Evaluation and Rehabilitation Design of I-495 in Delaware

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In 1991 the Delaware Department of Transportation initiated a comprehensive study to evaluate the performance of a portion of the Delaware Interstate highway system (including the turnpike). The highway systems evaluated included I-495 and associated ramps, including ramps to and from I-495 and I-295. A primary objective of the evaluation was to develop maintenance and rehabilitation strategies for the studied pavements. The pavements consisted of 228.6-mm (9-in.)-thick continuously reinforced concrete (CRC) pavement along most of I-495 and 254-mm (10-in.)-thick jointed reinforced concrete (JRC) pavement along the remaining portion of I-495 and the ramps. A major concern with the pavements of I-495 was the extensive occurrence of alkali-silica reactivity (ASR) and extensive joint deterioration along many of the jointed pavements. As part of the evaluation process, a field investigation was conducted to determine the current condition of I-495 and the associated ramps. The field investigation consisted of visual condition survey, nondestructive deflection testing with a falling-weight deflectometer (FWD), coring and boring, and laboratory testing. The field and laboratory data were evaluated to identify the current condition of the pavements, considering the widespread existence of ASR. The manifestation of the ASR along the CRC pavement was in the form of longitudinal cracking, that is, parallel cracks spaced generally about 50.8 to 304.8 mm (2 to 12 in.) apart along the width of the pavement. Spalls existed along the wheelpath at the intersection of the "normal" transverse cracking and the ASR-related longitudinal cracking. The FWD data were used to backcalculate concrete modulus of elasticity and the modulus of subgrade reaction values. In addition, joint load transfer analysis was performed for the JRC pavements. On the basis of the FWD test data and condition survey results, the pavements were delineated into several uniform projects. Maintenance and rehabilitation needs were then identified for each project, and rehabilitation priorities were assigned for each project. Several rehabilitation strategies were developed for each project to improve the structural and functional condition of the existing pavement to an acceptable serviceability level for the duration of the specified design/analysis period. Life cycle cost analyses were performed for each rehabilitation alternative for each project, and final rehabilitation designs were recommended. In 1993 and 1994 the I-495 section and the associated ramps were overlaid with a 304.8-mm (12-in.)-thick unbonded plain jointed concrete overlay. The details of the field investigation, data analysis, and the rehabilitation design process used to arrive at the final designs are presented.

In 1986 the Delaware Department of Transportation (DelDOT) initiated a study to evaluate the performance of the Delaware Interstate highway system (including the turnpike) and to identify at the network level future rehabilitation needs for the system. The systems studied included I-95, I-495, and associated ramps including ramps to and from I-95 and I-495 to I-295. The study areas were divided into 32 sections, and specific recommendations were prepared for future rehabilitation strategies for each section on the basis of present condition, future anticipated condition, and cost analysis. In 1990 DelDOT initiated evaluation of maintenance and rehabilitation strategies for I-495 and several associated ramp sections. As part of this evaluation a visual condition survey of I-495 and the ramp sections was performed in the fall of 1990 to update the data from the 1986 study. In March 1991 a project-level rehabilitation design study for I-495 and selected ramp sections was initiated.

A major concern with I-495 was the occurrence of alkali-silica reactivity (ASR) in the continuously reinforced concrete (CRC) pavement of I-495 and the presence of reactive aggregates in jointed reinforced concrete (JRC) pavement of the ramps. ASR appeared to be extensive in terms of extent and severity along the northern portions (both directions) of I-495. ASR did not appear to be as severe along the southern portions of I-495. There did not appear to be other significant design- or construction-related deficiencies in the CRC pavements of I-495, and these pavements would have undoubtedly been considered adequate for many more years of traffic if not for the ASR problem.

This paper presents a background on I-495 and the associated ramps under study and details of a field investigation conducted to evaluate the condition of the existing pavements. Finally, rehabilitation design alternatives including unbonded concrete overlays are discussed for each study section and life cycle cost estimates are presented.

OBJECTIVES AND SCOPE OF WORK

The objective of this study was to develop rehabilitation design alternatives for portions of I-495 and I-295 (associated ramp sections). Specifically, the study area consisted of the sections listed in Table 1. The section numbers were designated during the 1986 pavement rehabilitation study. As discussed the scope of work consisted of field investigation of the designated pavements to evaluate the condition of the existing pavement and development of rehabilitation strategies for those pavements.

BACKGROUND

The pavements along I-495 were constructed between 1972 and 1977 and were opened to traffic in 1978. The ramp sections associated with I-295 (Sections 4, 7, and 8) were constructed between 1964 and 1967 and were opened to traffic in 1967. Except for a small section along I-495N, none of these pavement sections had been overlaid.

