Evaluation of Cement Treated Base Courses

Technical Assistance Report Number 00-1TA

by

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INTRODUCTION

The Louisiana Department of Transportation and Development (DOTD) committed approximately $160 million to its overlay program in the 1999-2000 fiscal year. Many of the roadway projects resurfaced under this program include the stabilization or restabilization of the existing base course with cement. DOTD strives to construct roadways that function adequately for the duration of their projected design life. Many roadways previously constructed with soil cement base courses have experienced excessive shrinkage cracks which have led to premature roadway failures and is aesthetically unappealing to the traveling Public. Often these cracks are filled with a bituminous sealer but many are allowed to remain as is.

Soil cement is a composite material of pulverized soil, Portland cement, and water which forms a durable structural material. It has been used throughout the world to enhance the strength characteristics of bases for roadways, parking lots, and buildings. When Portland cement is blended with water and soil and compacted, a hydration process and chemical alteration of the soil begins. The hydration process forms a paste which acts like a glue to hold the soil particles together. This mixture hardens to form a rigid material that is durable and resistant to rutting. Unfortunately, it also causes the material to contract, which produces shrinkage cracks. Factors that can influence shrinkage cracking in soil cement bases are: cement content, moisture content, density, compaction, curing, and fine grain soils. In concrete pavement, the shrinkage due to hydration and thermal expansion/contraction is typically mitigated with joints and reinforcement. Soil cement is basically a low grade concrete slab. It has no reinforcement or joints to counteract stresses and therefore must rely on the tensile strength of the material and friction with the underlying soil to resist shrinkage.

In place cement stabilization of base courses is governed by Section 303 of the Louisiana Standard Specifications for Roads and Bridges, 1992 edition. The percent of cement used to stabilize the base courses is determined by one of four methods (A,B,C,D) in DOTD TR 432M/432-99. Method B was typically used to determine the cement percentages for the projects that will be discussed later in this report. The current practice is to determine the percentage of cement that produces a compressive strength of 300 psi at seven days for soil/aggregate or recycled bases. This cement percentage (eight percent minimum) is used to construct a soil cement base course that is 8.5 inches thick (hereafter referred to as stabilized cement design).

DOTD began to construct soil cement base courses at lower cement contents of four to six percent with thicker sections of 10 to 12 inches (hereafter referred to as cement treated design). This was based on the philosophy that a thicker section with lower cement content should produce an adequate structural base course and reduce shrinkage cracks. Some states had been successful with this procedure and it was endorsed by the Portland Cement Association (PCA). However, this design was based on experience and lacked empirical data or strength criteria. Consequently, the Federal Highway Administration (FHWA) Division's office required that the cement treated design be justified and proven to be sound. They also wanted a criteria established to select the cement percentage based on testing.

In addition to the projects constructed on roads, experimental test sections were constructed at the Accelerated Loading Facility (ALF). These tests were part of a research project called Experiment 1, "Construction and Comparison of Louisiana Conventional and Alternative bases under Accelerated Loading" [1]. Nine lanes were constructed and tested. Six of the nine lanes contained a soil cement base or subbase. Each of the nine lanes had a surface course of 3.5 inches of hot mix asphaltic concrete. Though not officially part of this study, the results of the soil cement section testing in "Experiment 1" have been included.

The objectives of this project are to determine the strength characteristics of soil cement bases that were constructed under stabilized procedures (DOTD TR 432M/432-99) and the cement treated design philosophy. This was accomplished by using the Falling Weight Deflectometer (FWD) to obtain resilient modulus (Mr), the Dynamic Deflection Determination System (Dynaflect) to obtain structural number (SN), unconfined compression testing (ASTM D 1633), and durability testing (AASHTO T-135). Additionally, the testing conducted at ALF yields the total lane passes and equivalent single axle loads at failure. The results of these tests were compared with established design values or standards of practice by DOTD, AASHTO, ASTM, and FHWA. If a cement treated design base course material meets the durability, resilient modulus, and layer structural number criteria, the base course should perform favorably for its projected design life and can be used as design option for soil cement base courses.

METHODOLOGY

In order to begin, specific construction sites had to be located that met the objectives of obtaining the resilient modulus, structural number, compressive strength, and durability. This was accomplished by conducting a written survey with the DOTD District Construction Engineers. Each was petitioned to identify previously constructed and proposed projects with low cement content design. Based on that survey, a list of projects to be evaluated in the time frame of this study was compiled. Cement treated design test sections were added on two projects in District 04 and test sections were already scheduled for monitoring in District 03 and District 08, table 1. The data collected from these four research projects are also included. The ALF experiment had already been completed and the data relevant to this study has been included.

Table 1
Test section projects for FWD evaluation

Route	Parish	District
LA 89	Vermilion	03
LA 792	Bienville	04
LA 531	Webster	04
LA 496	Rapides	08

The testing program, along with the results for resilient modulus, layer coefficient, material testing, and ALF are outlined in Chapters 1 – 4, respectively.

Chapter 1

FWD and Resilient Modulus

The Falling Weight Deflectometer (FWD) is a device that closely approximates the effect of a moving wheel load, both in magnitude and duration. The 9,000 pound load is applied through a circular plate which causes the pavement to deflect. Once the load is applied, it is measured by a precision heavy duty load cell which is above the loading plate. By means of a high speed transducer, the deflection data is acquired by a computer. Through a back calculation process, the resilient modulus (elastic modulus) is determined for each layer. The resilient modulus (Mr) is a measure of a material's stiffness and can provide an indication of the condition and uniformity of a material. This number was compared to typical values found in stabilized soil cement (200 k.s.i.) and cement treated soil (100 k.s.i.) [2].

In flexible pavement design, resilient modulus is one of five variables used to determine the design structural number (SN) [3]. The structural number represents the ability of a flexible pavement to withstand the projected axle loading. The formula for the structural number is the sum of the structural numbers for each layer in the pavement section and is listed below [3]:

$$\mathbf{SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3}$$

a_1, a_2, a_3 = layer coefficients (SN/in.) representative of surface, base, and subbase courses, respectively.

