FATIGUE LIMIT OF AXIALLY COMPRESSED CONCRETE

by

V.V. Levchich*
Federal Polytechnic, Idah.
*Dr. V. V. Lechich was a Reader in Design of Structures at Technical University, LVOV, USSR.
(Manuscript received May 5, 1980 and in revised from June 6, 1980)

ABSTRACT

An attempt to evaluate analytically the fatigue limit of axially loaded concrete depending upon the load parameters, number of load cycles and static short-term strength is presented. The conventional limit of concrete microcracking statical sustained strength of concrete, curvelinear relationship between fatigue limit and load asymmetry coefficient and straight-line relationship between logarithm of number f load cycles and fatigue limit are involved into a consideration.

The proposed method is applicable for the range of load cycles number from 10,000 to an indefinite large.

1. INTRODUCTION

In various structural applications, concrete and reinforced concrete are very often subjected to severe fatigue loadings. However, very little data for evaluating and predicting the influence of fatigue loading on the behaviour of such structures is available. Besides, data of different researchers frequently have contradictions in terms.

2. TEST PROGRAMME AND DETAILS

To investigate the fatigue limit of axially compressed concrete depending upon the load parameters, numbers of cycles and short-term static strength, tests were carried out on 70x70x300mm and 100xlOOx500mm prisms made of concrete grade 30 and 40. The static compressive strength was determined by tests on prisms as well as on 100mm and 200mm control cubes. A minimum of three specimens was used for all control tests.

Prisms were subjected to simusoidally varying cyclic loading at 550 cycles per minute. The maximum stress (δMAX) was varied from 35 to 85% of the short-term static strength.

The asymmetry coefficient (δ=δMIN/MAX) varies from 0.066 to 0.700.

An analysis was done for 4 groups:

1. Static test;
2. δ_{MAX} = constant, δ_{MIN} = VARIABLE; ρ = VARIABLE
3. δ_{MAX} = VARIABLE; δ_{MIN} = CONSTANT; ρ = VARIABLE
4. δ_{MAX} = VARIABLE; δ_{MIN} = VARIABLE; ρ = CONSTANT

To create IDENTICAL CONDITIONS for all specimens and to make their properties the same the characteristics and relative proportions of the constituent materials ,mixing, compacting, curing and testing processes were kept the same (adequate) for all samples. All 80 test and control specimens were cast from one batch of concrete at the same time. Since the properties of concrete change with age (especially just after hardening period) in order to have more uniform influence of this factor on the strength creep, shrinkage etc., the testing started 180 _days after casting. During this period the total set of test pieces were kept under indoor controlled environmental conditions [1].

Changes in the internal composition of concrete were estimated by an ultra-sound devise.

3. TEST RESULTS AND CONCLUSIONS

Based on the test data, the following results were obtained and the theoretical method of the fatigue limit calculation was elaborated.

(i) Fatigue limit of axially compressed concrete (f_F) depends upon the load asymmetry coefficient (p=δMIN/MAX) the number of load cycles (N) and the static strength of concrete (fcu). Generally, the fatigue limit can be expressed as a function of the above enumerated characteristics

i.e. $f_F=f(\rho;\ N;\ fcu)$ (1)

(ii) If the specimen does not collapse after $2x10^6$ cycles of loading it can resist this loading indefinitely long time.

(iii) The fatigue limit for axially compressed concrete after $2x10^6$ cycles of loading under *p=O(fp=O)* with a satisfactory accuracy can be predicted by the equation:

$$f_F^{\rho=0} = 1.5 f_{CR}^{10} \quad (2)$$

where F_{CR}^0 is the bottom conventional limit of concrete microcracking under statical short-term loading.

The value F_{CR}^0 can be calculated from the expression elaborated by Prof. O. Berg *[2]*.

NOTE: f_{PR} and due to this F_{CR}^0 should be in kg/cm^2

$$f_{CR}^{10} = f_{PR}(0.35\lg f_{PR} - 0.5) \quad (3)$$

where f_{PR} is the prism strength of concrete (usually

$f_{PR}=0.7\ f_{CU}$ (4)

The level of $f_{CR}{}^0$ is usually controlled by the ultra-sound devices.

(iv) The relationship between the fatigue limit and the load asymmetry coefficient can be expressed in the following way:

$$f_F^{\rho} = f_{\substack{SUST\\STAT}} - (f_{\substack{SUST\\STAT}} - f_F^{\rho=0})(1-\rho^2) \quad (5)$$

Where $f_{\substack{SUST\\STAT}}$ is the strength of concrete under static sustained load.

The value of $f_{\substack{SUST\\STAT}}$ can be taken as $0.85f_{PR}$ (85% of the static short-term concrete strength). This value corresponds to the USSR'S Code requirement [3].

