ABSTRACT

In this paper, the spatial restrain effects of the transverse steel beams between steel frame and concrete tube are applied to the two-dimensional model to give the pseudo-three-dimensional nonlinear seismic response analysis model of the hybrid structures. In the model, the element type of the transverse beam is selected rationally, i.e. one end of the transverse beam is hinged with the concrete tube, and the other end is rigid with the frame. Thus, the spatial restrain effect problem of the steel frame-concrete tube hybrid structures is solved in a simple and feasible way. And then, the pseudo-three-dimensional nonlinear seismic response analysis method of the hybrid structures is given by using the determined analysis model, and the corresponding analysis program is compiled on the basis of the large special computer program DRAIN-2D and added to DRAIN-2D as subroutines. Finally, the pseudo-three-dimensional nonlinear seismic response analysis method is illustrated by an example.

Keywords: Steel frame-concrete tube hybrid structures, Pseudo-three-dimension model, Nonlinear seismic response analysis, Transverse beam element

INTRODUCTION

At present, the steel-concrete hybrid structures have been applied to the tall buildings and super-tall buildings more and more widely in China. However, the study on behavior of the structures is not perfect and does not meet the needs of its development speed. There are many different viewpoints on seismic behavior and mechanics analysis of this kind of structures at home and abroad [1].

The reference [2, 3] gave the two-dimensional elastic-plastic seismic response analysis model and corresponding analysis method of steel frame-concrete tube hybrid structures. But the spatial restrain effects of around steel beam to concrete tube have a greater influence on the transverse capacity of structures, which can’t be considered using the two-dimensional analysis model. Owing to lacking the test data it is difficult to simulate the biaxial bending behavior of column and wall. So the full three-dimensional analysis is impossible to implement. At present, more effective method is pseudo-three-dimensional analysis method [4-7] which the spatial restrain effects of the transverse beam between steel frame and concrete tube are considered on the basis of two-dimensional analysis model. The pseudo-three-dimensional analysis model has characteristic of simple conception, convenient calculation, and using fully various mature achievements in two-dimensional analysis. In view of the above-mentioned facts, this paper will adopt the pseudo-three-dimensional method to conduct the nonlinear seismic response analysis of the hybrid structures.

1 Professor, Institute of Engineering Mechanics, CEA, Harbin, P.R. China, lingxin_zh@vip.0451.com
2 Master Student, Beijing University of Technology, Beijing, P.R. China, clwu@ncree.org.tw
3 Professor, Beijing University of Technology, Beijing, P.R. China, duxiuli@bjut.edu.cn
The pseudo-three-dimensional analysis model of the hybrid structures is obtained by applying the spatial restrain effects of the transverse steel beam to the two-dimensional model. According to the presupposition of plane lateral-force-resisting structure and rigid floor, the spatial steel frame in the hybrid structure can be regarded as being composed of plane comprehensive frames which are parallel to the direction of earthquake load. These plane frames have not influence each other and resist together the horizontal earthquake load by the connection of longitudinal beams. So each steel frame can be integrated into a plane frame, and the core-tube in the center of structure can be regarded as the tube which is composed of shear-wall with windows. The core-tube and its both sides’ frames which are connected by the longitudinal beams form the plane comprehensive frame-tube. The plane comprehensive frame and frame-tube are connected by horizontal rigid link with hinges in two ends which stands for the rigid floor slab action in the floor level. Thus those horizontal displacements in same level are same, and they resist the horizontal load together. So the spatial structure is simplified into plane two-dimensional model, as in Fig. 1.

Figure 1. Plane two-dimensional model of structure
On the basis of plane two-dimensional model, the spatial effects of the transverse steel beam between the steel frames and concrete core-tube are applied. The whole hybrid structure is idealized into a series of plane comprehensive steel frames and frame-tube connected by the transverse steel beam and horizontal rigid link, as in Fig. 2. The members of structure are modeled using beam element, beam-column element, multiple-vertical-line core-tube model, longitudinal and transverse steel beam element.

