Analysis of an Operational Rigid-Pavement System for Continuously Reinforced Concrete Pavements

R. F. Carmichael, Austin Research Engineers Inc., Texas
B. F. McCullough and W. R. Hudson, Center for Highway Research, University of Texas at Austin

A diagnostic study of four, in-service, continuously reinforced concrete pavements in Texas was prepared by using computerized performance models in the rigid-pavement design system. The performance models were developed by the American Association of State Highway Officials, and the rigid-pavement design system was developed by the Center for Highway Research of the University of Texas at Austin, the Texas Transportation Institute at Texas A&M University, and the Texas State Department of Highways and Public Transportation. The study shows that use of performance models in the rigid-pavement design system reliably predicts the change in serviceability for continuously reinforced concrete pavements. Data gathered and used for the diagnostic study show that the number of 8165-kg (18-kip) equivalent axle loads had a great influence on the condition of the pavements and the predictions made by the design program. The results indicate that not only does the design program reliably predict service life, but that the designs produced by the program, in light of the performance of the four pavement sections, are reasonable for these in-service sections. Information is also presented that begins to establish the correct level of confidence that should be used in the design of Interstate-type continuously reinforced concrete pavements. The conclusions include the belief that the capabilities of the program as a design tool should be further studied so that the ultimate goal of program implementation can be achieved. Future modifications of the system should include a simplification of program input by deleting those variables that are insensitive to the design. Thus, the program can be used as a design tool because of its economic capability that allows for ranking various designs based on the costs of construction, traffic delay, maintenance, and overlay strategies.

The working model for a rigid-pavement design system (RPS) can be used to analyze the variables associated with such a design. This study demonstrates the usefulness and accuracy of RPS service life and design thickness predictions by using input data obtained from four, continuously reinforced concrete pavements (CRCP) in Houston, Texas. By using RPS, the designer has the capability of choosing certain confidence levels for design, and the results of this diagnostic study can be used to establish a tentative level of confidence for use in designing urban freeway pavements. These analyses were undertaken during the development of RPS3, which is the current program version (1). That version contains the same performance models as the previous RPS2 version (2), and the results presented here can be verified by using either program version. The diagnostic study was made in cooperation with a study for the development of a design procedure for continuously reinforced concrete pavements (3). The reported findings partially validate the ability of RPS to correctly predict service life and support the further implementation of studies by using RPS. Detailed user's guides for RPS programs have been prepared (1, 4), and background information on the first methodology for conceptual systems and the first working model for RPS are found in two articles by Kher and others (5, 6).

The rigid-pavement system consists of performance, traffic, structural, and cost models that are solved to produce arrays of design strategies. The strategies are optimized because they are based on the total cost over the design life by considering design constraints to obtain the most economical designs. A summary flow chart for the working system is shown in Figure 1. The design process (5) is divided into the following major parts:

1. Reading, checking against invalid inputs, and printing input data;
2. Generating possible initial designs;
3. Selecting feasible initial designs;
4. Designing subbases, reinforcements, and joints;
5. Developing overlay strategies for feasible initial designs;
6. Analyzing cost of all strategies;
7. Storing, optimizing, and scanning; and
8. Printing output.

DATA GATHERING

A general performance survey was conducted to evaluate four concrete pavements in Houston, Texas (3), and a detailed study, using RPS2 (1), was made to determine why the observed sections performed as they did. Because there are many different combinations for designing concrete pavements, the four concrete pavements do not represent an experiment of adequate size. However, the pavements chosen are similar and allow for a study of RPS predictions for CRCP. The pavement sections are part of the Interstate system and are constructed with cement-stabilized base material that rests on mechanically stabilized clay subgrades. The four sections are characterized by current ratings of pavement conditions. These ratings are estimates based on (a) the current condition of each section made by highway and public transportation department engineers, (b) the present serviceability ratings (PSR) values estimated by National Cooperative Highway Research Program (NCHRP) personnel (3), and (c) the Mays meter readings, which are based on present serviceability index (PSI) values. Project study sections were chosen, and field measurements and material samples were taken. Laboratory tests were run on these samples, and the data were analyzed to ascertain, in particular, what caused the pavements to perform as they did. Table 1 gives the basic data gathered in February 1973 for each of the four test sections. The test sections were Memorial to Woodway (I-610W), Yale to Main (I-610W), San Felipe to Westheimer (I-610W), and Cavalcade to Patton (I-45N).

