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Research on the Application of Mixed Prefabricated Frames in the Seismic Design of Tall Buildings

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Abstract: As is well known, prefabricated concrete structures have the advantages of reducing on-site wet work volume, fast construction speed, saving materials, being conducive to building industrialization, and having good economic and social environmental benefits compared to cast-in-place concrete structures. Therefore, experts in the engineering industry actively advocate the application of prefabricated concrete structures. From the perspective of its structure, the hybrid prefabricated frame system has the characteristics of light weight, convenient construction, and large span, and has excellent seismic performance. According to the current specifications, propose reasonable seismic performance goals and measures, and conduct dynamic elastic-plastic supplementary analysis. The seismic performance can meet the needs of earthquake resistance, and the corresponding point is defined as the characteristic point of structural seismic performance, which can be based on the corresponding structural base shear force, vertex displacement, interlayer displacement, and crack development situation. Conduct performance testing and research on the seismic performance of the specimen, including hysteresis curve, load-bearing capacity, displacement ductility, strength degradation, and energy dissipation capacity.

1. Introduction

With the increasing height of modern buildings, hybrid structure system has been widely used in high-rise buildings. Under the strong earthquake, generally, the floors with weak structures yield first, forming the phenomenon of elastic-plastic deformation concentration. The checking calculation of elastic-plastic deformation of the structure is essentially whether the maximum elastic-plastic displacement between weak floors is within the allowable range of structural floor deformation capacity. As we all know, compared with the cast-in-place concrete structure, the prefabricated concrete structure has the advantages of reducing the wet work on site, fast construction speed, saving materials, being conducive to building industrialization and having good economic and social environmental benefits, so experts in the engineering field actively advocate the application of the prefabricated concrete structure. From the structural point of view, the hybrid assembled frame has the characteristics of light weight, convenient construction and large span, and has excellent seismic performance [1]. Even after the earthquake, it is highly repairable, and there is no unified standard for this kind of structure to be fortified. Among them, the frame-core tube structure is composed of core tube and peripheral frame columns. Because of the high concentration of people and wealth in high-rise buildings, once an earthquake occurs, its disaster is devastating, so its seismic design is very important. In order to study the seismic design of hybrid assembled frame in high-rise buildings, there is no doubt about the unique advantages of assembled structure. The problem is how to ensure the connection performance between prefabricated components and the overall performance of the structure [2]. According to the requirements of the current code, the reasonable seismic performance targets and measures are put forward, and the dynamic elastic-plastic supplementary analysis is carried out. On the one hand, it can save formwork, reduce the cost of formwork during construction, reduce embedded parts, reduce self-weight, increase span, shorten construction period, facilitate pipeline installation and reduce beam height; On the other hand, it increases the bending stiffness of the beam, thus reducing the deflection of the beam; The most important thing is that the steel beam has good seismic and impact resistance, which improves the safety performance of the whole structure. Seismic performance can meet the needs of earthquake resistance, and the corresponding point is defined as the characteristic point of structural seismic performance, which can be based on the corresponding structural base shear, vertex displacement, interlayer displacement and crack development [3-4]. The seismic performance of the specimen, such as hysteretic curve, bearing capacity, displacement ductility, strength degradation and energy dissipation capacity, is studied by experimental study.

2. Project overview

2.1 Outer frame tube

A certain World Trade Center, with a podium building of 10 floors, including two 150m high hotels and a 275m high office building. The main structure has three underground floors and 69 above ground floors, with a standard floor height of 3.8m. The bottom four floors and refuge layer are 5.2m. Its lateral resistance system is a reinforced concrete tube in tube structure, which consists of an external reinforced concrete frame tube and an internal reinforced concrete shear wall tube. The reinforced concrete core tube is the main lateral force resistant structural system of the tower. The use of reinforced concrete walls can effectively increase the ductility and stiffness of the core tube, thereby increasing the overall structural stiffness and improving lateral resistance. Under the action of horizontal seismic loads, the horizontal displacement of the steel frame and concrete core tube is equal at the floor elevation, that is, the two parts of the structure cooperate to resist horizontal loads. The frame tube is arranged according to the building shape, and all four facades are convex and curved inside and outside, with local concave parts at the four corners [5]. The outer wheel profile size is 48mX48m for layers 36 and below, and 43.5mX43.5m for layers 45-50. A cutter hinge device is arranged at the bottom of the specimen to achieve the goal of zero bending moment at the column's reverse bending point. Under the action of horizontal repeated loads, the displacement of the column top drives the node to undergo bending deformation, truly simulating the deformation capacity of nodes in actual frames. The basic column spacing of the outer frame tube is 3.5m, and there is a column spacing of 5.7 in the middle of each side to meet the clearance of the bottom entrance and exit gate without the need for a structural transfer layer. As the large column spacing is located in the middle of the outer frame tube, it has little impact on the overall stress of the frame tube structure [6].