Most pavements along I-495 consisted of 228.6-mm (9-in.)-thick CRC pavement constructed over a 101.6-mm (4-in.)-thick

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TABLE 1 Rehabilitation Study Sections

Section No.	Roadway	Ramp Route	Beginning Station	Ending Station	Pavement Surface	Length, ft
13a, b	495N	-	3147+51	3267+10	CRCP	11,959
14a, b	495N	-	3311+00	3413+30	CRCP	10,230
15	495N	-	3415+80	3668+95	CRCP	25,315
16	495N	495N-95N	3668+95	3713+00	JRCP	4,405
17	495S	95S-495S	4100+00	4164+17	JRCP	6,417
18a	495S	-	4164+17	4415+20	CRCP	25,133
18b, c	495S	-	4418+35	4521+57	CRCP	10,322
19a, b	495S	-	4563+03	4623+65	CRCP	6,062
20	495S	-	4626+80	4631+68	JRCP	488
21	495S	-	4633+58	4684+28	CRCP	5,070
4	295	295W-95S	5400+00	5437+78	JRCP	3,778
7	295	495S-295E	5507+12	5529+97	JRCP	2,258
8	295	495S-295E	5531+65	5560+08	JRCP	2,843

cement-treated base (CTB) placed over a select subbase material. The ramps and one section of pavement along I-495 consisted of 254-mm (10-in.)-thick JRC pavement over CTB placed over select subbase material. The JRC consists of 13.7-m (45-ft)-long slab panels reinforced with 152.4 × 15.4-mm (6 × 6-in.) welded wire fabrics. The shoulders along I-495 are typically asphalt concrete (AC), with an AC surface thickness of about 76.2 to 101.6-mm (3 to 4 in.). The study pavements were constructed in or near marshland areas and required considerable preconstruction soil stabilization and removal efforts. These activities included much excavation, subgrade removal, construction of sand blankets, and the use of sand wick drains to move, consolidate, or drain undesirable soils.

A considerable amount of information was collected during the 1986 rehabilitation study (*1*). The maintenance information collected indicated that maintenance along I-495 consisted primarily of crack sealing and repair of expansion joints at bridges. The longitudinal cracking (now confirmed to be related to ASR) was becoming more frequent and wider. As for the ramp sections, Section 8 was noted as having full-depth joint repairs at some joints. These repairs were noted to have been necessitated because of joint deterioration caused by reactive aggregates. Since 1986 more spalling had been reported along Sections 15 and 18 as a result of the extensive ASR-related longitudinal cracking, and these spalls had generally been patched with AC. One small section of the CRC pavement along Section 15 (northbound I-495) had been overlaid with 76.2-mm (3-in.) of AC a few years before. In addition, more full-depth joint repair had been made along the ramps of I-295. The 1986 rehabilitation study included field investigation consisting of the following:

1. Nondestructive deflection testing (NDT) with a Phoenix falling-weight deflectometer (FWD),
2. Pavement condition survey by a modified pavement condition index (PCI) procedure,
3. AASHTO pavement serviceability rating (PSR) survey, and
4. Roughness survey with a portable universal roughness device (PURD).

On the basis of the analysis of the field data and projected traffic data, a comprehensive evaluation was made of each roadway section, and future maintenance and rehabilitation needs were identified.

1990 Pavement Condition Study

In the fall of 1990 a visual condition survey along sections of I-495 and I-295 ramps was performed. The survey was conducted to determine whether the rehabilitation recommendations made during the 1986 study were still applicable because only limited maintenance and repair activities had been performed along the study sections. On the basis of that survey, Sections 4, 17, 15, and 18a were rated as requiring rehabilitation within the next 0 to 5 years, and rehabilitation was rated high priority. For the CRC pavement Sections 15 and 18a, the primary distresses were ASR-related longitudinal cracking, spalling at cracks, and many patches. Section 4 had numerous full-depth repairs. For Sections 13, 14, 18b, 19, and 21 it was recommended that these sections be monitored over the next 3 to 5 years and that the rehabilitation needs confirmed at that time. All these sections were exhibiting low-severity ASR-related longitudinal cracking. However, the longitudinal cracking at these sections was not considered to be a cause for concern at that time.

On the basis of the results of that study a full-scale project-level field investigation was recommended to identify rehabilitation needs for the study pavements.

ASR Problem

The most significant distress along the CRC pavements of I-495 and the I-295 ramps was the longitudinal cracking related to ASR. This problem had apparently been identified just a few years before. As noted previously ASR occurs when silica or silicates in aggregates react with alkali in the cement to form a gel-like substance. The gel absorbs water and expands. Within a few years this expanding gel can crack the concrete. The process is irreversible and can lead to severe deterioration of the concrete. The ASR phenomenon has been known since the 1940s, and extensive studies have been conducted in the affected central states of, for example, Colorado, Nebraska, and Kansas to minimize or eliminate the risks of ASR. Some of these states have reportedly not constructed ASR-affected pavements since the early 1960s and have rehabilitated or reconstructed most of their ASR-affected pavements. Recognition of the ASR problem was slower along the East Coast states of the United States, and the problem has been recognized only in recent years. The I-495 problem is an example of the nonrecognition of reactive aggregates within Delaware. Although techniques for retarding the ASR process (which can continue for a long time) have been proposed, techniques for correcting the damage from ASR are not yet available. The ASR process can be arrested or retarded if moisture is kept from entering the ASR-affected concrete.

The ASR-affected concrete pavements have generally been overlaid with hot-mix asphalt concrete to temporarily extend the service life of the pavements. In most cases it has been reported that these pavements are reconstructed after the AC overlay has served its purpose. Bonded concrete overlays cannot be used to rehabilitate ASR-affected pavements. However, unbonded concrete pavements can be used without any problems. Also, ASR-affected concrete pavement cannot be recycled as aggregate for concrete. Recently, as part of the Strategic Highway Research Program, extensive studies of the ASR problem and its mitigation have been conducted.

