

DELAMINATION IN BONDED CONCRETE OVERLAYS OF CONTINUOUSLY REINFORCED PAVEMENT

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The Texas State Department of Highways and Public Transportation (SDHPT) has placed over 25 lane miles of bonded concrete overlay (BCO) in the Houston area. Following the successful construction of a 1,000 foot test section in 1983, the SDHPT overlaid approximately 3.2 miles of an eight lane freeway. Debonding of some areas were reported within one year of completion. After debonding was discovered early in 1987, a study was initiated to determine the location, extent and cause of the delaminations. Furthermore, the investigation was to determine if debonding was a progressive phenomenon.

Several techniques were used to characterize the extent of debonding. For the conditions in Houston, manual sounding of the overlay followed by video tape recording of the pavement yielded the most practical and economical survey results. The use of ground penetrating radar to locate delaminated area was found to be inappropriate for the conditions presented in Houston. When assessing the development of delamination with time, operator variance in sounding and seasonal effects have a pronounced influence on the evaluation.

The survey results showed the use of portland cement grout as a bonding agent reduces the chance of debonding under conditions present in Houston. Also, the use of steel fiber reinforcement with siliceous river gravel or crushed limestone aggregate with welded wire fabric reduces the likelihood of delamination when compared to siliceous river gravel and welded wire fabric.

INTRODUCTION

Although bonded concrete overlays (BCO) have been used as a rehabilitation technique for many years, their use to rehabilitate continuously reinforced concrete (CRC) pavement is a relatively new procedure. The primary intent of this form of rehabilitation, in most cases, is to extend the life of the pavement by bonding a new pavement to the existing surface. The design assumes the resultant composite structure will react monolithically to environmental and traffic loadings, i.e., has a fully bonded interface, and it can be reasoned that debonding will adversely effect the long-term performance of the overlay. Identifying the location and extent of any delaminated areas will facilitate the assessment of BCO design and construction procedures.

Background

Portland cement concrete overlays have been used to resurface existing pavements for more than 60 years. Initially, the majority of construction experience with bonded overlays less than 4 inches thick was gained through the rehabilitation of bridge decks and airport runways and taxiways. In particular, the United States Air Force has considerable experience using thin bonded concrete overlays. Overlays ranging from 2 to 4 inches have been constructed on runways subjected to various levels of traffic loading. The condition of these overlays after up to 17 years of service ranges from good to very good. Problems have been encountered at one site and included severe and rapid deterioration following the loss of interface bond (1, 2).

The use of bonded overlays to rehabilitate PCC pavements was first undertaken on jointed pavements. Many state and local agencies have experience with the construction of bonded overlays on jointed pavements. Reflective cracking of existing joint patterns is encouraged by sawing the overlay above the existing joint as soon as possible following placement. Several highway departments have reported successful rehabilitation of jointed pavements using BCO (2, 3).

A bonded overlay of continuously reinforced concrete pavement was first attempted in Iowa in 1979 (5, 6, 7). A limited number of states have followed Iowa's lead by constructing bonded overlays on CRC pavements. As with earlier bonded overlays, varying degrees of success have been experienced. The Texas State Department of Highways and Public Transportation (SDHPT) constructed a small scale field section in 1983 and followed with approximately 25 lane-miles in 1985 and 1986.

Texas Experience

Bonded concrete overlays of CRC pavements have been recently completed at two locations in Texas. These projects, totalling approximately 175,000 square yards, were constructed on Interstate Highway 610 in the Houston area. Overlay sites are shown in Fig 1. Each of the projects is described below.

South Loop. The experimental bonded concrete overlay was placed between Cullen Road and Calais Street in Houston in 1983. One thousand feet of BCO was placed on the four

eastbound lanes in five 200-foot sections. The existing pavement, completed in 1970, consisted of 8 inches of CRC ($P_s = 0.5$ percent) resting on 6 inches of cement-treated gravel screenings, on 6 inches of compacted subgrade (8). An estimated 23,600,000 18-kip equivalent single axle load applications were applied to the outside lane before rehabilitation. The annual average daily traffic (AADT) in 1983 was 137,500 with five percent trucks (9).