Each of the four 366-m (1200-ft) sections was closed to traffic by crews from the Texas State Department of Highways and Public Transportation while measurements were made of deflection, crack width, crack spacing, steel reinforcement depth, and rideability. A tabulation of the various distress manifestations present was also

Figure 1. Summary flow diagram of rigid pavement system.

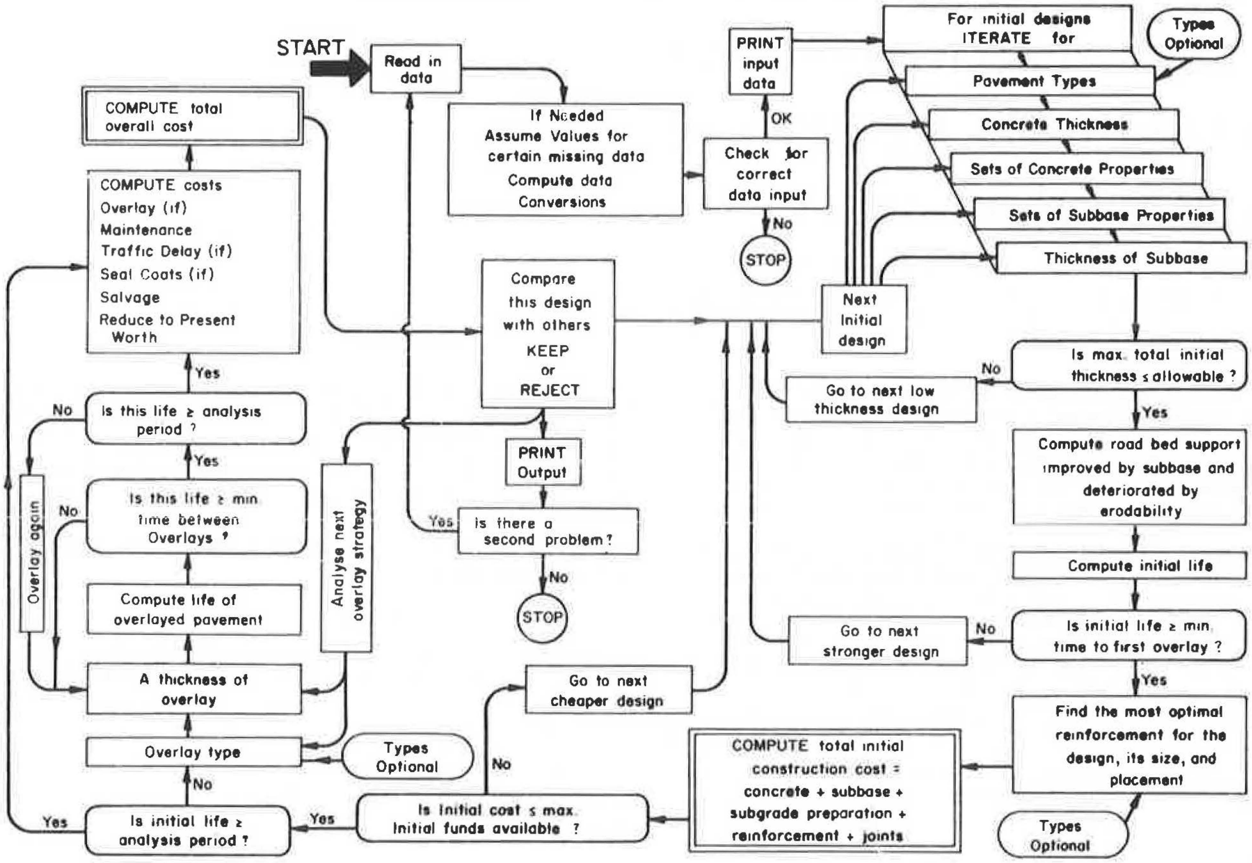

Table 1. Data for test sections.

