Life-Cycle, Cost, and Loading Characteristics of AASHO-Designed Rigid and Flexible Pavements in Louisiana (1965–1989)

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This report represents a study undertaken to determine the life cycle, load characteristics, and associated costs of a representative sample of the oldest rigid and flexible pavements designed in Louisiana (1963–1967) using the AASHO Guide for Design of Pavement Structures. Project selection resulted in a sampling of two classes of roads designed and constructed during this period—Interstate route jointed concrete pavements and secondary route asphaltic concrete pavements. An index, termed the Load Rate Index, was developed to compare actual and designed rates of equivalent single-axle loading (*EAL*) at any point in the life of a pavement. The total accumulated *EAL* was also compared with the total designed *EAL*. The typical jointed concrete pavement had not reached end of life by its 20th year (1989), having carried its design *EAL*. The effects of factors of safety used in the original design were removed by relating design *EAL* to actual section thickness. The typical flexible pavement in the sample reached end of life within 14 years. The performance of these pavements was characterized by cracking and settlement within the cement-treated bases. Total project costs (construction plus maintenance) prior to end of life were expressed in terms of cost per mile, per *EAL* ($*EAL*-mile), to represent pavement value or return on investment for each route class. It is concluded that expressions of pavement value to be incorporated into Louisiana's pavement management system should include the rate and quantity of designed load actually carried before end of life.

The purpose of this study was to select and evaluate a representative sample of rigid and flexible pavements from the original population of projects designed and constructed between 1963 and 1967 using the Louisiana—AASHO Design Guide for Pavements (*1,2*). It was hoped that, by studying the life-cycle and associated costs of the sampled pavements, a general indication of design adequacy could be formulated and that some of the basic information needed to characterize pavement types for life-cycle cost studies could also be obtained.

One data element of particular interest was the accumulated, equivalent 18-kip, single-axle loads (*EAL*s) as compared with original design estimates, both in terms of magnitude and rate of accumulation.

The sampling of jointed portland cement concrete pavements resulted in mostly Interstate route projects reflecting the typical type of rigid pavement designed during this period in Louisiana. The sample of asphaltic concrete pavement designs resulted in a set of pavements that could be described as secondary class routes or rural collector roads.

All of the project information collected during the study, including accumulated *EAL*, pavement age, condition, and associated costs, represents information available at the end of the 1987 calendar year. Actual *EAL*s carried by the Interstate concrete pavements and their ages have been updated through 1989.

PROJECT SELECTION

The group of projects most representative of rigid pavement construction typically consisted of 10 in. of jointed concrete with a 58.5-ft joint spacing constructed over a 6-in. base of either untreated granular material, cement-treated granular material (sand-clay-gravel), or cement-stabilized soil. This sample of jointed concrete was developed by selecting all available designs that exceeded one mile in length, for which construction costs could be determined, and that represented normal mainline section design. A smaller number of jointed concrete projects, 8 or 9 in. thick, with 20-ft joint spacing was also included to represent non-Interstate construction. Altogether, 22 concrete projects were selected for evaluation; 15 represented Interstate construction, and 7 represented U.S. route or state route construction.

Flexible pavements selected for evaluation were typically 3.0- to 5.0-in. asphalt concrete with an 8.5-in., cement-treated base course. Again, all available projects representing this type of design were selected for evaluation, resulting in 22 sample pavements. The base courses were constructed by stabilizing in place either sand-clay-gravel or select soils with portland cement.

PAVEMENT DESIGN CONSIDERATIONS

Concrete pavements in the study were constructed using a 5.8-sack, river gravel mix that was designed to provide a minimum of 3,600 psi compressive strength at 28 days. No routine measurements were made of flexural strength; however, a conservative value of 450 psi was used in design to provide a factor of safety.

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Published conversions of compressive to flexural strength indicate the following relationships (*3*):

flexural psi = (7 to 10) (compressive, psi)$^{0.5}$

Using the conversion, a factor of between 7 and 10 is multiplied by the square root of the compressive strength. Applying the formula to 3,600 psi results in values of flexural strength of between 420 and 600 psi. Measured values of flexural strength (third point loading) for the 5.8-sack, gravel aggregate concrete described are typically around 550 psi. The concrete used at the AASHO Road Test had a higher strength (690 psi) as a result of a higher cement factor and the use of dolomitic limestone as the coarse aggregate.