**Model of Steel Beam and Column**\(^{[8,9]}\)

The beams and columns of plane two-dimensional steel frame are modeled using two-component model which is composed of an elastic component and an elastic-plastic component. The yield interaction surface of beam-column is shown in Fig. 3. The flexural hysteretic model used here is bilinear model, as in Fig. 4.

**Model of RC Core-tube**

The reinforced concrete core-tube is modeled using multiple-vertical-line-element model, as in Fig. 5, in which the two outside truss elements represent the axial stiffness of flange of core-tube. The central vertical truss elements represent the axial stiffness of the panel of core-tube. All vertical truss elements give the flexural stiffness of core-tube wall together. The horizontal spring in the height of 0.5h represents the shear stiffness of core-tube wall. The partial revised model suggested by Jiang Jin-ren\(^{[10]}\) shown in Fig. 6 is adopted to describe the axial stiffness hysteretic characteristic and the revised
Takeda model with pinch\textsuperscript{[11]} shown in Fig. 7 is adopted to describe the shear hysteretic characteristic of horizontal spring.

![Figure 5. Multiple-vertical-line-element model](image1)

![Figure 6. Axial stiffness hysteretic model](image2)

![Figure 7. Revised Takeda model](image3)

**Model of Longitudinal Beam between Steel Frame and RC Core-tube**

The longitudinal beam between steel frame and RC core-tube is idealized as an element type with a hinge end connection with core-tube and a rigid end connection with steel frame. The yield interaction surface is shown in Fig. 3(1) and the hysteretic model adopted is the bilinear model shown in Fig. 4.

**Model of Transverse Beam**

As the longitudinal beam, the transverse beam is also idealized as an element type with a hinge end connection with core-tube and a rigid end connection with steel frame.

When the whole structure is subjected to horizontal earthquake, the tension end of core-tube becomes long as flexural deformation so that the obvious vertical displacement of transverse beam in a nodal end connected with wall is created, the opposite direction vertical displacement of transverse beam in other nodal end connected with steel frame is also created. So the two end of transverse beam bear different direction vertical displacement. Meantime the transverse beam also bears torsion because of the rotation and different rotation amount at two nodes. So the transverse beam applies a vertical load and a moment on walls of core-tube, an opposite direction vertical load and an opposite direction moment on columns of steel frame. The effect of transverse beam can be modeled using elastic vertical spring and rotation spring. In this paper, the vertical spring action is considered only and the smaller rotation spring action is omitted.

**PROGRAM OF NONLINEAR DYNAMIC RESPONSE ANALYSIS**
As above mentioned, the members of structure are modeled using beam element, beam-column element, multiple-vertical-line core-tube model, longitudinal and transverse steel beam element. In this paper, the program DRAIN-2D is selected to conduct the pseudo-three-dimensional analysis of the hybrid structure. But there is not the multiple-vertical-line-element and an element considering the spatial vertical effects of the transverse steel beam between steel frame and concrete tube in the program DRAIN-2D, the revised work is done. Firstly, the subroutine of multiple-vertical-line-element model is compiled and added to the program DRAIN-2D as a new element. Secondly, on the basis of plane two-dimensional analysis program, the subroutine considering the spatial vertical effects of the transverse steel beam between steel frame and concrete tube is also compiled and added to the program DRAIN-2D as a new element. So the program of pseudo-three-dimensional analysis of the hybrid structure is given.

EXAMPLE

A twenty-story steel-concrete hybrid structure from references [12] is regarded as an example. Its plan view is shown as Fig. 8. The detail of the structure can be seen in references [12]. The above analysis model and program are used to the plane two-dimensional and pseudo-three-dimensional analysis. The input earthquake motion is the El-Centro waves. The peak acceleration is adjusted to 220gal, 400gal and 620gal.

