AN ANALYSIS OF CRCP PERFORMANCE ON THE DAN RYAN EXPRESSWAY

by
Dr. B. Frank McCullough
Director

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I. Introduction

Background

As part of the modification of the Dan Ryan Expressway in Chicago, a 13-inch continuously reinforced concrete pavement (CRCP) with 0.7 percent longitudinal steel is being constructed. In the first few days of the construction operations, in May, 1988, a wide and erratic crack spacing was noted in one section, ranging from 2 feet to 100 feet. The wide spacings caused immediate concern for possible steel overstressing, steel rupture, and wide cracking and raised the question of whether to remove this section. The early investigations by the Illinois Department of Transportation (DOT) are summarized in Mr. Eric Harm's memorandum on "CRCP Crack Spacing on Dan Ryan Expressway," dated June 2, 1988 (Ref 1).

On May 31, 1988, Mr. Harm called on Dr. Frank McCullough, Director of the Center for Transportation Research at The University of Texas at Austin (CTR), relaying his observations and requesting Dr. McCullough to make an inspection of the work on June 15, 1989. On June 15, 1988, Dr. McCullough, together with Mr. Eric Harm and Mr. Jack Ebers, of the Springfield office of the Illinois DOT, and Mr. Henry Yamanaka of the Chicago District of the Illinois DOT, inspected the pavement of concern along with other sections constructed in the interim.

In an exit interview after the inspection, Dr. McCullough made the following observations based on the inspection and early analysis of the data.

1. The slab of concern experienced unusual temperatures during construction and for the first few days, since the pavement was constructed during an unusually cool front, and that was followed shortly thereafter by a warming trend. Therefore, for the first few days, the pavement was much warmer than it had been during the placement period. Thus, the concrete tensile stresses were not of sufficient magnitude to induce concrete cracking or produce high steel stresses.

2. It was postulated that the slab would continue to crack through the winter of the year when the temperatures decreased.

3. Because of the anticipated future cracking and the resulting reduced steel stresses, it was recommended that the slab not be removed, since it should give satisfactory performance, based on the first two observations.

Mr. Harm has continued to forward the crack spacing data for the selected sections to Dr. McCullough as they were collected over a six-month period. In addition, the weather data showing the hourly temperatures at the Midway Airport for May and June, 1988, were forwarded at, Dr. McCullough's request.

Objective

The primary objective of this study is to explain the phenomenon of the observed cracking and its implication on CRCP design. To accomplish this primary objective, the following sub-objectives are being pursued:

1. Summarize and analyze the extensive field data collected by the Illinois DOT and compare it with the experience of others.
2. Perform a mechanistic analysis, using the input parameters for the Chicago pavement, to further explain the field data.
3. Make any recommendations derived from the study.

Scope of the Report

This report summarizes the various activities associated with the study. Section II conceptually describes the approach used in the analysis. Section III is an analysis of the field data, and Section IV is the related mechanistic analysis. Section V presents a discussion of results and brings all the observations into perspective, to generate an explanation of the observed pavement performance and also to develop the pertinent design observations made from the study. Section VI presents the conclusions and recommendations resulting from the study.

II. Study Approach

Data Sources

The Illinois DOT has been recording the crack spacing history of numerous test sections along the Dan Ryan Expressway since May, 1988. The latest data provide a six-month history. The sections selected for detailed analysis are shown in Table 1.

Table 1: Description of Test Sections

Test Section Number	1	2A	2B	3
Date of Placement	05/13/88	05/20/88	05/20/88	05/26/88
Station Numbers	8+63 — 17+02	197+00 — 195+00	205+00 — 207+00	196+50 — 198+50

Test Section 1 is the initial pavement placement, and it represents the area of most concern to Illinois DOT personnel. Sections 2A and 2B are given the same number since they were placed on the same day and the temperature conditions and concrete strength data are the same for both. The observeddata on the crack spacing collected by the Illinois DOT, together with times, strength data, pertinent design details, and crack width data, are reported in Appendix A for each test section. Appendix B presents the hourly temperature data for May and June for the Midway Airport in Chicago as furnished by the Illinois DOT. From the field construction operations, there was not sufficient information about the concrete properties to perform a mechanistic analysis; therefore, these properties were interpolated from an extensive study for the Texas State Department of Highways and Public Transportation (SDHPT) in connection with CTR Project 422 (Ref 2).

Analysis of Field Data

The crack spacing data collected over a six-month time interval were analyzed, using several different approaches. First, the mean crack spacing, as it changes with time, was looked at. In addition, the distribution of crack spacing was reviewed, since a mean value does not give any indication of the variation in crack spacing. For example, in the early days of this project, the crack spacing ranged from 2 to 100 feet. Thus, the distribution is as important in terms of performance as the mean value, since too many small cracks will lead to punchouts, and large crack spacings can lead to overstressing of the steel. After the Dan Ryan Expressway data were reviewed, the data were compared with the experience of others to see if any unique factors existed or if it was typical of previous performance.

Mechanistic Analysis

Several computer programs, entitled CRCP (with an appropriate number), that provide a complete analysis for continuous pavement, have been developed by CTR (Refs 3, 4, 5). These computer programs predict the time history of crack spacing, crack width, steel stress, and concrete stress for a range of concrete properties, environmental conditions, and pavement structure geometry unique to the site. Two aspects of the selection and development of input parameters for the computer programs are very important. The first is the determination of the concrete properties by using the construction control flexural strength data as a baseline and then interpolating and/or extrapolating from a Texas research study of concrete with different aggregate types (Ref 2). The second is that reasonable values of other parameters, such as temperature, steel reinforcement, subbase friction properties, and soil support conditions, are required.

Figure 1 conceptually illustrates the complex nature of the programs. First, environmental stresses are predicted as a function of temperature and moisture changes, considering the concrete properties and other design conditions (Fig 1[a]). Then the wheel load stresses are added as the pavement is subjected to traffic (Fig 1[b]). Thus, the combined stress that causes cracking is a result of environmental and wheel load stresses and are coupled in the program. Since this is a very complex interaction, with numerous variables, the stress conditions change daily. The program is capable of predicting these changes.

At the present time, two programs are being used, CRCP-4 and CRCP-5. The first version predicts the mean crack spacing, steel stresses, and crack width associated with it (Refs 3, 4). CRCP-5 predicts not only the mean values but the distribution of crack spacing, along with a development of punchouts with traffic history (Ref 5). Both programs are used in this analysis.

III. Analysis of Field Data

This section presents the techniques used and the results from the field data analysis. It is divided into two subsections: (1) the analysis pertaining to the data collected on the Dan Ryan Expressway and (2) comparison with other experience.

Data from Dan Ryan Expressway

Figures 2 and 3 are graphic plots of the crack spacing at several ages during the first six months for Test Sections 2A and 2B. In Appendix C, similar plots are given for the other test sections. On the plots for each age, the cracks that occurred since the previous age are progressively shown as one moves from top to bottom of the graph. In general, the cracks new from observation to observation have occurred at or near the mid-span of the previous crack spacing. This is especially true for the data from Test Sections 2A and 2B. Similar observations are apparent for Test Sections 1 and 3, shown in Appendix C, Figs. C.1 and C.3, respectively. For Test Section 1 (Fig. C.1), the long spacings have cracked into smaller segments, but their variability is much higher. It should be noted that, using the slump data furnished by Mr. Harm as an indicator, the coefficient of variation for Test Section 1 is 22 percent, whereas it is only 12 percent for Test Section 2.

Before a pavement is opened to traffic, all cracks are due to environmental change as a result of temperature and moisture changes of the concrete, i.e., shrinkage. Thus, the concrete stress is directly proportional to the temperature difference from the setting temperature and to the increase in shrinkage. The shrinkage is progressive, whereas the temperature changes may vary substantially. Over a yearly cycle, then, the total temperature can be quite large. Since concrete is weak in tension and strong in compression, it is only the decrease in temperature below the set temperature that is of concern.

Figure 4 presents a relationship between the number of new cracks and the temperature drop on a given day for Test Section 1. As may be noted, there is a strong correlation between the temperature drop and the number of new cracks. On Day 1, no cracks were observed, although the temperature drop was 9°F, but the shrinkage was minimal since the weather was cool and cloudy. On Day 2, the lowest temperature was 10°F higher than the setting temperature, and hence no new cracks developed. On Day 3, there was a 2°F temperature drop, and six new cracks developed, probably primarily due to drying shrinkage. On Day 4, the temperature dropped 13°F, and 33 new cracks were observed. On Day 5, an 11°F temperature drop occurred, and nine new cracks developed. Figure 4 illustrates the significant effect of temperature changes, i.e., the decrease in the development of cracks in the early age. It also demonstrates the importance of the thermal coefficient of the concrete in cracking, since the stress is directly proportional to the thermal coefficient.

Figures 5 and 6 present the distribution of crack spacing with time for Test Sections 1 and 2. For cumulative distribution plots on these sections, see Figs. C.3 and C.4 in Appendix C. The reader may use a distribution chart by going to any given crack spacing and noting the number of cracks with that particular crack spacing. For the cumulative distribution plot, the reader may note that, for any crack spacing, the percent of cracks is equal to or less than the value selected. The cumulative distribution moves from right to left on the figures; as the cracks decrease, the mean shifts to the left. If the cumulative distribution in Test Section 1 had remained to the far right, a strong possibility of excessive stresses during the winter period would exist. However, because the distributions move to the left, the pavement is shown to have been normal, although at an early age it was abnormal.

Figure 7 is a plot of the mean crack spacing versus time for each of the test sections. In general, there has been progressively less cracking as the age increases. The primary exception to this is Test Section 1, since its unique conditions resulted in compressive stresses rather than tensile stresses during the early life of the pavement.

Comparison with the Experience of Others

Figure 8 presents the crack distribution for concretes made from two different coarse aggregate types in Texas. These are older pavements, i.e., 15 years old or greater, and thus the six-month distributions for Figs. 5 and 6 should be used for a more reliable relative comparison. In general, the Dan Ryan Expressway distributions are very similar, indicating the pavement is performing in a normal fashion. Figure 8 also points out that the different coarse aggregate types, and thus the different thermal coefficients, result in different performances.

Figure 9 presents crack spacing versus time for a typical Texas pavement, which may be compared with the Dan Ryan Expressway data in Fig. 7. Again, it may be noted that these aging processes are very similar.

Figure 10 presents the effect of the curing temperature. All the data points represent test sections that were placed at different temperatures; the setting temperatures were different, but all pavements experienced the same minimum temperature at an age of approximately 200 days. When the test section is placed at a lower temperature, there is less temperature change to the minimum temperature and the stresses are less, which results in decreased cracking. These data are quite similar to those presented in a different format in Fig. 4 for the Dan Ryan Expressway.

Summary

In general, the Dan Ryan Expressway crack spacing development experience is very similar to that for other projects, although Test Section 1 has unique characteristics because of its placement during a cold spell in the late spring. The concrete is cracking as expected, with the distribution becoming more and more normal with time. In addition, Test Section 1 has experienced greater variability in crack spacing, which probably can be attributed to a greater variability in the concrete properties, possibly due to the large variability in slump. Since slump in a general way can be related to strength, a greater slump variability means a greater strength variation, and thus more variable cracking.

IV. Mechanistic Analysis of the Dan Ryan Expressway on Pavements

As indicated in Section II, the proper characterization of input parameters is very important if a simulation of experience is to be reliably performed. The weather data, reported in Appendix B, were used to determine the low temperature on each day, and it was input into the program along with the temperature setting, which was taken as the value around noon on the day of placement. After the first two months, the temperature data were estimated. The concrete properties were developed by interpolating the data from Appendix A and selecting a shrinkage and a modulus of elasticity value from the Texas study. A typical input and output of the program for the analysis of Test Section 1 is presented in Appendix D.

Figure 11 presents a comparison of the computed mean crack spacing for each section with the actual Dan Ryan Expressway data from Fig. 9. In general, the shapes are very similar, and the magnitudes are reasonably close. If better indications of the strength, variability, temperature data, etc., were known, the output probably would be much closer.

Figure 12 is a plot of the steel stresses versus time. In general, the stresses decrease as the crack spacing decreases, but a very complex relationship is involved, since the temperature differential increases as the age increases towards the winter months, and the shrinkage continues to increase. In general, the maximum steel stress is experienced at the minimum annual temperature, but for these cases the stresses were high at the early age because of the wide crack spacings.

In summary, the mechanistic analysis shows the performance of the pavement is due to the unusual conditions that were experienced during the early life. The erratic nature of Test Section 1 is, again, due to the unique temperature variations during the early life and the greater variability of concrete properties.

V. Discussion of Results

This section is divided into two subsections: (1) a review of the Dan Ryan Expressway experience and (2) a discussion of the design implications. It combines the information from the field observations and the mechanistic analysis.

Summary of the Dan Ryan Expressway Experience

The analysis of the field data collected by the Illinois DOT and the mechanistic analysis of the pavement are in concurrence. First, the unusually wide crack spacings and slow development of Test Section 1 may be attributed to the unusual temperature conditions in the early life. Primarily, the pavement was in compression during the early cycles; thus, the tensile strength of the concrete was not exceeded and cracking did not occur. As the pavement aged and the temperature differentials became larger with the autumn and early winter conditions, the pavement cracked in a more normal pattern. The distribution of crack spacing is very similar to crack spacings reported elsewhere except in Test Section 1, especially during the early time periods, but that crack spacing has now developed a more typical pattern.

There is some indication (although substantial information is not available from field data) that the strength differences (shown in Appendix A for the different test sections) and the large variation in strength, as revealed by slump, may cause the variability of crack spacing. The effect of strength is shown by Figs. 13 through 15. Figure 13 shows a history of crack spacing with time where all conditions are identical except the strength, which has three different levels: the high value is 10 percent greater than the mean, and the low value is 10 percent less. At the end of analysis, i.e., 360 days, the mean crack spacings are 3.4 feet, 4.4 feet, and 5.2 feet for the low, medium, and high strength concretes. Figure 14 is a plot for concretes attaining the same strength at 28 days, but the simulated sections attain it at different rates, i.e., rapid strength gain. As may be seen from the figure, all the simulated sections arrive at the same crack spacing for a given set of temperature conditions. For a given concrete strength, an unusual cracking development is to be anticipated for unusual initial temperature variations, but it should stabilize with time. Figure 15 demonstrates the cumulative crack spacing for three different coefficients of variation for strength. The values of 10 percent and 20 percent are similar to the difference between Test Sections 1 and 2. Although there was no measure of the straightness of the cracks transversely across the pavement, it may be postulated that there will be more meandering with the higher variation, i.e., implied strength variation, which also sets up the possibility for wide crack widths.

An analysis was not made of the design details provided by the Illinois DOT, although a review indicated the need for several changes (Illinois Reinforcement for CRCP #2225-8, October 9, 1987). First, it is recommended, as it was during the field visit, that Lap Arrangement 3 be eliminated from the detail. Its use has no bearing on the observed crack spacing variability, but the diagram is a much weaker combination than Lap Arrangements 1 or 2, since 50 percent of the lapping occurs in only a 3-foot length. It is also recommended that the longitudinal steel be placed in the middle one-third of the slab, since it will give a better balance and be less susceptible to eccentric loading due to volume-change stresses.

Design Implications

The mechanistic design, as reflected in the analysis of the field data, led to important conclusions relative to the percent of steel and the bond area/concrete volume ratio. Figure 16 is a plot of crack spacing versus percent of steel that gives results typically used to decide the optimum percent of steel. Figure 17 shows similar crack spacings can be achieved by varying the bond area/concrete volume ratio. Both variables must be taken into account in design, as has been supported by field observations.

In summary, a design analysis should be based on the selection of an optimum percent steel and bar size, considering the limited criteria of steel stress, crack width, and crack spacing. Figure 18 is a conceptual illustration of the selection of the percent of steel. By applying the limited criteria, an acceptable design range is achieved. The relative position of each parameter depends on many factors, such as the minimum annual temperature, concrete coarse aggregate type, subbase friction, etc. This implies that one design detail should not be used for all conditions, but the design should be optimized to consider the specific material properties and environmental conditions in an area.

VI. Conclusions and Recommendations

Conclusions

The following conclusions are based on the results of this study.

1. The study presented herein supports the tentative recommendation made in June, 1988, that it is not necessary to remove the pavements represented by Test Section 1. Due to unusual initial environmental conditions and variability, the earlier performance was erratic, but subsequent performance is normal.

2. The variability of crack spacing on these projects is typical except for Test Section 1, where a large variation was experienced at the early age. This may be attributed primarily to an unusual temperature condition during the first few days, which resulted in compressive rather than tensile stresses in the concrete. There was a greater variation of slump, which may be postulated to have represented a larger strength variation, which led to greater crack variations on Test Section 1. On Test Sections 2A, 2B, and 3, the variation and crack spacing are typical.

3. The predicted steel stress and crack width during the life of Test Section 1 were not excessive, although they may have exceeded the yield point stress. Based on the mechanistic analysis, the findings also support the recommendation not to remove the slab.

4. It is obvious that the bond area/concrete volume ratio is as important as the percent of steel.

Recommendations

The following recommendations are made for the consideration of the Illinois DOT.

1. Leave the pavement represented by Test Section 1 in place.

2. In the field, concrete should be produced as uniformly as possible, since variability in strength results in more erratic crack spacing.

3. Develop specific design standards for any environmental area, considering the bond area/concrete volume ratio, thermal coefficient, environmental conditions, and percent of steel.

4. Remove Lap Arrangement 3 from the Illinois Standard Detail Bar Reinforcement for CRCP #2225-8, October 9, 1987. The bar placement should be in the middle one-third of the slab.