1991 FIELD INVESTIGATION

During early 1991 a field investigation was conducted to determine the current condition of the I-495 and I-295 ramp sections designated by DelDOT for possible rehabilitation. The field investigation consisted of visual condition survey, nondestructive deflection testing, and coring and boring.

Visual Condition Survey

The visual condition survey was conducted by a two-person team riding in a car. The objective of the survey was primarily to identify the extent and severity of ASR and to note areas exhibiting other distresses that would require localized repairs during future rehabilitation of the pavements. No attempt was made to determine a numerical index such as the PCI or the PSR.

The general observations made on the basis of the condition survey are given as:

1. The CRC and JRC pavements generally provided a smooth ride, even though many of these pavements exhibited ASR-associated cracking.
2. The primary distresses observed included longitudinal cracking in CRC pavements (ASR related), spalling, midslab cracking in JRC pavements, and joint deterioration/patching (reactive aggregate related) in JRC pavements. The transverse cracking in CRC pavements per se was not considered a distress. Only the severity of the transverse cracking was considered when evaluating the condition of CRC pavements.
3. The AC shoulders were rated in poor to fair condition. Only areas recently replaced were in very good to excellent condition.

One interesting phenomenon observed along I-495 was the variability in the severity of ASR between the northern portions (Sections 15 and 18; high-severity ASR) and the southern portions (Sections 13, 14, 19, and 21; low-severity ASR). Interstate 495 was constructed over a period of many years, and portions were constructed under different contracts. Thus, the difference in the ASR activity may have been a result of age or different sources of aggregate and cement. The longitudinal cracking caused by ASR along the northern portions of I-495 was more pronounced because of truck traffic loadings and was more damaging in the CRC pavement because of the closely spaced transverse cracking. The wheelpaths in the outside lanes of I-495 exhibited numerous spalls and patch areas as a result of accelerated concrete deterioration in these areas. These spalls and patch areas generally occurred at intersections of longitudinal and transverse cracks along the wheelpaths.

A review of available construction data indicated that Sections 15, 16, 17, and 18a, which exhibited the high-severity ASR, were placed the earliest, during 1972 and 1973. Also, Sections 15, 16, 17, and 18a constructed by one contractor exhibited a unique combination of coarse aggregates, fine aggregate, and cement suppliers, resulting in a different (higher) rate of ASR development in the CRC pavement than for the other contracts/sections.

The concrete deterioration in the I-495 CRC pavements as a result of the ASR-related longitudinal cracking was expected to continue. However, the rate of deterioration could not be predicted. This deterioration would necessitate a continuing need for repairs such as patching along the northern portions of I-495, and these repairs could be considered temporary only because such repairs have low useful service life. On the basis of the condition survey it was clear that corrective action would soon be needed for Section 15 and Section 18 (northern half portion of I-495). A visual condition survey of the interchange ramps along I-495 was also conducted. The survey indicated that these ramps were in generally good condition and required only minor patch repair and resealing of some joints.

Nondestructive Deflection Testing

An NDT program was conducted along the study sections to evaluate the structural condition of the pavements. The NDT was conducted with a Dynatest 8002E FWD.

For the CRC pavement deflection basin testing was conducted, and for the JRC pavement deflection basin testing and joint load transfer testing were conducted. All testing was conducted along the outside lane. Load levels of 4081.5, 5442.0, and 7256.0 kg (9,000, 12,000, and 16,000 lb) were used. For the CRC pavements the basin testing was conducted at a spacing of 30.5 m (100 ft). For the JRC pavements basin testing was conducted at the midslab of every third slab panel. Joint testing was conducted at every third joint at corner locations.

Coring and Boring

To ascertain the actual thicknesses of the various pavement layers and to characterize the base, subbase, and subgrade materials, a coring and boring program was conducted by DelDOT staff. Cores were 101.6 to 152.4 mm (4 to 6 in.) in diameter. Borings were made at each core location and went to a depth of about 1.5 m (5 ft) from the pavement surface. The CTB was generally recovered intact and appeared to be in excellent condition. A total of 28 concrete cores were tested for splitting tensile strength. Also, subbase and subgrade characterization was performed by DelDOT staff by using materials recovered from the borings.

OTHER DATA COLLECTION

Although a significant amount of data was available from the 1986 study reports, additional data were also collected to update that information. These data types included traffic data and unit cost data.

Traffic Data

Updated traffic data for a 40-year period were requested from DelDOT. DelDOT had asked that the rehabilitation designs be prepared to provide a 40-year service life. Early discussions with DelDOT staff indicated that there was no reliable way of projecting traffic for 40 years because the common practice was to project traffic for only 20 years. It was suggested that the 20-year projections be used and that these projections be doubled to provide the 40-year traffic projections. The average annual daily traffic (AADT) projected for 2010 for various sections of the study area was available, and these data also indicated the level of service (LOS) at Level C for these sections for 2010. For 2010 most of I-495 and many of the ramp sections were projected to approach LOS C. The AADT data and LOS traffic data are summarized:

- AADT along I-495 Projected year 2010 ranged from 59,000 to 84,000 vehicles.
- LOS capacity along I-495 Projected year 2010 ranged from 44,000 to 69,000 vehicles per day.

