Effect of Rainfall on the Performance of Continuously Reinforced Concrete Pavements in Texas

C. SARAF, CHIA-PEI CHOU, AND B. FRANK MCCULLOUGH

The effect of rainfall on the performance of continuously reinforced concrete (CRC) pavements in Texas was studied by analyzing the condition survey data on CRC pavements throughout the state. A study of the annual rainfall data within the state of Texas indicated that it varies from 10 to 52 in. Rigid pavement condition survey data have been collected for 10 years, beginning in 1974. For the purpose of this study, the data were grouped into districts, and the average performance of pavements in each district was estimated for each survey year (surveys were conducted in 1974, 1978, 1980, 1982, and 1984). The average performance of CRC pavements was determined by adding the number of patches and punchouts in the pavement and estimating the number of failures per mile. The average rate of failures per mile (*RFPM*) per year was estimated for a period of 10 years for each district and a simple relationship was determined: log (*RFPM*) = − 4.05 + 2.35 log (*P*) where *P* is the average annual precipitation in the district. The results of this study indicated that the effect of average annual rainfall on the performance of CRC pavements in Texas is significant. Therefore the existing rigid pavement design procedures in Texas require review and possible modifications to accommodate the effect of this important variable on the performance of CRC pavements. A study of some individual pavement sections was also performed. This study indicated that the initial performance of pavements located in different rainfall areas is practically the same. However, when the pavement starts developing failures (punchouts and patches), the *RFPM* is affected by the average rainfall of the area. Pavements located in 10-in. rainfall areas generally showed an almost zero rate of failure development, whereas pavements located in 52-in. rainfall areas developed failures at a rate of about one failure per mile per year.

The structural performance of continuously reinforced concrete (CRC) pavements is generally influenced by several factors, among which construction materials, traffic loads, and environment are most important. Past research in pavements has yielded methods that can be used to estimate the effects of construction materials and traffic loads on the performance of rigid pavements *(1)*. However, the research on the effects of environmental factors on the performance of rigid pavements is not adequate. The effects of environmental factors, such as temperature, rainfall, and freeze-thaw cycles, on the performance of rigid pavements are only partly known. In general, existing design methods will consider the worst environmental conditions to arrive at a suitable design. For example, the current test procedures generally recommend that the modulus of subgrade reaction for rigid pavement design be determined under the most unfavorable saturated subgrade conditions *(2)*. This will yield only one thickness of pavement if the soil type, traffic, and other design parameters are the same. If these pavements are built in two different rainfall zones, their performance will be different. The pavement built in a low-rainfall zone will perform better than the pavement built in a high-rainfall zone. Therefore, to estimate the difference in their performance, it is essential that the effect of environmental factors such as rainfall on the performance of pavements be considered. The new AASHTO Design Guide *(3)* recommends the testing of materials for actual site conditions not the worst conditions, as was the case in the past.

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The effect of other environmental factors can be similarly determined and incorporated appropriately in the design procedures.

The objective of the study summarized in this paper was to investigate the possibility of developing a model that could provide an estimate of the effect of rainfall on the performance of CRC pavements. The pavements in Texas were selected for this study because there is a rigid pavement condition survey data base for the state of Texas that contains a pavement condition history of CRC and other types of rigid pavements throughout the state for the past 10 years. Also, the geographic locations of the pavements cover a wide range of rainfall areas, from 10 to 52 in. per year.

For the purpose of this study, the effect of rainfall on pavement performance was determined in the following manner:

1. A relationship was developed between rainfall and the performance parameter of pavements located in the areas of known rainfall and
2. A relationship was developed between the subgrade soil characteristics and the performance of pavements located in areas where rainfall may affect the characteristics of subgrade soil and subsequently the performance of pavements built on these subgrades.

The details of this study are described in the following paragraphs.