Summary statistics that involve "design *EAL*" in this report are provided across a range of flexural strengths to illustrate the sensitivity of design *EAL* (from the design guide) for a given thickness of concrete to variation in 28-day flexural strength. The values selected for this purpose are 450, 550, and 600 psi.

The modulus of subgrade reaction (composite *K*-value) used in the original designs was typically set at 120 for both cement-treated and granular subbases. Recommended design thickness was rounded upward to the next higher inch, and Interstate route pavements were specified to be a minimum of 10 in. thick. For the purposes of this study, values referred to as "design *EAL*" represent the *EAL*s that a 10-in. concrete pavement should, according to the AASHO design relationship, be able to carry. This was done to provide continuity between pavement section, performance, and *EAL* by effectively removing the factors of safety from the design data analysis.

The Louisiana-AASHO design for flexible pavements required a regional factor of 1.5 for projects constructed in northern Louisiana (above the 31st parallel) and 1.0 for those constructed below that line. The effect of the 1.5 regional factor was "factored out" of the data analysis in this study by relating design *EAL* to the actual structural number specified for construction. This process therefore allowed all of the asphaltic concrete pavements to be represented by the same basic design relationships.

LIFE CYCLE AND PERFORMANCE

The number of years between opening to traffic and structural overlay or rehabilitation was determined for each project that reached end of life. This was accomplished using a Louisiana Department of Transportation and Development (DOTD) computer file named Record of Control Units and Jobs (RCUJ). The file lists each construction project undertaken within specified project limits. For those projects where no action was indicated, a field condition survey was conducted to determine the condition of each pavement section.

The results of the 1987 project life survey indicated that out of a sample of 22 jointed concrete pavements, 19 had not reached end of life and the average age of the surviving projects was 17.5 years. Of the three concrete projects that were considered to have reached end of life, one had been resurfaced. The other two pavements had not been scheduled for overlay but contained frequent joint spalling and blowups and, therefore, were considered to be at end of life. None of the 10-in. jointed concrete pavements constructed on Interstate routes fell into the end-of-life group. An update in 1989 indicated that these pavements had not reached end of life at an average age of 20 years.

A survey of the flexible pavement projects indicated that, out of a sample of 22 pavements, 17 had reached end of life and the average age of the projects overlaid or reconstructed was 14.2 years. The condition of the five surviving, asphaltic concrete over cement-treated base pavements provided a clue to the probable mode of failure of this group. The performance of this group was characterized by a loss in serviceability due to transverse and longitudinal block cracking, which was heavily spalled in the wheel paths occasionally having required patching. Pavement ride was adversely affected by depressions that occurred along transverse cracks and by occasional buckling, somewhat similar to blowups that occur on jointed concrete pavements. This mode of failure is characteristic of this type of pavement in Louisiana and is thought to be principally related to performance of the cement-treated base course.

Table 1 contains a summary of the life cycle and the number of projects reaching end of life for each pavement type. Within the rigid pavement group, the surviving projects are considered to be representative of performance as they represent 86 percent of the sample. Within the flexible pavement group, the projects that reached end of life are considered representative as they make up 77 percent of that sample.

TRAFFIC LOAD

The magnitude and rate of application of traffic *EAL* are among the most difficult design factors to predict correctly over an extended design period and are often overlooked in analyses of project life-cycle cost. In historical studies of specific paving projects, it seems reasonable to include *EAL* as a factor that contributes to performance, where this type of information is available.

Estimates of actual accumulated *EAL* were calculated from traffic classification data and traffic volume data provided by the department's Traffic and Planning Section. Past research studies have indicated that this method provides reasonable results compared to similar data obtained from Weigh-in-Motion and vehicle classification studies (*3*).

The variable of traffic loading was evaluated from two perspectives: (1) the rate of accumulation of *EAL* and (2) the ratio of actual to design *EAL* over the life of each project. An index termed the Load Rate Index (*LRI*) was developed to compare actual to design rates of loading at any stage in the life of a pavement:

$$LRI = \frac{Yd\ (EAL\ \text{actual})}{Ya\ (EAL\ \text{design})}$$

where

Yd = design period in years,
Ya = current age in years,
EAL actual = current accumulated EAL, and
EAL design = designed total EAL.

Using a design period of 20 years, the relationship can be

TABLE 1 PROJECT LIFE CYCLE (1987)

	End of Life		Survivors	
	Sample %	Age (yrs)	Sample %	Age (yrs)
Rigid (22 projects) (std)	13.64	17.97 (1.34)	86.36	17.54 * (1.94)
Flexible (22 projects) (std)	77.27	14.16 * (4.18)	22.73	17.58 (0.80)

* This group is considered to be representative of each respective pavement type.

