Evaluation of the Performance of Bonded Concrete Overlay on Interstate Highway 610 North, Houston, Texas

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The objective of the study was to evaluate the performance of the bonded concrete overlay project on IH 610 North in Houston and implement the findings in other studies on bonded concrete overlay. The performance of the bonded concrete overlay was monitored on ten experimental sections selected from the 3-½-mi project and ranging from 400 to 600 feet long. Periodic field measurements were conducted, and an assessment of overlay pavement life was made. The resulting conclusions and recommendations were to be used by the Texas State Department of Highways and Public Transportation to design overlays for rehabilitation programs on continuous reinforced concrete pavement (CRCP).

Since 1956 the United States has been involved in the largest public works project ever undertaken, the 42,500-mi system of interstate highways. Unfortunately, these highways have begun to wear out. Not only are we reaching the end of the design life of many sections of highways, but the amount of traffic is far exceeding the design estimates (*1*). In recent years, the general interest of the highway administration has shifted from construction to maintenance, rehabilitation, and resurfacing.

Portland cement concrete (PCC) overlays have been used to resurface pavements for more than 60 years. However, experience in the use of bonded concrete overlays is mostly with airport runways and bridge decks, although there are instances in which bonded concrete overlay has been used for improving skid resistance on highways (*2,3*).

The U.S. Air Force has more than 20 years of experience with thin bonded concrete overlay (*4*). Overlays ranging from 2- to 4-in thick have been constructed on runways subject to light as well as heavy traffic and used by small as well as large aircraft. The condition of the overlays over a period of 17 years has ranged from good to very good, but there have been a number of cases where problems were encountered. For example, severe reflection cracking and rapid deterioration following loss of interface bond was experienced in a taxiway at the Tulsa Airport.

During the past two to three years, several research studies were undertaken at the Center for Transportation Research to address questions concerning the use of thin bonded concrete overlays for highway pavement rehabilitation. Tests were made on laboratory specimens and cores from constructed slabs in the field in which a bonding agent was used. A major finding of this research (*5*) was that the interface between existing slab and overlay develops a shear strength three to four times the theoretically predicted shear stress due to wheel loads of the expected traffic. Also, a condition survey of the overlay section soon after overlaying and again in six months did not show any significant distress. This experience encourage the SDHPT to use a 4-in bonded concrete overlay on a length of about 3-½ mi to improve the pavement condition of Loop 610 North in Houston. It was suggested that several sections of this pavement be identified and monitored to father performance information periodically. It was planned that the analysis carried out using the resulting data would help answer questions about the relative merits of different types of overlay materials.

The overlay project is located on IH 610 North in Houston between East T.C. Jester Blvd. and IH 45 (see figure 1). At this location, the roadway is an eight-lane divided highway with four through lanes in each direction and a concrete median barrier. The main lanes are 12 feet wide and shoulders are 10 feet wide.

The 4-in bonded concrete overlay was placed on the existing 8-in continuous reinforced concrete pavement (CRCP). The existing concrete pavement rests on 6-in thick stabilized subbase. The typical cross section of the project is presented in figure 2.

OBJECTIVE OF THE STUDY

The primary objective of the study was to evaluate the performance of the bonded concrete overlay on IH 610 North in Houston and implement the findings of other studies on bonded concrete overlays.

The sub-objectives were—

1. To identify several sections to represent the variation in the original pavement condition and the material used for the overlay,
2. To observe and record the materials actually used for the overlay,
3. To make observations of the behavior parameters before and after-overlay, and
4. To perform statistical analyses to evaluate the field data.

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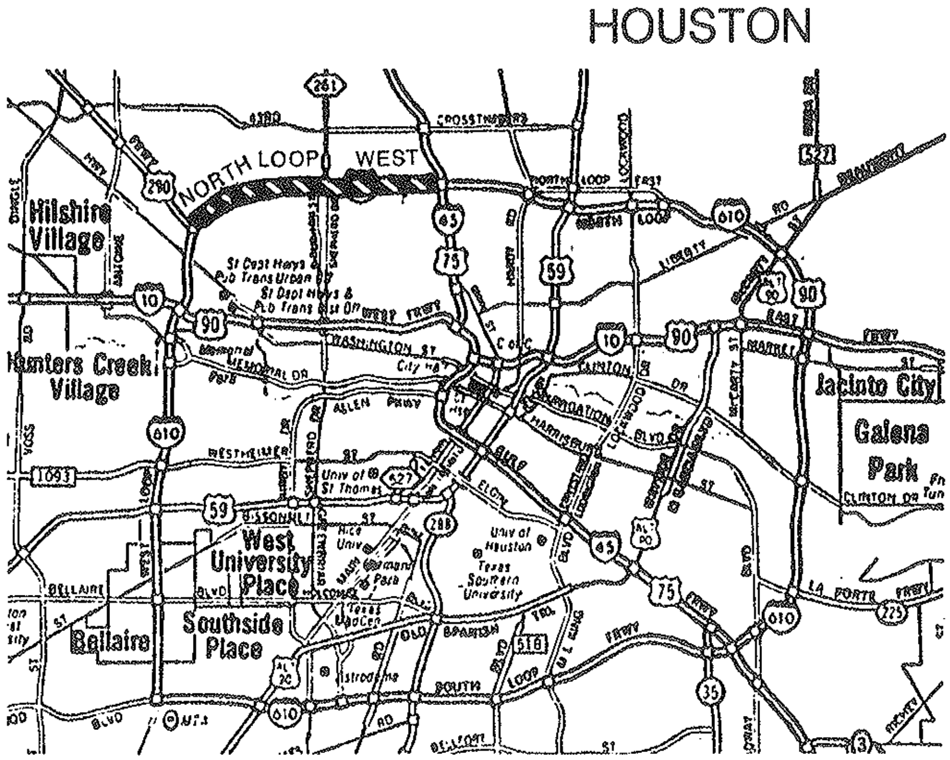


FIGURE 1 Location of the overlay project.

