EVALUATION OF GRADED LIMESTONE BASE COURSE
ON A LOW VOLUME ROAD

Final Report

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Research Report No. 175

Research Project No. 79-1P(B)

Conducted by
LOUISIANA DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

APRIL 1985

SUMMARY

Due to decreasing supplies of native aggregate which may be incorporated into a base course, other materials need to be evaluated for constructibility and performance. To this end, a graded limestone base was constructed on a low volume road and evaluated for a period of four years.

For comparison, two limestone sections and two sections utilizing a standard department design (soil cement) were constructed in 1981. Measurements and observations indicate that after four years both limestone and soil cement sections have retained a "good" ride quality; that the limestone sections rutted approximately 50% more than the soil cement sections; that both base types have experienced base failure; and that fatigue cracking of pavement surface has occurred. Deflection measurements indicate that the limestone sections are prematurely deteriorating in structural capacity and that uniform construction (thickness, density, mixing, etc.) was not achieved throughout the project.

Based upon the observations and data collected, recommendations are made in an effort to enhance the constructibility and performance of limestone bases.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
Length		
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
Volume (Capacity)		
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
Mass per Volume		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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INTRODUCTION

Louisiana has two naturally occurring aggregates which are used as base course materials. These aggregates are siliceous gravel and dredged shell, either clam or reef shell. As the gravel and shell become increasingly expensive and harder to find, the search for alternate materials becomes more important. Environmentalists have for years been calling for an end to shell dredging due to its possible negative effects on Louisiana coastal areas. In addition, the known supply of quality gravel is rapidly being depleted.

Graded limestone is currently in use as a base course aggregate in many portions of the United States and is a potential substitute for Louisiana's naturally occurring aggregate. The purpose of this study is to evaluate the constructibility and performance of a graded limestone base course on a low volume road. Since the Department and in-state contractors have limited experience with the construction of limestone base courses, it is important to evaluate the material relative to the ability of a contractor to construct such a base course. Also, the performance of this base course as incorporated into a roadway structure needs to be evaluated with regard to time and traffic.

OBJECTIVE/SCOPE

Although other states routinely use graded limestone as a base course, Louisiana has little experience with this material in relation to its constructibility and performance.

The objective of this study is to determine if raw graded limestone will provide an acceptable alternate to naturally occurring Louisiana aggregates. To this end, a project utilizing a graded limestone (experimental) and a soil cement (control) base course was constructed and evaluated.

PROJECT DESCRIPTION

Louisiana Route 358 in Acadia Parish was selected for the construction of the experimental limestone base course. This is a rural road with an ADT (average daily traffic) of 250 and an ADL (average daily load) of 5.36 equivalent 18-kip single axle load applications. Prior to construction of the experimental base, Louisiana Route 358 was a gravel road which wound its way past rice fields, ponds and other low lying areas. The four-mile-long project required raising the embankment approximately 1-2 feet, widening the embankment, and softening several harsh horizontal curves.

