KTC-00-2

Pavement Design Evaluations
I-275 Boone and Kenton Counties
MP 1.05 - 7.15

by

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INTRODUCTION

Interstate 275 in Boone and Kenton Counties (MP 1.05 - 7.15) has been in service for more than 20 years. The eastbound lanes from MP 1.05 - 4.07 was rehabilitated by rubblization of the existing continuously reinforced concrete pavement, the addition of an open-graded drainage layer and a 9-inch PCC overlay in 1991. The remaining sections have been broken down into two rehabilitation projects as follows:

Section 1
I - 275, Boone/Kenton Counties Kentucky
Eastbound from MP 1.05 - 4.06
3 - lanes
Original Construction--1973
11" Jointed Reinforced Concrete Pavement over 6" of Dense-Graded Aggregate Base
MP 1.99 - 4.06
    56,000 AADT, 11.5% Trucks
    14,603,000 ESALs for 20 years
MP 1.05 - 1.99
    76,000 AADT, 11.5% Trucks
    21,400,000 ESALs for 20 years

Section 2
I-275, Boone County, Kentucky
East and Westbound MP 4.06 - 7.15
3-lanes
Original Construction--1977
11" Jointed Reinforced Concrete Pavement over 6" of Dense-Graded Aggregate Base
47,000 AADT, 11.5% Trucks
10,700,000 ESALs for 20 years

REHABILITATION ALTERNATIVES

Two rehabilitation alternatives were evaluated for each of the previously mentioned sections. Alternate 1 would break and seat the existing concrete pavement with an application of an asphaltic concrete overlay. Alternate 2 would involve overlaying the existing concrete pavement with a open-graded bond breaker material and then apply a unbonded concrete overlay. The thickness designs were determined based on a design CBR of 3.0 which was used on the previous rehabilitation in the westbound lanes of Section 1.

To allow for the comparison of both the concrete and asphalt alternatives, a 40- year structural design of the pavement was evaluated. Due to the difficulties of forecasting traffic for a 40-year period, the 20-year ESALs were doubled to obtain a 40-year ESAL estimate.

Asphalt Alternative

Thickness designs were developed using the 1993 AASHTO Guide for Design of Pavement Structures and the procedures outlined in Research Report KTRP 87-29 "Pavement Designs Based on Work". The following design parameters were utilized for each design procedure.

Ky Procedure UKTRP Report 87-29

Broken Concrete Modulus – 25, 100, and 250 ksi
Subgrade CBR – 3.0

1993 AASHTO Procedure

Broken Concrete Layer Coefficient – 0.18 and 0.21
Asphalt Surface Layer Coefficient – 0.44
Asphalt Base Layer Coefficient – 0.40
Effective Layer Coefficient of Existing DGA – 0.10
Initial Serviceability – 4.5
Terminal Serviceability – 3.0
Overall Deviation – 0.49
Reliability – 95%
Subgrade CBR – 3.0, M_r = 4,500

Using these parameters, thickness designs have been developed for design ESALs from 10,000,000 - 50,000,000. The thickness designs for Section 1 (MP 1.05 - 4.06) are given in Figure 1. The designs for Section 2 (MP 4.06 - 7.15) are given in Figure 2.

