National
Cooperative
Highway
Research
Program

RESEARCH RESULTS DIGEST

DIGEST 73 - JUNE 1975

Fatigue Strength of High-Yield Reinforcing Bars

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 4-7, "Fatigue Strength of High-Yield Reinforcing Bars," by Thorsteinn Helgason, John M. Hanson, Norman F. Somes, W. Gene Corley, and Eivind Hognestad, Portland Cement Association, Skokie, Illinois

THE PROBLEM AND ITS SOLUTION

Because of an economic advantage gained in many circumstances, use of high-yield reinforcing bars in concrete construction has increased greatly in recent years. Acceptance of high-yield reinforcement (generally Grades 60 and 75) in American highway bridge design practice has been slow, although highway bridge design specifications now allow use of high-yield reinforcement in all bridge members. Concern over a number of possible countereffects, including fatigue effects, has been responsible for the slow acceptance. The results of research have now overcome most of the earlier apprehension. The study reported herein has made an important contribution with respect to the avoidance of a fatigue problem.

No fatigue fracture of the reinforcement in a reinforced concrete structure in service has ever been reported. However, fatigue fractures in the reinforcement of the overloaded test bridges in the AASHO Road Test directed attention to the importance of fatigue considerations in bridge design.

To attain the study objective of determining safe fatigue criteria for utilizing high-yield-strength reinforcing bars, the Portland Cement Association performed a statistically valid experiment consisting of 353 fatigue tests on concrete beams, each of which contained one reinforcing bar. Test results were entered in an over-all multiple linear regression analysis to develop a suggested design specification.

The investigation was directed mainly at obtaining fatigue test data on ASTM A 432 steel bars (60,000-psi yield strength). Major emphasis was placed on evaluating the effects of stress range, minimum stress (including reversal of stress), bar diameter, and bar lug geometry. Other factors included were type of specimen and grade of bar. Three minimum stress levels were used: 6 ksi compression, 6 ksi tension, and 18 ksi tension. Five bar sizes were included in the investigation: No.'s 5, 6, 8, 10, and 11. Tests were conducted on bars of Grades 40, 60, and 75. Bars from the mills of five manufacturers were used to introduce the lug geometry variable. Test beams had effective depths of 6, 10, or 18 inches.

Properties of the reinforcing bars tested are given in Table 1. Lug geometry parameters are defined in Figure 1.

FINDINGS

Stress range, minimum stress, bar diameter, grade of bar, and bar geometry were found to affect the fatigue properties of reinforcing bars. The effective depth of a reinforced concrete beam was found to have no direct influence on the fatigue strength of the main reinforcement.

The stress range to which a reinforcing bar is subjected is the primary factor determining its fatigue life. For design purposes, there is a limiting stress range, the fatigue limit, above which a reinforcing bar will have a finite fatigue life and is certain to fracture. At stress ranges below the fatigue limit, a reinforcing bar will have a long fatigue life and may be able to sustain a virtually unlimited number of stress cycles.

The magnitude of the fatigue limit depends on the minimum stress during each stress cycle and the shape of the deformations rolled onto the bar surface. It may also depend on the diameter and the grade of the bar. For a fatigue life of 5 million cycles, the mean fatigue limit for No. 8 Grade 60 bars from five U.S. manufacturers was found to range from 23.0 to 28.5 ksi when the minimum stress was 6 ksi tension. The lowest stress range at which a fatigue fracture was obtained was 21.3 ksi. This occurred in a No. 11 Grade 60 reinforcing bar subjected to a minimum stress of 17.5 ksi.

Increasing a tensile minimum stress was found to result in a decrease in fatigue strength. On the other hand, the fatigue strength, in terms of stress range, was found to increase with an increasing compressive minimum stress. Changing the minimum stress of a stress cycle by 3 ksi was found to be equivalent to changing the stress range by about 1 ksi.

Bar diameter and grade of bar were found to influence the finite-life fatigue strength of reinforcing bars. The existence of a long-life fatigue effect due to these variables could not be established. Larger-size bars have a lowered fatigue strength whereas higher-grade bars have an increased fatigue strength. Other things being equal, replacing No. 5 bars with No. 11 bars results in a decrease in fatigue strength of 3.6 ksi. Replacing a Grade 60 bar with a Grade 75 bar results in an increase in fatigue strength of 1.7 ksi.

