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Research on the Seismic Design of High-rise Steel Building Based on Security Perspective

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Abstract

In recent years, with the continuous development of the construction industry, the development of high-rise steel structure growth fast in China. At the same time, it is very important to analyze the structure of these high-rise steel Building, especially the seismic performance analysis. In this paper, the authors analyze the seismic performance of high rise buildings by using finite element modeling, dynamic and static analysis. Through the static analysis of steel structure that combined with dead load, live load and wind load, the result shows that when steel support under the force, the maximum node stress mainly appears in the low-end and the ninth layer, which is located in 19, 22 axis node stress is the largest, respectively as 65.9Mpa, 62.6Mpa, it is safety and within the strength limit. The results can provide a theoretical basis for the seismic design of steel structure buildings

Keywords*: Security performance; anti-seismic; steel building; static analysis*

1. Introduction

In recent years, with the continuous development of the cause of building, steel structure building in our country has developed very rapidly, high-rise buildings not only to meet the people's use of space, also as a landmark in the city, to the city add scenery. At the same time, it is very important to analyze the structure of the steel structures, especially for the seismic performance analysis, which has brought many problems. In order to adapt to the structural analysis of the steel structure building, the analysis method and the analysis software of the building structure need to be studied and explored. With the continuous development and improvement of technology, finite element technology and general finite element analysis software, for this large complex engineering structure analysis and seismic analysis provides favorable conditions, but also greatly promote the development of complex high-rise steel building structure analysis and design technology of electronic computer analysis [1]. At present, the steel structure of our country is mainly composed of light steel and concrete filled steel tube. Light steel structure not only in the construction of large span can be applied, and due to the advantages of our resources and energy, steel structure prefabricated high degree and residential structural components and light, later will in the small and medium sized public buildings and housing can more applications [2]. Another is the steel pipe concrete structure, due to the advantages of overall structure seismic compression and plastic properties, such as good, cost saving and convenient installation and, its structure in our country widely used in high-rise steel structure buildings, and in the world are in a leading position. In the future, steel structure building will be widely used and popularized widely in our country, mainly has the following several reasons: one is the state of the construction process of steel use from the limit, reasonable to encourage, leading to the development of steel structure residential building in China already has the basic conditions; two is the steel structure building can be produced in factories, factory, design and manufacturing to achieve standardization and serialization, so as to improve the construction of steel structure building speed and

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cost saving; three is the steel structure building is a kind of green building, high production efficiency, environmental pollution and noise pollution little has been the national Ministry of construction as a key promotion project; four is to change people's ideas and concepts, to the steel structure acceptance increased

Earthquake disaster statistics analysis found in the same location and intensity condition, damage of the steel structure housing than the reinforced concrete structure housing the damage to small, multi and tall steel structure in the earthquake damage in the form of mainly has three kinds: node failure; failure of the components; structural collapse [3-4]. There are two main types of failure of the joint connection: support connection failure and failure of the steel column connection. According to the 1978 Miyagi Prefecture of Japan Sea steel structure building earthquake damage types and damage Statistics survey found that the beam column connection failure occurs in the lower flange of the beam at the top flange, and the damage is much less likely the main reasons are: (a) crack, owe detonation, slag inclusion and porosity caused welded seam defect, they lead to support and steel column joint damage and fracture; (b) the welding seam metal makes the connection is very easy to produce the impact toughness of low brittle failure, become an important factor caused the node destruction; (C) beam-column connection construction process, to facilitate the welding, and column connection with the beam wing margin line pull, after construction lining without dismantling, formed a "artificial" crack, become one of the node failure reasons; (d) three axial stress. Natural deformation of beam-column joints welded seam, and thus the dry joints of triaxial stress, brittle materials. The damage of components, high-rise steel building structure damage mainly has four forms: one is the earthquake fault, the parent material of steel column in fracture and steel column in Weld Fracture splicing is connected with the supporting column, namely horizontal cracks or fracture, two is girder repeatedly bending in the earthquake, in the vicinity of the maximum the bending moment due to excessive bending may occur flange local buckling failure[5]. Beam column local buckling, three is supported in the earthquake by the pressure exceeds the critical buckling stress, buckling failure is generated, buckling is four floor support, the horizontal bearing capacity along the height of mutation, form a weak layer, first destroy in the earthquake, to reduce the stiffness, deformation increases and continue to develop, produce significant plastic deformation, once more than all the structural deformation capacity of the whole structure collapse, is the most severe form of structural damage in the earthquake[6-7].

