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Prediction of The Fatigue Strength of Steel–Concrete Sandwich Beams by FEM

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1. INTRODUCTION

Steel- concrete sandwich beams consist of core concrete which is sandwiched by upper and lower steel plates. Shear connectors are provided at the interface between the concrete and the steel plates. The flexural capacity and also the shear capacity of this type of beams have been thoroughly investigated under static loading conditions. However, the strength of this type of beams under fatigue loading conditions has not. Hence, this study presents analytically the fatigue strength of steel-concrete sandwich beams by using a computer program for nonlinear finite element method (WCOMR)[1].

2. ANALYTICAL MODEL

The analytical model used in this study is based upon reducing the compressive strength and the tensile strength of concrete, with increasing the number of load cycles or increasing the external load range. Similarly, the compressive and tensile strength of bond elements which represent shear connectors are also reduced to simulate the deterioration of bond between the concrete and the steel plate under fatigue loading. Therefore, the strength of the concrete elements and the bond elements is reduced according to the following equation,

$$(F_r / F_u) = 1.0 - 0.0685 \times (1.0 - R) \times \mathrm{Log}\, N \qquad (1)$$

Where : F_u = the static strength
F_r = the reduced strength
N = the number of loading cycles
$R = F_{min} / F_{max}$, $(0 \leq R \leq 1.0)$
F_{min} , F_{max} = the minimum and maximum stress

This equation was proposed by Tepfers [2][3] to predict the tensile and compressive fatigue strength of plain concrete.

3. ANALYSIS PROCEDURE

The analytical procedure used in this study is illustrated in Fig.1. At first, a static loading cycle (OAB) is applied. The maximum principal compressive and tensile stresses at every concrete gauss point, F_{max} in Eq.(1), are stored at point A. Similarly , the minimum principal compressive and tensile stresses at every concrete gauss point, F_{min} in Eq.(1), are stored at point B. Then, a second loading cycle (BCD) is applied with input number of fatigue loading cycles (N). Hence, the compressive strength and the tensile strength of each concrete gauss point are reduced according to Eq.(1), using the input number of cycles (N) and the stored principal stresses (F_{max}, F_{min}). The above mentioned procedure is also applicable for the gauss points of the bond elements. These bond elements are provided to simulate the interface between the concrete and the steel plates. Finally, the sandwich beam is considered to fail due to the fatigue loading (N cycles) if the peak load of the second cycle (point C) is approximately equal to the peak load of the first cycle (point A). In this case, the input number of cycles (N) is considered to be equal to the fatigue life of the sandwich beam.

