

CHARACTERISTICS OF 3D STEEL SUBASSEMBLAGES WITH STEEL RHS COLUMN AND WIDE FLANGE BEAM STIFFENED BY EXTERNAL DIAPHRAGM UNDER BIAXIAL LATERAL FORCE

SUI WeiNing¹ and YAMANARI Minoru²

¹Graduate School of Science and Technology, Kumamoto University

²Department of Architecture, Faculty of Engineering, Kumamoto University
2-39-1, Kurokami, Kumamoto 860-8555 Japan

ABSTRACT

This paper describes about elastic-plastic characteristics of steel frames, which are made of rectangular hollow section columns and wide flange beams connected with external diaphragms. There are a lot of studies have been done with a planar frame method, and many important data have been concluded from it. But in fact, the structure is a three-dimensional frame. In order to know the data of the frame characteristics and use it to have design, the information only by planar frame's analysis is not enough, It is important to have a study with three dimensions method. In the other paper, a study about circular columns and wide flange beams had been studied with three dimensions method. Here, a study of subassemblages with RHS columns was also done with three dimensional methods. The external force is a biaxial lateral force, and the local deformation is generated at two directions' flanges.

KEYWORDS

Rectangular hollow steel column, beam-to-column connection, external diaphragm, biaxial lateral force, finite element analysis, three-dimensional method

1. INTRODUCTION

In this paper, a study is introduced about subassemblages' analysis result which is made of rectangular hollow section columns and wide flange beams connected with external diaphragms. The study is done with Finite Element Analysis (FEA) program and is based on three-dimensional analysis methods. It is different from planar frame analysis method. As known the external force, such as seismic, wind force, blast act on the frame from an arbitrary direction. The direction of the external force did not known before they are happened. With three dimensional theory, the analysis model is similar to the real structures, and the reliability is higher. So it is superiority in designing of frame. A study about a subassemblages which is made of circular hollow columns and wide flange beams is introduced in the other papers

(Refs, [1], [2]), and it is known that the change of the force's direction does not have clearly influence on the characteristics of the frame. The frame with CHS column and wide flange beam is an anisotropy frame, the characteristics of the panel zone did not change with the force's direction. However the effective plastic modulus of the frame's panel zone which used in here is changed with the change of the force's direction. So it is necessary to have a study of the subassemblages' characteristics with the change of the external force direction.

2. FINITE ELEMENT ANALYSIS RESULTS OF 3D STEEL SUBASSEMBLAGE UNDER BI-AXIAL HORIZONTAL FORCES

There were two kinds of 3D space subassemblages shown in Figure 1, and the models are named as TXR Frame and XXR Frame. TXR Frame is partial frame of side column and XXR Frame is partial frame of middle column. T and X is the form of the part frame looked from the axis of columns, and they are named as TXR Frame and XXR Frame. The boundary condition of each analysis model is also shown in Figure 2. As the subassemblages is drawn from a frame by cutting the frame in the middle of the beams and columns, the beams and columns are continuous members, the twist in the axis direction of the beam is restricted. And the boundary condition is roller support. The column's boundary conditions same with the beams boundary conditions, in order to prevent the rigid moving, the boundary conditions of the frame's bottom were restricted, the external force is a biaxial force applied on the top of the column. A series of analysis was done with the finite element analysis program in computer.