D_1, D_2, D_3 = actual thicknesses (in) of surface, base, and subbase, respectively.

m_2, m_3 = drainage coefficients for base and subbase layers, respectively.

Once the survey of the District Construction Engineers was completed, a list of previously constructed sites was compiled for evaluation by the FWD, as shown in table 2. Data from the test section sites listed in table 1 included cement bases that were constructed under stabilized cement design procedures as well as the cement treated design. The goal was to locate as many sites as possible in various parts of the State. Twelve sites were available in the time frame of this study for evaluation in Districts 03, 04, 07, 08, 58, 61, and 62. Such a scatter of locations throughout the State has provided representative samples. By evaluating soil cement base courses developed by stabilized cement design and cement treated design, it was possible to compare the cement treated design resilient modulus values to both stabilized cement design and established design resilient modulus values. This provided an additional performance indicator for cement treated design base courses.

Two sequences of data acquisition were used. On the projects listed in table 1, ten FWD readings were taken on each test section and then averaged to provide a representative resilient modulus for that test section. For the projects listed in table 2, FWD readings were taken every 0.25 miles in alternating lanes for the length of the project. The results were averaged to provide a representative resilient modulus for the limits of that project. The raw data from the FWD was processed by Dynatest's ELMOD 4 software to obtain the resilient modulus.

Table 2
Previously constructed projects for FWD evaluation

Route	Parish	District
LA 991	Iberville	61
LA 1054	Tangipahoa	62
LA 109	Calcasieu	07
LA 1217	Sabine	08
LA 547	Caldwell	58
LA 1221	Natchitoches	08
LA 1085	St. Tammany	62
LA 135	Franklin	58

It should be noted that six of the12 projects evaluated had multiple cement content sections used within its limits. For clarity purposes, figure 1 illustrates the high, low, and average resilient modulus values for each cement content section.

The data for each project is listed in Appendix 1. The cement treated sections (four percent, five percent, six percent) yielded average resilient moduli of 183, 203, and 175 k.s.i., respectively. The stabilized cement sections (seven percent, eight percent, nine percent, ten percent) yielded average resilient moduli of 174, 229, 237, and 145 k.s.i., respectively.

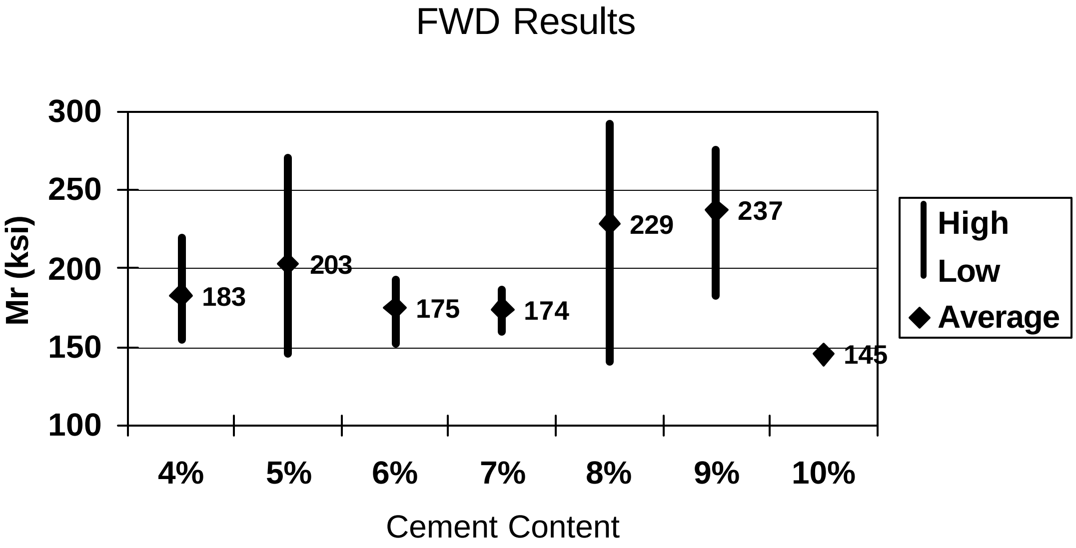

Figure 1

Summary of resilient moduli values

In order to compare the methods, the data from the four percent to six percent cement content sections were grouped into the cement treated design (CTD) and the data from the seven percent to ten percent cement content sections were grouped into the stabilized cement design (SCD). Figure 2 illustrates the high, low, and average resilient modulus for both groups. The cement treated design's average resilient moduli was 195 k.s.i. while the stabilized cement design's average resilient moduli was 220 k.s.i.

Utilizing the Statistical Analysis System (SAS) version 6.12, a statistical analysis (TTEST) was performed comparing the cement treated design with the stabilized cement design. The results indicated that there was no statistical difference between groups and that both had equal variance.

Therefore, based on the results obtained, cement treated design bases met the established criteria and were statistically the same as stabilized cement design.