Fig.9 shows the top displacement time history curves of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration. Fig.10 shows the base shear force time history curves of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration. Fig.11 shows the displacement envelope curves of every story of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration. Fig.12 shows the interstory drift ratio curves of every story of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration.
Figure 9. Top displacement time history curves of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration

(a) Two-dimensional (220gal)  Pseudo-three-dimensional (220gal)
(b) Two-dimensional (400gal)  Pseudo-three-dimensional (400gal)
(c) Two-dimensional (620gal)  Pseudo-three-dimensional (620gal)

Figure 10. Base shear force time history curves of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration

(a) Two-dimensional (220gal)  Pseudo-three-dimensional (220gal)
(b) Two-dimensional (400gal)  Pseudo-three-dimensional (400gal)
(c) Two-dimensional (620gal)  Pseudo-three-dimensional (620gal)

Figure 11. Displacement envelope curves of every story of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration

(a) Two-dimensional (220gal)  Pseudo-three-dimensional (220gal)
(b) Two-dimensional (400gal)  Pseudo-three-dimensional (400gal)
(c) Two-dimensional (620gal)  Pseudo-three-dimensional (620gal)

Figure 12. Interstory drift ratio curves of every story of the plane two-dimensional and pseudo-three-dimensional analysis model subjected to different peak ground acceleration

(a) Two-dimensional (220gal)  Pseudo-three-dimensional (220gal)
(b) Two-dimensional (400gal)  Pseudo-three-dimensional (400gal)
(c) Two-dimensional (620gal)  Pseudo-three-dimensional (620gal)

From the Fig. 9 and 10, we can see that the top displacement and base shear force of the plane two-dimensional and pseudo-three-dimensional analysis model have not more different subjected to different peak ground acceleration. So the whole structural responses of two models have not more different. From the Fig. 11 and 12, we can see that the displacement envelope curves of story and interstory drift ratio of the plane two-dimensional and pseudo-three-dimensional analysis model have
not more different subjected to the peak ground acceleration 220gal. But under the peak ground accelerations 400gal and 620gal, the maximum displacement of story and interstory drift ratio of pseudo-three-dimensional analysis model are larger than those of the plane two-dimensional model, specially it is more obvious above 10-story. So we can say that the spatial restrain effects of the transverse steel beam isn’t obvious in early stage of nonlinear (220gal), but the spatial restrain effects of the transverse steel beam is displayed as the nonlinear development. In order to the structural safety, the pseudo-three-dimensional analysis model considering the spatial restrain effects of the transverse steel beam is more rational.

CONCLUSIONS

In this paper, the transverse beam element between steel frame and concrete tube is considered rationally, i.e. one end of the transverse beam is hinged with the concrete tube, and the other end is rigid with the frame. The spatial restrain effects of the transverse steel beam between steel frame and concrete tube are applied to the two-dimensional model to give the pseudo-three-dimensional nonlinear seismic response analysis model of the hybrid structures. Thus, the spatial restrain effects problem of the steel frame-concrete tube hybrid structures is solved in a simple and feasible way. And then, the pseudo-three-dimensional nonlinear seismic response analysis method of the hybrid structures is given by using the determined analysis model, and the corresponding analysis programs are compiled on the basis of the large special computer program DRAIN-2D and added to DRAIN-2D as subroutines. Finally, the pseudo-three-dimensional nonlinear seismic response analysis method is illustrated by an example and the following results are obtained: 1) The top displacement and base shear force of the plane two-dimensional and pseudo-three-dimensional analysis model have not more different subjected to different peak ground acceleration. 2) The spatial restrain effects of the transverse steel cause that the maximum displacement of story and interstory drift ratio of pseudo-three-dimensional analysis model are larger than those of the plane two-dimensional model. In order to the structural safety, the pseudo-three-dimensional analysis model considering the spatial restrain effects of the transverse steel beam is more rational.

ACKNOWLEDGMENTS

The research reported here was supported by Joint Earthquake Science Foundation Grant Number 103094 and Key Project of Science and Technology Plan of Beijing Education Committee Grant Number KZ2004 1000 5003.

REFERENCES