2.2 Inner core

It is convenient to connect the specimen with the test loading device, and the steel bar at the bottom of the column is firmly welded on the circular steel plate. The concrete strength grade of the hybrid assembled frame joint is C30, and the specimen is cast in situ as a whole. The middle of the column and the end of the beam are embedded with the same reinforcing bars as the precast joint specimen to ensure the same physical characteristics as the precast joint. The core tube is not only the main lateral force resisting member, but also an important supporting system for vertical load, so it also plays an important role in the vertical stability of the structure [7]. The core wall adopts cast-in-place reinforced concrete. The inner simple of the main tower is a bundle of four small tubes connected by connecting beams, and each small tube is composed of multi-channel shear walls, which has clear stress and good seismic performance. The thickness of the inner tube wall gradually decreases from bottom to top, and the concrete strength also changes from C60 to C40, which reduces the structural self-growth under the condition of ensuring the structural strength and deformation. The bottom of the column and the right end of the beam are hinged, which can bear shear force and transmit axial pressure. The column top bearing is composed of hinged bearing and horizontal sliding bearing, which can not only release the column top bending moment, but also meet the requirements of column top shaft pressure transmission and horizontal displacement loading [8-9].

3. Seismic design analysis

Based on the complexity of the structural forces in this project, in order to ensure that the structure does not collapse severely under rare earthquakes, the structural design needs to analyze the key components according to the elastic-plastic time history under large earthquakes, and effectively strengthen the key components to ensure the reliable safety of the structure [10]. When conducting structural time history analysis, the seismic waves are adjusted proportionally, that is, the acceleration values of each step of the seismic wave are adjusted proportionally according to the defined acceleration values of the input.

In order to reduce the strength of nodes to a certain extent and facilitate the observation of concrete cracking in the node area, strip plates and cylindrical wall panels are usually used for welding. The method of welding steel plates is to use gas shielded welding for the welding of steel drums. The quality of the welding seams must reach level two. When calculating, the horizontal seismic effects in two main directions are considered separately, and a 5% accidental eccentricity is considered. At the same time, the bidirectional seismic effects are calculated to consider the torsional effects under the bidirectional seismic effects. The calculation results of SATWE and MIDASBuilding are now compared, as shown in Table 1.

Table 1: Total force of gravity, wind, and earthquake

Item		SATWE calculation results		MIDAS calculation results	
Direction		X	Y	X	Y
Earthquake action	Total shear force of the first floor	31024.12	30245.36	27624.59	28719.64
	First layer shear weight ratio	4.08%	4.11%	4.02%	4.09%
	Normative limits	3.97%	3.43%	4.11%	4.08%
	Base overturning bending distance	3374722.1	34285902.7	2884430.5	2869120.51

From Table 1, it can be seen that the control parameters such as wall column axial compression ratio, shear weight ratio, and displacement angle obtained by using SATWE and MIDAS analysis under frequent earthquake actions are basically the same, with very small errors.

4. Seismic performance and design strategies

4.1 Overlimit Overview

According to the relevant provisions of the "Code for Seismic Design of Buildings", "Technical Specification for Concrete Structures of Tall Buildings", and the "Technical Key Points for Special

Review of Seismic Fortification of Overgauge Tall Building Projects" issued by the Ministry of Construction, the following indicators of the structure of this project exceed the requirements of the specifications and belong to the design of complex high-rise building structures beyond the limit. The overview of the exceeding limit is shown in Table 2.

Table 2: Overview of Structural Overrides

Item	Structural characteristics	Specification requirements	Notes
House height	95m	130m	Satisfy
Span of connected structure	35.2m	26m	Dissatisfaction
Discontinuities in floor slabs	The effective width of the 20th floor slab of the right tower is 40%, which is connected	Less than 50%	Dissatisfaction
Component discontinuity	The effective width of the 20th floor slab of the right tower is 40%, which is connected	-	Dissatisfaction

The RC columns with beam column nodes on the top that have been manufactured in the factory will be transported to the construction site. The RC columns will be lifted in place first, and then high-strength bolts will be used to connect the middle section of the horizontal and vertical steel beams with the ends of the prefabricated steel beams. This can improve work efficiency and save costs. In the square steel tube concrete column steel beam composite frame structure, when the stiffness of the steel beam remains unchanged, as the column size decreases, the linear stiffness ratio of the beam to column gradually increases. At this time, the overall lateral stiffness of the composite frame is significantly reduced, and the deformation capacity and seismic performance of the structure are significantly reduced. When the linear stiffness ratio reaches 1.041, the plastic hinge of the structure first appears on the column, seriously violating the basic design requirements of the "strong column weak beam" code. Therefore, from the perspective of design requirements and economic and reasonable utilization of steel, it is recommended that the stiffness ratio of the beam column line of this composite frame structure should not be greater than 0.45.