DESCRIPTION OF THE STUDY

The following variables were considered in the study:

1. Overlay reinforcement: CRCP and fiber reinforced concrete pavement,
2. Overlay aggregate: siliceous river gravel and limestone, and
3. Old pavement condition: no distress, moderate distress, and severe distress.

The use of the variables in 1 and 3 above is self-explanatory. The variables in 2 were used for two reasons: (1) the old pavement was constructed using siliceous river gravel, and (2) research done at the Center for Transportation Research at The University of Texas at Austin (*10*) showed that limestone is a better coarse aggregate than siliceous river gravel from a long-term performance standpoint. Therefore, siliceous river gravel was used in some sections and limestone was used in others.

From the 3-½-mi overlay project on eastbound IH 610 North ten test sections ranging from 400 to 600 feet long were identified, to maintain homogeneity within a section (similar overlay reinforcement, overlay aggregate, and distress) and also to have a length adequate for the desired observations. The ten sections were divided into two fiber-reinforced concrete overlay sections, two reinforced concrete overlays sections using limestone aggregate, and six reinforced concrete overlay sections using siliceous gravel aggregate. The reinforced concrete overlays were reinforced with a grade 70 wire fabric mesh with spacing and size of 6 × 12 − D16 × D10 throughout the sections. Across transverse construction joints, bars of the same grade and size as the mesh were used at 12-in intervals, in addition to the mesh. For the fiber reinforced concrete overlays, 85 pounds of fibers per cubic yard were used. The method of construction included the following steps:

1. Scarifying the old pavement to a ¼-in depth,
2. Placing reinforcing steel,
3. Grouting over reinforcing, using 11 gallons of water per sack of cement grout, and
4. Placing the concrete by slip forming.

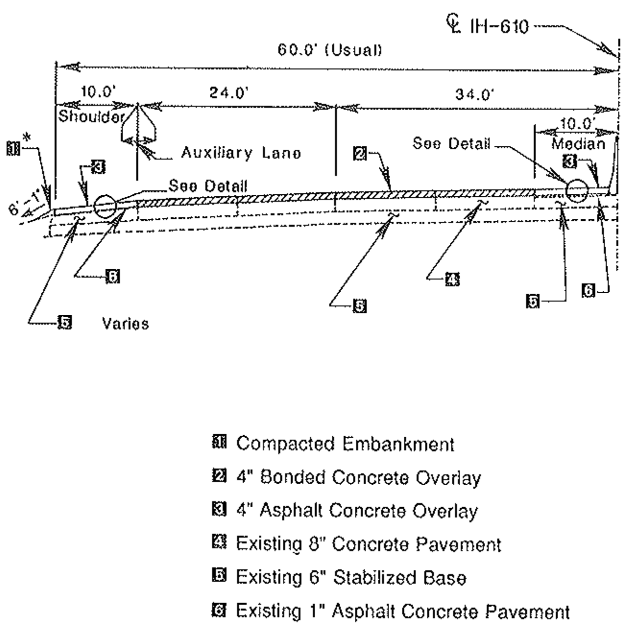


FIGURE 2 A typical cross section of the bonded concrete overlay pavement on IH 610 North, Houston.

TABLE 1 CONCRETE MIX DESIGNS

Material	Mix Using: Silicious River Gravel	Limestone	SRG with Fibers
Cement (lb)	658	658	752
Coarse Aggregate (lb)	1950	1770	1218
Fine Aggregate (lb)	1055	1235	1715
Retarder (POZZ.300R) (oz.)	30	30	38
Air Entrainer (AE-10) (oz.)	7	7	5
Water (lb)	233	233	250

Note: All weights are based on material in the SSD condition.

A summary of the concrete mix design data is shown in table 1. Summaries of tensile and flexural strengths are shown in tables 2 and 3, respectively. The average tensile strengths of fiber reinforced sections, welded wire fabric with limestone sections, and welded wire fabric with siliceous river gravel section are 698, 642, and 615 psi, respectively.

It was suggested that the ten experimental sections selected be monitored for at least three years so that it would be possible to identify any correlation between materials and performance based on the different environmental conditions.

Based on the results of the first condition survey, the distress indexes of each experimental section were determined using the following formula (*6*):

$$Z_c = 1.0 - 0.065\,FF - 0.015\,MS - 0.009SS$$

where

Z_c = distress index,
FF = number of failures per mile (sum of punchouts and patches),
MS = percent minor spalling, and
SS = percent severe spalling.

The distress values are subtracted from 1 and the value obtained in a maximum value. As the distress index decreases, the quality of the road deteriorates, with zero being the value where major rehabilitation is necessary.

