# LIFE CYCLE, COST, AND LOADING CHARACTERISTICS OF AASHO DESIGNED RIGID AND FLEXIBLE PAVEMENTS IN LOUISIANA

## FINAL REPORT

BY

WILLIAM H. TEMPLE, P.E.
PAVEMENT MANAGEMENT RESEARCH ENGINEER

AND

STEVEN L. CUMBAA, P.E.
SPECIAL STUDIES RESEARCH ENGINEER

AND
DEBORAH A. BOLEWARE
RESEARCH ENGINEER I

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of a representative sample of the oldest rigid and flexible pavements designed in Louisiana (1963-1967) usin
Guide for Design of Pavement Structures.  Project selection resulted in a sampling of two classes of roads
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quantity of designed load actually carried prior to end of life.

# ABSTRACT

This report represents a study undertaken to determine the life cycle, load characteristics, and associated costs of
of the oldest rigid and flexible pavements designed in Louisiana (1963-1967) using the AASHO Guide for Design
Project selection resulted in a sampling of two classes of roads designed and constructed during this period--mostl
concrete pavements and secondary route asphaltic concrete pavements.

An index, termed the Load Rate Index, was developed to compare actual and designed rate of equivalent single-a
point in the life of a pavement. The total EAL accumulated versus designed EAL were also compared.

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to be incorporated into Louisiana's Pavement Management System should include the rate and quantity of designed l
to end of life.

# IMPLEMENTATION STATEMENT

The pavement data management concepts developed for this study will be incorporated into Louisiana's Pavement Management System as that system develops. Specifically, the Load Rate Index calculation will serve as a means of monitoring cumulative loading rate data as compared to the loading rate originally planned in each pavement design. This procedure will provide an indication of the reliability or accuracy of traffic load prediction procedures and the resulting data. The concept of cost per unit load carried by a pavement prior to "end-of-life" will be included as a means of comparing pavements within a route class, and within a pavement type. Using this procedure pavements which deviate significantly from an established norm can be identified and evaluated in terms of possible problems in materials, design, construction, or other factors which have reduced the value of that pavement to the transportation agency.

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# INTRODUCTION

The purpose of this study was to select and evaluate a representative sample of the oldest rigid and flexible pavements from the original population of projects designed with the AASHO Design Guide for Pavements (1, 2) and constructed between 1963 and 1967. 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 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) as compared to original design estimates, both in terms of magnitude and rate of accumulation.

The sampling of jointed portland cement concrete pavements resulted in an evaluation of 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 an evaluation of a set of pavements which 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 represent information available at the end of the 1987 calendar year.

## OBJECTIVE

This research study was initiated to examine and document the life cycle, load characteristics, and associated cost of Louisiana pavements designed by procedures outlined in the original AASHO Guide for Design of Pavement Structures.

## SCOPE

The scope of this research effort is limited to both flexible and rigid pavements designed in the mid 1960's and initially constructed between 1963 - 1967. Design, construction, traffic, and cost data were obtained from existing LADOTD files or procedures. Field evaluations to determine existing conditions were limited to those projects that to date have not received a structural overlay or have not undergone rehabilitation.

# METHODOLOGY

## Project Selection

The group of projects most representative of rigid pavement construction typically consisted of 10 inches of jointed concrete with a 58.5-foot joint spacing, placed over a 6-inch 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 which exceeded one mile in length, for which construction costs could be determined and which represented normal mainline section design. A smaller number of jointed concrete projects of 8- and 9-inch thickness with 20-foot joint spacing were also included to represent non-Interstate construction. Altogether 23 concrete projects were selected for evaluation, with 15 representing Interstate construction and 8 representing U.S. route or state route construction.

Flexible pavements selected for evaluation were typically 1.5- to 5.0-inch asphaltic concrete with an 8.5-inch cement-treated base course. Again, all available projects representing this type of design were selected for evaluation resulting in 27 sample pavements. The base courses were constructed by stabilizing in-place either sand-clay-gravel or select soils with portland cement.

For both pavement types there were projects considered to be outliers by either statistical analyses of factors involving load and cost, or because the pavement section was considered to be uncharacteristically thin. These projects were excluded from all summary statistics reported involving load and cost data. Therefore, the flexible pavements that were less than 3 inches thick and the rigid pavements that were less than 10 inches were eliminated from these summary statistics.

## Pavement Design Considerations

Concrete pavements in the study were constructed using a 5.8 sack, river gravel mix which was designed to provide a minimum of 3600 psi compressive strength at 28-days. There were no routine measurements made of flexural strength; however, a conservative value of 450 psi was used in design to provide a factor of safety.

