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Research on Seismic Design of High-Rise Buildings Based on Framed-Shear Structural System

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ARTICLE INFO

Article history
Received: 9 October 2020
Revised: 16 October 2020
Accepted: 24 October 2020
Published Online: 30 October 2020

Keywords:
Frame shear wall structure
Displacement-based seismic design
Shear deformation

ABSTRACT

Under the rapidly advancing economic trends, people's requirements for the functionality and architectural artistry of high-rise structures are constantly increasing, and in order to meet such modern requirements, it is necessary to diversify the functions of high-rise buildings and complicate the building form. At present, the main structural systems of high-rise buildings are: frame structure, shear wall structure, frame shear structure, and tube structure. Different structural systems determine the size of the load-bearing capacity, lateral stiffness, and seismic performance, as well as the amount of material used and the cost. This project is mainly concerned with the seismic design of frame shear structural systems, which are widely used today.

1. Introduction

As the rapid development of domestic social economic in recent years, all kinds of buildings, especially the height of the public building has gradually developed higher, at the same time of building structure space free flexibility requirement also has become higher. It is necessary to consider adopting a structural system that can not only meet the seismic requirements but also adapt to the functional requirements.

Currently, the main structural systems commonly used in high-rise buildings are frame structures, shear wall structures, frame shear wall structures, and tubular structures. Frame structures are less rigid and are used in high-rise buildings with large component cross-sections, which affect their use and are not economical. Although shear wall structures are more rigid, the spacing between the shear walls cannot be too large, resulting in limited room space and making them less suitable for office buildings that require large spaces. The frame shear wall structure is a combination of frame structure and shear wall structure, which draws on the strengths of each, providing both a large space for the building layout and good resistance to lateral forces. In a frame shear wall structure, the seismic wall is the first line of defense against earthquakes due to its lateral stiffness, and the frame is the second line of defense against earthquakes.

Seismic damage investigations have shown that, under seismic action, frame shear structures are less susceptible to earthquake damage than other structure types. Under horizontal seismic action, two elements, the shear frame and the curved shear wall, work together through the connection of floor slabs that are infinitely stiff in plane at each level. To meet consistent deformation within the same floor, the frame in this structure differs from the frame in a pure frame structure, and the shear walls in a framed shear structure differ from the shear walls in a shear wall structure. When working together, the shear wall units are much more rigid than the frame, and the shear walls carry most

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 DOI: https://doi.org/10.30564/frae.v3i3.2670

of the horizontal external loads. Whereas at the bottom of the structure, the shear walls deform less and the frame deforms more, the shear walls constrain the deformation of the frame, which reduces the deformation of the frame. In the upper part of the structure, the lateral deformation of the shear wall increases and the deformation of the frame decreases, while the frame bears part of the shear force.

It can be seen that framed shear wall structures are superior to pure frame structures or pure shear wall structures in terms of both stiffness and load-bearing capacity. The structure combines the two advantages of good ductility of the frame and high seismic performance of the shear wall. By proper arrangement of the shear wall, the structure not only has the advantages of flexible space arrangement of the frame structure, but also has the characteristics of strong wind and seismic resistance of the shear wall structure. Therefore, frame shear wall structures are widely used in the design of high-rise buildings, both in seismic and non-seismic areas.

In this paper, the seismic design of the Rizhao Highway Engineering Design and Supervision Information Complex is taken as an example, and the seismic design points of the frame shear structure are briefly discussed.

2. Project Overview

Rizhao Highway Engineering Design and Supervision Information Complex Building is located in Yantai North Road, Rizhao City. The first underground floor is a garage and equipment room; the height above ground is 62.01m, and the total construction area is 23369.80m^2.

3. Structural Design Solutions

3.1 Floor Plan

Due to the high functional requirements of this office building, a frame and shear wall structure is used. The shear walls and frames of the main building (15 floors) of this project have a seismic rating of Grade II. The basement ~ second floor is the reinforced part at the bottom, the third floor and above is the non-reinforced part, and the end sub-story is a frame structure, separated from the main building by a seam, with a seismic rating of grade III.

