# NUMERICAL SIMULATION OF A BEAM COLUMN JOINT WITH COMPLEX REINFORCEMENT ARRANGEMENT BY 3D DISCRETE MODEL

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## 1. INTRODUCTION

A comprehensive study of the behavior of the beam column joint is needed to reduce the reinforcement congestion in a beam column joint, which can cause difficulties during the compaction and furthermore, resulting a poor quality of construction. However, the behavior of the beam column joint has not been clarified well yet since many aspects are involved in a relatively small dimension of a beam column joint. Our research group has used RBSM to simulate the behavior of reinforced concrete by 3-dimensional models, in which the local reinforcement arrangement is considered by modeling the rib of the reinforcement. Meanwhile, the applicability of RBSM in modeling a beam column joint with complex reinforcement arrangement has not been investigated. In this study, by modeling a complex reinforcement arrangement, the applicability of RBSM in predicting the beam column joint failure is investigated.

## 2. RIGID BODY SPRING MODEL

In RBSM, proposed by Kawai (1978), a 3 dimensional reinforced concrete model is meshed into some rigid bodies. Each rigid body consists of 6 degree of freedoms at some points within its interior and connects with the other rigid bodies by 3 springs. In order to prevent cracks propagated in a non-arbitrary direction, a random geometry, called Voronoi Diagram, is used for element meshing (see Fig. 1). To properly account for the interlock between reinforcement and concrete, a 3-dimensional arrangement of reinforcement bar is modeled. The properties of the springs are determined so that the elements, when combined together, enable to predict the behavior of the model as accurate as that of the experimental result. In this study, the simulation system, developed by Nagai et.al (2005), is used and the constitutive models of the elements are adopted from Ikuta et.al (2012). Fig.2 shows the constitutive model of the concrete element. A bilinear model was assumed for modeling the normal springs and shear springs of the steel elements.

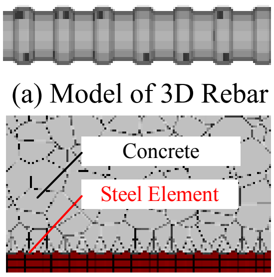


**Fig.1** Mesh Arrangement

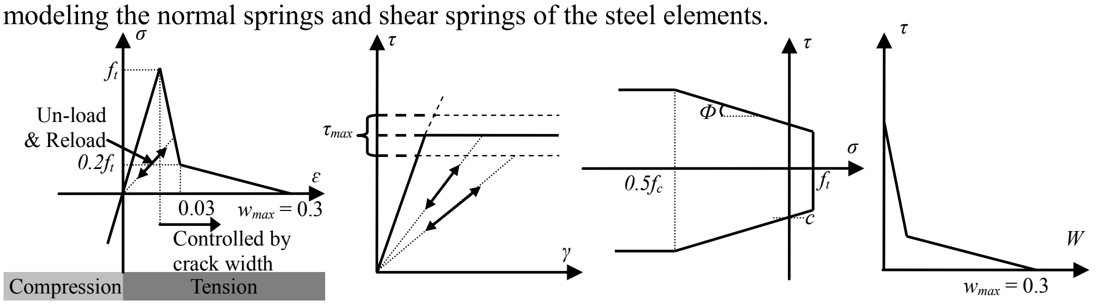


**Fig.2** Constitutive Model of Concrete

## 3. NUMERICAL MODEL

Simulation was conducted for an example of a typical beam column joint of viaducts structure in Japan. Fig.3 shows the geometry and boundary condition of the numerical model. In order to model the hinged condition, a pin element is introduced, located in the steel plates. Furthermore, forces are transferred only through normal springs of the pin element. Cyclic load of displacement control was applied to the pin, located at the end of the beam. Table 1 shows the material properties and dimension of the model.

