ALL SENSORS

State Route: 000 Date Tested: 06-27-88
Lane: NBML Date Printed: 07-01-88
Y-Scale: 0.00 - 2.00 X-Scale: 0.270/Pg
a: 00000nm1.000 Job Limits: 0.010 - 0.270

DYNAFLECT DEFLECTION (10^-3 in.)

Driveway

Parking Lot
3. It retards setting time so that continuity at the cold joints is assured.

Quality of aggregates play an important role on strength properties of RCC and concrete in general. Central Florida's limestone may not be suitable for projects where strength in excess of 2500 psi is needed.

Moisture content in the mixture is very critical in the paving operation. High moisture content in the mixtures will result in water flowing up to the top surface, therefore, hindering the compactive effort.