Test Section	Subgrade[a]	Condition	Number	Age (years)	Thickness (cm)		PSR	PSI	Traffic[c] (thousands)		ESAWL (millions)
					Concrete	Subbase[b]			Avg	Com. Veh.	
Memorial to Woodway	Clay	Fair	271-17-8	7	20.3	15.2	3.2	3.15	80	5.3	9.2
Yale to Main	Clay	Poor	271-14-26	9	20.3	15.2	2.8	3.15	58	4.2	10.2
San Felipe to Westheimer	Clay	Poor	271-17-19	10	20.3	15.2	2.6	3.25	80	5.3	13.1
Cavalcade to Patton	Clay	Good	500-3-68	13	20.3	15.2	3.8	3.30	56	2.3	3.6

Note: 1 cm = 0.394 in and 1 kg/m^3 = 0.0624 lb/ft^3.

[a] Houston geological group average modulus of subgrade reaction = 1842 kg/m^3 (115 lb/ft^3).

[b] Cement-stabilized, sand-shell base.

[c] In one direction per day.

prepared for each individual section. Cores of the concrete, subbase, and subgrade in each section were taken at cracks and between cracks. Before tests were made, all cores were photographed and measurements of height, diameter, and mass were made to determine densities.

Indirect tensile tests were performed on the uncracked concrete and subbase samples to obtain Young's modulus of elasticity values and indirect tensile strengths. Table 2 gives the results of these tests to determine the mean indirect tensile strengths and elastic moduli for each section. Construction information was also obtained from the files of the Texas State Department of Highways and Public Transportation on each of the four sections.

RPS DIAGNOSTIC STUDY

Once data collection was complete, diagnostic studies were initiated. The objective of the diagnois was to explain the performance of each section with respect to its individual characteristics and design.

Comparison of Section Differences

A comparative study of section characteristics was performed to determine if there were any obvious differences in the sections that would explain their behavior. The bar graphs, shown in Figures 2 through 6, were plotted from the data given in Table 1 to ease assimilation. For the four sections chosen, age does not appear to be a critical factor. Although the Cavalcade to Patton section is the oldest section (Figure 2), its current condition is rated good (Table 1). It also has a PSR value of 3.8, which is the best value given by personnel from the Center for Highway Research to the four sections.

PSI values based on the Mays meter readings are shown in Figure 3. The Cavalcade to Patton section has the best average PSI value; however, from the Mays meter readings, which are based on measurements alone, all the sections appear to be at approximately the same level of serviceability. The small difference in PSI values may have more significance than normally expected because the values represent the range of acceptability for Interstate-type pavements. This theory could be verified by checking the personnel ratings because those ratings seem to reflect the type of facility being rated in relation to the Interstate function. The current condition ratings, given in Table 1, are significant because personnel from the Texas State Department of Highway and Public Transportation are aware that each section requires maintenance and user response. The personnel rated the Memorial to Woodway section in fair condition, the San Felipe to Westheimer and Yale to Main sections were rated in poor condition, and the Calvalcade to Patton was rated in good condition. The PSR values of these sections, given by personnel from the Center for Highway Research, confirmed this appraisal.

The traffic variables considered are the average daily traffic (ADT), commercial vehicles, and number of 8165-kg (18-kip) equivalent single-axle loads (ESAWL) as shown in Figures 4 through 6 respectively. As indicated in these figures, the section that is in the best

Table 2. Results from indirect tensile tests on cores from test sections.