According to the construction of our country mainly use the material type, high-rise steel structure, steel reinforced concrete structure of concrete and steel concrete mixed structure of high-rise building is divided into application in the main structure of the three structures respectively frame structure, frame - anti lateral force component structure, tube structure and to the three kinds of structure system is derived out of the architecture, our country related standard of architecture provides maximum suitable height, as shown in Table1.

Table 1. The Maximum Height of the Structure System

type	structure	Non seismic fortification	Seismic fortification			
			6	7	8	9
steel structure	frame	110	110	110	90	50
	Frame support	260	220	220	200	140
	Cylinder and mega	260	300	300	260	180
Steel coagulation	Steel frame	210	200	160	120	70
Soil mixing	Steel concrete	240	220	190	150	70

The structural system and arrangement of steel structures should meet the basic requirements for seismic design in accordance with the code. Steel structure housing should try to adopt the rules of the building program, when the irregular construction program should be set, and should not be less than 1.5 times the width of the concrete structure of reinforced concrete structures. Multi-storey steel structure generally adopts frame structure, frame support structure[8]. Requires support frame arranged symmetrically braced frame structure are used. Therefore multi-storey steel structure use support center, and the use of cross braced, also can use herringbone braced or monoclinic rod support, not by K - shaped support; support the axis should converge at the intersection of beam to column axis of the member, if it is truly difficult to deviate from the center should not more than support bar width, and should be included in the resulting additional bending moment

2. Finite Element Analysis of Complex High Rise Steel Building

Complex high-rise steel structure building is a typical three-dimensional structures, the characteristics of the three-dimensional structure is composed of parts of nodes and 3 d unit under a lot of freedom. If reduced to a two-dimensional one dimensional structure, even greater error will inevitably appear in analysis. In addition, the high building of the computer configuration requirements are very high, especially in the design and calculation process. In the lack of hardware and economic considerations, try to minimize cell, node, and the operation time. For this, desktop is used for hardware, software, the use of international large software ANSYS [9]. In international large software ANSYS, the high-rise construction the key lies in the choice of units and the model of dynamic analysis. High-rise building dynamic analysis generally adopts the shear and bending shear layer model, pole model and single column model, based on the proposed to simplify the structure of high-rise building structure form[10], but is not 3D model, and the high-rise buildings to use most of the dynamic analysis is a 3D model, widely used in construction engineering, in order to ANSYS introduced considering the elastic properties of materials in ANSYS three-dimensional beam element and shell element, and a combination of 3D model

2.1. Finite Element Theory

With a is divided into finite element of continuous elastic body under external force in the state of equilibrium, and the nature of each unit can be expressed by node, thus forming a continuum of nodal degrees of freedom expression under the external force balance equation:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \Lambda & a_{1m} \\ a_{21} & a_{22} & a_{23} & \Lambda & a_{2m} \\ a_{31} & a_{32} & a_{33} & \Lambda & a_{3m} \\ M & M & M & M & M \\ a_{n1} & a_{n2} & a_{n3} & \Lambda & a_{nm} \end{bmatrix} \cdot \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ M \\ x_n \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ M \\ f_n \end{Bmatrix} \tag{1}$$