4.2 Analysis of time history calculation results

Simulating the action of artificial wave USERI earthquake, the reinforced cage of RC column made in the field and the composite member of column top node are hoisted and fixed in place as a whole, then the steel beam is connected to the prefabricated node parts with high-strength bolts, profiled steel plates and floor steel bars are laid, and finally the column formwork is set up and concrete is poured. Time 60s, acting in X direction, the basic conclusion is: there is no plastic hinge at the column end and the support end; The plastic hinges at the beam end of the left tower gradually increased from the tenth floor, mainly concentrated at the beam end in X direction; 90% of the X-beam ends of the 12th-15th floors become plastic hinges, but the number of plastic hinges of the tower begins to decrease from the 16th floor. On the right tower, the number of plastic hinges suddenly increased from the 12th floor. ABAQUS software was used to carry out pushover analysis of the structure, and the static elastic-plastic analysis method of monotonically increasing the horizontal load along the X direction was adopted. Because this structural system is regular, with a height of 70m, it is a low-rise system, so the influence of high vibration mode can be ignored, and only the effect of the first vibration mode can be considered, that is, the loading mode in the form of inverted triangle horizontal force distribution can be adopted. The horizontal force of each layer is divided into four parts and added to the intersection of axis 1 and axes A, C, E and G in Figure 1 respectively. The combination of live load and dead load is considered in the vertical load. The final vertex displacement-base shear vertex displacement is shown in Figure 1.

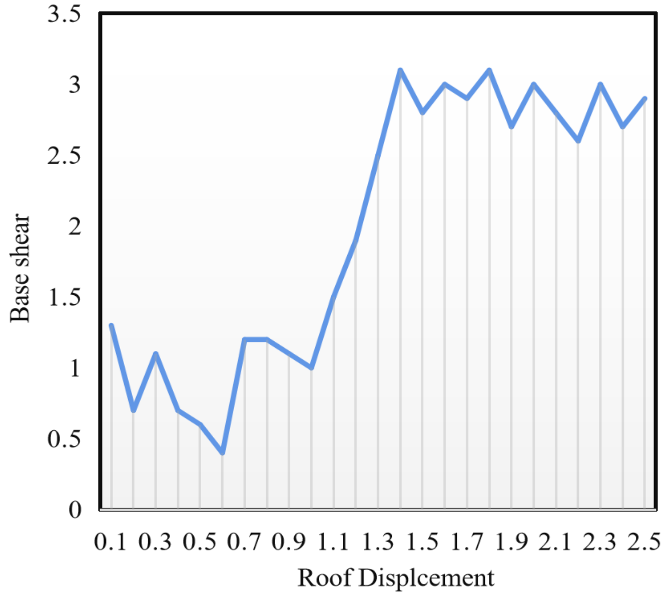

Figure 1: Bottom Shear Force-Vertex Displacement

There is no plastic hinge at the supporting end, but there is a plastic hinge at the column end falling on the transfer beam in the 13th floor. The distribution of beam plastic hinges is as follows: there are more plastic hinges in the Y-direction beams around the two towers on the 12th and 15th floors, but there are fewer plastic hinges in the beams connected with the shear wall tube. Considering the difference between the site seismic safety evaluation results and the code method in the long period of the structure, after adjusting the peak acceleration of seismic waves, the calculated maximum elastic story displacement angle is 1/410, which can still meet the requirement of the code that the story displacement angle of tube-in-tube structure should not exceed 1/130. It shows that the structure is safe under the action of a rare earthquake of 7 degrees.

5. Conclusions

In summary, when conducting seismic design of high-rise building structures, it is necessary to comprehensively consider factors such as building functionality, fortification intensity, structural type, the ability of the structure to exert ductile deformation, and cost, and choose a reasonable structural system. Analysis shows that factors such as the maximum displacement limit, damping ratio, and input direction of seismic waves have a significant impact on the seismic performance of high-rise steel-concrete hybrid structures. The seismic response of buildings can be effectively reduced by setting dampers. The elastic-plastic response and failure mechanism of the hybrid fabricated frame core tube structure system under the action of rare earthquakes meet the seismic conceptual design requirements of structural engineering, and the seismic performance reaches the seismic performance goal of "no collapse in a big earthquake". Although the time history analysis method is relatively complete, there is still a need for in-depth research in the selection of seismic waves and the determination of component resilience models. Overall, despite the problems of large computational complexity and long computational time, selecting more seismic waves and using different resilience models for analyzing super high-rise building structures is currently a better choice. Utilizing a rigorous scientific testing attitude to account for test results, in order to truly obtain scientifically sound test results. This is not only responsible for the safety of the use of engineering materials, but also has promoting significance for the development of construction projects.

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