IOP Conference Series: Earth and Environmental Science

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To cite this article: Juming Ao *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **267** 042072

Nonlinear Simulation Analysis of the Shear Force Redistribution Performance of the RC Frame-Shear Wall Structure with Different Seismic Performance Targets*

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Abstract. Seismic performance design has become the basic requirement of tall building structures design, and the research on the impact of seismic performance target on the anti-side mechanism of RC frame-shear wall structure first and second anti-seismic defense lines is rarely involved. In this paper, the nonlinear finite element analysis method of degenerated three-dimensional solid virtual laminated element is adopted to consider the space synergy effect of beam-slab-column wall, and the nonlinearity of the 17-story RC frame-shear wall space structure model is designed according to seismic performance targets B, C and D respectively.

1. Introduction

The rate of lateral stiffness reduction based on RC shear wall is greater than that of RC frame and RC frame-shear wall structure. Therefore, the frame-shear wall structure has different lateral displacement stiffness characteristics, and the floor shear force is in the frame. The degree of redistribution with the shear wall is also different. Regarding the RC frame-shear wall structure lateral displacement stiffness degradation and floor shear force redistribution performance, there has been a lot of researche at home and abroad and many achievements[1,2], such as China's standard based on the second seismic resistance line concept to bear the frame part. The adjustments have been clearly defined and gradually revised and improved[3]. With the full development of structural performance design, the impact of structural seismic performance targets on the lateral stiffness of RC frame-shear wall structure and the redistribution of floor shear force will be of great concern. So far, research on this aspect is still rarely involved. Therefore, the impact of the seismic performance target on the redistribution of RC frame-shear wall structure floor shear force and the corresponding design adjustment of the frame part to share the shear force are worthy of discussion or in-depth study.With the rapid development of computer technology, the nonlinear finite element method has become an important means of research on reinforced concrete structures. The common treatment method is to simplify the structural members into rods, beams, slabs, etc, although this treatment can reduce the computational workload. However, when describing the geometry of the variable section and the beam-slab column joint zone, the accuracy is not sufficient.The degenerated three-dimensional solid virtual laminated element is composed of different geometric shapes and material properties, which can accurately reflect the complex force of the node region, and the calculation accuracy is obviously improved. In addition, the finite element method has a reduced number of structural division units and high calculation efficiency. It is suitable for nonlinear simulation analysis and research of large-scale high-level space structures.

2. Introduction to degenerated 3-D solid virtual laminated element analysis

The degenerated 3-D solid virtual laminated element introduces the virtual node concept, defines a non-real node that can describe the geometric shape and deformation features, and establishes a finite element model that can describe the structural geometry and stress characteristics by using the laminated beam and shell degenerated solid elements. The finite element is divided into different blocks, and the geometric shape of each block is a hexahedron of 8-20 nodes. The geometric information and material properties of each block can be independently defined, and the stiffness matrix of the element can be obtained by Gauss integral of each block. The definition of component geometry parameters and material properties is independent of element meshing, and structural modeling is extremely convenient. The introduction of virtual nodes also reduces the number of structural unit nodes, thereby greatly improving the efficiency of finite element analysis. In this paper, considering the geometric nonlinearity and material nonlinearity, considering the space cooperating effect of beam-slab column, the simulation modeling of degenerated three-dimensional solid virtual laminated element is carried out for different seismic fortification RC frame structures. Among them, the TL method is used to calculate the geometric nonlinearity of the structure. The diffusion steel reinforcement model is used, that is, the 3-node one-dimensional isoparametric element describes the steel reinforcement, and the steel reinforcement is used as a region in the degenerated solid element. The elastic-plastic constitution model of concrete adopts Ohtani and Chen [[4]] multiple reinforced plastic model, concrete cracking using orthogonal distribution crack model. In this paper, the finite element analysis method based on degenerated 3-D solid virtual laminated element is well applied in bridge structure[5], and its feasibility and superiority are especially prominent in RC frame structure and frame-shear wall structure application[6]. The calculation result is accurate and the efficiency is high. In the simulation analysis of the frame-shear wall structure model, the vertical load is applied once, and the horizontal load is gradually applied step by step according to the stiffness parameter method[7] until the structural damage.