The matrix is simplified as:

$$[K]_{n\times m}\{\delta\}_n = \{F\}_n \tag{2}$$

The balance equation of the element can be established by the principle of virtual work, the variational principle and the discrete operator, and the element stiffness matrix is obtained. An external force of the elastic body, by the external force has according to static equivalent principle relocated to the nodes of the element on become element joint force $\{F\}^e$, caused by the elastic body stress $\{\delta\}$, generating unit of virtual shift for $\{\delta\}^e$, caused by the virtual variable $\{\varepsilon^*\}$. According to the virtual work force in the virtual displacement, the virtual work is equal to the internal force in the virtual strain on the virtual work equation as:

$$\left(\{\delta^*\}\right)^T \{F\}^e = \iiint \{\varepsilon^*\}^T \{\sigma\} dxdydz \tag{3}$$

According to the principle of inverse matrix multiplication, and can be shown as:

$$\left(\{\delta^*\}\right)^T \{F\}^e = \iiint \left(\{\delta^*\}^e\right)^T [B]^T [D][B][\delta]^e dxdydz \tag{4}$$

Because of arbitrary displacement, can be the right end of the virtual displacement equation mentioned integral front, thus obtains the balance equation of element

$$\{F\}^e = \iiint [B]^T [D][B]\{\delta\}^e dxdydz \tag{5}$$

The displacement of the unit is removed and replaced as:

$$\{F\}^e = \iiint [B]^T [D][B] dxdydz \quad \{\delta\}^e \tag{6}$$

$$\{F\}^e = [K]^e \{\delta\}^e \tag{7}$$

In formula, the stiffness matrix for $[K]^e$ unit, with representation as:

$$[K]^e = [B]^T [D][B] V \tag{8}$$

2.2. Typical Element Equilibrium Equation and Stiffness Matrix

Finite element analysis of high rise building structure, the common element types are rod element, beam element and arbitrary quadrilateral element. In this project, the main element is the beam element and quadrilateral element. For this purpose, the balance equation and the stiffness matrix of the element are introduced.

(1) The displacement mode of the quadrilateral element

$$\left.\begin{aligned} U &= \alpha_1 + \alpha_2 X + \alpha_3 Y + \alpha_4 XY \\ V &= \alpha_5 + \alpha_6 X + \alpha_7 Y + \alpha_8 XY \end{aligned}\right\} \tag{9}$$

By the displacement of the element, the relation between the displacement component and the four nodes is obtained:

$$\left.\begin{aligned} U &= N_i \mu_i + N_j \mu_j + N_k \mu_k + N_i \mu_l \\ V &= N_i \nu_i + N_i \nu_j + N_i \nu_k + N_i \nu_l \end{aligned}\right\} \tag{10}$$

In this formula, Ni, Nj, Nk, Nl are shape function for quadrilateral element:

$$\left.\begin{aligned} N_i &= \frac{1}{4}(1-\xi)(1-\eta) \\ N_j &= \frac{1}{4}(1+\xi)(1-\eta) \\ N_k &= \frac{1}{4}(1+\xi)(1+\eta) \\ N_l &= \frac{1}{4}(1-\xi)(1+\eta) \end{aligned}\right\} \tag{11}$$

With the shape function, we can get the displacement of any point in the unit:

$$\begin{Bmatrix} U \\ V \end{Bmatrix} = [N]\{\delta\}^e \tag{12}$$

(2)Stress - strain relation of element
Element strain:

$$\{\varepsilon\} = \begin{Bmatrix} \varepsilon_y \\ \varepsilon_z \\ \varepsilon_{yz} \end{Bmatrix} = [B]\{\delta\}^e \tag{13}$$

Element stresses:

$$\{\sigma\} = \begin{Bmatrix} \sigma_y \\ \sigma_z \\ \sigma_{yz} \end{Bmatrix} = [D]\{\varepsilon\} = [D]\{B\}\{\delta\}^e \tag{14}$$