References

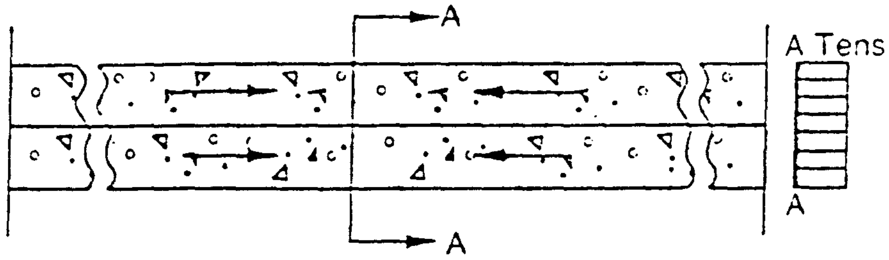
1. Harm, Eric, "CRCP Crack Spacing on Dan Ryan Expressway," memorandum dated June 2, 1988.

2. Green, William J., Ramon L. Carrasquillo, and B. Frank McCullough, "Coarse Aggregate for PCC—Pilot Study Evaluation," Research Report 422-1, Center for Transportation Research, The University of Texas at Austin, September 1987.

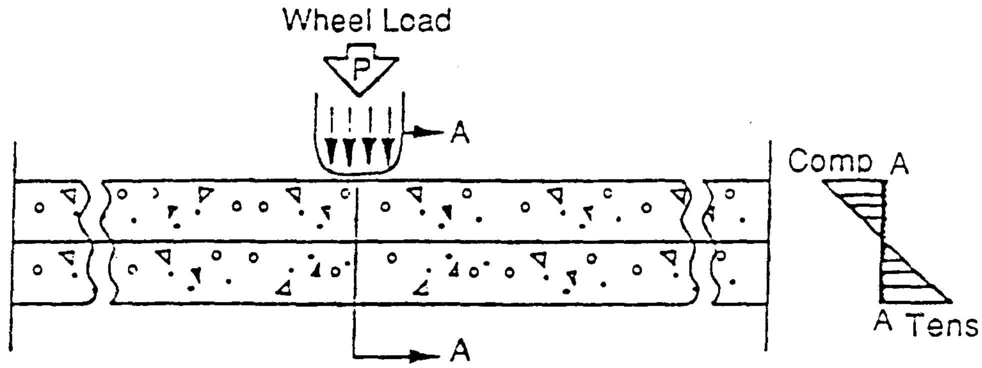
3. McCullough, B. Frank, A.A. Ayyash, W.R. Hudson, and J.P. Randall, "Design of Continuously Reinforced Concrete Pavements for Highways," Research Report, NCHRP 1-15, Center for Highway Research, The University of Texas at Austin, August 1975.

4. McCullough, B. Frank, J.C.M. Ma, and C.S. Noble, "Limiting Criteria for the Design of CRCP," Research Report No. 177-17, Center for Highway Research, The University of Texas at Austin, August 1979.

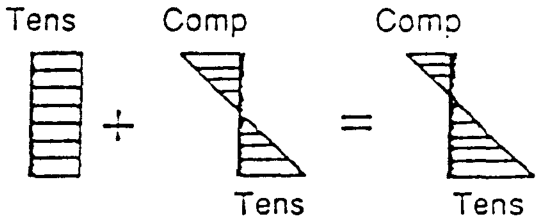
5. Won, Moon-Cheol, Kenneth D. Hankins, and B. Frank McCullough, "Mechanistic Analysis of Continuously Reinforced Concrete Pavement Considering Material Characteristics, Variability, and Fatigue," Research Report 472-4, Center for Transportation Research, University of Texas at Austin, pending.



(a) Concrete restrained volume change stresses at A-A



(b) Concrete stresses due to bending mechanism at A-A



(c) Combined concrete stresses due to restrained volume changes and bending mechanism at A-A

Fig 1. Restrained volume change and bending stresses and the combined effect (Ref 5).

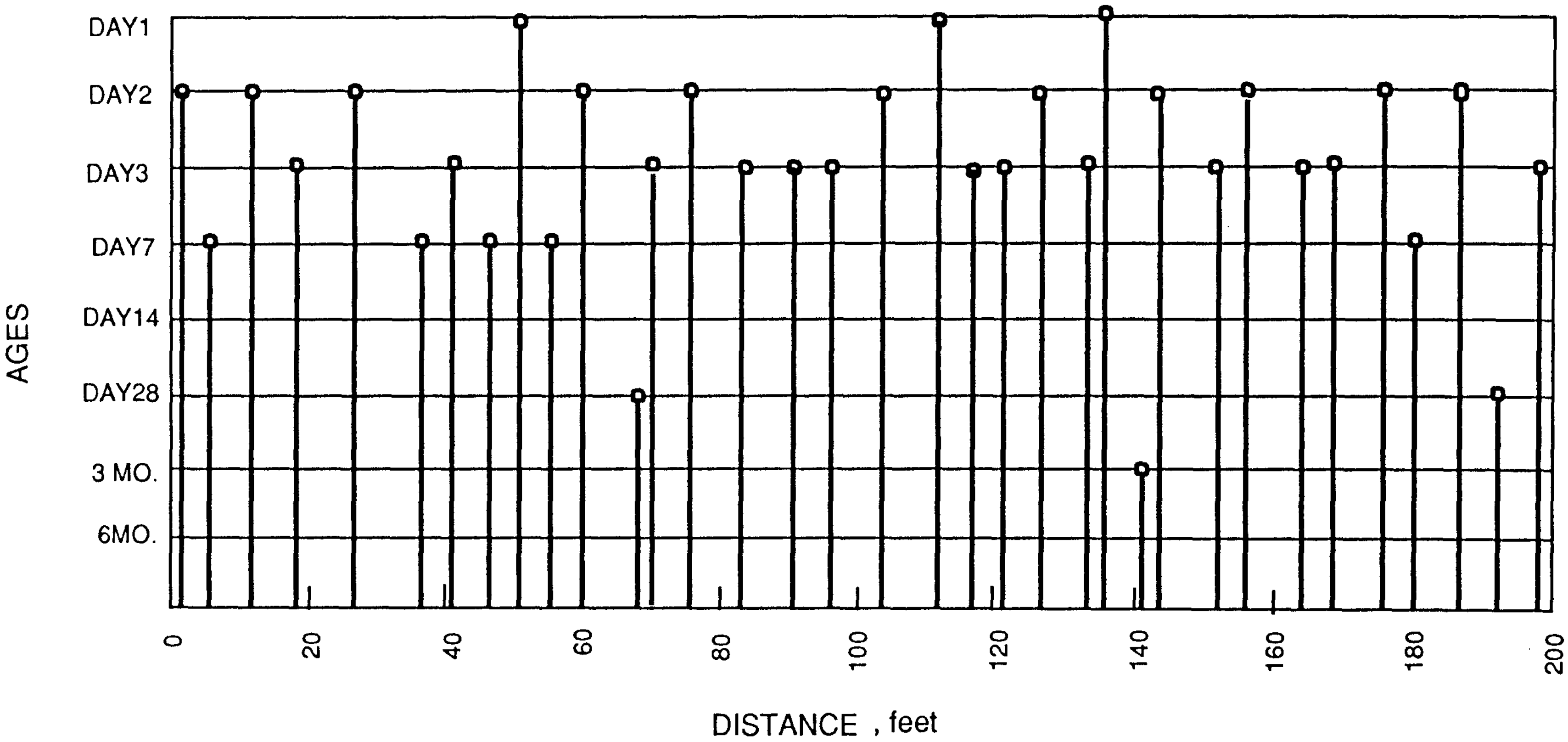


Fig. 2. Plot of crack spacing for Test Section 2A at different ages during the first six months.

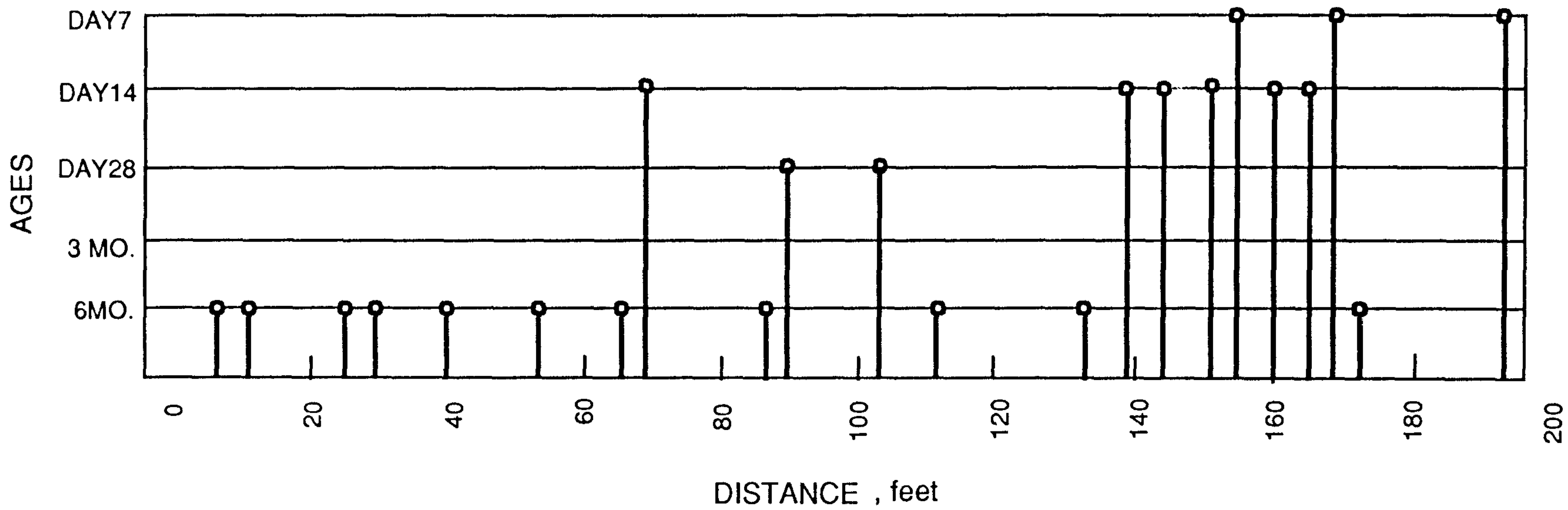


Fig. 3. Plot of crack spacing for Test Section 2B at different ages during the first six months.

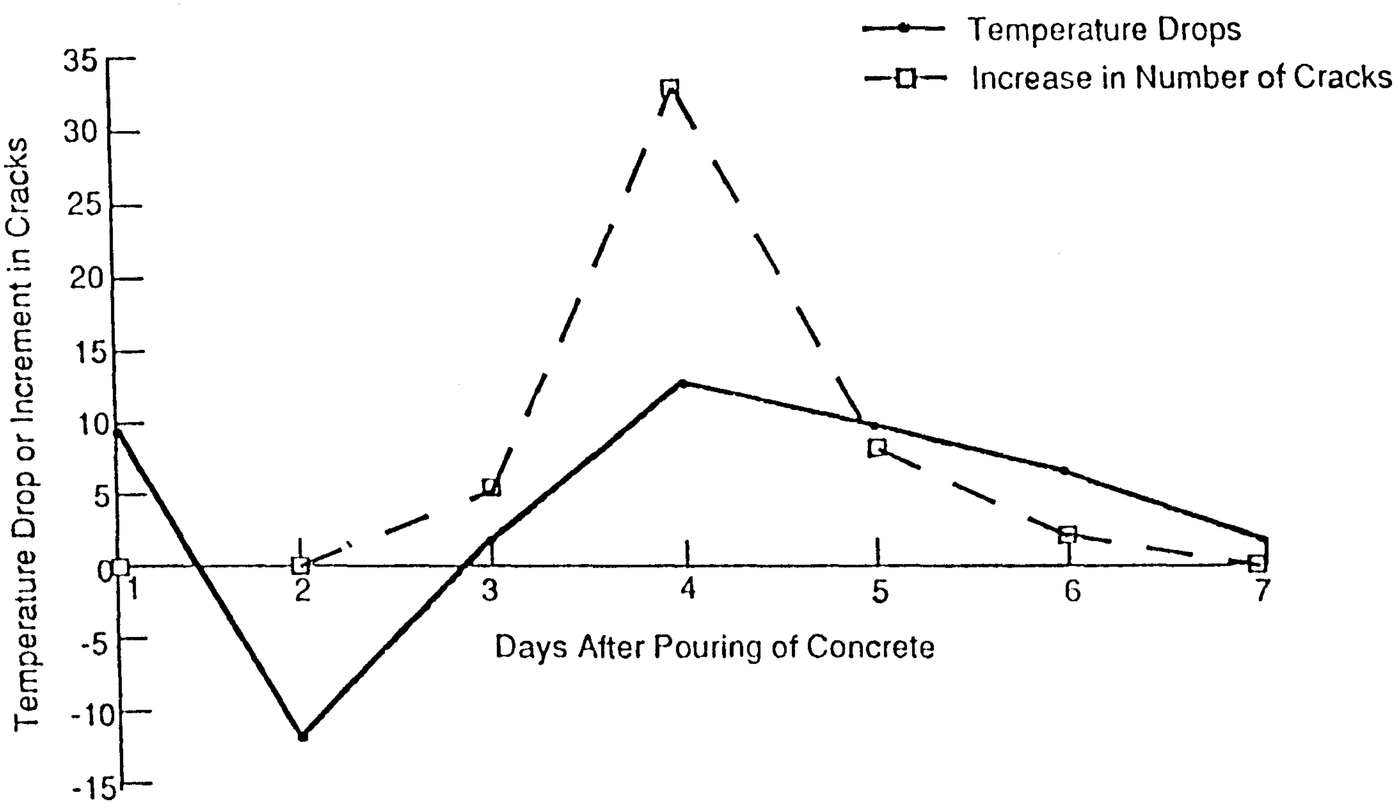


Fig. 4. Effect of temperature drop on the development of new cracks (Ref 5).

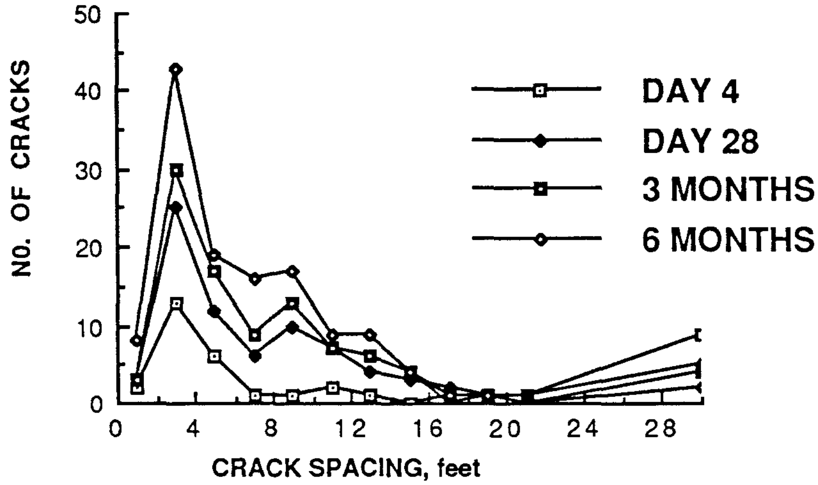


Fig. 5. The distribution of crack spacing for Test Section 1 at different ages.

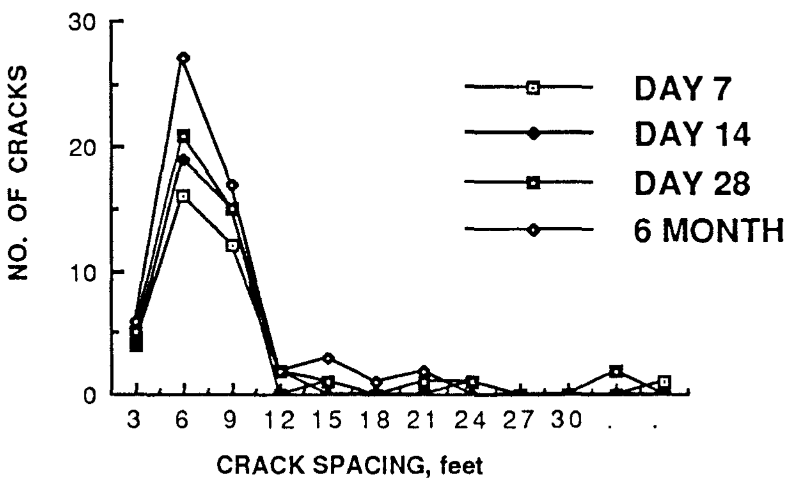


Fig. 6. The distribution of crack spacing for Test Section 2 at different ages.

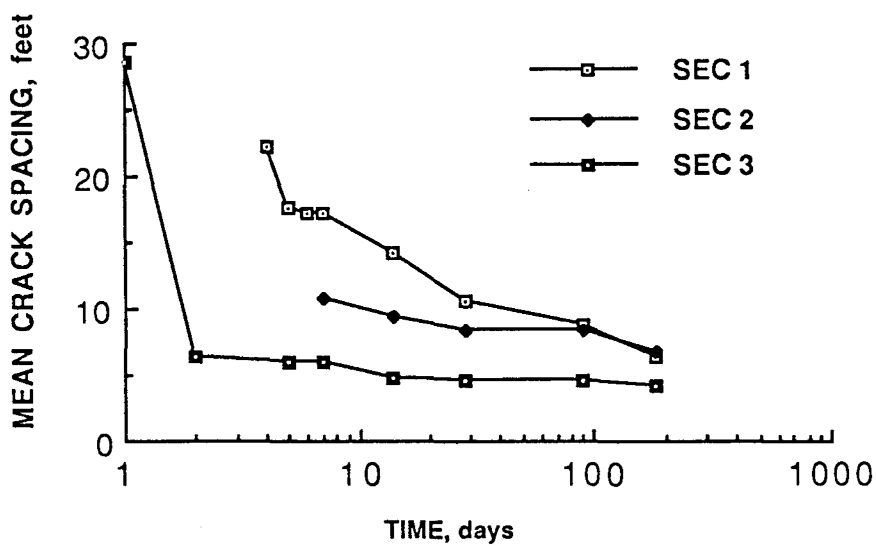


Fig. 7. History of mean crack spacing for each test section during the first six months.

