Fatigue Behavior of Concrete under High Stress Level

○ Koji MASTUMOTO (Student member), Hokkaido University Graduated School
Yasuhiko SATO (Regular member), Hokkaido University Graduated School

1. INTRODUCTION

Structural performance under fatigue loading is arrested by S-N curve such as Tepfer's equation in current design codes. Generally, it is assumed that the damage consumed in concrete under fatigue loading would be predicted based on the linear cumulative damage law. However there are no rational ways to predict deformational history under fatigue loading up to failure. As a tool for prediction of not only fatigue life but also deformation, non-liner analysis such as finite element method is useful.
The authors have developed the stress-strain model based on the experimental observation[1]. In the model, creep strain greatly affects deformational characteristics and fatigue life. However the applicability of creep strain prediction equation used in the model has not verified yet for fatigue test with high stress level. In this study, therefore, fatigue tests of concrete under high stress level are carried out and its deformational characteristics are discussed.

2. EXPERIMENTAL OUTLINE

2.1 Specimens

Some experiments of concrete under high stress compressive cyclic loading were carried out in order to obtain deformational properties of concrete. The size of specimens is 150mmx75mmx60mm. Strain gauges were attached on four faces vertically and laterally as shown in **Fig.1**. In this paper, only axial strain is used for discussion. **Table 1** shows the mix proportion of concrete. For all specimens, concrete was cured in water over one month. **Table 2** shows the stress level for four specimens and the compressive strength and the maximum strain.

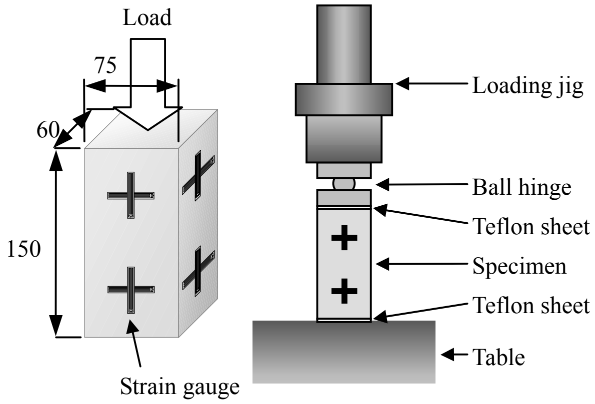

Fig.1 Specimen and loading system

2.2 Loading method

In the static and fatigue tests, load was applied by the actuator. Eccentric load was eliminated by ball hinge, which is inserted between the loading jig and the specimen as shown in **Fig.1**. Friction between specimens and steel plates were reduced using Teflon sheets, which is inserted between steel plate and specimen.

2.3 Measuring method

Axial and lateral strains shown in this paper are the average of four strains observed by strain gauges. The measuring system whose sampling speed is 100Hz, was used. In the system, load and strains measured during test were saved in a computer.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Fatigue life and ultimate strain

Number of loading cycles and ultimate strains are shown in **Table 3**. In the table, ultimate strain, at fatigue test, normalized by that observed in the static test is also shown.
The fatigue life and the normalized ultimate strain become longer and larger with lower stress ratio or smaller stress amplitude, respectively. Tateishi has reported that this tendency could be explained by considering non-damaging

Table 1 Mix proportion of concrete

Air (%)	W/C (%)	S/a (%)	W (kg/m^3)	C (kg/m^3)	S (kg/m^3)	G (kg/m^3)	AE (cc/m^3)
5.0	60.0	41.0	160.0	266.7	780.5	1152.3	117.3

Table 2 Stress amplitude and static test results

No.	Max stress ratio (%)	Min stress ratio (%)	Compressive strength under static (MPa)	Ultimate strain under static (mic)
F-1	80	0	27.4	1911
F-2	80	20	27.4	1911
F-3	80	40	26.2	1580
F-4	90	0	26.2	1580

Table3 Fatigue life cycles and ultimate strain

No.	Fatigue life cycles	Ultimate strain (mic)	Normalized ultimate strain
F-1	626	2370	1.240
F-2	15,467	2522	1.320
F-3	47,049	2094	1.325
F-4	31	1843	1.166