For computing traffic over a 40-year period it was assumed that the roadway sections would not be able to accommodate traffic beyond the LOS C. The 40-year traffic projections in terms of 18-kip equivalency single axle loads (ESALs) (from 1990) are summarized in the in-text table.

Period (years)	*Cumulative 18-kip ESAL*
8	12,000,000
15	34,000,000
20	59,000,000
40	166,000,000

For developing the rehabilitation designs by using various pavement schemes, the following initial design periods were used in estimating design traffic (PCC is portland cement concrete):

Pavement Scheme	*Initial Design Life*
AC overlay	8
AC reconstruction	15
PCC reconstruction	20
PCC unbonded overlay	20

Unit Cost Data

Typical pavement construction-related unit costs were compiled by using current bid tabulations from recent Delaware and Maryland highway construction projects and consultant's in-house files. These costs were used in developing cost estimates for the various proposed pavement rehabilitation strategies.

Bridge Clearances

Bridge clearance data were tabulated to identify possible constraints in the development of specific rehabilitation designs. Information on bridge clearance is critical since bridge clearance is a critical item for overlay alternatives. The designed bridge clearance was 4.9 m (192 in.) for I-495.

ANALYSIS OF DATA

Analysis of the results of the field investigations are presented in this section. The data were analyzed to evaluate the extent and severity of the distresses in the existing pavements and to estimate material properties for use as input in developing rehabilitation designs.

Visual Condition Survey

The visual condition survey data indicated that the CRC pavements along Section 15 and the northern portion of Section 18 were exhibiting high-severity ASR-related longitudinal cracking. The condition of the transverse cracking was not considered unusual considering that the pavements were opened to traffic in 1978. The pavements of the other CRC sections exhibited ASR-related longitudinal cracking but at a very low to low level of severity. The CRC pavements were providing a good ride, and a rough ride was encountered generally only at expansion joints near bridge structures. As noted previously the CRC pavements would be considered to be performing in accordance with the design if it had not been for the ASR-related longitudinal cracking.

The JRC pavements of Sections 16 and 17 were also exhibiting reactive aggregate problems, and this was noticeable at joints within the southern portions of Sections 16 and 17. The northern portions of Sections 16 and 17 did not exhibit this problem and were apparently constructed under a different contract.

Section 4 had numerous full-depth joint repairs because of joint deterioration caused by reactive aggregate. The repaired joints appeared to be performing satisfactorily. Section 7 appeared to be performing well, with no indication of reactive aggregates. Midslab cracking was nonexistent and joints looked good. On the other hand, the adjacent Section 8 was exhibiting extensive reactive aggregate-related deterioration at joints. Many of the joints had been replaced full depth, and AC patches were applied to joints not so repaired. Section 8 also rode poorly.

Nondestructive Deflection Testing

The NDT data were used to backcalculate concrete modulus of elasticity and the modulus of subgrade reaction values. In addition, joint load transfer and void analyses were performed for the JRC pavements. No significant presence of voids was detected along the JRC pavement sections. Load transfer at joints of the JRC pavements ranged from 65 to 85 percent. Load transfer for

Sections 4, 8, and 20 was poor. A review of the deflection basin data and the extent and severity of ASR indicated that the study areas could be delineated into several uniform projects. The project delineation is summarized in Table 2.

Projects A, B, C, and D were designated primarily on the basis of the extent and severity of ASR. Project A was the better-performing project and Project D was the worst-performing project along I-495.

The backcalculated effective concrete modulus of elasticity value for Project D of 21,760 MPa (3,200,000 psi) was considerably lower than the values obtained at other projects. This reflected the poor condition of the pavements in Project D. Project C also exhibited lower modulus of elasticity values for the concrete. Projects C and D were most affected with ASR, and the extent of concrete deterioration was clearly reflected in the backcalculated concrete modulus of elasticity values. Projects A and B, on the other hand, exhibited high modulus of elasticity values for the concrete, indicating that the concrete in these projects was not deteriorated or not deteriorated to the extent as in Projects C and D.

For the JRC projects the backcalculation also provided high concrete modulus of elasticity values. These values were high, even though these pavements had reactive aggregates. This was because the deflection basin testing was conducted in the midslab locations of the slab panels where there was little damage caused by the reactive aggregates.

The characteristics of the CTB, subbase, and subgrade were modeled as a composite modulus of subgrade reaction value. The modulus of subgrade reaction was generally lower in the southern portions of I-495. The backcalculated modulus of subgrade reaction values ranged from about 150 to 270 pci.

Core Testing

Concrete cores obtained from the study sections were tested for splitting tensile strength. Cores were cut into top and bottom portions, and one or both portions were tested depending on the presence of steel reinforcement within the core. Cores were maintained in a soaked state for about 40 hr before testing. The splitting tensile strength ranged from 1,482 to 3,827 kPa (215 to 555 psi) for top portions of the cores and ranged from 1,758 to 5,068 kPa (255 to 735 psi) for the bottom portions of the cores.

Although no clear trend could be determined from the core testing, it appeared that the north portions of I-495N and I-495S had relatively lower strength concrete. No petrographic studies were conducted directly as part of the field investigation because the presence of reactive aggregates in the I-495 pavements had been established by previous studies.