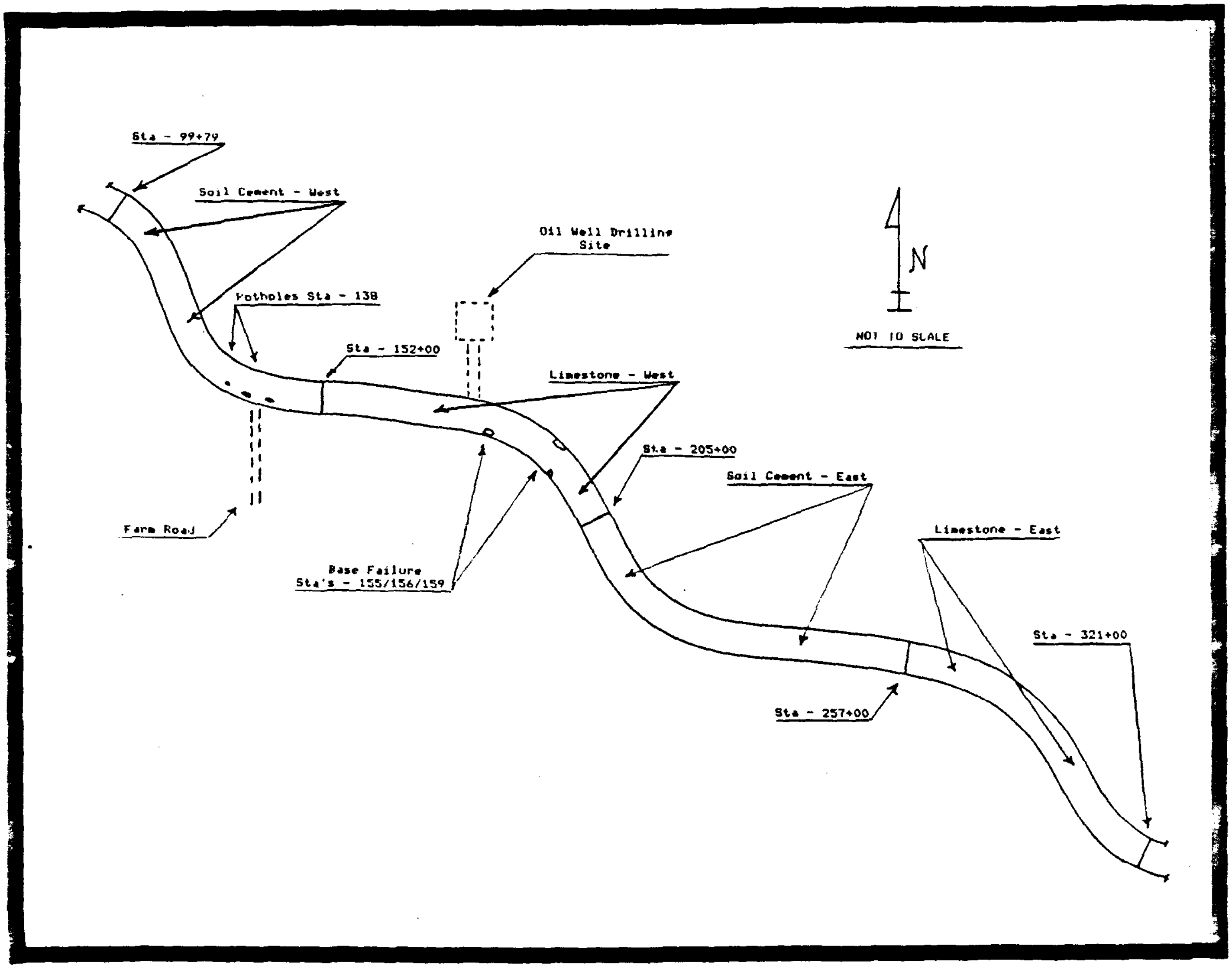
DESIGN/CONSTRUCTION

For evaluation purposes, the project, which is approximately four miles in length, was constructed with two one-mile-long graded limestone sections alternated with two one-mile-long soil cement sections (see Figure 1). The soil cement sections were included to serve as "control" sections, representing a standard department design and familiar construction procedures.

Structural design of the soil cement sections indicated an AASHTO SN (structural number) required of 1.95. Utilizing a soil cement thickness of 8.5 inches and an asphaltic concrete surfacing thickness of 1.5 inches, a structural number of 1.90 was supplied in the design. In the graded limestone sections, the soil cement thickness was replaced inch for inch with limestone, resulting in 8.5 inches of graded limestone and 1.5 inches of asphaltic concrete surfacing.

The graded limestone sections were constructed under special provisions (Appendix A) covering abrasion, gradation, plasticity and construction requirements. Construction of the test sections was completed in the early part of 1981.

Compaction of the limestone base course was considered experimental and differed from standard departmental procedures in the following manner. A compaction test section was to be constructed with the degree of compaction monitored in a "control strip" fashion. The maximum density obtained in the test section was to be the minimum acceptable density for the base course; however, this was modified to the mean of ten tests to be the minimum acceptable density if the target density was not obtained. The target density for the base course, established in the laboratory prior to initial field construction of a test section, was 98% of the maximum theoretical density as determined in accordance with AASHTO Designation: T-180.



PLAN VIEW
LOUISIANA'S LIMESTONE BASE PROJECT

Figure 1

The target density was 143.86 pounds (dry) per cubic foot with the maximum theoretical dry density being 146.80 pounds per cubic foot.

After two attempts, an acceptable control strip was constructed. The contractor was not experienced in construction techniques normally used with limestone aggregate in other states. In constructing the first two test sections he elected to use a sheepsfoot roller and compact the base course in one 8½-inch lift while applying excessive water directly to the in-place aggregate. The attempt to densify the base course using this type equipment was not successful. Addition of excessive water aggravated the effort considerably. The underlying clay embankment soils became saturated causing a loss of firm foundation to compact against, as well as intrusion of the clay into the base aggregate.

Prior to construction of the third test section, recommendations were made to the contractor to use a medium size vibratory roller for compaction of the aggregate base; also to compact the base in two lifts of approximately four inches each, and prewet the limestone prior to hauling to the test site, adding water to the in-place material only as needed and in light and controlled quantities. Using this technique the contractor substantially improved his densification effort. The mean of ten test density tests was less than the target value; therefore, it was established as the minimum acceptable density for each 1,000-foot section of limestone base to be constructed on the project. The mean of the ten sites tested was 142.75 pounds (dry) per cubic foot. Construction of the soil cement base sections followed "standard" Louisiana soil cement construction practices.

Due to excessive moisture, several portions of the embankment throughout the project had to be reworked prior to base construction.

PERFORMANCE/CONDITION MEASUREMENTS

Periodic observations and measurements were obtained at the project site for both the graded limestone and soil cement sections. This portion of the evaluation consisted of visual condition surveys, and measurements of rut depth, ride quality and deflection. Selected photographs of each test section are presented in Appendix B of this report.

A. Visual Condition Surveys

Approximately seven months after completion of the paving operations, reflected shrinkage cracks began to appear in both of the soil cement "control" sections. These block type cracks presently extend over 100% of the pavement surface. The longitudinal edges of the block cracking typically coincide with the inside and outside wheel paths of each lane. Two years after surfacing, two areas of base failure were observed in the soil cement west section. A year later two additional areas of base failure were observed adjacent to the first two. This is an isolated area located at the entrance to a farm haul road.

Seven months after completion of the paving operations, longitudinal cracks six to eight inches from the pavement edge were observed in the limestone west section. At this time, three patched edge failure areas were also observed in the limestone west section. These edge failures appear to have occurred and were patched immediately following construction. Presently, the limestone east and west sections have Class I fatigue cracking in the outside wheel paths for approximately 30% to 40% of their length. Class II fatigue cracking was recently observed in a portion of the outside wheel path of the limestone west section, near the entrance road of an oil drilling site.

B. Rut Depth Measurements

Rutting measurements were obtained after construction as indicated below in Table 1. As can be seen in this table, the limestone sections have rutted approximately 50% more than the soil cement sections. It is believed that the heavy rutting in the limestone sections is due in part to intrusion of the unbound aggregate into the embankment soils.

