Behaviour of partially concrete-filled steel box columns under a cyclic loading

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Abstract

In this paper, numerical results of a partially concrete-filled steel box column under a cyclic loading are described. In the analysis, detachment at the interface of the concrete and steel is taken into account and inelasticity of the concrete is considered. The numerical results indicate that the detachment decreases the load bearing capacity of the column. The deformation pattern of the plate also differs between the model with or without detachment.

Keywords: concrete-filled, steel box column, detachment, cyclic load

1. Introduction

Steel box columns, used as a motorway viaduct, are often filled with the concrete. It is known that the filled-in concrete improves the ductility of the column under the seismic and the cyclic load.

Many studies have been made on behaviour of a concrete-filled steel column experimentally and numerically. The authors also made a series of numerical studies on the seismic behaviour of such columns with considering detachment between the filled-in concrete and the steel plate.

In the current study, following to the authors' previous studies [1-4], a numerical analysis is made on a partially concrete-filled steel box column with considering inelasticity of the filled-in concrete together with detachment under the cyclic load.

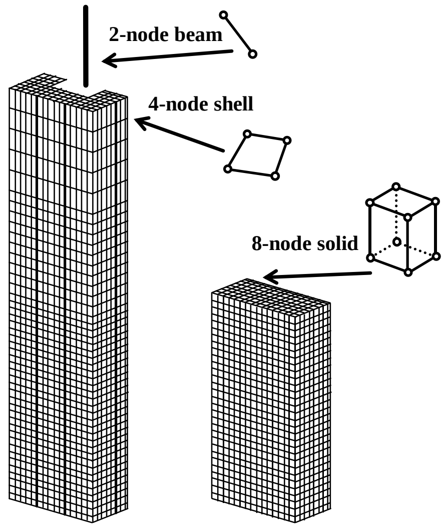

Figure 1: FE mesh discretization

2. Numerical method

2.1. General

Concrete-filled steel box column dealt in this study has the square section of 2.1m x 2.1m, and the depth is 10m. Plate thickness of the steel box is 19mm, and the stiffeners with the section of 250 mm x 19 mm and the diaphragms of the thickness of 14 mm are installed inside the column. Concrete is filled up to 10% or 40% of the column depth.

2.2. Numerical model

The column targeted in this study is discretized by three types of the elements as shown in Figure 1, i.e. the 4-nodes shell elements are used for the steel plates, and the concrete is modelled using 8-nodes solid elements. The upper part of the column is replaced with the 2-nodes beam elements to reduce the degree of the freedom. In the boundary between the beam element and the shell elements, the degree of freedom is constrained to satisfy Bernoulli-Euler theory and fixed section shape.

At the top of the column, the constant axial load which is corresponding with the superstructure is considered. The cyclic load shown in Figure 2 is applying as the lateral displacement at the top of the column. Because of symmetricity, the analysis is made on only the half of the column.

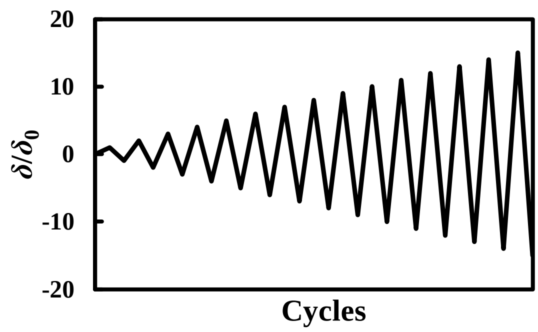

Figure 2: Cyclic loading

2.3. Detachment

At the interface of the steel and the concrete, they repeat separating and contacting many times under the cyclic load. In this study, this phenomenon is considered as a contact problem, and the Direct constrains method is utilized. With this method, when the distance between the concrete and the steel is less than a certain value, they are assumed to behave together. When the tensile stress applies, the continuity of displacement of steel and concrete is not kept, and it is considered that detachment arises. To simplify, it is assumed that the friction between the steel and the concrete does not arise.