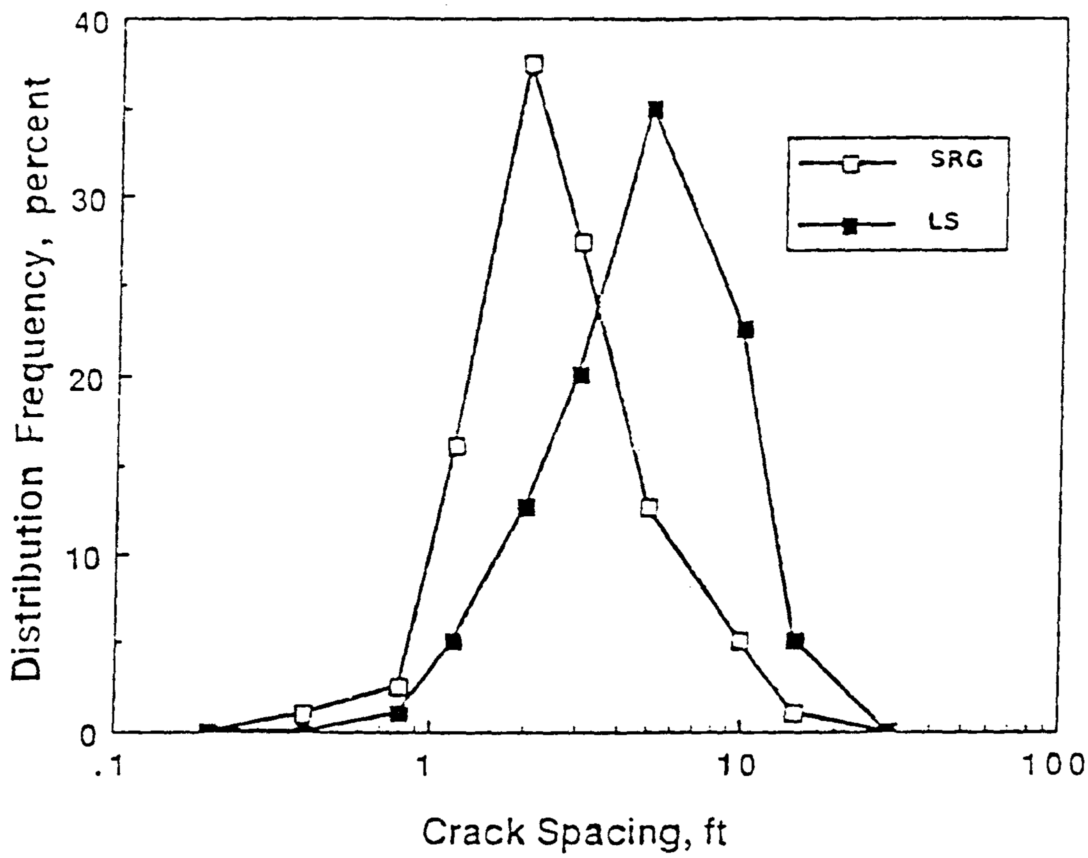


Fig. 8. Crack spacing distributions of concrete containing SRG and LS for pavements in Texas (Ref 5).

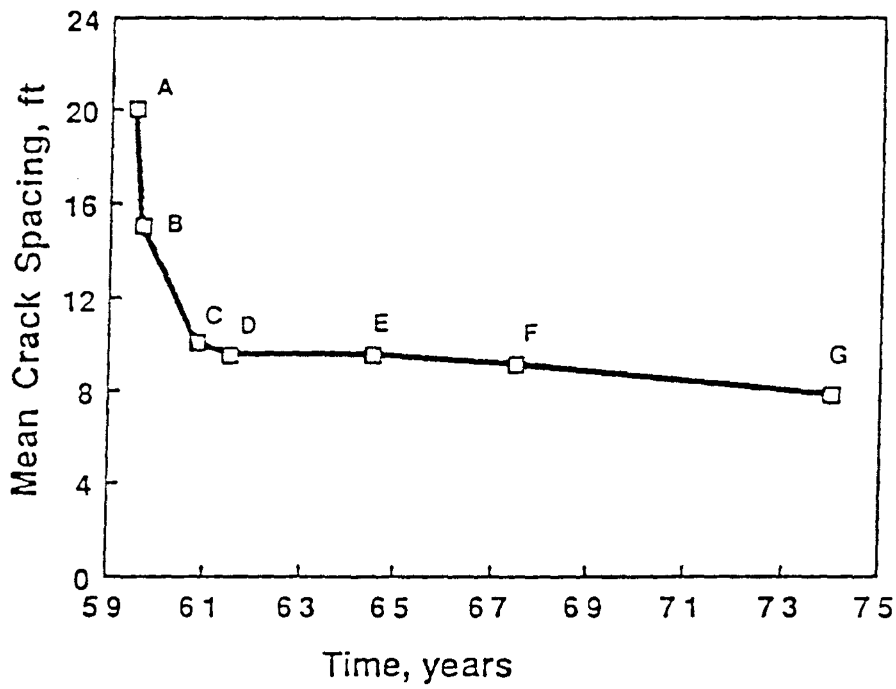


Fig. 9. Change of mean crack spacings with age (Ref 3).

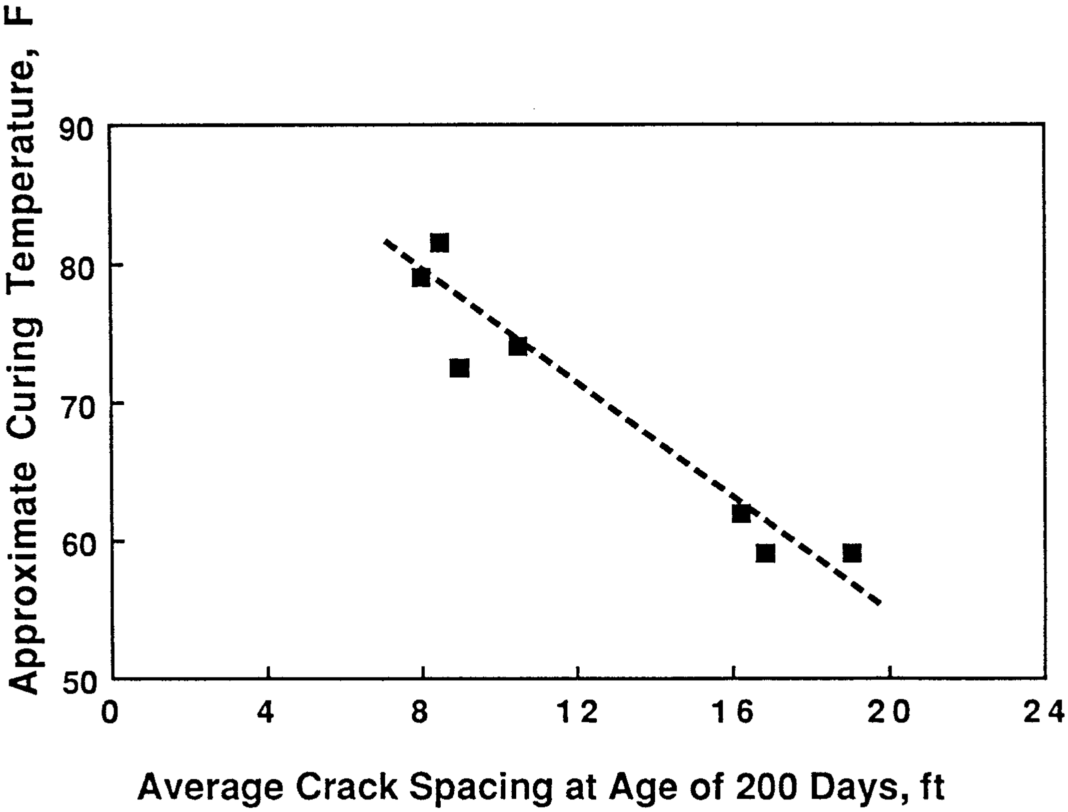
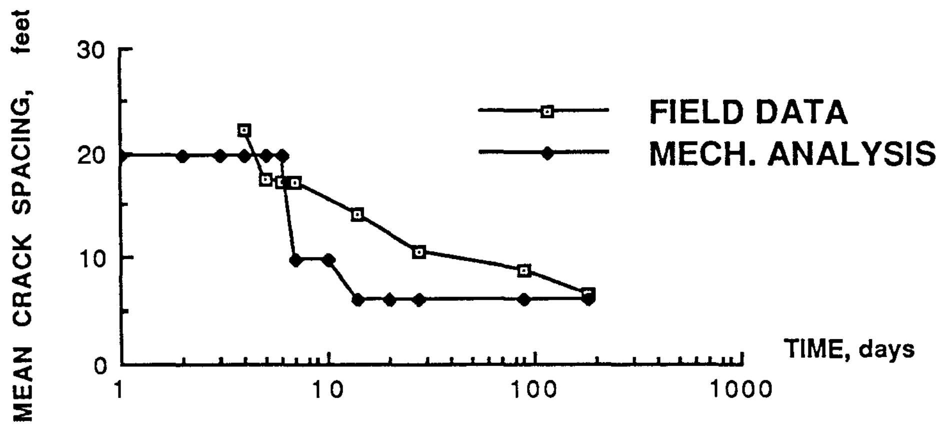
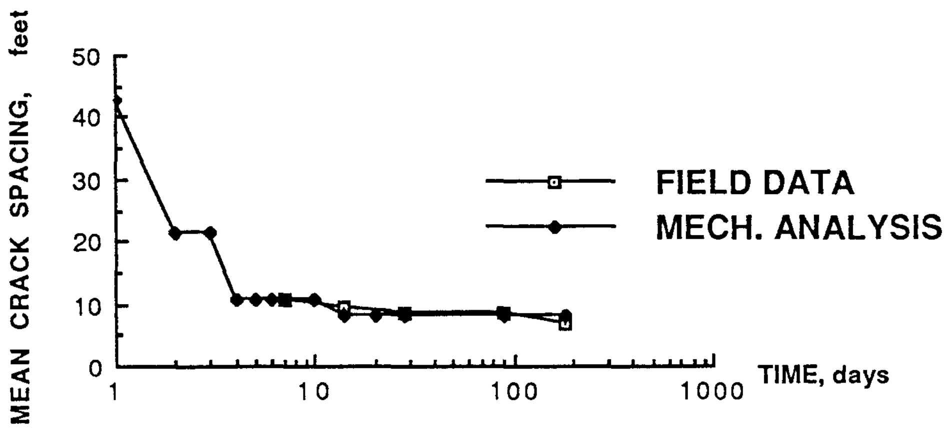


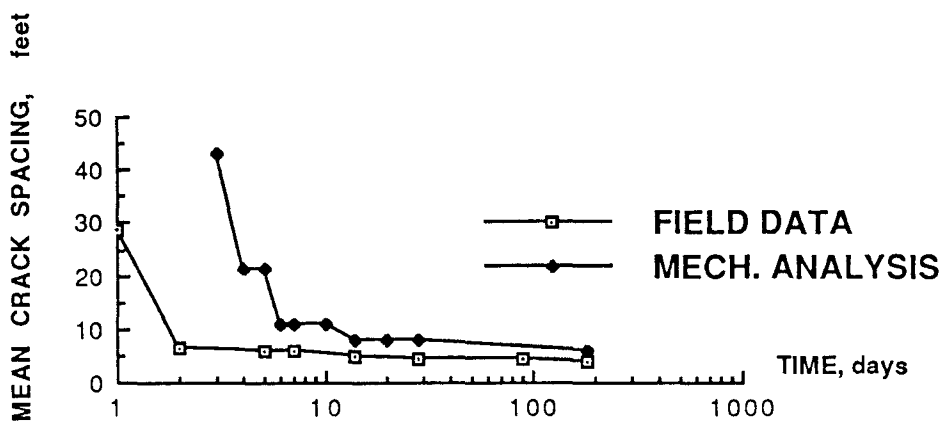
Fig. 10. Effect of setting temperature on crack spacing (Ref 5).



(a) Section 1



(b) Section 2



(c) Section 3

Fig. 11. The historical trend of predicted and actual crack spacing for each test section

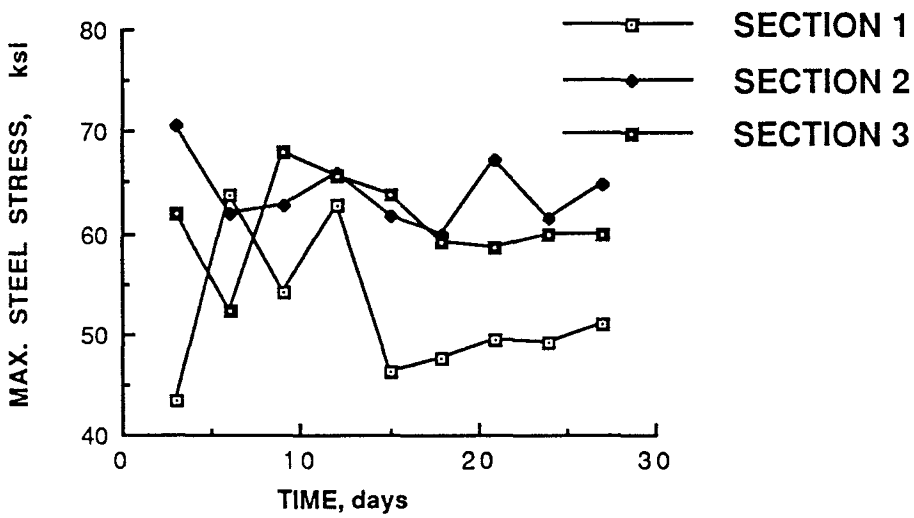


Fig. 12. Steel stress versus time

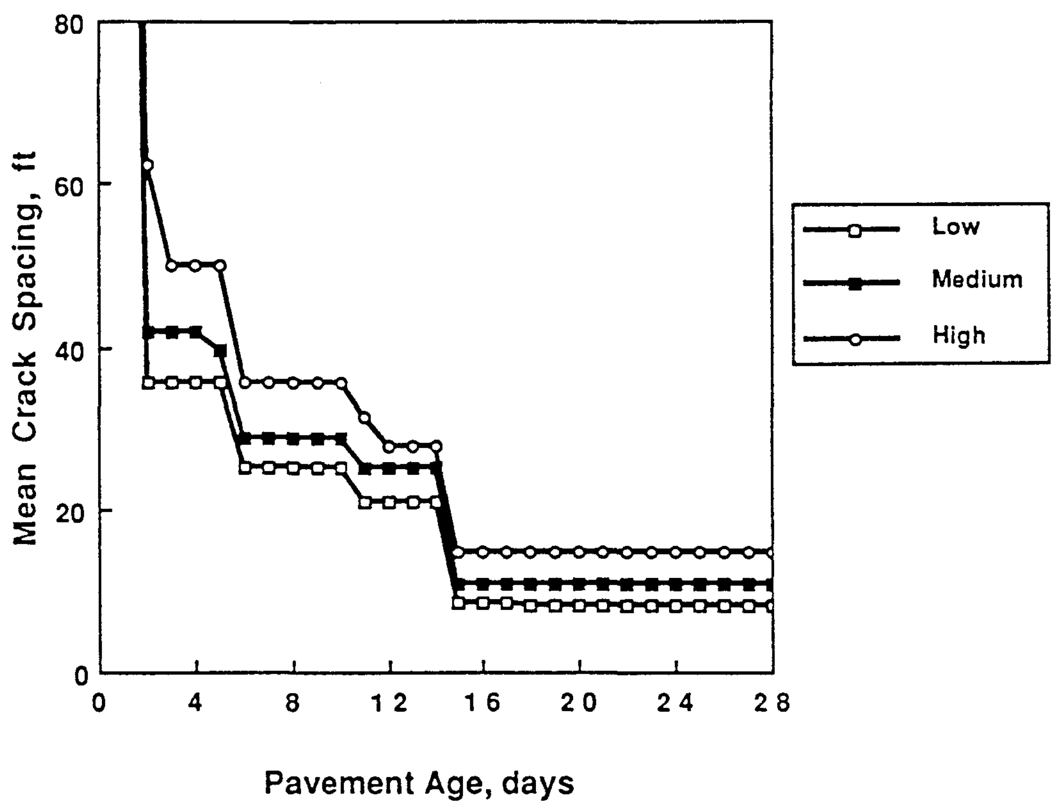


Fig. 13. A history of crack spacing with time with all conditions being equal but the strength (Ref 5).