The pavement was selectively repaired using polymer concrete before the overlay was placed. Longitudinal cracks were routed to be 3/4-inch wide and 3/4 to one inch deep, and then filled with dry sand and liquid monomer (10). The existing pavement was then scarified to a depth of 1/4 to 3/8 inch using a cold milling machine. Cuttings and longitudinal joint sealant were removed and the surface was lightly sandblasted. Immediately prior to overlay, the surface was airblasted and a bonding agent applied. The bonding agent consisted of water, cement, and plasticizer (Daraweld C). This mixture was broomed onto the dry surface immediately before the concrete was placed (11).

The following test sections were constructed, each four lanes wide and 200 feet long:

- (1) a 2-inch-thick plain concrete overlay,
- (2) a 2-inch-thick steel reinforced (welded wire fabric) concrete overlay,
- (3) a 3-inch-thick steel reinforced (welded wire fabric) concrete overlay,
- (4) a 3-inch-thick steel fiber (Bekaert Dramix ZP 50/50) concrete overlay, and
- (5) a 2-inch-thick steel fiber (Bekaert Dramix ZP 50/50) concrete overlay.

Concrete used with welded wire fabric consisted of seven sacks of cement, 4.5 gallons of water per sack, and 1/2-inch maximum size coarse aggregate. Fiber-reinforced concrete had 8 sacks of cement per cubic yard and 5 gallons of water per sack. A siliceous river gravel was used to match the existing CRCP coarse aggregate (8). Additional details of the construction may be found in References 5, 8 through 11.

This project was considered a success for a variety of reasons. First, it demonstrated that bonded concrete overlays could be constructed under Texas environmental conditions on CRC pavements. Second, the reduction in distress and the associated increase in remaining life of the facility were substantial. Estimates range from 6 to 16 years, with an average increase in facility life of 10 years. Details of the technique used to estimate remaining life can be found in Reference 5. Third, although roughness values were higher than expected, it was felt longer sections and better construction control would assure good rideability. The performance of this experimental section over the last five years has been excellent.

North Loop. The success of the BCO on the South Loop of IH610 prompted the SDHPT to undertake the rehabilitation of another section of IH610 using the bonded concrete overlay technique. This section is located on North IH610 between T. C. Jester and Airline Boulevard, a distance of approximately 3.2 miles (see Fig 1). As with the South Loop project, the existing pavement consisted of 8 inches of CRC on 6 inches of cement-treated subbase over compacted subgrade. The original pavement was completed in 1965. Estimates of 18-kip equivalencies applied prior to rehabilitation were not available.

Selected longitudinal cracks were repaired using polymer concrete as before. Some partial and full depth repairs were used to restore the integrity of the existing pavement in highly distressed areas. Scarification of the surface was accomplished using shot blasting rather than the milling technique utilized on

the South Loop. The experiences of other highway agencies led the Texas SDHPT to this change in surface preparation technique. Shot blasting reduces the steps before overlay placement by removing cuttings as it scarifies, thus eliminating the need for sand blasting, and resulting in a cost saving of approximately 50 percent. Airblasting and a bonding agent were used to insure a well-prepared, bondable surface. The bonding agent consisted of a cement and water mixture in the ratio of one sack of cement to 11 gallons of water. Plasticizer was not used in this grout mixture (12).

Four-inch-thick bonded concrete overlay was placed over approximately 17,000 feet of the eight-lane facility. Variable combinations included in the North Loop BCO are shown in Table 1, along with the length of each section. These sections were placed between September 1985 and September 1986.

