Draft Report

Goal 4 Long Life Pavement Rehabilitation Strategies—Rigid:

Flexural Fatigue Life of Hydraulic Cement Concrete Beams

Part of PPRP Strategic Plan Item 4.2

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EXECUTIVE SUMMARY

This document compares the results of flexural fatigue tests performed on experimental concrete beams made of the standard Caltrans concrete mix and five other fast-setting mixes. The three research objectives were: to investigate the fatigue characteristics of the fast-setting mixes, to compare the fatigue life of all the mixes tested, and to contrast this experiment's results with those of similar published studies.

The experimental concrete samples included the standard Caltrans mix (using Portland cement type I/II) and five fast-setting mixes that used one of three cements: Portland cement type III, calcium sulfoaluminate, or calcium aluminate. Beams were fabricated from each mixture were used to determine the materials' flexural strength (or *modulus of rupture)* and fatigue life (or *number of cycles to failure*) at stress ratio levels of 0.70 and 0.85, and, in most cases 0.75.

Three subsequent data analyses compared the number of cycles to failure of each mix at each stress ratio level, applied regression to compare the fatigue life of each fast-setting mix with the Caltrans standard mix, and applied regression to compare this study's results with common models for beam flexural fatigue life found in the literature.

The study's main conclusions were: (a) fast-setting concrete mixes present similar or higher fatigue resistance than the standard Caltrans type, (b) at a stress ratio 0.70 all the mixes presented similar fatigue resistance, but at a stress ratio of 0.85 the Type III Portland cement mix displayed the longest fatigue life, and (c) linear regression curves generated by the tested mixes compared better to the "zero maintenance" model — the most common fatigue-life model used in concrete pavement engineering — than they did to the NCHRP 1-26 model.

1.0 INTRODUCTION

The work presented in this document is part of the strategic plan 4.2 Long-Life Pavement Rehabilitation Strategies (LLPRS) Rigid Pavement Evaluation, which evaluates performance of Fast-Setting Hydraulic Cement Concrete (FSHCC).The repeated flexural load testing performed for this experiment complements previous results reported by Zhang et al. (2004) on the same concrete mixes. The aforementioned report covered flexural and compressive strength, elastic modulus, free shrinkage, and thermal expansion properties, and included background details on Caltrans' need for fast-setting concrete for use in pavements, as well as an extensive review of previous work performed by the PPRC as part of the LLPRS-rigid project.

1.1 Background

Concrete pavement consists of relatively thin slabs that deform under traffic and environmental loading. Because of these flexural or bending loads, the stress state is a combination of tensile, compressive, and/or shear stresses. The tensile stress at the bottom of the slab is generally considered the critical condition, and therefore, the flexural strength or modulus of rupture (MOR) is one of the most important concrete properties for pavement design. The number of repeated loads that a concrete mix can sustain in flexure before fracture depends on the ratio of applied flexural stress to the ultimate static flexural strength or modulus of rupture.

The materials studied in this experiment consisted on a typical Caltrans mix with Portland cement Type I/II, and fast-setting mixes made with three types of cement: Portland cement Type III, calcium sulfoaluminate, and calcium aluminate. All mixes were tested so their fatigue resistance could be compared directly.

1.2 Research Objectives

The specific objectives of this study are the following:

1. Investigate and compare the flexural fatigue characteristics of the different FSHCC mixes in terms of stress-ratio versus fatigue-life curves.
2. Compare the FSHCC fatigue-life data with the standard Caltrans Type I/II concrete fatigue-life data.
3. Contrast the experimental results against similar studies on flexural fatigue life reported in the literature.

2.0 EXPERIMENT DESIGN AND TESTING PROCEDURES

Concrete beams made of six different concrete mixes were loaded to failure at the Richmond Field Station (RFS). The mix designs, exactly the same ones used for the rest of the work reported in the Pavement Research Center project 4.2, and were developed to optimize their mix properties while obtaining a minimum flexural strength for opening the pavement to traffic under different construction closure scenarios. The first mix is called Type I/II in this report and corresponds to a standard Portland Cement Concrete (PCC) mix that is expected to develop the required strength of 2.8 MPa (400 psi) at 28 days. Two mixes with Portland cement Type III were engineered to reach that level of strength between 12 and 16 hours. The other mixes are called CSA and CA. They contain respectively calcium sulfoaluminate and calcium aluminate cements instead of Portland cement, and develop their minimum flexural strength between 4 and 8 hours. All mixes contain the same type of aggregates (except for Type III B, which was made with crushed stone aggregate), but different admixtures in order to obtain the desired properties. The two Type III mixes differed from each other in that their cement came from independent manufacturers. There were also two CSA mixes, which again were made with cement form different manufacturers. There is only one CA mix. Table 1 details the mix designs used in this project. Details on cement composition can be found in the report by Zhang at al. (2004).

Table 1. Mix designs

Mix name (cement type)	Water/cement ratio	Cement content kg/m^3	Aggregate content kg/m^3	Aggregate (%) by weight
Type I/II	0.42	362.5	1,864.9	78.37%
Type III A	0.38	446.1	1,851.4	75.58%
Type III B	0.36	474.6	1,831.6	74.69%
CSA-A	0.37	390.4	1,943.0	78.42%
CSA-B	0.37	415.3	1,874.3	76.85%
CA	0.32	390.4	1,955.1	79.14%

A third Type III mix was evaluated and finally excluded from this study as it was found that the concrete obtained using lab mixing equipment resulted was not representative, and a mixer truck was needed.