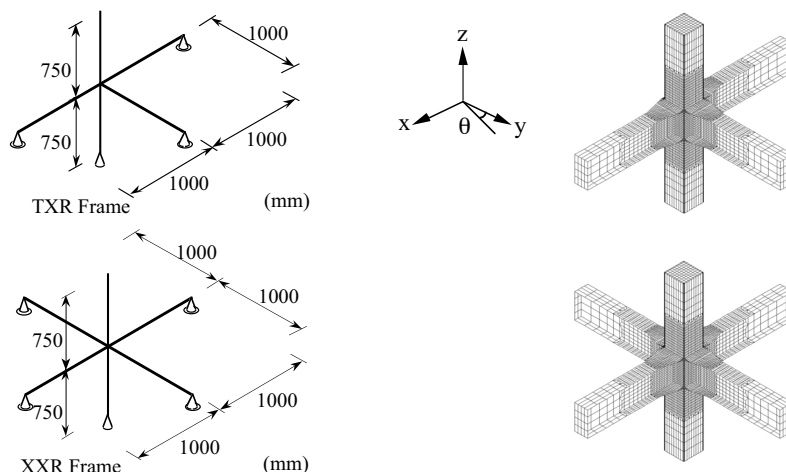


Figure 1: Boundary Conditions and Finite Element Analysis Models

3. RESULTS OF ANALYSES

3.1 Load-deformation curves

The analysis results of the side column part frames (TXR Frame) about the relationship of load-deformation are shown in Figure 2. Angle (θ) is the angle between lateral load's direction and y axes direction. The coordinate system is shown in Figure 1. With the increase of the angle (θ), the gradation of load-deformation curves is increasing. Because with the increase of the angle, the shape of the frame was changed from T shape to X shape. When the angle is changed from 0 degree to 45 degree, the change of curve is sharply. Between 60 degree and 90 degree, the change of curve is smaller. The analysis result of the middle column part frames (XXR Frame) are shown in Figure 3. XXR Frame is different from TXR Frame, it is a symmetrical frame. The results from 0 degree to 45 degree is same to the results between 45 degree to 90 degree. From the graphs of the relationship of load-deformation, it can be seen when the increase of the external force's angle is changed from 0 degree to 45 degree, the strength is raised after the yield of the frame. Although the initial stiffness is invariable. Because the effective plastic modulus of the rectangular hollow section is changed with the force's direction, then when the angle is increased the local deformation and local buckling is generated easier than before.

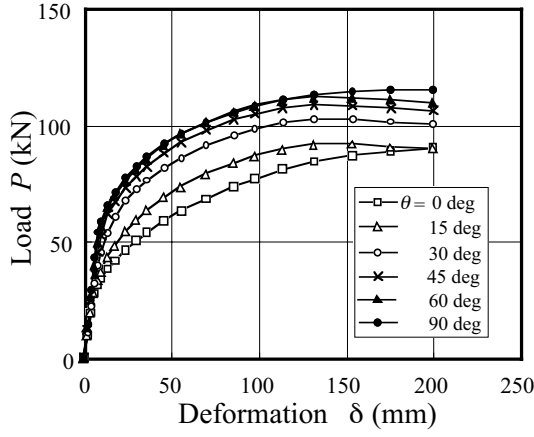


Figure 2: FE Analysis Results of TXR Frame

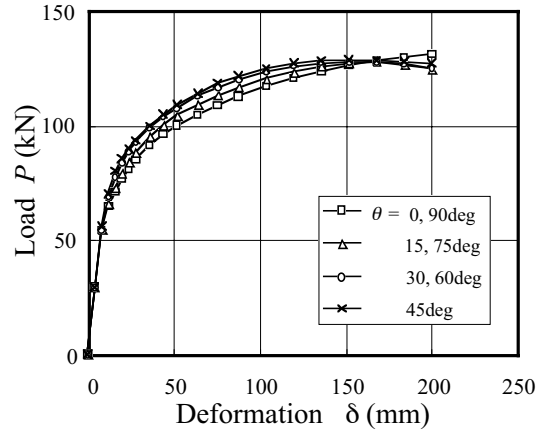


Figure 3: FE Analysis Results of XXR Frame

3.2 Initial stiffness

In Figure 2 and Figure 3, initial stiffness of TXR Frame is changed with the the external force's direction. However, that of XXR Frame is unchanged with the external force's direction. Here, with structural mechanics method, the initial stiffness of TXR Frame when θ is 0 degree is calculated (Ref. [2]), and the process is wrote in below:

When the deformation of the frame is generated only by the deform of the beams, the stiffness (K_B) of the frame (only relate to the stiffness of beams) can be written as

$$K_B = \frac{l}{4h^2} \left(\frac{L^2}{3EI_B} + \frac{\kappa_B}{GA_B} \right)^{-1} \quad (1)$$

When the deformation of the frame is generated only by the deformation of the columns, the stiffness (K_C) of the frame (only relate to the stiffness of columns) can be written as

$$K_C = \frac{1}{2H} \left(\frac{H^2}{3EI_C} + \frac{\kappa_C}{GA_C} \right)^{-1} \quad (2)$$

When the deformation of the frame is generated only by the deformation of the panel zone, the stiffness (K_P) of the frame (only relate to the stiffness of panel zone) can be written as

$$K_P = \frac{1}{\kappa_C} GA_C \frac{D_B l (2L + D_C)}{(4LH - D_B D_C)(2hL - D_B l)} \quad (3)$$