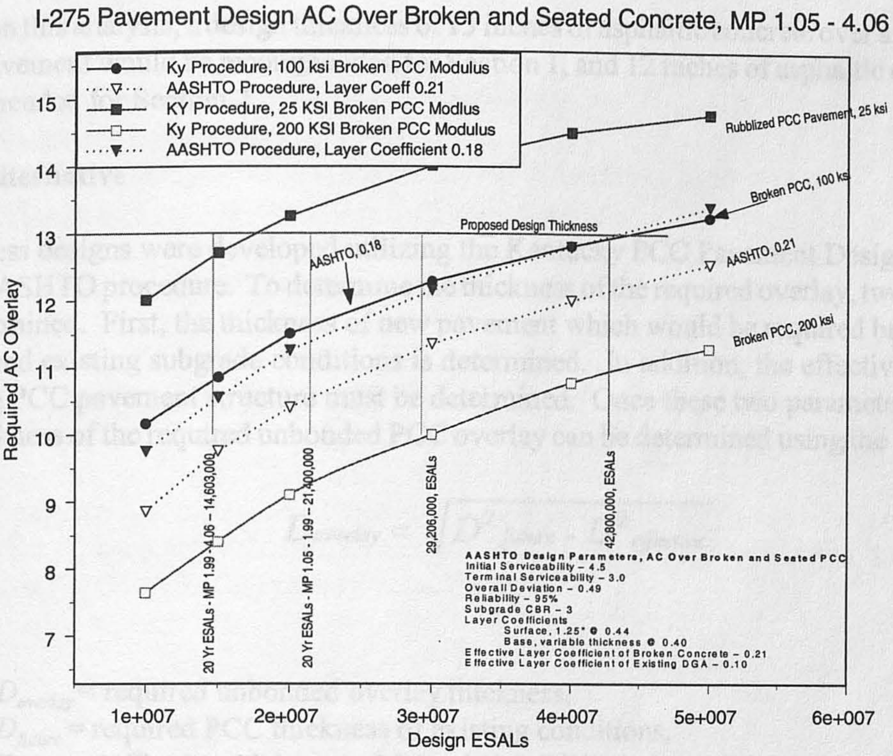

Figure 1 Asphalt Pavement Design, MP 1.05 - 4.06

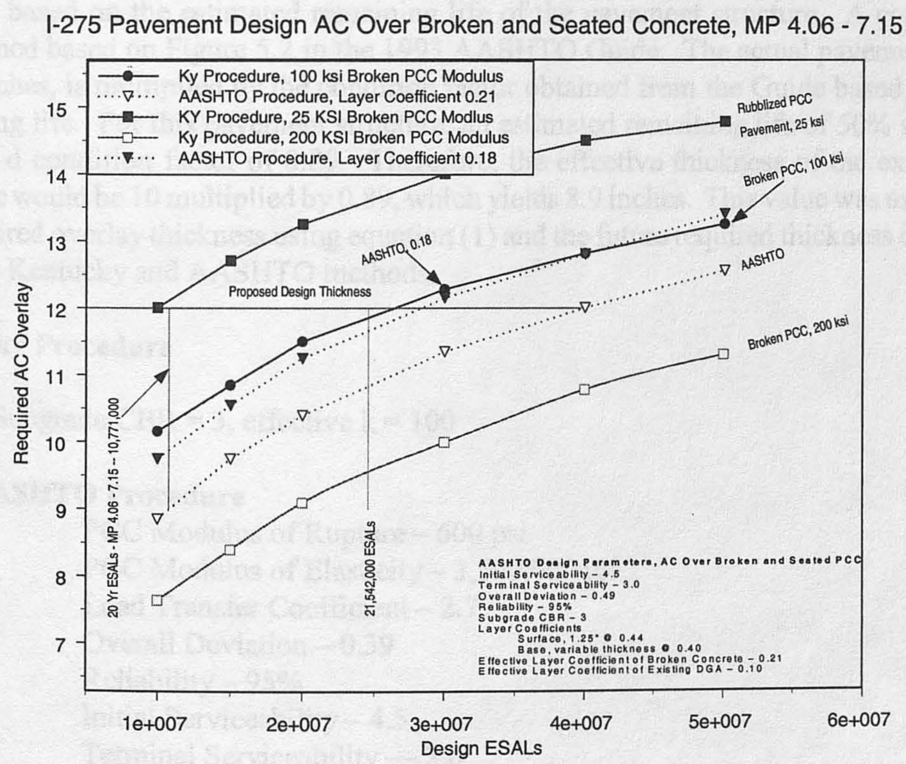

Figure 2 Asphalt Pavement Design MP 4.06 - 7.15

Based on this analysis, a design thickness of 13 inches of asphaltic concrete over a broken and seated PCC pavement would be recommended for Section 1, and 12 inches of asphaltic concrete would be recommended for Section 2.

PCC Alternative

Thickness designs were developed utilizing the Kentucky PCC Pavement Design Catalog and the 1993 AASHTO procedure. To determine the thickness of the required overlay, two parameters must be determined. First, the thickness of new pavement which would be required based on the design traffic and existing subgrade conditions is determined. In addition, the effective thickness of the existing PCC pavement structure must be determined. Once these two parameters are determined the thickness of the required unbonded PCC overlay can be determined using the flowing equation:

$$D_{overlay} = \sqrt{D^2_{future} - D^2_{effective}} \qquad (1)$$

Where:

$D_{overlay}$ = required unbonded overlay thickness,
D_{future} = required PCC thickness of existing conditions,
$D_{effective}$ = effective thickness of the existing PCC pavement based on condition.