The concrete batching, mixing, and specimen casting followed the ASTM C192 procedure. All the beams were prepared during July 2000. Twelve beams were prepared from each one of the mixes; four of them were used to estimate the modulus of rupture (MOR) and the other eight were used for fatigue testing. All the samples were de-molded after twenty four hours, cured in the standard curing room (23°C, 98 percent RH) for 28 days, and moved to a dry curing room (20°C, 50 percent relative humidity) for a minimum of three months. Fatigue testing for each mix began immediately after determination of the average MOR, in order to minimize error in the assumed stress ratios.

The ASTM C 78 standard test method for flexural strength of concrete was used to determine MOR. Using the “third-point loading configuration,” the load was applied at a rate of 50 psi per minute until failure. Flexural stress was then obtained from equation 1

$$s = \frac{Mc}{I} = \frac{PL}{bd^2} \qquad \text{Eq.1}$$

in which s is the applied stress, *P* is applied load, *L* is the concrete beam loading span, *b* is the width of the concrete beam, and *d* is the depth of the beam. Table 2 shows the calculated average and standard deviation of flexural strength for each mix, based four samples per mix. Appendix A presents the beam dimensions, applied load, and strength results from each sample. At the time of testing, the ages of the concrete samples ranged between 11 and 14 months.

Table 2. Average and standard deviation of long-term modulus of rupture (MOR)

Mix	Mean (psi)	Standard Dev. (psi)
Type I/II	639	47.6
Type III-A	790	87.0
Type III-B	1026	61.8
CSA-A	840	43.1
CSA-B	910	69.6
CA	679	41.9

The flexural fatigue load tests were performed using the same MTS servohydraulic machine employed for strength testing (see Figure 1). The average MOR of each mix type was used to determine the loads required to achieve the predefined stress ratio levels. Four beams were tested using a stress ratio of 0.85 and four others were tested at stress ratios of 0.7 to 0.75. All fatigue samples were tested using a haversine waveform load at 3 Hz without a rest period, and the ratio between minimum and maximum stress within a cycle was 0.1.

Figure 1. MTS loading frame and actuator

Table 3 shows the total number of beams tested at each stress ratio from the six different mixes. Table 4 presents the average fatigue life (in number of repetitions) obtained in the study based on the number of replicates shown in Table 3. It must be noted that not all the 48 specimens gave useful results, mostly because of equipment malfunction. Individual results of fatigue life from the tested beams are presented in Appendix B.

Table 3. Number of beams tested (replicates) in the study

Mix	Stress ratio			Total
	0.85	0.75	0.7	
Type-I/II	4	1	3	8
Type-III-A	3	1	2	6
Type-III-B	4	0	2	6
CSA-A	4	1	2	7
CSA-B	3	1	2	6
CA	2	1	2	5
Total	20	5	13	38

Table 4. Average fatigue life (repetitions) for each mix at each stress ratio

Mix	Stress ratio		
	0.85	0.75	0.7
Type-I/II	87	6,754,880	812,977
Type-III-A	10,305	5,403,656	2,807,798
Type-III-B	836	-	1,660,597
CSA-A	94	3,940,687	2,454,531
CSA-B	346	2,808,461	2,120,466
CA	3,068	2,969,200	887,444

3.0 ANALYSIS OF RESULTS

3.1 Modulus of Rupture

The purpose of determining MOR was to calculate the load level to be applied to obtain the predetermined stress ratios. The magnitude of the MOR is not critical in fatigue studies, given that the fatigue life is controlled by the stress ratio. However, since comparison between the mixes is important, the MOR results are analyzed and compared to MOR results from previous work with the same mixes.

Figure 2 presents individual MOR from beams made with each one of the six mixes. The mixes were evaluated when the beams were between 11 and 14 months old.

(Mix Type CSA-B I/II was 11 months old, mix Type I/II was 13 months old, and the rest were 14 months old.) The highest strength corresponds to mix type III-B, while the lowest strength corresponds to mixes type I/II and CA. The coefficient of variation ranged between 5 and 11 percent, obtained from average and standard deviations presented in Table 2.

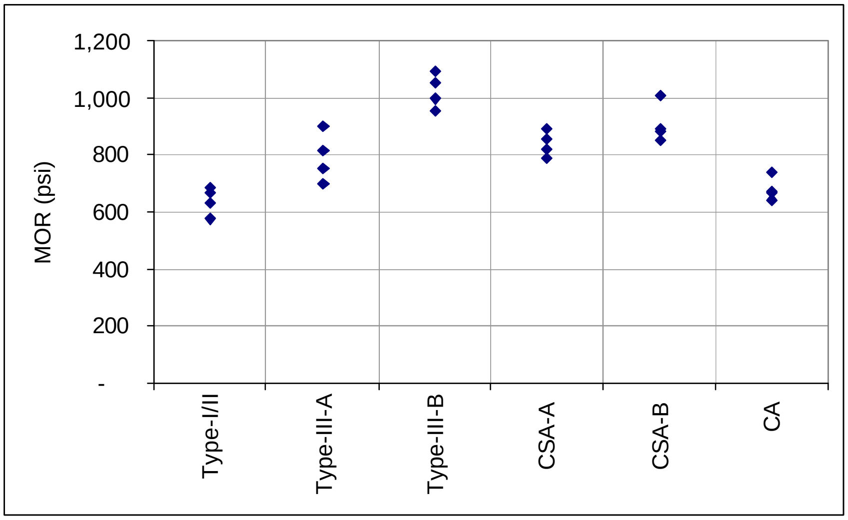

Figure 2. Modulus of rupture measured for fatigue life tests

Previous work in this project (Zhang et al 2004) had evaluated flexural strength for the same mixes at early age. To evaluate the effect of curing conditions on early age strength development, specimens were subjected to various curing conditions. In the first curing regime, which served as the standard curing condition, room temperature was 23ºC (73.4ºF) and relative humidity (RH) was 97 percent. The second curing regime was 20ºC (68ºF) and 50 percent RH. This regime was designated the “dry” condition in which moisture was not supplied to the concrete. In the third regime, the “cold” condition, the temperature was 10ºC (50ºF) and RH was 50 percent.