The balance equation and the stiffness matrix of the element are obtained by the virtual work principle:

$$\{F\}^e = [K]^e\{\delta\}^e \tag{15}$$

The structure stiffness matrix is formed by the element stiffness matrix:

$$[K] = \sum [K]^e \tag{16}$$

Finally, the load of structure node is obtained by using the nodal equilibrium equation:

$$\{R\} = [K]\{\delta\} \tag{17}$$

3. Static Analysis of Steel Structure

3.1. Static Analysis of Steel Structure

The static structure analysis is used to analyze the response of the structure under the given static load. It is used to calculate the influence of the time varying load (wind load and seismic load) on the structure, without considering the influence of mass, damping and so on[11]. In general, analysis of the calculated structure or components caused by the stress, displacement, strain and constraint force parameters. The analysis is based on general dynamic equation of object theory in classical mechanics:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \tag{18}$$

In the formula, [M] is mass matrix; [C] is damping matrix; [K] is stiffness matrix; {x} is displacement vector; {Ft} is force vector. In the static structural analysis, the time dependent option is ignored.

$$[K]\{x\}=\{F\} \tag{19}$$

Engineering object is a tall steel building, the shape of the building structure is complex, in the construction process, the whole building, many parts are irregular, for finite element analysis is simplified, the construction steel structure analysis is to find a steel structure under dead load, under live load, weak part of the structure to build process, to take the necessary measures for reinforcement. According to the above criteria and the finite element model, the condition of the static analysis is determined.

1) ***Condition one, dead load function:*** For dead load condition, the main structure of the dead weight, including primary and secondary beams, floor, curtain wall, and column. In the finite element modeling, when the material properties are defined, the density of the material is defined, so the application of the acceleration is applied to the weight of the material.

2) ***Condition two, live load action:*** For live load condition, based on uncertain factors, such as each layer of specific functions, and part of the live load of the location and area of, so the compromise, the finite element model not roof applied 0.5kN/m generally roof applied 2.0kN/m and other load is not considered.

3) ***Condition three, wind load:*** The vertical load of the project only consider the weight. Horizontal load only consider the role of wind load, in accordance with the basic wind pressure value as clever =350N/m3, for high-rise building, consider once in 100 years, the basic wind pressure set value of 1.1 times.

According to the whole deformation, the maximum displacement of the structure under dead load and live load is mainly concentrated in the top layer, which is down and the deformation is large. Under the action of wind load, the structural deformation is mainly the horizontal deformation of the glass curtain wall, and the deformation displacement is not large. In ANSYS in the analysis of results shows that stress, must make the whole structure of size and shape controlled synthesis of the true shape of the display, space structure model based on the complex, the model built by the number of units have 123581, nodes are 87244, along with the lack of hardware conditions, in the equivalent should force display, cannot see the whole building under the real shape of the whole structure stress. The whole structure stress analysis aims to find out the structure of stress concentration, so that the structure which is easy to be destroyed, so consider the four conditions. Through the continuous replacement of the H value, finally get on each floor of the maximum stress value and the maximum displacement value, and draw on each floor of the maximum stress value and the maximum displacement value changes with the floor, and shows that the floor stress maximum value in the third layer, 171Mpa, maximum floor displacement value of random variable height.

Table 2. The Maximal Displacement and Appearing Position

Calculation condition	Load project	Maximum displacement (mm)	Appear position
dead load	Structural weight	48.23	top floor
live load	accessible roof	13.279	top floor
wind load	changed with height	3.688	third layer
All load	Above three kinds	61.097	top floor

3.2. The Steel Support Force Analysis

The steel support node shows that under the effect when the steel brace, the maximum node stress mainly appears to support low-end and ninth layers in the steel, these are the most concentrated areas of stress. Which is located in the 19 and 22 axis steel support node on the surface of the maximum stress, respectively 62.6Mpa, 65.9Mpa, are in the ultimate strength, so safe? But the most concentrated stress, the preferred location is damaged, so pay attention to strengthening.