3.Model design and simulation analysis

The structure of the model is shown in Figure 1. The Y-direction of the model is 16m (9m+7m) two-span frame, and the X-direction is 18m (4.5m×4). A transverse shear wall is arranged at each end of the model, and a three-inch frame is arranged in the middle.the bottom floor of the model is 3.6m high, and the storey height of the second layer and above is 3.3m, a total of 29 layers. Seismic fortification intensity of 7 degrees (the first group, designed basic seismic acceleration value of 0.1g), class II site. The model only considers horizontal horizontal seismic action, regardless of wind load, the load on the beam is arranged according to the infill wall, and the floor load is arranged according to the office use function. The model concrete grade is C40 and the steel grade is HRB400. The component dimensions are shown in Table 1.The frame-shear wall spatial structure analysis model (models 1, 2 and 3) of three different seismic performance targets of B, C, and D was designed by PKPM software. The shear ratio of the bottom frame was 23%, calculated by SATWE. Analyze the model reinforcement information. Considering the efficiency of analysis, this paper intercepts the lower 17 layers from the 29-layer model and models it by the nonlinear finite element analysis method of the three-dimensional solid degenerate virtual lamination unit (the vertical load effect of the 18th to 29th layers is equivalent to the top of the 17th layer) . The bottom of the first frame and the bottom of the shear wall are set to be embedded, and the results of SATWE analysis are used for reinforcement. The vertical load of each layer of the model (including the load of the infill wall and the load on the floor) is applied once (the structural weight is automatically calculated by the program), and the horizontal load of the Y is applied by the stiffness method of this step. The model 1 reinforcement grid elevation and the reinforcement grid elevation are shown in Figures 2 and 3.

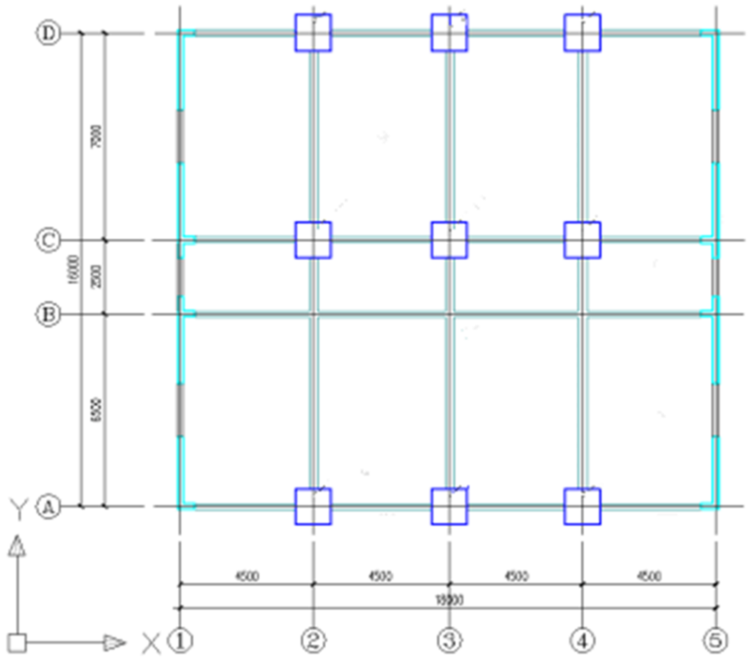

Figure 1. Model structure floor plan

Table 1. Each analysis model number and component size (mm)

Model number	Wall thickness	Frame column	Y-direction frame beam length (short) span	X-direction frame beam	Secondary beam	Connecting beam
Model 1	330	1200×1200	400×800（700）	400×700	250×500	330×1300
Model 2	300	1200×1200	350×800（700）	350×600	250×500	300×1300
Model 3	280	1200×1200	300×800（700）	300×500	250×500	280×1300

