LOW CYCLE FATIGE BEHAVIOR OF REINFORCING STEEL

The University of Tokyo Student member Ho Thai Hung
The University of Tokyo Member An Xuehui

1. ABSTRACT

In this paper, the study about Low Cycle Fatigue (LCF) of steel bar in RC structures has been carried out. At first, the method to count numbers of cycles until damage and the cumulative damage criteria by using Coffin–Mansion formation combined with Miner Rule has been expressed. As the LCF failure of main steel bars is depending on the stirrup's arrangement, the cumulative damage criteria considering the free spacing of main steel bar between stirrups has been developed.

2. INTRODUCTION

When the reverse lateral force is applied to a RC column as shown in (Fig.1), after 20-30 cycles, spalling of cover concrete, buckling of reinforcing steels bars and the breaking of steel bars are occurred [1]. This breaking of steel bars is carried out by low cycle fatigue (LCF). But in FEM analysis [2], this kind of failure is not included (Fig.2). This paper's purpose is to establish a model of low cycle fatigue damage for reinforcing bar and simulate the breaking of steel bar in RC column under reverse lateral load.

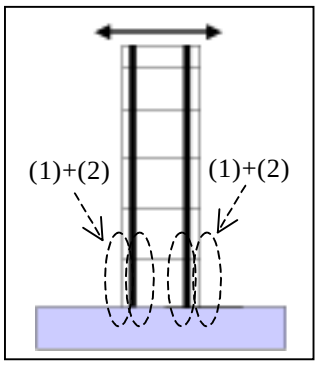

Fig1: The lateral force
(1): Concrete's spalling
(2): main steel bar's buckling

3. LOW CYLCE FATIGUE'S DAMAGED CRITERIA

Definition of Low Cycle Fatigue (LCF): LCF is generally defined as the phenomenon that causes a material or component to fail in early stage, even though the level of load is not high enough to cause failure on the first cycle of application.

Numerical Simulation for Fatigue Life: Fatigue life is usually measured as the number of cycles to failure for a given applied level. The total strain is a summary of elastic and plastic strain. When the strain is high, an elastic one can be ignored. Following Coffin-Mansion Formulation [3], the relation between plastic strain (also total strain) and cycle to failure in case of constant amplitude of strain is expressed as:

$$\varepsilon_p = 0.0777\,(2N_f)^{-0.486} \qquad (1)$$

Here ε_p is the total strain's amplitude and N_f is numbers of cycle to failure. But when the earthquake occurs, the response strain is varies all the times. To determinate the damage of LCF, the cumulative fatigue criteria, Miner Rule [3], has been used as follow.

$$\sum_{(c_i)} \frac{1}{N_{if}} = \frac{1}{N_{1f}} + \frac{1}{N_{2f}} + \frac{1}{N_{3f}} + \ldots \geq 1 \qquad (2)$$

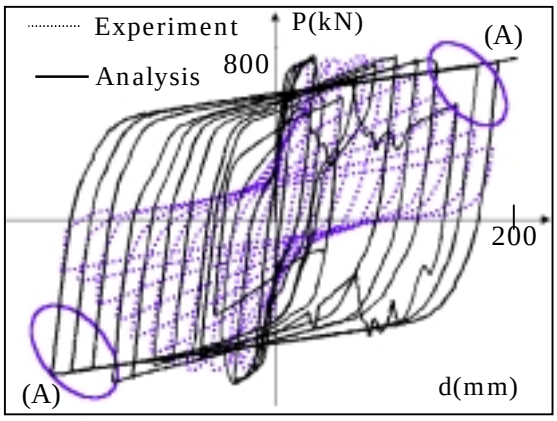

Fig.2: Experiment and Analysis' results
No breaking of main steel bar occurs made the difference in zone A.

ε_p	Analysis	Test
2%	9.25	9.2
3%	4.25	4.1
4%	2.25	2.5

Table1: Strain-Fatigue Life's Relation

KEY WORDS: Low cycle fatigue, Coffin-Mansion formulation, cumulative failure, Miner rule.
Address: Hongo 7-3-1, Bunkyo-ku, Tokyo 113, Japan. Tel: +81-3-5841-6146, Fax: +81-3-5841-6010

If this summary($\sum$) is greater than 1, the breaking of steel bar occurs.

4. VERIFICATION IN CASE OF STEEL BAR ONLY

It can be seen from Table 1 that the analytical results based on above model can get a very good agreement with the Mander test result [3].