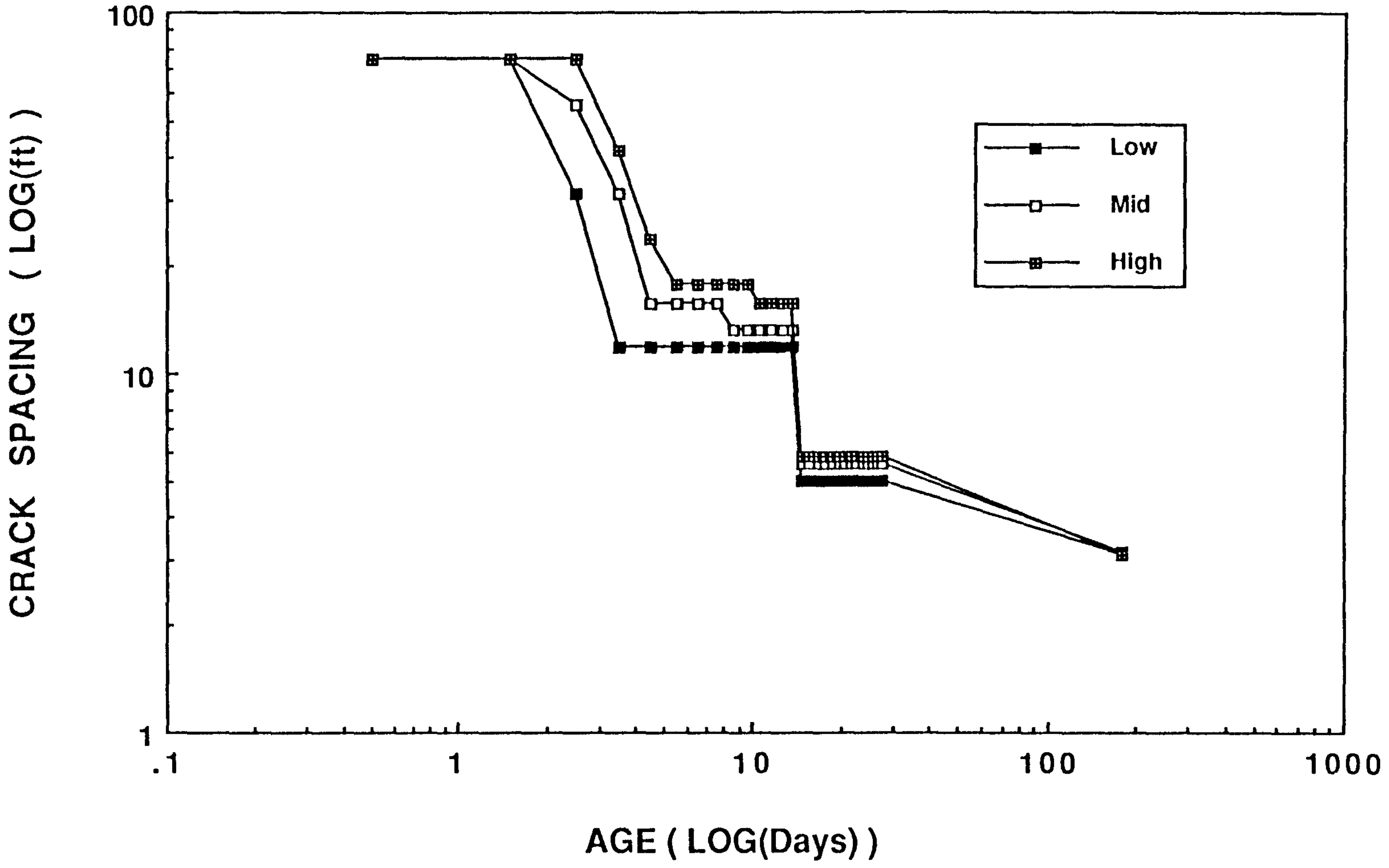


Fig. 14. A history of crack spacing with time with all conditions being equal, except that one section has a more rapid strength increase to the same maximum value.

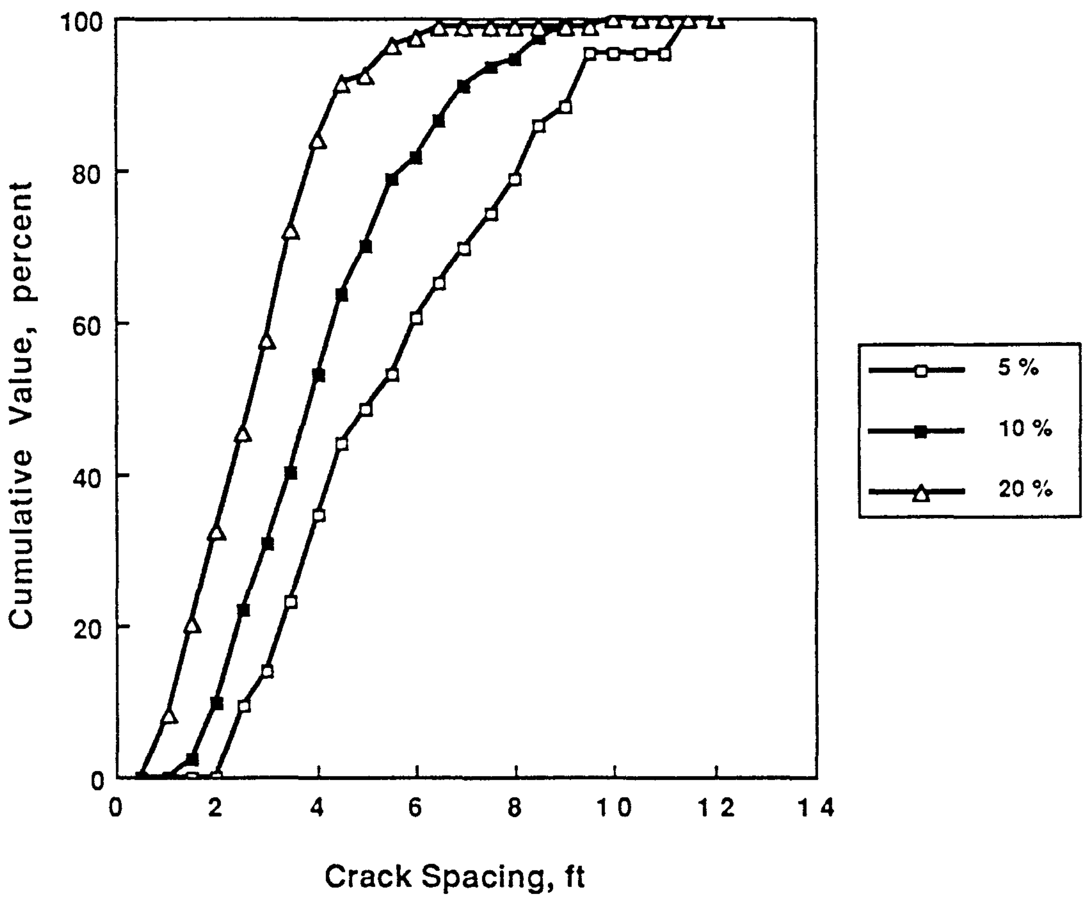


Fig. 15. A history of crack spacing with time for different values of strength variability.

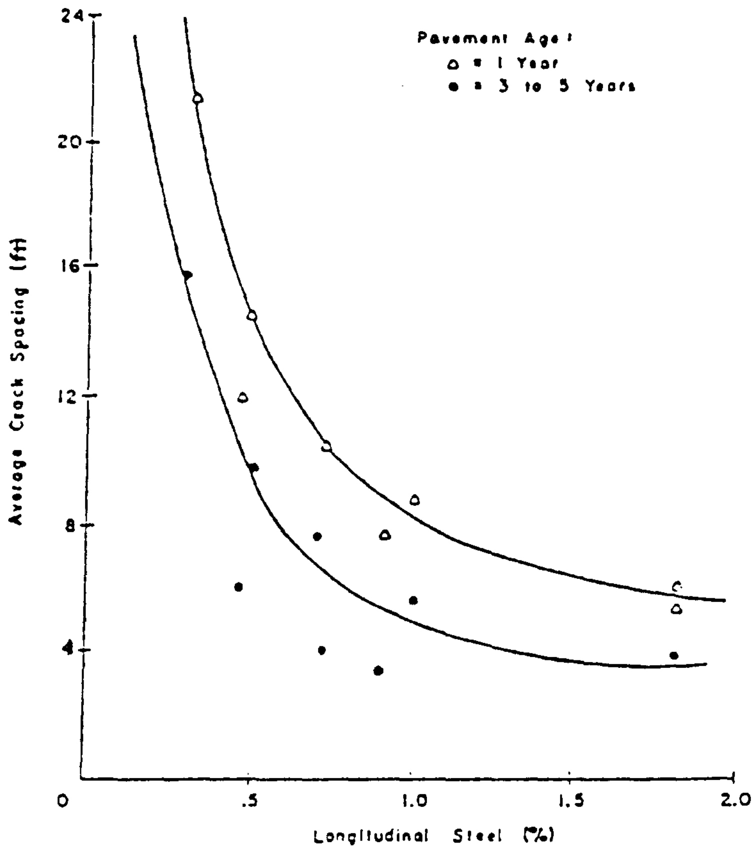


Fig. 16. Effect of percent steel on crack spacing (Ref 5).

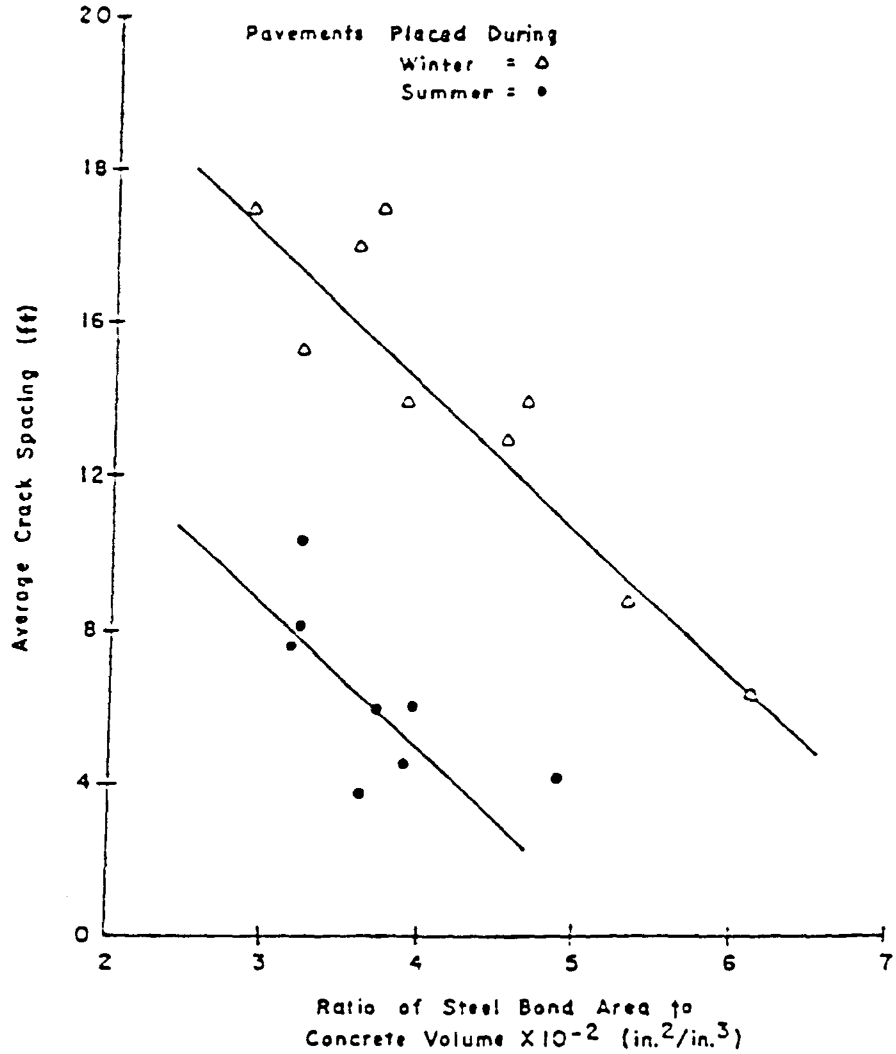


Fig. 17. Relationship between steel bond area and crack spacing (Ref 5).

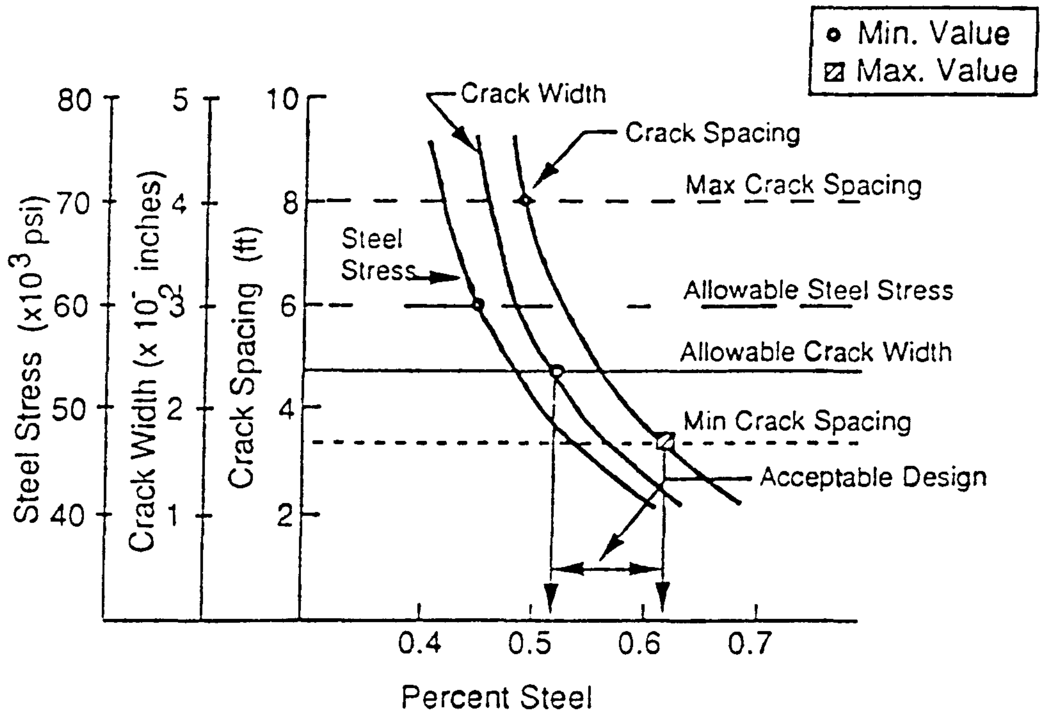


Fig. 18. Conceptual illustration of selecting percent longitudinal steel (Ref 5).

Appendix A

Field Data Furnished by Illinois DOT

CRC PAVEMENT MONITORING

:cation of pour: RIGHT LANE 8+63.5 - 17+02.6 SB. ML.
:te Placed: 5-13-88
:MPERATURE:
Air: 55 - 60
Concrete: 70 - 75
:pe of subbase: 4" BAM
:signed pavement thickness: 13"
:signed depth of rebar: 3 1/2"
:tual avg. depth: 3.64"
:ncrete Admixtures: AIR, WATER REDUCER
:ncrete Strength: 600 PSI @ 3 DAYS /810 PSI @ 5 DAYS

County: Cook
Section 1985-080R
Route: FAI 90/94
(Dan Ryan Expwy)
District: 1
CONTRACT NO.: 80063
Job No: C-91-433-85
Project: IDR-94-3 (268)52

:cation of Test Area: 12+00 - 14+00, Day 1, 2, 3
8+63.5 -17+02.6 DAY 4, 5, 6, 7
:erage Crack Width: HAIRLINE DAY 3,4,5,6,7,14.28,3 MO.,6MO.

CRACK SPACING

STATION	DAY 1 14-May-88	DAY 2 15-May-88	DAY 3 16-May-88	DAY 4 17-May-88	DAY 5 18-May-88	DAY 6 19-May-88	DAY 7 20-May-88	DAY 14 27-May-88	DAY 28 10-Jun-88	3 MONTH 13-Aug-88	6 MONTH 15-Nov-88
8+63.5				START	START	START	START	START	START	START	
											11.1
											3.7
											6.0
											6.0
											3.0
											3.0
											2.3
											24.3
											2.0
											2.0
											6.3
											12.0
											15.5
											9.0
											6.3
											3.1
											1.3
											1.9
				174.7	174.7	174.7	174.7	174.7	150.3	135.1	6.1
										15.2	15.2
									11.9	11.8	11.3
										6.2	6.2
									12.7	6.5	6.5
											5.9
										9.4	2.5
								17.1	17.1	8.7	8.7
											6.0
										15.1	9.1
										3.1	3.1
									23.9	5.7	5.7
										5	5.0
									9.3	4.3	4.3
										3.9	3.9
									15.2	11.3	11.3
									3.2	3.2	3.2
								53.8	2.3	2.3	2.3
				30.5	20.5	30.5	30.5	9.6	9.6	9.6	9.6
				4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
					1.8	1.8	1.8	1.8	1.8	1.8	1.8
											4.2
											1.8
									3.6	8.6	2.6
									11.6	11	11.6
				32.2	30.4	30.4	30.4	30.4	10.7	10.7	10.7
				2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
				2.3	2.8	2.3	2.8	2.8	2.3	2.3	2.3
				2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
				9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
	NO	NO						15.1	15.1	15.1	15.1
				18.7	18.7	18.7	18.7	3.6	3.6	3.6	3.6

Section #1

	CRACKS	CRACKS			24.5	24.5	9.6	9.6	9.6	9.6	9.6	9.6
										8.2	0.2	8.2
	VISIBLE	VISIBLE			2.4	2.4	14.9	14.9	14.9	6.7	6.7	6.7
					5.0	5.0	2.4	2.4	2.4	2.4	2.4	2.4
							5.0	5.0	5.0	5	5	5.0
									9.7	9.7	9.7	9.7
											5.3	5.3
									13.5	13.5	8.2	8.2
									2.5	2.5	2.5	2.5
												12.0
									14.7	14.7	14.7	2.7
											12.2	12.2
												6.1
												3.0
												3.9
												5.4
										34.5	22.3	3.9
											13	13.0
						95.6	95.6	95.6	55.2	20.6	7.6	7.6
13+22.3			122.3		98.6	3.0	3.0	3.0	3.0	3	3	3.0
					2.0	2.0	2.0	2.0	2.0	2	2	2.0
					3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
					3.0	3.0	3.0	3.0	3.0	3	3	3.0
					3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
					2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
					0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
					2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
					3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
					1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
										3.4	3.4	3.4
												21.0
											31.4	10.4
											12.2	12.2
											12.8	12.8
										64.8	8.4	8.4
										8.8	8.8	8.8
									79.9	2.9	2.9	2.9
										4.3	4.3	4.3
					102.3	97.8	97.8	97.8	17.9	13.5	13.5	13.5
					3.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
					82.6	3.0	3.0	3.0	3.0	3	3	3.0
					4.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9
										7.4	7.4	7.4
										6	6	6.0
												5.5
												1.0
												8.6
												9.2
												14.8
											51.1	12.0
												2.7
												2.6
									70.3	56.9	5.8	0.5
					6.0	79.7	79.7	79.7	9.4	9.4	9.4	9.4
					10.0	4.0	4.0	4.0	4.0	4	4	4.0
											2.4	2.4
					16.1	6.0	6.0	6.0	6.0	6	3.6	3.6
					2.9	10.0	10.0	10.0	10	10	10	10
					4.5	7.2	7.2	7.2	7.2	7.2	7.2	7.2
									4.7	4.7	4.7	4.7
					20.3	8.9	8.9	8.9	4.2	4.2	4.2	4.2
					4.2	2.9	2.9	2.9	2.9	2.9	2.9	2.9
					10.1	4.5	4.5	4.5	4.5	4.5	4.5	4.5
					48.1	20.3	20.3	20.3	20.3	12.6	12.6	12.6
					13.1	4.2	4.2	4.2	4.2	7.7	7.7	7.7
					5.9	10.1	10.1	10.1	10.1	4.2	4.2	4.2
					24.4	10.9	10.9	10.9	10.9	10.1	10.1	10.1
										10.9	10.9	10.9
										8.7	8.7	3.7
										18.1	18.1	18.1
											7.4	7.4
						37.2	37.2	37.2	37.2	10.5	3.1	3.1
						2.6	2.6	2.6	2.6	2.6	2.6	2.6
						6.6	6.6	6.6	6.6	2.1	2.1	2.1