When the deformation of the frame is generated only by the deformation of beam and column connections, the stiffness (K_L) of the frame (only relate with the stiffness of beam and column connections) can be written as

$$K_L = \frac{K_r l}{4HhL} \quad (4)$$

With the stiffness relate to the deformation of the frame's members, the initial stiffness of the frame (K) can be calculated, the equations can be written as

$$K = \left(\frac{1}{K_B} + \frac{1}{K_C} + \frac{1}{K_P} + \frac{1}{K_L} \right)^{-1} \quad (5)$$

where E is Young's modulus, G is shear modulus, l is the length of beams and h is the height of columns which is shown in Figure 1, D_B is the height of the panel zone, D_C is the length of panel zone, $L = l - D_C / 2$ and $H = h - D_B / 2$, κ_B and κ_C is the shape factor of beams and columns' cross section relate to shear. I_B and I_C are the moment of inertia of area of beams and columns, A_B and A_C is the sectional area of beams

and columns. K_r is the stiffness of rotational spring which represents a beam-column connection (Ref. [3]).

The calculation with equation (7) is written in Figure 4 in break line, in Figure 4, the solid line is the analysis result, and the dot line is the calculation of the frame's initial stiffness which ignored the influence of the panel and beam-column connections. The initial stiffness of the frame based on structural mechanics is decreased about 5% of FEM analysis result when all the members' deformation of the frame is thought. And it can be said the result of two theories method traced each other. When the analysis only thought about the deformation of beams and columns and the stiffness of panel zone and beam-column connections is ignored, the initial stiffness of the frame based on structural mechanics is increased about 25% of FEM analysis result. Here the influence of the frame's connect section on the initial stiffness of the frame can be seen easily.

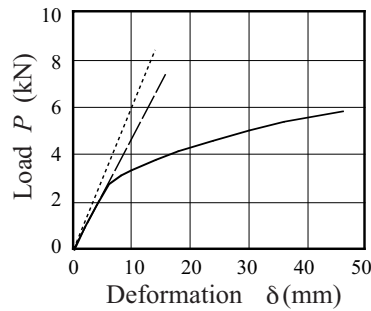


Figure 4: Initial stiffness of different manner of calculation

3.3 General yield load

General yield load of TXR Frame and XXR Frame is shown in Figure 5. It is gotten From the analysis results of the frame about load-deformation relationship. The general yield load here is defined as the strength of the frame when the stiffness of the frame is decreased to 1/3 of the initial stiffness. And it is expressed as the graph which is shown in Figure 6. In TXR Frame, with the increase of the angle, the general yield load is increased. When the angle is over 45 degree, the increase of the general yield load get smaller. In XXR Frame the change of the general yield load is smaller. when the angle reached to 45 degree, the maxium general yield load result is got.

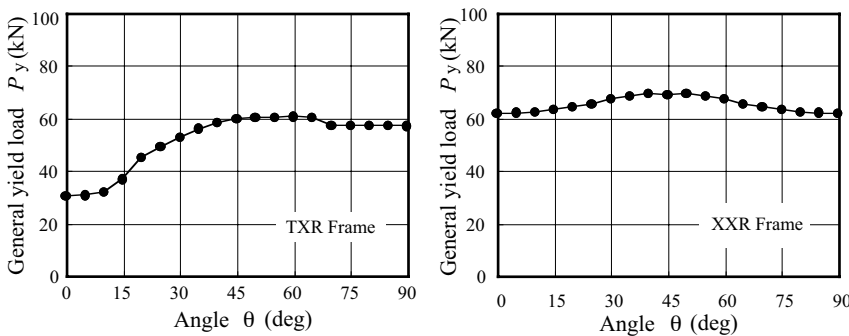


Figure 5: General yield load of TXR Frame and XXR Frame

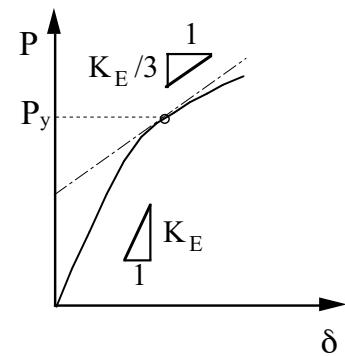


Figure 6: Definition of General Yield Load

4. THE ANALYSIS RESULTS OF THE FRAME WITH ONE DIRECTION'S BEAM OFF-CENTER ARRANGED

When the frame with y direction's beam tranfered from the center line, the frame become an asymmetrical frame. The distance between the center line of the frame and the center line of the off-center arranged beam is 15mm and 30mm. The analysis result is drawn in Figure 7. Only the analysis result of TXR Frame and XXR Frame when the angle θ is 0 degree is drawn in here. In Figure 7, it can be seen that with the off center arrange of the beam, the influence on the frame' behavior is rather smaller. In fact, even with the change of the external force's direction, the effect on the characteristics of the asymmetrical

frame is within 3%. The influence of the off-center frame can be ignored in the prequalification data here.