	Subbase		Pavement	
Test Section	Elastic Modulus[a] (GPa)	Tensile Strength[a] (MPa)	Elastic Modulus[b] (GPa)	Tensile Strength[b] (MPa)
Memorial to Woodway	11	1.4	39	3.4
Yale to Main	16	1.6	28	3.2
San Felipe to Westheimer	13	2.0	35	3.7
Cavalcade to Patton	12	1.5	37	3.9

Note: 1 Pa = 0.000145 lbf/in².

[a] Poisson's ratio of 0.25. [b] Poisson's ratio of 0.20.

Figure 2. Age of sections in years.

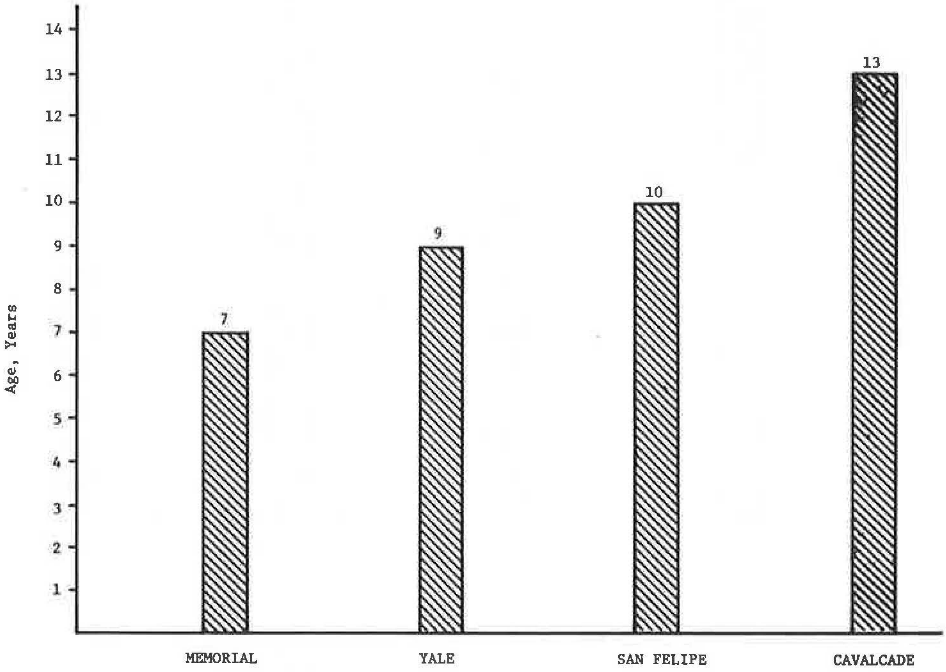

Figure 3. PSI values based on Mays meter readings.

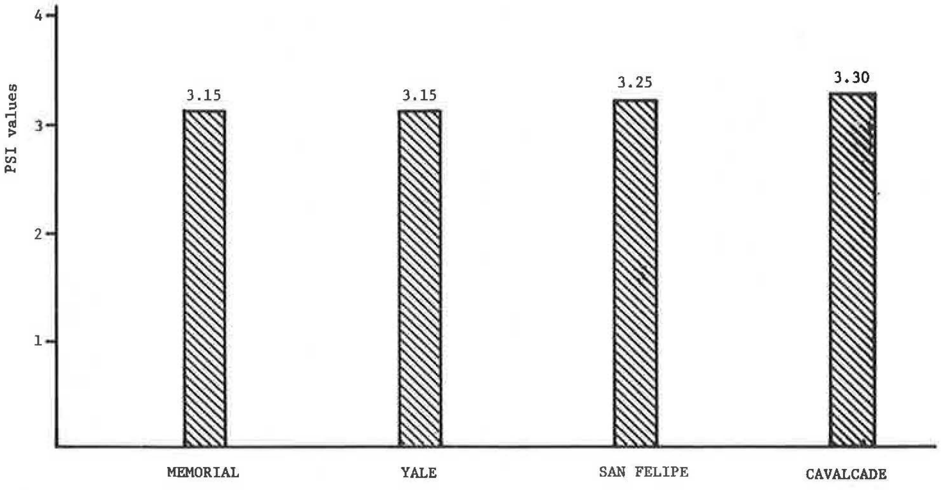

Figure 4. Average daily traffic in one direction.