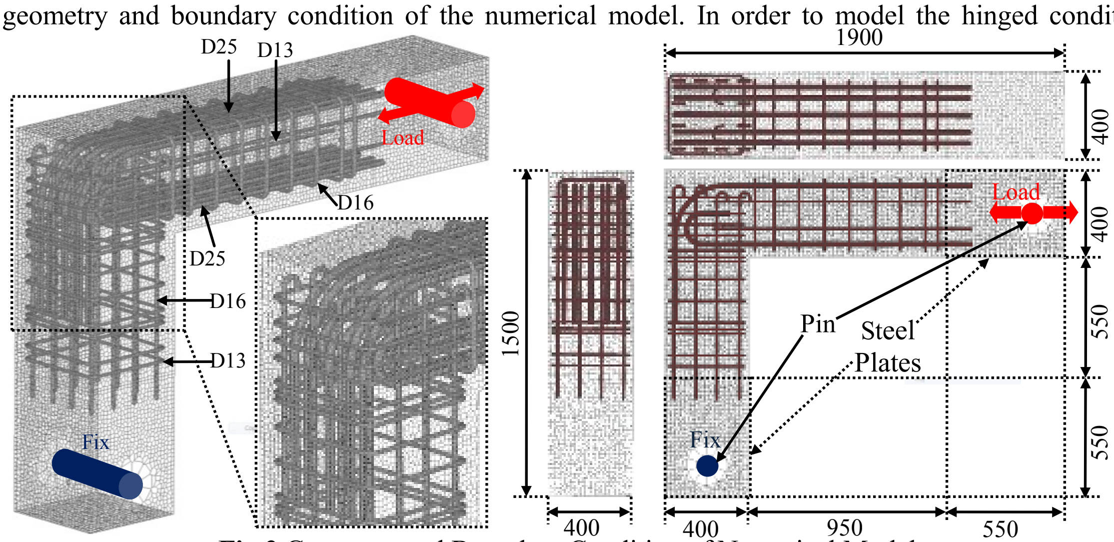


**Fig.3** Geometry and Boundary Condition of Numerical Model

Keywords: Rigid Body Spring Model, beam column joint, complex arrangement of re-bar, anchorages
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**Table.1** Dimension and Material Properties of Numerical Model

| Model | Dimension | | | Number of Element | Concrete | | Reinforcements | |
|---|---|---|---|---|---|---|---|---|
| | Width mm | Height mm | Length mm | | Compressive Strength MPa | Tensile Strength(JSCE) MPa | Modulus of Elasticity MPa | Yield Stress MPa |
| 1 | 400 | 1500 | 1900 | 679273 | 21.1 | 1.75 | 190000 | 770 |

## 4. SIMULATION RESULT

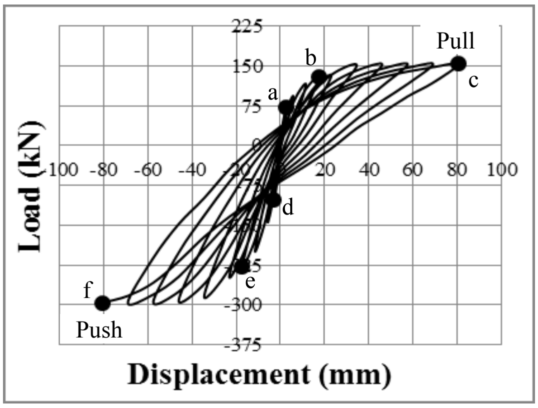


**Fig.4** Load-Displacement Relationship

Fig.4 shows the load-displacement relationship of the numerical results. The load-displacement relationship is the load and displacement in which the load was applied. Based on the simulation results, when the push load is applied, the maximum load of the beam column joint is higher than that of the pull load. Fig.5.a shows the internal cracks of the beam column joint when the pull load is applied. When the applied load is relatively small, at displacement of 2.875 mm, flexural cracks occur on the re-entrant corner of beam column joint (1). As the load increases, at displacement of 17.25 mm, typical diagonal cracks, roughly parallel to the bending portion of the anchorages, occur (2). At displacement of 80.5 mm, huge damage occurs in beam column joint. Meanwhile, Fig.5.b shows the internal cracks of the beam column joint when the push load is applied.

