STUDY OF FATIGUE PERFORMANCE OF HIGH STRENGTH PLAIN CONCRETE

Hokkaido University Student member ○Muhammad Aboubakar Farooq
Waseda University Regular Member Yasuhiko Sato

1. INTRODUCTION

In the recent years, there has been much progress in the development of high strength and durable concrete through different methods i.e. by using steel fibers, admixtures and industrial wastes like fly ash and blast furnace slag (BFS) (Farooq et al. 2017). Understanding the fatigue behavior of high strength concrete (HSC) is still a main concern due to its brittle nature compared to normal concrete and owing to conflicting information on fatigue performance of HSC presented in past research (Petkovic et. al. 1990, Do et al. 1993, Hordijk et al. 1995, Kim and Kim 1996). The authors intend to evaluate and propose the design equations for compressive fatigue of high strength plain concrete (HSPC) using BFS fine aggregates. Therefore, it is essential to have better understanding of past research work related to HSPC under fatigue loading in compression. In this paper, the fatigue behavior of HSC focusing on plain concrete without fibers is discussed based on previous studies. Moreover, the $S_{max.}$-N_f relationship of HSC developed in this study using the extracted data from literature is also compared with the $S_{max.}$-N_f relationships for normal concrete proposed by different codes.

2. GENERAL BACKGROUND ABOUT FATIGUE OF CONCRETE

Fatigue is the progressive and permanent damage caused by application of repetitive cyclic loading, leading to failure at much lower load level than the capacity of structure. With the increase in loading cycles, the strain development follows three phases in the form of inverted S-shaped curve due to occurrence of cracks i.e. phase-I is the disproportionate increase in strain due to development of microcracks, while there is linear increase in strain due to stable growth of cracks during phase-II followed by disproportionate and rapid increase in strain in phase-III due to formation of macrocracks. The transition of phases for normal strength concrete are 10-20% of fatigue life for first transition and 80-90% of fatigue life for second transition. However, phase-I and phase-III are shortened for high strength concrete (Kim and Kim 1996, Oneschkow et al. 2016). The number of cycles up to failure (N_f) are usually represented in the form of *S-N* curve, also known as Wohler curve, which is graph between maximum stress level (S_{max}) and number of cycles up to failure (N_f).

3. PREVIOUS STUDIES ON FATIGUE BEHAVIOR OF HIGH STRENGTH CONCRETE

Numerous research work has been carried out to evaluate the fatigue performance of ordinary concrete, but limited data is available related to fatigue behavior of HSPC in compression. Nevertheless, there is still disagreement in the literature that whether the compressive fatigue strength of concrete increases or decreases with the increase in compressive strength (f'_c).

Petkovic et al. (1990) investigated the fatigue properties of three types of high strength concretes i.e. normal density concrete ND65, ND95 and lightweight aggregate concrete LWA75. It was reported that fatigue life was increased when the stress range was reduced with S_{max} as constant. Moreover, no clear difference between the fatigue properties of concrete qualities (ND65, ND95, LWA75) was found, if the load levels were defined relative to static strength. A fatigue study was performed by Do et al., 1993 on two commercial concretes of f'_c of 70MPa and 95MPa. Longitudinal strain evolution and stiffness degradation with number of cycles in high-strength concrete were found to be same as that of normal concrete. Although, no clear statement about the fatigue life of high strength concrete compared with normal concrete is given, however, it can be said that there is no obvious difference between the fatigue life of high strength concrete and normal concrete based on similar strain evolution and stiffness degradation of both concretes.

Due to brittle nature of limestone concrete in fracture mechanics than gravel concrete, Hordijk et al. 1995 studied the fatigue behavior of HSC with limestone coarse aggregates in comparison with HSC using river gravel aggregates. Although for almost same f'_c of both concrete, there were differences in Young's modulus, fracture energy and brittleness under static loading, but, no significant difference in fatigue behavior of both concrete was found. The S-N relationships for normal strength concrete from the previous study were found to be valid for investigated more brittle HSC types. Kim and Kim 1996 investigated the fatigue behavior of concrete of different f'_c ranging from 26MPa to 103MPa. The decrease in fatigue life with the increase in concrete's f'_c was reported owing to higher rate of fatigue strain increment of high strength concrete resulting in brittle nature under fatigue loading compared to low strength concrete. It was found that 2nd phase of cycle strain curve in high strength concrete was longer and fatigue strain at failure was smaller due to great localization of internal damage for HSC at fatigue failure.