To determine the effective thickness of the existing pavement, the actual pavement thickness is reduced based on the estimated remaining life of the pavement structure. A condition factor is determined based on Figure 5.2 in the 1993 AASHTO Guide. The actual pavement thickness, up to 10 inches, is multiplied by the condition factor obtained from the Guide based on an estimated remaining life. For this pavement structure, an estimated remaining life of 50% was chosen, this yields a d condition factor of 0.89. Therefore, the effective thickness of the existing pavement structure would be 10 multiplied by 0.89, which yields 8.9 inches. This value was used to determine the required overlay thickness using equation (1) and the future required thickness determined from both the Kentucky and AASHTO methods.

Kentucky Procedure

Subgrade CBR = 3, effective k = 100

1993 AASHTO Procedure

PCC Modulus of Rupture – 600 psi
PCC Modulus of Elasticity – 3,500,000 psi
Load Transfer Coefficient – 2.7
Overall Deviation – 0.39
Reliability – 95%
Initial Serviceability – 4.5
Terminal Serviceability — 3.0
Modulus of Subgrade Reaction – 100 pci

Example:

Existing Pavement Thickness – 11 inches
Estimated Remaining Life – 50%
Condition Factor – 0.89, Figure 5.2, 1993 AASHTO Guide
Required Pavement Thickness for Future Traffic – 12.8"

Effective Pavement Thickness = 0.89 x 10 = 8.9"

$$D_{overlay} = \sqrt{12.8^2 - 8.9^2} = 9.2''$$

Using these parameters, thickness designs have been developed for design ESALs from 10,000,000 - 50,000,000. The thickness designs for Section 1 (MP 1.05 - 4.06) are given in Figure 3. The designs for Section 2 (MP 4.06 - 7.15) are given in Figure 4.

