3D FATIGUE LIFE ANALYSIS OF RC SLABS

University of Tokyo Student Member Peerapong SUTHIWARAPIRAK
University of Tokyo Member Takashi MATSUMOTO

1. INTRODUCTION

The life prediction of infrastructure facilities is essential for strategies of maintenance engineering. It provides the information for deciding suitable time and a repair method. A typical case is seen in RC slabs that deteriorate significantly due to rapid increase in traffic. The prediction of life and behaviors under fatigue load of them becomes an urgent task.

The material deterioration under a fatigue load is considered as one of the main causes of the damage of RC slabs. The initiation and the propagation of cracks under fatigue loading lead to punching shear failure in slabs. In this study, an analytical approach for predicting fatigue life of RC slabs is developed. An FEM model that considers governing failure mechanisms allows for different geometries or boundary conditions. Therefore, the analytical approach is not only applied for fatigue life prediction but also the design and development of repair method for structures.

2. FATIGUE LIFE ANALYSIS

The analytical scheme for predicting fatigue life of structures consists of two components: an analytical model and material models as shown in Fig. 1 [(1)]. An FE model is developed based on fatigue failure mechanisms of RC slabs. The propagation of cracks due to the degradation of materials under fatigue load is mainly considered in the model. Concrete and a reinforcing bar are tested in order to obtain material models. With this scheme, the fatigue properties of structures, such as fatigue life and displacement evolution, can be predicted with materials' properties, geometries, and loading conditions given.

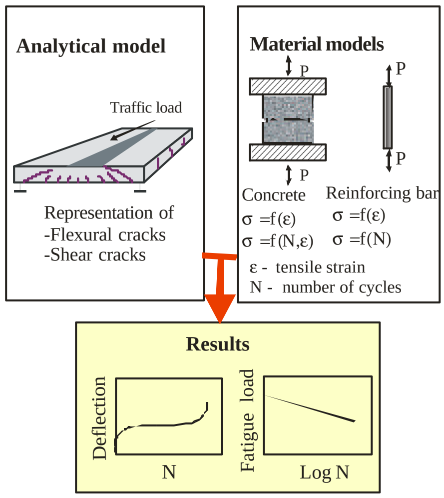

Fig. 1 Components of fatigue life analysis

2.1 ANALYTICAL MODEL OF RC SLABS

RC slabs loaded repeatedly at the center usually collapse in the punching shear mode. The deterioration of materials under fatigue load promotes the initiation of distributed cracks and the propagation of the cracks, and it leads to the failure of the structures. In order to represent these cracks, the concept of smeared elements is adopted. The 3D analytical model consists of smeared elements representing concrete and rod elements representing reinforcing bars. A distributed fatigue load is applied at the center of the slab. By taking advantage of symmetry with respect to the centerline, only one-fourth of the model is analyzed. In order to verify with experiment results, the slab of 2.5x3.8x0.18m with 1.3% reinforcement ratio in longitudinal and 0.5% in transverse direction is adopted from the reference [(2)].

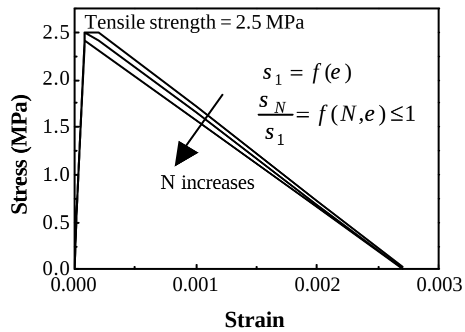

Fig. 2 Tensile Stress-strain relation of concrete under fatigue load

2.2 MATERIAL MODELS

Materials treated in the analysis are concrete and reinforcing bars. For static loading, the constitutive relation of concrete (σ–ε relation) in tension including the cracking stress criteria is assigned in a smeared element and the bilinear stress-strain relation is assigned for a rod element representing a reinforcing bar. Material properties used in this analysis are from the reference [(2)]. The Young's modulus of concrete and steel are $3\text{x}10^4$ MPa and $2\text{x}10^5$ MPa respectively. The tensile strength of concrete and the yielding stress of steel are 2.5 MPa and 452 MPa respectively.