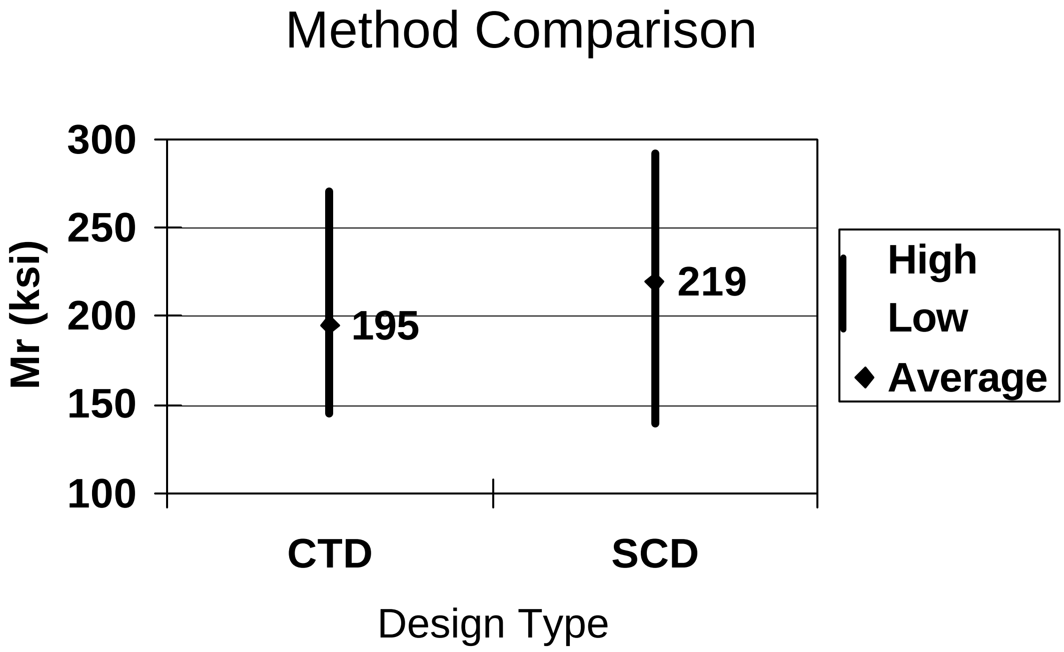

Figure 2

Resilient moduli method comparison

Chapter 2

Dynaflect and Structural Number

The Dynamic Deflection Determination system (DYNAFLECT) is a trailer mounted device which induces a dynamic load on the pavement and measures the resulting slab deflections by use of geophones spaced under the trailer at approximately one foot intervals from the application of the load. The pavement is subjected to a 1,000 pound dynamic load at a frequency of eight cycles per second, which is produced by a counter rotation of two unbalanced flywheels. The generated cyclic force is transmitted vertically through two steel wheels spaced 20 inches apart, center to center. The dynamic force during each rotation of the flywheels at the proper speed varies from 1,100 to 2,100 pounds. The deflection measurements induced by the system are expressed in terms of milli-inches of deflection. Through a series of equations and graphs, the structural number (SN) is determined. The layer coefficient, which is the structural number divided by the thickness of base layer, used for soil cement base courses in flexible pavement design by DOTD is 0.14 SN/in. Refer to Chapter 1 for details on the AASHTO pavement design formula.

Once the survey of the District Construction Engineers was completed, a list of sites was compiled for evaluation by the Dynaflect, table 3. Data from the test section sites listed in table 3 included cement bases that were constructed under stabilized cement design procedures as well as the cement treated design. The goal was to locate as many sites as possible in various parts of the state. Six sites were available in the time frame of this study for evaluation in Districts 03, 04, 58, 08, and 61. By evaluating soil cement base courses developed by stabilized cement design and cement treated design, it was possible to compare the cement treated design layer coefficient values to both stabilized cement and established design layer coefficient values. This provided an additional performance indicator for cement treated design base courses.

Table 3
Project sites for Dynaflect evaluation

Route	Parish	District
LA 531	Webster	04
LA 870	Franklin	58
LA 960	E. Feliciana	61
LA 792	Bienville	04
LA 89	Vermilion	03
LA 496	Rapides	08

Test zones for each project except LA 496, were 1000 feet long. Segments measuring 100 feet were established in each test zone for Dynaflect readings. Ten readings were taken in each segment. On LA 496, each test zone was approximately one mile long. One hundred feet segments were established in two locations within each test zone for Dynaflect readings. Ten readings were taken in each segment. The Dynaflect provides the structural number of the layers below it. It does not distinguish between layers such as subbase and base. In order to acquire the structural number of the base course (SN_2), two readings were taken. One reading was taken on the subbase (SN_3) and the other was taken on the stabilized soil cement base course (SN_{3+2}). The structural number for the soil cement base course was determined by subtracting (SN_{3+2}) from (SN_3). The layer coefficient (a_2) for the soil cement base course was determined by dividing (SN_2) by the thickness (d_2) of the base course.

$$\mathbf{SN_2 = SN_{3+2} - SN_3}$$
$$\mathbf{a_2 = SN_2 / d_2}$$

It should be noted that four of the six projects evaluated had multiple cement content sections used within its limits. For clarity purposes, figure 3 illustrates the high, low, and average layer coefficient values for each cement content section. The data for each project is listed in Appendix 2. The cement treated design sections (four percent, five percent, and six percent) yielded average layer coefficients of 0.19, 0.21, and 0.22 SN/in., respectively. There were two layer coefficient values in the five percent cement content sections that were anomalous and not used in this evaluation. One of the layer coefficient values was 0.39 SN/in. This value was high due to a weak subbase. The other layer coefficient value was 0.02 SN/in. This value was low due to a strong subbase. Each of the cement treated design sections produced layer coefficients that exceeded the 0.14 SN/in. criteria. The stabilized cement design sections (seven percent, eight percent, and nine percent) yielded average layer coefficients of 0.18, 0.32, and 0.23 SN/in., respectively. Each of the stabilized cement design sections produced layer coefficients that exceeded the 0.14 SN/in. criteria.