Table 3.The Maximum Stress Value of Steel Support

Steel support position	Maximum stress value (pa)	Appear position
Axis 18	4.42 x107	Thirteenth layer
Axis 23	4.57x107	Thirteenth layer
Axis 19	6.26x107	First layer
Axis 22	6.59 x107	First layer
Axis 1/A	3.68 x107	Ninth layer partial
Axis 1/K	3.17x107	Ninth layer partial

The floor is mainly made of concrete, and the experimental results of rock and concrete are in line with the second strength theory, so the strength analysis is based on the second principal stresses. The maximum principal stress value of the floor is 0.136 X108Pa, which is located on the floor of the second floor, but no more than the strength limit of the concrete, which is in line with the requirements of the second floor. Through the selection of ANSYS command, the steel will contain all the surface of the wall as the current selection unit, and shows the current selection of the unit of the equivalent stress cloud, as shown in. As can be seen from Table 4, the maximum stress on the wall of the support is located on the axis 18, and the value is 171Mpa, which is located in the forty-first layer. Can be seen at the same time, in the 5, third layer also appears greater value.

Table 4. The Maximum Nodes Stress Value and Position of Steel Support in Face Wall

Position of steel support side wall	SEQV (pa)	Appear position
Axis 18	0.171x109	Third layer
Axis 23	0.117x109	Third layer
Axis 19	0.125x109	Forty-first layer
Axis 22	0.148 x109	Forty-first layer
Axis 1/A	0.149 x109	Fifth layer
Axis 1/K	0.127x109	Fifth layer

Under the action of dead load and live load, the maximum displacement of the structure is mainly concentrated in the top layer, which is down, and the deformation is large. Under the action of wind load, the structural deformation is mainly the horizontal deformation of the glass curtain wall, and the deformation displacement is not large. By means of axial force, bending moment and axial stress, we can know the specific weak parts of the structure, and know the internal force of the related components, as shown in Table 5; the size of the internal force will provide the basis for the design of the component section.

Table 5. The Internal Force of the Steel Structure Building Component

name	Axial force	Axial stress	Bending moment MY	Bending moment MZ
Steel column	23700 (619)	51400 (664)	841.985 (504)	1010 (468)
steel beam	2590 (16518)	111000(16518)	592.324(15918)	19.542 (23116)
Steel support	18500 (37052)	56900 (38444)	1220 (36396)	290.454(37139)

4. Modal Analysis

4.1. Modal Theory

The purpose of modal analysis is to determine the natural frequencies and modes of the structure. Modal analysis is a prerequisite for the analysis of the response, and also an important basis for the occurrence of structural resonance. In the design of rotating machinery, such as automobiles, trains, ships and aircraft, the modal analysis is carried out to prevent the occurrence of harmful resonance. It is not possible to completely avoid resonance during the operation or use of these machines, but some measures can be taken to avoid the harmful resonance. Due to the resonance occurs depends both on the machine itself, depending on the working environment (conditions), so you can from the mechanical design and operation condition of the two aspects to solve the resonance problem. Modal analysis theory is based on object dynamics general equation, which assumes that objects do free vibration and neglecting damping, and make u = Usin(wt), in order to get the modal analysis of the classical eigenvalue equation as:

$$\left([k]-\omega_t^2[M]\right)\{\Phi_t\}=0 \qquad (20)$$

4.2 Results Analysis

Modal analysis is to understand the dynamic characteristics of the structure itself, therefore on structure of 26 modal analysis, Table 6 lists the structure before 26 order modal frequency value, can be seen, the structure in the number of low order frequency rarely, and slope of the curve indicated that frequency values increased greatly; as the mode number increases, the slope gradually tends to be horizontal, frequency domain frequency dense, said a smaller increase in frequency values, indicating that there are a large number of the frequency domain modal.