Figure 3 presents early-age MOR under the different curing conditions, and the MOR results from the four beams tested as part of the present study. Although the exact same mixes were used in both experiments, the loading machine and operator were different. In every case but one a strength gain was clearly observed. The calcium aluminate (CA) mix presented an unclear pattern of strength gain, which is probably explained by the composition of the hydrates in it. These hydrates go through a metastable phase that combines more water, lowers densities, and can lead to variable strength. (Lea 1998).

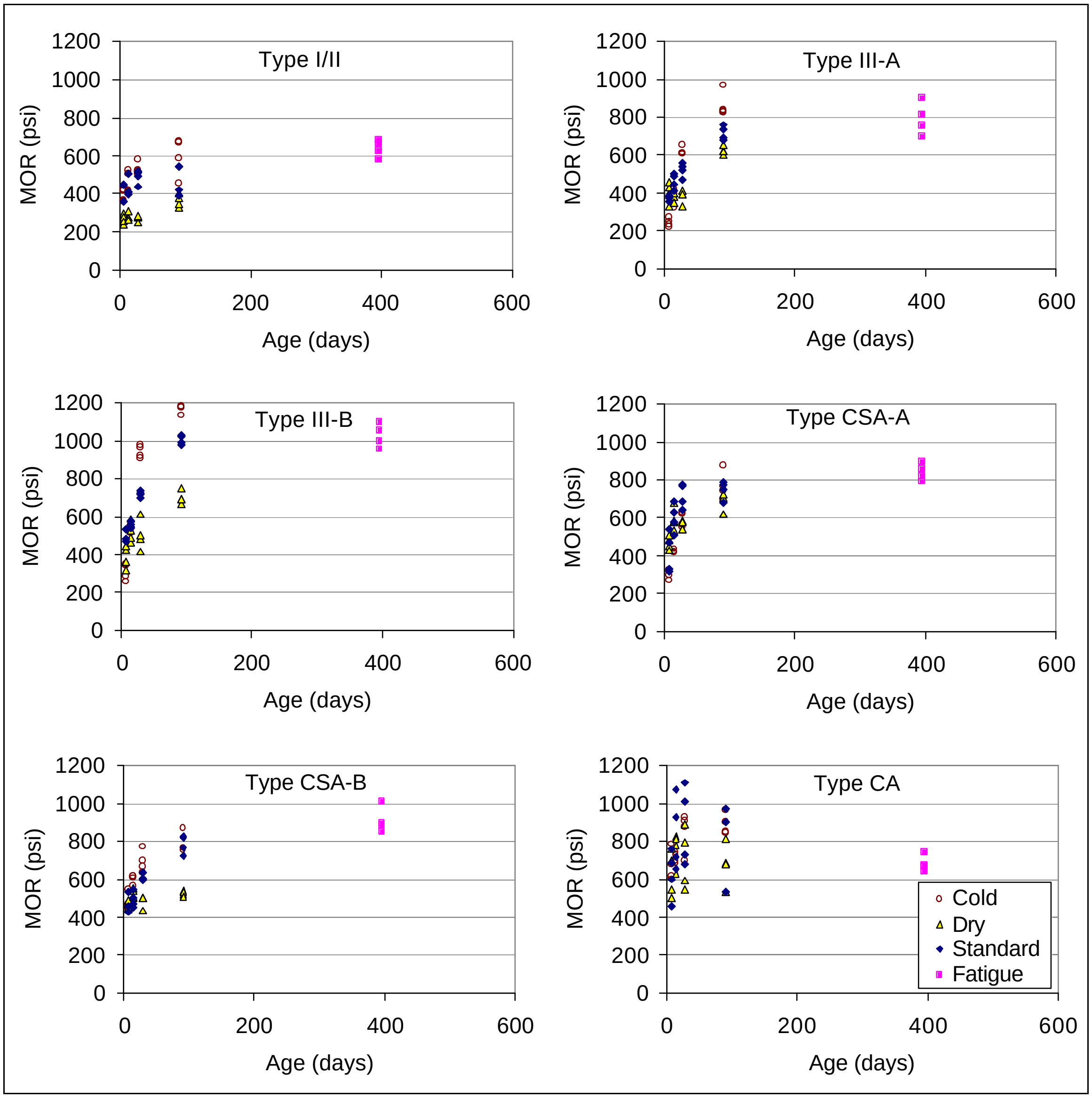

Figure 3. MOR at early age and long term, as determined for fatigue test

3.2 Fatigue resistance

Three analyses were performed with the results of fatigue resistance tests: (1) a comparison of fatigue life at individual stress ratio levels, (2) a comparison of the different mix types versus the standard type I/II mix, using regression, and (3) an overall comparison with common models for beam flexural fatigue life found in the literature, using results of regression.

3.2.1 Comparison of fatigue life at individual stress ratio levels

All mixes performed similarly in terms of fatigue life when the number of cycles to failure was compared at a stress ratio of 0.70, while at a stress ratio of 0.85 there are some differences. Figure 4 shows the fatigue life at both stress ratio levels. The highest range of fatigue life was obtained from specimens of mix Type III-A. At a stress ratio of 0.85, the lowest fatigue-life range was found in specimens of mix types I/II and CSA-A.