Three levels of distress were used in this study:

- No significant distress, with distress index ranges from 0 to 1,
- Moderate distress, with distress index ranges from −2 to 0, and
- Severe distress, with distress index less than −2.

The factorial design of the study is shown in figure 3. It is important to note that the factorial experiment design does

TABLE 2 SUMMARY OF AVERAGE TENSILE STRENGTH (PSI) (OVERLAY PORTION), IH 610 NORTH, HOUSTON

Test Section Number	Dates Core Taken: February 1986	January 1987
1	676	615
2	582	544
3	422	575
4	671	625
5	650	950
6		718
7		638
8		652
9		868

TABLE 3 SUMMARY OF FLEXURAL STRENGTH VALUES OF CONCRETE SAMPLES FROM TEST SECTIONS

Test Section	Flexural Strength
1	870
2	- -
3	835
4	885
5	800
6	880
7	760
8	775
9	- -
10	- -

Overlay Aggregate \ Overlay / Pavement Condition	Welded Wire Fabric ND	Welded Wire Fabric MD	Welded Wire Fabric SD	Fiber ND	Fiber MD	Fiber SD
SRG	2 10	1 3	6 9			4 5
LST	8		7			

ND – No Distress
MD – Moderate Distress
SD – Severe Distress
SRG – Siliceous River Gravel
LST – Limestone

FIGURE 3 Factorial design of the eastbound IH 610 North, Houston, experimental project.

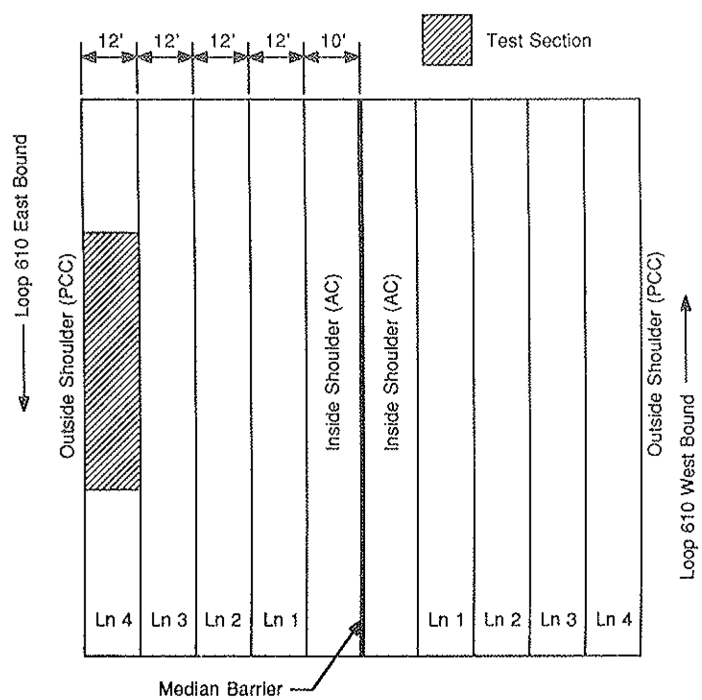


FIGURE 4 Plan view of a typical test section on IH 610 experimental project showing details of layout.

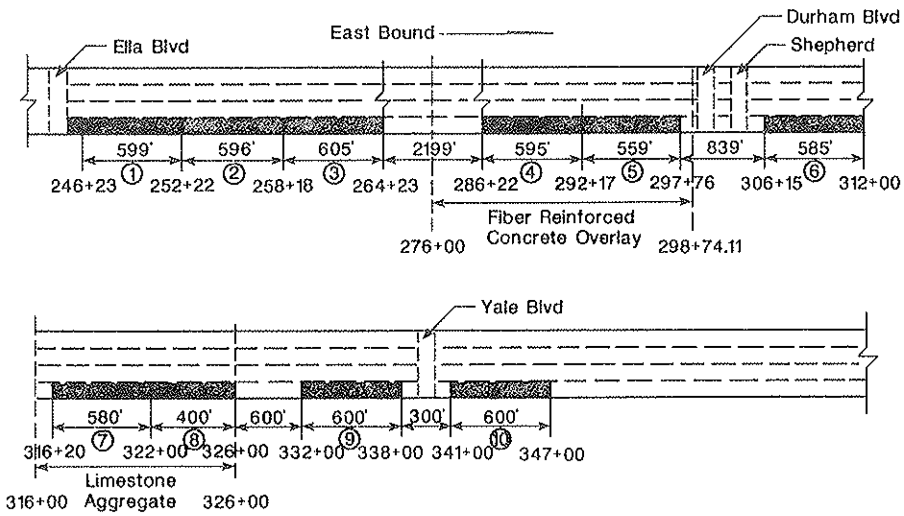


FIGURE 5 Plan view showing locations of the ten test sections, eastbound IH 610 North, Houston.

not include fiber reinforced concrete with limestone aggregate and is, therefore, a partial factorial.

DESCRIPTION OF TEST SECTION

The ten test sections are located on eastbound IH 610 North between Ella Boulevard and about 700 feet beyond Yale Boulevard. At this location, the roadway is a four-lane highway in each direction. All the test sections are in the outside lane (the lane furthest from the median barrier). A plan view of a typical test section is shown on figure 4. Figure 5 shows the locations and dimensions of each test section.