Transverse lugs and manufacturer's bar identification marks cause stress concentrations at their juncture with the barrel of a bar. The magnitude of the stress concentration is primarily related to the ratio of the radius, r, at the base of the deformation to its height, h. In this investigation, all fatigue fractures were initiated at the base of a transverse lug or a bar mark.

The effect of lug geometry on fatigue strength was found to be coupled with that of bar diameter. The larger the bar diameter, the greater was the effect of lug geometry. For a No. 8 bar, a change in the ratio of lug base radius to lug height, r/h, from 0.1 to 1.0 results in an increase in fatigue strength of 7.2 ksi. The effect is potentially larger.

APPLICATION

The findings of this study led the researchers to suggest wording for a design specification for fatigue of reinforcing bars as follows:

Suggested Specification

> The stress range in a deformed reinforcing bar used as the main reinforcement for a flexural reinforced concrete member subjected to cyclic or repeated loads shall not exceed
>
> $$f_r = 21 - 0.33\, f_{min} + 8\, (r/h)$$
>
> in which
>
> f_r = stress range, in ksi;
>
> f_{min} = corresponding minimum tensile stress (positive) or maximum compressive stress (negative), in ksi; and
>
> r/h = ratio of base radius to height of rolled-on deformation.
>
> When r/h is not known, a value of 0.3 may be used.
>
> No welding or bending of main reinforcement shall take place at locations where the stress range is near the above limit.

As a guide to the designer in cases where well-defined stress range, higher than that allowed by the suggested specification, must be designed for, the researchers present the following finite-life fatigue equation:

$$\begin{aligned} \log N &= 6.1044 - 0.0407\, f_r - 0.0138\, f_{min} + 0.0071\, f_u \\ &\quad - 0.0566\, A_s + 0.3233\, Dr/h \end{aligned}$$

in which

$\log N$ = logarithm to the base 10 of the number of stress cycles that a given bar can safely sustain;

f_u = tensile strength of reinforcing bar, in ksi;

A_s = nominal area of reinforcing bar, in square inches; and

D = nominal bar diameter, in inches.

A comparison of the design specification and the finite-life fatigue equation with test results from the investigation is shown in Figure 2. A comparison with previously published test results for North American bars is shown in Figure 3. The compatibility of the equations with the test data is evident.

The specification seems applicable except in those special circumstances where a time-dependent effect may cause change in reinforcing bar properties. Among such factors should be included the possible hazards of severe salt-water corrosion and extreme temperature conditions.

Findings of this study should be of interest to structural engineers involved in the design of reinforced concrete members subjected to fatigue loading, researchers working in the subject area, and members of specification writing bodies providing specifications for fatigue design of reinforcing bars.

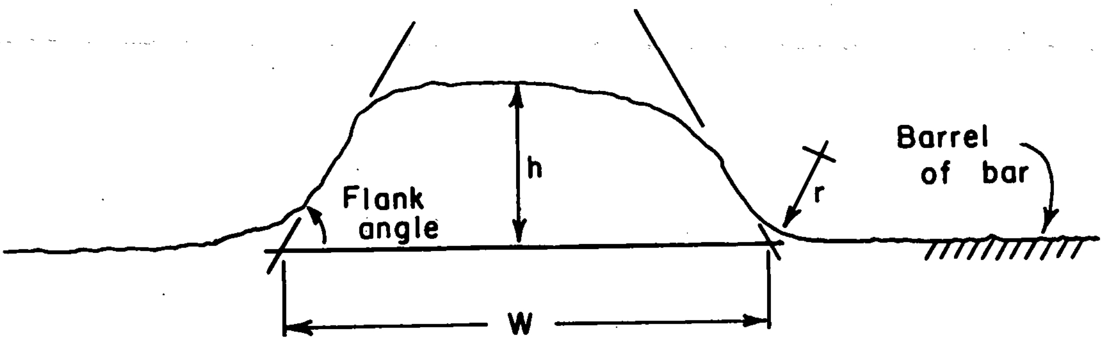

Figure 1. Lug geometry parameters.

