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16. Abstract

This report presents the research and recommendations regarding the rehabilitation of an urban section of IH-30 in west Fort Worth, Texas. Bonded concrete overlays have proven to be a viable solution for rehabilitation of heavily traveled pavement sections. The main objective of this project is to evaluate the technical and economical feasibility of an expedited bonded concrete overlay and to monitor its performance. In addition to the materials characterization of the existing pavement and the rehabilitation design, the report presents a strategy to expedite the BCO in conjunction with the widening of the road. The expedited construction will allow the opening of the rehabilitated pavement to traffic as early as possible and, therefore, can minimize user-associated costs. The economic analysis included in the report shows the feasibility of implementing a BCO in lieu of a full-depth reconstruction.

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FULL-SCALE BONDED CONCRETE OVERLAY ON IH-30 IN FT. WORTH, TEXAS

by

Manuel Treviño, B. Frank McCullough, and Tony Krauss

Research Report Number 9-572-1

Research Project 9-572
"Full-Scale Bonded Concrete Overlay on IH-30 in Ft. Worth, Texas"

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION
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B. Frank McCullough, P.E. (Texas No. 19914)

Research Supervisor

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Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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CHAPTER 1. INTRODUCTION

BACKGROUND

In large metropolitan areas such as Fort Worth, various sections of the interstate highway system are approaching the end of their pavement lives. The Fort Worth District has many miles of continuously reinforced concrete pavements (CRCP) that were constructed in the late 1950s and throughout the 1960s and 1970s that have given excellent performance throughout the years and that, at the present stage of their lives, requiring some type of rehabilitation, may be at the optimum point of application of bonded concrete overlays (BCO) to extend their useful life. The structural and functional capabilities of these pavements can be improved by rehabilitation, routine maintenance or reconstruction. Bonded concrete overlays have proven to be a viable technical and economical solution for pavement rehabilitation in large metropolitan areas such as Houston (Loop 610 and Beltway 8; see Refs 1 and 2). Therefore, the construction of a BCO in the Fort Worth District has the potential of providing years of additional service life at minimum life cycle cost.

The rehabilitation of a roadway always causes traffic disturbances and implies user-associated costs and an increase in pollution problems. Therefore, in order to keep all these to a minimum while providing an adequate repair, a strategy for the rehabilitation must be devised. The economical and technical feasibility of a BCO as a solution for rehabilitation for the heavily urbanized and traveled pavement sections on Interstate Highway 30 is presented in this study.

The project is located in Tarrant County (Fort Worth District) on IH-30. The original roadway section was constructed in 1967 and consists of a pavement structure of 20 cm of continuously reinforced concrete pavement (CRCP) over a 15 cm layer of lime-stabilized subgrade. In 1975, the pavement received an 11.4-cm thick hot mix overlay to correct some longitudinal roughness and surface polish. A plant mix seal was applied in 1981 to improve the surface texture. In 1993, the accumulated hot mix layers were removed because of their excessive deterioration. A 5-cm asphalt cement overlay was placed to provide an interim acceptable riding surface until the rehabilitation takes place. This stratum will be removed prior to overlaying and the BCO will be placed on top of the 20-cm CRCP. The existing pavement structure is shown in Figure 1.1.

OBJECTIVES OF PROJECT

The purposes of this project are to evaluate the technical and economical feasibility of an expedited BCO on IH-30 in Tarrant County (Fort Worth District) and to monitor its performance. The subobjectives of the project are:

- To expedite the construction of the BCO to allow early opening to the traffic (12 to 24 hours after last placement).
- To recommend materials, construction procedures, and techniques for the BCO.
- To evaluate and propose a strategy for the widening of the existing pavement section.

- To evaluate the most desirable conditions for the BCO placement and to identify when the BCO should be placed only with carefully controlled precautions.
- Identify acceptable precaution measures and techniques that may be used under marginal climatic conditions.
- To observe and record the actual materials, construction techniques, and climatic conditions during overlay construction.
- To evaluate the existing CRCP rotomilled surface conditions as to acceptability for bonding at the interface.
- To make observations on the behavior parameters before and after the overlay construction and to periodically repeat the measurements in a long-term performance monitoring procedure.
- To statistically analyze and evaluate field data before, during, and after construction of the BCO.
- To make final recommendations on materials, construction procedures, and techniques for the BCO in the Fort Worth District.
- To provide the Fort Worth District with a procedure for evaluating and designing BCOs for in-service CRCP.

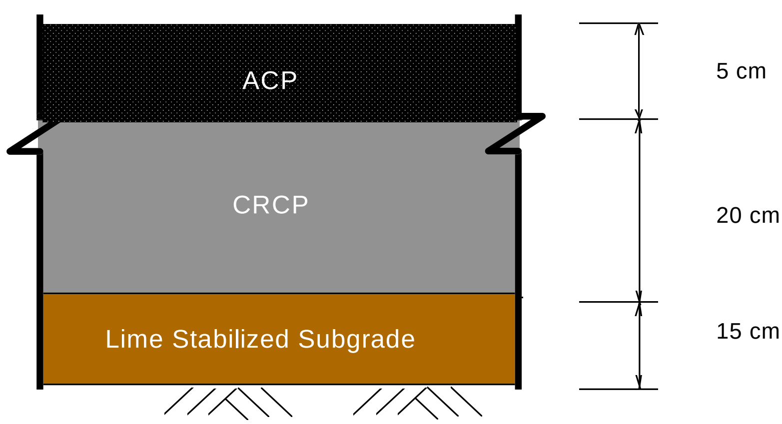

Figure 1.1 Existing cross section

OBJECTIVES OF REPORT

The objectives of this report are to document:

- The coring and deflection testing plans and results.

- The calculation of the layer properties of the existing pavement.
- The overlay thickness design and the reinforcement design.
- The construction phases.
- The cost analysis.
- The construction recommendations.

SCOPE OF REPORT

The section considered for this project is approximately 2 km long, including bridges and ramps. There are 2,112 m of roadway and 52 m of bridges. The section is located in Fort Worth, Texas, on IH-30 between Loop 820 (West Loop) and Las Vegas Trail (Fig 1.2). The section in question lies between station markers 962 + 00 and 1033 + 00. Station markers are designated according to the original plans and, therefore, are in feet; each station represents 30.48 m (100 ft). Figure 1.3 shows the project location on the west side of Fort Worth; its scope includes both the eastbound and westbound directions.

Figure 1.2 Fort Worth, Texas

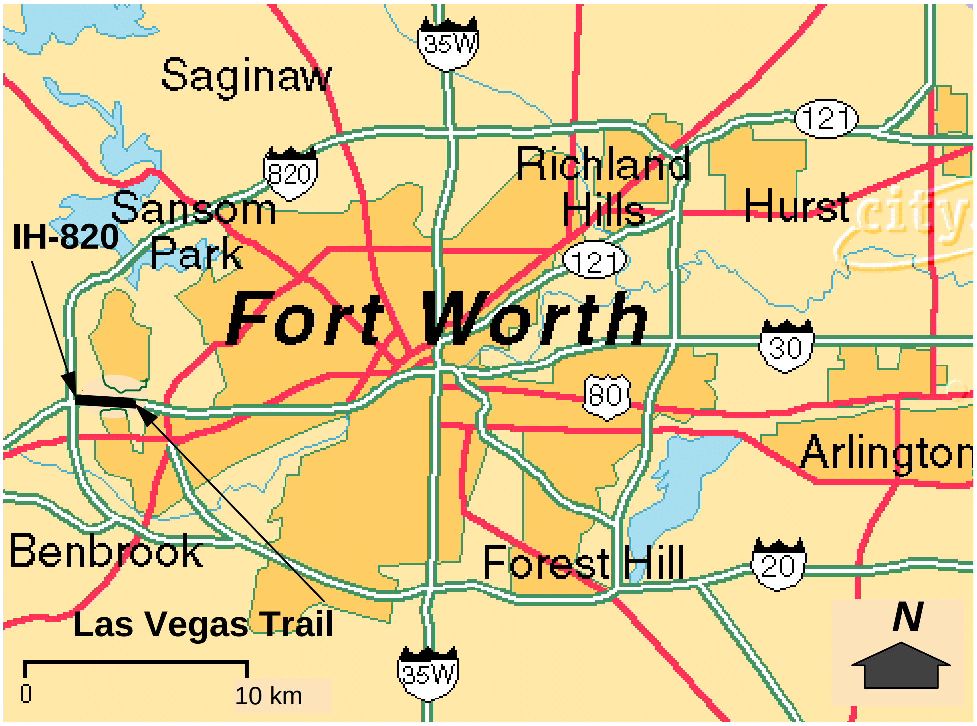

Figure 1.3 Project location

Besides the rehabilitation of the existing pavement, the project also includes increasing the capacity by widening the cross section to provide more lanes. For this, a new CRCP will be constructed, spanning up to 14.6 m, which will add one lane in each direction. After the rehabilitation and widening, the resulting cross section will be a 14.6-m portland cement concrete pavement (PCCP) slab for each traveling direction. In certain areas, both directions will be joined to form a continuous 29.3-m PCCP cross section.

The tests conducted on the pavement included deflection and core testing. Deflections were measured with the falling weight deflectometer (FWD). Twenty cores were obtained from the pavement section. The cores were tested for modulus of elasticity, coefficient of thermal expansion, splitting tensile strength, and compressive strength. They were also used to verify the original pavement thickness. Chapter 2 addresses the field and laboratory testing.

Chapter 3 presents the rehabilitation design, including both the overlay thickness design and the reinforcement design. Using the testing results and traffic data, the researchers designed the overlay using the AASHTO method and a mechanistic design procedure.

In Chapter 4, the construction phases for the project, involving the overlay placement as well as the road widening, are detailed. Chapter 5 presents the cost analysis and shows the economic feasibility of a BCO for this project. Costs are compared both between the new pavement structure and the BCO in this project, and among this project and two other similar projects.

Finally, Chapter 6 contains concluding remarks and recommendations. Special provisions are presented in Appendix A. Appendix B shows an output of the thickness design computer program, and Appendix C lists the tabulation of costs involved in the project.

CHAPTER 2. MATERIALS CHARACTERIZATION AND DESIGN INPUT

This chapter covers the materials characterization for the existing pavement layers. Two types of tests were conducted on the pavement to characterize its properties: deflection measurements and cores. Several tests were then performed on the cores.

PAVEMENT DEFLECTION MEASUREMENTS

Deflection measurement is a nondestructive testing (NDT) procedure performed to characterize the properties of each pavement layer. Deflection testing represents a fundamental step for overlay design, since deflections reflect the capacity of the pavement structure to carry traffic loadings.

There are different devices to perform these measurements. These devices can be classified into two categories: those that measure point deflections and those that provide the measurement of a deflection basin based on several recordings of sensors in the proximity of the load source. In this project, the deflection measurements were made with the falling weight deflectometer (FWD), which is a heavy-load deflection-basin device. Two sets of measurements were taken at each one of the measurement locations. The first set was measured at the midspan of two adjacent transverse cracks to obtain a deflection bowl and calculate elastic moduli of the pavement layers, and the other one was taken just beside the crack, placing one of the sensors to one side of the crack and the remaining sensors across the crack, to evaluate the load transfer efficiency at the discontinuity.

Sensors were located at different distances from the load source: 0, 30.48, 60.96, 121.92, 152.40, and 182.88 cm. The remaining sensor was at 30.48 cm from the load, but was placed to the other side of it. This geophone provided the deflections needed to calculate load transfer efficiencies at the discontinuities, i.e., cracks. The FWD device provides deflection measurements for several load drops. The load magnitude utilized for calculations in this case was 40 kN, which corresponds to the second drop height of the FWD; this target load simulates the 80 kN standard wheel load at one spot, as recommended by AASHTO (Ref 3).

The surface deflection data collected were analyzed using a microcomputer-based procedure called RPEDD1 (Rigid Pavement Evaluation Program; Ref 4). This program is designed to process data collected with the FWD using a linear elastic procedure prior to the backcalculation process. The goal of this process is to estimate the pavement material properties, trying to find a set of parameters that correspond to the best fit of the measured deflection basins, minimizing the differences between the measured and the calculated deflection bowls. The program iterates until the measured and computed deflections converge.

Load Transfer Efficiency

The load transfer efficiency of a pavement structure refers to its ability to transfer loads across such transverse discontinuities as joints or cracks. A pavement structure with a high value of load transfer efficiency indicates that the loads are adequately distributed at the discontinuities. One of the purposes of collecting deflections was to evaluate load transfer efficiencies at cracks. To accomplish this, deflections were measured at cracks (with one of the sensors being placed on the unloaded part of the slab) and the load transfer was calculated using an analytical procedure.

