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Finite element analysis of composite beam-column connection utilizing permanent steel form

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ABSTRACT

This paper proposes a three-dimensional (3D) non-linear finite element analysis (FEA) of the steel-concrete composite beam-column connection utilizing prefabricated permanent steel form subjected to cyclic loading. The reference FEA model was created based on the detailed experimental results of the beam-column connection tested at a laboratory. The joint was modeled in ABAQUS software by utilizing 3D solid elements and surface-to-surface contact elements between steel and concrete faces. Also, the nonlinear material behavior of the concrete was taken into account in this model. As a result, it was found that the analysis results coincided with test measurements. Therefore, the numerical analysis could be accomplished as an alternative approach in predicting the cyclic behavior of such composite joints. It is expected as a practical and economical tool with possible design optimizations.

1. INTRODUCTION

Since the composite structures were first investigated in construction industry and applied in developed countries in the early twentieth century, it has currently become popular, so the composite construction methods gain attention nowadays (Nie et al. 2019). The reason for increased interest is the superior performance due to the combination of materials. Moreover, the composite structure could lead to material and subsequent cost savings and give better resistance to corrosion and fire compared with

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the traditional reinforced concrete and steel structures (Johnson 2018). There are different methods of how combinations can be applied in design of buildings or bridges such as composite beams and slabs or columns and frames, thus each method is analyzed separately and under different load types. Most of the previous researches compared relatively new composite construction methods with common practices in terms of their performance based on the experiments and proved the desirable performance of the composite structures (Adam et al. 2008; Choi and Park 2011; Guo et al. 2012; Hwang at el. 2015; Johnson 2018; Lee et al. 2020; Nie et al. 2018; Oh et al. 2015; 2016; Parra-Montesinos and Wight 2000; Wang et al. 2012; 2016). On the other hand, the question of the use of material combinations is still open for discussion.

The connection of members is the most susceptible for deterioration, therefore, it requires the stronger structural capacities than those at mid-span or -height of a member. The design based on the strength of the connection region is not cost effective due to the large cross section size that should resist the larger negative bending moment and shear force. In addition, the price for the steel is much higher than other common construction materials used. In the study of Lee et al. (2020), the steel-concrete composite beam-column connections utilizing prefabricated permanent steel form were investigated by conducting full-scale cyclic loading test. The investigated composite system doesn't need the falseworks which are necessary for conventional reinforced concrete structures, because permanent steel form provide the function of the formwork as well as structural contribution. Due to different strength and ductility demands along the members the size of steel part is also different in the mid-span and at the beam-column joint regions, therefore, in the connection region high-strength reinforcing bars in combination with permanent steel form can be used in order to meet design requirements. Furthermore, permanent steel form can provide structural integrity of the construction so that it acts as a monolithic structure (Lee et al. 2020).

Meanwhile, due to the complexity of the design, it was difficult to fully capture details of the seismic behavior of the joint connection, especially at different sections. This paper focuses on structural performance of the composite beam-column connection under cyclic loading by carrying out the three-dimensional (3D) non-linear finite element analysis (FEA) using ABAQUS software. Numerical modeling is alternative tool which can be further used according to different design parameters and provides a possibility to determine the stress, strain and displacement at any location. The modeling simulation in this study considers the composite beam-column connection consisted of the steel-reinforced composite (SRC) column, reinforced concrete (RC) slab and wide flange beam (WFB). In addition, WFB is asymmetric section with bigger bottom flange. For simplicity, the stud bolts placed at the interface between slab and WFB, shear plates at the end section near the connection and transverse reinforcement in the slab were ignored.

2. ANALYSIS DETAIL

2.1 Geometry and material detail

All materials and dimensions used in the analysis were determined based on the experimental data in the previous study (Lee et al. 2020) as presented in the Table 1. The FEA was conducted with the geometry of the beam-column connection from the full-scale test. The reinforced concrete slab was 1600 mm in length and 150 mm in width connected with the 600x600 mm size steel-reinforced composite column. The reinforcement of the column was implemented by providing W-300x300x10x15 steel WFB and additional D22 rebar, whereas the D10 size rebar was used for longitudinal and transverse reinforcement of the slab at 200 and 220 mm spacing, respectively.