PAVEMENT SECTIONS

Figure 1 shows the boundaries of districts within the state of Texas where the pavement sections used in this study are

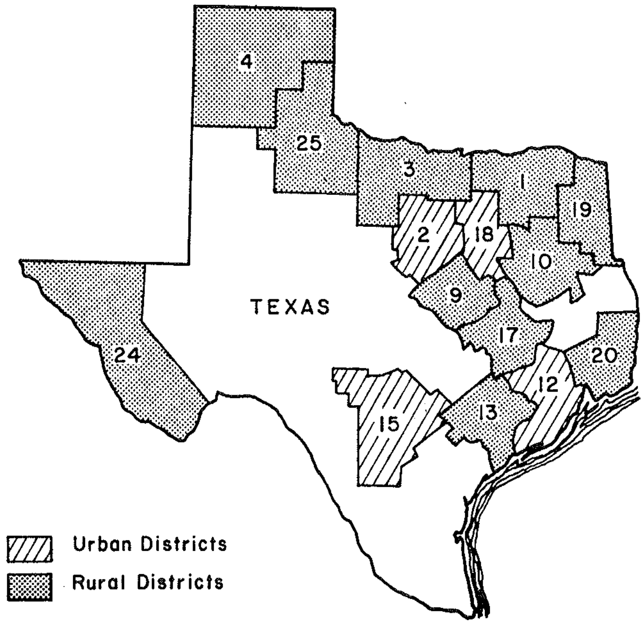

FIGURE 1 Location of districts within the state of Texas that were included in rigid pavement condition surveys.

TABLE 1 SUMMARY OF CRCP CONDITION SURVEY DATA AND ANNUAL RAINFALL FOR VARIOUS DISTRICTS IN THE STATE OF TEXAS (1979–1984 data)

District Number	Total Length of Unoverlaid Sections, Miles	Annual Rainfall (Inches)	Rate of Failures Per Mile/Year (FPM)
1	48	43	.69
3	95	29	.14
4	105	18	.07
9	47	34	.30
10	167	42	.71
13	166	38	.68
17	225	40	.49
19	112	46	.73
20	57	52	.80
24	122	10	.02
25	62	22	.20
Total	1,206		

located. The average annual rainfall in these districts varies from 10 to 52 in., as indicated by the data in Table 1. The total mileage of unoverlaid pavement sections in each district is also listed in Table 1.

All pavement sections were designed using the standard procedures in existence at the time of their construction. A design period of 20 years was used for all pavements.

About 90 percent of the CRC pavements in Texas were built with 8-in.-thick slabs and 0.52 percent longitudinal steel. The remaining 10 percent are 9, 10, and 13 in. thick with 0.52 percent steel. Practically all sections are on the Interstate highway system. According to the surveys conducted in 1980, the traffic on these sections ranges from 1.2 to 7.8 million equivalent single axle loads (ESALs) per year.

The following four types of subbases were used underneath the CRC pavement slabs:

1. Cement treated (37 percent of sections),
2. Asphalt treated (29 percent of sections),
3. Lime treated (25 percent of sections), and
4. Flexible (9 percent of sections).

Subgrade soils contain sandy and clayey materials in different proportions. Some clays found in Texas are highly swelling clays. However, the swelling characteristics of each clay are not the same as those reported by Machado *(4)*.

PAVEMENT CONDITION SURVEY DATA

Pavement condition survey data have been gathered for the past 10 years for the pavement sections included in this study. These surveys were conducted for the first time in 1974. Subsequent surveys were conducted in 1978, 1980, 1982, and 1984. Only continuously reinforced concrete pavements (CRCPs) were included in this study.

The condition survey data included the following distress manifestations of the pavements *(5)*:

1. Transverse cracks with severe spalling.
2. Minor and severe punchouts, and
3. Asphalt and cement concrete patches.

The definitions of these types of distress and the procedures used to record them are described in the condition survey manual *(6)*.

The portions of the pavements that were overlaid during the study period were excluded from this study. However, the sections that were subjected to routine maintenance were retained without any special consideration.