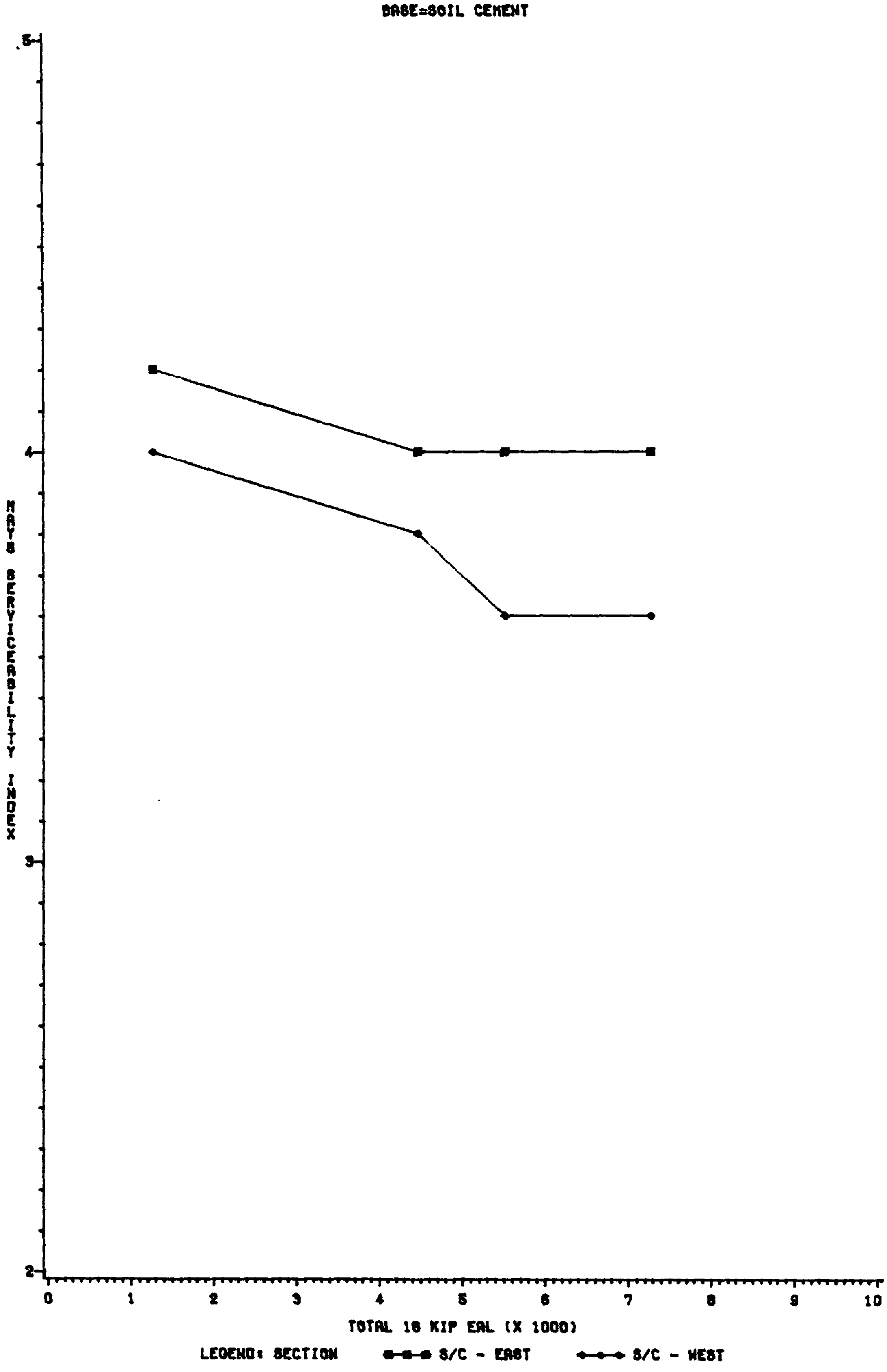
TABLE 1

AVERAGE MEASURED RUT DEPTHS (INCHES)

Date Measured	3/81	9/83	4/84	3/85
Limestone Sections	0.00	0.13	0.15	0.16
Soil Cement Sections	0.00	0.05	0.07	0.10