RESULTS

Various measurements were taken in order to gather data to use to evaluate the parameter behavior before and after overlay construction. The various data obtained pertain to deflection, condition survey, and roughness. In addition, data were gathered on a number of cores that were secured from various test sections.

Deflection Measurements

The Dynaflect was used to measure the pavement deflections before and after overlay. The deflection readings were taken at 50-ft intervals, approximately on the center line of the outside lane of each experimental section. In order to evaluate the performance of the pavement before and after overlay, measurements were taken at approximately the same test points before and after overlay construction. During the period of the study, Center for Transportation Research personnel took deflection measurements five different times.

Figures 6 and 7 show before and after overlay deflections of sensor 1 and sensor 5, respectively. As can be seen, the average deflection after overlay construction was significantly less for all test sections. The before-overlay data show that the deflections increased in the second set of readings. The increase may have been caused by a combination of factors. Weather conditions and pavement temperature may have influenced the pavement performance.

CRC sections, fiber reinforced concrete sections, and sections with limestone performed differently in deflection. CRC sections showed a better performance that the other sections did, with a 37.1 percent decrease in the average deflection of sensor 1. Limestone and fiber sections had 30.5 percent and 26.8 percent decreases in the average deflection of sensor 1.

Condition Survey

Condition surveys were conducted to monitor the development of distress and distress types found in the pavement before and after overlay construction. The method used in this study is called the Small Section Method. It is a detailed procedure and is conducted by a team of two people. The team walks along a lane; one person walks with a rolling meter, and the other maps all visible distress with reference to a highway milepost. The distress types that are mapped are transverse and longitudinal cracks, spallings, punchouts, and patches. This detailed procedure is appropriate for roadway that is experimental in nature (*6*).

The transverse cracking was presented as average crack spacing, which was obtained by dividing the total length of the test section by the number of transverse cracks on the section. The longitudinal cracking was measured in units of linear feet per 100-ft section.

Before overlay placements, the average crack spacings were fairly uniform for all test sections (figure 8). After overlay, the average crack spacings varied. Overlay materials can affect the crack spacing of the pavement. Section 8 (CRCP with limestone aggregate) had the greatest transverse crack spacing, with section 10 (CRCP with siliceous river gravel) and section 4 (Fiber reinforced concrete overlay), second and third, respectively. Overlay materials may not be the only cause of the large variations in after-overlay crack spacings. Concrete temperature during overlay placement, which is not considered in this study, may be another cause of variation.

The longitudinal cracks before the overlay was placed var-

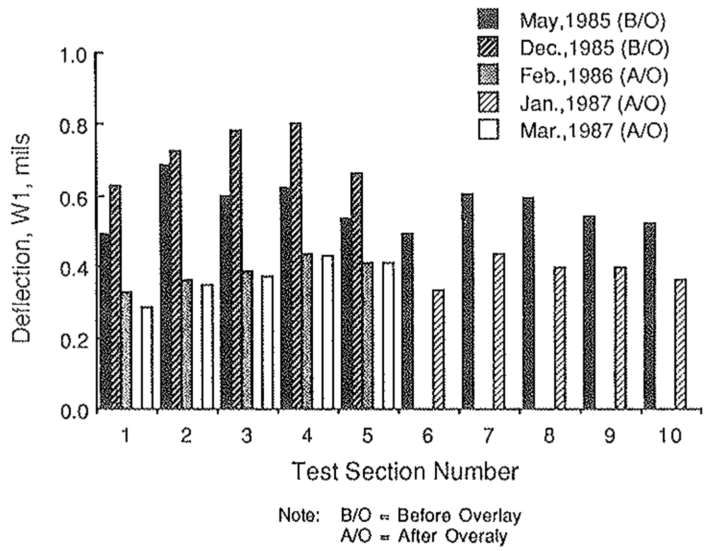


FIGURE 6 Comparison of before and after-overlay average deflection of sensor 1, IH 610 North, Houston.

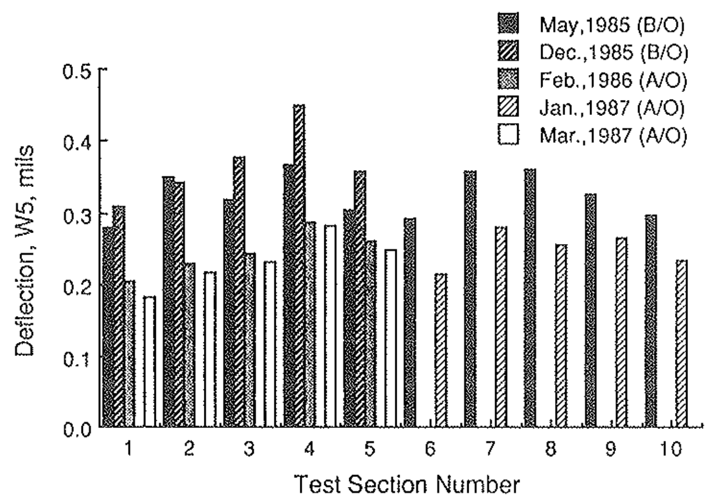


FIGURE 7 Comparison of before and after-overlay average deflection of sensor 5, IH 610 North, Houston.

ied for the ten test sections (figure 9). After overlay, the only longitudinal cracks were in section 4 (fiber reinforced) and section 10 (CRCP).