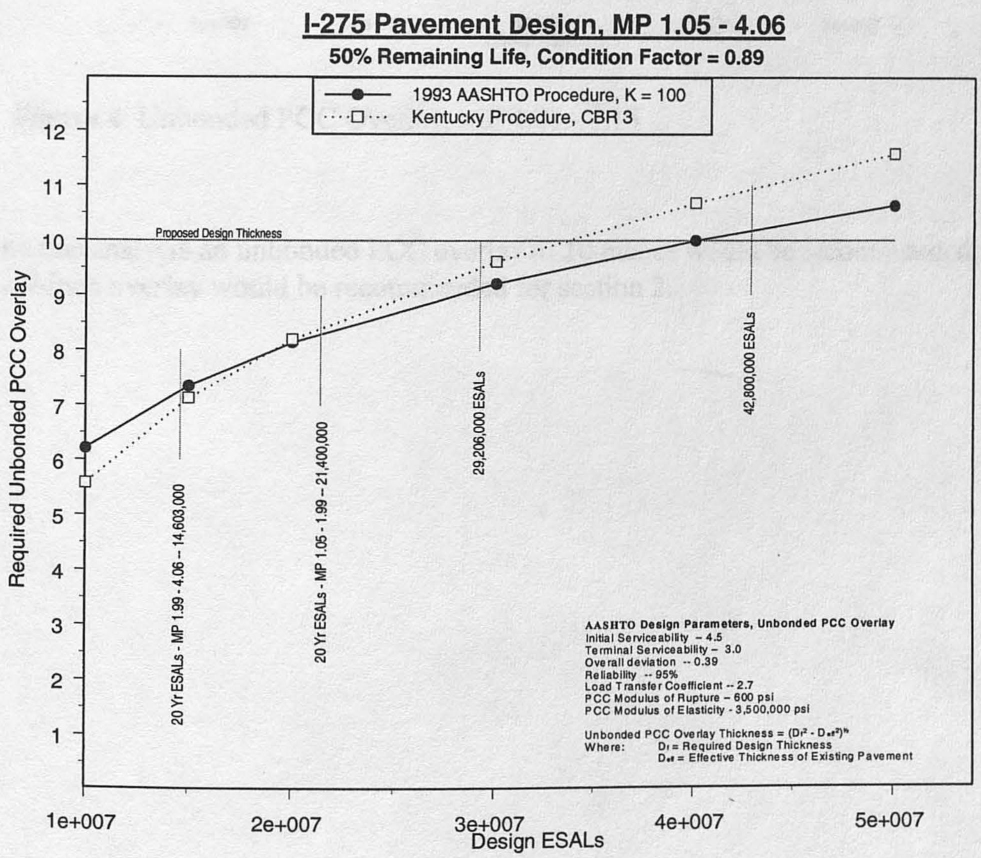

Figure 3 Unbonded PCC Overlay, MP 1.05 - 4.06

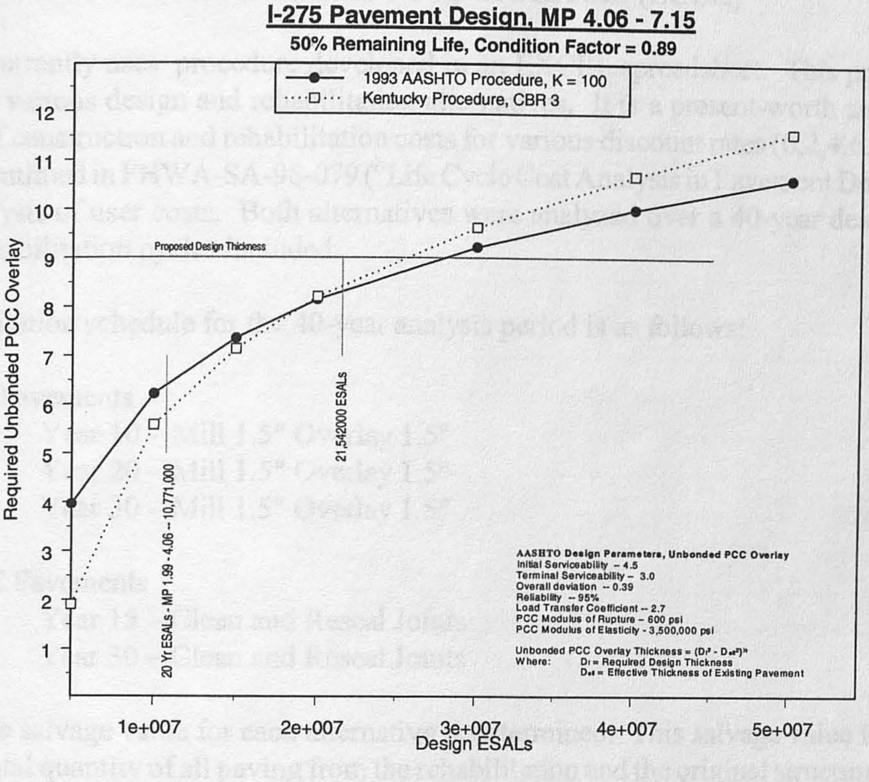

Figure 4 Unbonded PCC Overlay, MP 4.06 - 7.15

Based on this analysis an unbonded PCC overlay of 10 inches would be recommended for Section 1, and a 9-inch overlay would be recommended for section 2.

LIFE CYCLE COST ANALYSIS (LCCA)

Kentucky currently uses procedure developed in an EXCEL spreadsheet. This procedure is used to compare various design and rehabilitation alternatives. It is a present-worth analysis based on estimates of construction and rehabilitation costs for various discount rates (0,2,4,6,8, and 10). The procedure outlined in FHWA-SA-98-079 ("Life Cycle Cost Analysis in Pavement Design") was used for the analysis of user costs. Both alternatives were analyzed over a 40-year design period with periodic rehabilitation cycles included.

The rehabilitation schedule for the 40-year analysis period is as follows:

AC Pavements
- Year 10 – Mill 1.5" Overlay 1.5"
- Year 20 – Mill 1.5" Overlay 1.5"
- Year 30 – Mill 1.5" Overlay 1.5"

PCC Pavements
- Year 15 – Clean and Reseal Joints
- Year 30 – Clean and Reseal Joints

At year 40, a salvage value for each alternative is determined. This salvage value is calculated by taking the total quantity of all paving from the rehabilitation and the original structure and assigning a value equal to that of dense-graded aggregate.