Structural shear wall layout, in order to try not to affect the use of building function, the wall as far as possible arranged in the plane around the perimeter, the type of shear wall is appropriate for the L-shaped, T-shaped. The wall arrangement follows the principle of regularity and symmetry, and the lateral stiffness of the two main axis directions should not differ too much from each other. Elevator and stairwells are arranged with shear walls to form a "safe island" in the event of an earthquake, which is conducive to its evacuation function and reduces the adverse effects of stair stiffness on the structure. Based on the above principles, the office building is arranged with shear walls, and the standard floor plan of the main building is as follows:

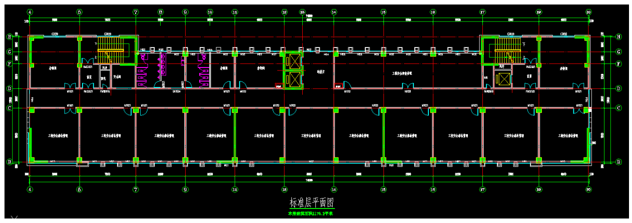

Figure 1. Standard floor plan

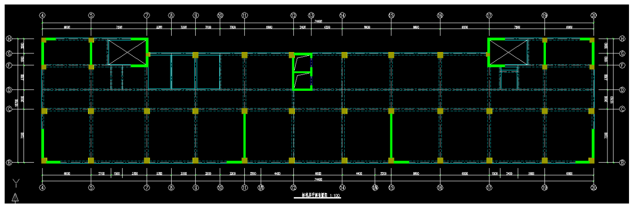

Figure 2. Structural Floor Plan

3.2 Calculation Parameters and Analysis

3.2.1 Structural Rigid Center of Mass

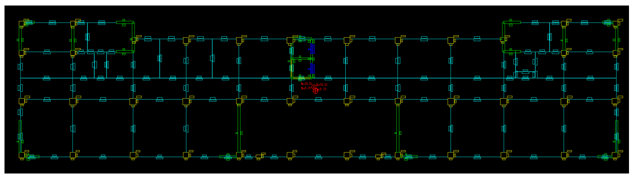

Figure 3. Structural rigid center of mass

The figure shows that the rigid centers of the standard floors of the main building structure basically coincide.

3.2.2 Cycle Parameters

Table 1. Cycle parameters

Cycle, Seismicity, and Root Type Output Files (VSS solver)				
Consider the root motion period (seconds), X, Y direction translation coefficient, torsion coefficient when torsional coupling is considered				
Root Type	Cycle	Corner	Translation coefficient (X+Y)	Torsion coefficient
1	2.0440	178.29	1.00 (1.00+0.00)	0.00
2	1.6633	88.66	1.00 (0.00+1.00)	0.00
3	1.5617	113.23	0.00 (0.00+0.00)	1.00
4	0.6228	179.82	1.00 (1.00+0.00)	0.00
5	0.4073	90.09	0.97 (0.00+0.97)	0.03
6	0.3969	89.94	0.03 (0.00+0.03)	0.97
7	0.3133	0.26	1.00 (1.00+0.00)	0.00
8	0.1939	0.31	1.00 (1.00+0.00)	0.00
9	0.1762	90.38	0.93 (0.00+0.93)	0.07
10	0.1718	89.32	0.07 (0.00+0.07)	0.93
11	0.1355	0.52	1.00 (1.00+0.00)	0.00
12	0.1044	90.81	0.95 (0.00+0.95)	0.05
13	0.1015	177.61	0.83 (0.82+0.01)	0.17
14	0.1000	16.86	0.21 (0.18+0.03)	0.79
15	0.0853	91.41	0.02 (0.00+0.02)	0.98
The direction of the greatest earthquake action = -0.671 (degrees)				

Notes: The cycle ratio is Tt/T1 = 0.764, which meets the requirements.

DOI: https://doi.org/10.30564/frae.v3i3.2670

Table 2. 1.2.3 Structural displacement parameters (from which two conditions were selected).