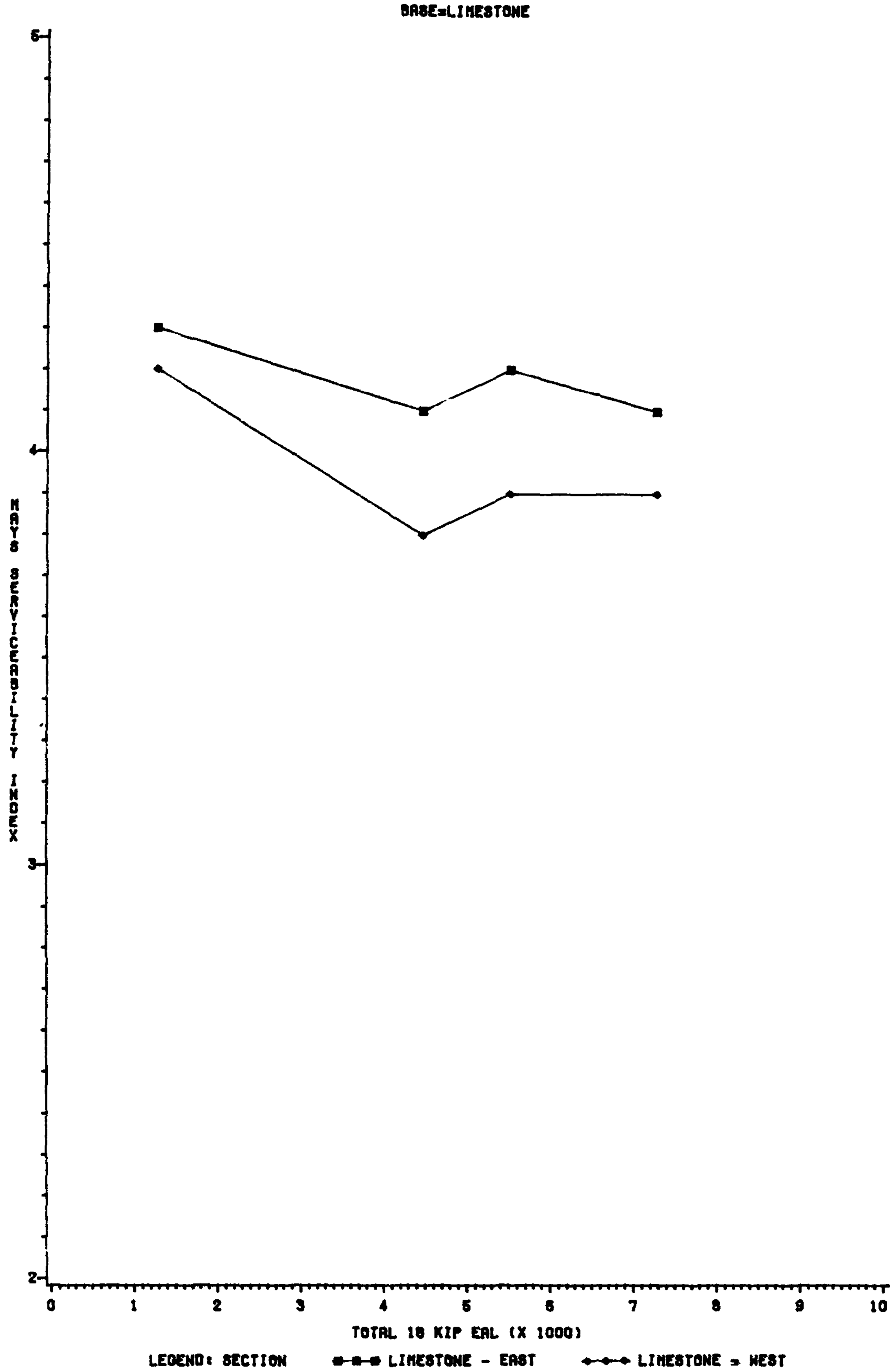
C. Ride Quality Measurements

Ride quality as indicated by the pavement's SI (serviceability index) was measured periodically with the Mays Ride Meter (Appendix C). A decline in SI indicates that the pavement surface is becoming rougher. Figures 2 and 3 present graphs which indicate the measured SI for each section and the corresponding accumulated traffic load of the sections. The graphs indicate that all sections had a relatively high SI immediately after construction and have declined slightly with time, but have retained for the most part a fair to good ride. The largest decline in SI has occurred in the soil cement west section, largely as a result of the base failures mentioned previously under the visual condition survey portion of this report. As can be seen in Figure 3, the limestone sections experienced a slight but temporary increase in measured SI. This slight increase may be the result of additional pavement smoothness due to rutting of the asphaltic concrete surface and limestone base.



Plot of Mays Serviceability Index Versus Total 18 Kip EAL (Soil Cement)

Figure 2



Plot of Mays Serviceability Index Versus Total 18 Kip EAL (Limestone)

Figure 3

D. Deflection Measurements

Deflection measurements were obtained with the Dynaflect (Appendix C). These measurements were obtained for the embankment and base courses as construction permitted and the entire pavement structure upon completion of construction and periodically thereafter.

Deflection measurements were translated to the AASHTO design strength parameter SN (structural number) and an indicator of relative upper pavement layer strength SCI (surface curvature index) by methods outlined by Kinchen (1).*

The field-measured SNs of the 8.5-inch soil cement and crushed stone bases with 1.5-inch asphaltic concrete surfacing are illustrated in Figure 4. At the outset of the experiment the cement-treated base sections exhibited a higher strength level primarily due to the greater stiffness of cement-treated materials over raw aggregate materials. An alternate analysis of the deflection data indicates that the ratio of layer moduli between the cement-treated and aggregate bases is 2.5:1.0.

The larger as-built stiffness of the cement-treated base course does not necessarily mean that its performance will exceed the performance of the crushed stone in terms of serviceability. As load transfer is reduced across the cracks where the block cracking intersects the wheel paths, the CTB section will become increasingly rougher. From a deflection standpoint, much of the section will remain stiff with relatively low deflections, and therefore a more gradual decrease in SN is observed. The crushed stone sections, on the other hand, are experiencing a weakening which occurs more uniformly along the wheel paths. The SN decrease, based on deflections measured in the wheel paths, is therefore more pronounced.

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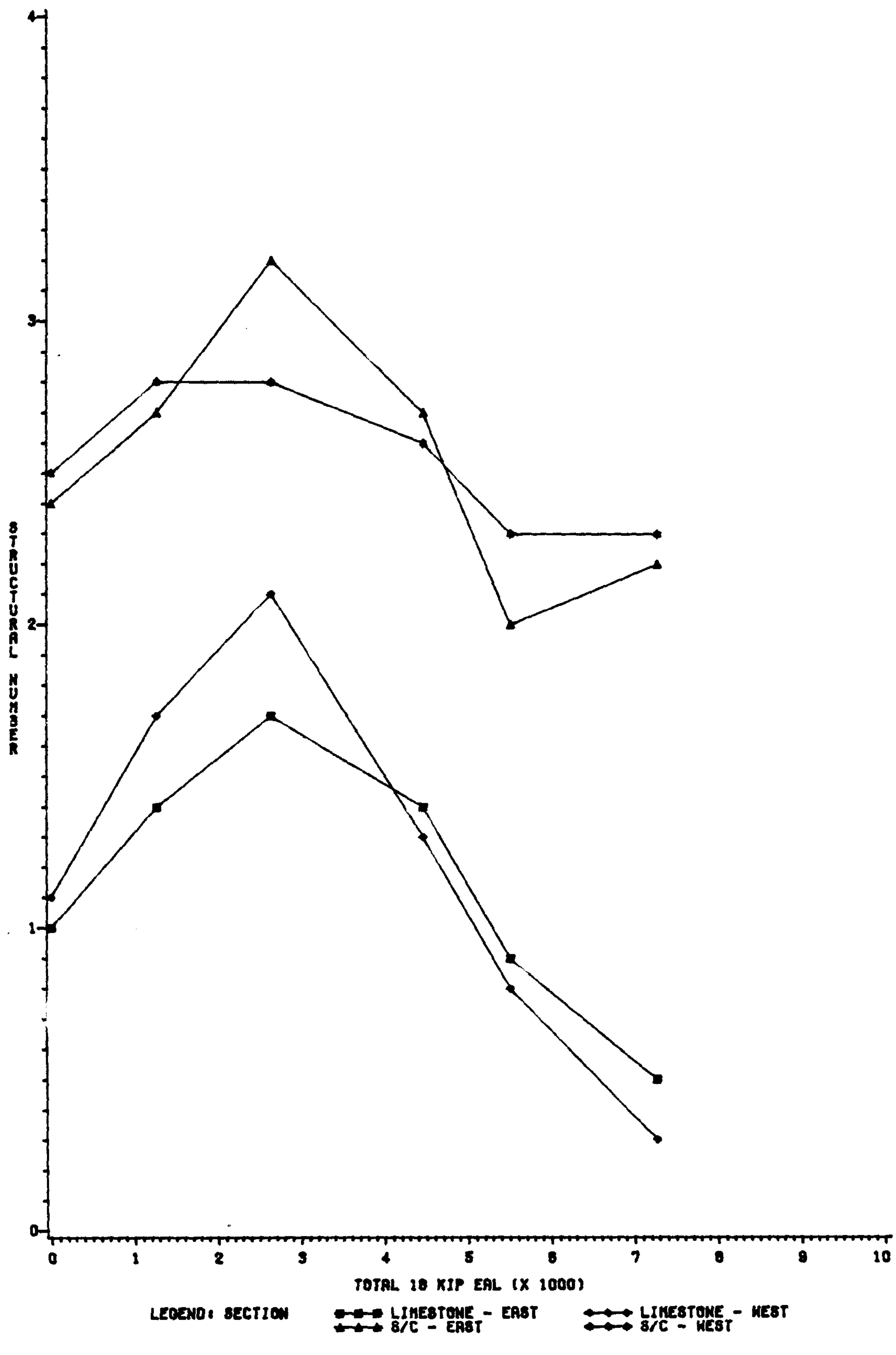
*Underlined numbers in parentheses refer to numbered entries in the section of the report entitled "References."