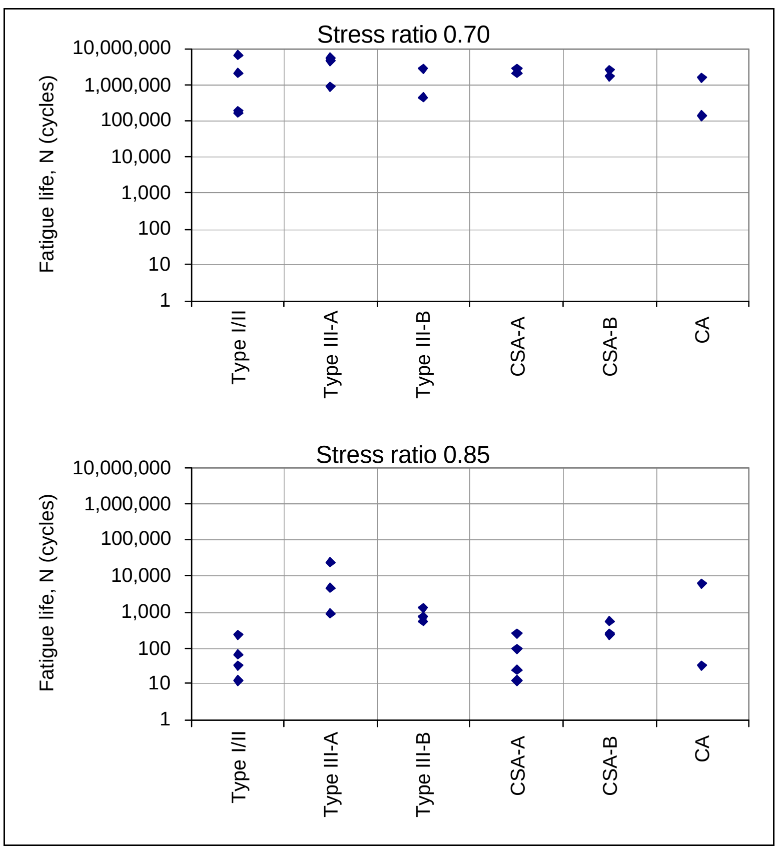

Figure 4. Fatigue life of all beams at 0.70 and 0.85 stress ratio

An ANOVA-type analysis was performed in order to test for significant differences between mixes at individual stress ratio levels. The least square means analysis was run with the GLM procedure in the SAS system to test the null hypothesis of equal fatigue life (log-10 of number of cycles). The p-values for the interaction effects between mix type and stress ratio were compared to two levels of significance. The following assertions are the result of the analysis:

a) at stress ratio 0.70:

    a. all mixes could have the same average fatigue life at 95% significance level (fail to reject null hypothesis)

    b. all mixes could have the same average fatigue life at 99% significance level (fail to reject null hypothesis)

b) at stress ratio 0.85:

    At 95% significance level:

    a. mix Types III-A and III-B have different fatigue life than Type I/II

    b. mix Types CSA-A and CSA-B are different from mix Type III-A

    c. mix Type CSA-A is different from mix Type III-B

    At 99% significance level:

    d. only mix Type III-A is different than mix Type I/II

    e. only mix Type III-A is different mix than Type CSA-A

Table 5 and Table 6 present the probability values for this analysis for stress ratios 0.70 and 0.85, respectively. A p-value higher than the desired significance level (0.05 or 0.01) should be interpreted as not enough evidence to say that the results are different.

The combinations that can be called different, are highlighted in Table 6 with one asterisk (*) or two (**) indicating significance at 0.05 and 0.01, respectively. The complete table with p-values for all the interactions is included in Appendix C.

Table 5. P-values for null hypothesis of equal average fatigue life, stress ratio 0.70

Mix type	Type I/II	Type III-A	Type III-B	CSA-A	CSA-B	CA
Type I/II						
Type III-A	0.2096					
Type III-B	0.4149	0.6771				
CSA-A	0.1684	0.9049	0.5927			
CSA-B	0.2087	0.998	0.6753	0.9069		
CA	0.9022	0.2977	0.5255	0.2478	0.2966	

Table 6. P-values for null hypothesis of equal average fatigue life, stress ratio 0.85

Mix type	Type I/II	Type III-A	Type III-B	CSA-A	CSA-B	CA
Type I/II						
Type III-A	0.0003**					
Type III-B	0.0103*	0.1084				
CSA-A	0.9676	0.0004**	0.0113*			
CSA-B	0.0925	0.028*	0.4066	0.0992		
CA	0.0812	0.0787	0.6434	0.0865	0.7951	

3.2.2 Comparison of the different mix types versus the standard type I/II

Regression analysis was used to obtain the best fit lines for each set of data, as well as for some dataset combinations. The Log functional form (base-10 logarithmic) was selected for further analysis because it showed a slightly better prediction capability in terms of the coefficient of determination, R^2, than the power functional form did. The coefficient of determination R^2 for the two types of predictive equations are shown in

Table 7 for each one of the mixes tested. Results are consistent and very similar. The regression coefficients for the Log-type equation are presented in Table 8. Only three stress ratio levels were utilized on the experiment, which reduces the confidence in linear regression, however the use of Log transformation is supported by results of extensive previous research (for list of references see Shi et al. 1993). In the formulas in Table 7 and Table 8, the term N refers to the number of cycles to failure, and the term S refers to the stress ratio.