A load transfer efficiency (LTE) of zero means that no load is transferred from the loaded slab to the adjacent unloaded slab. In the case of perfect load transfer, the load is distributed completely from the loaded slab to the unloaded adjacent slab (i.e., the deflection is the same in both slabs).

The average load transfer efficiency obtained for the Fort Worth project section was 98.5%, indicating a good behavior of the pavement regarding load distribution. The LTE is an important design parameter for overlays.

Deflection Results

According to the backcalculation process described, the mean results obtained from the RPEDD1 program are presented in Table 2.1.

Table 2.1 Modulus of elasticity backcalculated from pavement deflections

Modulus of Elasticity (MPa)		
Slab	Subbase	Subgrade
32,422	405	185

CORING

Twenty core specimens were extracted from the eastbound and westbound lanes of the Fort Worth pavement. They were tested by the Construction Materials Research Group of The University of Texas at Austin. The cores had a diameter of 10 cm and a typical length of 20 cm. Six cores were tested for modulus of elasticity, four were tested for coefficient of thermal expansion, four were tested for splitting tensile strength, and eight for compressive strength. Table 2.2 shows the length and tests performed on the cores.

Table 2.2 Tests performed on cores

Core Number	Average Length (cm)	Direction	Tests Performed
1	20.6	Westbound	Splitting tensile
2	20.4	Westbound	Modulus, Compressive
3	20.3	Westbound	Thermal coefficient
4	20.6	Westbound	Compressive
5	20.1	Westbound	Splitting tensile
6	20.6	Westbound	Modulus, Compressive
7	20.0	Westbound	Splitting tensile
8	19.8	Westbound	Modulus, Compressive
9	19.7	Westbound	Thermal coefficient
10	17.9	Westbound	Damaged in testing
11	19.6	Eastbound	Thermal coefficient
12	19.2	Eastbound	
13	19.3	Eastbound	Modulus, Compressive
14	20.5	Eastbound	Splitting tensile
15	20.1	Eastbound	Modulus, Compressive
16	20.0	Eastbound	Splitting tensile
17	19.8	Eastbound	Splitting tensile
18	19.8	Eastbound	Thermal coefficient
19	19.5	Eastbound	Modulus, Compressive
20	19.1	Eastbound	

The length of each core was measured four times and averaged. The mean pavement thickness was 19.86 cm, and the standard deviation of the pavement thickness was 0.65 cm. None of the cores appeared to have been cracked. Core 7 had an indentation from reinforcing steel at middepth. The diameter of the cores was also measured, and it was within 0.16 cm of the nominal 10-cm diameter in all the cases. For all calculations, the nominal 10-cm diameter was used.

Testing Program

Four different tests were performed on the cores: modulus of elasticity, coefficient of thermal expansion, splitting tensile strength, and compressive strength. A brief description of the test program follows.

<u>Modulus of Elasticity:</u>

Elastic modulus testing of the cores was performed prior to compressive strength testing. Loads were applied using the Forney cylinder testing machine. Deformations were measured using a compressometer with a 14-cm gage length and a Mitutoyo Digimatic Indicator. Specimens were loaded to approximately 45% of estimated compressive strength.

Coefficient of Thermal Expansion:

Each of the cores selected for thermal expansion testing was prepared according the ASTM C341 guidelines. This preparation ensured that all the cores were of the same length and the ends of the cores were perpendicular to the longitudinal axis. Holes were drilled at the center of the ends of the cores, and gage studs were epoxied to them in both ends. Approximately half of each gage stud extended out of each end of the core. The length of the gage studs extending out of the core and the length of the cores were noted at room temperature.

After the epoxy bonding the gage studs to the cores was sufficiently cured, the cores were placed in an oven and heated overnight. Actual testing of all the cores was done in two cycles to reduce error. The changes in temperature for the two cycles were 75 and 78 ºC. The change in length of the steel gage studs and the change in length of the core were measured. The change in temperature and the change in length of the concrete cores were then used to obtain the coefficient of thermal expansion for each core. The results obtained for each core during both cycles were averaged to obtain one overall thermal coefficient.

Splitting Tensile Strength:

Splitting tensile tests were performed according to ASTM C496-90. The diameter and length of each core were noted prior to testing. These values, along with the failure loads, were used in determining the splitting tensile strength of each core tested. Testing was performed on a 54,500-kg capacity Tinius Olsen testing machine at slow loading rate.

Compressive Strength:

Each of the cores used in performing compressive strength tests were tested in accordance with ASTM C39-86. Six of the cores used in performing modulus of elasticity tests were used in conducting compressive strength tests. The ends of these cores were capped with sulfur capping compound. Testing was performed on a 272,400 kg capacity Forney cylinder testing machine at a loading rate of 18,000 to 27,000 kg per minute.

Test Results

This section reports the results of the concrete core testing program.

Modulus of Elasticity:

Measured core moduli varied from 27,850 to 29,575 MPa. The results for Core #13 do not appear to be correct. They are unreasonably low. The core may have had some damage that was not observed prior to testing. Disregarding core No. 13, the mean value is 27,500 MPa and the standard deviation is 2,192 MPa. The coefficient of variation is 8%.

These are secant moduli values at approximately 45% of the compressive strength of the cylinder (Table 2.3).

Table 2.3 Elastic modulus of cores

Core Number	Modulus (MPa)
2	27,850
6	29,575
8	29,440
13	20,890
15	24,340
19	26,400

As expected, because of the higher stresses applied to the pavement cores (as opposed to those stresses occurring during the deflection tests), these moduli are significantly lower, as compared with those obtained from the backcalculation procedure. This finding is illustrated in the concrete stress-strain curve, where the two different slopes of the curve (elastic moduli), corresponding to coring and deflection testing, can be compared (Fig 2.1).

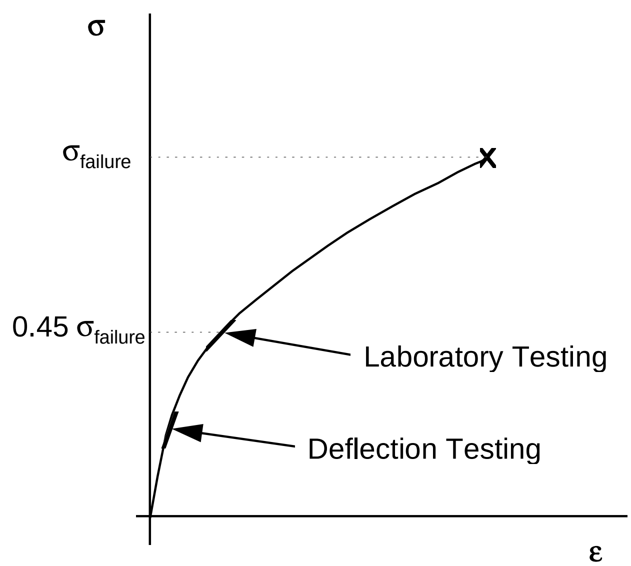

Figure 2.1 Moduli of elasticity for coring and deflection testing

Coefficient of Thermal Expansion:

The cores were heated to 94 to 99 ºC and cooled to room temperature (22 to 27 ºC) seven times. The first three sets of results were discarded, as were the results from Core 18, which gave unreasonably low results for the last two cycles.

The coefficient of thermal expansion of the cores tested varied from 4.30 x 10^{-6} / ºC to 13.05 x 10^{-6} / ºC. The mean value was 8.15 x 10^{-6} / ºC, the standard deviation was 2.92 x 10^{-6} / ºC, and the coefficient of variation was 36 %. A possible explanation for such a high coefficient of variation in this test could be that the gage studs were affixed to the cores with epoxy and this may have caused the variability.

Splitting Tensile Strength:

Splitting tensile strength varied from 3.97 to 5.03 MPa. The mean value was 4.36 MPa, the standard deviation was 0.39 MPa, and the coefficient of variation was 9%. Table 2.4 presents the splitting tensile strength test results.

Table 2.4 Splitting tensile strength of cores

Core Number	Splitting Tensile Strength (MPa)
1	4.19
5	4.25
7	5.03
14	3.97
16	4.14
17	4.61

Compressive Strength:

Compressive strength varied from 32.66 to 40.84 MPa. The mean value was 36.10 MPa, the standard deviation was 3.05 MPa, and the coefficient of variation was 8%. Normally core compressive strength is expected to be 85% of cylinder strength (f'c); accordingly, f'c can be predicted by dividing core strength by 0.85 (Ref 5). Similarly, the elastic modulus may be predicted by multiplying 57,000 times the square root of the cylinder strength, in psi (Ref 5).

The predicted and measured modulus values are compared in Table 2.5. The mean predicted value is 30,815 MPa, and the mean measured value is 27,500 MPa (excluding the value for Core 13, as previously noted). Except for Core 8, the predicted modulus values are significantly higher than those measured.

Table 2.5 Compressive strength test results and predicted values

Core Number	Compressive Strength (MPa)	Predicted f'c (MPa)	Predicted E (MPa)	Measured E (MPa)
2	32.97	38.79	29,506	27,850
6	37.43	44.05	31,437	29,575
8	32.66	38.41	29,368	29,440
13	36.77	43.26	31,161	20,890
15	40.84	48.04	32,815	24,340
19	35.91	42.25	30,747	26,400

SUMMARY

The deflection tests were used to backcalculate the pavement layered properties under loadings similar to those that occur under normal traffic. The moduli of elasticity obtained from the cores were not as high as compared to those backcalculated from the deflection measurements. This is because the stresses applied to the pavement in the deflection test are lower than the stresses placed upon the cores. Lower stresses lead to higher moduli, since at that point, the concrete is tested at an earlier stage of the stress-strain curve, still in the elastic interval; thus, the slope of the curve, i.e., the modulus of elasticity, is higher. Discontinuities in the pavement (cracks) performed adequately regarding load distribution, reaching an average value of 98.5% load transfer efficiency for the entire project section. This value indicates an excellent behavior of the cracks when transferring loads.

The test results obtained from the cores appear to be reasonable, except for those obtained from the coefficient of thermal expansion test. The coefficient of variation for that test was very high (36%). The use of epoxy to affix the gage studs may have influenced the results. The coefficients of variation obtained from all the other tests were less than 10%.

CHAPTER 3. REHABILITATION DESIGN

This chapter presents the rehabilitation alternative selection, the overlay thickness design and the reinforcement design for the Fort Worth bonded concrete overlay. The data presented on materials characterization, shown in the previous chapter, are utilized now as input parameters for the design. In addition, the other input such as traffic, remaining life, etc. are developed and/or presented. Using this information the thickness and reinforcement for the BCO are developed.

REHABILITATION ALTERNATIVE SELECTION

Several rehabilitation alternatives are available for CRCP. The final decision depends on factors such as the state of the existing pavement, the type and cause of distress mechanisms, rehabilitation costs and environmental influences. The wide range of alternatives starts with the selection of rehabilitation with an overlay or rehabilitation with methods other than overlay. If an overlay is chosen, it could be either a portland cement concrete (PCC) overlay or an asphalt concrete (AC) overlay. PCC overlays can be bonded, unbonded and even partially bonded.

Since the inception of this project, a thin bonded concrete overlay was the preferred rehabilitation alternative proposed by the District. Originally, the reasons for this were that the pavement did not seem to be in poor condition, and that vertical clearances were a concern at three different structures along the pavement section. Visual inspection and testing of the pavement indicate that it is structurally sound. Therefore, no major repairs are necessary, which makes this pavement an ideal candidate for a bonded concrete overlay rehabilitation. Three main advantages of a BCO, from Ref 6, were especially important in this case and led to the selection of a BCO over other alternatives:

- The BCO can cost-effectively extend pavement life, improve riding quality and load-carrying ability, thereby protecting infrastructure investment.
- The overlay expedites construction, since it requires only a minimum number of operations.
- A BCO minimizes clearance problems.

In addition, this project presented an excellent opportunity to demonstrate the concept of expediting construction using a BCO on an existing pavement

TRAFFIC ANALYSIS

The traffic data are used in this section to develop two additional design inputs: ESALs anticipated during the design life and remaining life of the existing pavement.

Traffic data are an important design parameter, since a pavement structure is designed to perform for a number of years in which an expected amount of traffic is to circulate over it. Traffic loads have a damaging effect, which is cumulative over the pavement performance period and will ultimately determine the end of its life. The accumulated traffic since the pavement opening until the present was used to estimate the remaining life of the pavement.

Design ESALs

The most common approach while counting traffic at any location is to count either vehicles or axles during a certain period of time. Since not all the axles cause the same damage to the pavement structure, following the findings of the AASHO Road Test, any traffic load (mass) can be represented by an equivalent number of 80 kN equivalent single axle loads (ESALs). This concept is applied in the design equations. Therefore, the mixed traffic stream of different axle loads and axle configurations that has circulated through a section of roadway should be converted to ESALs in order to quantify the damage to the pavement.