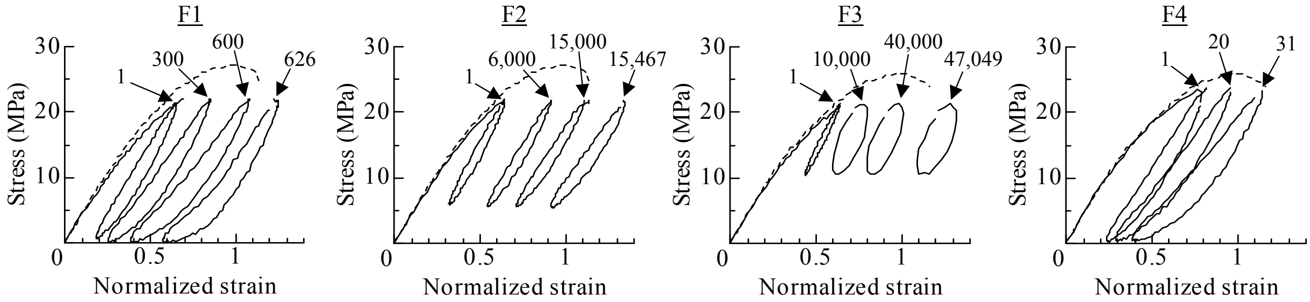

Fig.2 Stress-strain relationships

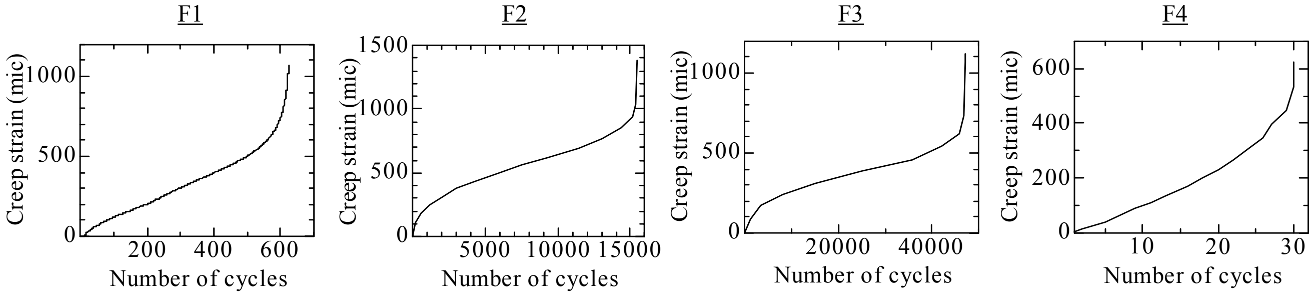

Fig.3 Creep strain-number of cycle relationships

strain as a component of total strain[2]. In the case of lower stress or smaller stress amplitude, ratio of non-damaging strain to total strain becomes greater so that ultimate strain increases.

3.2 Stress-strain relationships

Fig.2 shows stress-strain relationships of each specimen. Solid line shows fatigue one and broken line shows static one. The strain is normalized by ultimate strain observed at static test. Unloading and reloading curves at certain number of loading cycles are picked up and drawn in this figure. The numbers in the figure show the number of loading cycles at each loop. The specimens failed just after the last loop shown in the figure; the number for the last loop indicates the fatigue life.

Shape of unloading and reloading curve is convex downward in F1, F2, F4, and ellipse shape in F3. This difference in loop shape could be caused by difference of loading speed. Loading speed was 1Hz for F1, F2, F4 but 5Hz for F3. In case of high loading speed, stress-strain curve may be affected by viscosity.

3.3 Creep strain-number of cycle relationships

In this study, creep strain is defined as time-dependent strain increment at maximum stress; the total strain minus the maximum strain at the virgin cycle.

Fig.3 shows relationships between the number of cycles and the creep strain. With higher stress ratio or bigger stress amplitude, greater creep strain was observed. The curve of the specimen F2 and F3 whose fatigue life cycles is over 10,000, can be divided into 3 stages. Firstly, creep strain rapidly increases but its increment gradually become small. Secondly, creep strain increases lineally. And finally, the creep strain increases dramatically and it reaches to failure. However, the first stage cannot be observed from the specimen F1 and F4 whose fatigue life is under 1,000. Their creep strain increases lineally from initial fatigue loading.

4. CONCLUSIONS

In this paper, following things are concluded.

1) With higher stress or smaller stress amplitude, fatigue life and ultimate strain become bigger and greater creep strain occurs.
2) When concrete is applied speedy fatigue loading, it is affected by loading speed.
3) Under high damaging condition whose fatigue life is under 1,000, the creep strain increases lineally from the initial fatigue loading.

References

1) Koji MATSUMOTO, Yasuhiko SATO and Akihiro TATEISHI, “A Study on Prediction Method of Concrete Deformation under Compressive Fatigue Loading”, Proceedings of the First International Conference of Asian Concrete Federation, Vol.1, pp.399-408, 2004
2) Akihiro TATEISHI, Yasuhiko SATO and Yoshio KAKUTA, “Investigation of Deformational Characteristics of Concrete under Sustained and Cyclic Loading”, Proceedings of the Japan Concrete Institute, Vol.25, No.2, pp.1123-1128, 2003 (in Japanese)