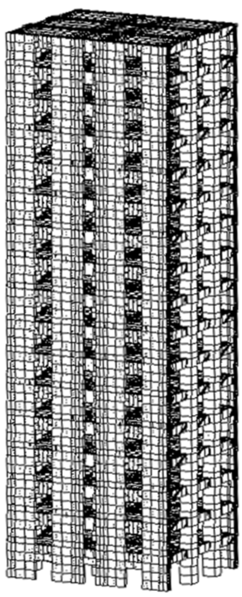

Figure 2. Element grid elevation of model 1

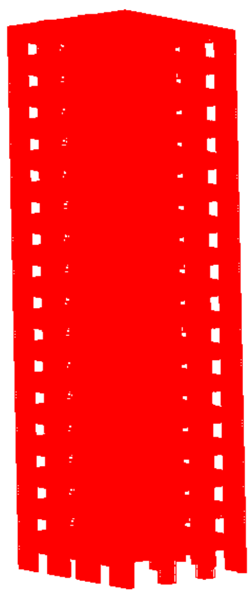

Figure 3. Reinforcement grid elevation of model 1

4. Results of simulation analysis

4.1. Analysis of load and lateral displacement curves

The top-load-displacement curves for models 1, 2 and 3 are shown in Figure 4. It can be seen from the figure that in the initial stage of loading, with the gradual application of the horizontal load, the top displacement of the model gradually increases. At the middle and the loading stage, the top floor displacement of the analytical model begins to increase rapidly. The horizontal ultimate load values of models 1, 2 and 3 (the total horizontal shear force at the bottom of the structure) are 41989.25kN, 32307.47kN, and 21172.52kN respectively. The maximum horizontal displacement of the corresponding top floor of the model is 523.13mm, 573.74mm, and 637.04mm respectively. It is obvious that the model 1 designed according to the seismic performance target B is significantly larger than the model 2 designed according to the seismic performance target C and the model 3 designed according to the seismic performance target D. Obviously, the higher the seismic performance target of the RC frame-shear wall structure, the smaller the limit lateral displacement and the worse the corresponding ductility. In addition, the RC frame-shear wall structure designed according to the seismic performance target B (model 1) can be seen from the figure, the bottom shear force value of the large earthquake elastic analysis is much lower than its horizontal ultimate bearing capacity, indicating that the structure has strong safety redundancy degree. Figure 5 is the Inter-layer displacement curve of the analysis model along the floor height under the limit. As shown in the figure, as the floor height increases, the inter-layer displacement of the structure also changes. The maximum displacement between the layers occurs on the middle floor (8 layers) of the structure. The maximum inter-layer displacement of the models 1, 2 and 3 is 36 mm and 49 mm and 56mm respectively. In the model 1 with seismic performance B, the inter-story displacement angle of the weak layer is the largest under the ultimate load, and the inter-story displacement angle reaches 1/92, exceeds the requirement that the elastoplastic displacement angle of the frame-shear wall structure layer is 1/100 in the Technical Specification for Concrete Structures of High-rise Buildings. which indicates that the higher the seismic performance target, the smaller the maximum inter-story displacement angle of the structure.

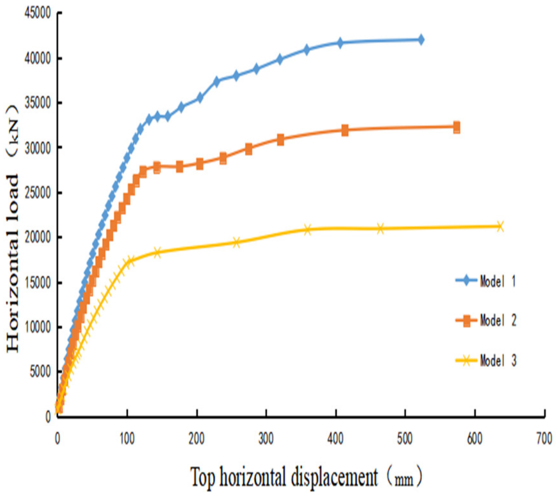

Figure 4. Top load displacement curve of each analysis model

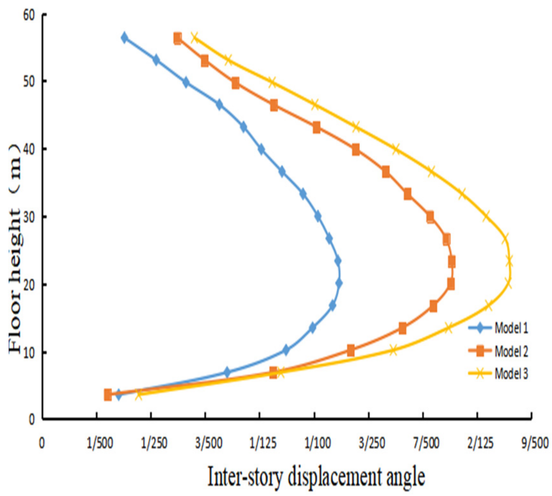

Figure 5. Curve of Inter-story displacement angle under ultimate load of each analytical model

4.2. Analysis of model floor shear force redistribution

Figures 6, 7 and 8 are shear distribution curves for each analytical model. It can be seen from the figure that under the primary load, the shear distribution coefficient of the bottom frame of the model