Section # 1 cont'd

										4.5	4.5	4.5
						3.9	3.9	3.9	3.9	3.9	3.9	3.9
						5.9	5.9	5.9	5.9	5.9	5.9	5.9
						5.2	5.2	5.2	5.2	5.2	5.2	5.2
						2.5	2.5	2.5	2.5	2.5	2.5	2.5
13+02.6						16.7	16.7	16.7	16.7	16.7	16.7	16.7

CRC PAVEMENT MONITORING

Location of pour: Left lane 184+60 to 203+00 S.B. Lanes
Date Placed: 5-20-88
TEMPERATURE:
Air: 70 TO 75
Concrete: 68 TO 74
Type of subbase: 4" BAM
Designed pavement thickness: 13"
Designed depth of rebar: 3 1/2"
Actual avg. depth: 4"
Concrete Admixtures: AIR, WATER REDUCER
Concrete Strength: 790 PSI @ 3 DAYS
875 PSI @ 5 DAYS
945 PSI @ 7 DAYS
Location of Test Area: 195+00 TO 197+00

County: Cook
Section 1985-080R
Route: FAI 90/94
(Dan Ryan Expwy)
District: 1
CONTRACT NO.: 80063

Job No: C-91-433-85
Project: IDR-94-3 (268)152

Average Crack Width: HAIRLINE: 3,4,5,6,7,14,28 DAYS
HAIRLINE: 3, 6 MONTH

CRACK SPACING

STATION	DAY 1 21-May-88	DAY 2 22-May-88	DAY 3 23-May-88	DAY 7 27-May-88	DAY 14 03-Jun-88	DAY 28 17-Jun-88	3 MONTH 28-Aug-88	6 MONTH 22-Nov-88
197+00	START	START	START	START	START	START	START	START
		0.8	0.8	0.8	0.8	0.8	0.8	0.8
				4.3	4.3	4.3	4.3	4.3
		10.0	10.0	5.7	5.7	5.7	5.7	5.7
			6.6	6.6	6.6	6.6	6.6	6.6
		14.9	8.3	8.3	8.3	8.3	8.3	8.3
				9.8	9.8	9.8	9.8	9.8
			15.0	5.2	5.2	5.2	5.2	5.2
				6.6	6.6	6.6	6.6	6.6
	51.1	25.4	10.4	3.8	3.8	3.8	3.8	3.8
				4.3	4.3	4.3	4.3	4.3
		8.9	8.9	4.6	4.6	4.6	4.6	4.6
						7.9	7.9	7.9
		16.2	10.0	10	10	2.1	2.1	2.1
			6.2	6.2	6.2	6.2	6.2	6.2
			7.3	7.3	7.3	7.3	7.3	7.3
			7.1	7.1	7.1	7.1	7.1	7.1
			5.4	5.4	5.4	5.4	5.4	5.4
		27.1	7.3	7.3	7.3	7.3	7.3	7.3
	60.5	8.3	8.3	8.3	8.3	8.3	8.3	8.3
			4.7	4.7	4.7	4.7	4.7	4.7
			4.7	4.7	4.7	4.7	4.7	4.7
		14.3	4.9	4.9	4.9	4.9	4.9	4.9
	23.9	9.6	7.2	7.2	7.2	7.2	7.2	7.2
			2.4	2.4	2.4	2.4	2.4	2.4
							5.4	5.4
		7.7	7.7	7.7	7.7	7.7	2.3	2.3
			8.3	8.3	8.3	8.3	8.3	8.3
		13.0	4.7	4.7	4.7	4.7	4.7	4.7
			7.6	7.6	7.6	7.6	7.6	7.6
			4.5	4.5	4.5	4.5	4.5	4.5
		19.2	7.1	7.1	7.1	7.1	7.1	7.1
				4.8	4.8	4.8	4.8	4.8
		11.2	11.2	6.4	6.4	6.4	6.4	6.4
						5.4	5.4	5.4
			11.3	11.3	11.3	5.9	5.9	5.9
195+00	64.8	13.7	2.4	2.4	2.4	2.4	2.4	2.4

NO
NEW
CRACKS
DEVLPD

Section #2A

CRC PAVEMENT MONITORING

Location of pour: Left lane 184+60 to 203+00 S.B. Lanes
Date Placed: 5-20-88
TEMPERATURE:
Air: 70 TO 75
Concrete: 68 TO 74
Type of subbase: 4" BAM
Designed pavement thickness: 13"
Designed depth of rebar: 3 1/2"
Actual avg. depth: 3.5"
Concrete Admixtures: AIR, WATER REDUCER
Concrete Strength: 790 PSI @ 3 DAYS
875 PSI @ 5 DAYS
945 PSI @ 7 DAYS
Location of Test Area: 207+00 to 205+00

Cook
1985-080R
FAI 90/94
(Dan Ryan Expwy)
1
80063

C-91-433-85
IDR-94-3 (268)52

AVERAGE CRACK WIDTH: HAIRLINHAIRLINE: 7,14,28 DAYS
HAIRLINE: 3,6 MONTHS

CRACK SPACING

STATION	DAY 7 27-May-88	DAY 14 03-Jun-88	DAY 28 17-Jun-88	3 MONTH 20-Aug-88	6 MONTH 22-Nov-88
207+00	START	START	START	START	START
	154.2	69.0	69.0	69.0	6.3
					4.5
					14.8
					3.9
					10.3
					13.7
					12
					3.5
					17.5
			20.6	20.6	3.1
			13.3	13.3	13.3
					8.7
					20.7
		69.6	35.7	35.7	6.3
		6.1	6.1	6.1	6.1
		6.2	6.2	6.2	6.2
		3.4	3.4	3.4	3.4
		6.3	6.3	6.3	6.3
		4.3	4.3	4.3	4.3
	14.7	4.0	4.0	4.0	4
					3.8
	24.0	24.0	24	24	20.2
205+00	7.1	7.1	7.1	7.1	7.1

Section 2B

11/28

Location of pour: Right lane 184+13 to 206+25 S.B. Mainline Lane 5
Date Placed: May-26-88
TEMPERATURE: CCook
Air: 60 to 78 S1985-080R
Concrete: 68 to 70 RFAI 90/94
Type of subbase: 4" BAM (Dan Ryan Expwy)
Designed pavement thick 13" D !
Designed depth of rebar 3.5" C 80063
Actual avg. depth: 4.25
Concrete Admixtures: Air, Water RJC-91-433-85
Concrete Strength: 775 PSI @ 3 PIDR-94-3 (263)52
860 PSI @ 7 DAYS

Location of Test Area: 196+50 to 198+50
Average Crack Width: Hairline: 1,2,5,7,14,28 DAYS
HAIRLINE: 3, 6 MONTH
CRACK SPACING

STATION	DAY 1 27-May-88	DAY 2 28-May-88	DAY 5 31-May-88	DAY 7 02-Jun-88	DAY 14 09-Jun-88	DAY 28 23-Jun-88	3 MONTH 26-Aug-88	6 MONTH 28-NOV-88
196+50	START	START	START	START	START	START	START	START
		2.6	2.6	2.6	2.6	2.6	2.6	2.6
					5.0	5.0	5.0	5
								3.7
		10.7	10.7	10.7	5.7	5.7	5.7	2
						5.0	5.0	5
			8.0	8.0	8.0	3.0	3.0	3
	26.4	13.1	5.1	5.1	5.1	5.1	5.1	5.1
								6.5
		9.5	9.5	9.5	9.5	9.5	9.5	3
		5.7	5.7	5.7	5.7	5.7	5.7	5.7
	20.7	5.5	5.5	5.5	5.5	5.5	5.5	5.5
								3.5
	9.0	9.0	9.0	9.0	9.0	9.0	9.0	5.5
					5.7	5.7	5.7	5.7
	10.3	10.3	10.3	10.3	4.6	4.6	4.6	4.6
		2.7	2.7	2.7	2.7	2.7	2.7	2.7
		2.3	2.3	2.3	2.3	2.3	2.3	2.3
		1.9	1.9	1.9	1.9	1.9	1.9	1.9
					2.4	2.4	2.4	2.4
					2.3	2.3	2.3	2.3
		9.8	9.8	9.8	5.1	5.1	5.1	5.1
								2
		8.0	8.0	8.0	8.0	8.0	8.0	5
		4.0	4.0	4.0	4.0	4.0	4.0	4
		4.5	4.5	4.5	4.5	4.5	4.5	4.5
		4.9	4.9	4.9	4.9	4.9	4.9	4.9
					6.6	6.6	6.6	6.6
					1.2	1.2	1.2	1.2
								2.9
		15.2	11.7	11.7	3.9	3.9	3.9	1
	53.3		3.5	3.5	3.5	3.5	3.5	3.5
		4.6	4.6	4.6	4.6	4.6	4.6	4.6
		4.7	4.7	4.7	4.7	4.7	4.7	4.7
		5.2	5.2	5.2	5.2	5.2	5.2	5.2
		5.8	5.8	5.8	5.8	5.3	5.8	5.8
	23.9	3.6	3.6	3.6	3.6	3.6	3.6	3.6
		4.5	4.5	4.5	4.5	4.5	4.5	4.5
		4.1		2.6	2.6	2.6	2.6	2.6
			4.1	1.5	1.5	1.5	1.5	1.5
		5.1	5.1	5.1	5.1	5.1	5.1	5.1
					4.5	4.5	4.5	4.5
		6.4	6.4	6.4	1.9	1.9	1.9	1.9
		7.7	7.7	7.7	7.7	7.7	7.7	7.7
		5.0	5.0	5.0	5.0	5.0	5.0	5
		6.0	6.0	6.0	6.0	6.0	6.0	6
					6.7	6.7	6.7	6.7
		9.8	9.8	9.8	3.1	3.1	3.1	3.1
		7.2	7.2	7.2	7.2	7.2	7.2	7.2
198+50	(end) 56.3	(end)	(end)	(end)	(end)	(end)	(end) No new cracks	(END)

Section #3

Appendix B

Hourly Temperature Data at Midway Aiport
for May and June, 1988

NOAA Form 79-1d
(4-71)

UNITED STATES DEPARTMENT OF COMMERCE, NOAA

DATA SHEET; HOURLY RECORDS

STATION: MIDWAY AIRPORT 3 SW 11-1577-2

DATA: HOURLY TEMPERATURES (F) MAY 1988

ALL TIMES CENTRAL STANDARD...

Date	A.M. 1	2	3	4	5	6	7	8	9	10	11	Noon	P.M. 1	2	3	4	5	6	7	8	9	10	11	Mid't	Sum	Mean	Date
1	51	49	46	45	45	45	53	58	60	64	67	69	67	70	68	68	67	65	60	57	54	54	52	48			1
2	47	48	46	47	47	51	59	65	68	70	72	73	74	76	75	73	72	71	66	62	54	53	54	53			2
3	53	52	51	50	54	57	59	61	62	65	68	70	69	66	67	66	64	61	58	57	55	51	52	51			3
4	50	49	49	48	48	51	54	57	59	60	61	62	63	64	65	64	64	62	60	57	56	56	55	55			4
5	54	51	51	49	48	47	56	58	63	66	68	69	68	69	70	68	69	68	67	65	62	60	59	58			5
6	58	55	52	53	53	56	63	68	69	72	75	75	76	76	75	73	72	71	67	63	55	53	52	52			6
7	50	49	48	47	48	51	59	63	69	72	77	79	82	83	83	83	82	81	78	77	76	75	74	70			7
8	69	68	67	68	68	68	68	70	76	78	81	84	85	84	82	75	72	72	58	57	59	59	58	57			8
9	56	56	56	56	55	58	57	57	59	59	59	62	60	57	57	57	58	58	58	58	58	59	60	60			9
10	59	58	57	56	55	56	58	58	59	59	59	58	60	62	63	66	65	65	62	58	56	56	55	55			10
11	55	55	53	51	51	52	53	58	59	63	63	69	70	73	75	70	70	68	65	64	61	63	62	63			11
12	65	63	61	60	59	58	58	59	62	67	72	75	78	79	81	82	79	78	75	72	70	67	67	68			12
13	69	68	68	68	66	62	58	54	55	54	54	53	54	55	55	57	57	56	53	52	49	48	47	46			13
14	46	47	46	47	48	49	51	57	61	68	71	74	76	77	78	80	82	83	79	76	74	72	70	69			14
15	69	68	67	67	71	73	74	73	71	70	76	72	78	82	80	63	68	73	72	69	68	65	65	65			15
16	63	59	58	56	55	58	61	63	66	67	69	63	59	54	52	49	50	49	49	49	49	48	47	46			16
17	46	45	45	44	44	45	48	51	53	57	59	62	64	61	61	59	58	55	53	50	49	49	49	48			17
18	47	47	46	46	48	51	56	59	61	61	66	69	70	68	68	69	66	65	60	56	54	54	53	53			18
19	52	52	51	50	50	54	60	63	67	72	72	74	75	76	77	75	72	71	66	62	60	57	57	56			19
20	55	56	56	55	55	57	61	65	70	72	76	78	78	75	75	74	74	73	69	65	63	61	61	62			20
21	61	60	60	58	56	58	61	65	72	77	78	79	78	79	80	77	76	74	72	69	64	60	60	60			21
22	60	60	60	59	61	62	64	69	72	73	74	77	82	78	76	71	69	66	65	65	65	64	63	60			22
23	58	58	57	56	55	56	55	56	56	56	57	58	57	56	55	56	56	56	55	56	56	56	57	56			23
24	56	57	52	51	52	52	54	55	56	58	59	61	63	62	57	55	56	55	52	51	48	46	45	44			24
25	44	43	43	42	45	47	49	51	51	53	54	59	61	63	63	61	59	60	57	55	53	51	49	48			25
26	47	46	45	46	47	51	56	60	65	66	69	72	75	77	78	79	78	76	75	69	68	66	64	63			26
27	63	63	63	62	61	57	60	63	67	71	74	77	79	82	84	83	81	79	77	75	74	73	72	70			27
28	69	69	68	67	67	67	71	75	76	78	81	83	85	87	88	87	86	85	81	79	78	75	74	74			28
29	71	70	69	68	65	66	68	71	79	83	84	86	88	89	90	88	87	86	85	83	79	77	76	75			29
30	74	72	72	72	69	68	72	77	79	81	85	87	89	90	92	91	89	87	85	80	79	77	76	75			30
31	72	70	69	69	67	66	71	76	83	86	88	89	90	91	92	90	88	85	84	81	79	79	78	77			31
Sums																											Sums
Means																											Means

NOAA FORM 79-1d (4-71) Supersedes WB Form 920--11D Which May Be Used

☆ U.S.GPO:1980-668-115/1097-6

NOAA Form 79-1d (4-71)

UNITED STATES DEPARTMENT OF COMMERCE, NOAA

DATA SHEET; HOURLY RECORDS

STATION: MIDWAY AIRPORT 3 SW 11-1577-2

DATA: HOURLY TEMPERATURES (F) JUN 1988

ALL TIMES ARE CENTRAL STANDARD

Date	A.M. 1	2	3	4	5	6	7	8	9	10	11	Noon	P.M. 1	2	3	4	5	6	7	8	9	10	11	Mid't	Sum	Mean
1	76	74	71	70	73	73	76	85	88	89	90	91	93	93	92	90	89	89	86	83	82	80	79	79		
2	77	80	77	74	72	70	72	73	69	66	67	68	67	70	71	70	67	66	64	55	55	56	57	57		
3	54	53	53	53	54	55	57	60	62	63	65	66	68	69	68	67	65	63	63	61	60	60	59	57		
4	55	53	54	53	52	54	61	65	68	71	72	74	76	78	78	77	75	74	71	69	67	65	63	62		
5	61	62	62	61	60	63	69	74	78	81	83	85	86	88	88	87	86	84	82	78	76	73	73	70		
6	71	70	67	67	66	69	73	75	77	83	84	88	89	90	91	90	88	86	84	81	78	75	71	70		
7	70	67	67	66	65	69	76	79	84	87	88	91	92	93	92	91	89	87	84	81	80	79	77	74		
8	74	73	70	70	69	71	74	77	80	81	70	68	70	71	67	65	65	64	60	56	54	53	53	52		
9	51	51	51	51	50	51	54	58	59	60	63	64	63	64	62	63	63	62	59	57	56	55	55	54		
10	53	52	52	51	51	54	57	59	61	63	68	69	70	69	68	67	67	66	64	63	61	59	58	56		
11	55	54	53	51	52	56	62	68	71	75	77	80	81	83	86	86	85	84	80	78	74	70	67	65		
12	64	61	59	58	58	61	68	74	78	81	84	86	87	89	91	90	87	86	84	80	77	75	72	70		
13	68	68	67	67	66	66	69	73	77	81	85	89	91	93	94	94	92	90	88	85	81	79	78	75		
14	75	74	73	71	70	72	75	79	85	89	91	92	93	95	95	93	91	89	87	84	82	80	77	75		
15	74	73	72	71	71	75	78	81	83	84	85	88	92	93	94	93	89	87	83	78	75	71	70	70		
16	70	69	68	66	64	64	67	70	71	75	77	79	81	83	83	81	80	79	77	75	73	69	67	65		
17	64	64	63	62	62	65	67	69	73	76	78	79	81	81	79	78	77	76	76	74	69	65	65	64		
18	63	63	63	62	62	64	69	72	77	82	85	88	89	90	92	93	91	89	87	84	81	79	77	75		
19	73	72	72	71	70	70	75	79	83	87	89	91	92	93	94	93	92	91	89	86	83	81	80	78		
20	77	77	77	78	79	79	80	85	89	92	95	99	100	103	102	100	97	80	81	78	78	78	78	77		
21	77	77	76	75	75	77	80	83	87	91	95	98	99	100	101	99	97	95	94	91	88	85	84	83		
22	81	81	80	80	81	80	83	86	88	90	93	91	95	98	97	95	93	91	76	75	76	70	69	69		
23	69	68	67	67	67	69	71	72	75	74	77	79	80	81	79	78	77	75	70	68	67	67	67	67		
24	67	67	67	69	70	71	71	71	73	75	79	82	86	89	91	92	89	86	85	83	82	82	83	82		
25	83	83	82	81	79	80	84	86	91	95	98	100	102	104	104	102	99	89	80	75	74	74	73	71		
26	71	69	68	67	65	63	62	64	65	66	67	68	72	73	71	69	69	68	67	65	65	65	64	64		
27	63	63	62	60	59	63	67	69	71	72	75	76	78	77	76	75	74	73	70	68	67	67	66	65		
28	65	65	65	64	64	61	64	70	77	80	82	83	85	88	86	83	77	69	66	65	63	63	63	63		
29	63	62	62	62	61	62	62	63	64	65	65	66	69	71	72	71	69	68	66	64	61	60	60	60		
30	59	58	58	58	58	59	62	63	64	67	69	70	71	72	72	69	65	64	63	62	61	60	59	59		
31																										
Sums																										
Means																										