Plot of Measured Structural Number Versus Total 18 Kip EAL

Figure 4

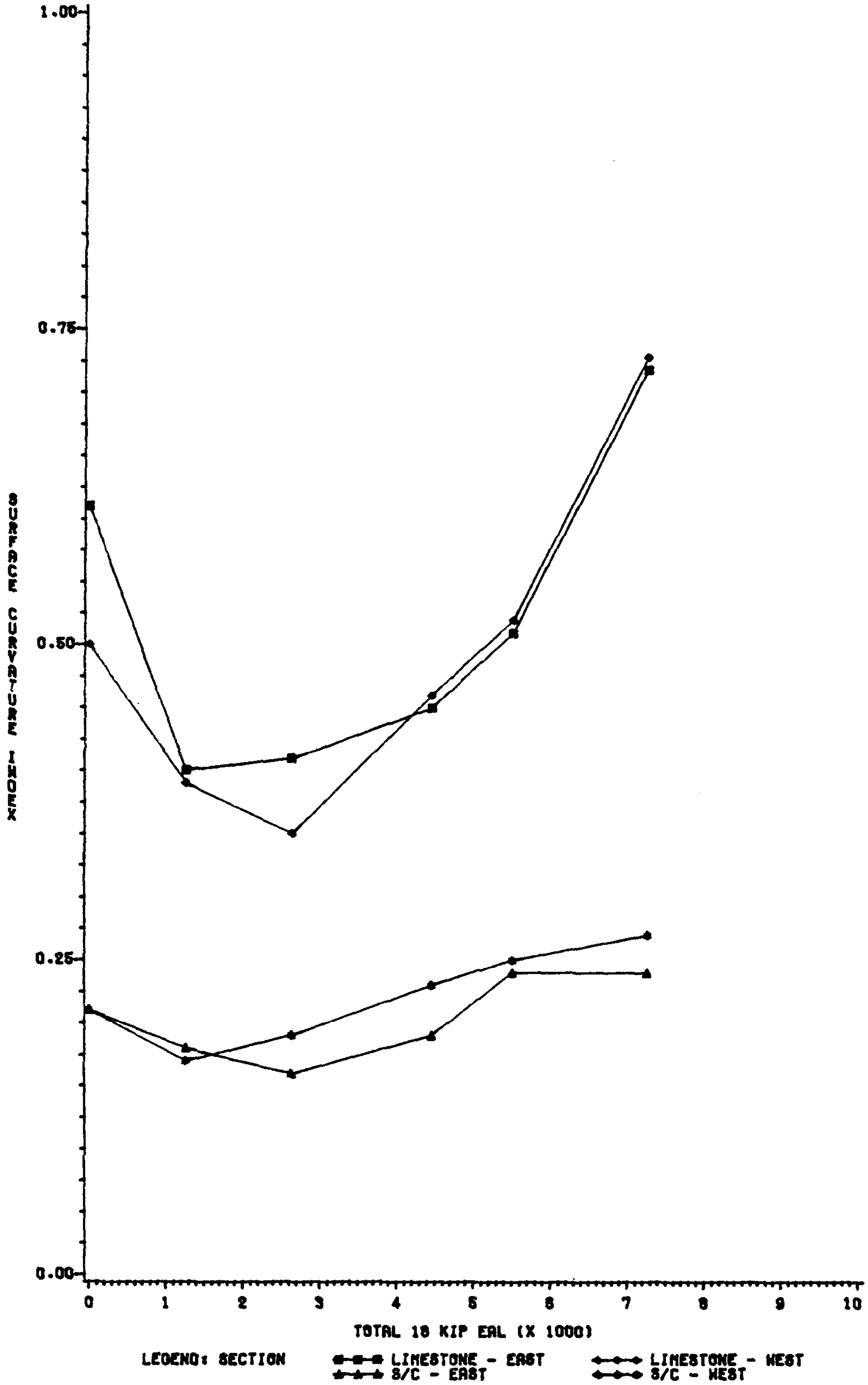
Another deflection-generated indicator of relative pavement strength, the Surface Curvature Index (SCI), Figure 5, also indicates the strength peak and subsequent weakening with traffic load of the test pavements. Lower SCI values indicate greater stiffness and an implied superiority in load carrying ability.

Table 2 presents the average and range of the field-measured SN for the dates tested. As indicated in the table, the field-measured SNs for each section vary considerably. This degree of variation is not expected in base course materials of uniform construction (thickness, compaction, gradation, cement content, etc.). In an effort to explain the variability of the calculated SNs, a coring operation was conducted during the later portion of the study. Cores were taken at locations representing a high and a low SN within each section. All cores were drilled through the entire depth of the base course to facilitate thickness measurements. Data obtained from the coring operation is presented in Table 3.