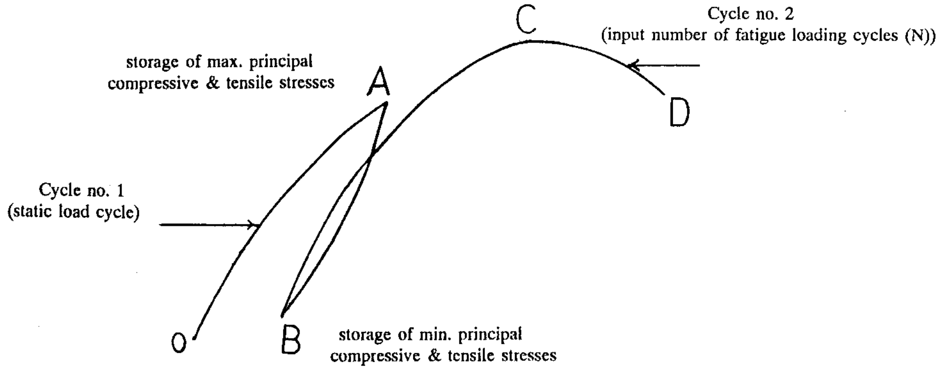

Fig.1 Analysis procedure

4. RESULTS OF THE FINITE ELEMENT ANALYSIS

The finite element method was used to analyze the steel-concrete sandwich beam shown in Fig.2, which has a span length of 265 cm and a cross section of 25 × 40 cm. The shear span to effective depth ratio (a/d) is equal to 3.0. The thickness of the upper and lower steel plates is 16 mm. The compressive strength and the tensile strength of concrete are 250 kgf/cm^2 and 25 kgf/cm^2, respectively. The yield strength of the steel plates is equal to 2450 kgf/cm^2. The sandwich beam is not provided with web reinforcement. Bond elements are provided to simulate the interface between the concrete and the lower steel plate. Enforced displacements are given at the loading point as shown in Fig.2.

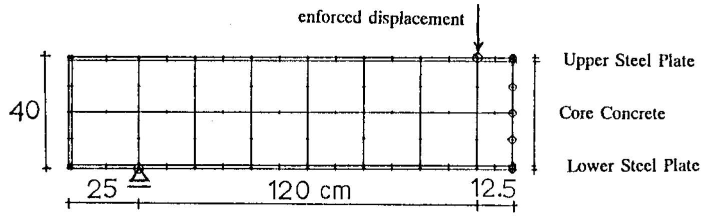

Fig.2 The finite element mesh

At first, the sandwich beam is analyzed under static monotonic loading. The monotonic load-deflection curve is shown in Fig.3. It is observed that the load increases with high stiffness until about 23.0 tons. At this load, main diagonal cracking occurs (point C in Fig.3). This could be illustrated by the crack pattern in Fig.4. Then, the load-deflection curve increases again with small stiffness until the ultimate failure load which is about 34.0 tons. In this study, the fatigue life for the main diagonal cracking is investigated.

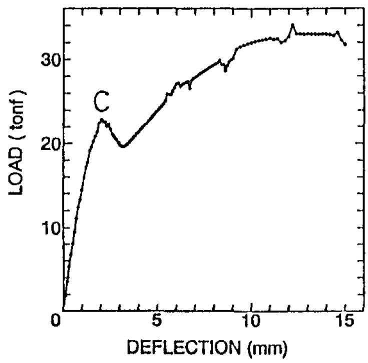

Fig.3 Load-deflection curve (static monotonic load)

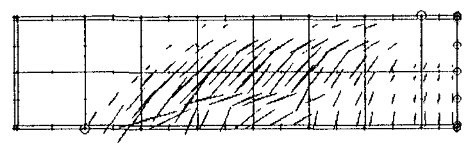

Fig.4 Crack pattern (load =23.0 tf)

The fatigue life is investigated by analyzing the sandwich beam for different external load ranges. The minimum fatigue load is kept constant at 2.0 tons (8.8% of the static strength). The maximum fatigue load (P_{max}) is chosen to be 97% ,88% ,82.7% , 81.7% , and 75.2% of the static strength ($P_{stat.}$). For these maximum load percentages, the obtained fatigue lives are 6000 ,13000 ,10^5 , $2x10^6$, and 10^7 cycles, respectively. The output load-deflection curves for three cases as well as the correspo-nding crack patterns are shown in Figs.5 ,6 ,and 7. The crack patterns correspond to point C in the load-deflection curve at which the main diagonal cracking is considered to occur (see point C in Fig.3). Also, the obtained S-N curve for the sand-wich beam is shown in Fig.8.

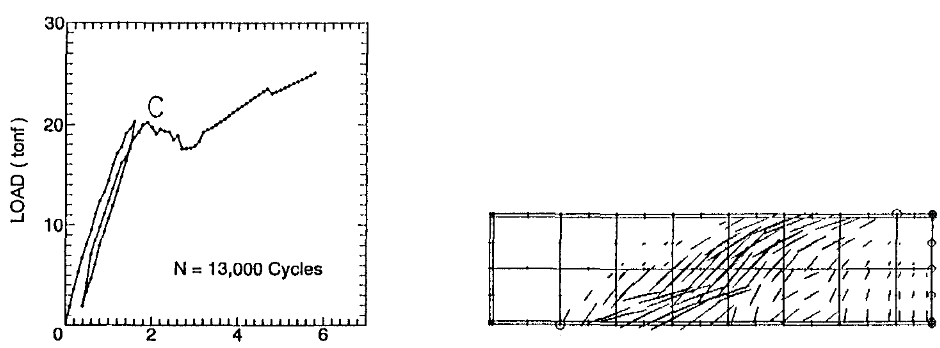

Fig.5 Load-deflection curve and crack pattern (P_{max} = 88% of $P_{stat.}$)