TABLE 2 Project Delineation

Project	Roadway	1986 Study Section No.	Design Section Limits
A	495N	13	3147-3267
		14 (part)	3379-3413
	495S	18b (part)	4406-4453
B	495N	14 (part)	3311-3379
	495S	19	4563-4623
		20	4626-4631
		21	4633-4684
		18b (part)	4453-4497
		18c	4497-4521
C	495N	15 (part)	3415-3476
	495S	18a part)	4256-4406
D	495N	15 (part)	3476-3669
	495S	18a part)	4164-4256
E	495N	16	3669-3713
	495S	17	4100-4164
F	295W-95S	4	5400-5437
	495S-295E	7	5507-5529
	495S-295E	8	5531-5560

Materials Characterization

As part of the coring and boring effort DelDOT also performed laboratory analysis and characterization of the subbase and subgrade samples obtained from the study pavements. The subbase and subgrade sampling was conducted only to a depth of 1.5 m (5 ft). The subbase material was typically coarse to fine sand: AASHTO Classification A-1-a, A-1-b, A-2-4, and A-2-6. The sand layer at some locations had silt and traces of gravel. The nominal 101.6-mm (4-in.)-thick CTB under the CRC pavement was in excellent condition, and intact cores were recovered from the soil cement layer. In a few instances the CTB was bonded to the surface concrete layer. Also, in a few instances an A-6 (silty clay) layer was encountered within the upper 1.5 m (5 ft) of the pavement and was considered to be the natural subgrade material. No water was encountered within the 1.5-m (5-ft) depth of the boring.

The materials study indicated that the existing CRC pavement was constructed on a sound CTB and a relatively free-draining layer of coarse to fine sand. Lack of adequate drainage did not appear to be a matter of concern along the I-495 pavements. This was also evidenced by lack of drainage-related distresses in the CRC pavement.

Summary

The field investigation indicated that sections of I-495 and the ramps to and from I-295 were exhibiting extensive distresses resulting from ASR. It was considered that Projects D, E, and some of the I-295 ramp projects would need to be rehabilitated in the near future. Without major rehabilitation, an increased level of maintenance would be needed along these projects in the future.

On the basis of the discussions presented the following levels of priorities were assigned for rehabilitation of the study area:

Priority Level	*Projects*	*Rehabilitation Time*
Very high	C, D, E, F	0–3 years
Medium	A, B	5 years

It was realized that other extrinsic factors such as future traffic control and traffic disruptions may dictate the need to select rehabilitation strategies on the basis of minimizing future traffic disruptions along the heavily used I-495. Thus, even though Projects A and B were not in immediate need of rehabilitation, serious consideration was given to including Projects A and B with the other projects in need of immediate rehabilitation.

REHABILITATION DESIGN ALTERNATIVES

The primary objective of the study was to develop and identify rehabilitation alternatives for the pavements of I-495 and I-295 ramps. Under normal circumstances the development of practical rehabilitation strategies is a complex process because the forecasting of pavement performance is not an exact science. For the present study the task was further complicated because of the presence of ASR and the lack of knowledge of rate of deterioration of concrete structures affected by ASR. As indicated previously Projects C, D, E, and F (I-295 ramp sections) were designated as requiring rehabilitation in the near future, whereas the remaining projects were not in urgent need of rehabilitation. However, it was considered a prudent alternative strategy to perform rehabilitation of all projects together on the basis of administrative decisions related to minimizing multiple traffic control operations within a short time. Therefore, design alternatives were prepared for all projects.

The rehabilitation of concrete pavements can be performed by using concrete pavement restoration (CPR), resurfacing (overlays), and reconstruction.

Because of extensive ASR-related deterioration, the CPR technique was not considered feasible. With respect to overlays and reconstruction both AC and PCC were considered equally acceptable construction materials. As part of the rehabilitation design process numerous overlay design procedures were reviewed and considered for use. In addition, some preliminary analyses were perfromed by using both the layer elastic method and the finite-element method of analysis. The reviews provided some preliminary guidance on possible overlay thicknesses and other design features to be considered. However, the final rehabilitation designs were based on the 1986 *Guide for Design of Pavement Structures* (*2*) and the June 1990 proposed *Revision of AASHTO Pavement Overlay Design Procedures* (*3*). Eight design strategies were evaluated for rehabilitation of each project, as applicable. These included

1. AC overlay,
2. Unbonded jointed plain concrete (JPC) overlay,
3. Unbonded CRC overlay,
4. Reconstruct with AC pavement,
5. Rubblize with AC overlay (JRC pavement sections only),
6. Reconstruct with JPC pavement,
7. Reconstruct with CRC pavement, and
8. Maintain the existing condition of the pavement.

A brief description of some of the key design parameters used for development of required pavement thicknesses is presented in the following section.

Design Period

For the AC overlay design an initial design period of 8 years was selected for analysis. For the new AC design and rubblize design an initial design period of 15 years was selected for analysis. For the new rigid design and rigid overlay design an initial design period of 20 years was selected for analysis.

Condition Factor

Revised (1990) AASHTO Overlay Design

The condition factor was selected on the basis of the level of the ASR and the number of existing and new repairs required in the pavement. A parametric study of required thickness was performed by selecting a maximum and minimum condition factor for design.

1986 AASHTO Overlay Design

The condition factor was selected on the basis of the visual condition of the pavement and the backcalculated "cracked" modulus of elasticity. A required thickness was determined for each condition factor.