===condition 1==== Maximum floor displacement under the action of earthquake in X direction

Floor	Tower	Jmax JmaxD	Max-(X) Max-Dx	Ave-(X) Ave-Dx	Ratio-(X) Ratio-Dx	h Max-Dx/h	DxR/Dx	Ratio_Ax
17	1	5834	36.38	36.05	1.01	3900.	25.9%	1.00
		5834	1.43	1.36	1.06	1/2721.		
16	1	5540	35.19	34.87	1.01	3600.	12.2%	0.97
		5540	1.59	1.58	1.01	1/2261.		
15	1	5360	33.85	33.53	1.01	3600	11.0%	1.04
		5360	1.80	1.77	1.01	1/2002.		
14	1	5078	32.30	32.01	1.01	3600.	9.4%	1.07
		5085	1.99	1.97	1.01	1/1810.		
13	1	4804	30.58	30.31	1.01	3600.	7.6%	1.01
		4698	2.17	2.15	1.01	1/1658.		
12	1	4529	28.66	28.40	1.01	3600.	6.2%	0.98
		4422	2.34	2.32	1.01	1/1541.		
11	1	4253	26.54	26.31	1.01	3600.	2.7%	0.96
		4146	2.48	2.46	1.01	1/1451.		
10	1	3978	24.26	24.05	1.01	3600.	4.4%	0.91
		3978	2.56	2.53	1.01	1/1405.		
9	1	3704	21.85	21.66	1.01	3600.	3.8%	0.90
		3598	2.66	2.64	1.01	1/1352.		
8	1	3429	19.30	19.13	1.01	3600.	3.3%	0.90
		3322	2.77	2.74	1.01	1/1302.		
7	1	3153	16.61	16.47	1.01	3600.	2.3%	0.90
		3153	2.86	2.83	1.01	1/1258.		
6	1	2772	13.81	13.69	1.01	3600.	1.7%	0.88
		2878	2.94	2.90	1.01	1/1225.		
5	1	2498	10.91	10.82	1.01	4800.	10.5%	0.87
		2498	3.96	3.93	1.01	1/1213.		
4	1	2183	6.98	6.91	1.01	3900.	17.7%	0.76
		2290	2.89	2.86	1.01	1/1348.		
3	1	1901	4.10	4.05	1.01	3900.	36.8%	0.64
		1901	2.38	2.35	1.02	1/1636		
2	1	1676	2.13	1.90	1.12	4200.	86.8%	0.49
		1676	2.04	1.79	1.14	1/2064.		
1	1	1175	0.12	0.06	1.00	5100	99.9%	0.02
		1175	0.12	0.06	1.00	1/9999.		

Maximum displacement angle between layers in X direction 1/1213.（5th floor bottom 1 tower）
The ratio of the maximum displacement in the X direction to the average layer displacement 1.12（2nd floor bottom 1 tower）
The ratio of the maximum interlayer displacement in the X direction to the average interlayer displacement 1/14（2nd floor bottom 1 tower）

===condition 4==== Maximum floor displacement under the action of earthquake in Y direction