The material unit costs were determined by developing a weighted average cost based on information obtained from three years of unit bid prices. This weighted average was determined based on the quantity of materials in each bid. The unit costs utilized in the LCCA analysis are given in Table 1.

Table 1. Weighted Average Unit Bid Prices

Item Code	Description	Unit Cost ($)	Units
1	DGA	13.09	TON
18	DRAINAGE BLANKET TYPE II	23.79	TON
134	BIT CONC BASE CLASS CK PG64-22	30.20	TON
137	BIT CONC BASE CLASS CI PG64-22	31.66	TON
139	BIT BASE CL CI PG76-22 W/50%ER	37.70	TON
190	BIT MIX LEVEL & WEDG PG64-22	31.57	TON
243	BIT SURF CL AK/A PG76-22/50%ER	46.12	TON
246	BIT CONC SURF CL AK/S PG64-22	31.48	TON
356	BIT TACK COAT	233.49	TON
2069	PCC PAVEMENT-10 INCH NON-REINF	29.87	SQ YD
2073	PCC PAVEMENT-9 INCH NON-REINF	28.15	SQ YD
2107	BREAKING & SEATING PVMNT.	1.00	SQ YD
2115	SAW-CLEAN-RESEAL TVERSE JOINT	2.35	LIN FT
2116	SAW-CLEAN-RESEAL LONGIT JOINT	1.75	LIN FT
2677	PAVEMENT MILLING	17.62	TON

User Cost Analysis

As was previously outlined, the user costs for the project were evaluated based on procedures outline in Research Report FHWA-SA-98-079. This procedure calculates the user delay cost based on the reduction in capacity of the highway which was based on the parameters of the construction work zone. Separate analyses of user costs were conducted for each design section due to the differences in traffic volumes. User costs were calculated both for the initial construction phase of the project and for rehabilitation at years 10,15, 20, and 30. These user costs were based on current and projected traffic levels in each of the rehabilitation years. Daily user costs and average length of queue were determined at each of these time intervals. Costs associated with user delay, idling, stopping, and etc. were determined from Research Report FHWA-SA-98-079. During the initial construction and each of the subsequent rehabilitations the work zone parameters, such as number of lanes and working hours must be identified. The following scenarios were utilized for this analysis

Initial Construction
- 2 lanes open, 24 hours per day

Rehabilitation Years 10, 15, and 20
- 2 lanes open, 6 p.m. - 6 a.m.
- 3 lanes open, 6 a.m. - 6 p.m.

Rehabilitation Year 30
- 2 lanes open 7 p.m. - 6 a.m.
- 3 lanes open 6 a.m. - 7 p.m.

Based on this analysis, the expected user costs for both sections of the project are given in Table 2

Table 2. User Cost Analysis

Activity	Improvement Year	Project Length (days)	Traffic Vol. One Way	1-Direction Daily User Cost ($)	1-Direction Project User Cost ($)	Avg. Queue Length (mi)
Section 1 MP 1.05-4.06						
Initial Construciton	2000	120	43,000	16,186	1,942,377	0.8
Year 10 Rehabilitation	2010	30	52,417	5,318	159,547	0.3
Year 15 Rehabilitation	2015	30	57,872	10,463	313,888	0.7
Year 20 Rehabilitation	2020	30	63,896	28,518	855,533	1.8
Year 30 Rehabilitation	2030	30	77,889	27,634	829,006	1.0
Section 2 MP 4.06 - 7.15						
Initial Construction	2000	120	26,500	5,179	621,504	0.0
Year 10 Rehabilitation	2010	30	32,303	5,867	176,018	0.0
Year 15 Rehabilitation	2015	30	35,666	2,853	85,604	0.0
Year 20 Rehabilitation	2020	30	39,378	3,150	94,514	0.0
Year 30 Rehabilitation	2030	30	48,001	2,445	73,343	0.0

The summary of the LCCA is contained in Table 3 for Section 1 and Table 4 for Section 2 and in Figures 5 and 6