Overlay Designs

Rigid and flexible overlay designs were based on the effective structural capacity of the existing pavement. For rigid pavements the effective structural capacity was defined as the effective concrete thickness and for flexible pavements as the effective structural number. Both of these values were determined on the basis of the original material characteristics and the existing condition factor as described in the AASHTO design guide (*3*).

New Construction Designs

The AC and rigid pavement designs and the design for the rubblized section were based on the expected ESAL loadings over a specified design period. The required AC design thicknesses including that for the rubblized section were determined from the 1986 AASHTO flexible design equation. The required concrete thickness was determined from the 1986 AASHTO rigid design equation.

Design Thicknesses

The overlay and pavement design thicknesses were calculated for each rehabilitation design for each project. A sensitivity analysis was also performed for each design alternative to identify the effect of the various design inputs. The final thicknesses were based on the results of the sensitivity study. It should be noted that the designs were for an initial design life, which varied on the basis of the rehabilitation design selected. In the life cycle cost analysis presented later, details are provided on the assumed future maintenance and rehabilitation needs for each rehabilitation strategy on the basis of a 40-year analysis period. A summary of future rehabilitation activities for each pavement type is listed in Table 3.

The computed pavement and overlay design thicknesses were critically reviewed in light of the various assumptions made for the input parameters. On the basis of this review it was determined that Projects A and B could be considered together because the rehabilitation design requirements were similar. Also, Projects C and D were found to require similar rehabilitation and were therefore considered together. The final selected design thicknesses are

TABLE 3 Estimated Key Construction and Maintenance Activities

Year	AC Overlay	PCC Overlay	JPC Recon	CRC Recon	AC Recon
0	Initial Construction	Initial Construction	Initial Construction	Initial Construction	Initial Construction
5		Clean & Seal 5% Trans, 25% Long	Clean & Seal 5% Trans, 25% Long	Clean & Seal Shoulder 5% Trans, 25% Long	
8	Mill 3 in., 3% Patch Replace 4 in., AC +1 in. FC				3% AC Patching, Mill 3 in., Replace 2 in., +1 in. FC
10		Clean & Seal 5% Trans, 25% Long	Clean & Seal 5% Trans, 25% Long	Clean & Seal Shoulder 5% Trans, 25% Long	
14					
15		Clean & Seal 10% Trans, 25% Long	Clean & Seal 10% Trans, 25% Long	Clean & Seal Shoulder 10% Trans 25% Long	
16	Mill 5 in., 3% Patch Replace 7 in., AC +1 in. FC				Mill 3 in., 3% Patch Replace 2 in., +1 in. FC
20	1% AC Patching	Clean & Seal; 100% Trans & Long; 1% Spall Repair; 5% PCC Patching; Grinding	Clean & Seal; 100% Trans & Long; 1% Spall Repair; 5% PCC Patching; Grinding	5% PCC Patching; Grinding	1% AC Patching
24	Mill 5 in., 3% Patching Replace 4 in., +1 in. FC				Mill 3 in., 3% Patching Replace 2 in., +1 in. FC
25		Clean & Seal 5% Trans, 25% Long	Clean & Seal 5% Trans, 25% Long	Clean & Seal Shoulder 5% Trans, 25% Long	
29					
30		.5% Spall Repair; 2.5% PCC Patching;4" AC Overlay, +1 in. FC	.5% Spall Repair; 2.5% PCC Patching;4" AC Overlay, +1 in. FC	.5% Spall Repair; 2.5% PCC Patching; 4 in. AC Overlay, +1 in. FC	
32	Mill 3 in., 3% Patching Replace 4 in., +1 in. FC				Mill 3 in., 3% Patching Replace 2 in., +1 in. FC
34		1% AC Patching	1% AC Patching	1% AC Patching	
38		Mill 3 in., 3% Patching Replace 2 in., +1 in. FC	Mill 3 in., 3% Patching Replace 2 in., +1 in. FC	Mill 3 in., 3% Patching Replace 2 in., +1 in. FC	

NOTE: FC = open graded friction course

summarized later for each design project. Portions between adjacent bridges within Projects A and B were too short to allow construction of either AC or PCC overlays. For these projects reconstruction was the only practical rehabilitation option.

Asphalt Concrete Overlay

Minimum AC overlay thicknesses were selected for each design project. This thickness was required to maintain a functional serviceability level over an initial design life of 8 years.

- Projects A and B: 50.8-mm (2-in.) Type "C" AC over 101.6-mm (4-in.) Type "B" AC;
- Projects C and D: 50.8-mm (2-in.) Type "C" AC over 152.4-mm (6-in.) Type "B" AC; a thinner overlay was specified at the Myrtle Avenue bridge overpass to allow for minimum clearance;
- Project E: 50.8-mm (2-in.) Type "C" AC over 76.2-mm (3-in.) Type "B" AC; and
- Project F: 50.8-mm (2-in.) Type "C" AC over 127-mm (5-in.) Type "B" AC; a thinner overlay was specified at the I-95 North bridge overpass to allow for minimum clearance.

Rigid Overlay (JPC and CRC Pavements)

Minimum concrete overlay thicknesses were selected for each design project. This thickness was required to maintain a functional serviceability level over an initial design life of 20 years. It was assumed that CPR activities at 20 years would provide an additional 10 years of acceptable level of serviceability before an overlay would be required.