(std) = sample standard deviation

TABLE 2 PROJECT LOAD DATA

	Concrete Flexural Strength (psi)	Load Rate Index (LRI)	Actual EAL / Design EAL
Rigid (Survivors) (std) (1989)	450	2.61 (0.65)	2.58 (0.60)
	550	1.35 (0.34)	1.33 (0.31)
	600	1.00 (0.25)	0.98 (0.23)
Flexible (End of Life) (std) (1987)		1.11 (0.88)	0.79 (0.58)

These values are considered to represent each respective pavement type. (Thin pavements are not included.)

(std) = sample standard deviation

expressed as

$$LRI = \frac{20\ (EAL\ \text{actual})}{Ya\ (EAL\ \text{design})}$$

$LRI = 1.0$, indicates actual loading rate is as designed;
$LRI < 1.0$, actual loading rate is less than designed; and
$LRI > 1.0$, actual loading rate is greater than designed.

Tables 2, 4, and 5 contain the *LRI* values that characterize the rigid and flexible pavements in the study. All values of actual load carried for the rigid survivors were calculated as of 1989. The data indicate a higher than anticipated rate of loading for the 10-in. Interstate pavements and generally a lower than anticipated rate for most of the 8-in. and 9-in. concrete pavements. The thinner concrete pavements were found to occur primarily in urban areas where automobile and pickup trucks comprised a majority of the traffic volume. The typical flexible pavement (Table 2) was loaded at a rate closer to the rate envisioned in the original pavement designs. Figures 1 and 2 depict the project frequency distribution of *LRI* for projects considered to represent each pavement type.

The actual accumulated *EAL* carried prior to end of life is an important indicator of the performance of any pavement. A simple ratio of actual-to-design accumulated *EAL* is provided in Table 2 for this purpose. It can be seen that, even at a concrete flexural strength of 600 psi, the 10-in. Interstate

TABLE 3 INTERSTATE PROJECTS—TOTAL LOAD AND AGE (1989)

PROJECT NUMBER	LIFE CYCLE as of 1989	ACTUAL LOAD 1989
450-04-13	22.92	27,963,900
450-05-04	20.17	20,278,032
450-06-01	16.75	24,365,979
451-06-21	20.08	20,883,251
451-06-22	21.08	19,677,409
451-07-03	21.08	16,132,426
451-07-07	20.50	15,817,774
451-07-09	19.17	12,362,491
454-01-07	18.33	24,701,277
454-02-01	19.25	18,342,650
454-02-05	18.42	18,016,512
454-02-06	21.00	16,947,768
454-02-07	18.33	14,624,318
454-02-08	20.00	14,895,236
454-02-09	20.00	15,104,098
Averages	19.81	18,674,208

pavements have carried their design *EAL*. The magnitudes of estimated *EAL* as of 1989 are listed in Table 3 for the 15 Interstate pavements along with years of service. The data indicate an average total *EAL* of 18.7 × 10^6 carried at an average age of 19.8 years. Table 4 contains a listing of traffic loading characteristics by project.

The sample representing flexible pavement construction typically carried less than their design load (79 percent) prior to end of life. This effect is thought to be due to the absence of a factor of safety in the design procedure and to surface roughness caused by the performance of the cement-treated bases used in most of the pavements in the sample. In general, if these pavements had performed for 5 additional years and had carried an additional 21 percent designed load, they would have met minimum design load expectations. Table 5 contains a listing of traffic loading characteristics by project.

These findings closely parallel the results of a 1979 research study entitled "Performance Evaluation of Louisiana's AASHO Satellite Test Sections" (*4*), in which the life cycle and *EAL* of a sample of rigid and flexible pavements were investigated. The projects in the 1979 study were not actually designed using the AASHO procedure; therefore, design *EAL* had to be backcalculated from pavement thickness information. In the study it was concluded that the typical flexible pavement reached end of life in 13 years and carried less than the designed *EAL*.

The design adjustments made as a result of these findings provided a more realistic link between the flexible pavement materials design coefficients for asphaltic concrete ($c = 0.44$ lowered to $c = 0.40$) and the specified Marshall properties. The effect of these changes could possibly have extended the life of the flexible pavements in the current study had the adjusted design values been used back in the mid-1960s. For example, the effect would have been to add approximately 1 in. of asphaltic concrete to the 5.0-in. A.C./8.5-in. C.T.B. pavements in this study.