Oneschkow 2016 studied the fatigue behavior of high strength concrete with respect to strain and stiffness. The influence of S_{max}, f and wave type on the number of cycle to failure, strain development and stiffness degradation was evaluated. For f=10Hz and sinusoidal wave, the fatigue life of high strength concrete was compared to that of high strength grout, concrete available in literature and normal concrete as well. Overall comparison suggested that fatigue life of high

Keywords: Fatigue performance, High strength plain concrete, *S-N* relationships.
Address: 307-Civil Engg. Building, Graduate School of Engg., Hokkaido University, Sapporo, Japan, Tel: 011-706-6207.

strength concrete is not necessarily worse than that of normal concrete. Moreover, it was found that frequency and waveform influence the fatigue life of HSC in the similar manner as that of normal concrete at high stress levels. In addition, overall strain growth increases with the reduction in S_{max} and change in waveform to triangular in contrast to loading frequency. The comparison between the results on effect of increased f'_c of high strength concrete on fatigue life of concrete is given in Table 1, whether the enhanced f'_c have any effect on fatigue life of concrete or not as stated by different authors.

Table 1: Comparison between results on effect of f'_c of high strength plain concrete on N_f in literature

Reference	Max. $f'_{c,mean}$ (MPa)	S_{max}	S_{min}	f (Hz)	Effect of increased f'_c on N_f
G. Petkovic et al., 1990	80	55% to 95%	varies	1	No effect
M-T Do et al., 1993	95	70% to 95%	5%	1	No effect
D.A. Hordijk et al., 1995	78.2	65% to 80%	5%	6	No effect
J-K Kim and Y-Y Kim, 1996	103	75% to 95%	25%	1	N_f decreases
Oneschkow N., 2016	116	60% to 95%	5%	0.1-10	Overall No effect

f'_c: Compressive strength; S_{max}, S_{min}: Maximum and Minimum Stress level; f: Frequency; N_f: Fatigue life

4. COMPARISON OF S-N RELATIONSHIPS OF HIGH STRENGTH CONCRETE

Figure 1 shows the data points of N_f at different $S_{max.}$ for HSC by different authors along with those for normal concrete extracted from literature. The S-N curve for HSC is obtained using the regression of data points shown for $S_{min.}$ of 5% and various frequencies and compressive strengths. The S-N relationships for normal concrete proposed by Hsu (cited in Oneschkow et al. 2016), Model Code 1990, Eurocode 2, and Model Code 2010 are also drawn. Model code 1990 underestimates the fatigue life of HSC (Oneschkow et al. 2016). However, the regression of data points for HSC (≥C45: Eurocode 2) show that overall fatigue performance of HSC is almost similar to normal concrete as determined by Model Code 2010. The $S_{max.}$-N_f curve for normal concrete developed by Hsu et al. 1981 show slight longer fatigue life than HSC, but with same slope. At higher stress levels (>0.8), the $S_{max.}$-N_f curves show conservative results due to intersection at (1,1).

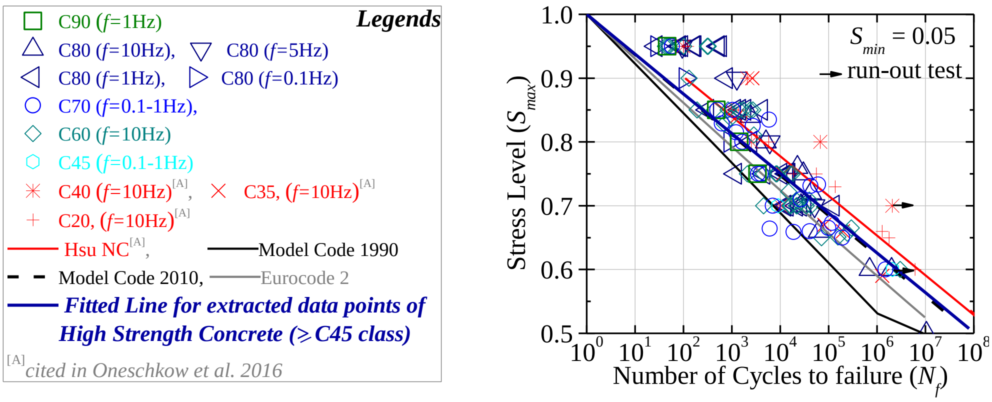

Figure 1: Comparison between S-N relationships of high strength and normal concrete extracted from literature

5. CONCLUSIONS

In this study, the fatigue behavior of high strength concrete is investigated in comparison with normal concrete based on available data in the past research work. In literature, there is conflicting information regarding fatigue behavior of HSC. However, the $S_{max.}$-N_f relationship for HSC obtained through regression of data from literature shows that overall fatigue performance of HSC is same as that of normal concrete. Further research work is needed to more clarification of fatigue behavior of HSC and to propose the design equations for high strength plain concrete under cyclic loading in compression.

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