For Projects A, B, C, D, and E, a 254-mm (10-in.) concrete overlay with tied-concrete shoulders over 38.1- to 50.8-mm (1.5- to 2-in.) Type "C" AC bond breaker is required. The thicknesses are applied to both JPC and CRC pavement, although the CRC pavement was not recommended for Project E.

It should be noted that, because of the need to maintain grade at bridge approaches and to maintain vertical clearances under overpasses, it was considered necessary to require removal of sections of the existing CRC pavement at these locations and in effect reconstruct the pavement. This would require elimination of the terminal anchorages at bridge approaches and loss of continuity in the existing CRC pavement at critical overpasses.

It should also be noted that, although a 254-mm (10-in.) thickness was determined to be the minimum thickness for the PCC overlay, the use of thickness required for reconstructed PCC was considered appropriate for the concrete overlays. Thus, up to 304.8-mm (12-in.)-thick concrete overlay was considered an acceptable solution. The use of the larger thickness would provide significantly improved pavement performance with only a minimal increase in overall cost. Joint spacing of 4.6 m (15 ft) was recommended for the JPC pavement.

For I-295 ramps (Project F), a 228.6-mm (9-in.) concrete overlay over 38.1- to 50.8-mm (1.5- to 2-in.) Type "C" AC bond breaker is required.

New Asphalt Concrete Pavement

Minimum AC pavement thicknesses were selected for each design project. This thickness was required to maintain a functional serviceability level over a design life of 15 years. For all projects 101.6-mm (4 in.) of Type "C" AC over 279.4 mm (11 in.) of Type "B" AC is required.

New Concrete Pavement

Minimum concrete pavement thicknesses were selected for each design project. This thickness was required to maintain a functional serviceability level over an initial design life of 20 years. It was assumed that CPR activities at 20 years would provide an additional 10 years of acceptable level of serviceability before an overlay would be required. For all projects 304.8 mm (12 in.) of concrete pavement with tied-concrete shoulders is required. This thickness applied to JPC and CRC pavements, although the CRC pavement was not recommended for Projects E and F. A joint spacing of 4.6 m (15 ft) was recommended for the JPC pavement.

Rubblize with Asphalt Concrete Overlay

Minimum AC pavement thicknesses were selected for each design project. This thickness was required to maintain a functional serviceability level over a design life of 15 years. For all JRC pavement projects 2 in. of Type "C" AC over 6 in. of Type "B" AC is required. This rehabilitation method was recommended only for Project E and Project F (I-295 ramps). A thinner thickness was specified at the I-95 North overpasses to allow for minimum clearance.

Maintain Without Overlay or Reconstruction

Projects A and B exhibited very low to low-severity ASR and other distresses and therefore were not considered to require immediate structural rehabilitation. Under this rehabilitation design initial improvements would include only localized repairs. As noted previously structural rehabilitation could be delayed for at least 5 years.

LIFE CYCLE COST ANALYSIS

An economic analysis incorporating life cycle cost was performed to evaluate the feasibility of the various rehabilitation strategies. This analysis enabled selection of preferred design alternates on the basis of the cost of the rehabilitation over a specified analysis period. This was done because the benefit of a particular rehabilitation strategy solely on the basis of initial cost may often be misleading if future costs were not considered. For this study each rehabilitation type was evaluated for its respective life cycle costs over a 40-year analysis period.

A discount rate of 2 percent was used for the life cycle cost analysis. The discount rate is the difference between the interest rate and inflation rate. The difference between interest and inflation rates, that is, the discount rate, stays within a narrow range over the long term even if the individual rates may experience changes with time. For highway construction projects a discount rate of between 2 and 4 percent is typically used to estimate the present cost of future construction. On the basis of discussions with DelDOT staff a discount rate of 2 percent was selected for this analysis.

Life cycle costs were determined for each rehabilitation design for each design project. These analyses resulted in a set of life cycle cost values for each project. Several project rehabilitation strategies that incorporated one rehabilitation design and life cycle cost values from each design project were then developed. A total life cycle cost for each project rehabilitation strategy was determined. In the life cycle cost analysis the costs considered included initial cost, maintenance cost, rehabilitation cost, civil costs, and maintenance of traffic cost. No user costs were incorporated. User costs would be higher for strategies requiring more frequent maintenance and rehabilitation activities.

The format for establishing future maintenance activities was based on Chapter 2 of the Pennsylvania Department of Transportation's *Roadway Management Manual* (*4*). The AC overlay, AC reconstruction, and rubblize rehabilitation design strategies included AC patching at 4-year cycles. The concrete overlay and concrete reconstruction design strategies included cleaning and sealing of joints at 5-year cycles. The timing and thickness of future structural rehabilitation activities were based on fatigue life consumption as determined by the AASHTO rigid and flexible design equations.

The rehabilitation designs for each project were grouped to develop overall rehabilitation strategies for all projects. Twelve distinct strategies were identified and summarized in Table 4.

STUDY FINDINGS AND RECOMMENDATIONS

The primary objective of the study was to identify immediate pavement rehabilitation needs along I-495 and I-295 ramps. As noted previously the primary reason that there was a concern about the need for rehabilitation was that there was extensive ASR-related deterioration along projects of the study areas. As discussed previously Projects C, D, E, and F were in need of major rehabilitation, possibly within the next 3 years, to ensure that adequate levels of service were maintained along these projects.