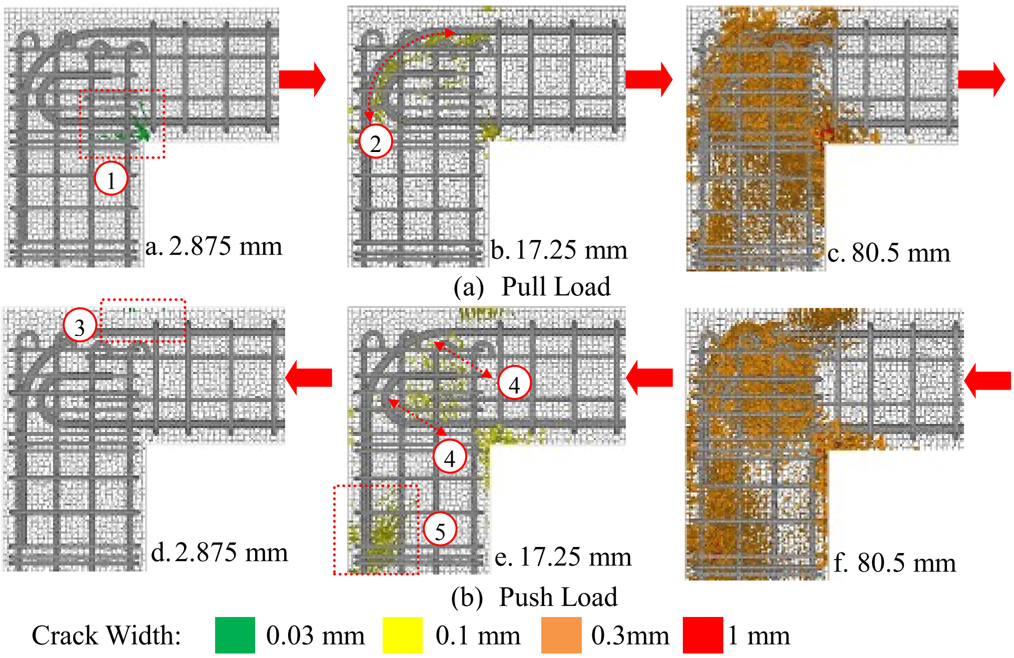


**Fig.5** Internal Cracks

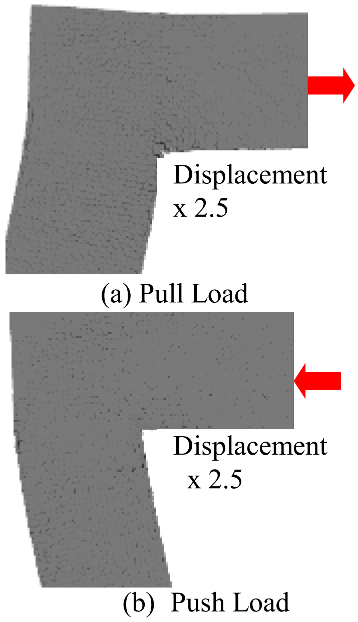


**Fig.6** Surface Cracks

When the applied load is relatively small, at displacement of 2.875 mm, flexural cracks occur outside the bend of the bar anchorages, inside the beam column joint portion (3). As the load increases, at displacement of 17.25 mm, typical diagonal cracks, roughly perpendicular to the bending portion of the anchorages (4), and cracks at the end of the anchorages (5 ) occur. At displacement of 80.5 mm, huge damage also occurs in beam column joint.

## 5. CONCLUSION

RBSM could simulate different failure pattern due to different loading condition in beam column joint. When the pull load was applied, typical diagonal cracks, roughly parallel to the bending portion of the anchorage occur. When the push load was applied typical diagonal cracks, roughly perpendicular to the bending portion of the anchorage occur.

## REFERENCES


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