It is important to note that until the last condition survey was conducted, spalling and puchout did not exist in any of the test sections.

Roughness Data

The profilometer was used to evaluate the riding quality and changes in profile of the pavement. The profilometer readings were conducted before and after overlay. The after-overlay readings give an indication of improvement in the riding quality. It can be seen in figure 10 that, after overlay construction, a general increase in present serviceability index (PSI) occurred on all test sections except section 10.

ANALYSIS OF DATA

The existing pavement materials were characterized by using deflection measurements. The moduli of elasticity of the concrete layer (E_1), subbase (E_2), and subgrade (E_3) were determined by back-calculating from deflection data within each test section before and after overlay. The back-calculating was accomplished by using program RPEDD1 (*8*), which is available in the Center for Transportation Research.

Note that some test sections are on the embankment and some are on the flat area (natural grade). The moduli versus

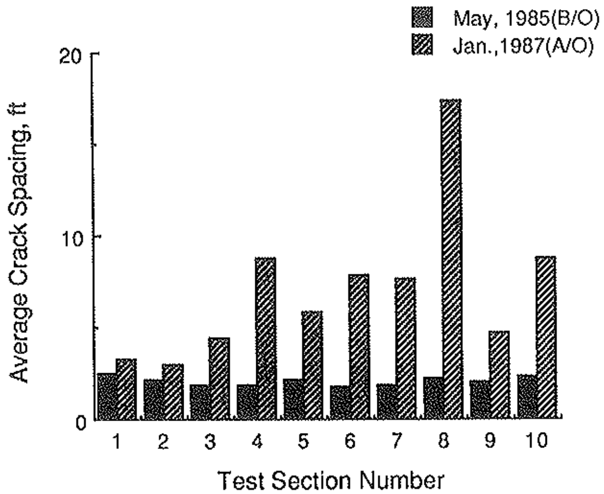


FIGURE 8 Comparison of before and after-overlay transverse crack spacing of the ten test sections, IH 610 North, Houston.

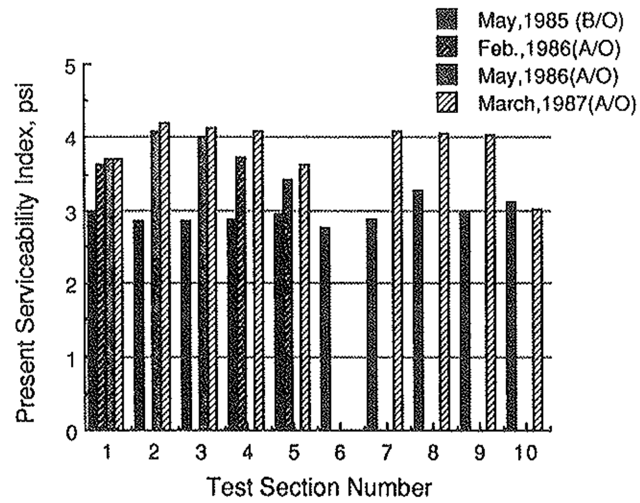


FIGURE 10 Comparison of before and after-overlay present serviceability indices of the ten test sections, IH 610 North, Houston.

the locations of test sections and various seasons are plotted on figures 11 through 13. Also note that the moduli vary with test section location and the environmental conditions when deflection readings are conducted.

CAUSES OF VARIATION IN LAYER STIFFNESS

CRC Layer

As can be seen in figure 11, modulus values of the CRC layer, E_1, for the first five sections were higher in May 1985 than those in December 1985, and the modulus values for sections 6 through 10 were higher in May 1985 than those in January 1987. This trend could be caused by the higher temperatures in May 1985. A high temperature condition results in a decrease in pavement deflection due to pavement expansion and narrowing of transverse cracks in CRC pavement. As the cracks narrow, the load transfer increases, which results in a stiffer CRC.

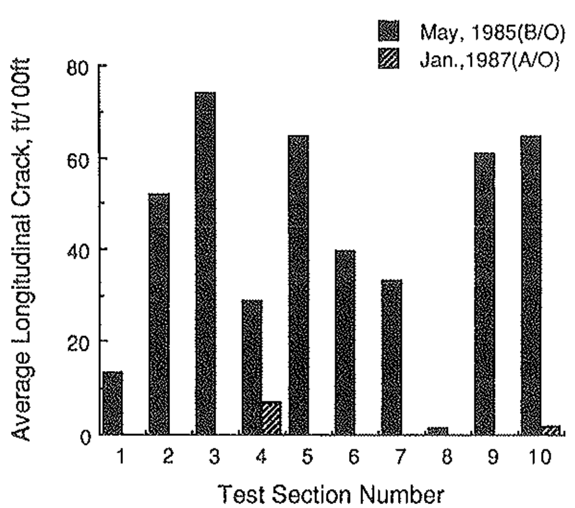


FIGURE 9 Comparison of before and after-overlay average longitudinal cracks per 100-ft section of the ten sections, IH 610 North, Houston.