The initial performance of the North Loop BCO as characterized by test sections identified before overlay and monitored shortly after overlay placement, coupled with the continued good performance of the South Loop, led the SDHPT to begin design work on a third BCO section. This large-scale BCO project, again on the South Loop of IH610, was scheduled to be constructed in FY 87-88. However, late in 1986, the discovery of areas on the North Loop in which the overlay had separated from the existing CRC pavement prompted the SDHPT to postpone construction of the third BCO project pending an investigation into the nature, extent, and cause of these delaminations.

Objective

The Texas SDHPT sponsored research to investigate several facets of the construction and performance of the bonded concrete overlay placed on the North Loop of IH610 in Houston. The primary intent of this paper is to describe the results of condition surveys conducted in 1987 and 1988. Several methods used to detect delamination in concrete overlays are discussed and the suitability of each is assessed. Finally, bonded overlay types for future work, are recommended based on the results of these condition surveys.

DELAMINATION DETECTION

Several methods have been used to detect delamination and cavities in concrete bridge decks and pavements. These include subjective audio assessment (sounding), ultrasonic transmission, spectral analysis of surface waves (SASW), infrared thermography, radar, and coring. Only sounding, SASW, coring, and radar were used on the North Loop of IH610. Cores were taken to confirm the existence of debonded regions and for use in laboratory studies. Some techniques were not attempted due to perceived limitations in applying the method to the conditions present on IH610.

Specifically, ultrasonic transmission works best when the direct transmission mode can be utilized (13). Using the direct transmission mode requires the receiver and transmitter to be on opposite surfaces of the material being tested. Obviously, this introduces a serious practical problem when it is used on highway pavements.

Infrared thermography was eliminated due to recommendations gleaned from the literature and equipment manufacturers regarding required temperature differentials between bonded and unbonded zones. Although many infrared scanners are capable of detecting temperature differentials as small as 0.2°C, differentials on the order of 1.5 to 2.0°C are desirable (13). Measurements taken during one field survey showed temperature differentials of only 0.5 to 1.0°C between delaminated and sound zones. Elimination of the ultrasonic

transmission and thermography left only the deflection methods discussed in the following section.

Manual Soundings

The established technique used to detect delamination relies on the operator subjectively assessing audio feedback obtained from striking the pavement. Typically, the operator strikes the pavement with a steel bar, hammer, or chain and determines the limits of an unbonded area from the resulting "hollow" sound produced. This technique has the lowest first cost; furthermore skill and experience requirements are minimal. There are substantial user costs associated with this procedure due to the long facility closure times required to thoroughly sound and record survey results from a given area.

Early in 1987, an investigation into the extent and location of delamination on the IH610 North Loop was initiated following the discovery of several debonded areas. Manual sounding of one-half the total project area was conducted in March 1987. The two inside lanes in both directions were sounded for the entire project length. Debonded areas were delineated with spray paint as they were discovered. Survey teams consisting of two or three persons were assigned to each lane during sounding. Following sounding and marking, a recording crew of two persons logged the sounding results as well as transverse crack locations using standardized forms and a rolling tape. The aggregate time used in collecting these data was 360 man-hours. To avoid peak traffic flows, lane closures were permitted only between 9 a.m. and 3 p.m. Approximately 30 minutes at the beginning and end of this available survey period were used to set up or remove traffic control cones and signing. The two inside lanes were closed in lengths of 1/2 to 3/4 of a mile, resulting in lane closures totalling 54 hours. Reduction of data from the survey forms to the project computer database required an additional 80 hours.

The two inside lanes were surveyed again in March 1988 using the same manual sounding technique. However, hand recording was not used; instead the SDHPT-owned Automated Road Analyzer (ARAN) unit taped the road using a shuttered video camera directed downward at the rear of the vehicle. The sounding was completed in one weekend using two crews. Each crew consisted of a sounding party of five persons. One crew worked in the westbound direction while the other worked on the eastbound side. In total nearly 220 man-hours were used for this survey. Data reduction from the ARAN video tape required approximately 40 man-hours. Details of the reduction process and recording of the results are available elsewhere (14).