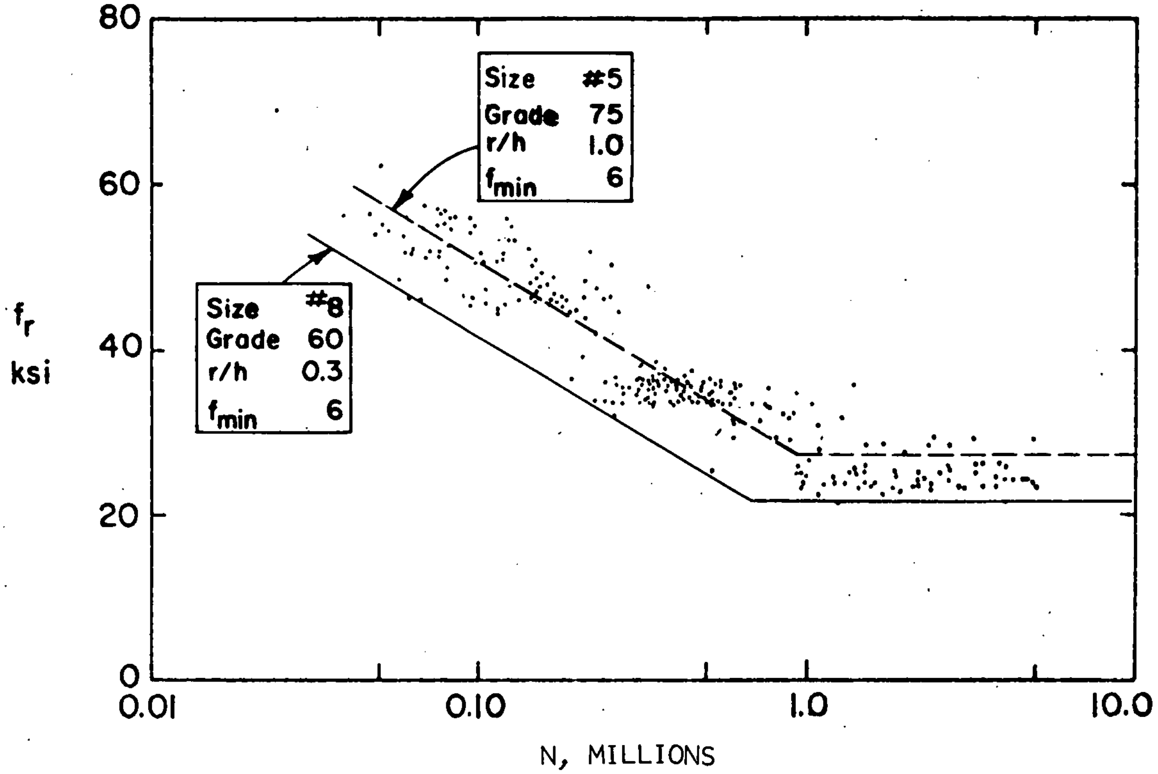

Figure 2. Suggested design provision compared with test results obtained in the present investigation.