NOAA FORM 79-1d (4-71) Supersedes WB Form 920-110 Which May Be Used

☆ U.S.GPO:1980-665-115/1097-6

Appendix C

Additional Graphs
Supporting Material in Main Body of the Report

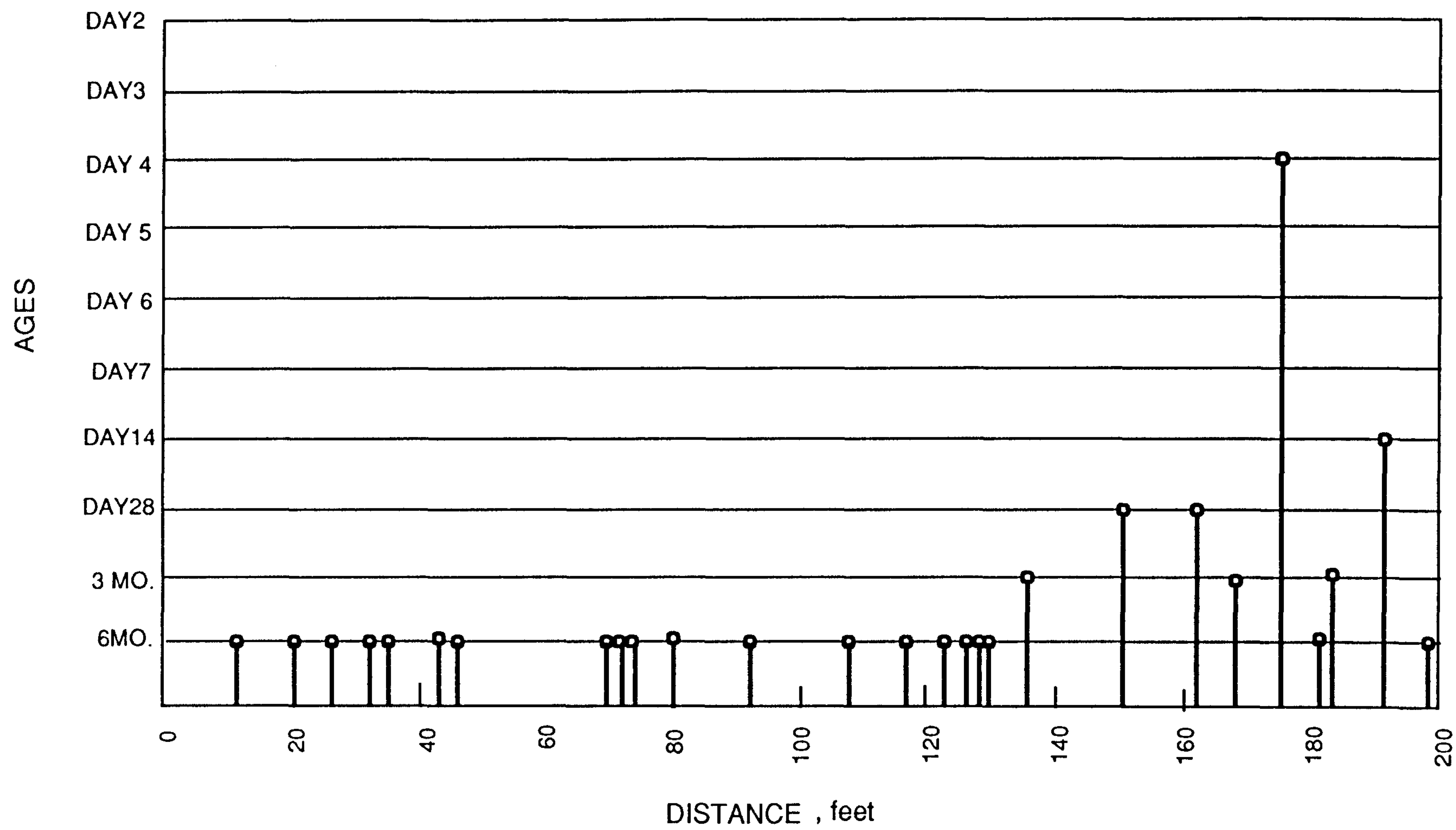


Fig. C.1. Plot of crack spacing for Test Section1 at different ages during the first six months

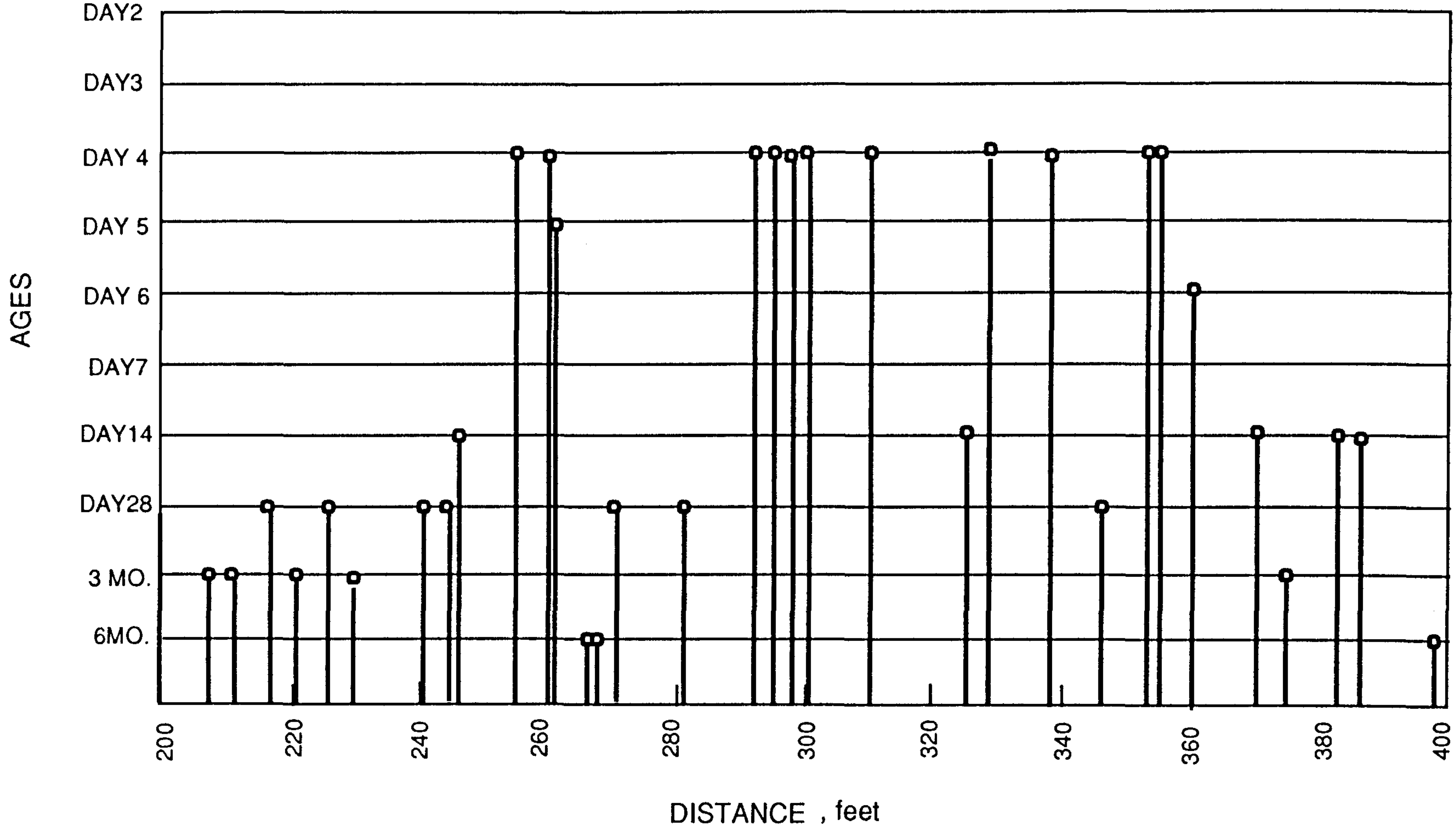


Fig. C.1. Plot of crack spacing for Test Section 1 at different ages during the first six months (continued)

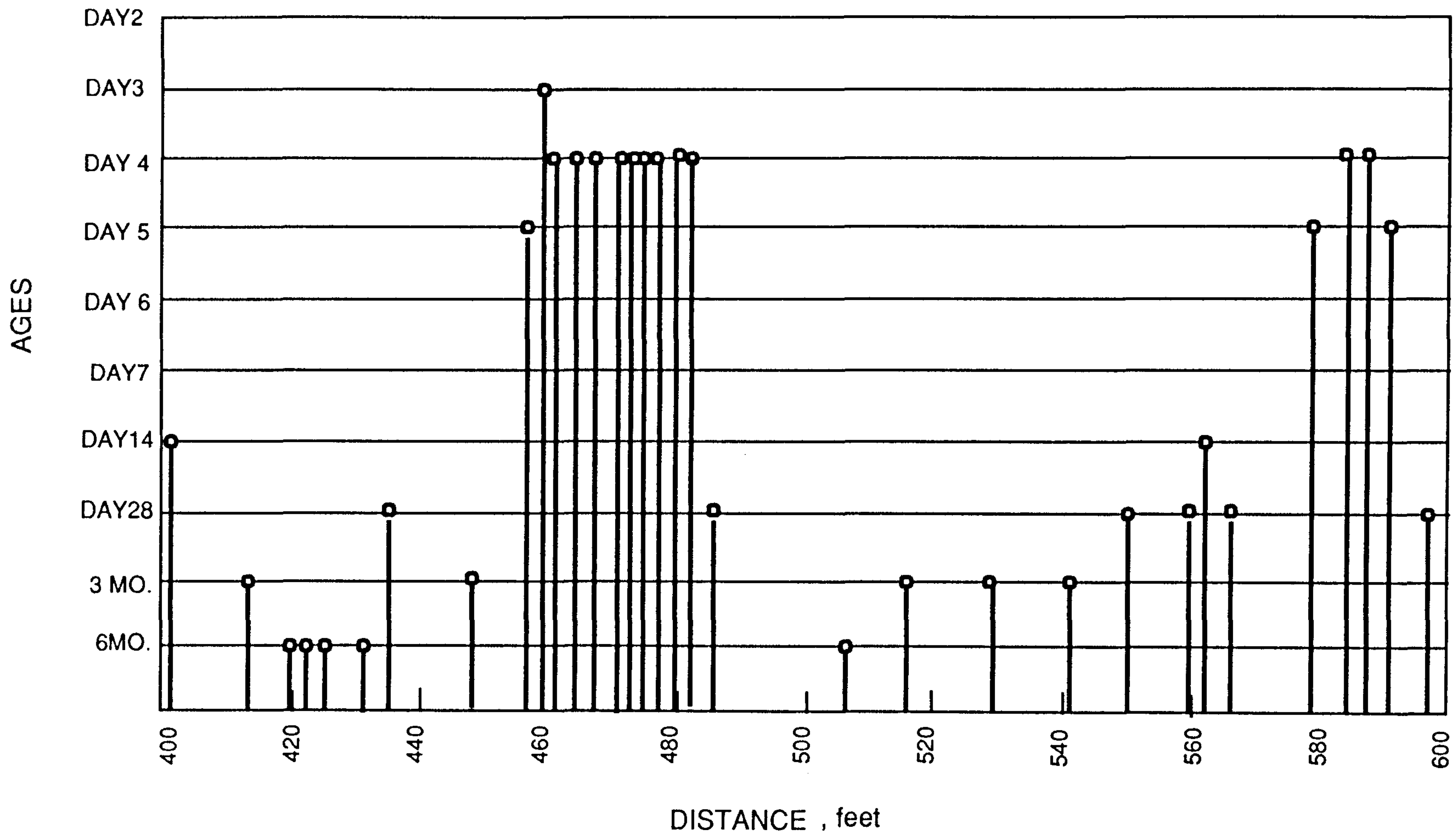


Fig. C.1. Plot of crack spacing for Test Section 1 at different ages during the first six months (continued)

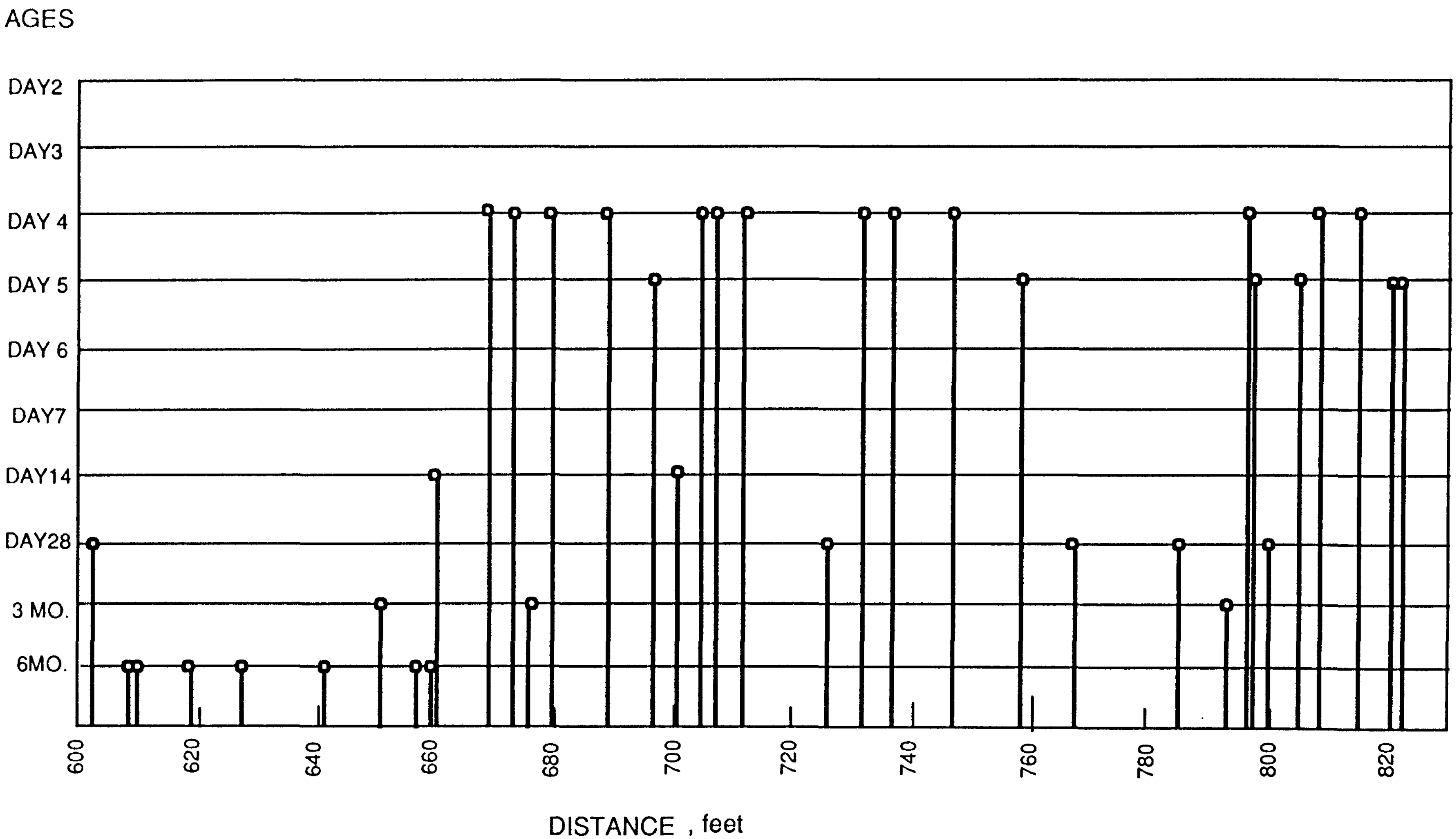


Fig. C.1. Plot of crack spacing for Test Section 1 at different ages during the first six months (continued)