Comparisons of the man-hours necessary for data collection, reduction, and recording as well as lane closure times are shown in Table 2. Clearly, use of the ARAN unit lessened the data collection costs, but, more important, the delay to the public was considerably reduced. Also, because the survey could be completed in one weekend, less traffic was affected by the March 1988 survey, resulting in fewer complaints to the SDHPT District office.

Spectral Analysis of Surface Waves

Limited testing of the spectral analysis of surface waves (SASW) technique was conducted during the March 1987 survey. This method relies on the accurate measurement of travel times of various waveforms generated by an impulse shock applied to the surface of the pavement. Details of the theory and operational techniques are available elsewhere (13, 15). Testing of the SASW technique was conducted on a single delaminated region approximately 8 square feet in area in March 1987. Results clearly showed this method capable of

locating the debonded region. In addition to the detection of debonded regions, this procedure can provide information as to the thickness and stiffness of the pavement layers. Nevertheless, delineation of the boundaries of this one delaminated zone required nearly 4 man-hours, making the technique impractical for large-scale surveys, given the current state-of-the-art. Automation of the method has been proposed and prototypes are being tested.

Ground Penetrating Radar

Ground penetrating radar has been used to detect deterioration of pavements and bridge decks since the mid 1970's. The technique relies on the measurement of reflected microwave pulses. A tuned antenna transmits a microwave pulse. As the energy pulse passes through an interface between two substances with different dielectric constants (such as concrete and air) some of the energy is reflected. If the overlay is sound, reflections would occur at the surface and the bottom of the existing slab (assuming no steel reinforcement). However, if the overlay has separated from the existing slab, an intermediate reflection would be detected.

A mobile ground penetrating radar unit was tested on the North Loop BCO in April 1988. The area chosen for testing had been manually sounded in March and delaminated zones previously marked were still visible. The inner lane of eastbound IH610 was closed to traffic for a distance of approximately 2,000 feet to allow operation of the vehicle at slow speeds. Examination of the output from a strip chart recorder did not show any obvious trends enabling differentiation between the bonded and debonded regions. Several passes were made at different speeds and with the antenna positioned over different areas in the lane without success. On-site technicians familiar with this radar system suggested the use of a magnetic tape to record the oscilloscope waveforms for later analysis might allow the debonded regions to be located (16). Due to equipment failures, this technique was not evaluated.

Of all of the techniques evaluated to determine the location and extent of delamination in Houston, only manual sounding was shown to be practical for large-scale surveys of heavily trafficked highways. Although manual sounding appeared to best suit the needs of this investigation from the practical standpoint, the subjective nature of the method raised questions as to the influence of the operator. This question of operator variance was addressed through a small-scale field study conducted on IH610 in December 1987.

Operator Variance

Two 50-foot sections on the inner lane of IH610 that were known to have some debonded zones from previous surveys were selected. A one-foot by one-foot grid was established on each section. Four operators then sounded the area independently and recorded the results. The results and the mean and variance for each section are shown in Table 3. The pooled variance, $(S_p)^2$, is :

$$\begin{aligned} (S_p)^2 &= \frac{(n_A - 1) \{ (S_A)^2 \} + (n_B - 1) \{ (S_B)^2 \}}{n_A + n_B - 2} \\ &= 0.12 \end{aligned}$$

where

n_A, n_B = number of observations from area A and B, respectively, and

$(S_A)^2, (S_B)^2$ = variances of observation from areas A and B, respectively.

It follows that the best estimate of the standard deviation is 0.35 percent. If the observations are assumed to be normally distributed, then the critical value associated with the operator error can be represented by the multiplication of the standard deviation by the appropriate Z-value. For a 95 percent confidence level, Z equals 1.96 and the critical change in delamination is 0.7 percent. Thus, the change in delamination in a given area must exceed 0.7 percent between two successive surveys if one is to be 95 percent confident that a change has, in fact, occurred (13).