Table 7. Comparison of R^2 for Log and Power functional forms

Mix name	Coefficient of determination R^2	
	Log fit, Log $N=a+b\times S$	Power fit, $N=a\times S^{b}$
Type I/II	0.815	0.804
Type III-A	0.795	0.785
Type III-B	0.783	0.783
CSA-A	0.883	0.879
CSA-B	0.664	0.654
CA	0.654	0.642

Table 8. Regression coefficients for Log functional form

Mix name	Regr. Coefficients for Log N=a+b×S.	
	‘a’	‘b’
Type I/II	-28.04	25.71
Type III-A	-19.16	20.07
Type III-B	-21.08	20.82
CSA-A	-33.52	30.33
CSA-B	-27.04	25.62
CA	-21.69	21.33

The results of the fatigue tests are depicted in Figure 5, which shows the typical S-N plot, also known as a Wohler diagram, in which a logarithmic scale in the x-axis is associated with the number of cycles to failure. The y-axis represents the stress ratio and it is scaled between 0.5 and 1.0, since at stress ratios below approximately 0.45 to 0.5 the fatigue life of concrete can be considered unlimited (endurance limit). For all the specimens in this study, the range of the fatigue lives — the number of cycles at the time of beam breakage — extend from just a few cycles to more than 6.75 million cycles. The lines fitted to each mix data is presented in Figure 6.

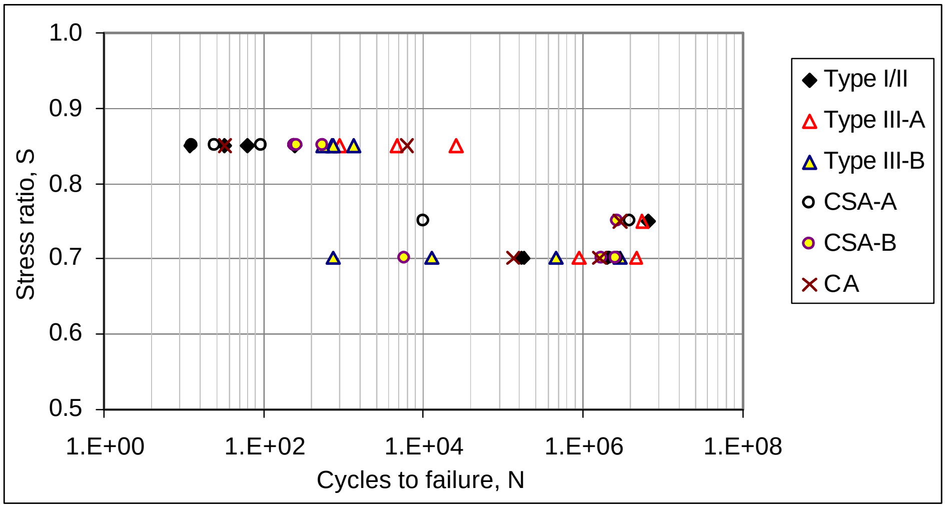

Figure 5. Datapoints for all the mixes on the study

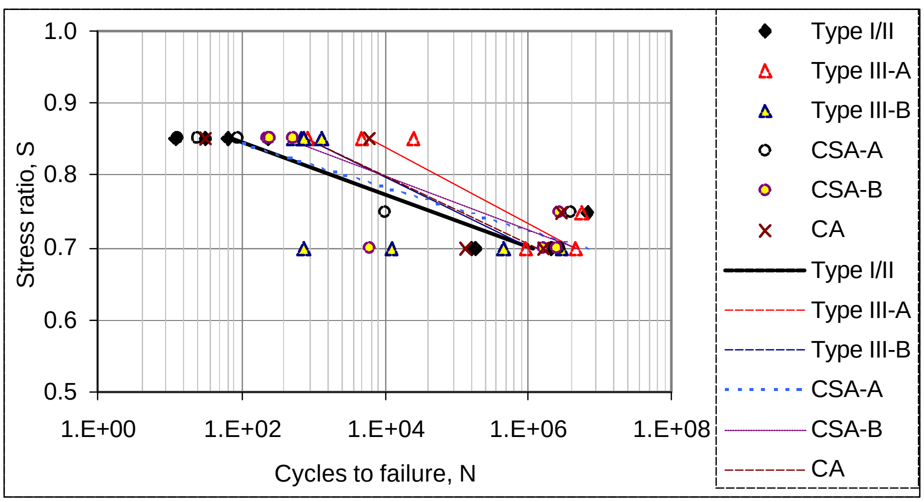

Figure 6. Datapoints and regression lines for all the mixes on the study

The different mixes were compared against the standard Type I/II mix to determine whether the faster strength gain affected the fatigue life. While interpreting the model, it must be kept in mind that the regression models come from a limited number of datapoints.

Figure 7 shows that the Type III A mix resisted a greater number of cycles before failing, while the Type III B mix behaved in a similar way to the standard Type I/II mix. The lines have been plotted within the range of stress ratios actually used in the experiment. At higher stress ratios, S, the fatigue life of the Type III mixes was increasingly greater than the standard mix, while for lower values of S they seemed to converge.

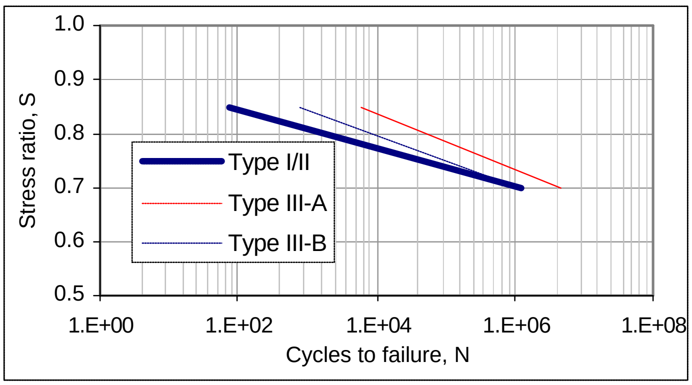

Figure 7. Type III mixes compared with Type I/II

The two mixes with calcium sulfoaluminate responded to fatigue testing in a manner similar to the Type I/II mix. This is evident from Figure 8 and from the results shown in Figure 4.