2.4. *Material properties*

For the steel plates, the multi-linear stress-strain relationship shown in Figure 3 is used. The von Mises criterion is employed to define the yield criteria. In addition, the combined hardening rule is adopted to consider the moving the yielding surface.

For the concrete, the stress-strain relationships shown in Figure 4 is utilized. Under the compressive stress, the stress-strain relationship is suggested by Popovics [5] shown in Figure 4(a) is adopted with the Drucker-Prager criterion. Under the tensile stress, when the stress of the concrete exceeds the tensile strength, it is known that tangential modulus becomes negative gradient. However, this negative gradient destabilizes the analysis. Therefore, in this study, the simple Bi-linear stress-strain relation without considering the negative gradient is used as shown in Figure 4(b).

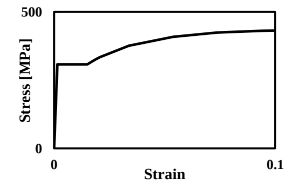

Figure 3: Stress-strain relationship of steel

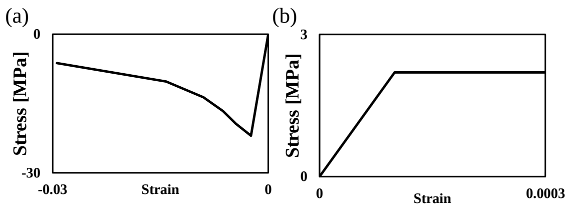

Figure 4: Stress-strain relationship of concrete

3. Results

3.1. *Effect of detachment*

Figure 5 shows the load-displacement relationship at the top of the column of the model in which concrete is filled up to 40 % of the column depth. In this figure, the solid line indicates the load-displacement relationship of the model with considering detachment, and the dotted line the model without detachment. Hereafter, the model with considering detachment is denominated as a "Detachment model", and the model without detachment as a "Bond model".

This figure shows that the bond model has the maximum load of 8 600 kN and it is larger by 1 800 kN than the detachment model. After the peak load, the envelope of the bond model decreases rapidly although it decreases gradually in the detachment model.

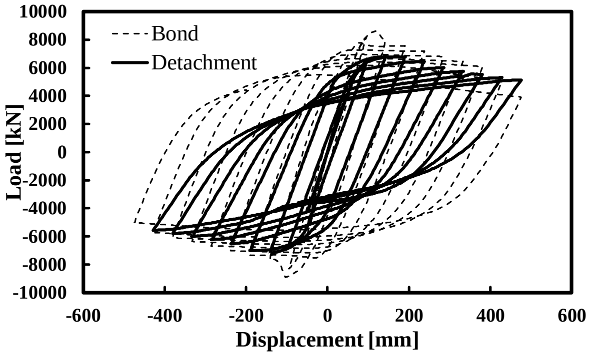

Figure 5: Load-displacement relations

3.2. *Deformation patterns*

Figure 6 shows the example of the deformation patterns of the columns at the final stage of the loading. The black solid lines in the figure indicate that the concrete is filled up to this level. In this model, concrete is filled up to 30% of the column depth.

In the both models of the bond and detachment, the out of plane deformation pattern due to local buckling is observed just around the top surface of the filled-in concrete. In the bond model, the deformation is found only above the concrete, however, in the detachment model, the upper part of the concrete-filled zone also deforms.

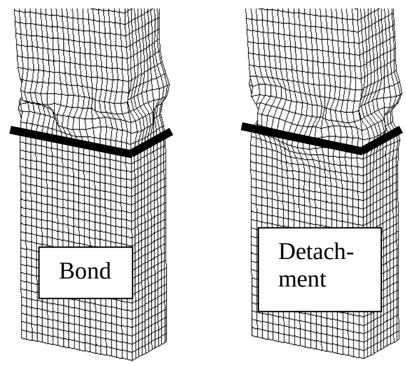

Figure 6: Deformation patterns

4. Conclusion

The results shown in this paper indicate that detachment at the interface of the steel and the concrete influences the load-deflection relations and the deformation pattern, and decreases the strength of the column.

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