The soil cement at stations with low SNs proved to be under thickness and in poor condition. Cores at these locations were broken by the coring operation and could not be tested for compressive strength.

Solid cores, suitable to be tested for compressive strength were obtained at soil cement stations with high SNs. These cores had compressive strengths of 549 and 589 psi. This is well above the 250 psi design value for soil cement.

All core locations in the limestone sections showed plan thickness or greater and the limestone appeared to be uniformly compacted.



Plot of Surface Curvature Index
Versus Total 18 Kip EAL

Figure 5

TABLE 2

AVERAGE AND RANGE OF FIELD-MEASURED SN

	Date Tested					
	3/81	11/81	8/82	8/83	3/84	3/85
Soil Cement - East						
Average	2.4	2.7	3.2	2.7	2.0	2.2
Range	1.9	2.0	2.8	2.5	2.9	3.0
Soil Cement - West						
Average	2.5	2.8	2.8	2.6	2.3	2.3
Range	1.7	1.6	1.9	2.1	3.5	3.9
Limestone - East						
Average	1.0	1.4	1.7	1.4	0.9	0.5
Range	2.1	1.1	1.5	1.3	1.1	0.6
Limestone - West						
Average	1.1	1.7	2.1	1.3	0.8	0.3
Range	2.3	2.1	3.0	2.6	2.5	1.3

TABLE 3

CORE DATA

Section	Station	SN*	Asphalt Thickness (Inches)	Base Thickness (Inches)	Remarks
S/C West	122	0.1	1.5	4.5	Core not suitable for testing
S/C West	126	3.5	1.5	8.5	Compressive strength = 549 PSI
Limestone West	158	0.3	1.5	8.5	Core not suitable for testing
Limestone West	202	2.5	1.5	9.5	Core not suitable for testing
S/C East	214	3.8	1.6	9.0	Compressive Strength = 589 PSI
S/C East	238	0.5	1.8	8.0	Core not suitable for testing
Limestone East	271	0.8	1.8	9.4	Core not suitable for testing

*SN as measured on date cored.

CONCLUSIONS

The following conclusions are based upon the visual observations made and data obtained during four years (March 1981 - March 1985) of study. Although this study was very limited in scope, much valuable information was obtained.

1. With sufficient controls, a graded limestone base course can be constructed with relatively little difficulty.
2. In the limestone sections, uniformity of construction appeared to be fair to good.
3. In the soil cement sections, uniformity of construction appeared to be poor to good.
4. Deflection measurements and observations of performance indicate that the strengths of the soil cement and crushed stone pavements have peaked and are beginning to decline. This is true also for the serviceability or ride quality.
5. The limestone sections experienced isolated edge failures shortly after construction in several locations. Class I fatigue cracking has begun in the outside wheel paths and spans 30-40% of the sections' length. A small amount of Class II cracking has also occurred but is limited to one isolated area. Wheel path rutting averages 0.16 inches. Ride quality has not changed appreciably. Deflection tests indicate a consistent strength loss since the sections' peak strength measured approximately 2.5 years ago.
6. The soil cement sections developed block type shrinkage cracking within a year of construction. The longitudinal edges of the block cracking have surfaced in the wheel paths indicating the influence of traffic loads on the location of shrinkage crack development. Several isolated pothole-type failures have occurred, primarily adjacent to a farm haul road. Wheel path rutting is minimal, 0.1 inches on the

average. Ride quality has decreased slightly. Deflection tests indicate that the soil cement is experiencing a gradual reduction in stiffness. Isolated areas of high deflection were related to locations where only 4-1/2 inches of the 8-1/2-inch base course was actually stabilized.

7. Early edge failures, early rutting, and a progressive increase in deflection indicate that performance of crushed limestone base could be improved by treating the embankment prior to placement of the base. The treated working table would enhance compaction, retard intrusion of the embankment into the crushed stone layer, and reduce the rate of rutting and wheel path cracking.

RECOMMENDATIONS

1. Additional projects should be constructed with a graded limestone base course.

2. To increase uniformity of construction, density of base, and to prevent or limit intrusion of the unbound aggregate into the embankment soils, the graded limestone base should be constructed on a stabilized subbase or treated working table.

3. Additional study is needed to optimize limestone base construction specifications in relation to gradation, abrasion, compaction and subbase requirements.

REFERENCES

1. Kinchen, R. W. and W. H. Temple, Asphaltic Concrete-Overlays of Rigid and Flexible Pavement. Research Report No. 147, Louisiana Department of Transportation and Development, 1980.

APPENDIX A

SPECIAL PROVISIONS FOR CRUSHED LIMESTONE BASE COURSE

STATE PROJECT NO. 801-38-03
SPECIAL PROVISIONS

BASE COURSE: Section 301 of the Standard Specifications is amended to include the following requirements for crushed limestone base course.

Crushed limestone base course shall conform to the requirements for untreated aggregate type base course with the following modifications.

(a) Materials: Limestone shall show not more than 45% loss when tested in accordance with AASHTO Designation: T 96; shall show not more than 15% loss when tested in accordance with AASHTO Designation: T 104; and shall be graded as follows:

Sieve Size	% Passing
1 1/2"	100
3/4"	70 - 100
3/8"	50 - 80
No. 4	35 - 65
No. 10	25 - 50
No. 40	10 - 26
No. 200	4 - 12

The fraction passing the No. 200 sieve shall not be greater than two-thirds the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6. Samples for acceptance testing will be taken from stockpiles either at the source or at the project site. The materials shall conform to the specified requirements prior to placement on the subgrade.

(b) Construction Requirements: Placing and compacting of the limestone shall be as continuous as practicable. Compaction of the limestone base course will be considered as experimental. The target density for the base course will be 98% of maximum theoretical density as determined in accordance with AASHTO Designation: T 180. A 500-foot test section of the base course shall be constructed, and the maximum density obtained in this section will be the minimum acceptable density for the base course; however, if the target density is met or exceeded in the test section, the target density will be the minimum acceptable density for the base course. The density shall be uniform for the entire depth of base course. In order to obtain uniform target density, it is recommended that the base course be constructed in two layers of approximately equal thickness. The material shall be substantially maintained at optimum moisture during compaction. When additional moisture is needed, the required amount of water shall be added in a manner that will moisten all limestone particles without damaging underlying materials. Roadway density will be determined in accordance with DOTD Designation: TR 401. Five roadway density tests will be taken for each 1,000-foot section of base course, and the average of these test results will be the density value for the section.