RAINFALL DATA

The average annual rainfall data for each district included in this study were obtained from records compiled by the Texas Department of Water Resources. These records have been collected since 1951 and the averages were obtained for a period of 30 years (1951–1980). Table 1 gives these data.

EFFECT OF RAINFALL ON CRC PAVEMENT PERFORMANCE

The rigid pavement condition survey data collected during the past 10 years (1974–1984) have been stored in a data base, which is maintained by the staff of the Center for Transportation Research (CTR) at The University of Texas at Austin. The data base contains the condition history of CRC and other types of rigid pavements recorded at every 0.2 mi of the pavement section except in 1984, when the data were recorded at every 0.4 mi of the section.

Condition survey data for the years 1974 and 1984 were selected for this study. Those pavement sections that were overlaid during this period were not included in the study. The condition survey data for each district were summarized by combining the patches and punchouts in the following manner:

Total number of failures per mile (*NFPM*) = Sum of total number of patches and punchouts in the unoverlaid part of the pavement/total length of the overlaid part of the pavement (1)

The average rate of *NFPM* per year (*RFPM*) was calculated by the following relationship:

$$\text{Average } RFPM = \frac{\text{Total } NFPM \text{ in 1984 } - \text{ Total } NFPM \text{ in 1974}}{10} \quad (2)$$

The estimated values of *RFPM* for each district are given in Table 1.

A regression analysis of the data in Table 1 was performed to determine the relationship between the average rate of *RFPM* and the average annual precipitation (*P*) of the district. The following equation was obtained:

$$\log(RFPM) = -4.05 + 2.35 \log(P)$$
$$(R^2 = 0.94;\ S = 0.129) \quad (3)$$

This is a simple one-variable regression analysis. The value of $R^2 \approx 1.0$ indicates that there is a strong correlation between *RFPM* and *P*. *RFPM* increases with an increase in *P* as shown in Figure 2.

Three districts with typical low, medium, and high rainfall were selected to study the development of failures in the CRC pavements located in these areas. Figure 3 shows a plot between *NFPM* and the age of pavements. It is evident that the *NFPM* in high-rainfall regions (46 in./year) increases at a greater rate than in medium- (38 in./year) or low- (18 in./year) rainfall regions, as was indicated by Equation 3. Also, the *NFPM* in these districts remains low for several years irrespective of rainfall. However, when the pavements start developing some initial damage, the *NFPM* in high-rainfall areas increases at a greater rate than in lower-rainfall areas. In an area with 18 in. of rainfall per year (District 4), only about one failure per mile was observed after about 15 years, whereas District 19, with 46 in. of rainfall per year, developed about seven failures per mile during the same time, as shown in Figure 3.

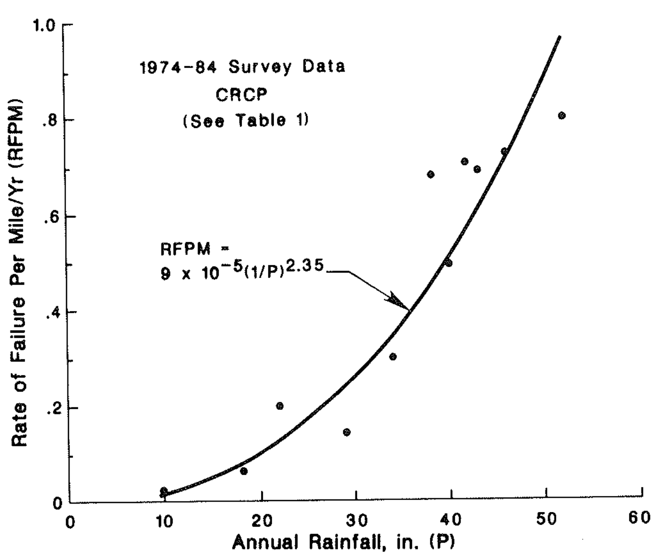

FIGURE 2 Effect of rainfall on the rate of failure per mile per year.