Published conversions of compressive to flexural strength indicate the following relationships:

Flexural, psi = (7 to 10) (compressive, psi) $^{0.5}$, (3)

Using the conversion, a factor of between 7 and 10 is multiplied by the square root of the compressive strength. Applying the formula to 3600 psi results in values of flexural strength of between 420 and 600 psi. Measured values of flexural strength (3rd point loading) for the type of 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 which involve "design EAL" in this report are provided across a range of flexural strengths to illustrate the sensitivity of EAL from the design guide for a given thickness of concrete and 28-day flexural strength. The values selected for this purpose are 450, 550, and 600 psi; however, the 550 psi value is considered most representative of the 28-day strengths.

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 pavements were specified to be a minimum of 10-inches in thickness. For the purposes of this study, values referred to as "design EAL" represent the EAL's which a 10-inch concrete pavement (at the indicated strengths) should be able to carry according to the

AASHO design relationship. This was done to provide continuity between pavement section, performing, 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 north Louisiana (above the 31st parallel) and 1.0 for those constructed below that line. The use of a 1.5 regional factor increased pavement thickness beyond the level required by the true traffic load projections. As with the rigid pavement analysis, all values referred to as "design EAL" represent the EAL's which the as-constructed pavements should have been able to carry according to the design relationship. This process therefore allowed all of the asphaltic concrete pavements in the study 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 which reached end of life. This was accomplished using the LADOTD computer file, "Record of Control Units and Jobs" (RCUJ), which lists each construction project undertaken within specified limits. For those original projects where no overlay or rehabilitation was indicated, a field condition survey was conducted to determine the condition of each pavement section.

It is not known to exactly what terminal Serviceability Index level any project may have declined prior to overlay or reconstruction; however, these actions are very rarely taken prior to functional and/or structural end of life.

### Traffic Load

Estimates of actual accumulated EAL were calculated from traffic classification data and traffic volume data provided by the Department's Traffic and Planning Section. This was accomplished by calculating an average daily load. The average daily load was expanded to obtain a yearly load and the yearly loads for the project's life were summed to find the accumulated EAL as of end of the year 1987. A summary example is given in Appendix B. Past research studies have indicated that this procedure provides reasonable results when compared to similar data obtained from Weigh-In-Motion and vehicle classification studies (4). Total EAL was updated to include 1989 for the rigid pavement sample which had not reached end of life.

## 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 cost, 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 only the cost of the pavement section surface, base, and subbase for a 24-foot wide pavement section, expressed as cost per mile. Maintenance cost data includes all maintenance work undertaken within the original project limits but does not include the cost of a structural overlay for those projects which reached end of life and were subsequently resurfaced.

# RESULTS

## Life Cycle and Performance

The results of the project life survey as of 1987 indicated that out of a sample of 23 jointed concrete pavements, 20 had not reached end of life and the average age of the surviving projects was 17.5 years. Of the three concrete projects which 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 blow-ups, and therefore were considered to be at end of life. (Refer to Appendix A, Table A-1, page 33, for actual pavement conditions.) None of the 10-inch jointed concrete pavements constructed on Interstate routes fell into the end of life group. The results of the 1989 updates indicated that the Interstate concrete 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 27 pavements, 21 had reached end of life and the average age of the projects overlaid or reconstructed was 14.2 years. Table A-2 in Appendix A, page 36, lists the conditions of these pavements. The condition of the five surviving asphaltic concrete (cement-treated base) pavements provided a clue to the probable mode of failure of this group (Appendix A, Table A-3, page 37). The performance was characterized by a loss in serviceability due to transverse and longitudinal block cracking, which was heavily spalled in the wheel paths, occasionally requiring patching. Pavement ride was adversely affected by depressions which occurred along transverse cracks and by occasional buckling, somewhat similar to blow-ups which 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, page 10, contains a summary of the life cycle and the number of projects reaching end of life for each pavement type as of December 1987. Within the rigid pavement group, the surviving projects are considered to be representative of performance since they represent 87% of the sample. Within the flexible pavement group, the projects which reached end of life are considered representative since they make up 78% of that sample.

## Traffic Load

The magnitude and rate of application of traffic EAL are among the most difficult design factors to correctly predict 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 which contributes to performance, where this type of information is available.

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 as follows:

$$\text{LRI} = \frac{Y_d \text{ (EAL actual)}}{Y_a \text{ (EAL design)}} \text{, where}$$

$Y_d$ = design period in years
$Y_a$ = current age in years
EAL actual = current accumulated EAL
EAL design = designed total EAL

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

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

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

Table 2, page 13, contains the LRI values which characterize the representative (excluding the thin sections) rigid and flexible pavements in the study. The data indicates a higher than anticipated rate of loading for the 10-inch Interstate pavements. The typical flexible pavement (Table 2) was loaded at a rate close to the rate envisioned in the original pavement designs. Figures 1 and 2, pages 14 and 15, 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-inch Interstate pavements have carried their design EAL. The magnitudes of estimated EAL as of 1989 are listed in Table 3, page 16, for the 15 Interstate pavements along with years of service to date. The data indicates an average total EAL of $18.7 \times 10^6$ carried at an average age of 19.8 years.