COST DATA

Project cost information was obtained by examination of the final estimate data for construction projects, which also included any changes in planned quantities or materials. Maintenance costs were available on computer file and were cross-referenced to original construction project limits using log-mile as a location identifier. Construction costs, which make up a majority of the total project costs, were not adjusted forward or backward to reflect the time change in dollars since most projects were constructed during the same time period.

Construction costs reflect the cost of only the pavement section itself—surface, base, and subbase for a 24-ft-wide

TABLE 4 PROJECT LIFE CYCLE AND LOAD DATA RIGID (SURVIVORS)

PROJECT NUMBER	CONCRETE THICKNESS (inches)	LIFE CYCLE (years)	ACTUAL EAL / DESIGN EAL	LOAD RATE INDEX
052-30-06	8.0" PCCP	19.42	0.06	0.06
424-04-04	8.0" PCCP	21.00	1.06	0.77
055-30-03	9.0" PCCP	22.42	0.11	0.12
062-01-09	9.0" PCCP	14.50	1.23	1.38
450-04-13	10.0" PCCP	22.92	2.00	1.74
450-05-04	10.0" PCCP	20.17	1.45	1.44
450-06-01	10.0" PCCP	16.75	1.74	2.08
451-06-21	10.0" PCCP	20.08	1.49	1.49
451-06-22	10.0" PCCP	21.08	1.41	1.33
451-07-03	10.0" PCCP	21.08	1.15	1.09
451-07-07	10.0" PCCP	20.50	1.13	1.10
451-07-09	10.0" PCCP	19.17	0.88	0.92
454-01-07	10.0" PCCP	18.33	1.76	1.92
454-02-01	10.0" PCCP	19.25	1.31	1.36
454-02-05	10.0" PCCP	18.42	1.29	1.40
454-02-06	10.0" PCCP	21.00	1.21	1.15
454-02-07	10.0" PCCP	18.33	1.04	1.14
454-02-08	10.0" PCCP	20.00	1.06	1.06
454-02-09	10.0" PCCP	20.00	1.08	1.08

TABLE 5 PROJECT LIFE CYCLE AND LOAD DATA FLEXIBLE (END OF LIFE)

PROJECT NUMBER	ASPHALT THICKNESS	LIFE CYCLE (years)	ACTUAL EAL / DESIGN EAL	LOAD RATE INDEX
058-02-06	3.0" AC	12.25	1.22	1.99
859-12-05	3.0" AC	17.33	0.35	0.40
070-02-10	3.5" AC	14.17	0.66	0.93
071-02-01	3.5" AC	15.25	2.08	2.73
071-03-01	3.5" AC	16.00	1.48	1.86
156-03-07	3.5" AC	22.33	0.64	0.57
173-01-17	3.5" AC	10.25	0.36	0.71
177-01-06	3.5" AC	21.00	1.04	0.99
224-02-16	3.5" AC	14.42	0.63	0.88
228-06-12	3.5" AC	13.92	0.06	0.08
414-02-02	3.5" AC	9.17	0.14	0.30
414-03-04	3.5" AC	7.08	0.06	0.17
005-07-34	4.5" AC	9.00	0.22	0.49
028-02-13	5.0" AC	10.33	1.63	3.15
034-04-08	5.0" AC	17.58	0.89	1.01
034-05-14	5.0" AC	14.50	1.08	1.49
805-15-03	5.0" AC	16.08	0.89	1.11

pavement section—expressed as cost per mile. Maintenance cost data include that of all maintenance work undertaken within the original project limits but do not include the cost of a structural overlay for those projects that reached end of life and were subsequently resurfaced.

Calculations were made of maintenance cost expressed as a percentage of total cost (maintenance plus construction) to provide an indication of the relative magnitude of maintenance expenditures. This information, included in Table 6, indicates that approximately 7 to 9 percent of the total project cost is represented by maintenance expenditures, for both rigid and flexible pavements in this study.