Table 3. LCCA summary MP 1.05 - 4.06

Alternate 1A 13" AC Overlay	Improvement Year	Discount Rate 0 Cost ($) Agency	User	2 Cost ($) Agency	User	4 Cost ($) Agency	User	6 Cost ($) Agency	User	8 Cost ($) Agency	User	10 Cost ($) Agency	User
Initial Construction Alt 1A	2000	2,241,879	1,942,377	2,241,879	1,942,377	2,241,879	1,942,377	2,241,879	1,942,377	2,241,879	1,942,377	2,241,879	1,942,377
Rehabilitation #1	2010	334,292	159,547	274,236	130,884	225,836	107,784	186,667	89,090	154,842	73,901	128,884	61,512
Rehabilitation #2	2020	334,292	855,533	224,969	575,749	152,567	390,454	104,234	266,759	71,722	183,553	49,690	127,170
Rehabilitation #3	2030	334,292	829,006	184,553	457,670	103,069	255,598	58,204	144,338	33,221	82,384	19,158	47,509
Salvage	2040	-2,023,762		-916,542		-421,527		-196,755		-93,156		-44,715	
	Subtotal	1,220,995	3,786,464	2,009,095	3,106,681	2,301,823	2,696,214	2,394,230	2,442,565	2,408,509	2,282,216	2,394,897	2,178,568
	Total NPV		5,007,458		5,115,776		4,998,037		4,836,795		4,690,725		4,573,465

Alternate 1B 10" PCC Overlay	Improvement Year	Discount Rate 0 Cost ($) Agency	User	2 Cost ($) Agency	User	4 Cost ($) Agency	User	6 Cost ($) Agency	User	8 Cost ($) Agency	User	10 Cost ($) Agency	User
Initial Construction Alt 1B	2000	2,742,815	1,942,377	2,742,815	1,942,377	2,742,815	1,942,377	2,742,815	1,942,377	2,742,815	1,942,377	2,742,815	1,942,377
Rehabilitation #1	2015	145,260	313,888	107,930	233,223	80,658	174,291	60,612	130,975	45,792	98,951	34,774	75,142
Rehabilitation #2	2030	145,260	829,006	80,194	457,670	44,786	255,598	25,291	144,338	14,436	82,384	8,325	47,509
Salvage	2040	-1,834,075		-830,635		-382,018		-178,313		-84,424		-40,524	
	Subtotal	1,199,260	3,085,272	2,100,304	2,633,271	2,486,241	2,372,266	2,650,405	2,217,690	2,718,618	2,123,712	2,745,390	2,065,029
	Total NPV		4,284,532		4,733,575		4,858,508		4,868,096		4,842,331		4,810,419

Table 4 LCCA Summary, MP 4.06 - 7.15

Alternate 1A 12" AC Overlay	Improvement Year	Discount Rate											
		0		2		4		6		8		10	
		Cost ($)		Cost ($)		Cost ($)		Cost ($)		Cost ($)		Cost ($)	
		Agency	User	Agency	User	Agency	User	Agency	User	Agency	User	Agency	User
Initial Construction Alt 1A	2000	4,315,106	1,243,009	4,315,106	1,243,009	4,315,106	1,243,009	4,315,106	1,243,009	4,315,106	1,243,009	4,315,106	1,243,009
Rehabilitation #1	2010	686,354	352,037	563,050	288,793	463,676	237,824	383,257	196,576	317,915	163,061	264,619	135,725
Rehabilitation #2	2020	686,354	189,027	461,897	127,210	313,243	86,269	214,009	58,940	147,256	40,555	102,022	28,098
Rehabilitation #3	2030	686,354	146,687	378,916	80,981	211,616	45,226	119,501	25,540	68,208	14,577	39,334	8,406
Salvage	2040	-4,017,626		-1,819,544		-836,827		-390,602		-184,935		-88,769	
	Subtotal	2,356,543	1,930,759	3,899,425	1,739,993	4,466,814	1,612,328	4,641,270	1,524,063	4,663,550	1,461,203	4,632,312	1,415,238
	Total NPV		4,287,303		5,639,417		6,079,142		6,165,334		6,124,753		6,047,551