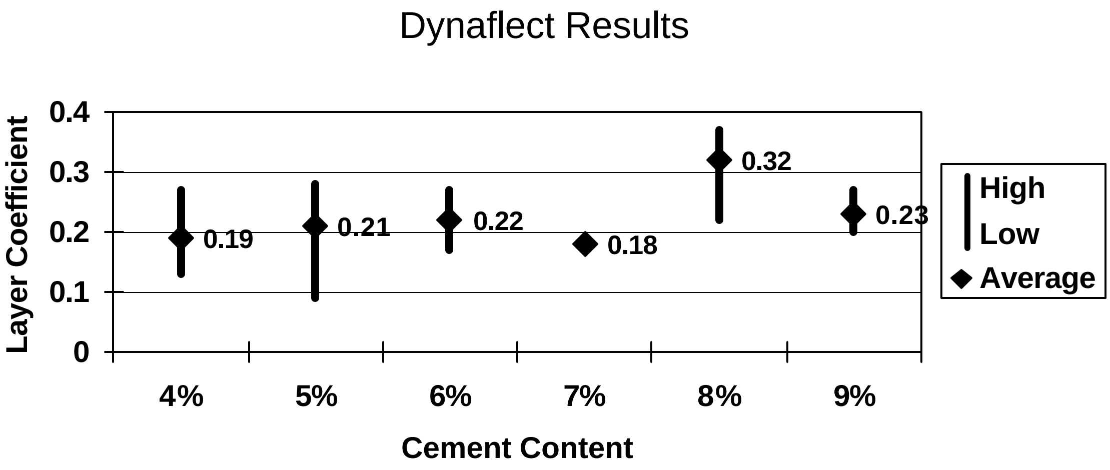

Figure 3

Layer coefficient summary

In order to compare the methods, the data from the four percent to six percent cement content sections were grouped into the cement treated design (CTD) and the data from the seven percent to nine percent cement content sections were grouped into the stabilized cement design (SCD). Figure 4 illustrates the high, low, and average layer coefficient for both groups. The cement treated design’s average layer coefficient was 195 k.s.i. while the stabilized cement design's average layer coefficient was 220 k.s.i.

Utilizing the Statistical Analysis System (SAS) version 6.12, a statistical analysis (TTEST) was performed comparing the cement treated design with the stabilized cement design. The results indicated that there was no statistical difference between groups and that both had equal variance.

Therefore, based on the results obtained, cement treated design bases met the established criteria and were statistically the same as stabilized cement design.

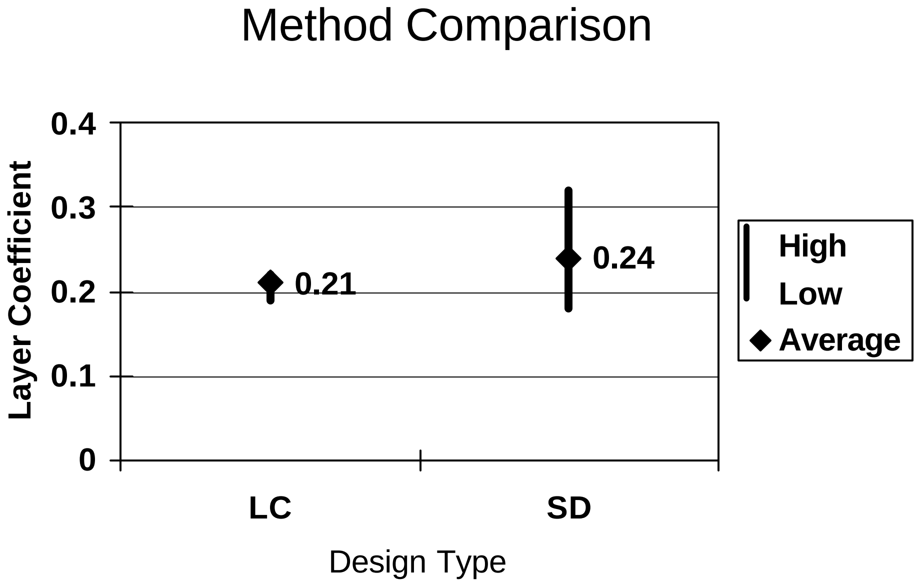

Figure 4

Layer coefficient method comparison

Chapter 3

Materials Testing

While the FWD and Dynaflect provide the in place resilient modulus and layer coefficient, they do not give the unconfined compressive strength or durability of the material. Current DOTD soil cement design criteria is based on the seven day unconfined compressive strength of the material. In order to compare the material properties of cement treated design with resilient modulus, layer coefficient, DOTD design criteria, AASHTO criteria, and stabilized cement design, samples were acquired from the locations of the Dynaflect Test sites listed in table 4. Samples were acquired after pulverization and just prior to cement stabilization for evaluation at the LTRC laboratory. Copies of the Density and Moisture Content worksheet were obtained from the Project Engineer. In order to reproduce field conditions, the laboratory samples were prepared at the cement and moisture content that was constructed in the field. It should be noted that the soils tested were from areas of the state where good bases and subgrades exist. Additionally, the results of material testing for LA 89 is not included in this report. Due to variability in laboratory testing results, a separate testing program is being conducted on the LA 89 soil and the results will be included in a separate report.

Table 4

Materials testing projects

Route	Parish	District	Soil group
LA 531	Webster	04	A-2-4 *
LA 960	E. Feliciana	61	A-1-b *
LA 792	Bienville	04	A-2-4 *

* See Appendix 3

It is the premise of the Portland Cement Association (PCA), that durability (AASHTO T-135) is the primary indicator of a soil cement base course's long term performance. Unfortunately, it can take up to six weeks to obtain the results from a durability test. In order to alleviate this, the PCA conducted a study that compares the unconfined compressive strength to durability. They found, depending upon the soil chemistry, that in general an unconfined compressive strength ranging from 300 to 800 psi represents a durable soil cement. However, the curves from their chart are not representative for all soils [4]. It is believed that most States have adopted the unconfined compressive strength criteria, which is of secondary importance according to the PCA, because it is a simple test that can be completed in seven days, unlike the durability test that can take up to six weeks.

The durability test (AASHTO T-135) consists of exposing soil cement specimens to a series of wet and dry cycles. The procedure was begun by molding two specimens at the desired cement and moisture content. One specimen was used to monitor weight loss and the other was used to determine volume change. After the specimens were molded, they were placed in a damp room at 100 percent humidity for seven days. The specimens were then removed from the damp room and submerged in water for five hours. Next, both specimens were placed in the oven at 160^o F for a minimum of 48 hours. The specimens were removed from the oven. Specimen 1 was weighed and measured. Specimen 2 was subjected to brushing with a wire scratch brush on its ends as well as longitudinally and then was weighed. Both specimens were put through twelve cycles of wetting and drying as previously outlined. Specimens pass the test when there was less than a two percent change in volume in Specimen 1 and when the weight loss criteria was met in Specimen 2, as outlined in table 5.