Remaining Life

The traffic data obtained from the Fort Worth District for the project segment of IH-30 are the anticipated average daily traffic (ADT) volumes for the years 1996, 2016, and 2026. ADT is the average number of vehicles per day carried by the facility, and in this case, this number is an estimated average for each year. Also, a tabulation showing traffic analysis, in ESALs through the year 2026, was provided by the District, for one direction and a 65% directional distribution. The traffic information supplied by the District, from 1993, is summarized in Tables 3.1 and 3.2.

Table 3.1 IH-30 average daily traffic

Year	**ADT**
1996	58,800
2016	89,600
2026	102,000

Table 3.2 IH-30 number of ESALs

Design Period	Years	ESALs
1996-2016	20	14,652,000
1996-2026	30	23,812,000

With this information, and assuming a compound growth, a 1.45% annual growth rate was calculated for the ESALs. The analysis periods chosen for the thickness design of the overlay were 30, 40, and 50 years. ESAL estimations were performed for the different analysis periods using a 65% directional distribution and a 40% lane distribution factor, and the results are presented in Table 3.3.

Table 3.3 IH-30 estimated number of ESALs

Analysis Period (years)	Both Directions	Single Direction	Design Lane
30	36,073,259	23,447,619	9,379,047
40	51,999,387	33,799,602	13,519,841
50	70,391,462	45,754,450	18,301,780

Remaining life is one of the most important parameters considered in the development of the overlay thickness design and has a significant influence in the design outcome. Several methods exist to estimate the remaining life of a pavement structure. In this case, the mechanistic fatigue model proposed in the AASHTO Guide was implemented (Ref 3). Having the total number of ESALs to date and the AASHTO design equation, the remaining life of the pavement section was estimated. The above mentioned equation allows the designer to calculate the total number of ESALs to failure. The ratio of ESALs-to-date to ESALs-to-failure, in percentage, subtracted from 100%, will give the percentage of remaining life:

$$RL = 100\left[1 - \left(\frac{n}{N}\right)\right]$$

where

RL = remaining life, percentage
n = total traffic to date, 80 kN ESAL
N = total traffic to pavement failure, 80 kN ESAL

The total traffic to pavement failure (N) is defined by the minimum acceptable Pavement Serviceability Index (PSI). To calculate the remaining life, the total number of ESALs since the facility was built (1967) up to the present was estimated. With the traffic information obtained from the District extrapolated back to the year 1967 (since historical traffic data back to that year could not be obtained), the total number of ESALs to date (n) was determined to be 6,099,900. The total traffic to pavement failure (N) determined from the AASHTO design equation (Ref 3), using 50% reliability, was 28,520,000 ESALs. With these figures, the remaining life of the pavement section was estimated to be 80%. The estimated remaining life appears in a Technical Memorandum from 1995 (Ref 7). The validity of this estimation is supported by the fact that the number of pavement defects in the condition survey (i.e., punchouts or patches) was very low, which translates into a very high remaining life, according to a statewide condition survey of CRC pavements in Texas (Ref 8, pp.79-80). Furthermore, the pavement was overlaid only to correct skid resistance or roughness problems.

OVERLAY THICKNESS DESIGN

The overlay thickness design depends on the remaining life of the existing pavement as well as on the pavement properties found with the testing results discussed in the previous chapter. The BCO was designed using two procedures: the AASHTO 1993 design method (Ref 3) and a mechanistic overlay design method called Texas Rigid Pavement Overlay Design (RPOD), which was incorporated into the Rigid Pavement Rehabilitation Design System (RPRDS, Ref 8) developed by the Center for Transportation Research (CTR). The AASHTO method is an empirical method, since some empirical factors must be identified to classify the pavement strata, climate, and drainage conditions. The RPRDS method is mechanistic/empirical: It makes use of elastic layer theory and regression equations developed through a finite element model. The empirical part of the procedure incorporates fatigue damage relationships developed from the AASHO Road Test in order to predict failure. A computer program developed by CTR, called BCOCAD (Bonded Concrete Overlay Computer Aided Design), was utilized for the design (Ref 9). This program calculates the overlay thickness by both methods simultaneously using a common set of inputs. The input variables can be classified into the following categories:

a) Materials Information for each layer
- Modulus of elasticity
- Flexural strength (PCC only)
- Poisson's ratio

b) Traffic Information
- Average daily traffic
- 80 kN ESALs, past and future
- Analysis period

c) Other Design Information
- Remaining life
- Roadway cross section (width and thicknesses)
- Reliability
- Serviceability

The following general design parameters were considered in developing the design:

Desired level of reliability	99.5%
Serviceability index	
After overlay construction	4.5
At the end of performance period	2.5
Performance periods	30, 40, and 50 years
Overall standard deviation	0.39

As for the existing pavement materials inputs, some considerations were made to come up with reasonable values accounting for the variations in thickness and tensile strength found in the data:

The thickness of the existing pavement varies substantially along the length of the project. Cores taken from the existing concrete showed a mean thickness of 19.855 cm with a standard deviation of 0.645 cm. Assuming a t-distribution with 19 degrees of freedom, (20 cores, n = 20 - 1 = 19), and a 99.5% reliability (a = 0.005), $t_{99.5}$ equals 2.861. Using this value, the thickness of the existing pavement to use in overlay design equals 19.855 - 2.861 * 0.645 = 18.00 cm.

No direct flexural strength tests were performed on the existing concrete. To determine this value, a correlation equation, proposed in Ref 3, was used to calculate S'_C from the splitting tensile strength, IT. The equation used is $S'_C = 1.45 + 1.02$ IT. Six cores were tested for splitting tensile strength. Values of flexural strength for the cores estimated with the previous correlation equation are shown in Table 3.4.

Table 3.4 Flexural strength estimation

Core Number	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
1	4.19	5.72
5	4.25	5.78
7	5.03	6.57
14	3.97	5.50
16	4.14	5.67
17	4.61	6.15

The correlated values of S'_C had a mean of 5.90 MPa with a standard deviation of 0.39 MPa. To perform a design with a 99.5% reliability using the RPRDS method, a 99.5% value of S'_C must be calculated. With six cores, the degrees of freedom, n, equal 5. The corresponding t value is $t_{99.5} = 4.032$. Using this value, the design flexural strength, S'_C, equals 5.90-(4.032)*0.39 = 4.31 MPa.

The design results for the 1993 AASHTO Design Procedure and the RPRDS method are shown in Table 3.5 and Figure 3.1. Appendix B contains an example of the BCOCAD output for the 50-year analysis period design.

Table 3.5 Overlay design

Performance Period (years)	Design thickness (cm)	
	1993 AASHTO Method	RPRDS Method
30	4.3	5.1
40	6.1	7.6
50	7.4	8.9

From these results, a 9-cm BCO with a 50-year performance period is believed to be the optimum selection for the Fort Worth pavement rehabilitation. The proposed cross section is presented in Figure 3.2. Figure 3.3 shows the proposed cross section for the new CRCP, in which the slab thickness (29 cm) matches the thickness of the rehabilitated section (20 cm of existing pavement, plus 9 cm of BCO).

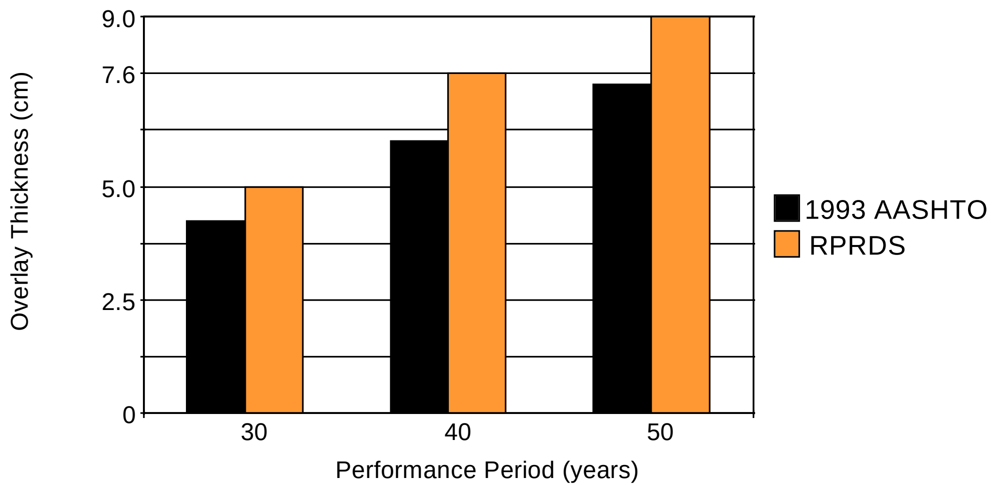

Figure 3.1 Overlay design

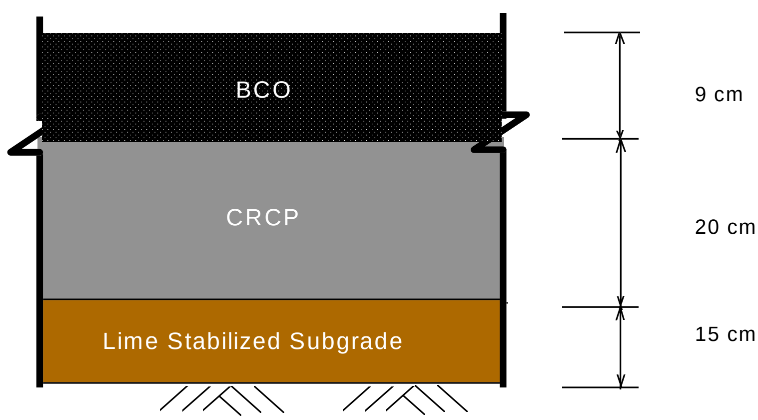

Figure 3.2 Proposed cross section for the BCO

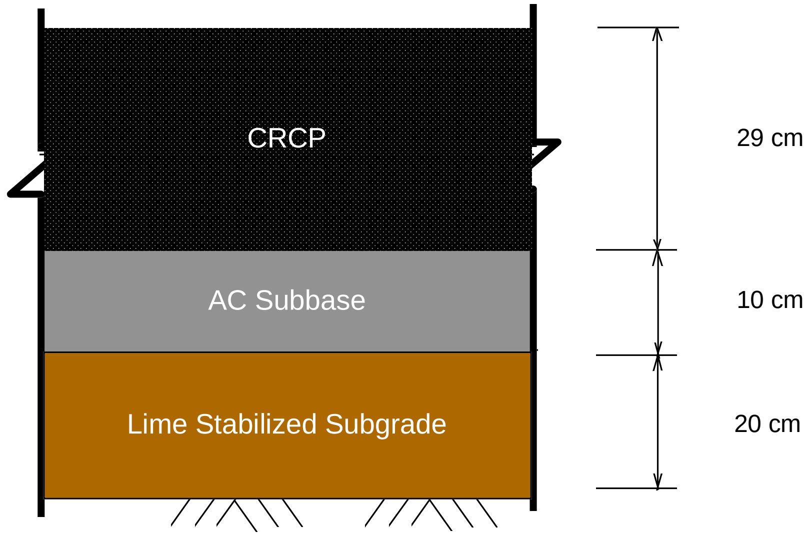

Figure 3.3 Proposed cross section for the new CRCP

REINFORCEMENT DESIGN

Longitudinal and transverse reinforcement, as well as tie bars for construction joints, were designed for the Fort Worth project. The design involves both the reinforcement for the bonded concrete overlay and the reinforcement for the new CRCP that will be built enclosing the existing depressed median, to facilitate the road widening. The steel design was performed using the analysis programs CRCP8 (Ref 10) and JRCP6 (Ref 11), developed by CTR, which calculate critical performance indicators such as steel stress, crack spacing, crack widths, and joint movement in the pavement for assumed loading conditions and design. The design was based on optimizing the performance indicators to provide a constructible pavement that will perform well over the design life. The following assumptions were made regarding required inputs for the analyses:

1. Construction is to be scheduled for the summer. The rationale behind this assumption is twofold: There is a probability that construction will actually happen in the summer, and a summer placement translates into the worst-case condition with regards to environmental loads on the pavement.

2. The concrete mix will contain limestone as coarse aggregate. This assumption is based on the aggregate availability in that region of Texas in which the project is located. The type of coarse aggregate in a mix determines several of the concrete properties relevant to design.

3. The annual minimum temperature was calculated using Fort Worth weather records for the past 25 years. The 99-percentile value for annual minimum temperature was calculated to be -18 °C. Maximum environmental stresses occur at the minimum temperature.