Although the effect of season on measured delamination was not quantified, the time of year the survey is performed does appear to effect the outcome. Selected sites were surveyed in August 1987 and again in December 1987. When compared against the results obtained in March 1987 and 1988, the August survey showed a substantially higher percent delamination in all sections. This discrepancy may be due to the higher temperatures and the associated warping, during August, or, conversely, the lower temperature and presence of moisture in the pavement in the spring may dampen the sounding reverberations. The "true" percent delamination in a given area probably can not be determined in a single manual sounding survey without correlating the results to a more objective method, such as SASW. However, an assessment of the change in delamination may be obtained by repeating the surveys at yearly intervals.

CONDITION SURVEY RESULTS

The condition survey conducted in March 1987 constitutes the baseline dataset for this project. Approximately 700 station-lanes make up the total dataset. However, due to traffic control difficulties experienced during the March 1988 survey, approximately 135 station-lanes of the most common BCO type could not be surveyed. Therefore, to allow comparisons between similar data, only those stations included in both datasets are discussed further. The total number of stations of each BCO type surveyed in both 1987 and 1988 are shown in Table 4. Due to the limited number of no-grout sections placed on the North Loop, these data are discussed separately. Sounding of the South Loop experimental sections was carried out by SDHPT personnel in 1987 and by CTR research staff in August 1988. No delamination was found in either survey.

The area delaminated, expressed as a percentage of the total area in each station-lane (100 feet x 12 feet = 1,200 feet²), is shown in Table 5 for each of the overlay types in the reduced dataset. Also shown in Table 5 are the March 1988 results and the changes in these parameters from the 1987 survey. The overlay that used siliceous river gravel (SRG) aggregate and welded wire fabric reinforcement with grout as a bonding agent had the largest percent debonded of the types considered. In one section, over 1/4 of the area had delaminated from the existing slab. The BCO that used limestone aggregate had no debonding in 1987 and only limited problems in 1988. The fibrous concrete overlay also had performed well through the analysis period.

These data show the average percent delamination on the inside lanes to be approximately 1.0 percent when weighted according to the amount of each BCO type present on the North Loop. This average typifies only the inner lanes. Because these lanes were placed separately from the two outer lanes, a potential bias exists. A limited survey was taken on the outermost lane in each BCO type. Approximately 6000 feet of the outer lane on the eastbound side were sounded in August 1987. Ideally the survey would have been completed in March 1987 when the inner lanes were surveyed. However, if the results

obtained in August can be assumed to be representative of the percent delamination in the outer two lanes, then the overall percent delamination on IH610 North is 0.6 percent.

A major concern is the progression of delamination under traffic and environmental loading. As noted above, seasonal influence on sounding results may be important, particularly when the purpose is to characterize the progression of delamination with time. This problem can be avoided by using data obtained in the same season in successive years. When the change in delamination between the March 1987 and 1988 surveys is examined, as shown in Table 5, none of the BCO types has significant increases beyond those attributable to normal operator error.

The data shown in Table 5 are the average of all station-lanes of the given type in the two inner lanes. When the individual results are examined a somewhat different picture is revealed.

A three point moving average of delamination was calculated by averaging the percent delamination for three consecutive 100-foot stations. This technique allowed the delamination data to be smoothed without masking the overall trends. Figures 2 and 3 show the moving average plotted against number of stations from the start of the survey. The shaded boxes indicate areas that had a significant increase or decrease in debonding between 1987 and 1988.

These plots reveal that (1) debonding is not uniform throughout the job, (2) some areas have more than 10 percent of the total area delaminated, and (3) the number of areas with significant decrease is approximately equal to the number with an increase. It is, of course, doubtful that the debonded areas have "rebonded" and therefore the decrease in delamination percentage must be ascribed to an error in the original survey. It is also noteworthy that the areas showing the highest percent delamination in both directions occurred in the vicinity of Yale Boulevard. This may indicate there is a pre-existing problem in the area that leads to the delamination of overlays since the eastbound and westbound sides were placed at different times and under dissimilar environmental conditions.