PAVEMENT VALUE

The value of a pavement system to an agency can be expressed in terms of total cost (at some identifiable point in time) per total *EAL* carried to that point. This measure of the return on an investment is a necessary recognition of the fact that pavement systems that are designed to carry a large total *EAL* during their life span will be relatively move expensive to construct. The identifiable time for calculation of total cost per *EAL*-mile for the flexible pavement sample in this study was selected to be end of life. A majority of the rigid pavements sampled did not reach end of life; however, since these pavements have carried more than the total *EAL* designed, the cost per *EAL*-mile statistic has meaning as an index of current value to the agency.

The total project cost per *EAL*-mile calculation can be accomplished using a variety of methods, since costs and loads vary with number of lanes. Table 7 contains six formulas for calculating this information, depending on the number of lanes (two or four) and on whether cost and load data are based on critical (design) lane only, direction (roadway), or total project data per mile. The critical lane approach was selected for this study because design loads typically are calculated on the basis of the critical or design lane.

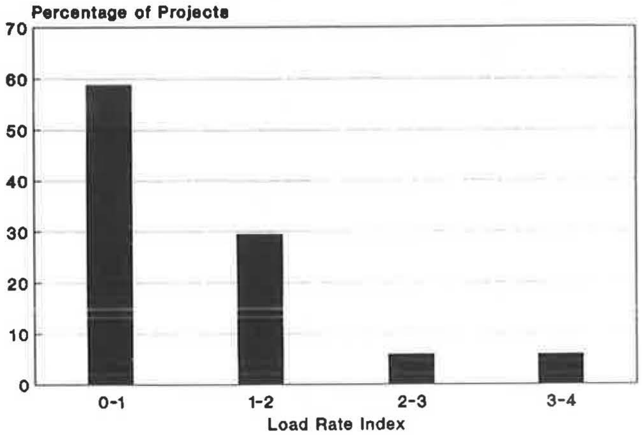
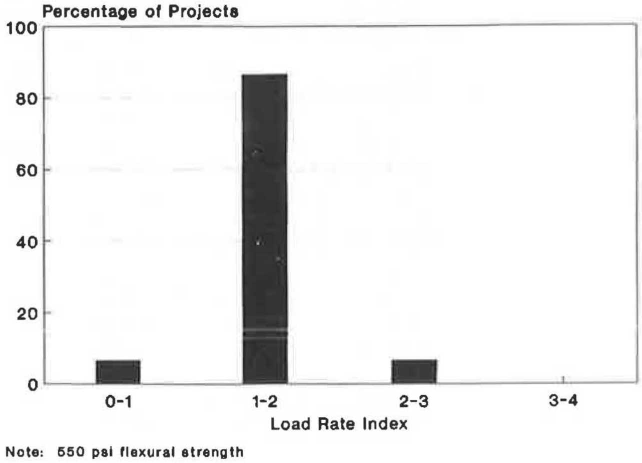


FIGURE 1 Load Rate Index for flexible pavements (end of life).



Note: 550 psi flexural strength

FIGURE 2 Load Rate Index for rigid pavements (survivors—10-in. pavements).

TABLE 6 PROJECT COST DATA

	Interstate Rigid (Survivors)	Secondary Flexible (End of Life)
Construction ($/mile)	134,040.81	70,222.28
Maintenance ($/mile)	7,601.18	5,234.21
Total ($/mile)	141,641.99	75,456.48
Maintenance / Total (%)	7.24	8.60
$ / EAL-mile (critical lane)*	0.01	0.12

* Note: The cost per unit load data should not be used to compare the two pavement types since they represent different road classes.

TABLE 7 FORMULAS FOR COMPUTATION OF TOTAL COST/*EAL*-MILE

Number of Lanes	Critical (Design) Lane	Directional Roadway	Project Basis
2	$\frac{\text{Total Cost} / 2}{\Sigma \text{ Actual EAL}}$	$\frac{\text{Total Cost} / 2}{\Sigma \text{ Actual EAL}}$	$\frac{\text{Total Cost}}{2 * \Sigma \text{ Actual EAL}}$
4	$\frac{\text{Total Cost} / 2}{0.9 * \Sigma \text{ Actual EAL}}$	$\frac{\text{Total Cost}}{\Sigma \text{ Actual EAL}}$	$\frac{2 * \text{Total Cost}}{2 * \Sigma \text{ Actual EAL}}$