4. All the newly constructed portland cement concrete pavement (PCCP) will be 29-cm thick. The new CRCP will be 29-cm thick and will have a flexible subbase. The BCO will be 9-cm thick on top of the existing 20-cm CRCP, which in turn is supported by a lime-stabilized base.

The following are assumptions and input variables utilized for the reinforcement design:

Concrete Properties

Thickness:	29 cm
Elastic modulus (28 days)	33,090 MPa
Tensile strength (28 days)	3.72 MPa
Thermal coefficient	10.8×10^{-6}/°C
Drying shrinkage (28 days)	0.00032

Steel Properties

Elastic modulus	199,930 MPa
Yield strength	414 MPa
Thermal coefficient	9×10^{-6}/°C

Other Parameters

Subbase type:	flexible
Setting temperature:	50 °C
Minimum concrete temperature 3 days after set:	32, 29, 27 °C
Annual minimum temperature:	-18 °C

Two cases exist for transverse steel design: (1) the case in which there are two unconnected 14.6-m PCC slabs, meaning that both directions of the road are separated; and (2) in which the full 29.3-m section is connected. It is proposed that the two 14.6-m sections remain unconnected where possible, since this reduces the reinforcing in the new 29-cm CRCP and eliminates the tie bars at the center. The tie bars between the new 29-cm CRCP and the existing 20-cm CRCP are essential, however, and cannot be eliminated. These tie bars will keep the new pavement from shrinking away from the existing slab (preventing a dangerous and detrimental longitudinal gap) and will provide the necessary load transfer.

The PCC slab at the joint with the new asphalt shoulder is expected to move a maximum of 0.5 to 1 cm annually as it expands and contracts in summer and winter. It is advised that a joint sealant be specified between the asphalt and the PCC slab to prevent a gap from opening up that will allow water into the supporting structure of the pavement.

Sensitivity analyses of the longitudinal and transverse steel are presented below. Figure 3.4 relates crack spacing with longitudinal steel percent and bar number. The steel percent for this design was 0.6% and No. 6 bars were chosen. For that amount of steel and bar diameter, the mean crack spacing is around 1.6 m, which is within the allowable limits of 2.4 m (maximum crack spacing) and 1 m (minimum crack spacing), according to Ref 3. These crack spacing limits are established in order to minimize the incidence of crack spallings and the potential for the development of punchouts, respectively. The crack distribution diagram illustrating those limits is presented in Figure 3.5.

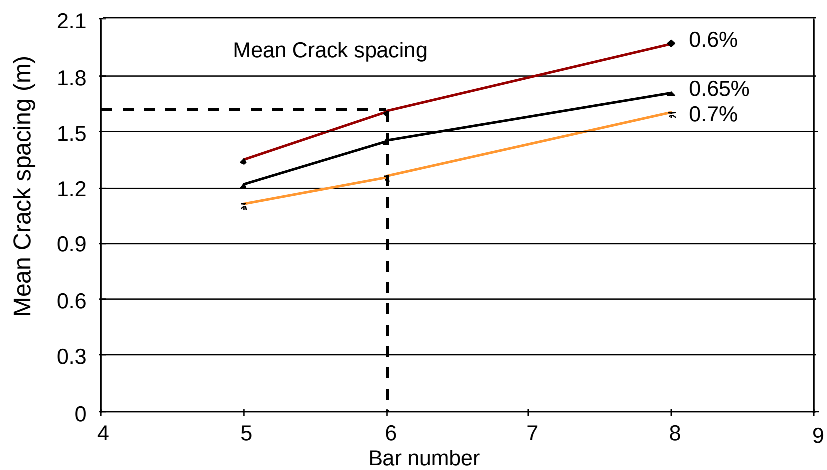

Figure 3.4 Longitudinal steel mean crack spacing sensitivity analysis

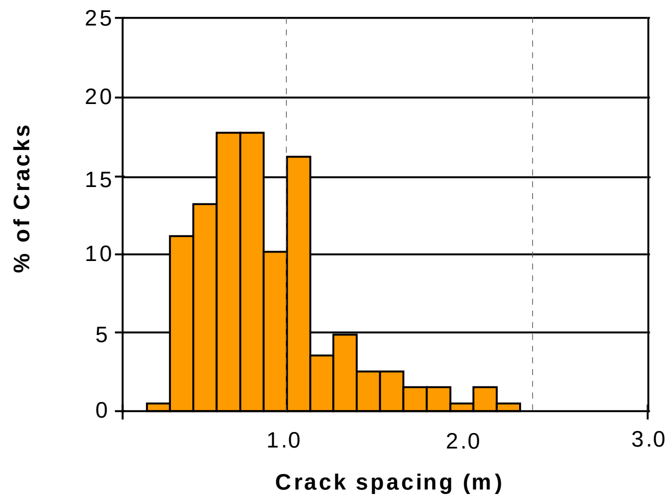

Figure 3.5 Crack distribution diagram

Figure 3.6 illustrates a relationship for the crack width and longitudinal steel stress with the bar number and percent of steel. The crack width, for 0.6% steel and No. 6 bars, is slightly above 1 mm, and the steel stress is 390 MPa, just within the allowable limit.

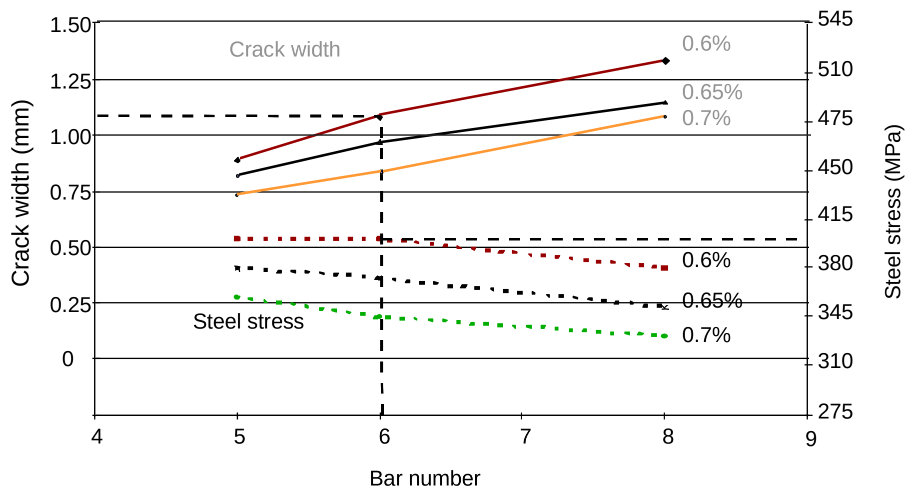

Figure 3.6 Longitudinal steel sensitivity analysis considering steel stress and crack width

Transverse steel designs are indicated on the transverse steel design chart (Fig 3.4), in which the tie bars and reinforcement are related by the encircled numbers to the details shown in the cross-section drawings that present the steel design results (Fig 3.5 and 3.6). In these figures, an alternative design is proposed for the longitudinal and transverse steel of the BCO, with D20 wire.

The following cross sections (Figs 3.7 and 3.8) illustrate both alternatives (29.3-m and 14.6-m sections), with the encircled numbers indicating the location of the transverse steel design shown in the sensitivity analysis chart (Fig 3.9).

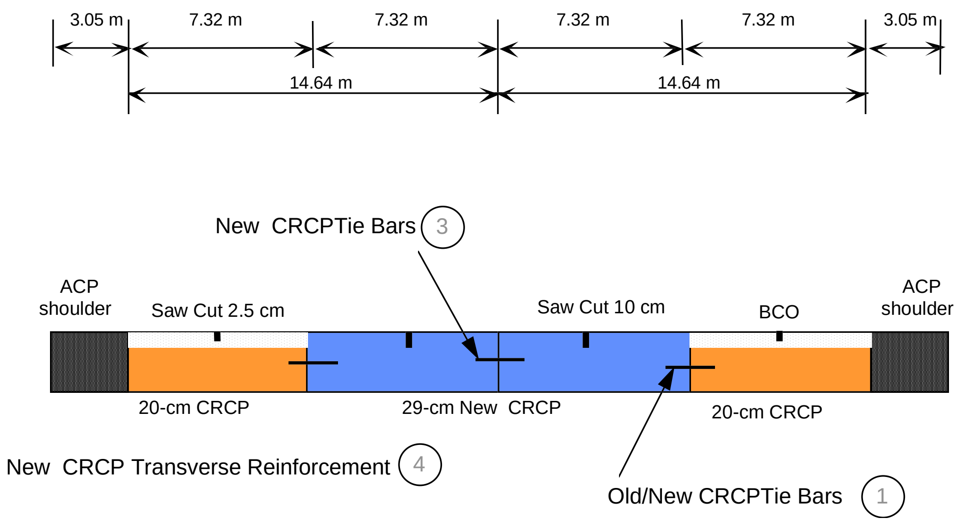

Figure 3.7 29.3-m section

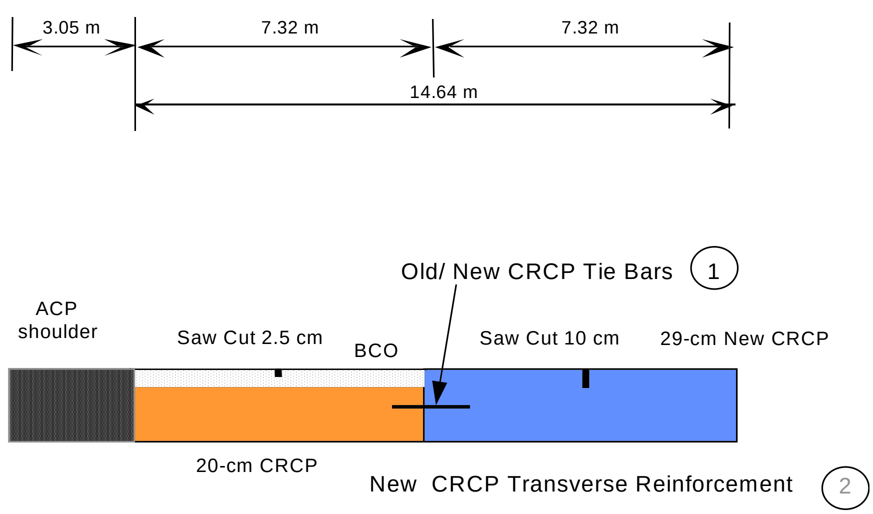

Figure 3.8 14.6-m section

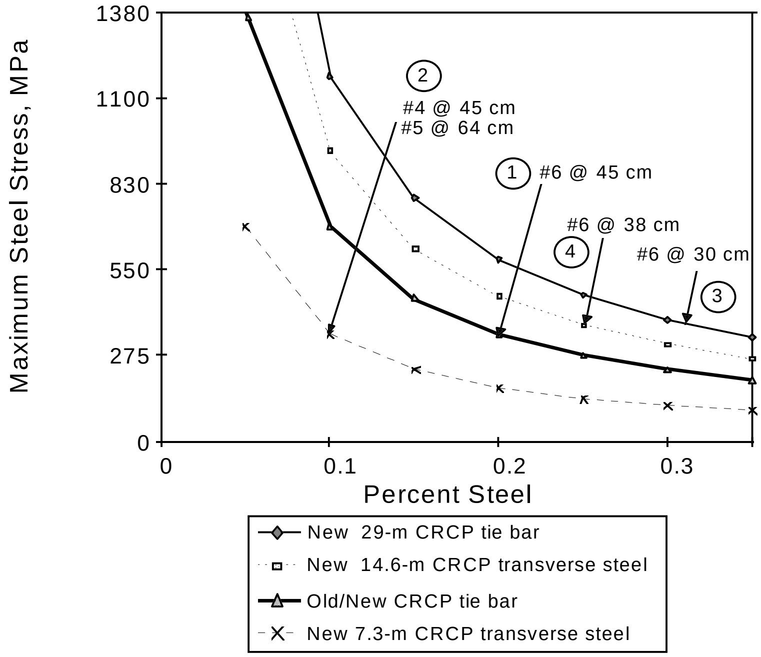

Figure 3.9 Transverse steel sensitivity analysis

Reinforcement Design Results

The reinforcement design results are presented in Figures 3.10 and 3.11.