The four no-grout sections showed the greatest increase in percent delamination of all BCO types. The debonded area had increased from 2.8 percent in 1987 to 3.1 percent by March 1988. The no-grout sections showed not only the greatest increase in delamination but also the highest overall average percent debonded area.

Further analysis of the delamination data was done to determine the influence of reinforcement type, aggregate type, bonding agent, traffic loading, and direction. The SAS general linear model procedure was used to determine the significance of each variable (18). The following model was used:

$$D_{xx} = \text{REINF} \mid \text{AGG} \mid \text{GROUT} \mid \text{LANE} \mid \text{DIR}$$

where

- D_{xx} = percent delamination in either 1987, or 1988 or the difference between 1988 and 1987;
- REINF = welded wire fabric or steel fiber reinforcement;
- AGG = limestone or siliceous aggregate;
- GROUT = grout or no-grout bonding agent;
- LANE = lane number; and
- DIR = direction of travel (east or west).

Lane number was used as an indirect measure of traffic loading due to the relatively light truck traffic on the innermost lane (19).

The Type III Sum of Squares and appropriate F-values were calculated by the SAS program. The significance of each

to the five classification variables is shown in Table 6. An α -level of 0.05 was used. Among the interactions available for evaluation, only the lane-direction interaction from the March 1988 data was statistically significant. These data show only reinforcement and aggregate types to be significant in explaining the variance in percent debonded in both the 1987 and 1988 surveys.

CONCLUSIONS

Based on the methodology used to collect data and the analysis of that data, the following conclusions appear warranted.

1. For the conditions present on the bonded overlay in Houston, infrared thermography was not feasible due to the low temperature differential between bonded and unbonded
2. Manual sounding of large areas requires considerable personnel and results in substantial delays to the traveling public.
3. Both man-power requirements and lane closure times can be reduced by approximately 50 percent through the use of automated recording of survey results using shuttered video cameras.
4. The spectral analysis of surface waves (SASW) technique was able to detect the limits of delaminated regions, but the current state of the art does not allow large areas to be surveyed rapidly.
5. The ground penetrating radar unit was not able to locate debonded regions. Furthermore, strip chart output could not be correlated with marked delaminated zones.
7. In order to be 95 percent confident that a change in delamination has occurred the change in percent debonded area must exceed 0.7 percent.
8. The time of year a survey is completed has an effect of the reported delamination.
9. Debonding was not uniform throughout the project.
10. No delamination has yet been found on the experimental sections placed on the South Loop of IH610 in 1983.
11. The overall percentage of delamination on the North Loop of IH610 in Houston is approximately 0.6 percent.
12. Bonded concrete overlays produced with limestone aggregate and welded wire fabric reinforcement or siliceous river gravel and steel fiber reinforcement had significantly lower percent delamination than BCO produced with SRG and welded wire fabric.
13. Siliceous river gravel concrete with fabric placed without grout had the highest percentage of debonded area.
14. Delamination does not appear to be progressive phenomenon on IH610 North.
15. Based on analysis of variance, only reinforcement and aggregate types were consistently significant in explaining differences in percent delamination. Traffic loading, as represented by lane, has not influenced delamination.
16. The South Loop experimental sections placed with no reinforcement and mesh and fiber reinforcement in thicknesses of 2 and 3 inches have shown no debonding after 5 years of service.

RECOMMENDATIONS

As a result of this investigation into the delamination of concrete overlays on IH610 in Houston, the following recommendations are offered.