Alternate 1B 9" PCC Overlay	Improvement Year	Discount Rate											
		0		2		4		6		8		10	
		Cost ($)		Cost ($)		Cost ($)		Cost ($)		Cost ($)		Cost ($)	
		Agency	User	Agency	User	Agency	User	Agency	User	Agency	User	Agency	User
Initial Construction Alt 1B	2000	5,307,153	1,243,009	5,307,153	1,243,009	5,307,153	1,243,009	5,307,153	1,243,009	5,307,153	1,243,009	5,307,153	1,243,009
Rehabilitation #1	2015	257,955	171,208	191,665	127,210	143,234	95,066	107,636	71,439	81,318	53,972	61,752	40,986
Rehabilitation #2	2030	257,955	146,687	142,410	80,981	79,532	45,226	44,913	25,540	25,635	14,577	14,783	8,406
Salvage	2040	-3,632,520		-1,645,133		-756,614		-353,162		-167,208		-80,260	
	Subtotal	2,190,544	1,560,903	3,996,094	1,451,200	4,773,305	1,383,300	5,106,540	1,339,987	5,246,898	1,311,558	5,303,429	1,292,401
	Total NPV		3,751,447		5,447,294		6,156,606		6,446,527		6,558,456		6,595,829

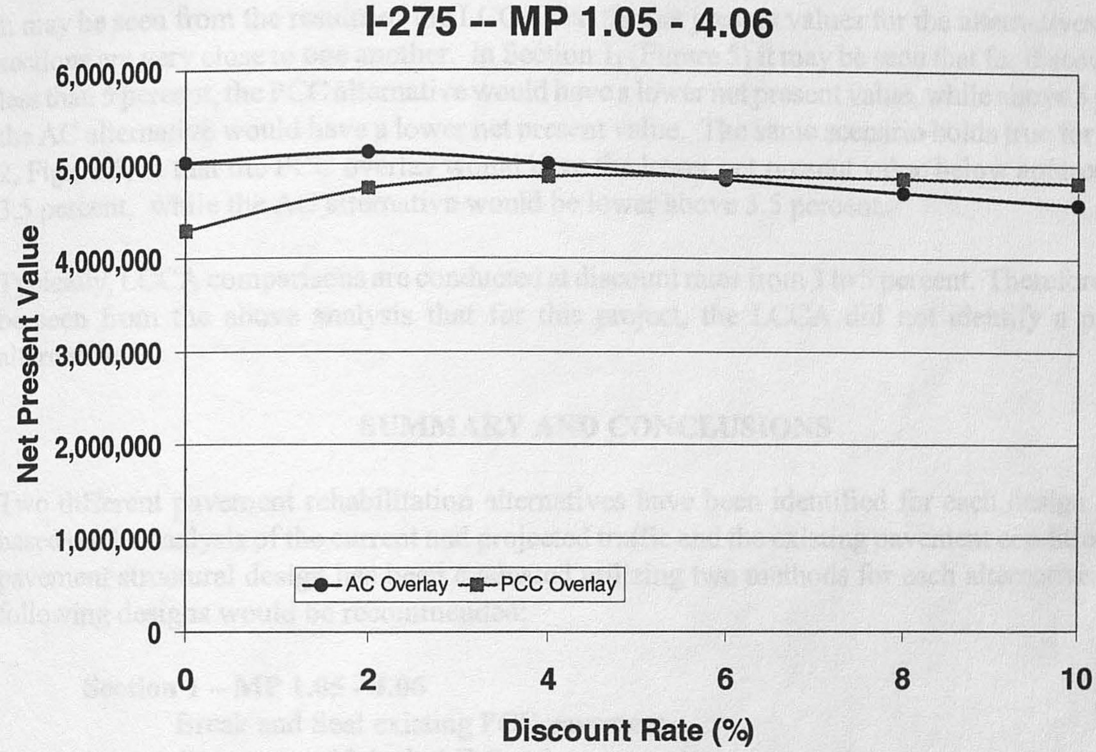

Figure 5 Net Present Value, MP 1.05 - 4.06

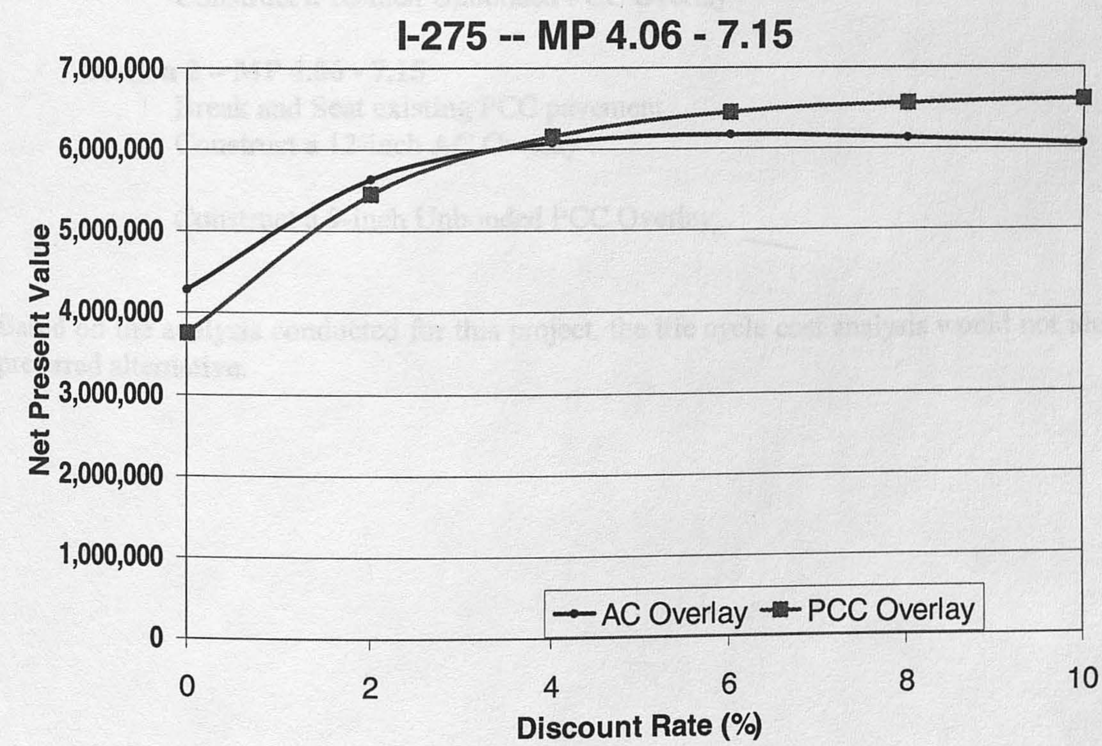

Figure 6. Net Present Value, MP 4.06 - 7.15

It may be seen from the results of the LCCA that the net present values for the alternatives in both sections are very close to one another. In Section 1, (Figure 5) it may be seen that for discount rates less than 5 percent, the PCC alternative would have a lower net present value, while above 5 percent, the AC alternative would have a lower net present value. The same scenario holds true for Section 2, Figure 6, in that the PCC overlay would have the lower net present value below approximately 3.5 percent, while the AC alternative would be lower above 3.5 percent.