1, 2, 3 is about 23%, and the shear distribution coefficient increases with the increase of the load, and the structural shear force redistribution characteristics are obvious. Under the ultimate load, the shear force distribution coefficient of the total frame decreases first and then increases along the floor height. According to the RC frame shear analysis model of different seismic performance targets, under the ultimate load, the model 1 (the seismic performance target is B) shear force. The degree of adequate allocation is lower than that of model 2 (the seismic performance target is C), and the model 2 (the seismic performance target is C) is less than the model 3 (the seismic performance target is D), indicating that the higher the seismic performance target, the RC shear structure redistribution is lower in the middle and late loading stages (near collapse).By comparison, it is found that The total frame of the three analytical models of Models 1, 2 and 3 and the shear force distribution coefficient of the total shear wall along the structural height at the initial stage of loading are not much changed, and the shear force distribution coefficient of the middle and lower floors of the structure is almost no change at all, and the shear distribution coefficient of the total frame of the higher floor of the model increases slightly, but the amplitude is small. The shear distribution coefficients of the three models of model 1, 2 and 3 have a large variation range under the ultimate load, and the degree of change of different analysis models is also different, but the overall trend is consistent. The shear distribution coefficient of the first floor of the model 1 general frame under the ultimate load is 0.405, and the top floor is 0.529. The shear distribution coefficient of the top floor is 30% higher than that of the bottom floor; the shear distribution coefficient of the first floor of the model 2 general frame under the ultimate load is 0.439, the top floor is 0.595, the shear distribution coefficient of the top floor is 36% higher than that of the bottom floor; the shear distribution coefficient of the first floor of the model 3 general frame under the ultimate load is 0.443, and the top floor is 0.702. The shear distribution coefficient of the top floor is up to 58% higher than the bottom floor, indicating that the RC frame-shear wall structure floor shear redistribution is related to the seismic performance target. By comparing the shear distribution curve of the analysis model, it is found that the higher the performance target, the lower the degree of structural floor shear redistribution.

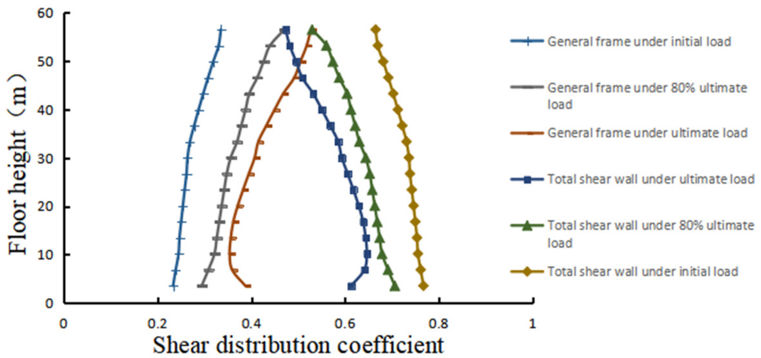

Figure 6. General frame and total shear wall shear force distribution curve of model 1

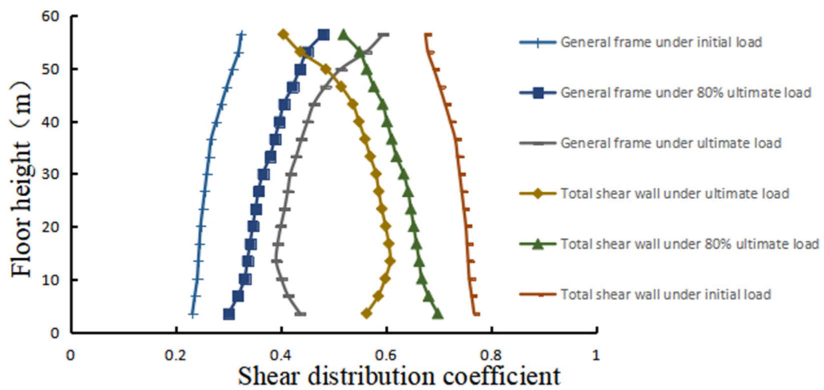

Figure 7. General frame and total shear wall shear force distribution curve of model 2

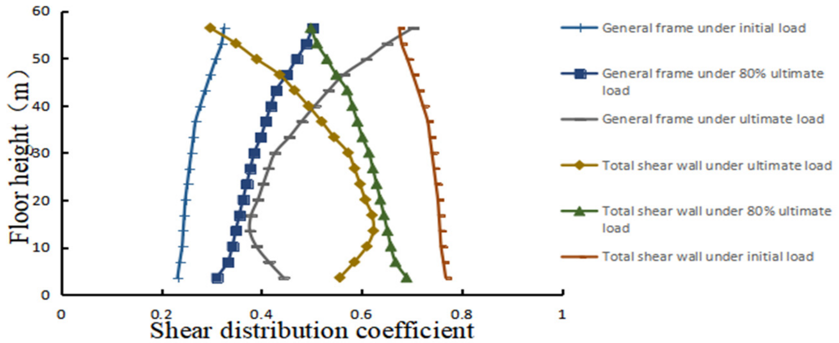

Figure 8. General frame and total shear wall shear force distribution curve of model 3

5. Conclusion

(i) The simulation results of RC frame shear structure with different performance design goals show that the performance-based design target has obvious influence on the lateral resistance of frame-shear structure. The higher the performance target, the larger the ultimate load value of the structure and the maximum structure. The smaller the displacement angle between inter-story, the smaller the ultimate displacement of the model and the worse the corresponding ductility.

(ii) After the structure enters the nonlinear stage, the degree of structural internal force redistribution under different performance targets is different, and the higher the performance target, the lower the internal force redistribution degree.

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