The overall structure of the modal analysis can not only get the inherent frequency and cycle of the overall structure of the, also can be obtained respectively in the six degree of freedom vibration mode participation coefficient, vibration mode participation coefficient and the first order vibration mode participation coefficient, the effective mass, cumulative mass fraction, the equivalent mass and total quality ratio. Through these parameters can analysis of the main vibration shape of the whole structure in all directions.

Table 6. The First 26 Order Free Frequency of High-Rise Steel Structure Building

modal	frequency	cycle	modal	frequency	cycle
1	0.445293	2.2457	14	3.00607	0.33266
2	0.531923	1.8800	15	3.00739	0.33251
3	1.1656	0.85792	16	3.03829	0.32913
4	1.51569	0.65976	17	3.06104	0.32669
5	1.74367	0.57350	18	3.07488	0.32522
6	2.83280	0.35301	19	3.07815	0.32487
7	2.89306	0.34565	20	3.08066	0.3246

8	2.95273	0.33867	21	3.08356	0.32430
9	2.97501	0.33613	22	3.08470	0.32418
10	2.97509	0.33612	23	3.08848	0.32378
11	2.97843	0.33575	24	3.09578	0.32302
12	2.99775	0.33358	25	3.11269	0.32127
13	3.00599	0.33267	26	3.11908	0.32061

Table 7. All the Main Vibration Direction Type of High-Rise Steel Structure Building

direction	Modal order	Frequency	cycle	coefficient	Vibration type
X	2	0.531923	1.8800	5277.3	X direction of translation and twist
	5	1.74367	0.57350	-3041.2	
Y	1	0.445293	2.2457	5325.6	Y direction of translation and twist
	4	1.51569	0.65976	-2985.9	
	6	2.83280	0.35301	1959.2	
Z	8	2.95273	0.33867	5396.1	Translational direction Z
ROTX	1	0.445293	2.2457	-5.84x105	Translational and torsional
ROTY	2	0.531923	1.8800	5.85x105	Translational and torsional
ROTZ	1	0.445293	2.2457	1.24x105	Twisting around Z
	3	1.16561	0.85792	89757	

5. Conclusions

In this paper, the finite element model and the static and dynamic analysis of the building are carried out by using ANSYS, and the reasonable suggestions are put forward. Domestic steel structure building started late, not much construction steel structure analysis software is applied. In this paper, the mechanical structure analysis of ANSYS software of the steel structure building the fine finite element modeling and static and dynamic analysis, which considered the influence of seismic amplitude, frequency and time effect of steel structure, confirmed that ANSYS can be applied to the design and analysis of steel structure building. Based on finite element model under dead load, under live load and wind load of the interaction, structural members under static load of the weak parts; steel support to bear the role, the weak parts of the mainly occurred in the steel supporting low-end; structural members under static load internal force at the same time, such as the axial force, axial should force and moment for component design and selection reference. By modal analysis of the finite element model, the main mode and basic natural period of the structure are obtained, and the difference of longitudinal and transverse stiffness of the structure is small, so the whole structure is uniform and the seismic performance is better.

The continuous development of steel structure building, the finite element analysis technology also needs to continue to improve, after the need to continue efforts in the following areas. Construction steel structure of main supporting members with steel tube concrete column finite element modeling, the definition of the attributes of the material by combination of material properties, while conforming to the code for seismic design of buildings, but with the actual situation of Engineering inconsistent and need to discuss how to establish with concrete filled steel tubular columns were given the material properties of the finite element model. For finite element modeling of complex high-rise steel structure, ANSYS by Gui interactive modeling is quite difficult, try using APDL language of ANSYS software to prepare for the pretreatment procedure for the analysis of tall building structures, which simplifies the structure of duplication of work in process modeling.

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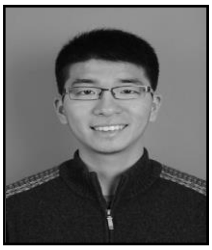

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