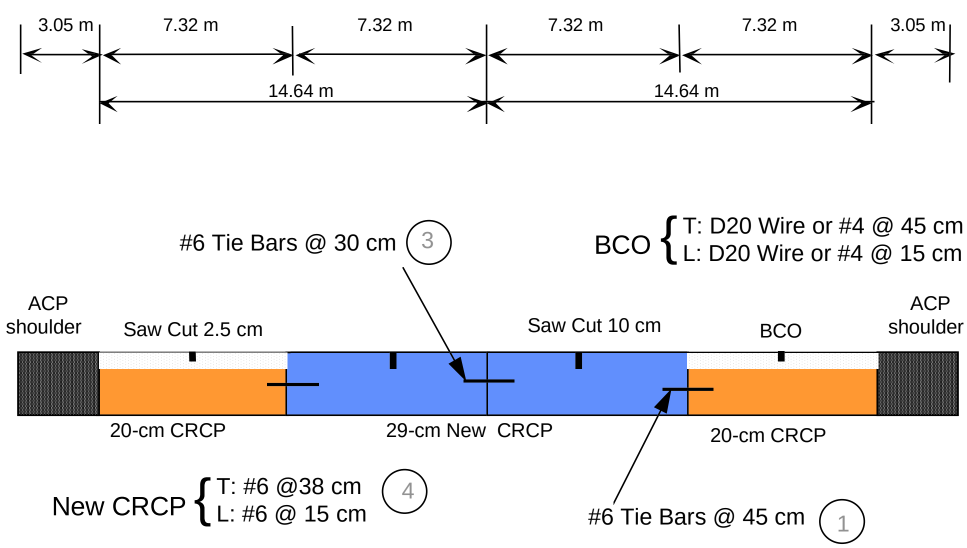

Figure 3.10 29.3-m section steel design results

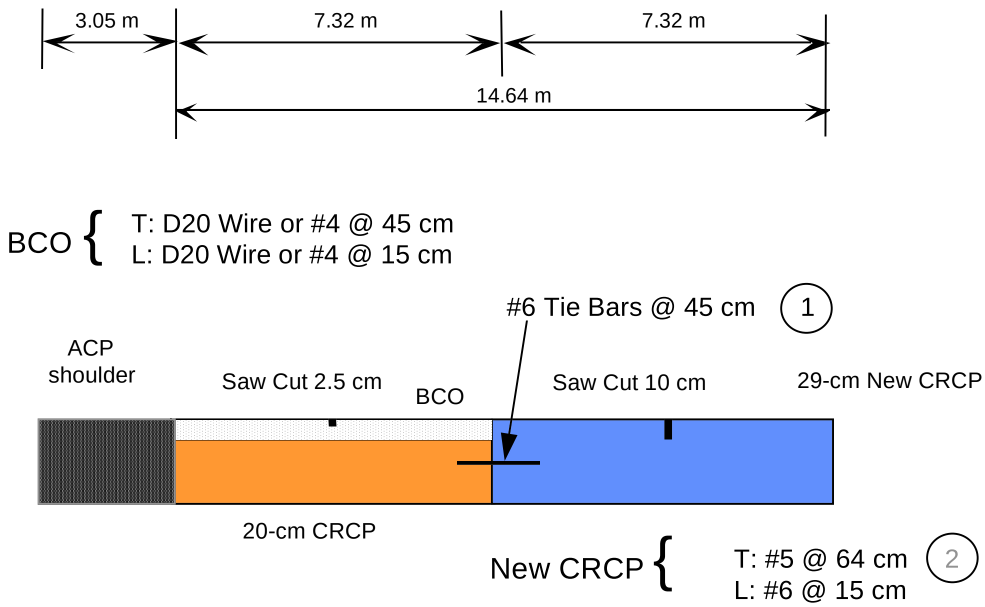

Figure 3.11 14.6-m section steel design results

Reinforcement Design Summary

Description	Tied 29.3-m Section		Independent 14.6-m Sections	
	Size	**Spacing**	**Size**	**Spacing**
BCO Transverse	#4 bars	45 cm	#4 bars	45 cm
BCO Longitudinal	#4 bars	15 cm	#4 bars	15 cm
New CRCP Transverse	#6 bars	38 cm	#5 bars	64 cm
New CRCP Longitudinal	#6 bars	15 cm	#6 bars	15 cm
Old/New CRCP tie bars	#6 bars	45 cm	#6 bars	45 cm
New CRCP tie bars	#6 bars	30 cm	-	-

SUMMARY

The proposed rehabilitation for the existing CRCP section consists of a bonded concrete overlay, which was selected over other alternatives because it permits a critical examination of expediting construction and, as a consequence, the road can be opened to traffic shortly after the BCO has been placed. Another reason for selecting a BCO is the existence of clearance problems, which are minimized by a BCO. The most important reason for selecting the BCO is that it can cost effectively extend pavement life, improve riding quality and load-carrying capacity, and, thus, protect infrastructure investment.

Traffic data were estimated from ADT and ESAL information provided by TxDOT. An annual growth of 1.45% was found for ESALs. Three different analysis periods were considered, namely, 30, 40, and 50 years. The remaining life of the pavement was estimated to be 80%.

Designs were performed following the AASHTO method and RPOD mechanistic method. A 9-cm-thick BCO is recommended, which corresponds to a 50-year performance period.

The reinforcement design was performed using the programs CRCP8 and JRCP6 for both the BCO and the new CRCP to be built to widen the road. There are two cases for the new CRCP steel design, one with both directions of the road in separate pavement structures (two 14.6-m-wide sections), and the other with a single structure (a 29.3-m-wide section).

CHAPTER 4. CONSTRUCTION PHASES

On urban highways serving heavy traffic — highways such as the IH-30 segment of this Fort Worth area project — any rehabilitation causes traffic interference and significant user-associated costs. In this project, the construction process becomes a foremost concern owing to the fact that it encompasses two major different activities: rehabilitation of existing pavement and expanding the capacity by widening the road. Accordingly, the construction process must be carefully planned to minimize traffic disturbance and reduce user-related costs.

The continuously reinforced concrete pavement (CRCP) rehabilitation design with a bonded concrete overlay (BCO), as described in the previous chapter, is one of the two major components of this project. The other part of the project consists in constructing new lanes. The road will be widened to the inside by enclosing the existing depressed median. One lane and one shoulder are to be built in each direction over the grassy area that currently is the median of the road.

The existing pavement is illustrated in Figure 4.1. Currently the roadway consists of two lanes in each direction, with an inside and an outside shoulder on each side. The widening will add 14.6 m to the width of the road, including two lanes and two shoulders.

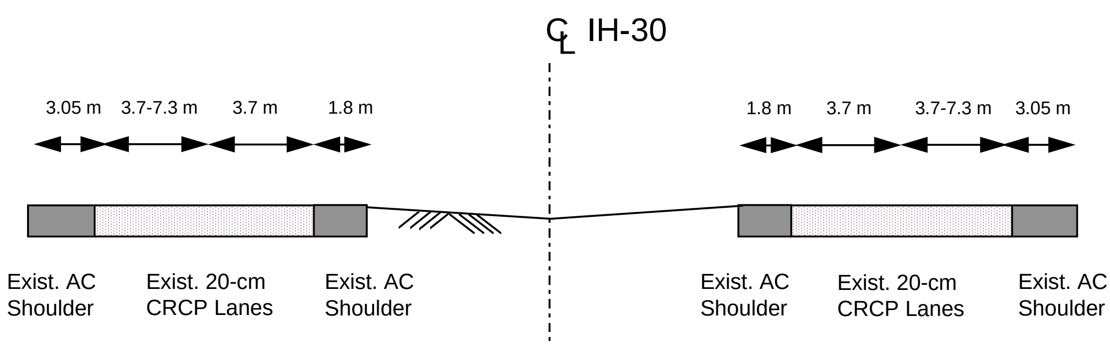

Figure 4.1 Existing pavement cross section

During the first phase of the project, the construction will take place in the median and on the inside shoulders of the road, where the new 29-cm CRCP will be constructed. The depressed median will be filled and a 20-cm-thick lime-treated subgrade will be constructed. The existing median slopes downhill towards the centerline of the highway with an approximate grade of 13:1. On top of the subgrade, a 10-cm-thick hot mix asphalt cement subbase and the 29-cm concrete slab will be built. The existing asphalt cement inside shoulders of the road will be removed to accommodate the new CRCP slab. Concrete traffic barriers will be placed at the edges of the inside lanes to separate the construction area from the lanes open to traffic. Traffic will be utilizing the existing main lanes and the outside shoulders. Such an arrangement will allow 9 m to be opened to vehicle travel in each direction (Fig 4.2).

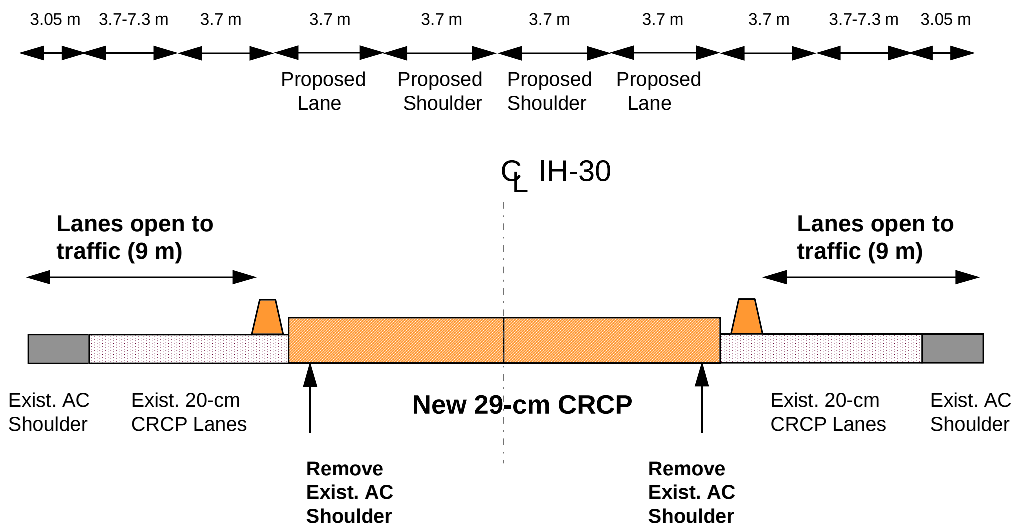

Figure 4.2 Phase I — Construction of median section

For the second phase of the project, the new CRCP in the middle will be finished and ready to accommodate traffic. Concrete traffic barriers will be placed at the edges of the new CRCP section to allow a 12-m section to be open to traffic. In this phase, the rehabilitation of the existing pavement will take place. The 9-cm-thick BCO will be placed over the existing 20-cm-thick lanes of CRCP. The outside ACP shoulders will be overlayed with asphalt to match the grade of the BCO (Fig 4.3).

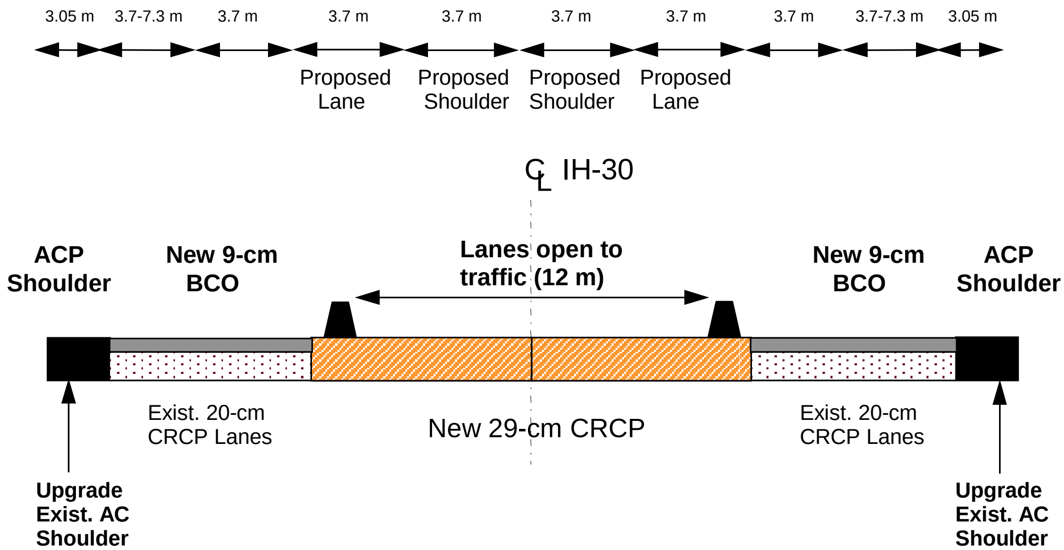

Figure 4.3 Phase II — BCO Construction

Traffic is scheduled to be placed back on the overlay shortly after it has been completed. The concept of an expedited overlay will play a major role in minimizing traffic disturbances. At the end of the construction work, the facility will have three main lanes in each direction, with inside and outside shoulders in both directions.

CHAPTER 5. COST ANALYSIS

The rehabilitation of an urban highway, such as the project section on IH-30 in Fort Worth, Texas, requires special attention to traffic disturbances and user-associated costs, owing to the high traffic volumes involved. In addition to evaluating the technical and economical feasibility of a bonded concrete overlay (BCO), another project objective is to turn traffic onto the BCO as soon as possible after placement to minimize user-related costs.