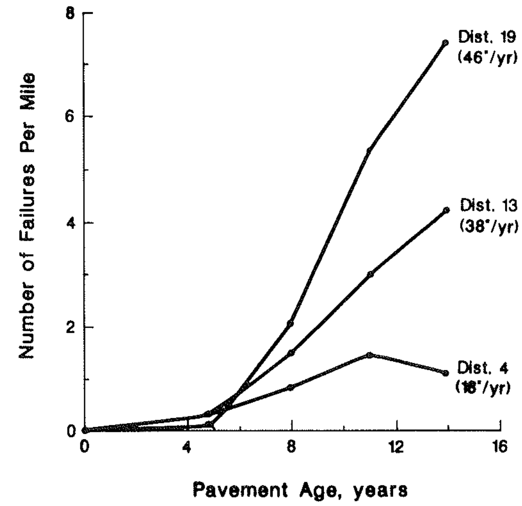

FIGURE 3 Performance history of CRCP located in different rainfall areas.

EFFECT OF SUBGRADE SOIL ON PERFORMANCE OF CRCP

It is generally assumed that if the modulus of subgrade reaction of soils at two different sites is the same, the pavement thickness will also be the same if all other conditions are the same. This assumption would be valid for sites where subgrade soils remain unaffected by rainfall during the service life of the pavement. However, the assumption will not be true if the soils at these sites differ in clay content and their swelling characteristics. This was revealed by an analysis of data collected from District 19, where the annual rainfall is 46 in. Two sections with different clays were selected for analysis. The performance of these two sections is plotted in Figure 4. This

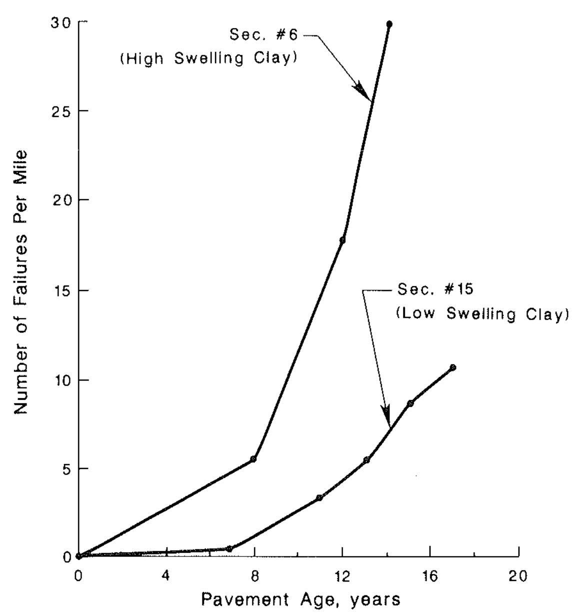

FIGURE 4 Performance history of pavements in District 19.

figure clearly shows that Section 15, built on subgrade containing low swelling clay, did not develop as many failures per mile as Section 6, which was built on soil with montmorillonitic clay mud (high swelling). Because rainfall and other conditions are approximately the same, it appears that the swelling clayey material is responsible for the higher *NFPM* in Section 6.

The effect of subgrade soil on the performance of CRCP was further studied by analyzing data from several other districts. Figures 5 and 6 show the effect of rainfall on the performance of CRCP in two different subgrade soil conditions. Pavements built on subgrade soil containing 100 percent clay were selected for Figure 5. These pavements are located in two different districts, which have rainfall of 43 and 18 in. per year, respectively. It is evident from this figure that the pavement built in the high-rainfall (43 in./year) area developed more failures per mile than the pavement built in the low-rainfall (18 in./year) area. On the other hand, if the clay content of subgrade soil is almost zero, then the effect of rainfall on pavement performance is almost negligible, as shown in Figure 6.