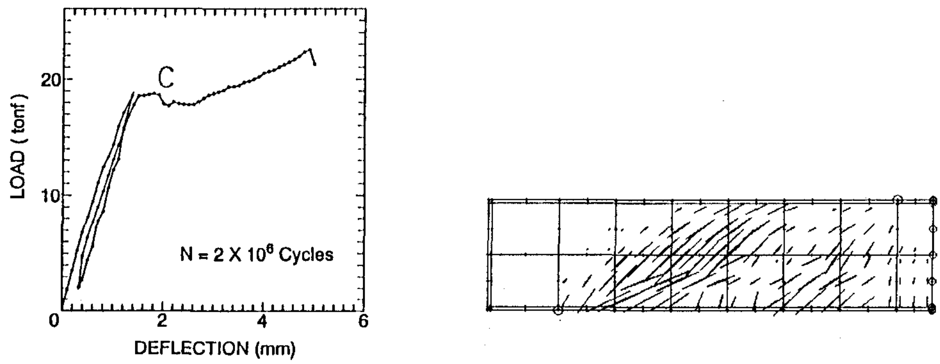

Fig.6 Load-deflection curve and crack pattern
(P_{max} = 81.7% of $P_{stat.}$)

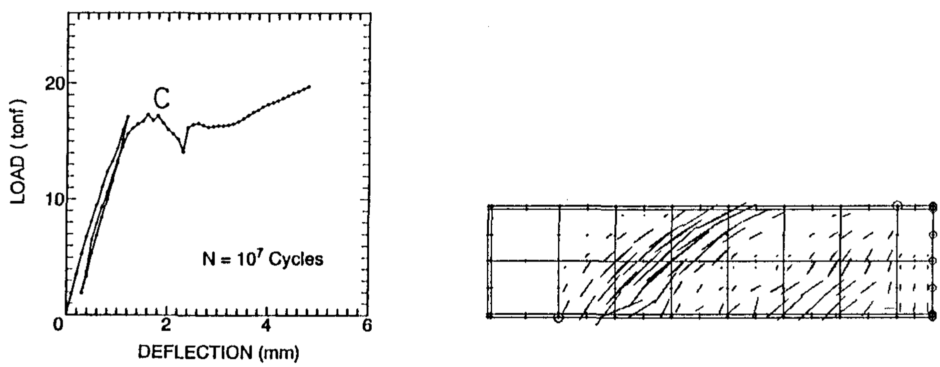

Fig.7 Load-deflection curve and crack pattern
(P_{max} = 75.2% of $P_{stat.}$)

5. CONCLUSIONS

The sandwich beam studied herein indicates a shear failure mode under static loading, which is characterized by main diagonal cracks. The fatigue life for this cracking could be estimated analytically by reducing the strength of concrete and bond elements. This strength reduction depends on the number of loading cycles (N) and also the stress range (R)(i.e.,the range of the externally applied load).

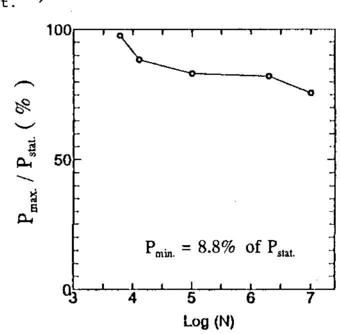

Fig.8 S-N curve for the sandwich beam

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