Table 5

Durability criteria

Soil groups	Passing weight loss
A-1, A-2-4, A-2-5, A-3	< 14%
A-2-6, A-2-7, A-4, A-5	< 10%
A-6, A-7	< 7%

Table 6 outlines the results of the durability tests and Appendix 3 lists the data for each project. For clarity purposes, the results are illustrated by cement content. It should be noted that there was one failing durability test in the five percent content specimens and that the unconfined compressive strength was also low. This was attributed to the fact that the specimen was made at a moisture content that was three percent below optimum, which matched the condition in the field. It is well know that a material prepared above or below optimum moisture content can show a significant decrease in strength whether it is stabilized or not. All other specimens ranging from 4 percent to 7 percent passed the durability tests.

Table 6

Durability test results

Cement content	Number of specimens	Durability test results
4%	2	Pass
5%	2	(1) Pass – (1) Fail
6%	3	Pass
7%	2	Pass

The unconfined compressive strength is governed by the soil/aggregate type, cement content, moisture content, compaction, and curing period. Because of this, procedures have been developed to determine the cement content based on a specified property such as compressive and tensile strength, resilient modulus, or durability. Compressive strength is typically used since it can be determined in a short period of time (seven days) and because of the simpliticity of the test. Unconfined compression testing was conducted in accordance with ASTM D1633. Briefly, it consists of molding specimens and allowing them to cure for seven days in a damp room at 100 percent humidity. The specimens are then loaded in compression to failure. The load divided by the cross sectional area of the specimen yields the unconfined compressive strength. DOTD TR 432M/432-99 outlines the required compression strengths for Methods B and C, as shown in table 7.

Table 7

DOTD compressive strength criteria

Material	Design compressive strength
Cement stabilized or treated soil, soil-aggregate and recycled materials	(300 psi) +
Cement stabilized sand clay gravel	(500 psi) +
Cement stabilized sand-shell	(600 psi) +

For clarity purposes, figure 5 illustrates the high, low, and average unconfined compressive strength values for each cement content section. The data for each project is listed in Appendix 3. There was one abnormally low unconfined compressive strength (56 psi) in the five percent cement content sections, and it was not illustrated in figure 5. This was attributed to the fact that the specimen was made at a moisture content that was three percent below optimum, which matched the condition in the field. It is well know that a material prepared above or below optimum moisture content can show a significant decrease in strength whether it was stabilized or not. The average unconfined compressive strengths for the (four percent, six percent, and seven percent) sections were 200, 279, and 443 psi, respectively. The unconfined compressive strength for the five percent cement content section was 338 psi. The results show that the unconfined compressive strength values for four percent and six percent cement contents are below and the five percent and seven percent cement contents are above the 300 psi requirement.

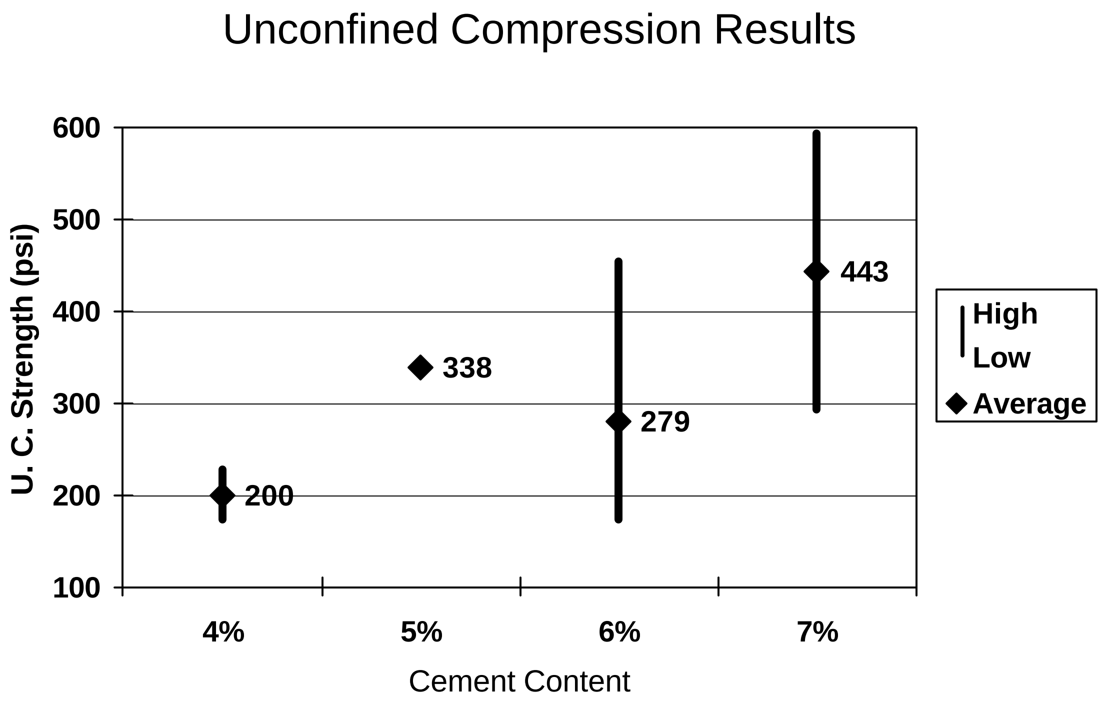

Figure 5

Unconfined compressive strength results

Chapter 4

Accelerated Loading Facility (ALF)