5. LOW CYCLE FATIGUE IN RC COLUMN

If the breaking of all main reinforcing bars happens at the same time, the response force of the RC column decreases to zero as shown in (Fig.3). It can be seen that the FEM analysis is different comparing with the experimental result, that the response force of RC column decreasing gradually in reality. Following this result, it is necessary to think about the breaking order of main bar. Observing result of main reinforcing bars' damaged situation shown in Figure 4a, it can be concluded that, from the places confined by stirrups in two directions, to the middle, the bars are broken consequently.

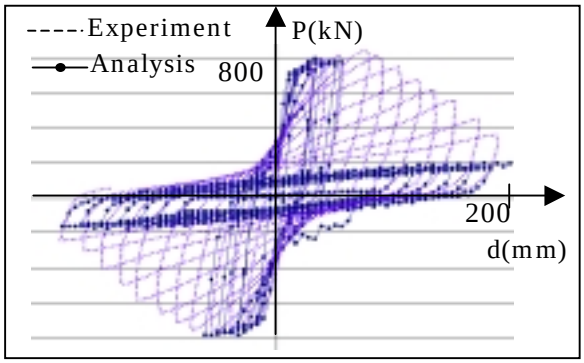

Fig3: Analysis and Test's Difference
(In case: all steel bars are damaged)

In the places confined by stirrups in two directions, the reinforcing bar's free spacing is shorter then the ones in the middle as shown in (Fig.4b). Then, when the same deformation is given, the former one's deformation is much more localized and is broken easilier. By assuming that the accumulative fatigue criteria have linear relationship with this distance: $\sum = a\,L + b$ (where a, b is coefficient numbers) , setting a= 0.5, b=-4.5 and L is between 20-40 (cm), analytical procedures can simulate the fatigue life as shown in (Fig.5).

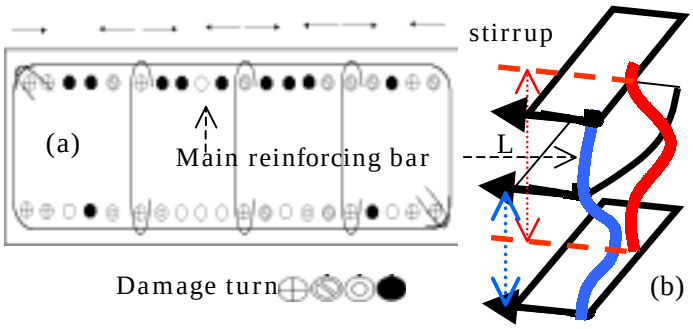

Fig. 4: Time-depended Damage in RC Column
a) Vertical view b) Horizontal view

6. CONCLUSION

By considering the stirrups' influence, the model of low cycle fatigue in the main steel bar is given. In response analysis of RC column, the RC column experiment is simulated successfully as zone (A) in (Fig.5). In this research, only the low cycle fatigue failure is carried out so that makes the difference between analysis and test's results as shown in zone (B) of (Fig.5). This problem can be solved if analysis by using the model of buckling [4] combined with the model of LCF of the main steel bar.

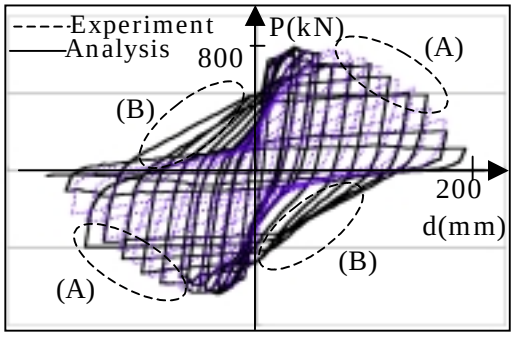

Fig.5: Compare result of experiment and analysis.

REFERENCES

[1] Expressway Technology Center: The first committee of an earthquake-resistant design, material 1, 2001/9.

[2] H. Okamura, K. Maekawa: Nonlinear analysis and constitutive model of reinforced concrete, 1991.

[3] J.B.Mander, F.D. Panthaki et all: Low-Cycle Fatigue Behavior of Reinforcing Steel, Journal of Materials in Civil Engineering. Vol.6, No.4, 1994/10.

[4] Rajesh P.Dhakal: Enhanced Fiber Model in Highly Inelastic Range and seismic performance assessment of reinforced concrete, Doctor thesis 2000/9.