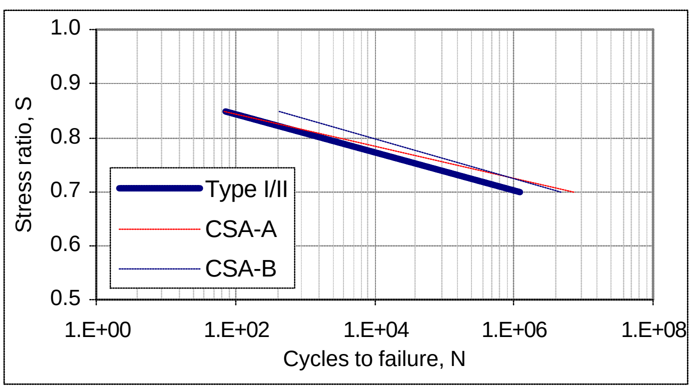

Figure 8. CSA mixes compared with Type I/II

The calcium aluminate mix presents fatigue life slightly higher than the Type I/II mix, particularly at the high end of stress ratios. Observation of the S-N plot in Figure 9 reveals that both mixes offer similar resistance to flexural fatigue. However, scatter in flexural fatigue life make the model for this material highly unreliable.

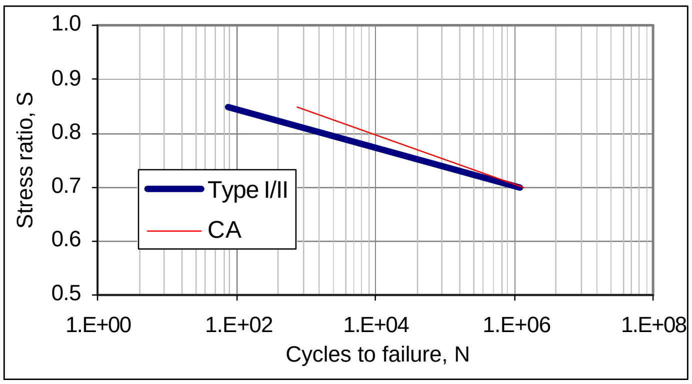

Figure 9. CA mix compared with Type I/II

These analyses show that the fast-setting mixes offer similar or greater fatigue resistance than the standard Portland cement mix Type I/II. This is as true for the Type III mixes, which can be identified as performing better than Type I/II, as it is for the calcium sulfoaluminate cements, which it can be said perform in a similar way to Type I/II. The performance of the calcium aluminate cement is similar to the Type I/II material.

3.2.3 Comparison with fatigue curves from the literature

This section compares the way the lines fit to the data in the present study with models available in the literature in order to assess similarities between the results obtained here and findings by other researchers regarding concrete beam fatigue life.

Darter (1977) compiled 140 beam-fatigue results from three published studies — Kesler (1953), Raithby and Galloway (1974), and Ballinger (1972) — into one regression equation. Darter's model, called "zero-maintenance," is presented in Eq.2. This model has been widely used in the design of jointed, plain concrete pavements.

$$\text{Log } N = 17.61 - 17.61 \times (S/MOR) \qquad \text{Eq.2}$$

Another equation for beams can be found in NCHRP 1-26 (Thompson and Barenberg 1992). The model is presented in Eq. 3

$$\text{Log } N = 2.8127 \times (S/MOR)^{-1.2214} \qquad \text{Eq.3}$$

A more complete list of fatigue models for beams and slabs can be found in another publication that is part of this project (Rao and Roesler 2004).

Figure 10 presents a comparison among the Type I/II mix, the two Type III mixes, and the zero-maintenance curve. The figure indicates that the number of cycles to failure predicted with the zero-maintenance model does not differ significantly from the number of cycles observed with the Portland cement mixes when the evaluation was taken at an intermediate stress ratio of about 0.77. As the stress ratio increases from this value, the difference in the slope makes the zero-maintenance curve predict longer fatigue lives than the fitted curve. This also applies to the CSA and CA mixes.

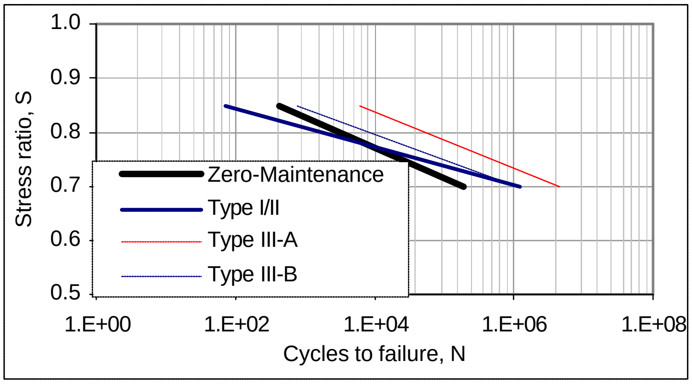

Figure 10. Type I/II and Type III mixes compared with the zero-maintenance model

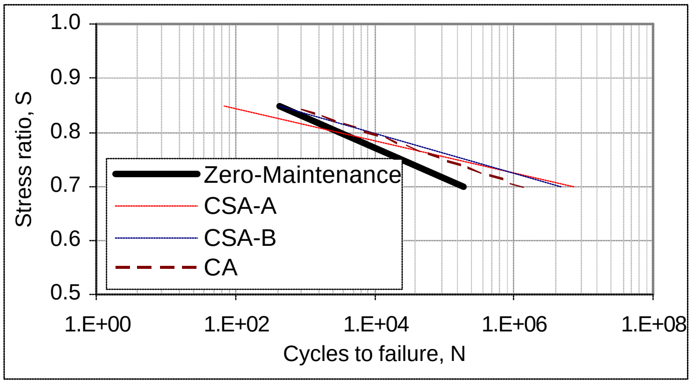

Figure 11. CSA and CA mixes compared with the zero-maintenance model

When the regression lines for all the mixes in this study were compared with the zero-maintenance and the NCHRP 1-26 models, it was concluded that the beams' behavior more closely followed the more widely accepted zero-maintenance model.