Table 4, page 17, contains a listing of traffic loading characteristics of each rigid pavement project. For the concrete pavements less than 10-inches thick there exists a wide variation in load rate depending whether the pavement was located on a U.S. route or a small-town urban section. Table 5, page 18, contains a listing of traffic loading characteristics of each flexible pavement project. The sample representing flexible pavement construction often carried less than their design load 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 as a result of surface roughness caused by the performance of the cement-treated bases used in most of the pavement sections in the sample. In general, if these pavements had performed for five additional years and had carried an additional 21% designed load, they would have met minimum design load expectations.

These findings closely parallel the results of a 1979 research study entitled "Performance Evaluation of Louisiana's AASHO Satellite Test Sections" (5), 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 back-calculated 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 have possibly extended the life of the flexible pavements in the current (1987) study sampling had the adjusted design values been used back in the mid 1960's. For example, the effect would have been to add approximately one inch of asphaltic concrete to the 5.0-inch A.C./8.5-inch C.T.B. pavements in this study.

## Cost Data

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, page 20, indicates that approximately 7 to 9% 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 which are designed to carry a large total EAL over their life span will be relatively more expensive to construct. The identifiable point in 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, page 22, contains six formulas for calculating this information depending on number of lanes (2 or 4), and whether cost and load data is based on critical (design) lane only, direction (roadway), or total project data per mile. The critical lane approach was selected for this study since design loads are typically calculated based on the critical or design lane.

The cost per unit load data provided is not thought to be an appropriate basis for comparing the two types of pavement presented since they represent significantly 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 design relationship between section thickness and load, i.e., much more total EAL carried for an increasingly smaller additional pavement thickness. A good use of cost per unit load data is in comparing the value of pavements within the same route class which are subjected to similar total applications of EAL. Another important consideration when using "unit load costing" to compare rigid and flexible pavements is that the AASHTO Design Guides provide different traffic equivalence factors for the two pavement types. For this reason the EAL factor calculations should be normalized for comparative purposes. This was not undertaken for the data in the current study since rigid and flexible pavements were not specifically compared.

Figures 3 and 4, on pages 24 and 25, provide a three-dimensional bar chart 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 (systems) which significantly vary from that norm.

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

### Life Cycle Cost

Traditional life cycle costing techniques are not considered appropriate for the projects in this study since most of the rigid pavements have not completed their initial life cycles.

Information which can be realized from this study may, however, provide insight into the expected initial life cycles, modes of failure, maintenance costs and loading characteristics, all of which should play a part in a determination of overall pavement value.

It is felt that research is needed to develop a rational method of expressing an "effective life cycle cost" by accounting for the ratio of actual to design load carried prior to the end of life of a pavement.

# CONCLUSIONS

1. 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.

2. 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).

3. The 10-inch jointed concrete pavements constructed 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 all factors of safety used in the original design procedure by associating effective design EAL with the final designed slab thickness.

4. These concrete pavements have required maintenance primarily due to joint deterioration, a result of unsealed joints, and due to the absence of internal drainage during the first 15 years of service.

5. The typical asphaltic concrete pavements with cement-treated bases (3.0 to 5.0-inch A.C./8.5-inch C.T.B.), designed for secondary class routes during the same time period (1963-1967) were correctly designed in terms of expected rate of loading. These pavements (on the average) reached end of life after 14.2 years of service. Cracking and surface distortion associated with the performance of the cement treated bases are believed to be the causes of the loss in serviceability.

6. A method of expressing an "effective" life cycle cost needs to be developed which will account for the ratio of actual to design load carried prior to the end of life of a pavement.

# RECOMMENDATIONS

1. It is recommended that the cost per EAL - Mile index be incorporated into Louisiana's Pavement Management System as an indicator of relative value.

2. The concept of an "effective" life cycle cost which accounts for the relative magnitude of actual load to designed load carried prior to end of life should be developed as an indicator of pavement value. The concept can be applied incrementally to each stage of pavement life and summed over a selected analysis period.

3. Transverse contraction joints should be cleaned and resealed and internal pavement drainage should be upgraded periodically. It is felt that these actions would have significantly extended the serviceable life of the jointed concrete pavements in this study.

4. Methods of improving the performance of cement treated bases used in flexible pavements need to be developed and implemented.

# REFERENCES

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# APPENDIX A

# APPENDIX B