APPENDIX B

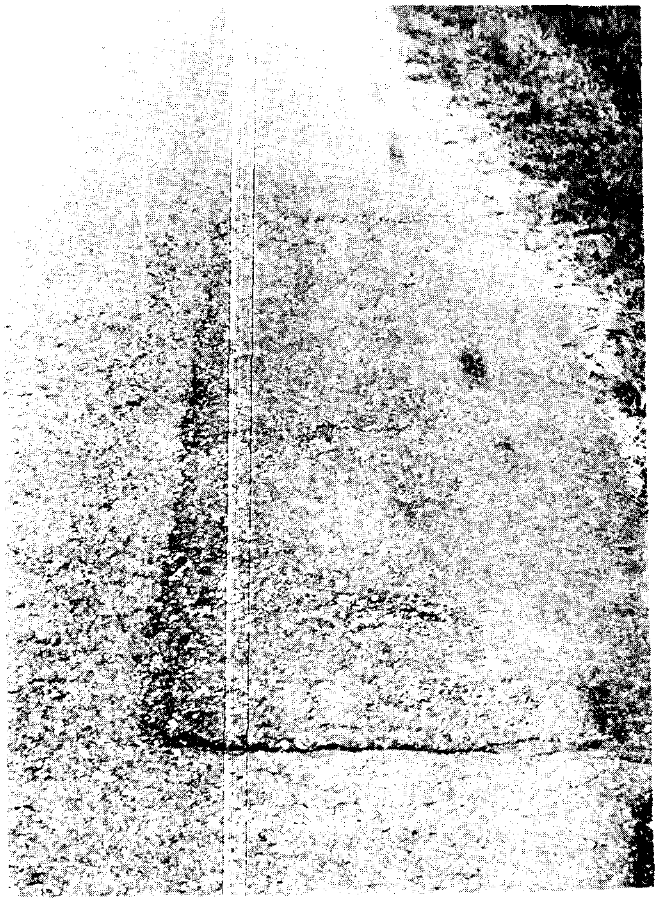
SELECTED PHOTOGRAPHS FROM CRUSHED LIMESTONE BASE PROJECT

Overall View - Limestone East Section

Figure 6

Overall View - Soil Cement West Section

Figure 7



Patched Base Failure - Limestone West Section

Figure 8

Unpatched Base Failure - Soil Cement West Section

Figure 9

Block Cracking -
Soil Cement East Section

Figure 10

C[illegible] [illegible]acking
Limest[illegible] [illegible]st Section

Figure 11

APPENDIX C

DESCRIPTION OF FUNCTIONAL AND STRUCTURAL PAVEMENT EVALUATION TECHNIQUES

FUNCTIONAL EVALUATION OF PAVEMENTS

The Mays Ride Meter (M.R.M.) operates from inside a standard size car and records road roughness as reflected by movement of the vehicle's axle with respect to its chassis. A transmitter attached to the differential collects this movement information and feeds it to a portable recorder located on the front seat. Quantitative and qualitative roughness measurements are presented on a strip chart produced by the recorder. . The base speed for the M.R.M. is 50 miles per hour, and correlation curves for each M.R.M. convert test data obtained at other speeds to that at the base speed.

M.R.M. measurements are reported in terms of a Serviceability Index (SI). This SI has been defined as a "numerical" index (ranging from 0.0 to 5.0) of the ability of a pavement in its present condition to serve traffic." Perfectly smooth pavement would have an SI of 5.0. Pavement so rough as to be impassable would have an SI of 0.0.

More specifically, a numerical-adjective description of SI is as follows:

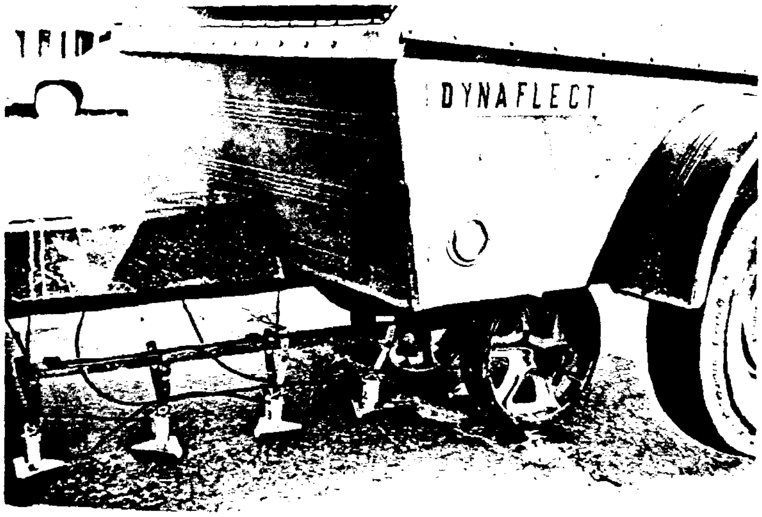
4.1 - 5.0	Very Good
3.1 - 4.0	Good
2.1 - 3.0	Fair
1.1 - 2.0	Poor
0.0 - 1.0	Very Poor

STRUCTURAL EVALUATION OF PAVEMENTS

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 (usually five) spaced under the trailer at approximately one-foot (39.5-cm) intervals from the application of the load. The pavement is subjected to a 1000-pound (454-kg) dynamic load at a frequency of eight cycles per second, which is produced by the counter-rotation of two unbalanced flywheels. The generated cyclic force is transmitted vertically to the pavement through two steel wheels spaced 20 inches (50.8 cm) center-to-center. Any horizontal reactions will cancel each other due to the opposing rotations. The dynamic force varies in sine wave fashion from 500 pounds (227 kg) upward to 500 pounds (227 kg) downward during each rotation. The entire force transmitted to the pavement, however, consists of the weight of the trailer (about 1600 pounds, 726 kg) and the dynamic force which alternately adds to and subtracts from the static weight. Thus, the dynamic force during each rotation of the flywheels at the proper speed varies from 1100 to 2100 pounds (499 to 953 kg). The deflection measurements induced by this system are expressed in terms of milli-inches of deflection (thousandths of an inch).