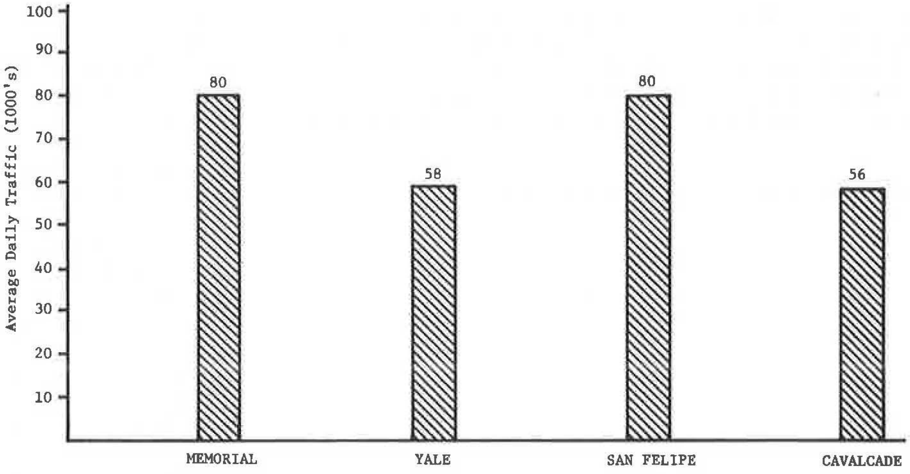

Figure 5. Commercial vehicles per day.

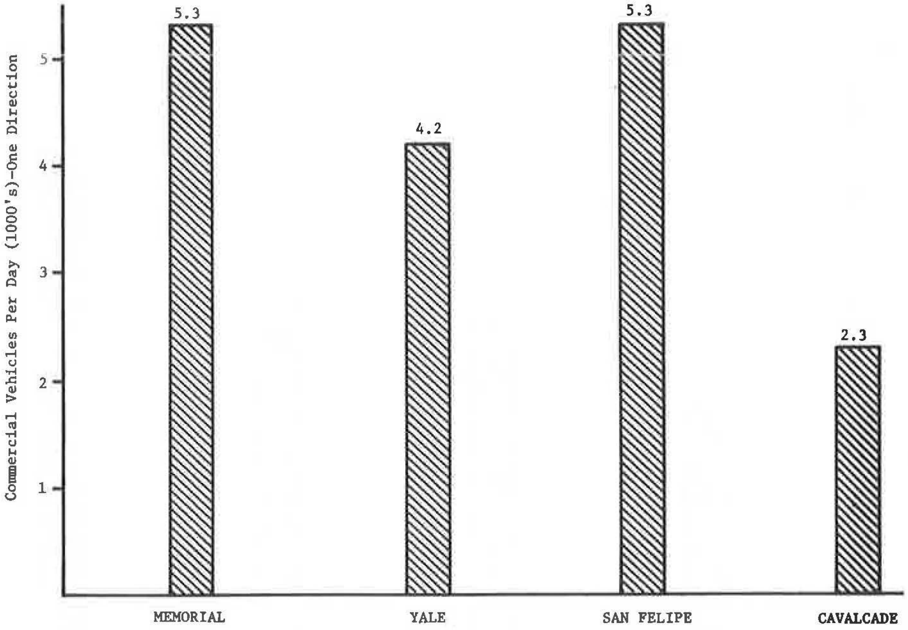

Figure 6. Total 8165-kg (18-kip) equivalent single axle wheel loadings to date.