Regarding material inputs, for concrete elastic properties include Young's modulus and Poisson's ratio of 24 GPa and 0.2, respectively, and the concrete damaged plasticity model was used to consider the concrete nonlinearity. For the WFB steel both in the beam and column, the Young's modulus of 200 GPa, Poisson's ratio of 0.3 and yield strength of 517 MPa were taken. Elastic properties for steel rebar are the same as for WFBs, but yield strength was different constituting 660 and 730 MPa for 10 and 22 mm size rebars, respectively (Lee et al. 2020).

Table 1 Detail of test specimen

Steel beam		Steel column		Reinforcing bar		Reinforcing bar	
Type	Yield strength	Type	Yield strength	Type	Yield strength	Type	Yield strength
W500x100x 200x10x16	517 MPa	W300x300 x10x15	517 MPa	10 mm	660 MPa	22 mm	730 MPa

2.2 Analytical model

The composite beam-column connection was modeled in accordance with dimensional details as illustrated in the Fig. 1. A typical nonlinear analysis procedure was applied for this case. First, each part was made as solid section followed by assigning material type and assembling them into one 3D model including assignment of interaction properties and constraints between different materials. The model should be discretized for the finite elements by creating a mesh, for which the hex element shape was used because of the complex shape of the concrete part. As an assumption, the Augmented Lagrange constraint enforcement method was applied with high displacements and lower strains. The loading point was at the distance of 3.5 m from the center point and the reversed cyclic loading protocol was implemented as in the experimental scheme (Lee et al. 2020) by the displacement-controlled method.

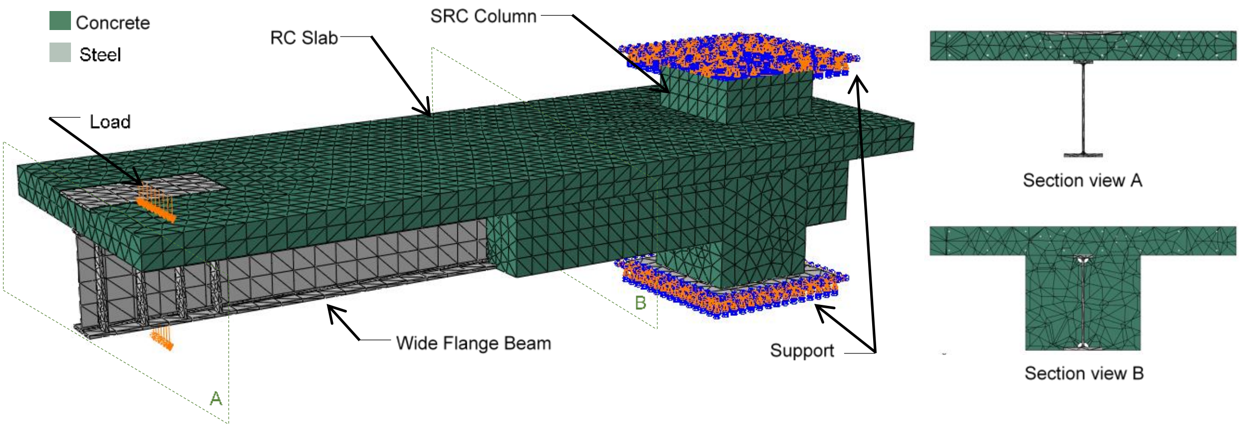

Fig. 1 3D model of steel-concrete composite beam-column connection

3. ANALYSIS RESULTS

As aforementioned, the full-scale specimen was tested under reversed cyclic loading. However, the target composite connection system has complex details, thus the cyclic response of the structure is time and memory consuming. Therefore, the non-linear finite element analysis was first conducted by applying the static load in order to obtain the backbone and find out the validity of the developed FEA model. Fig. 2 shows the comparison of test result and analysis results of the whole model under static loading and only steel parts under cyclic loading. For the whole model, the envelop curve (red line) is given in both negative and positive directions, which are represented as moment versus story drift. In addition, the hysteretic loop of only steel parts (blue line), namely WFBs of beam and column, is also included for this comparison.