1. When attempting to assess the progression of delamination with time, seasonal effects should be taken into account by repeating surveys at yearly intervals.
2. Bonded concrete overlays constructed with limestone aggregate and welded wire fabric or siliceous river gravel and steel fibers should be promoted over those constructed with SRG and wire fabric.
3. The use of portland cement grout as a bonding agent reduces the chance of debonding under conditions present in Houston.
4. The differences among the construction techniques and environmental conditions of the North Loop and those of the South Loop should be investigated further to determine why no delamination occurred on the South Loop.
5. Manual sounding remains the most viable technique for determining the location and extent of debonding; however, if possible, video recording results should be used to minimize agency and user delay costs.
6. Continued investigation of the North Loop is recommended to ascertain effects of the environment and construction procedures on the initiation of delamination.

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Bonding Agent	Fiber Reinforced		Welded Wire Fabric	
	Limestone	SPG	Limestone	SPG
Grout	- -	2,200	1,000	13,400
No Grout	- -	- -	- -	400

TABLE 1. LENGTH OF BONDED CONCRETE OVERLAY SECTIONS INCLUDED IN NORTH LOOP, IN FEET

Survey Date	Sounding	Data Recording		Entry of Data in Job Database	Total Hours	Lane Closure
		Field	Office			
March 1987	140	220	0	80	440	54
March 1988	140	0	40	40	220	24

TABLE 2. DELAMINATION SURVEY COSTS IN PERSONNEL AND LANE CLOSURE TIME REQUIRED TO SURVEY APPROXIMATELY 650 STATION-LANES (IN MAN-HOURS)

Operator/Parameter	Percent Delamination	
	Section A	Section B
Operator 1	1.90	3.90
Operator 2	1.40	4.10
Operator 3	2.20	4.20
Operator 4	2.00	3.50
Mean	1.90	3.90
Variance	0.15	0.31
Standard Deviation	0.39	0.56

TABLE 3. OPERATOR VARIANCE INVESTIGATION RESULTS

SESSION 3: PAVEMENT EVALUATION AND OVERLAYS

Bonded Concrete Overlay Type	Number of Station Lanes Surveyed in Both 1987 and 1988
Fiber SRG Grout	44
Wire Limestone Grout	20
Wire SRG Grout	496
Wire SRG No Grout	4

TABLE 4. NUMBER OF STATION-LANES SURVEYED BOTH IN 1987 AND 1988

Survey Date	BCO Type		Statistical Parameter, Percent			
	Aggregate Type	Reinforcement Type	Mean	Standard Deviation	Minimum Value	Maximum Value
March 1987	SRG	Wire	1.1	3.1	0.0	26.2
	SRG	Fiber	0.1	0.5	0.0	2.8
	Limestone	Wire	0.1	0.0	0.0	0.0
	Average		1.0	3.0	- -	- -
March 1988	SRG	Wire	1.1	3.3	0.0	26.5
	SRG	Fiber	0.1	0.3	0.0	1.7
	Limestone	Wire	0.1	0.2	0.0	0.6
	Average		1.0	3.1	- -	- -
Change ('88 - '87)	SRG	Wire	0.0	1.6	-11.9	13.6
	SRG	Fiber	0.0	0.2	-1.1	1.7
	Limestone	Wire	0.1	0.2	0.0	0.6
	Average		0.0	1.5	- -	- -

Note: Data from grouted areas only.

TABLE 5. DESCRIPTIVE STATISTICS FOR DELAMINATION RESULTS FROM MARCH 1987 AND 1988

Variable	March 1987	March 1988	Difference
Reinforcement	Yes	Yes	No
Aggregate	Yes	Yes	No
Grout	No	Yes	No
Lane	No	No	No
Direction	No	Yes	No

