# MECHANICAL BEHAVIOR OF STEEL-CONCRETE COMPOSITE BEAMS SUBJECTED TO NEGATIVE BENDING MOMENT


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## 1. INTRODUCTION

Steel-concrete composite structures are mainly used in highway bridges in Japan. Many existing studies have been conducted on the positive bending moment region. However, the negative bending moment region in continuous composite beams, which result in the cracking in the concrete slab that may lead to the buckling of the steel girder, can't be overemphasized. When subjected to a negative bending moment, there are disadvantages for steel-concrete composite structures in terms of durability and strength compared to other types of structures. The aim of this study is to investigate the mechanical behavior of the composite structure subjected to negative bending moment by three-dimensional nonlinear finite element (FE) analysis.

## 2. TEST SPECIMENS AND ANALYTICAL MODEL

The static loading test of this specimen have been performed in the previous study[1)]. The test specimen used in this study was 4,600 mm in length and 800 mm in width. It is simply supported at a span of 4,000mm and the loading is applied in the middle section. Headed shear studs were welded to ensure the composite action between steel and concrete slab. The details of the test specimen are shown in Fig.1. The numerical analysis in this study was done by the nonlinear analysis with the aid of the numerical software of DIANA[2)], as shown in Fig.2.

## 3. MATERIAL PROPERTIES

Compressive tests were carried out and the compressive strength of concrete was determined as 27.38 N/mm$^2$. Tensile tests for structural steel and reinforcing bars were performed. The results of the yield strength, tensile strength, and elastic modulus are shown in Table 1.

## 4. RESULTS AND DISCUSSION

### 4.1 Load-deflection behavior

The load-displacement curves are shown in Fig.3. Results show that the experimental data and the analysis data are in good agreement. Moreover, the cracking and yielding strength comparisons were performed and is shown in Table 2. As the stiffness of structures decreases when cracking occurs, the cracking load can be determined according to the initial slope change on the load-deflection curve. Based on the comparison between experimental and numerical results, the numerical model can be used to simulate the behavior of the test specimen.

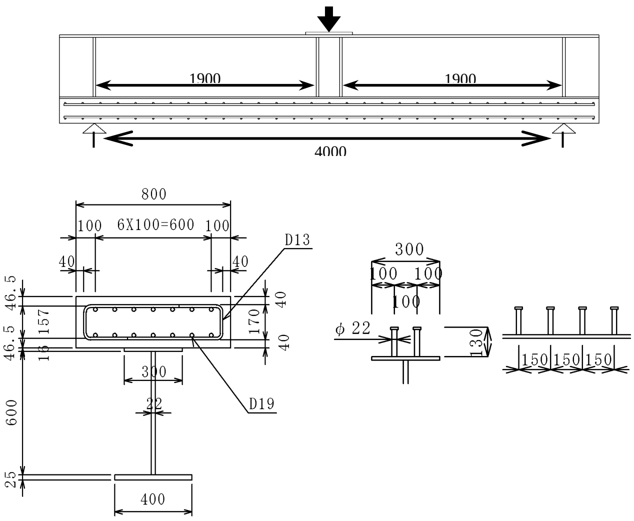


Fig.1 Details of the test specimen (mm)

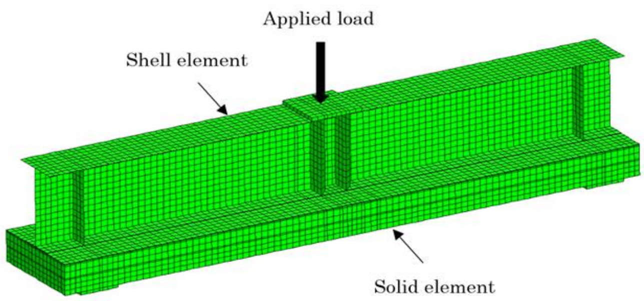


Fig.2 Overview of the numerical model

Table 1 Strength of steel and reinforcing bars (N/mm$^2$)

| *Component* | *Location* | *Yield Strength* | *Tensile Strength* | *Young's Modulus* |
|---|---|---|---|---|
| Structural steel | Top flange | 404.8 | 528.4 | 2.01x10$^5$ |
| | Web | 364.9 | 515.9 | 1.99x10$^5$ |
| | Bottom flange | 382.2 | 517.6 | 1.97x10$^5$ |
| Reinforcement | Longitudinal | 388.7 | 559.1 | 1.91x10$^5$ |
| | Transverse | 376.2 | 540.1 | 1.86x10$^5$ |

Table 2 Load-carrying capacity of the test specimen

| *Method* | *Cracking Load (kN)* | | *Yielding Strength (kN)* | | *Ultimate Strength (kN)* |
|---|---|---|---|---|---|
| Experiment | 200 | Ratio | 2922 | Ratio | 3981 |
| Analyses | 227 | 1.14 | 2890 | 0.99 | - |

Keywords: Steel-concrete composite beam, Finite element method, Negative bending moment
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### 4.2 Strain results of reinforcing bars

The load-strain curve of steel reinforcement is shown in Fig.4. The numerical model is in good correlation with the experimental model in the elastic zone. The yielding strength of the experimental value and the analytical value are also close, as shown in Table 2. But in the post-elastic zone, it can be told that the results of experiment and the numerical analysis are different. The results indicate that the slip between the reinforcing bars and the concrete can be neglected in the elastic state.