From the Equations *(5)* it is evident that under *p=1* (no cyclic variations of stress) the fatigue limit of concrete will be equal to its static sustained strength. Substituting the values of $f_F^{\rho=0}$ and $f_{\substack{SUST\\STAT}}$ into the equation (5) we obtain

$$f_F^{\rho} = 0.85 f_{PR} - [0.85 f_{PR} - 1.5 f_{PR}(0.351g f_{PR} - 0.5)](1-\rho^2) \quad (6)$$

after the transformation it becomes

$$f_F^{\rho} = f_{PR}[0.85 - (1.6 - 0.525\lg f_{PR})(1-\rho^2)] \quad (7)$$

Now let us denote

$\beta=0.85-(1.6-0.5251gf_{PR})(1-\rho^2)$ (8)

and after this equation (7) can be represented in the following way:

$$f_F^{\rho} = f_{PR}\beta \quad (9)$$

(v) Using the linear relationship between f_F^{ρ} and N we take into account the influence of cycles number on the fatique limit ($N \le 2x10^6$)

$$f_F^{\rho} = f_{PR}\beta\left(1 + \frac{\lg(2x10^6) - \lg N}{\lg(2\times10^6)}\right) = f_{PR}\beta(2 - 0.1591gN) \quad (10)$$

The relative fatigue limit of the axially compressed concrete (K_F) will be:

$$K_F f_F^{\rho} / f_{PR} = \beta(2 - 0.1591gN) \quad (11)$$

These equations are applicable within the cycles number from N=20000 to $N=2x10^6$ cycles. If N is more than $2x10^6$, $N=2x10^6$ can be taken instead of actual value. For other grades of concrete equation (3) should be corrected. Tests results which form the basis of the theoretical method presented in comparison with the results obtained by analytical calculations are given in Tables 1 and 2.

Table 1: Experimental and analytically calculated values of f_{CR}^{0}/f_{PR} and $f_{CR}^{p=0}/f_{PR}$

GRADE OF CONCRETE (N/MM^2)	EXPERIMENTAL (AVERAGE		CALCULATED BY EQUATIONS (3) AND (2)		CALCULATED BY EQU. (7)
	f_{CR}^{0}/f_{PR}	$1.5f_{CR}^{0}/f_{PR}$	f_{CR}^{0}/f_{PR}	$\frac{f_F^{\rho=0}}{f_{PR}}=1.5\frac{f_{CR}^{0}}{f_{PR}}$	$f_F^{\rho=0}/f_{PR}$
30	0.308	0.462	0.313	0 .470	0.469
40 .	0.365	0.547	0.356	0.534	0.535

Table 2: Experimental and analytically calculated values of the relative figure limit f_F^{ρ}/f_{PR}

ρ →	0.066	0.18	0.23	0.30	0.50	0.60	0.65	0.70
	GRADE 30 CONCRETE							
EXPERIMENTAL	0.430	0.515		0.540	0.560		0.675	-
ANALYTICAL	0.471	0.481	0.489	0.503	0.564	0.606	0.630	0.656
DIFFERENCE (%)	9.53	-6.60	-	-6.85	+0.74	-	-6.75	-
	GRADE 40 CONCRETE							
IEXPERIMENTAL	0.520	0.510	0.580	0.490	0.600	0.685	-	0.900
ANALYTICAL	0.536	0.545	0.552	0.563	0.614	0.648	0.668	0.689
DIFFERENCE (%)	+3.08	+6.86	-5.07	+14.89	+2.28	-5.40	-	-23.44

As it follows from the above tables a good agreement is found between the experimental data and theoretically calculated results.

4. Acknowledgment

The work reported in this paper is a part of an extensive programme of investigation of reinforced concrete structures under cyclic loads carried out at the Technical University, LVOV, USSR.

I am indebted to my scientific advisers Prof. A.S. Kuryllo, Merited scientist and researches, formerly Head, Design of Structures Department, and Dr. V.G. Kwasha, Reader in Design of Structures, (Both from Technical University, LVOV, USSR) with both of whom I had a great pleasure of working closely and fruitfully for many years. I am sincerely grateful to them.

REFERENCES

1. Levchich, V.V.; Kwasha, V.G. Compression Fatigue Strength and Strains of Concrete. Problems of Modern Construction. Technical University, LVOV, USSR J. of Technology, No.70, 1972, pp 24-29 (Article, in Russian).
2. Berg. O.Y.,Selected Problems of Concrete Deformations and Strength Theory. Proceedings of the USSR~s Higher Educational Institution, No.IO, 1967, pp 25-36. (Article in Russian).
3. USSR's Code of Practice for the Structural Use of Concrete. Moscow, 1976, p.23.