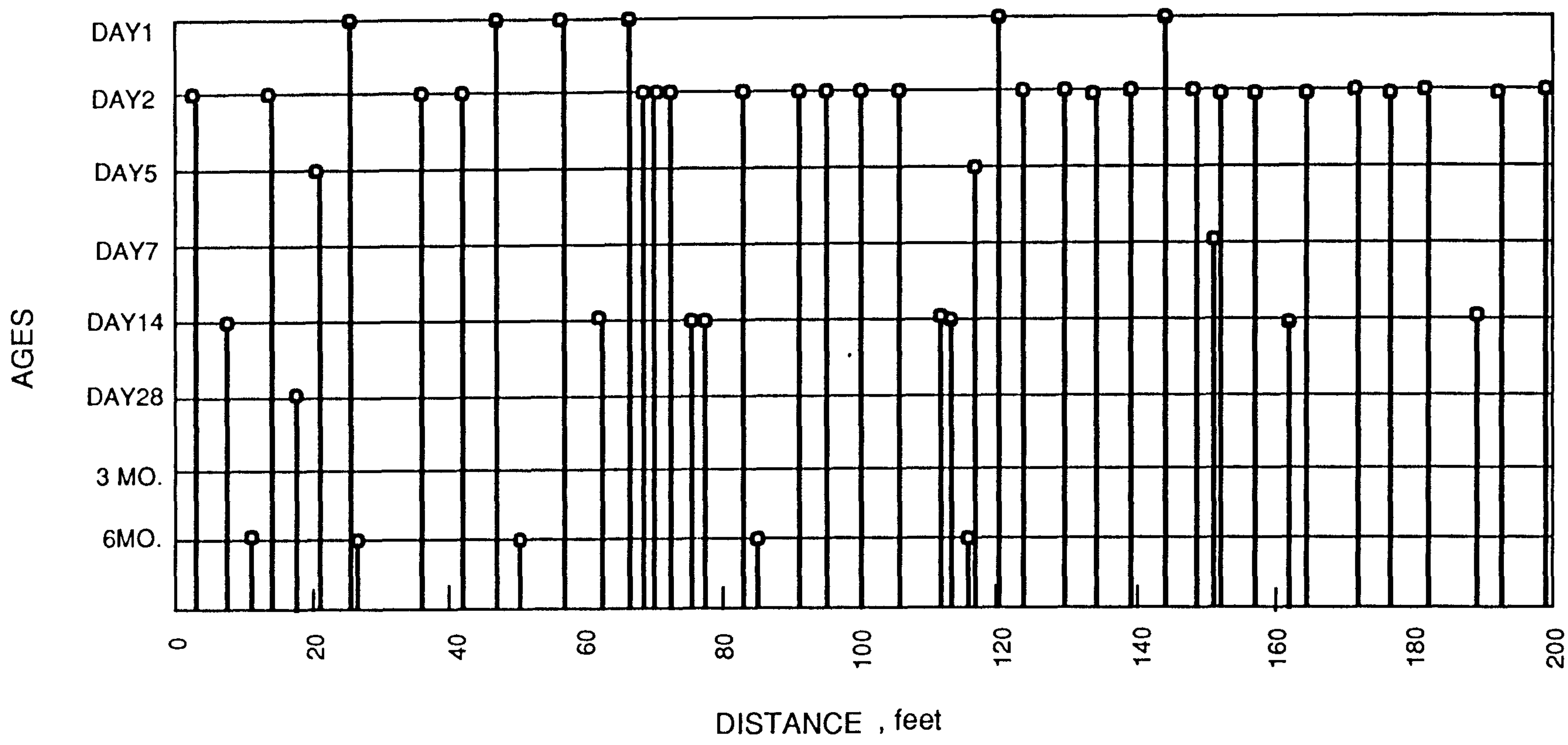


Fig. C. 2. Plot of crack spacing for Test Section 3 at different ages during the first six months

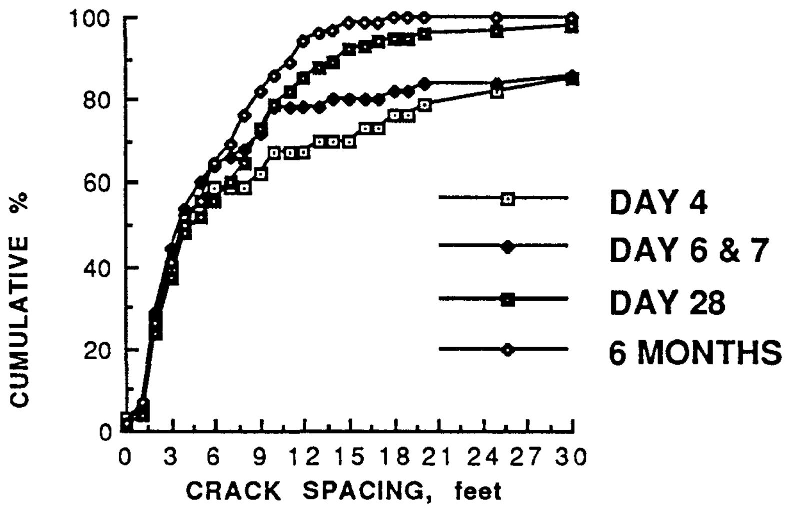


Fig. C. 3. Cumulative distribution of crack spacing for Test Section 1

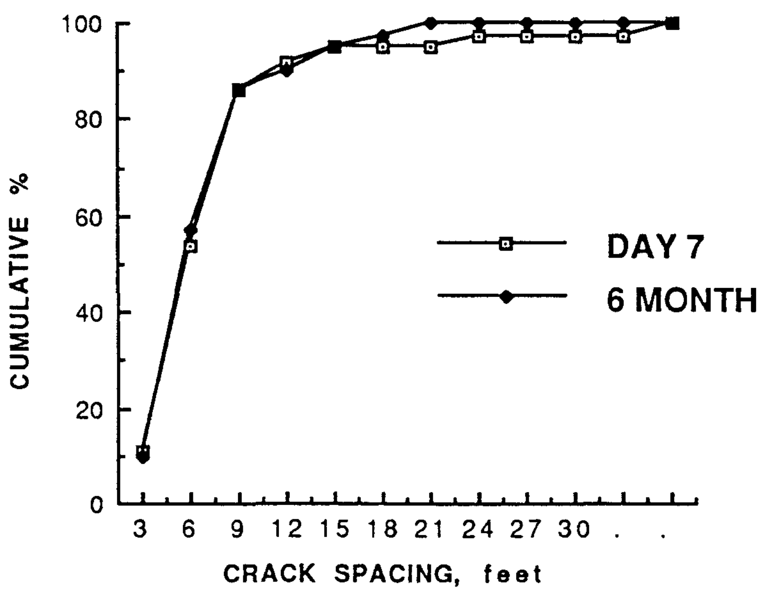


Fig. C. 4. Cumulative distribution of crack spacing for Test Section 2

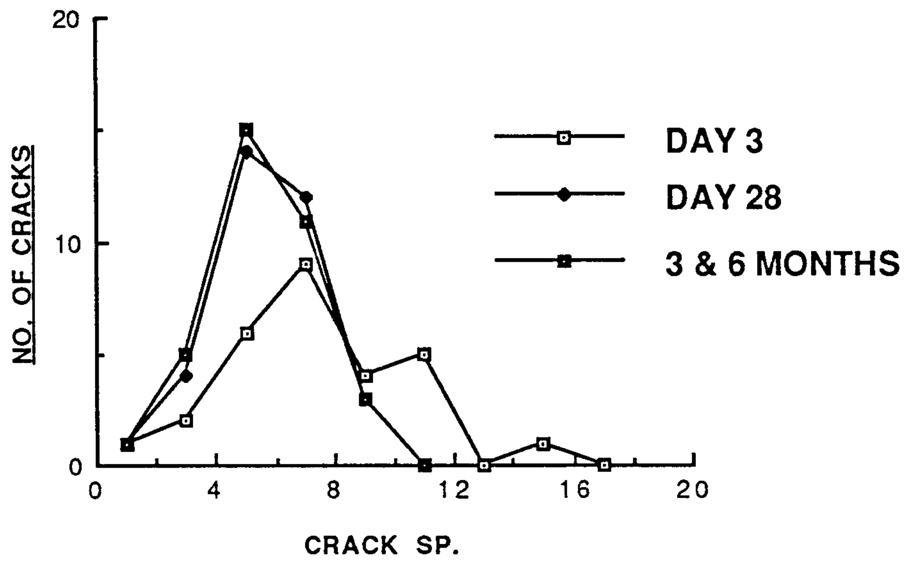


Fig. C. 5. Distribution of crack spacing for Test Section 2A

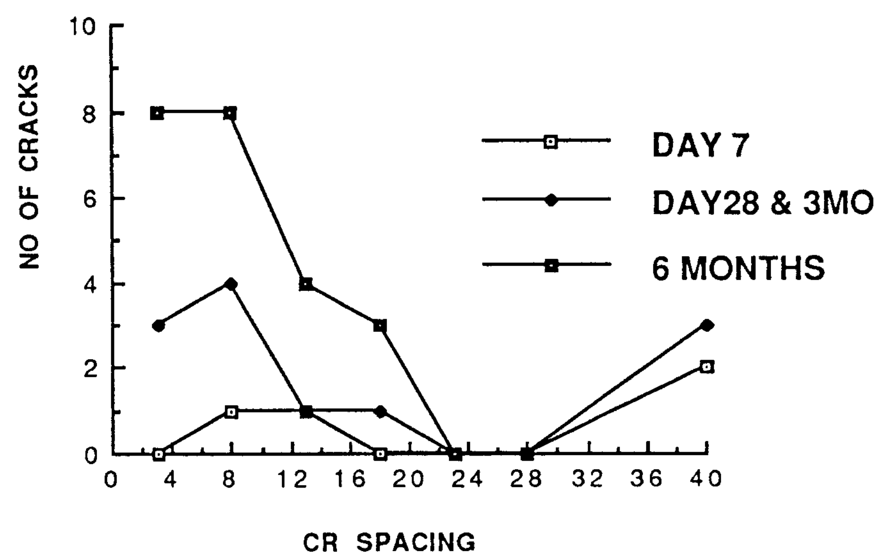


Fig. C. 6. Distribution of crack spacing for Test Section 2B

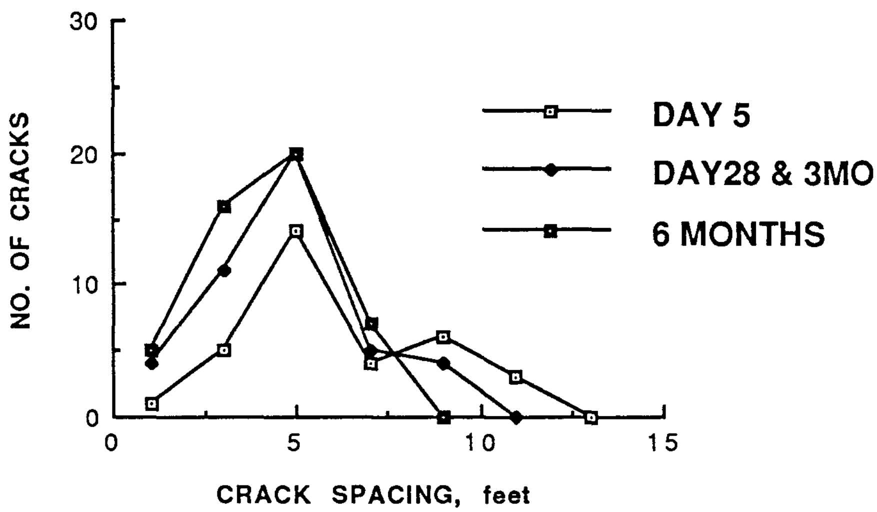


Fig. C. 7. Distribution of crack spacing for Test Section 3

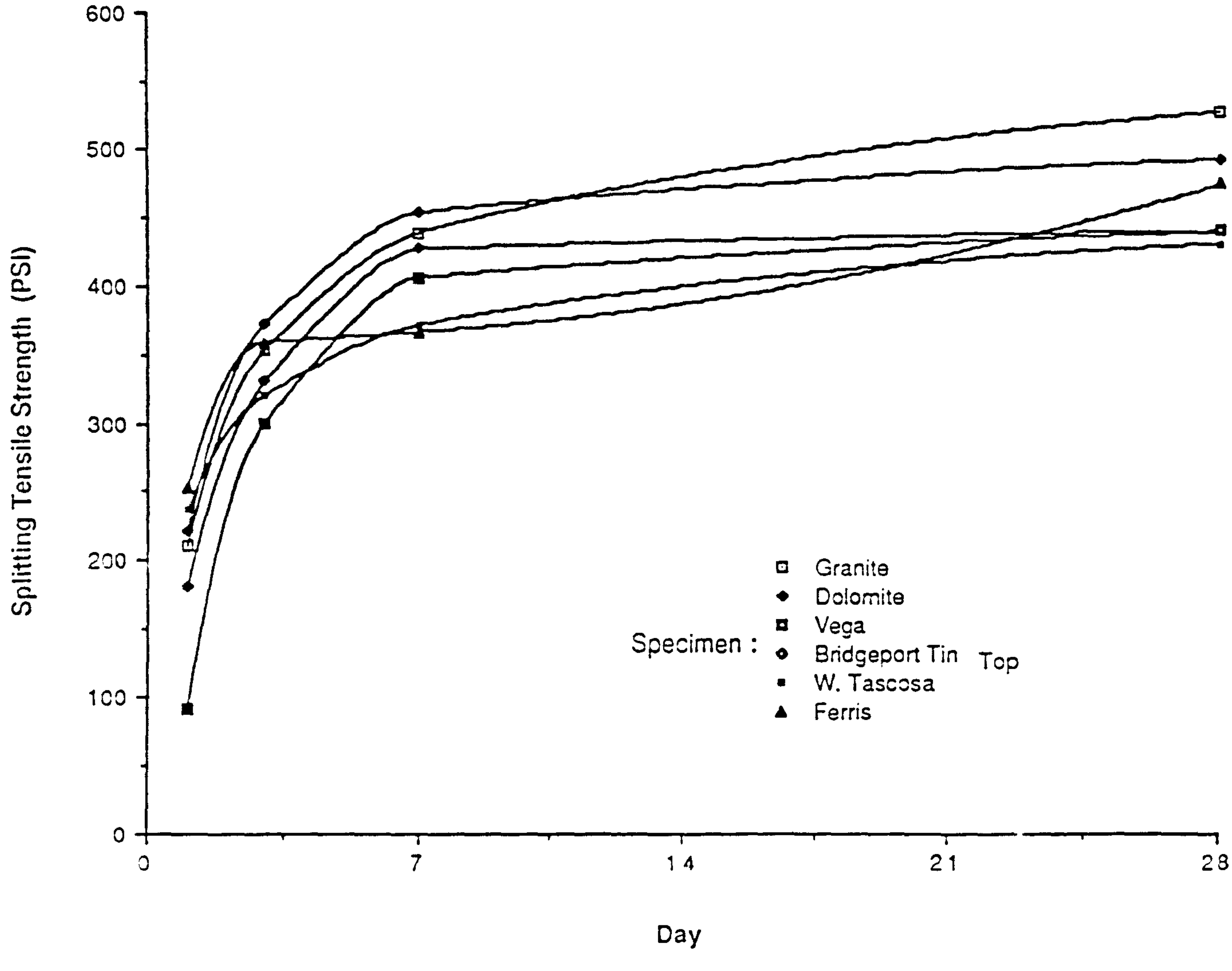


Fig. C.8. Effect of age on modulus of elasticity for different coarse aggregates in Texas (Project 422) (Ref 5).

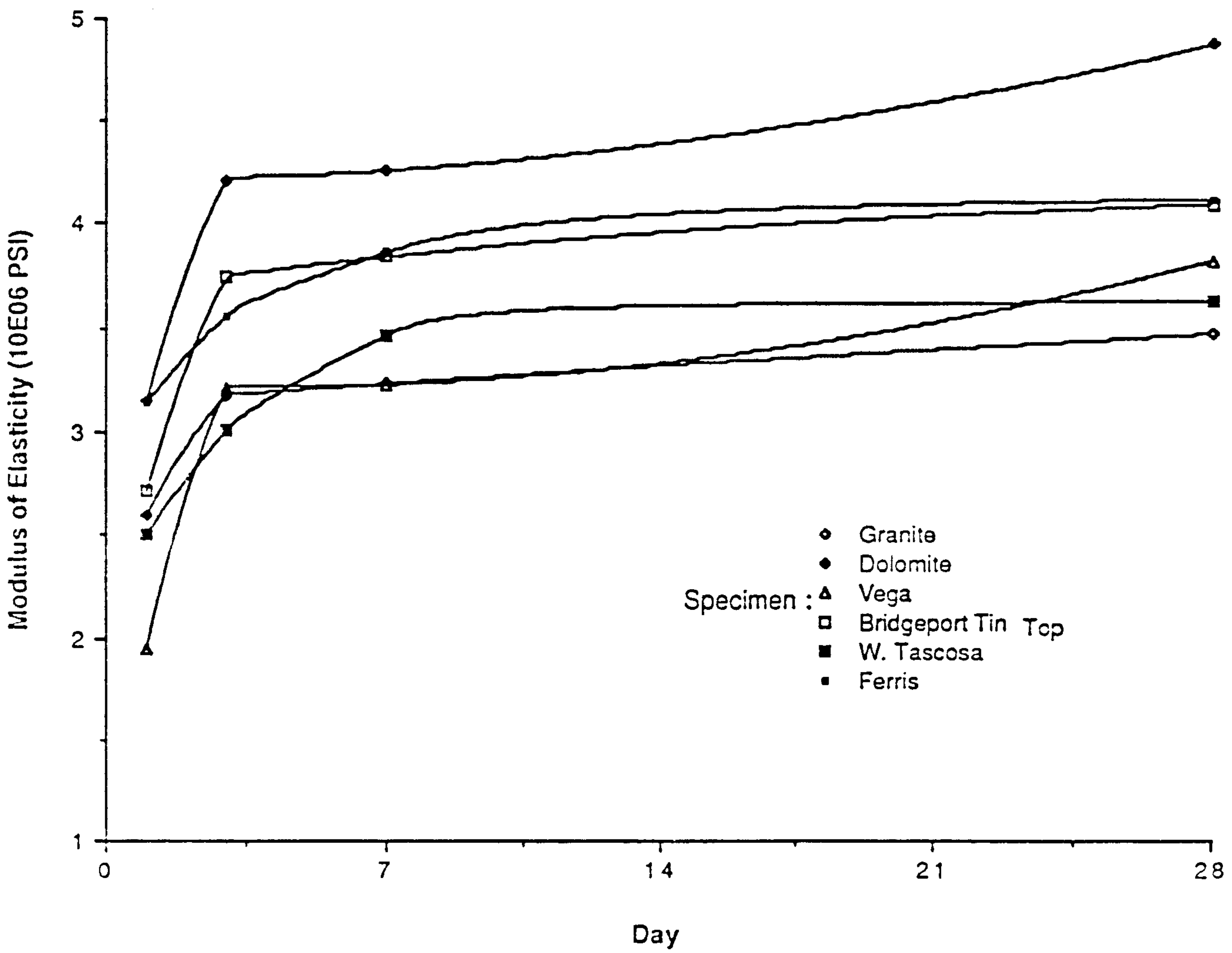


Fig. C.9. Effect of age on splitting tensile strength for different coarse aggregates in Texas (Project 422) (Ref 5).