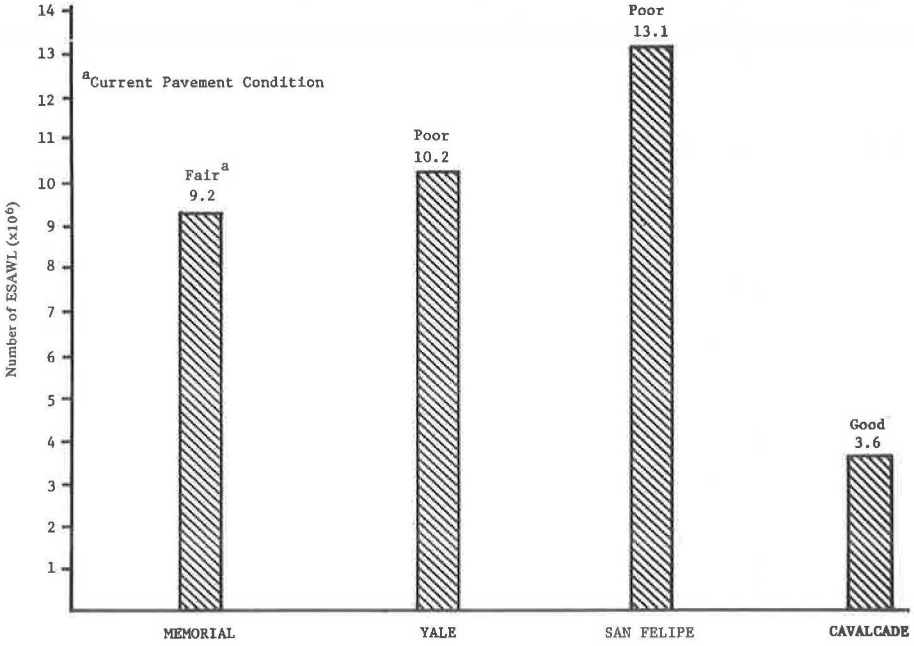

Table 3. Predicted age of test sections using RPS and AASHO performance models.

Test Section	Levels of Confidence (%) 50	80	95	99	99.9	99.99	Current Age[b] (year)
Memorial to Woodway	32	18	10	<7[a]	—	—	7
Yale to Main	44	20	<9	—	—	—	9
San Felipe to Westheimer	43	23	12	<10	—	—	10
Cavalcade to Patton	130	77	46	29	17	<13	13

[a] Predicted age less than actual age and overlays not allowed; therefore, there is no solution.
[b] The approximate age of the test sections as of April 1973.

Table 4. Thirty-year designs for test sections.

Test Section	Thickness[a] (cm)			Performance Periods[b]	
	Slab	Subbase	Overlay	Initial	Total
Memorial to Woodway	21.6	30.5	7.6	20	36
	22.9	15.2	7.6	20	35
	24.1	20.3	7.6	27	47
Yale to Main	27.9	15.2	7.6	21	36
	26.7	30.5	7.6	21	37
	29.2	20.3	7.6	27	46
San Felipe to Westheimer	24.1	20.3	7.6	21	37
	25.4	15.2	7.6	24	42
	26.7	20.3	0	32	0
Cavalcade to Patton	17.8	25.4	7.6	21	39
	19.1	15.2	7.6	23	40
	20.3	20.3	0	32	0

Note: 1 cm = 0.394 in.

[a] The design alternatives given by the RPS2 program.
[b] The initial performance periods are the times to the first overlay while the total performance periods are the amounts of time the pavements last with overlays.

condition has carried the least ADT, commercial vehicles, 8165-kg (18-kip) and ESAWL. In Figure 6, the 8165-kg (18-kip) ESAWL plot is especially significant because the current condition ratings and the PSR values both correlate exactly with the amount of 8165-kg (18-kip) ESAWL each section has carried. The current pavement condition is written on the graph for emphasis. Concrete cores from the Cavalcade to Patton section had the highest indirect tensile strength (Table 2), and this may also have contributed to its good performance. There are no specific material or structural differences because all four pavement cross sections consist of 20.3 cm (8 in) of continuously reinforced concrete in which quartz gravel and identical reinforcement were used, 15.2 cm (6 in) of cement-stabilized, sand-shell, subbase and clay subgrades.