The project consists in widening the road and rehabilitating the existing pavement. For the widening phase, a new 29-cm continuously reinforced concrete pavement (CRCP) will be constructed, spanning up to 14.6, which will add one main lane in each direction and will widen the inside shoulders. The rehabilitation phase will be accomplished by a 9-cm BCO for the 7.3-m of existing main lanes in each direction. The resulting cross section will be a 14.6-m portland cement concrete pavement (PCCP) slab for each traveling direction. In certain areas, both directions will be joined to form a continuous 29.3-m PCCP cross section. The total project section length is 2.16 km. Five contractors bid on this freeway widening and overlay project. The bid letting took place on March 11, 1997.

In this chapter, a cost analysis based on the contractors' bids is presented. The analysis includes comparisons with similar projects in Texas. The cost analysis consists of the following components:

- Comparison of costs of equivalent designs of full-depth pavement and BCO on this project
- Comparison of costs with other BCO projects in El Paso and Houston
- Comparison of total costs during construction

REVIEW OF BIDS

Table 5.1 presents a summary of the total bids with the bidders sorted by total project cost. The tabulation of bids including all the items is presented in Appendix A. The TxDOT engineers' estimated cost used for comparison is $4,325,026.28. Costs and percentages presented in the "Total Over/Under" columns in Table 5.1 are calculated in reference to this cost.

Two of the contractors bid under the reference cost, while the remaining three contractors bid over it, although Bid No. 3 is just slightly above the reference cost as shown in Table 5.1. Appendix C presents a list with all the cost items of the project by contractor.

In that tabulation, it can be seen that the 29-cm CRCP is by far the most costly item of the project, accounting for up to 23.50% of the total project cost for bidder No. 2, and being around 20% of the total project cost for the other four contractors.

Table 5.1. Comparison of bidders prices

Bid Order	TxDOT Bid No.	Contractor	Total Project Cost	Total Over/Under Dollars	Percent
1	2	Champagne-Webber Inc.	3,979,431.35	-345,594.93	-7.99 %
2	4	Sunmount Corporation	4,095,315.07	-229,711.21	-5.31 %
3	3	Apac-Texas, Inc.	4,356,110.61	31,084.33	0.72 %
4	5	J. D. Abrams, Inc.	4,489,885.73	164,859.45	3.81 %
5	1	Site Concrete, Inc.	4,697,123.11	372,096.83	8.60 %

On the items that appear on the tabulation, there are some that may require an explanation, such as Item 360, "Concrete Pavement." There are several classes of concrete, each differentiated by such factors as the minimum cement content, the minimum splitting tensile strength at seven days, the maximum water cement ratio, and the coarse aggregate grade. The classes that are to be used in this project, according to the bids, are:

DCN: Dense bonded concrete overlay with no fibers
CON: Bonded concrete overlay with no fibers

For detailed specifications for each type of concrete, refer to the Special Provisions (Appendix A).

Item 360, "Concrete Pavement," bid price includes surface preparation with appropriate shot-blasting equipment. Hydrocleaning may be substituted for shot blasting, if the same surface quality can be attained.

The price tabulation in Appendix C shows that there are several different thicknesses for the bonded concrete overlay. Most of the BCO required for this project is 9-cm thick, which will be placed on the existing main lanes. However, there are some sections of 15-cm existing CRCP on ramps "L" and "M." These sections will be overlaid as well, but with a 14-cm BCO, to get a total thickness that matches that of the new 29-cm CRCP. Additionally, there is a small section on a bridge, which will require a 5-cm BCO.

Assumptions for Analysis of Bids

The comparison made here features the 9-cm BCO and the 29-cm new pavement, since this is the equivalent design concept. The 9-cm BCO will be placed on the existing main lanes, which consist of a 20-cm CRCP layer over a 15-cm lime-stabilized subgrade. Over the CRCP layer, there is an asphalt pavement layer with variable thickness: In some sections, it is comprised of a 7.6-cm base, a 3.8-cm asphalt layer, and a 2.5-cm plant mix seal, adding up to a 14-cm layer; in other sections it consists of a 5-cm asphalt concrete pavement layer only. In either case, these strata are going to be removed, and the BCO will be placed on top of the 20-cm CRCP. The equivalent design concept will yield the same CRCP thickness for the top layer for both cases: 29 cm for the new pavement and 29 cm for the rehabilitated section (20 cm of existing pavement plus 9 cm of BCO). This comparison does not consider by any means that the end products (the BCO and the new CRCP) are the same.

The comparison of the costs of the 9-cm BCO and the new 29-cm CRCP includes all the costs involved. These are shown in Table 5.2.

Table 5.2 Cost items involved in 9-cm BCO and 29-cm new CRCP

9-cm BCO		**29-cm CRCP**	
Item	**Description**	**Item**	**Description**
305	Salv. Haul & Stkpl Rcl	260	Lime Treat Subgr. (20 cm)
360	BCO	260	Lime (TY A Slurry or TY B)
361	Repair Exist Conc. Pav. (20 cm)	360	Conc. Pav. (Cont. Reinf. Hy Stl.) 29-cm
		3063	Hot Mix Asph. (TY D) Base
		305	Salv. Haul & Stkpl. Rcl.

Item 305 also applies to the 29-cm new CRCP, because there is an existing flexible base that has to be removed prior to the placement of the new pavement. This base is currently under the existing 1.8-m shoulder. It was assumed that the cost of removal of the asphalt pavement is the same as the cost of removing an ACP base, as there are no items that specify ACP base removal. Also, it was assumed that the ACP removal from 0 to 10 cm-deep (Item 305, code 503) applies to the existing ACP (for the 9-cm BCO construction), while the removal from 10 to 20 cm-deep (Item 305, code 523) applies to the existing base removal. It should be noted that these are only assumptions for the purpose of this analysis, and that they were made owing to the lack of more precise information regarding the relationship of each bid item with the BCO and the new CRCP. While many different assumptions could be made for this type of analysis, these were the ones that CTR considered appropriate when performing the cost comparison.

Because there are two classes of concrete (Item 360) to be used for the overlay and the new construction (with different amounts of each required), the costs are first calculated including both quantities and then one cost is calculated per unit, in this case, one cost per m^2. The same procedure is applied to all the items that include a group of various codes that have to be distributed over the total quantity of work required.

9-cm BCO Costs

The bid items for the BCO by bidder are presented in Table 5.3. All the bids received for the project are listed here.

Table 5.3 Costs for 9-cm BCO ($\$/m^2$)

Bid Items		Bidder				
Item	**Description**	**2**	**4**	**3**	**5**	**1**
305	Salv., Haul & Stkpl. ACP (0-10 cm)	1.68	2.29	1.68	1.60	1.71
361	Repair Existing CRCP (20 cm)	2.45	3.08	3.51	2.72	1.76
360	9-cm BCO	27.53	26.63	26.93	27.83	42.67
Total		31.66	32.00	32.12	32.15	46.15

29-cm CRCP Costs

The bid items for the new CRCP by bidder are presented in Table 5.4.

Table 5.4 Costs for 29-cm new CRCP ($\$/m^2$)

Bid Items		Bidder				
Item	**Description**	**2**	**4**	**3**	**5**	**1**
260	Lime Tr. Subgrade (20 cm)	1.38	3.58	2.20	2.35	2.00
260	Lime (TY A or TY B)	2.18	1.95	1.90	1.90	1.95
305	Salv., Haul & Stkpl. ACP (10-20 cm)	0.66	0.44	0.73	0.73	0.72
3063	ACP (TY D Underlayment)	8.21	9.36	8.15	8.15	8.38
360	29-cm CRCP	43.09	38.31	39.50	41.90	47.28
Total		55.52	53.64	52.49	55.03	60.33

Using the 9-cm BCO price as a reference, the differences between the total cost of the BCO and the new CRCP are shown in Table 5.5. Those differences range from 31 to 75%. It can be noted that, regarding the new CRCP, all the contractors bid a similar cost. The top four bidders are very close to one another.

Table 5.5 Comparison of 9-cm BCO and 29-cm CRCP costs ($\$ / m^2$)

	Bidder				
Description	2	4	3	5	1
Total Cost of 9-cm BCO ($\$/m^2$)	31.66	32.00	32.12	32.15	46.15
Total Cost of 29-cm CRCP ($\$/m^2$)	55.52	53.64	52.49	55.03	60.33
Cost of 29-cm CRCP with respect to 9-cm BCO Cost	1.75	1.68	1.63	1.71	1.31
Cost of BCO as % of New Pavement (%)	57	60	61	58	76

Comparison with El Paso Project

The CRCP bonded concrete overlay project in El Paso on IH-10 involved a new

CRCP construction as well as a BCO. Two contractors bid on this project in February of 1996. In this project, both new construction of 30-cm CRCP and the 16.5-cm BCO account for approximately the same quantities. A comparison of their costs satisfying the same design requirements was performed, in a way similar to that used in this analysis. The information from El Paso costs is included elsewhere (Ref 11). The results obtained for the El Paso project are summarized in Table 5.6.

Table 5.6 El Paso Project: Comparison of bidders prices ($\$/m^2$)

Pavement Type	Low Bid. Dan Williams	2nd Bid. Abrams Co.
16.5-cm BCO ($\$/m^2$)	38.44	56.64
New 30-cm CRCP ($\$/m^2$)	83.40	94.84
Cost of 30-cm CRCP with respect to 16.5-cm BCO Cost	2.17	1.67
Cost of BCO as % of New Pavement (%)	46.1	59.9

These costs include all the activities involved, such as the repair of the existing pavement for the BCO and the removal of old pavement and placement of the ACP base for the new pavement. The costs are distributed over the total amounts of BCO and new CRCP, respectively, required for the project.

In comparing these costs with the Fort Worth project, the low bidder's cost for the El Paso BCO ($\$38.44/ m^2$) is very similar to the BCO costs obtained for Fort Worth from all the contractors, while the second bidder's cost surpasses the costs of all the contractors for the Fort Worth project. Both prices for the El Paso new CRCP are very high when compared to those of the Fort Worth bidders.

COST OF TRAFFIC HANDLING

The approximate cost of traffic handling during construction was estimated, considering both the BCO and the new pavement construction. For this analysis, all the items related to traffic were included. These items and their associated costs for each bidder are presented in Table 5.7.

Table 5.7 Cost items related to traffic handling and cost by bidder

	Bid No.	2	4	3	5	1
Code	Activity	Cost ($)				
502	Barricades, Signs and Traf Handle	28,034.93	99,000.00	15,950.00	275,000.00	22,000.00
512	Port Conc Traf Bar	84,074.76	91,080.99	98,087.22	112,099.68	98,087.22
512	Port Conc Traf Bar (Remove)	2,547.72	2,972.34	4,246.20	2,547.72	4,246.20
514	Perm Conc Traf Barrier (Ty 2)	121,080.00	153,368.00	133,188.00	84,756.00	141,260.00
514	Perm Conc Traf Barrier (Ty 1)	5,880.00	7,980.00	6,930.00	4,620.00	6,930.00
514	Perm Conc Traf Barrier (Ty 3)	30,368.00	26,280.00	32,120.00	23,360.00	8,760.00
514	Perm Conc Traf Barrier (Ty 10)	47,265.00	68,500.00	143,850.00	82,200.00	67,130.00
514	Perm Conc Traf Barrier (Ty 10) (Spl)	110,600.00	79,000.00	114,550.00	94,800.00	66,320.50
662	Wrk Zn Pav Mrk Remov (W) (10 cm) (Sld)	11,340.00	12,150.00	12,150.00	13,500.00	12,420.00
662	Wrk Zn Pav Mrk Remov (W) (10 cm) (Brk)	7,440.00	8,370.00	7,905.00	5,580.00	7,905.00
662	Wrk Zn Pav Mrk Remov (W) (20 cm) (Sld)	2,371.50	2,371.50	2,529.60	2,635.00	2,635.00
662	Wrk Zn Pav Mrk Remov (Y) (10 cm) (Sld)	9,030.00	9,675.00	9,675.00	10,750.00	10,320.00
662	Wrk Zn Pav Mrk Non-Remov (W) (10 cm) (Sld)	1,596.00	1,710.00	1,710.00	2,052.00	2,052.00
662	Wrk Zn Pav Mrk Non-Remov (W) (10 cm) (Brk)	1,144.25	1,234.75	1,234.75	995.00	1,194.00
662	Wrk Zn Pav Mrk Non-Remov (W) (20 cm) (Sld)	1,050.00	1,050.00	1,137.50	700.00	1,050.00
662	Wrk Zn Pav Mrk Non-Remov (Y) (10 cm) (Sld)	3,002.00	3,160.00	3,318.00	3,160.00	3,160.00
662	Wrk Zn Pav Mrk Sh Trm Remov (W) (10 cm)	3,750.00	300.00	1,800.00	1,500.00	1,350.00
662	Wrk Zn Pav Mrk Sh Trm Remov (Y) (10 cm)	3,750.00	300.00	1,800.00	1,500.00	1,350.00
	Total	474,324.16	568,502.58	592,181.27	721,755.40	458,169.92

As the costs presented in the preceding table are total project costs, there is no distinction on what amounts of these costs are associated with the BCO and with the new CRCP. Because of that, the total costs are distributed according to the total amounts of BCO and CRCP to be built in the project. It is understood that widening a pavement and a pavement rehabilitation with a BCO involve different traffic control procedures and activities; therefore, this cost distribution may not be as precise as desired, but with the information that CTR has on the bidders prices, this was considered to be a good approach for this analysis. Also, it should be acknowledged that this cost distribution leads to a conservative comparison.