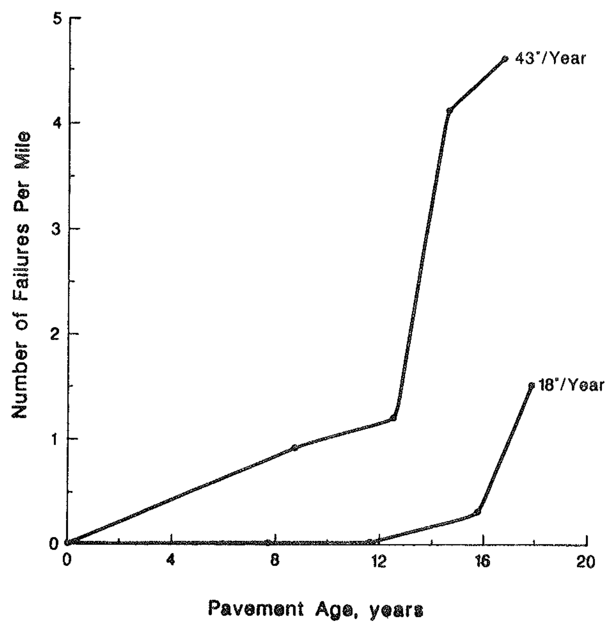

FIGURE 5 Effect of rainfall on pavement performance (subgrade = 100 percent clay).

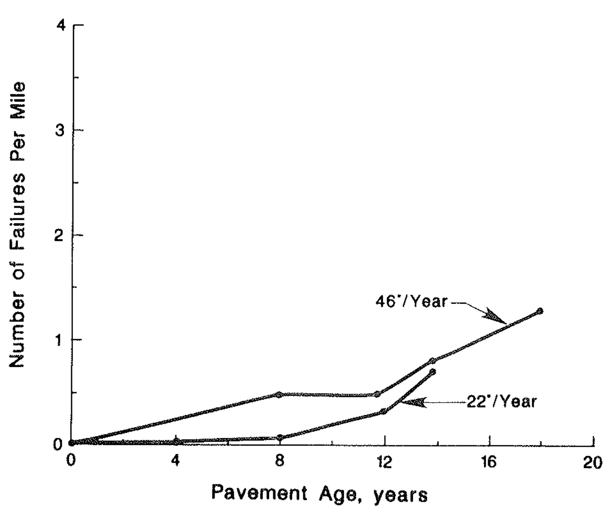

FIGURE 6 Effect of rainfall on pavement performance (subgrade = 0 percent clay).

SUMMARY OF RESULTS

The results of the study can be summarized as follows:

1. An analysis of condition survey data for the past 10 years indicated that the average annual rainfall in an area affects the performance of pavements significantly. Areas of high rainfall developed failures at a faster rate than areas of low rainfall (see Figures 2 and 3).
2. The effect of rainfall on the performance of pavement built in areas of different rainfall intensities is almost negligible for the first few years, until the pavements start developing failures. After the pavements develop failures, the effect of rainfall on pavement performance is significant (see Figure 3).
3. The swelling characteristics of clay in the subgrade soil affect the performance of pavements. A high swelling clay in subgrade soil causes more failures in pavements than a low swelling clay in the subgrade, when the pavements are located in areas of like rainfall (see Figure 4).
4. The effect of rainfall in areas where subgrades have high clay content is more intense than in areas where subgrades contain no clay (see Figures 5 and 6).

CONCLUSIONS AND RECOMMENDATIONS

The analysis of limited data reported in this paper indicates that swelling characteristics of subgrade clays and rainfall at the pavement site affect pavement performance during its service life. Current design procedures are based on material properties determined at the worst possible condition. In practice, these conditions may not always exist. Therefore the performance of these pavements is likely to be different if the soils at the site perform differently than assumed in the design. In view of this, it would be desirable to review current design procedures and incorporate necessary modifications to accommodate the effect of the two factors mentioned in this paper—rainfall and subgrade soil type. The new AASHTO design manual *(3)* recommends testing materials for actual site conditions.

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