Use of the Rigid Pavement System 2

The four CRCP sections provide a complete set of data that is used to evaluate the performance equations for concrete pavements developed by the American Association of State Highway Officials (AASHO) used in RPS. The study is separated into two distinct segments:

1. All the variables are fixed, and the program is used to predict pavement service life; and
2. The program is used to design pavements for a 30-year life with overlay at 20 years.

Initially, the RPS program is used as a tool to predict performance periods for the different sections. The actual pavement thicknesses, age, traffic, material properties, and serviceability at the time of the study are input into the program, and the thickness of the concrete and the subbase are held fixed. Thus, one design strategy results from the program. The output for every design strategy is a predicted performance period that is defined by the maximum and minimum serviceability levels, which are based on traffic, thickness, and material properties. The performance periods calculated by RPS were compared with the actual age of each pavement section to determine the capability of the program to predict performance periods correctly.

For each pavement section, this prediction was run at every confidence level, which began at 50 percent and increased until the program was stopped at some level. These results are given in Table 3. For example, the San Felipe to Westheimer section has a predicted performance life of 12 years at the 95 percent confidence level as compared with an actual performance life of 10 years. The reason the program was unable to design at a level higher than 95 percent is the program was not allowed to design an overlay. The analysis period input to the program is set at the actual performance life; therefore, at a confidence level of 99 percent for the San Felipe section to Westheimer, the predicted performance life is less than the 10-year actual performance life, and, with no overlay capability, the program stops. Analysis of the information in Table 3 indicates that the tentative level of confidence to be used in designing urban freeways may be 95 percent, since the Memorial to Woodway and San Felipe to Westheimer sections made good predictions at the 95 percent level.

The information from the diagnostic study was also used to check the design of each pavement. The procedure followed was to take the known traffic and increase it linearly to a 30-year total. This procedure was done by giving a range of values to the concrete and subbase thickness inputs while retaining the known material characteristics and allowing the program to overlay the facilities at 20 years. This information was supplemented with additional design information, and the RPS program was allowed to design each section.

Table 4 gives the three most economical designs that were computed by the program for each section. The program designs thicker sections for San Felipe to Westheimer, Memorial to Woodway, and Yale to Main sections than the actual 20.3-cm (8-in) CRCP and 15.2-cm (6-in) cement-stabilized subbase originally constructed. The program gives the Cavalcade to Patton section some designs that have thinner concrete than the current 20.3 cm (8 in); however, these designs have thicker subbases. The Yale to Main section, which is in poor condition, is designed by the program to have a minimum concrete thickness of 26.7 cm (10.5 in). These designs are made by using current traffic counts and extrapolating the values to 30-year totals. The accuracy obtained by using past traffic data on these sections enhances the chances of the RPS program to provide adequate design thicknesses.

CONCLUSIONS

These studies, conducted with RPS2, indicate that RPS program predictions that are made by using the modified AASHO performance equations (2) are reasonable. The designs generated by the program for the sections studied are valid and are what might have been built if the current traffic had been anticipated. The pavement-performance lives predicted by RPS agree closely with the actual performance lives of the pavements, thereby providing one verification of the program with data from CRCP freeway sections. The study also indicates that a 95 percent level of confidence is reasonable to use for the design of urban Interstate freeways. In practice, the quality control and high-quality materials, used in Interstate construction, assure high levels of confidence in the design and associated construction. The major conclusions from this study are as follows:

1. Confidence levels of 95 and 99 percent are reasonable for use in designing Interstate CRCP pavements with RPS;
2. Modified AASHO performance equations used in RPS give reasonable results;
3. In lieu of traffic rates, RPS thickness designs for a 30-year analysis period are valid; and
4. This study provides partial verification of RPS, CRCP design capability.