It was found that the BCO accounts for 56% of the project while the CRCP accounts for 44%. This distribution is made according to the number of m^2 of BCO (32,018 m^2) and CRCP (25,226 m^2). With these percentages, the cost of traffic handling is equally weighted between the BCO and CRCP, and the results are presented in Table 5.8. In this table, the cost of traffic handling is presented as if all of it corresponded to the new pavement construction exclusively.

Table 5.8 Cost of traffic handling distributed between BCO and CRCP

Bid No.	**2**	**4**	**3**	**5**	**1**
Total Cost of Traffic Handling ($)	474,324.16	568,502.58	592,181.27	721,755.40	458,169.92
BCO (56%) ($)	265,621.53	318,361.44	331,621.51	404,183.02	256,575.16
New CRCP (44%) ($)	208,702.63	250,141.14	260,559.76	317,572.38	201,594.76
Traffic Handling – equally weighted ($ / m^2)	8.28	9.94	10.34	12.60	8.01
Traffic Handling – New Pavement ($/$m^2$)	18.81	22.54	23.47	28.61	18.16

Bidder 5 provided a cost of traffic handling that exceeds that of the other bidders by at least 18%. Furthermore, Bidder 5 had the highest proportion of its bid allocated to traffic handling when compared to those of the other bidders, as shown in Table 5.9.

Table 5.9 Percentage of traffic handling cost from total project cost

Bid No.	**2**	**4**	**3**	**5**	**1**
Cost of Tr. Handling / Total Project Cost	12%	14%	14%	16%	10%

Bidder 1 has the lowest cost of traffic handling per m^2, even though it is the highest bidder for the whole project; therefore, it has the lowest percent of cost allocated to traffic handling activities among all bidders.

Comparison with Houston Project

A similar traffic handling cost analysis was performed for three of the contractors bidding on the IH-610 BCO project in Houston, from US 288 to IH-45, in November of 1988 (Ref 12). Table 5.10 contains a summary of the traffic handling costs for this project.

Table 5.10 Houston project: Traffic handling cost

Bidder	**Lowest**	**2nd Lowest**	**3rd Lowest**
Traffic Handling ($ / m^2)	5.35	4.94	4.50

The costs for traffic handling in Fort Worth are slightly more than twice the costs for such handling in Houston. This differential may result from the fact that the Houston project covered considerably more surface area for spreading the traffic handling cost.

DISCUSSION OF RESULTS

This project presents the opportunity of comparing the cost of a BCO with that of a new pavement. Moreover, the 9-cm BCO over an existing 20-cm CRCP will represent a thickness equivalent to that of the new 29-cm CRCP, thus characterizing the equivalent design concept.

The construction of the new 29-cm CRCP is the most costly item of the entire project according to its cost. This finding is obtained from just looking at the tabulation of bids shown in Appendix C, without adding items that may be considered together as a single item. For all the bidders, that item represents at least 20% of the total cost of the project.

The new pavement generally costs from 31% to 75% more than the BCO, with the lowest bidder having the highest difference between them (75%), and the highest bidder having the smallest differential (31%). Regarding the new CRCP, all of the contractors had very similar bids.

A similar comparison was made on the El Paso project, which had only two bidders. Both prices for the El Paso new CRCP were high when compared to those of the Fort Worth bidders. One of the El Paso bidders, the lowest, came up with a very similar cost per m^2 of BCO to those costs presented by the Fort Worth bidders. However, the second bidder for El Paso had a cost higher than any of those proposed by the Fort Worth bidders.

A traffic handling costs analysis was performed. Traffic handling represents from 10% to 16% of the total project cost, according to the bidders. The cost of traffic handling varies from \$8.01 / m^2 to \$12.60 / m^2. These costs were compared to those obtained in a similar study for a project in Houston in 1988. The traffic handling costs for Fort Worth are approximately twice as high as those calculated for that project in Houston. This difference could be attributed to the time gap between the projects.

Another interesting scenario is that which recognizes the potential cost saving that could accrue by allowing the traffic on the BCO within 12 hours after placement. This is the case for the Fort Worth project, and since the BCO will be placed over six successive weekends, the traffic handling costs may be assumed to be primarily related to the new CRCP construction, rather than to the BCO. Table 5.11 was prepared to compare two scenarios: the first one with the costs being equally distributed, and the second one with all the costs being assigned to the new construction.

Table 5.11 Pavement cost adjusted for traffic handling cost

Case	Description	Bidder				
		2	4	3	5	1
1	Total Cost of 9-cm BCO + Traffic Handling ($ / m^2)	33.38	35.02	35.48	37.39	45.23
	Total Cost of 29-cm CRCP+ Traffic Handling ($ / m^2)	53.31	53.11	52.50	56.51	57.09
	BCO as percent of New CRCP	63%	66%	68%	66%	79%
2	Total Cost of 9-cm BCO ($ / m^2)	26.45	26.72	26.83	26.86	38.54
	Total Cost of 29-cm CRCP+ Traffic Handling ($ / m^2)	62.09	63.64	63.47	69.88	65.57
	BCO as percent of New CRCP	43%	42%	42%	38%	59%

The Case 2 data demonstrate that up to a 62% (57% for the low bidder) savings could be expected for expediting the concrete overlay. This value does not cover the user costs, which would increase the difference. An expedited BCO is expected to significantly reduce the user costs when compared to the case in which the road is blocked during the whole week throughout the overlay construction period.

SUMMARY

The data presented in this chapter support the following conclusions:

As shown in Table 5.5, the direct unit cost comparison shows the BCO costs about 60% of the equivalent new design, i.e., a 40% savings. If the expedited concept is recognized for the overlay, then the BCO is only 43% of the equivalent new pavement cost, i.e., a 57% savings.

1. The costs for the previous BCO projects in Houston and El Paso are similar to those of the Fort Worth project.
2. The traffic handling costs for the Fort Worth project as a percent of the total job cost are larger than those of the Houston project, but this may be attributed to the smaller project quantities.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this project was to evaluate the technical and economical feasibility of an expedited BCO on IH-30 in Fort Worth.

To determine the feasibility of the proposed rehabilitation procedure, the researchers conducted field and laboratory tests as an essential step before design. Deflections measured with the FWD allowed the backcalculation of the structure's layer properties. The deflection test showed good pavement performance, thus indicating that the pavement structure is an appropriate candidate for a BCO rehabilitation. Concrete cores were extracted from the pavement to be tested for modulus of elasticity, splitting tensile strength, thermal expansion, and compressive strength. The next step towards the final design was the traffic analysis. ESALs were estimated from the information provided by the District. The remaining life of the existing pavement estimated from the traffic analysis was 80%.

Overlay designs were performed following the AASHTO method and RPRDS mechanistic method. As a result of the design a 9-cm thick overlay is recommended.

The economical adequacy of a BCO was studied. A full-depth reconstruction of the pavement will cost 1.3 to 1.7 times more than a BCO, without considering user-related costs.

A BCO was found to be a feasible rehabilitation alternative for the Fort Worth project, both technically and economically.

It is strongly recommended that climatic conditions be verified before scheduling the Fort Worth overlay. Special caution should be taken to avoid overlay construction during periods in which daily temperature variations and evaporation rates could be detrimental to the future overlay performance. Evaporation rates during construction should be limited to less than 1 kg/m^2/hr. Evaporation rates greater than this value lead to the development of plastic shrinkage cracks in fresh concrete. The maximum allowable daily temperature variation for the day following the concrete placement should be 14 °C (Refs 1 and 3). When the weather forecasts indicate that the variation is likely to be greater, the overlay should not be placed, or special curing precautions should be taken. The Portland Cement Association has developed a nomograph to calculate the water evaporation rate from freshly placed concrete (Ref 13).

Opening the road to traffic shortly after it has been overlaid will contribute to the reduction of user costs. To make this possible, a necessary condition that must be met is full bonding of the BCO to the underlying layer (Ref 14). The concrete should gain its normal strength at an accelerated rate; accordingly, the use of accelerating admixtures is advised.

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APPENDIX A:

SPECIAL PROVISIONS

SPECIAL PROVISION
TO
ITEM 360
CONCRETE PAVEMENT

For this project, Item 360, “Concrete Pavement” of the Standard Specifications is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Article 360.1. Description is voided and replaced by the following:

360.1 Description. This Item shall govern for the construction of bonded concrete pavement overlay with or without monolithic curbs on a previously placed concrete pavement in accordance with the typical sections shown on the plans, the lines and grades established by the Engineer and the requirements herein.

Article 360.3 Materials, Subarticle (1) Portland Cement Concrete. The first paragraph is voided and replaced by the following:

(1) Portland Cement Concrete. Classification and mix design shall conform to Class “CON,” Class “COP,” Class “COS,” Class “DCN,” Class “DCP,” or Class “DCS” portland cement concrete as defined in Item 421, “Portland Cement Concrete,” unless otherwise shown on the plans.

Article 360.3. Materials. is supplemented by the following :

(7) Steel Fiber. The steel fibers shall be Bekaert Dramix ZC 60/80 applied at the rate shown on the plans.

(8) Polypropylene Fiber. 1.5 in collated, fibrillated, polypropylene fibers manufactured by Forta CR or equal applied at the rate shown on the plans..

(9) Evaporation Retardant. The evaporation retardant shall be Master Builders Confilm or equivalent.

Article 360.4. Equipment is supplemented by the following:

(15) Existing Concrete Pavement Surface Preparation Equipment. Shot blasting equipment shall be power-operated and shall be capable of propelling steel shot against the pavement surface in a uniform manner so that the entire concrete surface is uniformly prepared. The shot blasting equipment shall include means of collecting used shot, which may be reused, and of collecting and disposing of dust. The shot blasting equipment shall be capable of removing all dirt, oil, paint, membrane cure compound, and other foreign material, as well as any laitance or loose concrete from the surface on which the new concrete is to be placed. Hydrocleaning equipment may be substituted for shot blasting equipment providing the required surface texture and cleanness can be achieved.

Article 360.5 Quality of Concrete. is amended as follows:

All references to Flexure Strength are changed to Splitting Tensile Strength.

Article 360.6. Subgrade, Subbase and Forms, Subarticle (1) Preparation of Subgrade or Subbase is supplemented by the following:

Where the existing concrete pavement is covered by an existing asphalt overlay, it must be removed by rotomilling. All asphalt must be removed prior to shotblasting or hydrocleaning. Where shown on the plans, the entire existing concrete pavement surfaces to overlay with bonded concrete pavement shall be prepared by shot blasting or hydrocleaning. All dirt, oil, paint, membrane cure compound, laitance and loose concrete shall be removed from the existing surface. The size shot used in shot blasting shall be appropriate for blasting concrete. All foreign material remaining on the existing concrete pavement after operating the shot blasting equipment shall be removed by sweeping, air blasting or other methods approved by the Engineer. The entire surface shall be air blasted just prior to the paving operation.

To minimize the possibility of contamination of the cleaned surface, the bonded concrete paving operation shall begin within twenty-four (24) hours following the shot blasting or hydrocleaning operation unless otherwise directed by the Engineer. If for any reason the cleaned surface becomes contaminated, reblasting or recleaning shall be required.

The surface texture of the cleaned, blasted concrete pavement shall have a minimum texture depth of 0.08 in as measured by Test Method Tex 436-A. The number and location of the tests will be as directed by the Engineer.

Article 360.8. Concrete Mixing and Placing, Subarticle (3) Placing is supplemented by the following:

At those times when the evaporation rate exceeds 0.2 lb /ft^2/hour for a period of time as specified by the Engineer, or greater than 20 minutes, measures shall be taken to control the moisture content of the newly placed bonded concrete overlay. Fogging, wet mat curing, or other approved methods shall be used to control the moisture content. The entire day's placement shall be protected and the protection shall remain in place for 36 hours or until such time as directed by the Engineer. These measures are in addition to the membrane curing required.