TABLE 6. SIGNIFICANCE OF VARIOUS CLASSIFICATION VARIABLES IN VARIATION OF DELAMINATION PERCENTAGES

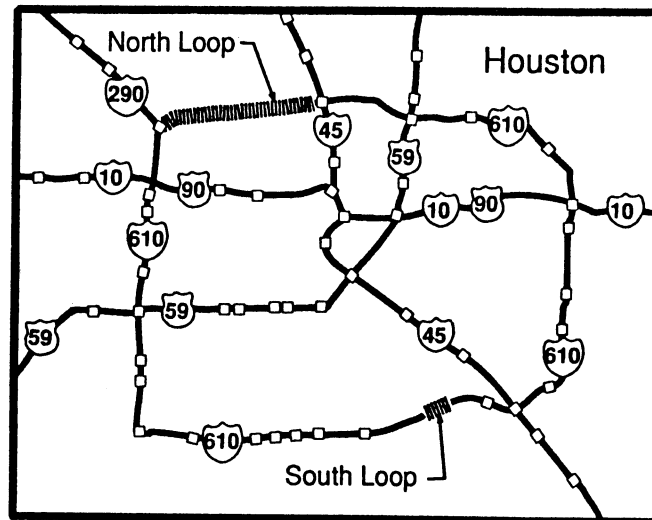


Fig 1. Map of Houston area showing BCO sites.

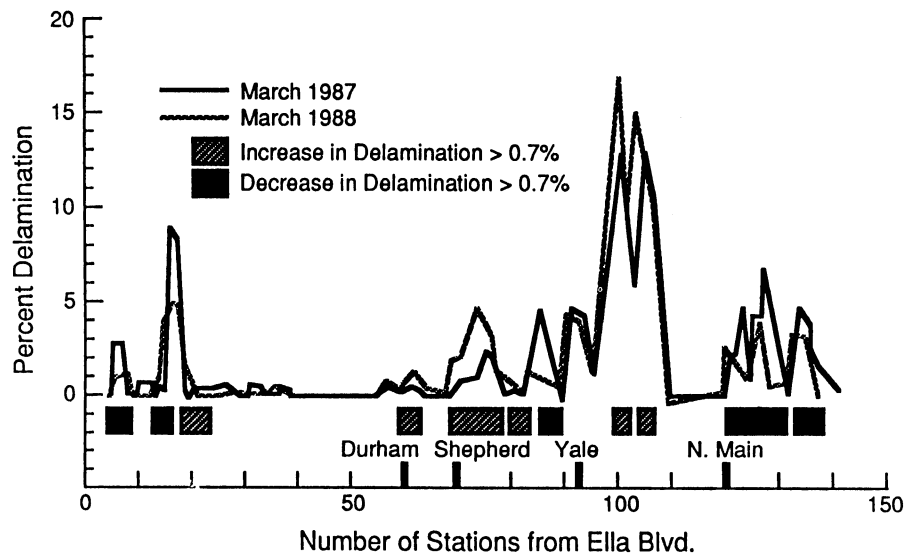


Fig 2. Moving average of percent delamination on two inner eastbound lanes IH610.

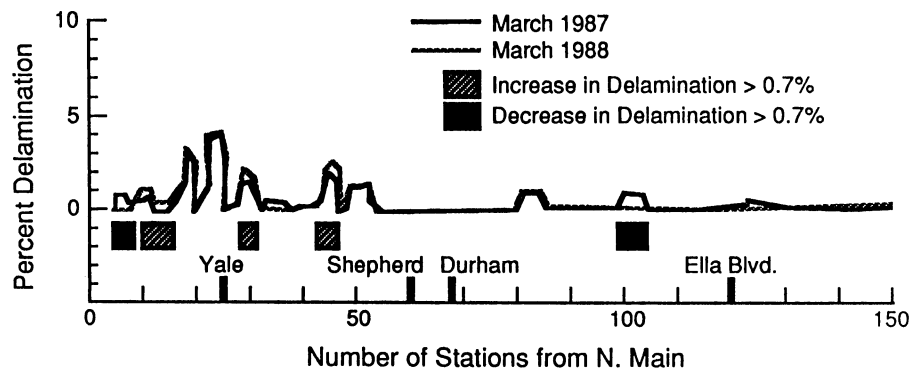


Fig 3. Moving average of percent delamination on two inner lanes westbound IH610.