TABLE 4 Summary of Rehabilitation Strategies

Rehabilitation Strategy	Project				Total LCC Cost, Millions $
	A & B	C & D	E	F	
I	Maintain Recon in 2000	AC Overlay	AC Overlay	AC Overlay	30.9
II	AC Overlay/PCC Recon	AC Overlay	AC Overlay	AC Overlay	30.9
III	Maintain Recon in 2000	PCC Overlay	PCC Overlay	PCC Overlay	33.8
IV	PCC Overlay/PCC Recon	PCC Overlay	PCC Overlay	PCC Overlay	33.5
V	Maintain Recon in 2000	AC Recon	AC Recon	AC Recon	36.2
VI	AC Recon	AC Recon	AC Recon	AC Recon	40.0
VII	PCC Recon	PCC Recon	PCC Recon	PCC Recon	39.9
VIII	Maintain Recon in 2000	PCC Recon	PCC Recon	PCC Recon	36.3
IX	Maintain Recon in 2000	1. AC Overlay 2. Reconstruct in 8 years with AC	1. AC Overlay 2. Reconstruct in 8 years with AC	1. AC Overlay 2. Reconstruct in 8 years with AC	38.4
X	1. AC Overlay/ PCC Reconstruct in 8 years 2. Reconstruct AC Overlays in 8 years	1. AC Overlay 2. Reconstruct in 8 years with AC	1. AC Overlay 2. Reconstruct in 8 years with AC	1. AC Overlay 2. Reconstruct in 8 years with AC	41.0
XI	1. AC Overlay/ PCC Reconstruct in 8 years 2. Reconstruct AC Overlays in 8 years	1. AC Overlay 2. Reconstruct in 8 years with PCC	1. AC Overlay 2. Reconstruct in 8 years with PCC	1. AC Overlay 2. Reconstruct in 8 years with PCC	39.8
XII	1. AC Overlay 2. PCC Reconstruct in 8 years	1. AC Overlay 2. PCC Reconstruct in 8 years	1. AC Overlay 2. PCC Reconstruct in 8 years	1. AC Overlay 2. PCC Reconstruct in 8 years	43.8

It should be noted that the I-495 pavements did provide a good ride, but this was primarily because of the CRC design of the pavement. In the northern portions of I-495 the good ride gave a false sense of security; actually the pavements were severely distressed and required constant attention to repair spalled concrete. An analysis of projected traffic data for I-495 indicates that traffic volumes were expected to grow at a high rate and truck traffic would continue to be a high percentage of the total traffic. In fact the projected traffic volumes indicated that an additional traffic lane would be needed soon.

Design Recommendations

In the evaluation of pavement rehabilitation alternatives several were studied. Pavement rehabilitation designs were prepared for the different sections of I-495 and for the ramps. Basically the I-495 roadway was divided into two sections: the northern portion (north of the Edgemore interchange) and the southern portion. The following were the primary design alternatives recommended:

1. AC overlay: 152.4-mm (6-in.) thickness for southern sections of I-495 and 203.2-mm (8-in.) thickness for northern sections of I-495;
2. Reconstruction with AC: 381-mm (15-in.) thickness;
3. Concrete overlay: 254-mm (10-in.) thickness but up to 304.8-mm (12-in.) thickness recommended; and
4. Reconstruction with concrete: 304.8-mm (12-in.) thickness.

Overlay Alternatives Compared with Reconstruction

The overlay strategies offer several important advantages over reconstruction strategies. These are listed below:

1. Overlay construction would require a shorter construction period.
2. No reconstruction of soil cement base or subbase would be required.
3. No drainage system changes would need to be made.

A major disadvantage of overlays was related to maintaining grade at bridge approaches and at overpasses (for vertical clearance). Removal of the existing CRC pavement would be required at these locations.

Asphalt Concrete Overlay Compared with Concrete Overlay

1. The AC overlay option would need more frequent traffic disruptions for future rehabilitation activities (normally resurfac-

ing was needed after about 8 years). In the case of I-495's northern sections it was possible that the pavement would need to be reconstructed after about 8 to 10 years if the ASR continued to deteriorate the existing CRC pavement.

2. The AC overlay would require extensive preoverlay repair of distressed areas.

3. The performance of a concrete overlay would not depend on the future condition of the existing CRC pavement.

4. The concrete overlay would provide 25 to 30 years of low-maintenance pavement before there would be a need for any rehabilitation activity.

SUMMARY

On the basis of the field investigation and the rehabilitation design evaluation the northern sections of I-495 and the associated ramps were recommended for rehabilitation soon, possibly within 3 years. The southern sections of I-495 were not considered in urgent need for rehabilitation, but if the ASR continued these sections would also need to be rehabilitated in the future, possibly within 5 years.

The northern portions of I-495 pavements were rehabilitated during 1993 with an unbonded concrete overlay. The overlay thickness selected by DelDOT was 304.8 mm (12 in.) to ensure a longer-lasting pavement with minimum maintenance needs over the first 20 to 25 years of service life. Also, a 3.7-m (12-ft)-wide tied concrete shoulder was constructed to serve as a travel lane in the future. The southern portions were rehabilitated in 1994.

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