### 4.3 Strain results of steel beam

The flexural strain results of steel beam were measured by 10 strain gauges attached at the bottom side of the top flange and the measured strain results from two gauge locations were selected, as shown in Fig.5, and reported in Fig.6. The results indicate that the experimental values are slightly higher than the numerical results, which might be due to the variation in the strain gauge readings, and the stress concentration on the experimental model. In addition, no local buckling of steel girder was observed during the loading process in the experiment, thus the test specimens could be bending dominated failure and can be assumed as the perfect compact section until the ultimate load.

## 5. CONCLUSIONS

Numerical study was carried out based on nonlinear analyses and the following conclusions can be made:

- The results show that the numerical model used in this study can be used to predict the behavior of the test specimen.
- The stiffness of structures decreases when cracking occurs, which leads to the initial slope change on the load-deflection curve.
- The steel-concrete section used for the test specimen can be assumed as the perfect compact section until the ultimate load.

## REFERENCE


1) Lin, W., Yoda, T., Taniguchi, N., Kasano, H., and He, J.: Mechanical Performance of Steel-Concrete Composite Beams Subjected to a Hogging Moment." J. Struct. Eng., 140(1), 2014, 1-11.

2) TNO DIANA BV.: DIANA - Finite Element Analysis User's Manual release 9.4.4. , 2012, Delftechpark 19a, 2628 XJ Delft, The Netherlands.


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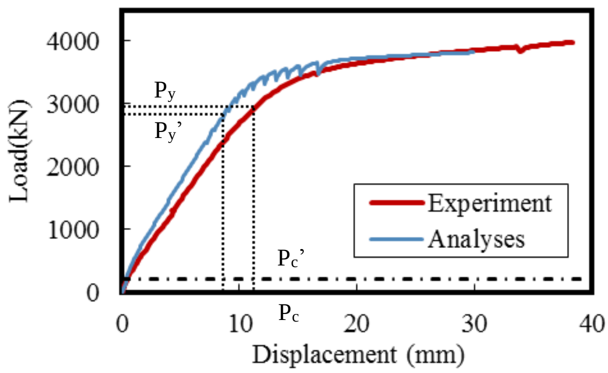



Fig.3 Loading- displacement relationship

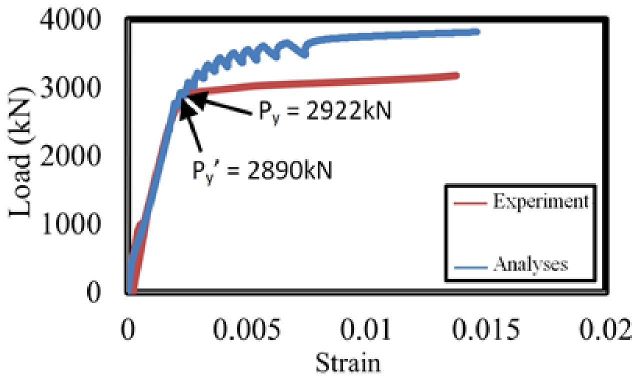



Fig.4 Loading-strain curve of reinforcing bars

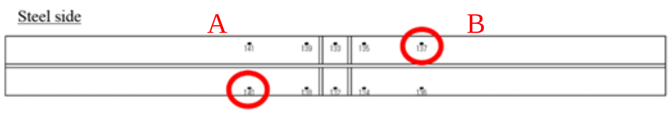
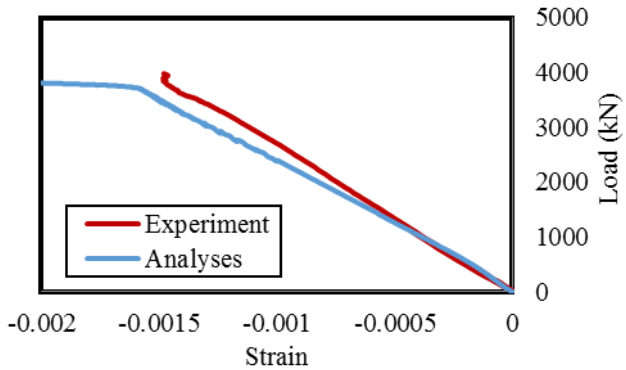
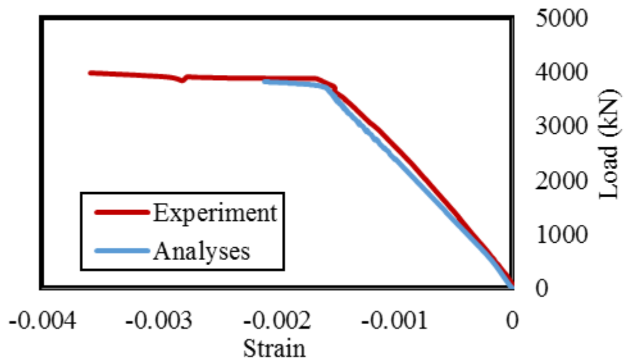



Fig.5 The position of 2 selected strain gauges




(a) Point A




(b) Point B

Fig.6 Loading-strain curves of steel beam