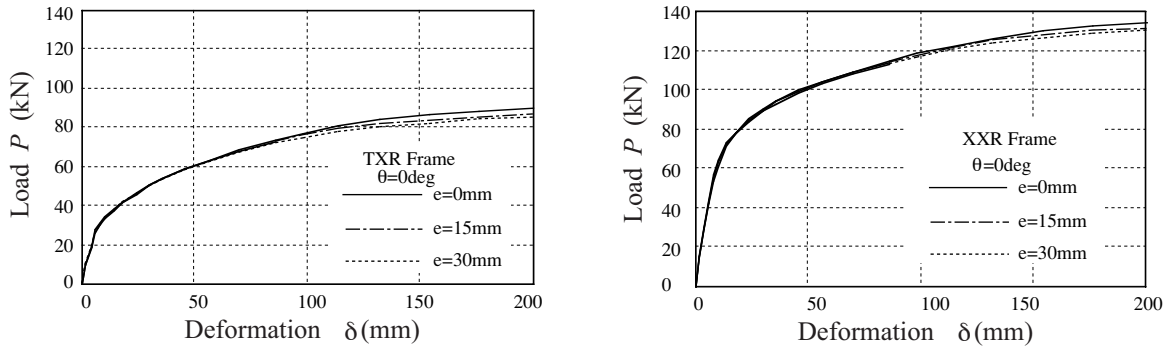


Figure 7: The Influence of the frame with off-center arranged beam

5 FRAMES WITH TWO DIRECTION BEAMS WITH DIFFERENT HEIGHT

Another reason can let frames become an asymmetrical frame. It is when the height of two direction's beams is different. And it is usual of the two direction's beams with different height in fact. Here, the characteristic of it under a biaxial external force is studied. The upper flange of the two directions' beams are on a surface. The lower flange of the shallower beam is connected to column with external diaphragm which is cut near the other direction's web of beams.

The characteristics of the frame when the external force's direction is 0 degree and 45 degree is studied in here. Parameter r is used to express the difference of two direction beams' height. And r is defined as the proportion of y direction's beam height and x direction's beam height. And the height of x direction's beam is fixed here. The value used in here is when $r=1, 0.75, 0.5$. The analysis result is write from Figure 8 to Figure 10. When the angle (θ) is 0 degree, the change of r have a clearly influence on the characteristics of the frame. When the angle (θ) is 45 degree, the influence is smaller. The influence by the changed of r is indistinct. It is said when the angle is 0 degree, the external force is main resisted by y direction's beams. And when the angle is 45 degree, x direction's beam together with y direction's beam resist the external force, and the action of x direction's beam is distinct. It can be said that the change of the ratio r ,

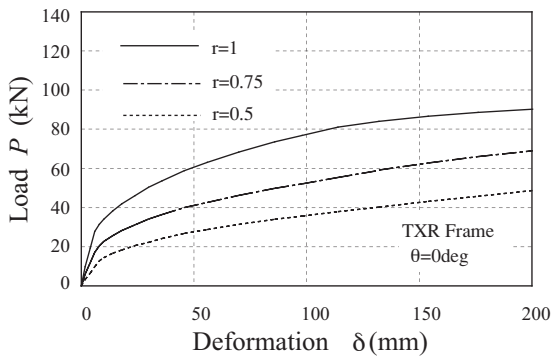


Figure 8: Analysis Result (TXR Frame)

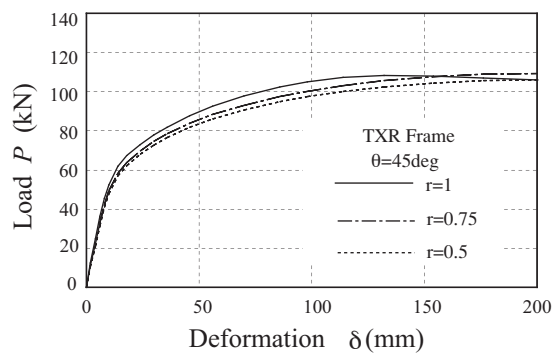


Figure 9: Analysis Result (TXR Frame)