The potential for use of RPS as a tool to design overlays on existing concrete pavements is another important aspect of RPS that should be stressed as well as the capabilities of the program to make economic comparisons of the designs. Results of this study provide one verification of RPS capabilities; however, other studies should be made to validate other areas of RPS design. The current RPS program version, RPS3, is well-documented for implementation (1) and should be used in other studies such as this one to validate and implement the program.

ACKNOWLEDGMENTS

This paper was developed as part of project sponsored by the Texas Department of Highways and Public Transportation. The work was carried out at the Center for Highway Research of the University of Texas at Austin. The opinions, findings, and conclusions expressed in this paper are ours and are not necessarily those of the sponsoring agency.

REFERENCES

1. R. F. Carmichael and B. F. McCullough. Modification and Implementation of the Rigid Pavement Design System. Texas Highway Department, Texas Transportation Institute, Texas A&M University; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-36, Jan. 1975.
2. R. K. Kher, W. R. Hudson, and B. F. McCullough. A Systems Analysis of Rigid Pavement Design. Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-25, Nov. 1970.
3. B. F. McCullough, A. Abou-Ayyash, W. R. Hudson, and J. P. Randall. Design of Continuously Reinforced Concrete Pavements of Highways. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. NCHRP 1-15, Aug. 1974.
4. R. F. Carmichael and B. F. McCullough. Rigid Pavement Design System Input Guide for Computer Program RPS2. Texas Highway Department; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-21, Feb. 1974.
5. R. K. Kher, W. R. Hudson, and B. F. McCullough. Comprehensive Systems Analysis for Rigid Pavements. HRB, Highway Research Record 362, 1971, pp. 9-20.
6. R. K. Kher, W. R. Hudson, and B. F. McCullough. A Working System Model for Rigid Pavement Design. HRB, Highway Research Record 407, 1972, pp. 130-145.
7. W. R. Hudson, B. F. McCullough, J. Brown, G. Peck, and R. Lytton. Overview of Pavement Management Systems Developments in the State Department of Highways and Public Transportation. Texas State Department of Highways and Public Transportation; Texas Transportation Institute, Texas A&M University; and Center for Highway Research, Univ. of Texas at Austin, Jan. 1976.

Publication of this paper sponsored by Committee on Rigid Pavement Design.

Report on an Experiment for Continuously Reinforced Concrete Pavement in Walker County, Texas

B. F. McCullough, Center for Highway Research, University of Texas at Austin

This report summarizes the findings that resulted from a 16-year study on the performance of a continuously reinforced concrete pavement placed on I-45 in Walker County, Texas. An examination of data provides numerous guidelines for design requirements and construction specifications of future projects in which this type of pavement will be used. Specifically, there were more failures for the pavement in which a lower percentage of reinforcing steel and higher curing temperatures were used. The data indicate that type 3 cement withstands higher steel stresses and that special attention should be given to concrete vibration at all times. The 7-year performance of a short section of an asphalt-concrete overlay with varying thicknesses indicates that the rate of failure and the deflection can be substantially reduced by increasing overlay thickness.

An experiment was conducted to evaluate the relative performance of 0.5 and 0.6 percent, longitudinal steel sections that were used to continuously reinforce a concrete pavement. The continuously reinforced concrete pavement (CRCP) used for this experiment was constructed during 1960 on I-45 in Walker County, Texas [Project I-45-2(3) 102; Control 675-7-4; Walker-Montgomery county line to Huntsville loop]. Since construction of the pavement, there have been numerous studies done by the Texas State Department of Highways and Public Transportation (SHPDT) and other agencies. Some of these studies have been reported in professional journals