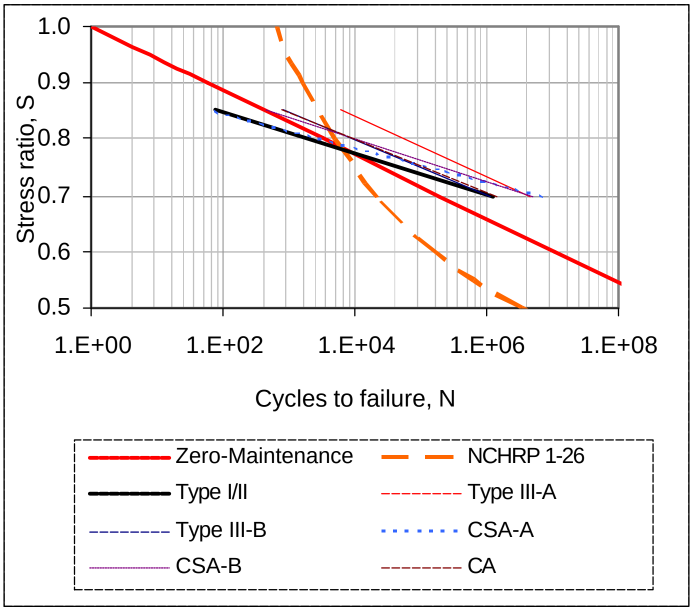

Figure 12. All mixes in the study compared with the zero-maintenance and NCHRP 1-26 models

4.0 CONCLUSIONS

The following conclusions can be drawn from this study's analysis of beam flexural fatigue life:

1. Fast-setting concrete mixes (Type III Portland cement, calcium sulfoaluminate, and calcium aluminate) offer fatigue resistance (number of cycles to failure) similar to or higher than the standard Type I/II concrete mix.
2. Concrete mix Type III-A exhibited the longest fatigue life among all tested mixes at the given stress ratio of 0.85. At stress ratio 0.70 all mixes presented similar fatigue lives. Comparing the ratio between logarithms of average number of cycles at a stress ratio of 0.85, the Type III-A mix can be said to last on average 2.1 times more cycles to failure than the Type I/II mix. The average was obtained by testing four beams made of each material.

3. When tested at the same stress ratio, the fatigue life of concrete mix Type III-B was comparable to that for the standard Type I/II mix, but shorter than mix Type III-A.
4. When tested at same stress ratio, calcium sulfoaluminate cement mix CSA-B offered a slightly longer fatigue life than mix CSA-A did, although the difference was not statistically significant. The differences between both CSA mixes and mix Type I/II were not significant either.
5. Calcium aluminate cement mix showed the largest variation among the specimens tested. The results indicate that a difference from the Type I/II mix cannot be detected, probably because of the scatter observed and the limited number of beams tested.
6. The slope of the zero-maintenance model in the typical S-N plots is steeper than the slope found for the data collected in this study. The models from this study better resemble the zero-maintenance equation than the NCHRP 1-26 equation.
7. The results of these tests are considered satisfactory, taking into account the high level of scatter usually associated with experimental fatigue research in the literature.

5.0 REFERENCES

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Appendix A
Flexural strength test results

Mix	Sample	Load (lbs)	Width (in)	Depth (in)	Length(in)	MOR (psi)
Type I/II	a	8,203	6.250	5.875	18	684
	b	6,901	6.250	5.875	18	576
	c	7,547	6.250	5.875	18	630
	d	7,967	6.250	5.875	18	665
Type III-A	a	8,426	6.100	5.980	18	695
	b	10,833	6.220	5.910	18	898
	c	10,163	5.940	6.140	18	817
	d	9,023	6.000	6.000	18	752
Type III-B	a	11,240	6.125	5.875	18	957
	b	12,605	6.125	5.813	18	1096
	c	12,202	6.125	6.000	18	996
	d	12,922	6.125	6.000	18	1055
CSA-A	a	10,375	6.100	5.980	18	856
	b	10,752	6.220	5.910	18	891
	c	9,855	5.940	6.140	18	792
	d	9,828	6.000	6.000	18	819
CSA-B	a	12,254	6.100	5.980	18	1011
	b	10,303	6.220	5.910	18	854
	c	10,937	5.940	6.140	18	879
	d	10,759	6.000	6.000	18	897
CA	a	8,947	6.100	5.980	18	738
	b	8,129	6.220	5.910	18	673
	c	7,965	5.940	6.140	18	640
	d	7,974	6.000	6.000	18	664