Key word: RC slab, fatigue life, S-N curve, crack propagation, punching shear failure
Address: Hongo 7-3-1, Bunkyo-ku, Tokyo, 113-8656, Japan TEL: 03-5841-7455 FAX: 03-5841-7496

Under cyclic loading, the degradation of tensile stress of cracked concrete or the ratio of stress at N cycle, σ_N, to stress at first cycle, σ_1, is assumed as a function of number of cycles, N, and tensile strain, ε. The stress-strain relations of concrete under fatigue load are shown in Fig. 2. The transferred stress across cracks decreases with the increase of crack opening displacement or tensile strain. The stress also reduces when N increases. The stress degradation relation of concrete under fatigue loading proposed by Zhang [3] is adopted in this study and it is given by:

$$\frac{s_N}{s_1} = 1-(0.08+4\times e\times l)\log(N) \quad , \quad l = \text{element size}$$

3. RESULTS AND DISCUSSION

3.1 MONOTONIC ANALYSIS

The load-midspan deflection relations of RC slab are shown in Fig. 3 and the ultimate load is 627.2 kN. The ultimate load from the analysis well agrees with that from the experiment result (627 kN).

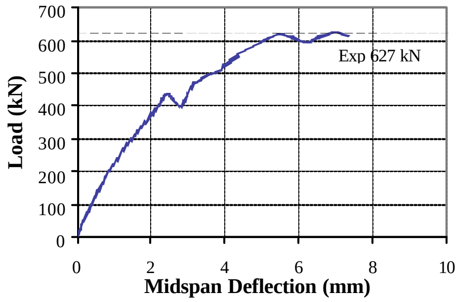

Fig. 3 Results from monotonic analysis

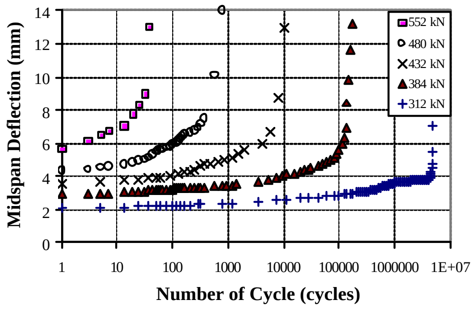

Fig. 4 Evolutions of midspan deflection at each loading level

3.2 FATIGUE ANALYSIS

The evolutions of midspan deflection at five fatigue loading levels are shown in Fig. 4 on a semi-logarithmic scale. At higher loading levels, the slab tends to fail by yielding of reinforing bars, while at lower loading levels, it tends to fail at concrete. The relation between fatigue stress ratio and cycles to failures (S-N) is shown in Fig. 5 and the results from the experiment are also plotted on the same scale with circular points. An arrow shows the specimen that did not fail in the experiment. Fig. 6 shows the punching shear failure typically seen in both monotonic and fatigue analysis.

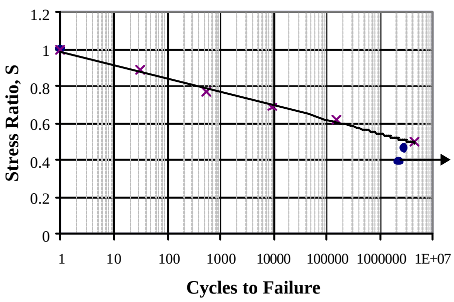

Fig. 5 S-N relation of RC slab

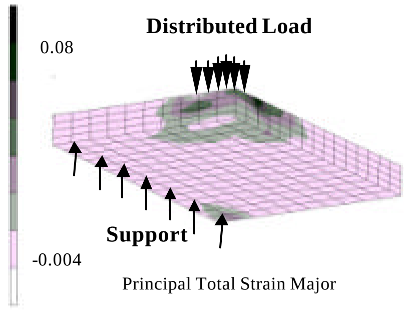

Fig. 6 Strain distribution and punching shear failure

4. CONCLUSIONS

The 3D fatigue life analysis for RC slabs under fatigue load has been conducted. By using this analytical approach, the fatigue life and fatigue characteristics of RC slabs can be predicted. Because of the limitation of experimental results, only a few results are used to verify the model. The more verification is necessary in the future.

For the futher study, in order to simulate traffic load, a moving load simulation should be considered. The consideration of fatigue fracture of reinforing bar is also necessary for the further development.

REFERENCES

1. Suthiwarapirak, P. and Matsumoto, T. “Fatigue Life Analysis of Reinforced Steel-Fiber-Concrete Beams”, Proceedings of the Japan Concrete Institute, Japan Concrete Institute, Vol. 23, No. 3, pp. 127-132, 2001.

2. Okada, K. and Okamura, H. “Fatigue Failure Mechanism of Reinforced Concrete Bridge Deck Slabs” Transportation Research Record, No. 664, pp. 136-144, 1978.

3. Zhang J. “Fatigue Fracture of Fiber Reinforced Concrete-An Experimental and Theoretical Study”, Ph.D. Thesis , Department of Structural Engineering and Materials, Technical University of Denmark. 1998.