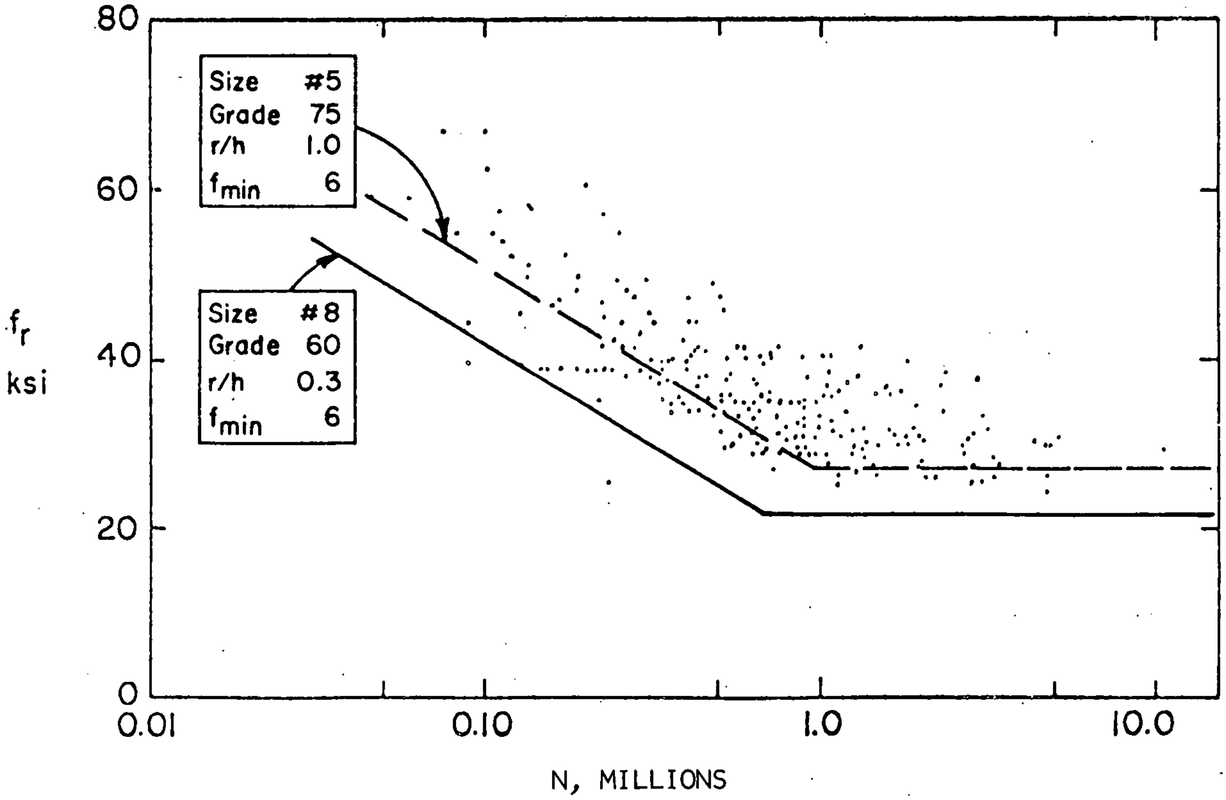

Figure 3. Suggested design provision compared with previously published test results for North American bars.

TABLE 1. PROPERTIES OF REINFORCING BARS

Manufacturer	Size of Bar	Grade of Bar	Tensile Properties				Critical Dimensions			Chemical Content (%)		Vickers Hardness
			Yield Stress (ksi)		Ultimate Stress (ksi)	Elongation (%)	r/h	h/w	Flank Angle (deg)	C	Mn	
			ASTM A615	ACI 318								
A	5	40	47.8	47.6	82.6	18.4	0.29	--	--	0.41	0.72	--
		60	69.5	67.9	109.7	13.5	0.24	--	--	0.40	1.42	--
		75	87.2	77.3	118.2	10.4	0.32	--	--	0.42	1.82	--
	6	60	71.4	69.4	112.1	14.3	0.25	--	--	0.40	1.57	--
	8	40	46.1	45.8	79.0	23.1	0.21	--	--	0.41	0.89	185
		60	61.6	61.4	102.0	18.0	0.33	0.50	35	0.36	1.32	262
		75	85.2	72.9	120.3	11.4	0.22	--	--	0.42	1.77	291
	10	60	59.2	58.7	102.0	17.8	0.17	--	--	0.36	1.29	--
	11	40	42.7	42.8	77.4	25.3	0.22	--	--	0.38	0.72	--
		60	67.4	66.1	110.6	15.5	0.26	--	--	0.36	1.32	--
		75	84.7	79.1	124.5	12.1	0.20	--	--	0.43	1.73	--
B	8	60	63.7	63.4	104.7	14.8	0.29	0.50	60	0.43	1.04	264
C	8	60	72.7	72.6	114.0	14.0	0.29	0.39	35	0.46	1.81	275
D	8	60	63.2	62.1	107.0	15.9	0.38	0.39	35	0.53	1.52	267
E	8	60	59.8	59.0	111.7	12.1	0.39	0.60	50	0.59	0.59	271

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

000015M001
JAMES W HILL

IDAHO TRANS DEPT DIV OF HWYS
3311 WEST STATE ST POBOX 7129
BOISE ID 83707