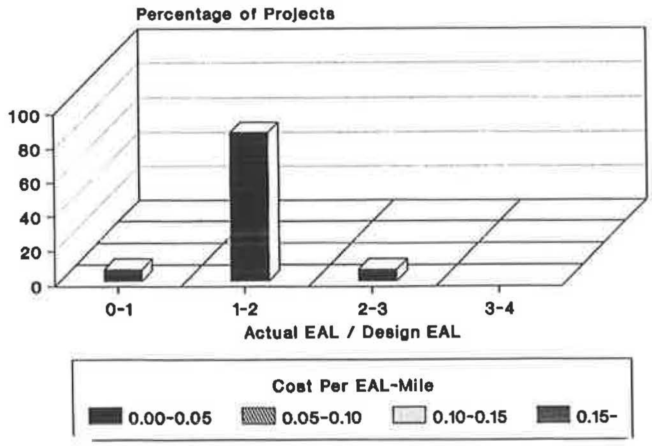
Total Cost = Cost for 24' width per mile

The costs per unit load data provided are not appropriate methods for comparing the two types of pavement presented since they represent quite different classes of road. Unit load costs will always be relatively higher for lower-class roads because of the lower total load carried by these systems and because of the relationship between section thickness and design load (i.e., much more total *EAL* carried for an increasingly smaller additional pavement thickness).

The best use of cost per unit load data is to compare the value of pavements within the same road class that are subjected to similar total applications of *EAL*. This process could have been used, for instance, to compare flexible and rigid pavement systems on Interstate routes. However, there was an insufficient number of full-depth asphaltic concrete pavements of similar age on Interstates to permit such a comparison in this study. Eventually, as the pavement management system of the Louisiana DOTD matures, it is expected that an improved database will be available for determination of relative pavement value.

Figures 3 and 4 provide three-dimensional bar charts of project distribution considering "cost per unit load" as an indicator of relative value and the quantity "*EAL* carried/*EAL* designed" as a general indicator of design adequacy. The pavement management process within an agency can utilize project analyses such as these to determine the expected norm for a route class and to identify individual pavements within that class that vary significantly from the norm.

It becomes obvious from such examples that pavement value analysis methods utilizing life-cycle costing techniques that do not account for the actual *EAL* carried by a pavement may not necessarily represent the true value of the system to the agency.



Note: 550 psi flexural strength

FIGURE 3 Load-cost characteristics for representative rigid pavements (sample percent).

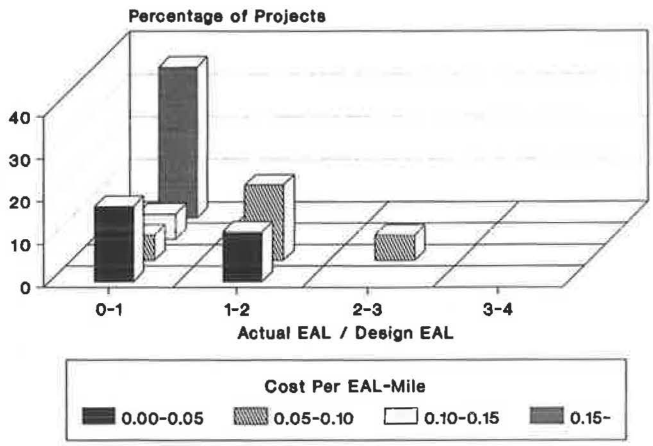


FIGURE 4 Load-cost characteristics for representative flexible pavements (sample percent).

CONCLUSIONS

An expression of the value of a pavement system to a transportation agency should ideally contain some index of the amount of total designed *EAL* carried prior to end of life. While it may be appropriate to assume that design loading rates and actual loading rates are equal for theoretical life-cycle analyses, this assumption can be misleading when evaluating actual project data.

One such indicator of relative pavement value is total cost (per mile) over the life of a pavement, expressed as a ratio of *EAL* carried prior to end of life ($/*EAL*-mile). This index will be incorporated into Louisiana's Pavement Management System as an indicator of relative performance.

The 10-in. jointed concrete pavements constructed on Interstate using early Louisiana—AASHO designs have carried their designed *EAL* and are continuing to perform after 20 years of service as of 1989. The analysis used to arrive at this conclusion effectively removed the factors of safety used in the original design procedure by associating design *EAL* with the final designed slab thickness.

The typical asphaltic concrete pavements with cement-treated bases (3.0- to 5.0-in. A.C./8.5-in. C.T.B.), designed for secondary class routes during the same period (1963–1967), were correctly designed in terms of expected rate of loading. The pavements reached end of life after approximately 14 years of service. Cracking and surface distortion associated with the performance of the cement-treated bases are believed to be the cause of the loss in serviceability.

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