Typically, LCCA comparisons are conducted at discount rates from 3 to 5 percent. Therefore, it may be seen from the above analysis that for this project, the LCCA did not identify a preferred alternative.

SUMMARY AND CONCLUSIONS

Two different pavement rehabilitation alternatives have been identified for each design section, based on the analysis of the current and projected traffic and the existing pavement conditions. The pavement structural design has been evaluated utilizing two methods for each alternative and the following designs would be recommended:

Section 1 – MP 1.05 - 4.06

Break and Seat existing PCC pavement
Construct a 13-inch AC Overlay
or
Construct a 10-inch Unbonded PCC Overlay

Section 2 – MP 4.06 - 7.15

Break and Seat existing PCC pavement
Construct a 12-inch AC Overlay
or
Construct a 9-inch Unbonded PCC Overlay

Based on the analysis conducted for this project, the life cycle cost analysis would not identify a preferred alternative.

REFERENCES

Walls, J, and Smith, M, "Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin", Federal Highway Administration, FHWA-SA-98-079, September 1998.

Deen, R.C., and Southgate, H.F., "Pavement Designs Based on Work", Kentucky Transportation Research Program, UKTRP-88-29, October 1988.

"AASHTO Guide for Design of Pavement Structures", American Association of State Highway and Transportation Officials, 1993.