Subbase Layer

Construction control may limit the variation in layer thickness and modulus. Some variation in subbase modulus, as shown in figure 12, may be caused by use of material from different sources in different areas of the project or use of different quantities of stabilizing agent. It also may be caused by different drainage conditions in different sections of the project. Sections with better drainage will have stiffer subbase layers. The subbase layer, which consists of sand and shell materials stabilized with cement, will be stiff with small amounts of moisture.

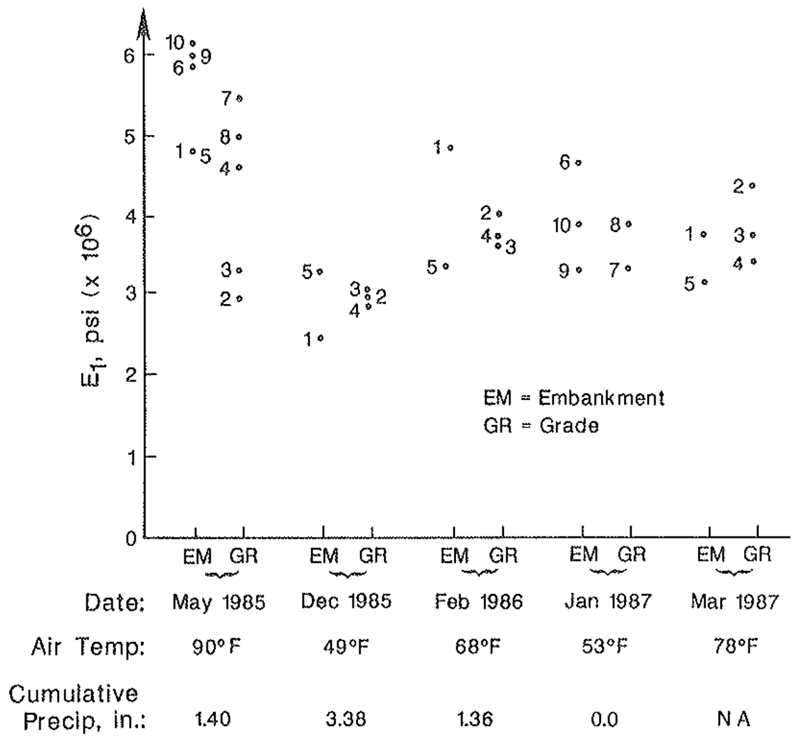
Subgrade Layer

Pavement in cut and fill areas may have different subgrade moduli of elasticity. In figure 13, most of the sections on the embankment have higher moduli. This may be the result of good drainage on the embankment sections; with good drainage, less water will remain in the subgrade layer. In contrast, low (flat) areas with higher water tables and poorer drainage will have a softer subgrade.

It also can be seen in figure 13 that the subgrade moduli vary with seasons. Periods of higher rainfall result in higher moisture content in the subgrade and a corresponding lower subgrade modulus.

COMPARISON OF PREDICTED AND MEASURED AFTER-OVERLAY DEFLECTION

Measured and predicted after-overlay deflections were compared for a partial verification of the design procedure; if these are similar then the life predictions are more reliable.



Note: Cumulative precipitation is total (cumulative) inches of rain from 10 days before deflection readings were taken.

NA = Data Not Available

FIGURE 11 Moduli of elasticity of concrete layer, E_1, versus test section locations and environmental conditions.

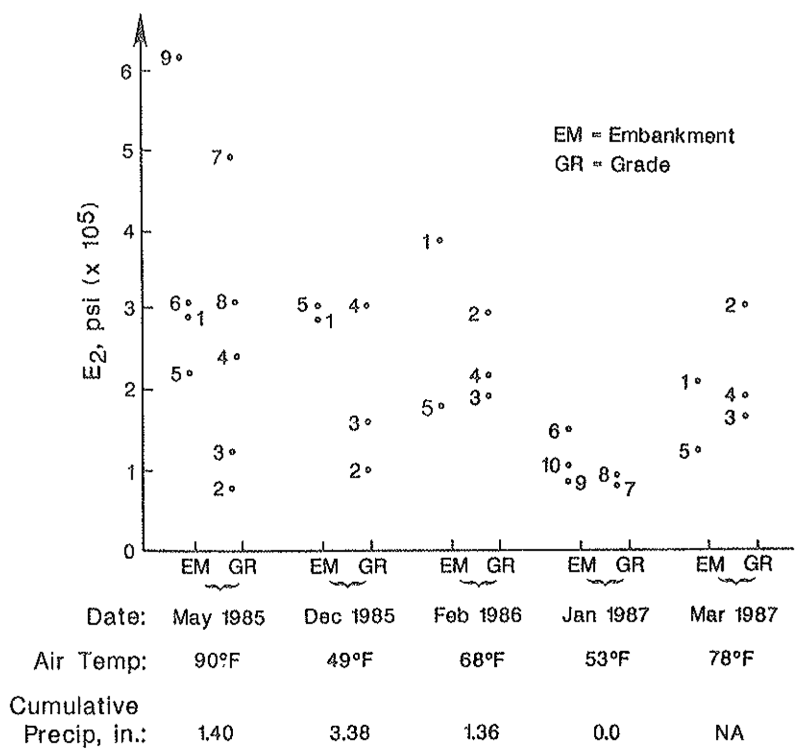


FIGURE 12 Modulus of elasticity of subbase layer, E_2, versus test section locations and environmental conditions.