The Accelerate Loading Facility (ALF) was completed in 1995. Its purpose was to provide accelerated loading to sections constructed under conditions similar to roadways. It is based on Australian developed technology and was built entirely in the United States of America by Engineering Incorporated of Hampton, Virginia at a cost of $1.9 million. The ALF device is a transportable, linear, full-scale accelerated loading facility which imposes a rolling wheel load on a 39 foot by 4 foot area test pavement. Loading is one direction only, at a constant speed of 10.4 miles per hour. Each loading cycle takes eight seconds and is applied through a standard dual truck tire capable of loads between 9,750 pounds and 18,950 pounds. This indicates that for each pass 1.38 to 19.7 equivalent single axle loads (EASLs) is applied to the pavement. This allows the ALF to simulate traffic loads on a test pavement at up to 8,100 wheel passes (11,200 to 160,000 EASLs) per day. Figure 6 displays a photograph of the ALF device. The facility is operated by the LTRC under a contract with Louisiana State University (LSU).

In 1995 nine test lanes were constructed and subsequently loaded to failure. The project was entitled, “Experiment 1, Construction and Comparison of Louisiana’s Conventional and Alternative Base courses Under Accelerated Loading”. Its purpose was to evaluate alternative soil cement base courses for shrinkage crack reduction and structural capacity. Table 8 lists the nine sections that were constructed under Experiment 1.

Table 8

ALF experiment 1 test lane summary

Lane number	Base course description
S-002	8.5” stone over fabric over 3.5” select soil
S-003	5.5” stone over grid and fabric over 6.5” select soil
S-004	4” stone over 6” stone stabilized soil over 2” select soil
S-005	8.5” plant mix soil cement (10% cement content) over 3.5” select soil
S-006	8.5” plant mix sol cement (4% cement content) over 3.5” select soil
S-007	8.5” plant mix soil cement (4% cement content) with polypropylene fibers over 3.5” select soil
S-008	8.5” in-place soil cement (10% cement content) over 2” select soil
S-009	4” stone over 6” in-place soil cement (10% cement content) over 2” select soil
S-010	12” plant mix soil cement (4% cement content)

Six of the nine lanes contained a soil cement base or subbase type. Each of the test lanes had a surface course of 3½ inches of hot mix asphaltic concrete placed over the base. The subgrade beneath the base was a 5 ft. embankment which consisted of an A-4 select silty soil. The six lanes that contain soil cement are S-005, S-006, S-007, S-008, S-009, and S-010. Lane S-008 is considered the standard cement design, while lane S-010 would be considered the low cement design. Lane S-009 has a stone base and a soil cement sub base, and it may be referred to as the stone interlayer design.

Structural characteristics of the pavement layers within the test lanes were measured during the construction process by the Dynaflect. The Dynaflect induces a 1,000 pound vibratory load and measures surface deflections. The structural number (SN) of each constructed pavement layer is determined through nomographs developed from Louisiana pavements and environmental conditions. Table 9 displays the structural numbers from ALF Experiment 1 for the six lanes that contain soil cement in the base or sub base. Measurements by Dynaflect revealed a subgrade SN of less than -2 on all six lanes, which means the subgrade was very weak. Since a negative structural number is impractical, a subgrade SN of 0 was assumed on all six lanes. Based on this assumption, lane S-010 received a base structural layer coefficient of 0.22/inch. As seen in table 9, this value for the cement treated design was higher than that on the other five lanes, and also compares favorably to the soil cement design coefficient of 0.14 SN/in. The overall SN on lane S-010 was 3.1, which was also higher than that on the other five lanes. Thus, lane S-010 provided the best overall structural characteristics as measured by Dynaflect.

Table 9

Structural numbers for ALF Experiment 1

Lane #	Base Type	Thickness (in)	Base SN	Base coefficient	Surface SN
S-005	Plant mix soil cement (10%)	8.5	0.8	0.09	2.4
S-006	Plant mix soil cement (4%)	8.5	0.4	0.05	1.5
S-007	Plant mix soil cement with fibers (4%)	8.5	0.8	0.09	1.5
S-008	In-place soil cement (10%)	8.5	1.4	0.16	2.6
S-009	Stone in-place soil cement (10%)	4.0 6.0	0.3 0.0	0.07 0.00	2.3
S-010	Plant mix soil cement (4%)	12.0	2.6	0.22	3.1

The test lane sections were loaded to failure in an accelerated fashion with the ALF device as part of Experiment 1. A development of 1 in. (25 mm) depth of rutting or 1.5 ft/ft^2 (5 m/m^2) rate of cracking constituted failure for a test lane. Six of the nine test lanes contained a soil cement base or sub base type. Table 10 lists the loading summary from ALF Experiment 1 for the six lanes. The table contains the lane number, the base course type and thickness, the total passes at failure, and the total equivalent single axle loads (ESALs) at failure. One ESAL is equivalent to 18 kips. Lane S-009 had a pavement performance life of 1,295,000 ESALs, which was by far the highest of any test lane. Lane S-010 had a performance life of 620,000 ESALs, which was considerably higher than that on the other four lanes with a soil cement base.

Table 10

Loading summary from ALF Experiment 1

Lane #	Base type	Thickness (in.)	Total passes	Total ESALs
S-005	Plant mix soil cement (10%)	8.5	225,000	310,000
S-006	Plant mix soil cement (4%)	8.5	200,000	275,000
S-007	Plant mix soil cement with fibers (4%)	8.5	225,000	310,000
S-008	In-place soil cement (10%)	8.5	148,000	298,000
S-009	Stone in-place soil cement (10%)	4.0 6.0	460,000	1,295,000
S-010	Plant mix soil cement (4%)	12.0	250,000	620,000

Figure 6 illustrates in bar chart form the data from table 10. The figure plots the total ESALs for each of the six test lanes with soil cement base or subbase. As seen in figure 6, the pavement performance life of the stone interlayer lane was two to four times as long as the other lanes. Also, the pavement performance life of the cement treated design lane was at least twice as long as the other four lanes.