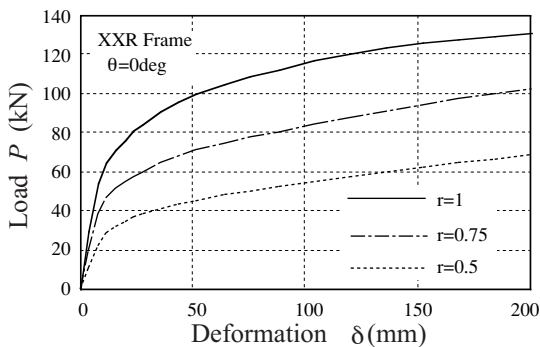


Figure 10: Analysis Result (XXR Frame)

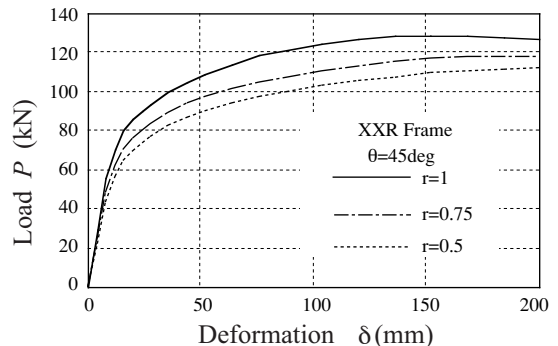


Figure 11: Analysis Result (XXR Frame)

and the change of the external force's direction of a frame with different beam height in two direction have a clearly influence on the characteristics of the frame. In Figure 9 and Figure 11, the local buckling and local deformation of $r=0.75$ and $r=0.5$ is happened uneasily than $r=1$ frame. The frame with difference height of the two directions' beams is good for the disperse of the stress on the connection of the beam's pull side flange. In Figure 9, when the external force's direction is 45 degree, the analysis result is similar even with the change of the ratio r . In order to know the influence of the external force's direction, a study is done of a frame with ratio $r=0.5$. The external force's direction (θ) is range by 5 degree between 0 degree and 90 degree. The characteristic of the frame about general yield load is showed in Figure 12. When the external force's angle is reached to 30 degree, the raise of general yield load is stopped, and the value keeps constant. After 30deg, the analysis of $r=0.5$ is same to $r=1$. It is said that the characteristics of the frame with two direction beams have difference height is changed clearly with the change of the external force's direction. And the influence can not be ignored during the design of the frame.

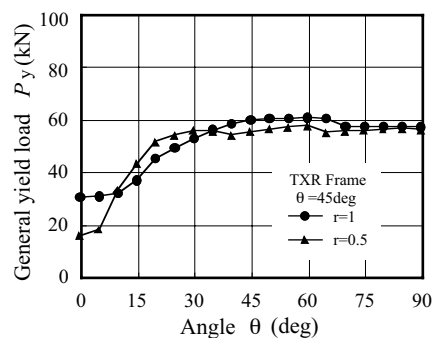


Figure 12: The analysis result of general yield load

6 CONCLUSIONS

From the analysis result of frame in this study, the conclusion can be obtained as below:

(1) The change of the external force's direction did not have clearly influence on the characteristic of the subassemblages that is made of steel rectangular hollow section columns and steel wide flange beams connected with external diaphragms. The analysis of subassemblages under biaxial lateral force have same conclusion with the study with planar frame analysis method. It is said it is enough to have a design with planar frame design method.

(2) The conclusion in (1) is based on the analysis of symmetrical subassemblages. The conclusion can be understood easily that the direction of the external force did not have influence on the symmetrical frame. During the analysis of the frame with off-center arranged beams and different beam's section in two direction of the subassemblages, the change of the external force's direction have a conspicuous influence on the subassemblages.

References

- [1] Sui W. and Yamanari M. (2004) A Study on Elasto-Plastic Characteristics of 3D Space Steel Subassemblage with CHS Column and Wide Flange Beam under Biaxial Loadings, Journal of Constructional Steel, Vol.12, pp.261-268, 2004.11 (in japanese)
- [2] Yamanari M., Ogawa K. and Kurobane Y. (1994) Inelastic Behavior of Semi-Rigid Corner Connections with RHS Column and Wide Flange Beam, Journal of Structural Engineering, Vol.40B, pp.703-710 (in japanese)
- [3] Yamanari M., Ogawa K., Kurobane Y. and Hiroyuki K. (1992) Evaluation of Rigidity of Connections with External Diaphragms Derived from FE Analysis (Study on Restoring Characteristics of Semi-Rigid Steel Beam-to Column connections), Journal of Structural Engineering, Vol.38B, pp. 475-484