At those times when the evaporation rate exceeds 0.1 lb /ft^2/hour but is less than 0.2 lb /ft^2/hour for a period of time as specified by the Engineer, or greater than 20 minutes, measures shall be taken to control the moisture content of the newly placed bonded concrete overlay. Evaporation retardant shall be applied in accordance with manufacturer’s recommendations after paving but before application of membrane curing to control the moisture content. The entire day's placement shall be protected and the protection shall remain in place for 12 hours or until such time as directed by the Engineer. Wet mats or fogging may be used instead of the evaporation retardant. These measures are in addition to the membrane curing required.

At those times when the difference in the ambient temperature at the time of placement versus the expected low temperature in a 24-hour period is expected to exceed 26°F, special measures shall be taken. The bonded concrete overlay shall be placed no later than 12 o'clock noon the preceding day or a minimum of 18 hours prior to the time the maximum temperature difference is expected. At those times when the difference in the ambient temperature at the time of placement verses the expected low temperature in a 24-hour period exceeds 26°F, the entire day's placement shall be protected by wet mat curing or other methods approved by the Engineer. The protection shall remain in place for a minimum of 36 hours, or until such a time as directed by the Engineer.

The Contractor will not be restricted from paving at night.

The temperature of all paving concrete shall not exceed 84°F when placed.

There shall be no free water on the surface of the existing concrete at the time of the placement of the concrete for the bonded overlay pavement.

Article 360.11. Curing, Subarticle (3) Membrane Curing. is voided and replaced by the following:

(3) Membrane Curing. After final finish and immediately after the free surface moisture has disappeared, the concrete surface shall be sprayed uniformly with a Type 2, Class A curing compound in accordance with Article 526.5 except that the membrane curing compound shall be applied in two applications of approximately 240 square feet per gallon each. A metering device to measure the rate of application shall be required. Should the membrane be damaged from any cause before the expiration of 72 hours after the final application, the damaged portions shall be repaired immediately with additional compound.

Special care shall be taken to ensure that the sides of the tining groves are coated with curing compound.

Article 360.12. Protection of Pavement and Opening to Traffic, Subarticle (2) Opening Pavement to Traffic. is voided and replaced by the following:

(2) Opening Pavement to Traffic. The pavement shall be closed to all traffic, including vehicles of the Contractor, until the last concrete placed is at least twelve (12) hours old and has been determined to meet a splitting tensile value of at least 500 psi.

At the end of this period the pavement may be opened for use by vehicles of the Contractor or the public. Such opening, however, shall in no manner relieve the Contractor for his responsibility for the work in accordance with Item 7, "Legal Relations and Responsibilities to the Public." On those sections of the pavement to be opened to traffic, all joints shall first be sealed and the pavement cleaned. Unless otherwise shown on the plans, stable material shall be placed against the pavement edges before permitting vehicles thereon.

SPECIAL PROVISION
TO
ITEM 421
PORTLAND CEMENT CONCRETE

For this project, Item 421, Portland Cement Concrete of the Standard Specifications is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Table 1, Coarse Aggregate Gradation Chart is supplemented by the following:

Grade 9:

Sieve Size	Percent Retained on Each Sieve
1 in	0
3/4 in	0-6
1/2 in	12-30
3/8 in	61-73
No. 4	69-75
No. 8	74-98

Table 3, Slump Requirements, A. Structural Concrete (3) Slabs, Concrete Overlay, Caps, Columns, piers, wall sections over 9 in, etc., and (6) Dense concrete overlay, are voided.

Table 4 , Classes of Concrete is changed as follows: Class CO and DC are voided and replaced by the following:

Class of Concrete: CON
Cement Content, Minimum: 656 lb/yd^3
Splitting Tensile Minimum Seven-Day Strength: 640 psi
Maximum Water Cement Ratio: 0.35
Coarse Aggregate Grade: 5
General Usage: Bonded Concrete Overlay With No Fibers

Class of Concrete: COP

Cement Content, Minimum: 656 lb/yd^3

Splitting Tensile Minimum Seven-Day Strength: 640 psi

Maximum Water Cement Ratio: 0.35

Coarse Aggregate Grade: 5

General Usage: Bonded Concrete Overlay Containing Polypropylene Fibers

Class of Concrete: COS

Cement Content, Minimum: 656 lb/yd^3

Splitting Tensile Minimum Seven-Day Strength: 640 psi

Maximum Water Cement Ratio: 0.35

Coarse Aggregate Grade: 9

General Usage: Bonded Concrete Overlay Containing Steel Fibers and Polypropylene Fibers

Class of Concrete: DCN

Cement Content, Minimum: 823 lb/yd^3

Splitting Tensile Minimum Seven-Day Strength: 719 psi

Maximum Water Cement Ratio: 0.32

Coarse Aggregate Grade: 5

General Usage: Dense Bonded Concrete Overlay With No Fibers

Class of Concrete: DCP

Cement Content, Minimum: 823 lb/yd^3

Splitting Tensile Minimum Seven-Day Strength: 719 psi

Maximum Water Cement Ratio: 0.32

Coarse Aggregate Grade: 5

General Usage: Dense Bonded Concrete Overlay Containing Polypropylene Fibers

Class of Concrete: DCS

Cement Content, Minimum: 823 lb/yd^3

Splitting Tensile Minimum Seven-Day Strength: 719 psi

Maximum Water Cement Ratio: 0.32

Coarse Aggregate Grade: 9

General Usage: Dense Bonded Concrete Overlay Containing Steel Fibers and Polypropylene Fibers

Article 421.2 (7) Materials. Admixtures. is supplemented by the following:

High range water reducer shall be permitted.

Article 421.8. Classification and Mix Design. is supplemented by the following:

Classes of Concrete CON, COP, COS, DCN, DCP, and DCS shall be designed to entrain 4% to 6% air regardless of the grade of coarse aggregate used.

Article 421.9 Quality of Concrete is supplemented by the following:

Unless otherwise directed by the Engineer, 4 in diameter by 8 in high cylinders will be required for testing splitting tensile specimens. The splitting tensile test values will be determined according to ASTM C496 Splitting Tensile Strength of Cylindrical Specimens.

Concrete in Classes CON, COP, and COS shall have a thermal coefficient less than 5.5×10^{-6} /°F when tested according to Corps of Engineers Test Method for Coefficient of Linear Thermal Expansion CRD C 39-81. The following additional requirements shall also apply:

Steel studs shall be cast into specimens for determining length measurements.
Specimens shall have a minimum dimension at least three times the nominal size of the coarse aggregate.
Specimens shall have a minimum aspect ratio of 2:1.
Specimens shall be tested in a dry condition after curing a minimum of 28 days.

APPENDIX B:

EXAMPLE OF BCOCAD OUTPUT FOR THICKNESS DESIGN

The following is an example of BCOCAD output for the 50-year design. All other design inputs were held constant for other performance periods.

```
************************************************************************
*         BONDED  CONCRETE  OVERLAY  COMPUTER  AIDED  DESIGN           *
*                        VERSION 1.0 alpha #2                          *
*======================================================================*
*                             WRITTEN BY                               *
*                    ROBERT OTTO RASMUSSEN, E.I.T.                     *
*                                FOR                                   *
*               THE CENTER FOR TRANSPORTATION RESEARCH                 *
*                    UNIVERSITY OF TEXAS AT AUSTIN                     *
*                           AUSTIN, TEXAS                              *
*                         PROJECT NUMBER 2911                          *
*======================================================================*

************************************************************************
* PLEASE BE ADVISED THAT NO WARRANTY IS MADE BY TEXAS DEPARTMENT OF    *
* TRANSPORTATION, CENTER FOR TRANSPORTATION RESEARCH, OR THE AUTHOR(S) *
* AS TO THE ACCURACY, COMPLETENESS, RELIABILITY, USABILITY, OR         *
* SUITABILITY OF THE COMPUTER PROGRAM, ITS DATA, AND DOCUMENTATION. NO *
* RESPONSIBILITY IS ASSUMED BY THE ABOVE PARTIES FOR INCORRECT RESULTS *
* OR DAMAGES RESULTING FROM THE USE OF THE PROGRAM.                    *
************************************************************************

*********************
MATERIALS INFORMATION
*********************

General Materials Information -
Standard Deviation: .39
Loss of Subbase Support:  .00
Coefficient of Drainage: 1.000

Overlay Materials Information -
Modulus of Elasticity (Eol) (psi):  5000000.
  Entered Directly
Poisson's Ratio: .15
Flexural Strength (S'c) (psi):  850.
  Entered Directly

Existing Pavement Materials Information -
Modulus of Elasticity (Epv) (psi): 3990000.
  Entered Directly
Poisson's Ratio: .15
Flexural Strength (S'c) (psi):  *** varies ***
Critical Stress Factor: 1.25
Concrete Stiffness after Cracking (psi):  800000.

Subbase Materials Information -
Modulus of Elasticity (Esb) (psi):   59464.
Poisson's Ratio: .40
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Subgrade Materials Information -
 Resilient Modulus (Mr) used to determine subgrade quality
 Resilient Modulus (Mr) (psi): 26948.
 Poisson's Ratio: .45

 *******************
 TRAFFIC INFORMATION
 *******************

 Traffic Specific Information -
 Initial AADT:  58800.
 Annual Growth in AADT (%):  1.450
 18kip ESALs:   45754460. (Cumulative over 50 years)
   In Single Direction, All Lanes
   Year 1 ESALs in Both Directions =      970000.
   Cumulative ESALs over Design Life for Design Lane =    18301780.
 Annual Growth in 18kip ESALs (%):  1.450
 Directional Split (%): 65.0
 Lane Distribution Factor (%): 40.0

Time Specific Information -
 Analysis Period (yrs): 50.0
 Maximum Allowable Years of Heavy Maintenance After
          Loss of Structural Load-Carrying Capacity:  4.0

 *****************************
 EXISTING PAVEMENT INFORMATION
 *****************************

 General Design Information -
 Project Description:
  BONDED CONCRETE OVERLAY
  PROJECT 572
  FT. WORTH, TEXAS
 Project Location:
  IH-30 FROM IH-820 TO LAS VEGAS TRAIL

 Roadway Geometry -
 Number of Lanes: 4.
 Project Length (miles):    .80
 Lane Width (feet): 12.00
 Shoulder Width (feet): 10.00

 Roadway Condition -
 Number of Existing Defects per Mile:   5.
 Cost of Repair per Defect ($): 2000.00
 Rate of Defect Development (#/mile/yr):  2.
 Remaining Life Factor Used to Determine Pavement Condition
 Remaining Life (%):  80.00

 Roadway Cross Section -
 Thickness of Existing Pavement (inches):  7.09
 Thickness of Subbase (inches):  6.00
 Depth of Subgrade (feet): Semi-Infinite
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Load Transfer Efficiency Used to Determine Load Transfer
Load Transfer Efficiency (%):  98.50
Pavement Type: CRCP
Shoulder Type: ACP
Shoulder Load Transfer: No

************************
OTHER DESIGN INFORMATION
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Reliability (%): 99.500
Initial Serviceability (Po): 4.50
Terminal Serviceability (Pt): 2.50

**********************
GEOGRAPHIC INFORMATION
**********************

City Name: Dallas/Ft. Worth

Average Temperatures -
January  : 46.0
February : 49.0
March    : 56.0
April    : 66.0
May      : 74.0
June     : 82.0
July     : 86.0
August   : 86.0
September: 78.0
October  : 68.0
November : 56.0
December : 48.0

Average Temperature Range -
January  : 20.00
February : 20.00
March    : 22.00
April    : 21.00
May      : 20.00
June     : 20.00
July     : 20.00
August   : 21.00
September: 21.00
October  : 22.00
November : 22.00
December : 20.00

Solar Radiation -
January  :  425.
February :  503.
March    :  628.
April    :  777.
May      :  893.
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June     :  963.
July     :  979.
August   :  944.
September:  856.
October  :  726.
November :  575.
December :  460.

Wind Speed -
January  : 11.10
February : 11.80
March    : 13.20
April    : 13.20
May      : 12.00
June     : 11.60
July     : 10.10
August   :  9.60
September:  9.70
October  :  9.80
November : 10.60
December : 11.00

Latitude (degrees):  32.833
Longitude (degrees):  96.950
Elevation (feet):  489

************************
THICKNESS DESIGN RESULTS
************************

1993 AASHTO Design Thickness (inches):  2.9
BCOPRDS Design Thickness (inches):  3.5
```

APPENDIX C:

TABULATION OF BIDS