Floor	Tower	Jmax JmaxD	Max-(X) Max-Dx	Ave-(X) Ave-Dx	Ratio-(X) Ratio-Dx	h Max-Dx/h	DxR/Dx	Ratio_Ax
17	1	6098	32.28	31.50	1.02	3900.	3.6%	1.00
		5968	2.29	2.17	1.06	1/701.		
16	1	5691	29.72	29.18	1.02	3600.	2.5%	0.80
		5691	2.11	2.07	1.02	1/1707.		
15	1	5388	27.69	27.18	1.02	3600	2.2%	0.87
		5388	2.16	2.12	1.02	1/1666.		
14	1	5104	25.61	25.14	1.02	3600.	1.7%	0.88
		5104	2.21	2.17	1.02	1/1630.		
13	1	4830	23.49	23.06	1.02	3600.	0.9%	0.87
		4830	2.24	2.20	1.02	1/1604.		
12	1	4555	21.33	20.94	1.02	3600.	0.3%	0.86
		4555	2.26	2.22	1.02	1/1589.		
11	1	4279	19.14	18.79	1.02	3600.	1.3%	0.85
		4278	2.27	2.23	1.02	1/1585.		
10	1	4004	16.94	16.63	1.02	3600.	1.4%	0.83
		4004	2.24	2.20	1.02	1/1607.		
9	1	3730	14.75	14.48	1.02	3600.	2.5%	0.82
		3730	2.21	2.17	1.02	1/1630.		
8	1	3455	12.59	12.35	1.02	3600.	3.7%	0.80
		3455	2.15	2.12	1.02	1/1671.		
7	1	3179	10.46	10.27	1.02	3600.	5.4%	0.79
		3179	2.07	2.04	1.02	1/1736.		
6	1	2904	8.41	8.25	1.02	3600.	9.0%	0.76
		2904	1.96	1.93	1.02	1/1835.		
5	1	2630	6.46	6.34	1.02	4800.	15.1%	0.72
		2630	2.38	2.34	1.02	1/2017.		
4	1	2297	4.10	4.01	1.02	3900.	20.0%	0.65
		2316	1.64	1.62	1.01	1/2379.		
3	1	2021	2.47	2.40	1.03	3900.	32.6%	0.62
		2021	1.32	1.29	1.02	1/2957		
2	1	1676	1.28	1.16	1.10	4200.	86.3%	0.52
		1676	1.13	0.99	1.14	1/3721.		
1	1	1474	0.21	0.11	1.00	5100	93.9%	0.07
		1474	0.21	0.11	1.00	1/9999.		

Maximum displacement angle between layers in Y direction 1/1585.（11th floor bottom 1 tower）
The ratio of the maximum displacement in the Y direction to the average layer displacement 1.10（2nd floor bottom 1 tower）
The ratio of the maximum interlayer displacement in the Y direction to the average interlayer displacement 1.14（2nd floor bottom 1 tower）

Notes: Two conditions were selected, both of which met the requirements.

4. Summary of Seismic Analysis of the Structure

By properly arranging the shear walls, the effective arrangement of the shear walls can improve the seismic performance of the structure without affecting the functional use of the building. From the results of the calculations, the following conclusions can be drawn:

(1) The rigid center of the standard floor of the main structure of this project basically overlaps, which will greatly improve the seismic capacity of the structure compared to the irregular structural form.

(2) The maximum displacement angle between floors under X-direction seismic action is at the 5th floor, and the maximum displacement angle between floors under Y-direction seismic action is at the 11th floor, which shows that the horizontal displacement of a frame-shear wall structure under horizontal force is controlled by the displacement angle between floors. The maximum interstory displacement generally occurs between 0.3H and 0.8H of the building.

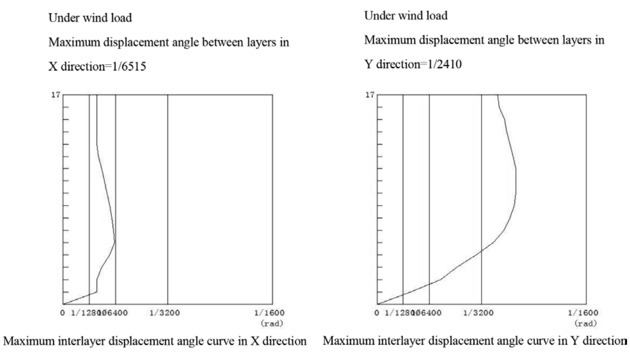

Figure 4. Maximum interlayer displacement curve

(3) The displacement of each layer is connected into a lateral displacement curve in the shape of S, without convexity and folding point. This shows that the number and location of the shear wall settings are reasonable, and also reflects the importance of shear wall seismic performance. However, how to determine the optimal stiffness of the shear wall and how to reduce the cost of the project while ensuring the seismic resistance and functionality of the structure is still a key issue to be addressed in the future design.

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