Appendix D

Input and Output Information Used with CRCP-4 Computer Program on Test Section 1

```
      1
 I-----TRIM
CRCP4
ILLINOIS FILED DATA

PROB
   1

          *********************************************
          *                                           *
          *          STEEL PROPERTIES                 *
          *                                           *
          *********************************************

 TYPE OF LONGITUDINAL REINFORCEMENT IS
        DEFORMED BARS

 PERCENT REINFORCEMENT = 7.000E-01
  BAR DIAMETER         = 8.750E-01
  YIELD STRESS         = 6.000E+04
 ELASTIC MODULUS       = 2.900E+07
 THERMAL COEFFICIENT   = 5.000E-06

          *********************************************
          *                                           *
          *          CONCRETE PROPERTIES              *
          *                                           *
          *********************************************

  SLAB THICKNESS      = 1.300E+01
  THERMAL COEFFICIENT = 6.300E-06
  TOTAL SHRINKAGE     = 8.000E-04
 UNIT WEIGHT CONCRETE= 1.440E+02
 COMPRESSIVE STRENGTH=    -0

 TENSILE STRENGTH DATA AS INPUT BY USER

 AGE,   TENSILE
(DAYS)  STRENGTH
   0      0
   3.0  408.0
   5.0  511.0
   7.0  551.0
  28.0  643.0
```

```
*********************************************
*                                           *
*   SLAB-BASE FRICTION CHARACTERISTICS      *
*          F-Y RELATIONSHIP                 *
*                                           *
*********************************************
```

TYPE OF FRICTION CURVE IS A STRAIGHT LINE

MAXIMUM FRICTION FORCE= 4.0000
MOVEMENT AT SLIDING = -.0600

```
****************************
*                          *
*    TEMPERATURE DATA      *
*                          *
****************************
```

CURING TEMPERATURE= 55.0

DAY	MINIMUM TEMPERATURE	DROP IN TEMPERATURE
1	46.0	9.0
2	67.0	0
3	55.0	0
4	44.0	11.0
5	46.0	9.0
6	50.0	5.0
7	55.0	0
8	56.0	0
9	59.0	0
10	55.0	0
11	51.0	4.0
12	42.0	13.0
13	45.0	10.0
14	57.0	0
15	67.0	0
16	65.0	0
17	68.0	0
18	66.0	0
19	70.0	0
20	70.0	0
21	53.0	2.0
22	52.0	3.0
23	60.0	0
24	66.0	0
25	65.0	0
26	69.0	0

27	50.0	5.0
28	51.0	4.0

DAYS BEFORE CONCRETE GAINS
FULL STRENGTH = 28 DAYS
MINIMUM TEMPERATURE EXPECTED AFTER
CONCRETE GAINS FULL STRENGTH = 15.0 DEGREES FAHRENHEIT
DAYS BEFORE REACHING MIN. TEMP. =180.0 DAYS

1

```
*************************************************
*                                               *
*          EXTERNAL LOAD                        *
*                                               *
*************************************************
```

WHEEL LOAD (LBS) = 9.000E+03
WHEEL BASE RADIUS (IN) = 6.000E+00
SUBGRADE MODULUS (PCI) = 3.000E+02
CONCRETE MODULUS (PSI) = 4.889E+06
LOAD APPLIED AT = 14. TH DAY
CALC.LOAD STRESS (PSI) = 7.341E+01

```
*************************************************
*                                               *
*    ITERATION AND TOLERANCE CONTROL            *
*                                               *
*************************************************
```

MAXIMUM ALLOWABLE NUMBER OF ITERATIONS= 60

RELATIVE CLOSURE TOLERANCE= 5.0 PERCENT

TIME (DAYS)	TEMP DROP	DRYING SHRINKAGE	TENSILE STRGTH	MAXIMUM CRACK SPACING	CRACK WIDTH	CONCRETE STRESS	STRESS IN THE STEEL
.50	9.0	4.915E-09	68.0	926.2	1.755E-03	2.877E+01	5.286E+03
.50	9.0	4.915E-09	68.0	235.9	1.561E-03	2.690E+01	4.988E+03
1.50	0	1.465E-05	204.0	235.9	2.647E-04	2.120E+01	2.995E+03
2.50	0	7.257E-05	340.0	235.9	5.661E-03	1.303E+02	1.786E+04
3.25	0	1.263E-04	420.9	235.9	1.381E-02	2.286E+02	3.078E+04
3.43	10.0	1.392E-04	430.2	235.9	2.626E-02	3.198E+02	4.358E+04
3.50	11.0	1.441E-04	433.8	235.9	2.823E-02	3.332E+02	4.536E+04
4.50	9.0	2.109E-04	485.3	235.9	3.874E-02	4.147E+02	5.525E+04
5.50	5.0	2.687E-04	521.0	235.9	4.540E-02	4.662E+02	6.110E+04
6.50	0	3.178E-04	541.0	235.9	4.906E-02	4.945E+02	6.390E+04
7.50	0	3.595E-04	553.2	118.0	3.259E-02	4.042E+02	4.977E+04
8.50	0	3.949E-04	557.6	118.0	3.638E-02	4.273E+02	5.214E+04
9.50	0	4.254E-04	562.0	118.0	3.968E-02	4.465E+02	5.406E+04
10.25	0	4.455E-04	565.2	118.0	4.187E-02	4.588E+02	5.528E+04
10.50	4.0	4.518E-04	566.3	118.0	4.526E-02	4.771E+02	5.765E+04
11.30	4.0	4.704E-04	569.8	118.0	4.732E-02	4.880E+02	5.870E+04
11.50	13.0	4.748E-04	570.7	118.0	5.394E-02	5.213E+02	6.313E+04
12.50	10.0	4.950E-04	575.1	118.0	5.416E-02	5.225E+02	6.281E+04
13.50	0	5.129E-04	579.5	118.0	4.936E-02	4.987E+02	5.913E+04
14.50	0	5.289E-04	583.9	73.7	3.365E-02	4.839E+02	4.576E+04
15.50	0	5.432E-04	588.2	73.7	3.469E-02	4.902E+02	4.627E+04
16.50	0	5.561E-04	592.6	73.7	3.563E-02	4.959E+02	4.672E+04
17.50	0	5.678E-04	597.0	73.7	3.648E-02	5.010E+02	4.712E+04
18.50	0	5.784E-04	601.4	73.7	3.726E-02	5.057E+02	4.748E+04
19.50	0	5.881E-04	605.8	73.7	3.798E-02	5.099E+02	4.780E+04
20.25	0	5.949E-04	609.0	73.7	3.848E-02	5.128E+02	4.803E+04
20.50	2.0	5.970E-04	610.1	73.7	3.953E-02	5.188E+02	4.877E+04
21.37	2.0	6.041E-04	613.9	73.7	4.006E-02	5.219E+02	4.900E+04
21.50	3.0	6.052E-04	614.5	73.7	4.059E-02	5.248E+02	4.936E+04
22.50	0	6.127E-04	618.9	73.7	3.982E-02	5.206E+02	4.861E+04
23.50	0	6.197E-04	623.3	73.7	4.035E-02	5.236E+02	4.884E+04
24.50	0	6.262E-04	627.7	73.7	4.084E-02	5.264E+02	4.905E+04
25.50	0	6.323E-04	632.0	73.7	4.130E-02	5.291E+02	4.924E+04
26.25	0	6.365E-04	635.3	73.7	4.163E-02	5.309E+02	4.938E+04
26.50	5.0	6.379E-04	636.4	73.7	4.396E-02	5.437E+02	5.102E+04
27.50	4.0	6.432E-04	640.8	73.7	4.393E-02	5.435E+02	5.087E+04

1 AT THE END OF THE ANALYSIS PERIOD

CRACK SPACING = 6.143E+00 FEET
CRACK WIDTH = 7.179E-02 INCHES
MAX CONCRETE STRESS= 6.760E+02 PSI
MAX STEEL STRESS = 6.423E+04 PSI,
CONC.TENS.STRENGTH = 6.923E+02 PSI

STA- TION	DIS- TANCE	CONCRETE MOVEMENT	FRICTION FORCE	CONCRETE STRESS	STEEL STRESS
1	0	0	0	6.026E+02	-2.139E+04
2	3.7	-3.456E-04	2.304E-02	6.026E+02	-2.139E+04
3	7.4	-6.911E-04	4.608E-02	6.026E+02	-2.139E+04
4	11.1	-1.037E-03	6.913E-02	6.026E+02	-2.139E+04
5	14.7	-1.382E-03	9.217E-02	6.026E+02	-2.139E+04
6	18.4	-1.728E-03	1.152E-01	6.026E+02	-2.139E+04
7	22.1	-2.073E-03	1.383E-01	6.026E+02	-2.139E+04
8	25.8	-2.419E-03	1.613E-01	6.026E+02	-2.139E+04
9	29.5	-2.765E-03	1.843E-01	6.026E+02	-2.139E+04
10	33.2	-3.110E-03	2.074E-01	6.026E+02	-2.139E+04
11	36.9	-3.456E-03	2.304E-01	6.026E+02	-2.139E+04
12	40.5	-3.801E-03	2.535E-01	6.026E+02	-2.139E+04
13	44.2	-4.147E-03	2.765E-01	6.026E+02	-2.139E+04
14	47.9	-4.492E-03	2.995E-01	6.026E+02	-2.139E+04
15	51.6	-4.838E-03	3.226E-01	6.026E+02	-2.139E+04
16	55.3	-5.184E-03	3.456E-01	6.026E+02	-2.139E+04
17	59.0	-5.529E-03	3.687E-01	6.025E+02	-2.139E+04
18	62.7	-5.875E-03	3.917E-01	6.025E+02	-2.139E+04
19	66.3	-6.220E-03	4.148E-01	6.025E+02	-2.139E+04
20	70.0	-6.566E-03	4.378E-01	6.025E+02	-2.139E+04
21	73.7	-6.911E-03	4.608E-01	6.025E+02	-2.139E+04
22	77.4	-7.257E-03	4.839E-01	6.025E+02	-2.139E+04
23	81.1	-7.603E-03	5.069E-01	6.025E+02	-2.139E+04
24	84.8	-7.948E-03	5.300E-01	6.025E+02	-2.139E+04
25	88.5	-8.294E-03	5.530E-01	6.024E+02	-2.139E+04
26	92.1	-8.639E-03	5.760E-01	6.024E+02	-2.139E+04
27	95.8	-8.985E-03	5.991E-01	6.024E+02	-2.139E+04
28	99.5	-9.330E-03	6.221E-01	6.024E+02	-2.139E+04
29	103.2	-9.676E-03	6.452E-01	6.024E+02	-2.139E+04
30	106.9	-1.002E-02	6.682E-01	6.024E+02	-2.139E+04
31	110.6	-1.037E-02	6.913E-01	6.023E+02	-2.139E+04
32	114.3	-1.071E-02	7.143E-01	6.023E+02	-2.139E+04
33	118.0	-1.106E-02	7.373E-01	6.023E+02	-2.139E+04
34	121.6	-1.140E-02	7.604E-01	6.023E+02	-2.139E+04
35	125.3	-1.175E-02	7.834E-01	6.023E+02	-2.139E+04
36	129.0	-1.210E-02	8.065E-01	6.022E+02	-2.139E+04
37	132.7	-1.244E-02	8.295E-01	6.022E+02	-2.139E+04
38	136.4	-1.279E-02	8.526E-01	5.973E+02	-2.070E+04
39	140.1	-1.313E-02	8.757E-01	5.878E+02	-1.935E+04
40	143.8	-1.348E-02	8.988E-01	5.784E+02	-1.800E+04
41	147.4	-1.383E-02	9.220E-01	5.689E+02	-1.665E+04
42	151.1	-1.418E-02	9.452E-01	5.595E+02	-1.530E+04
43	154.8	-1.452E-02	9.685E-01	5.500E+02	-1.396E+04
44	158.5	-1.487E-02	9.918E-01	5.405E+02	-1.261E+04
45	162.2	-1.522E-02	1.015E+00	5.311E+02	-1.126E+04
46	165.9	-1.558E-02	1.039E+00	5.216E+02	-9.911E+03
47	169.6	-1.593E-02	1.062E+00	5.121E+02	-8.563E+03
48	173.2	-1.628E-02	1.085E+00	5.027E+02	-7.215E+03
49	176.9	-1.663E-02	1.109E+00	4.932E+02	-5.867E+03
50	180.6	-1.699E-02	1.133E+00	4.837E+02	-4.519E+03
51	184.3	-1.734E-02	1.156E+00	4.743E+02	-3.171E+03

52	188.0	-1.769E-02	1.180E+00	4.648E+02	-1.823E+03
53	191.7	-1.805E-02	1.204E+00	4.553E+02	-4.749E+02
54	195.4	-1.841E-02	1.227E+00	4.458E+02	8.731E+02
55	199.0	-1.876E-02	1.251E+00	4.364E+02	2.221E+03
56	202.7	-1.912E-02	1.275E+00	4.269E+02	3.569E+03
57	206.4	-1.948E-02	1.299E+00	4.174E+02	4.917E+03
58	210.1	-1.984E-02	1.323E+00	4.080E+02	6.265E+03
59	213.8	-2.020E-02	1.347E+00	3.985E+02	7.613E+03
60	217.5	-2.056E-02	1.371E+00	3.890E+02	8.961E+03
61	221.2	-2.092E-02	1.395E+00	3.795E+02	1.031E+04
62	224.8	-2.128E-02	1.419E+00	3.701E+02	1.166E+04
63	228.5	-2.164E-02	1.443E+00	3.606E+02	1.301E+04
64	232.2	-2.201E-02	1.467E+00	3.511E+02	1.435E+04
65	235.9	-2.237E-02	1.491E+00	3.416E+02	1.570E+04
66	239.6	-2.273E-02	1.516E+00	3.321E+02	1.705E+04
67	243.3	-2.310E-02	1.540E+00	3.227E+02	1.840E+04
68	247.0	-2.346E-02	1.564E+00	3.132E+02	1.975E+04
69	250.6	-2.383E-02	1.589E+00	3.037E+02	2.109E+04
70	254.3	-2.420E-02	1.613E+00	2.942E+02	2.244E+04
71	258.0	-2.456E-02	1.638E+00	2.847E+02	2.379E+04
72	261.7	-2.493E-02	1.662E+00	2.753E+02	2.514E+04
73	265.4	-2.530E-02	1.687E+00	2.658E+02	2.649E+04
74	269.1	-2.567E-02	1.712E+00	2.563E+02	2.783E+04
75	272.8	-2.604E-02	1.736E+00	2.468E+02	2.918E+04
76	276.4	-2.641E-02	1.761E+00	2.373E+02	3.053E+04
77	280.1	-2.678E-02	1.786E+00	2.278E+02	3.188E+04
78	283.8	-2.715E-02	1.811E+00	2.183E+02	3.323E+04
79	287.5	-2.753E-02	1.835E+00	2.089E+02	3.457E+04
80	291.2	-2.790E-02	1.860E+00	1.994E+02	3.592E+04
81	294.9	-2.828E-02	1.885E+00	1.899E+02	3.727E+04
82	298.6	-2.865E-02	1.910E+00	1.804E+02	3.862E+04
83	302.3	-2.903E-02	1.935E+00	1.709E+02	3.997E+04
84	305.9	-2.940E-02	1.960E+00	1.614E+02	4.131E+04
85	309.6	-2.978E-02	1.985E+00	1.519E+02	4.266E+04
86	313.3	-3.016E-02	2.011E+00	1.424E+02	4.401E+04
87	317.0	-3.053E-02	2.036E+00	1.329E+02	4.536E+04
88	320.7	-3.091E-02	2.061E+00	1.234E+02	4.671E+04
89	324.4	-3.129E-02	2.086E+00	1.139E+02	4.805E+04
90	328.1	-3.167E-02	2.112E+00	1.044E+02	4.940E+04
91	331.7	-3.205E-02	2.137E+00	9.494E+01	5.075E+04
92	335.4	-3.243E-02	2.163E+00	8.544E+01	5.210E+04
93	339.1	-3.282E-02	2.188E+00	7.594E+01	5.345E+04
94	342.8	-3.320E-02	2.214E+00	6.645E+01	5.479E+04
95	346.5	-3.358E-02	2.239E+00	5.695E+01	5.614E+04
96	350.2	-3.397E-02	2.265E+00	4.745E+01	5.749E+04
97	353.9	-3.435E-02	2.290E+00	3.794E+01	5.884E+04
98	357.5	-3.474E-02	2.316E+00	2.844E+01	6.019E+04
99	361.2	-3.512E-02	2.342E+00	1.894E+01	6.153E+04
100	364.9	-3.551E-02	2.368E+00	9.437E+00	6.288E+04
101	368.6	-3.590E-02	2.393E+00	-6.696E-02	6.423E+04

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