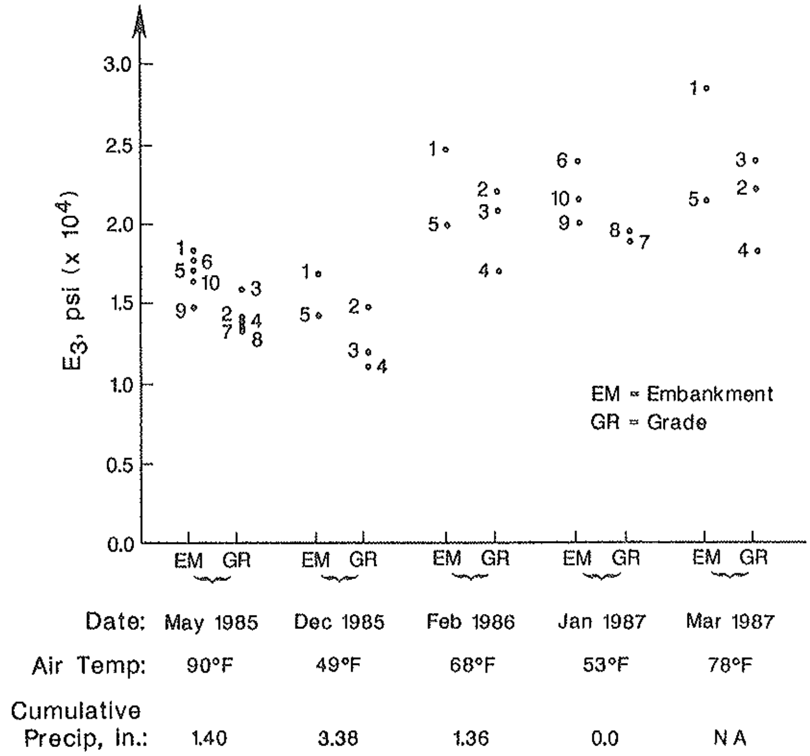


FIGURE 13 Modulus of elasticity of subgrade layer, E_3, versus test section locations and environmental conditions.

Layer characterization should be established before the predicted after-overlay deflection can be calculated. Calculating the after-overlay deflection involves the following steps:

1. Calculate the mean, $\bar{x}$, and standard deviation of before-overlay deflection for each experimental section.
2. Determine the moduli of the concrete layer (CRCP), subbase, and subgrade by back-calculating three deflection values ($\bar{x}$, $\bar{x} + s$, $\bar{x} - s$).
3. Assume the modulus value for the concrete overlay layer. Note that E_0 = 5,000,000 psi was used for the after-overlay deflection calculation in this study.
4. Measure the overlay thickness of the cores secured from the test sections. Use the average thickness for deflection calculation.
5. With the new four-layer system, the after-overlay deflections were calculated using program RPEDD1.

The accuracy of this method is reflected in the results presented in figure 14 (deflections of sensor 1) and figure 15 (deflections of sensor 5). In these figures, calculated deflections are a little above the equality line, which reflects conservatism in the predicted measurements.

There are a number of factors that may result in inaccurate prediction of after-overlay deflections:

- Seasonal effects,
- Concrete temperature effects, and
- Assumptions made for overlay layer modulus of elasticity.

As mentioned before, the first two factors lead to significant changes in the deflection measurements and, consequently, to the moduli predicted from these deflections.

ESTIMATION OF PAVEMENT FATIGUE LIFE AFTER OVERLAY PLACEMENT

Bonded concrete overlay is used not only to improve the riding quality and to correct grade problems but to add fatigue life to an existing pavement by utilizing the existing structural capacity. A pavement experiencing distress on the basis of condition surveys can be enhanced and its remaining life can be increased by using a bonded concrete overlay. Estimating the pavement fatigue life and pavement life in years after-overlay placement includes the following steps (*9*):

1. Calculate the mean after-overlay deflection, $\bar{x}$, of each experimental section.
2. Determine the moduli of pavement layers and predict the fatigue life of the pavement in 18-kip ESAL after the overlay was placed. Note that 12.5-in monolithic pavement was used in the calculation, which was performed by back-calculating the deflection obtained from step 1 using program RPEDD1.
3. Calculate the total 18-kip ESAL per lane for overlaid pavement for the first year opened to traffic.
4. Predict the pavement life after overlay using the following formula.