The drift ratio was calculated by the dividing the vertical displacement at the section of loading point by the distance from center of the column to the loading point (3.5 m). the moment represented on the vertical axis is obtained by multiplying the reaction force from the column support by the distance 3.5 m.

As shown in the Fig. 2, the analysis results well captured the response backbone curve of experimental result both in negative and positive directions. Therefore, it can be concluded that the proposed modeling is quite reliable. The small difference of results after 1% story drift can be attributed to idealization of modeling and material interaction. As regards simulation result of steel part only under cyclic loading, the peak moment is less than that of the test result by one third in all stages of cyclic loading as was expected. Therefore, the composite effect would be quite favorable to improve the overall behavior of the structure and the energy dissipation would also significantly increase when applying the steel-concrete composite member system in this study.

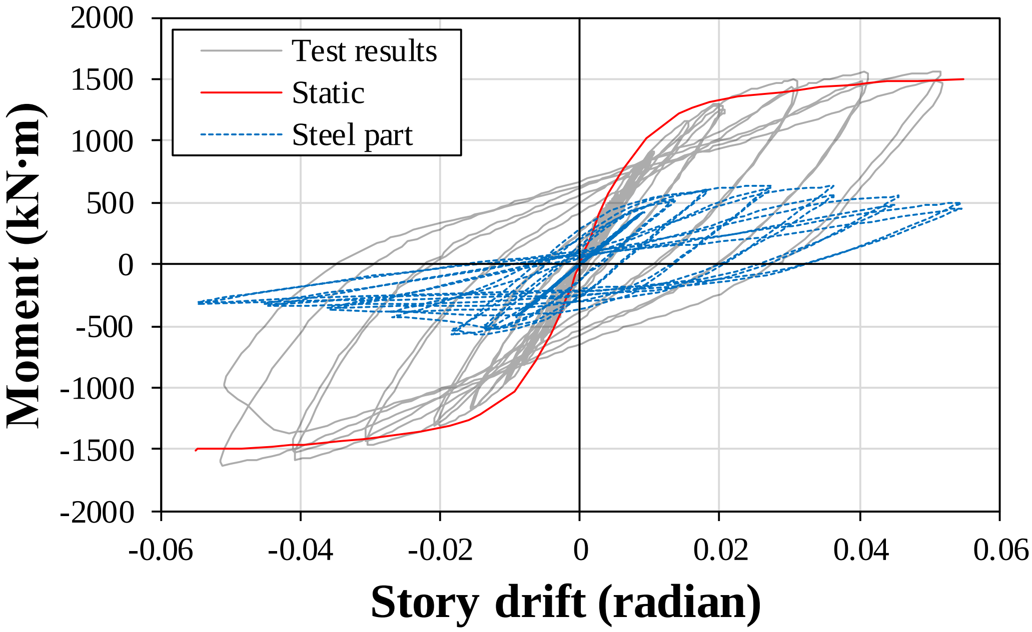

Fig. 2 Comparison of test and analysis results

4. CONCLUSIONS

In this study, the non-linear FEA of the steel-concrete composite beam-column connection utilizing prefabricated permanent steel form subjected to cyclic loading were provided. For this purpose, ABAQUS FEA analysis software was used. Obtained data of simulation results was compared to the experimental results of the proposed beam-column connection tested at a laboratory. In order to create simulation environment close to the real conditions all stages of analysis were emphasized, including material properties, meshing and boundary conditions. The conclusions can be summarized as follows:

- It was confirmed that the results of FEA and the test results correlated fairly with each other both in positive and negative directions.
- The response backbone from the FEA of beam-column connection under static loading coincides with test results before 1% drift ratio, and substitutes less after 1% due to modeling assumptions.
- The FEA modeling can be successively utilized as an alternative tool for investigation of cyclic response allowing the further design optimization without material spending and inefficient time consuming.

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