Appendix B
Flexural fatigue resistance test results

Mix	Sample	Specimen Age (Days)	Beam Dimentions (W,D,L, inches)			Applied Load (lbs)	Stress Ratio	Cycles to failure
Type I/II	a	396	6	6	18	6,506	0.85	33
	b	396	6	6.3	18	6,506	0.85	64
	c	396	6	6.0	18	6,506	0.85	12
	d	396	6	6.0	18	6,506	0.85	237
	e	412	6	6.0	18	5,358	0.75	6,754,880
	f	396	6	6.0	18	5,358	0.70	184,437
	g	397	6	6.0	18	5,358	0.70	165,537
	h	398	6	6.0	18	5,358	0.70	2,088,957
Type III-A	a	441	6	6.1	18	8,169	0.85	25,386
	b	441	6	6.1	18	8,169	0.85	866
	c	461	6	6.1	18	8,169	0.85	4,662
	d	441	6	6.1	18	7,208	0.75	5,403,656
	e	441	6	6.1	18	6,727	0.70	903,110
	f	441	6	6.8	18	6,727	0.70	4,712,485
Type III-B	a	441	6	6.1	18	10,405	0.85	705
	b	441	6	6.1	18	10,405	0.85	746
	c	441	6	6.8	18	10,405	0.85	550
	d	441	6	6.1	18	10,405	0.85	1,344
	e	442	6	6.1	18	8,569	0.70	2,861,073
	f	461	6	6.1	18	8,569	0.70	460,120
CSA-A	a	441	6	6.1	18	8,673	0.85	13
	b	441	6	6.1	18	8,673	0.85	246
	c	442	6	6.1	18	8,673	0.85	92
	d	461	6	6.1	18	8,673	0.85	24
	e	441	6	6.1	18	7,652	0.75	3,940,687
	f	441	6	6.1	18	7,142	0.70	2,717,437
	g	441	6	6.1	18	7,142	0.70	2,191,625
CSA-B	a	333	6.1	6	18	9,404	0.85	543
	b	333	6	6.0	18	9,403	0.85	239
	c	333	6	6	18	9,403	0.85	256
	d	354	5.9	6.3	18	8,850	0.75	2,808,461
	e	361	6	6	18	7,744	0.70	1,661,630
	f	333	6	6	18	7,744	0.70	2,579,301
CA	a	441	6	6.1	18	7,016	0.85	6,102
	b	441	6	6.1	18	7,016	0.85	33
	c	441	6	6.1	18	6,190	0.75	2,969,200
	d	441	6	6.1	18	5,777	0.70	1,641,567
	e	441	6	6.8	18	5,777	0.70	133,321

Appendix C
P-values for null hypothesis of equal average fatigue life

Mix type		Type I/II			Type III-A			Type III-B		CSA-A			CSA-B			CA		
	Stress ratio	0.7	0.75	0.85	0.7	0.75	0.85	0.7	0.85	0.7	0.75	0.85	0.7	0.75	0.85	0.7	0.75	0.85
Type I/II	0.7		0.0925	0.0001	0.2096	0.1194	0.0008	0.4149	0.0001	0.1684	0.1684	0.0001	0.2087	0.2377	0.0001	0.9022	0.225	0.0001
	0.75	0.0925		0.0001	0.4934	0.9106	0.0002	0.3094	0.0001	0.556	0.7866	0.0001	0.4947	0.6597	0.0001	0.1316	0.68	0.0001
	0.85	0.0001	0.0001		0.0001	0.0001	0.0003	0.0001	0.0103	0.0001	0.0001	0.9676	0.0001	0.0001	0.0925	0.0001	0.0001	0.0812
Type III-A	0.7	0.2096	0.4934	0.0001		0.5775	0.0001	0.6771	0.0001	0.9049	0.7075	0.0001	0.998	0.8579	0.0001	0.2977	0.8326	0.0001
	0.75	0.1194	0.9106	0.0001	0.5775		0.0003	0.3728	0.0001	0.6452	0.8739	0.0001	0.5789	0.7424	0.0001	0.1652	0.7636	0.0001
	0.85	0.0008	0.0002	0.0003	0.0001	0.0003		0.0003	0.1084	0.0001	0.0004	0.0004	0.0001	0.0007	0.028	0.0016	0.0006	0.0787
Type III-B	0.7	0.4149	0.3094	0.0001	0.6771	0.3728	0.0003		0.0001	0.5927	0.4764	0.0001	0.6753	0.6044	0.0001	0.5255	0.5822	0.0001
	0.85	0.0001	0.0001	0.0103	0.0001	0.0001	0.1084	0.0001		0.0001	0.0001	0.0113	0.0001	0.0001	0.4066	0.0001	0.0001	0.6434
CSA-A	0.7	0.1684	0.556	0.0001	0.9049	0.6452	0.0001	0.5927	0.0001		0.781	0.0001	0.9069	0.935	0.0001	0.2478	0.9093	0.0001
	0.75	0.1684	0.7866	0.0001	0.7075	0.8739	0.0004	0.4764	0.0001	0.781		0.0001	0.709	0.8648	0.0001	0.2242	0.8868	0.0001
	0.85	0.0001	0.0001	0.9676	0.0001	0.0001	0.0004	0.0001	0.0113	0.0001	0.0001		0.0001	0.0001	0.0992	0.0001	0.0001	0.0865
CSA-B	0.7	0.2087	0.4947	0.0001	0.998	0.5789	0.0001	0.6753	0.0001	0.9069	0.709	0.0001		0.8595	0.0001	0.2966	0.8342	0.0001
	0.75	0.2377	0.6597	0.0001	0.8579	0.7424	0.0007	0.6044	0.0001	0.935	0.8648	0.0001	0.8595		0.0001	0.3042	0.9777	0.0001
	0.85	0.0001	0.0001	0.0925	0.0001	0.0001	0.028	0.0001	0.4066	0.0001	0.0001	0.0992	0.0001	0.0001		0.0001	0.0001	0.7951
CA	0.7	0.9022	0.1316	0.0001	0.2977	0.1652	0.0016	0.5255	0.0001	0.2478	0.2242	0.0001	0.2966	0.3042	0.0001		0.2898	0.0001
	0.75	0.225	0.68	0.0001	0.8326	0.7636	0.0006	0.5822	0.0001	0.9093	0.8868	0.0001	0.8342	0.9777	0.0001	0.2898		0.0001
	0.85	0.0001	0.0001	0.0812	0.0001	0.0001	0.0787	0.0001	0.6434	0.0001	0.0001	0.0865	0.0001	0.0001	0.7951	0.0001	0.0001	