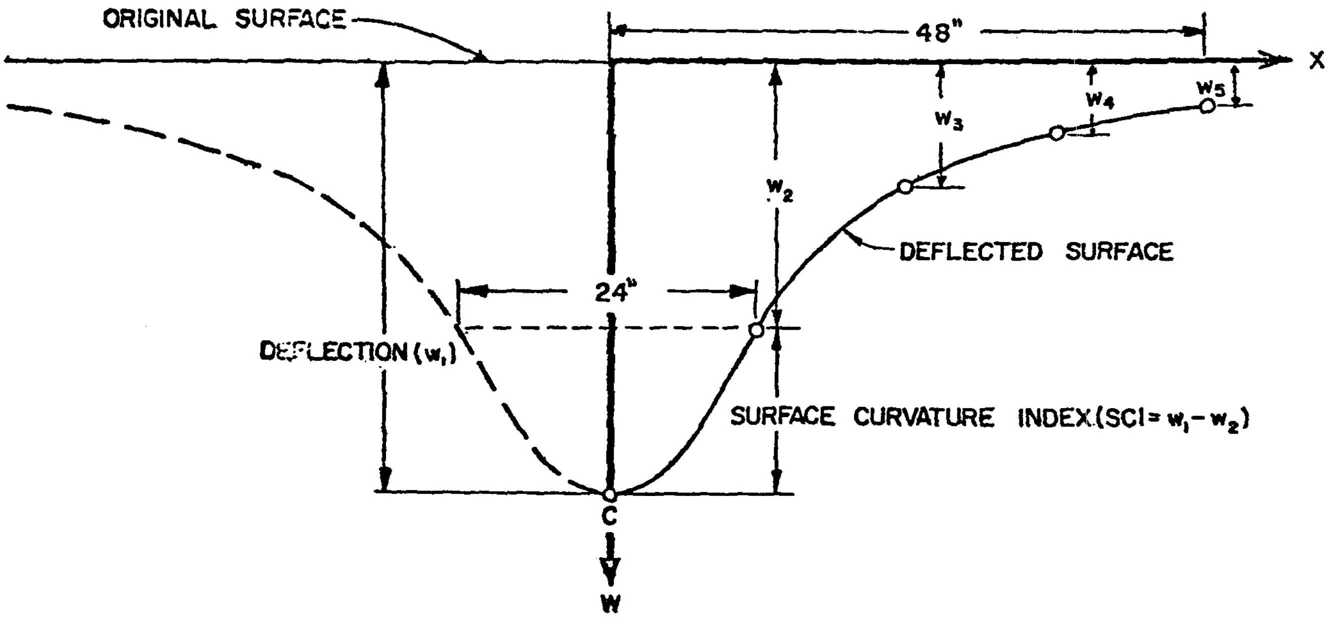
Figure 12 is a photograph of the Department's Dynaflect device. Figure 13 is a representation of the deflection basin which the Dynaflect generates. The Dynaflect actually measures the extent of only one half of the deflection bowl, with the other half assumed to be a mirror image of the measured portion. In Figure 13 the measurement W_1 is the maximum depth of the deflection bowl and occurs near the force wheels. The terms W_2, W_3, W_4, and W_5 are the deflections related by geophones 2 through 5, respectively.

The maximum (first sensor) deflection W_1 provides an indication of the relative strength of the total road section. The Surface Curvature Index, SCI (W_1-W_2), provides an indication of the relative strength of the upper (pavement) layers of the road section. The Base Curvature Index, BCI (W_4-W_5), and the fifth sensor value W_5 provide a measure of the relative strength of the foundation. For all four parameters, W_1, SCI, BCI and W_5, lower values indicate greater strength.



Louisiana Department of Transportation and Development
Dynamic Deflection Determination System (Dynaflect)

Figure 12



Typical Dynaflect Deflection Bowl

Figure 13

APPENDIX D

SUMMARY OF LIMESTONE BASE COURSE
SUPPLEMENTAL EXPERIMENTAL PROJECT

A similar experiment with limestone as a base course material was conducted on Louisiana Route 3134 in Crown Point, which is in Jefferson Parish and District 02. This project has only one thousand feet of limestone base, with soil cement control sections on each end. The Pitreville project and the one in Crown Point were both constructed in 1981.

The Crown Point project is different in that it has a moderate volume of traffic instead of a low volume. Crown Point had an ADT (average daily traffic) of 5000 vehicles in 1983, which is 20 times the amount of traffic in Pitreville. The ADL (average daily load) per 1000 ADT was 28.33 18-kip loads per day. As of December 31, 1983, the Crown Point project had accumulated 48,618 18-kip loads.

Another major difference in these projects is that the asphaltic concrete is six inches thick in Crown Point, whereas it is only 1-1/2 inches thick in Pitreville. Also, the embankment at Crown Point is sand, rather than clay as in Pitreville.

Dynaflect tests were run on the completed base courses prior to placement of the asphaltic concrete. The average structural number for both soil cement base course control sections was 2.4, while the limestone base course test section had an average SN of 0.7

Approximately one year after the asphaltic concrete surface course was constructed, deflection tests were run again. The limestone test section had an average SN of 4.2, and the soil cement sections averaged 4.6. One year later, both these averages had increased by 0.2.

Roughness and rutting measurements were not taken; however, the rutting appeared to be a tenth of an inch or less. The roughness is estimated to be in the good to very good category.

One of the reasons for this road's excellent performance appears to be the more than adequate thickness of the asphaltic concrete for the moderate traffic volume. Also, there were fewer construction problems with the compaction of the limestone base course than experienced on the Pitreville job. This was mainly due to the non-plastic embankment used at the Crown Point project.