$$N_{18} = n_{18}\left[\frac{(1 + g)^n - 1}{g}\right]$$

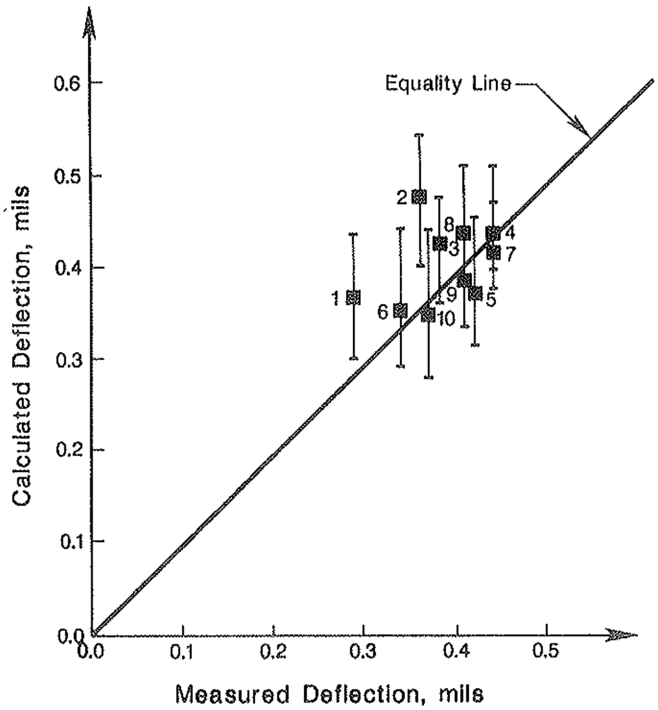


FIGURE 14 Comparison of calculated and measured after-overlay deflections of sensor 1.

where:

N_{18} = predicted fatigue life in 18-kip ESAL, as calculated by RPEDD1,
n_{18} = total 18-kip ESAL for the first year,
n = predicted pavement life in years, and
g = growth rate/100.

The predicted fatigue life of each of the ten test sections and the corresponding predicted pavement life are presented in table 4.

CONCLUSIONS

The conclusions from the field and laboratory measurements and the theoretical analysis are summarized as follows:

Deflections

1. A bonded concrete overlay reduces the pavement deflections by increasing the stiffness of pavement structure.
2. Siliceous river gravel sections show the greatest reduction in deflection.
3. High temperature conditions result in a decrease in pavement deflection, due to pavement expansion and reduction of transverse crack widths.

Material Properties

1. The limestone sections have the least number of transverse cracks.

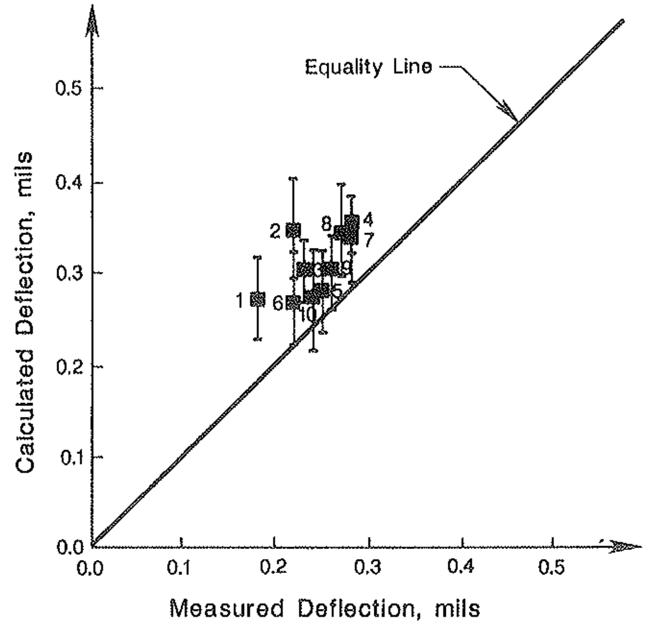


FIGURE 15 Comparison of calculated and measured after-overlay deflections of sensor 5.

2. The fiber and limestone sections showed a good bond strength at the layer interface.

Environmental Effects

1. The subbase layer is stiffer in sections with better surface drainage conditions.
2. The roadbed modulus varies with the season. Periods of higher rainfall result in higher roadbed moisture contents and a corresponding lower modulus.

Pavement Conditions

1. Bonded concrete overlay increases the load transfer across the CRCP cracks.

TABLE 4 PREDICTED FATIGUE LIFE

Test Section Number	Predicted Fatigue Life (18-kip ESAL)	Predicted Pavement Life (Years)
1	109,389,698	24.7
2	108,527,896	24.6
3	94,766,533	22.5
4	87,176,902	21.1
5	95,764,724	22.6
6	73,963,028	18.9
7	72,673,279	18.6
8	76,668,727	19.4
9	76,668,727	19.4
10	74,778,917	19.2

2. Bonded concrete overlay improves the riding quality.

3. Existing pavement conditions do not affect the overlay pavement performance as long as most of the existing distress is repaired before overlay placement.

4. Deflection measurements indicate that a bonded concrete overlay adds fatigue life to an existing rigid pavement.

RECOMMENDATIONS

The recommendations are presented in two parts: field implementation and future studies.

Field Implementation

1. A condition survey should be conducted shortly after a light rain, when the cracks on CRCP are most visible.
2. New cores should be taken close to the points where the old cores were secured, to monitor the progress of bond strength.
3. Steel rod sounding should be included in monitoring activities so that the progress of delamination can be monitored periodically.

Future Studies

1. The long term monitoring program should be continued in order to evaluate the long-term bonded concrete overlay performance.
2. Gathering of information on past and future traffic loading should continue. This information is very important for predicting the life of the overlay pavement.
3. The mode of failure of bonded concrete overlay pavement needs to be documented for future modeling.
4. The nature of interface bond failure should be modeled so that the delaminated sections may be formulated in terms of the distress producing mechanisms.
5. The effect of the temperature differential between the substrata and the overlay should be modeled.

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Publication of this paper sponsored by Committee on Pavement Rehabilitation.