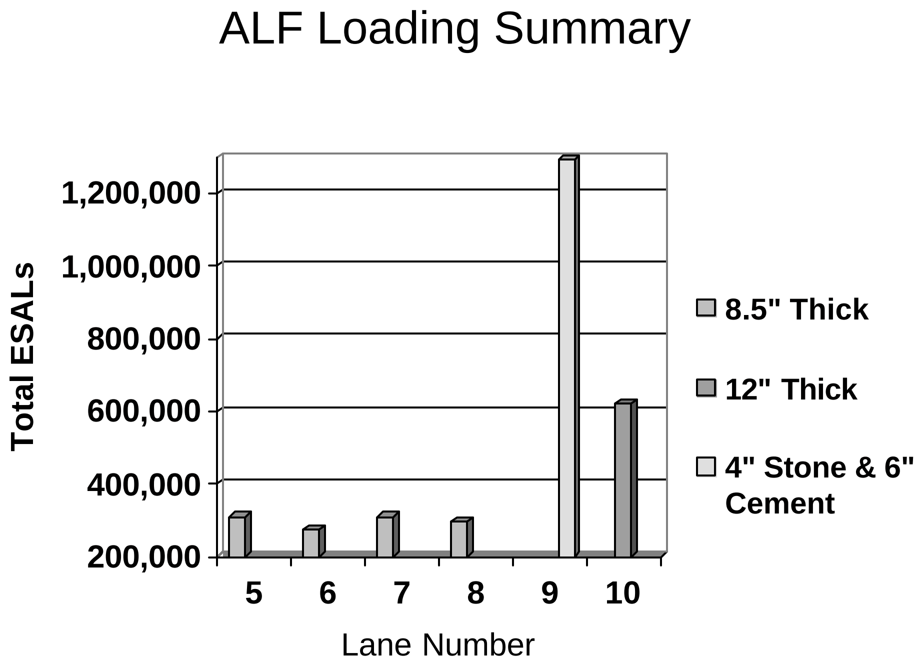

Figure 6

ALF loading summary

In summary, the test section with the stone base and soil cement stabilized subbase provided the best pavement performance of all the soil cement test lanes, according to ALF testing. Also, the test section with the cement treated design provided better pavement performance than the other stabilized soil cement base course test sections.

CONCLUSIONS

The objectives of this report were to determine the low cement content philosophy and the strength characteristics of soil cement bases constructed under standard procedures (DOTD TR 432M/432-99). This was accomplished by using the Falling Weight Deflectometer (FWD) to obtain resilient modulus (Mr), the Dynamic Deflection Determination System (Dynaflect) to obtain the structural number (SN), unconfined compression testing (ASTM D 1633), durability testing (AASHTO T-135), and ALF to determine the total lane passes and equivalent single axle loads at failure. A summary of these tasks and the corresponding conclusions of the study follows:

a) The cement treated design sections (four percent, five percent and six percent), yielded average resilient moduli of 183, 203, and 175 k.s.i., respectively. All of the cement treated design sections produced averaged resilient moduli in or above the 100 to 200 k.s.i. criteria.

b) The stabilized cement design sections (seven percent, eight percent, nine percent, and ten percent) yielded average resilient moduli of 174, 229, 237, and 145 k.s.i., respectively. All of the stabilized cement design sections produced average resilient moduli in or above the 100 to 200 k.s.i. criteria.

c) The cement treated design's average resilient modulus was 195 k.s.i. while the stabilized cement design's average resilient modulus was 219 k.s.i. The statistical analysis (TTEST) indicated that there was no statistical difference between the cement treated design and stabilized cement design and that both had equal variances. Therefore, based on the results obtained, cement treated design bases met the established resilient modulus criteria and were statistically the same as stabilized cement design bases.

d) The cement treated design sections (four percent, five percent, six percent) yielded average layer coefficients of 0.19, 0.21, and 0.22 SN/in., respectively. Each of the cement treated design sections produced layer coefficients that exceeded the 0.14 SN/in. criteria.

e) The stabilized cement design sections (seven percent, eight percent, nine percent) yielded average layer coefficients of 0.18, 0.32, and 0.23 SN/in., respectively. Each of the stabilized cement design sections produced layer coefficients that exceeded the 0.14 SN/in. criteria.

f) The cement treated design's average layer coefficient was 0.21 SN/in. while the stabilized cement design's average layer coefficient was 0.24 SN/in. The statistical analysis (TTEST) indicated that there was no statistical difference between the cement treated design and stabilized cement design and that both had equal variances. Therefore, based on the results obtained, cement treated design bases met the established layer coefficient criteria and were statistically the same as stabilized cement design bases.

g) The durability tests performed on the soils tested at cement contents ranging from four percent to seven percent cement content all passed, with the exception of one specimen at five percent cement content. The failing specimen was prepared at three percent below optimum moisture content to match field conditions. Passing durability tests indicates that the cement treated design bases should perform favorably.

h) The average unconfined compressive strengths for the (four percent, six percent, and seven percent) sections were 200, 279, and 443 psi, respectively. The unconfined compressive strength for the five percent cement content section was 338 psi. The results indicated that the unconfined compressive strength values for four percent and six percent cement contents were below the 300 psi requirement while the five percent and seven percent cement contents were above it. It should be noted that the soils tested were from areas of the state where good bases and subgrades exist.

i) The cement treated design section at ALF failed at 620,000 EASLs while the average of the stabilized cement design sections failed at 238,600 EASLs. Since the cement treated design section withstood approximately twice the loading of the standard design cement sections, it can be concluded that they should perform as well or better than the standard cement design sections.

RECOMMENDATIONS

The stabilized soil cement design method had two primary governing factors for determining the minimum cement content, 300 psi minimum compressive strength and an eight percent minimum cement, which can be modified by an aggregate correction factor. Some soils may achieve the 300 psi compressive strength minimum at less than eight percent cement, but the cement content must be increased due the established minimum. This policy should be reviewed and perhaps modified, requiring a lower minimum compressive strength with a five percent minimum cement content. On the soils tested during this study, soils with four percent cement content yielded compressive strengths as low as 172 psi and passed the wet and dry cycle durability tests. According to the PCA, durability tests should be used to determine the minimum cement content.

Furthermore, the layer coefficients from Dynaflect and resilient moduli from the FWD indicated that on the soils tested, the cement treated design bases met or exceeded current design values. Perhaps a study could be launched to correlate lower compressive strengths categorized by soil groups versus durability tests supported with results from the Dynaflect and FWD. A compressive strength standard, based on soil group and parish, could be established while the corresponding tables in DOTD TR 432M/432-99 could be revised.

Because this report contains a summary based on projects that were available in this time frame, we recommend that a research study be conducted statewide. The base course soil groups tested were predominately granular materials (A-1 to A-3), which are generally good structural materials. Additional sites should be tested with fine grain soils (A-4 to A-7).

REFERENCES

[1] Metcalf, J.M., Rasoulian, M., Romanoschi, S., and Yongqi, Li. “Construction and Comparison of Louisiana’s Conventional and Alternative Base Courses Under Accelerated Loading” Interim Report 1, Phase 1. Louisiana Transportation Research Center Research Report No. 302.

[2] Rada, G.R., Rabinow, S.D., Witczak, M.W., and Richter, C.A. “Strategic Highway research Program Falling Weight Deflectometer Quality Assurance Software.” In Transportation Research Record 1377, TRB, National Research Council, Washington, D.C., 1992, pp 42, table 3.

[3] AASHTO Guide for Pavement Structures, “Highway Pavement Structural Design.” AASHTO, Washington D.C. 1993, chapter 3.

[4] Portland Cement Association, “Soil Cement Laboratory Handbook”, Portland Cement Association, Skokie, IL, 1992, chapter 4, pp 29, figure 31.

Appendix 1

Summary of falling weight deflectometer site tests

Route	Parish	District	Cement content (percent)	Base thickness (inches)	Surface thickness (inches)	Base modulus (ksi)
LA 991	Iberville	61	4%	12	3.5	154
			5%	12	3.5	145
			6%	12	3.5	152
LA 1054	Tangipahoa	62	5%	12	3.5	246
LA 109	Calcasieu	07	5%	12	3.5	216
LA 1217	Sabine	08	5%	12	3.5	177
LA 547	Caldwell	58	5%	10	3.5	172
LA 1221	Natchitoches	08	5%	12	3.5	162
LA 1085	St. Tammany	62	5%	12	3.5	191
LA 135	Franklin	58	5%	10	3.5	162
			10%	8.5	3.5	145
LA 531	Webster	04	4%	12	3.5	191
			5%	12	3.5	192
			6%	12	3.5	193
			7%	8.5	3.5	160
LA 792	Bienville	04	4%	12	3.5	167
			5%	12	3.5	186
			6%	12	3.5	180
			7%	8.5	3.5	187
LA 496	Rapides	08	8%	8.5	3.5	217
			8%	8.5	3.5	140
			8%	8.5	3.5	292
			8%	8.5	3.5	266
			5%	12	3.5	222
			4%	12	3.5	219

(continued on next page)

Route	**Parish**	**District**	**Cement Content (Percent)**	**Base Thickness (Inches)**	**Surface Thickness (Inches)**	**Base Modulus (ksi)**
LA 89	Vermilion	03	9%	8.5	3.5	250
			9%	8.5	3.5 #	222
			9%	8.5	3.5 #	182
			9%	8.5	3.5	241
			9%	8.5	3.5	276
			9%	8.5	3.5	257
			9%	8.5	3.5	236
			5%	12	3.5	265
			5%	12	3.5 #	230
			5%	12	3.5 #	270

 # Base course contains polypropylene fibers

Appendix 2

Summary of Dynaflect Test Sites

Route	Parish	District	Cement content (percent)	Thickness (inches)	Layer Structural Number (SN)
LA 531	Webster	04	4%	12	0.16
			5%	12	0.26
			6%	12	0.23
LA 870	Franklin	58	5%	10	0.39 * (&)
LA 960	E. Feliciana	61	6%	12	0.27
LA 792	Bienville	04	4%	12	0.13
			5%	12	0.02 ** (&)
			6%	12	0.17
			7%	8.5	0.18
LA 496	Rapides	08	8%	8.5	0.33
			8%	8.5	0.22
			8%	8.5	0.36
			8%	8.5	0.37
			5%	12	0.28
			4%	12	0.27
LA 89	Vermilion	03	9%	8.5	0.24
			9%	8.5	0.25 #
			9%	8.5	0.27 #
			9%	8.5	0.22
			9%	8.5	0.20
			9%	8.5	0.21
			5%	12	0.18
			5%	12	0.09 #
			5%	12	0.18 #

*	Layer SN is high due to a weak subgrade
**	Layer SN is low due to a strong subgrade
#	Base course contains polypropylene fibers
(&)	These values were not used in the data analysis process

Appendix 3

Summary of unconfined compression and durability tests

Route	Parish	District	Cement Content (percent)	Unconfined compressive strength (psi)	Durability AASHTO T-135	Soil grade group {1}
LA 531	Webster	04	4%	172	Pass	A-2-4
			5%	56 **{2}**	Fail	A-2-4
			6%	172	Pass	A-2-4
			7%	292	Pass	A-2-4
LA 960	E. Feliciana	61	6%	211	Pass	A-1-b
LA 792	Bienville	04	4%	228	Pass	A-2-4
			5%	338	Pass	A-2-4
			6%	455	Pass	A-2-4
			7%	593	Pass	A-2-4

{1} The group determination is based upon the gradation and classification of a recycled soil cement base course.

{2} This sample was prepared at the field moisture content that was used in the field which was about three percent below optimum moisture content.