



ARTICLE

Dynamic Performance Analysis of Steel Frame Structure under Seismic Action

Xiaojun Yuan* Jinlong Liu Yanmu Qu Kailin Wei Haifeng Zong

Jiangsu Testing Center for Quality of Construction Engineering Co., Ltd., Nanjing, Jiangsu, 210028, China

ARTICLE INFO

Article history

Received: 19 March 2019

Revised: 1 April 2019

Accepted: 23 April 2019

Published Online: 30 April 2019

Keywords:

Steel frame structure

Dynamic time-history analysis

Dynamic performance

ABSTRACT

In order to find out the dynamic characteristics of a steel frame structure project in the 8 degree (0.3g) area, the artificial wave, Taft wave and El Centro wave were input by using the finite element analysis software ANSYS. The dynamic time-history analysis of the structure shows the dynamic performance of the structure under the frequent earthquakes and rare earthquakes.

1. Introduction

The Earth is currently in an active period of geological structure, and earthquakes occur more frequently, research on earthquakes has once again become a major research issue. The assessment of the seismic performance of existing buildings is also of great practical significance. Taking the 8 degrees (0.3g) six-layer three-span steel frame structure in high-intensity area as an example, the finite element software ANSYS is used to analyze the dynamic time-history under earthquake action. The seismic resistance of the structure is obtained to verify whether it can meet the deformation requirements under strong earthquake conditions.

2. Engineering Overview and Finite Element Model

2.1 Engineering Overview

There is a six-layer three-span steel frame structure with a height of 3.6 m and a longitudinal span of 6 m. The structural arrangement is shown in Figure 1 and Figure 2. The dead load on the roof is 4.65kN/m², and the load on the beam partition is equivalent to 6kN/m for line load, 2kN/m² for live load, 2kN/m² for roof load, the basic wind pressure is 0.4kN/m², and the snow load is 0.4kN/m². The seismic fortification intensity is 8 degrees (0.3g), the ground roughness is Class B, the site category is Class II, and the design earthquake group is the first group. The cross-sectional dimensions of the structure are shown in

*Corresponding Author:

Xiaojun Yuan,

Jiangsu Testing Center for Quality of Construction Engineering Co., Ltd., No. 107 Hongshan Road, Nanjing, Jiangsu, 210028, China;

E-mail: 1476892342@qq.com

Table 1. The above parameters are input into PKPM to obtain the periodic seismic forces of the structure as shown in Table 1.

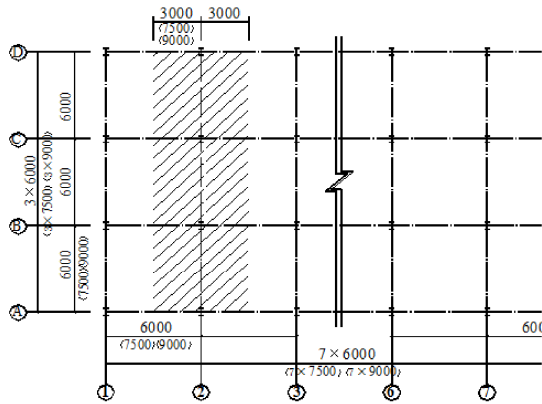


Figure 1. Plane layout diagram of steel frame structure

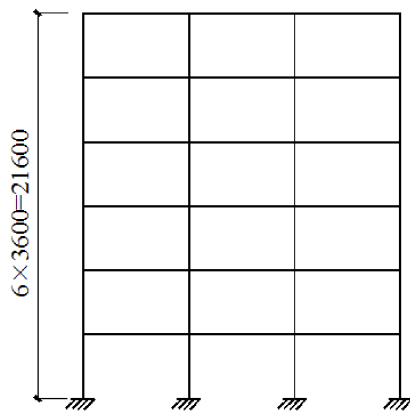


Figure 2. Facade layout diagram of steel frame structure

2.2 Finite Element Model

Plan the frame unit when ANSYS builds the model. The unit selects the international standard unit system (SI system). Beam and column adopt beam188 unit; material adopts steel with yield strength of 235N/mm², elastic modulus is E=2.06×10⁵ N/mm², material density ρ=7.85×10³kg/m³, Poisson’s ratio ν=0.03; the resilience model adopts the bilinear follow-up strengthening model, and the late stiffness of the beam and column is taken as 0.02 times of the initial stiffness.^[1]

The load that the structure bears, the dead load is calculated by actual calculation, and the live load is reduced by 0.5, which can be expressed as q=q constant +0.5q. The input of the load is equivalent, and the load of the structure is converted into the density of the structure. Taking Model 1 as an example, it is known that h=0.25, b=0.25, t_w=0.008, t_r=0.014. A=(h-2t_r)* t_w+2*b * t_r, ρ = 7849+q*k_w/(Ab₁*9.8); The gravitational acceleration g is 9.8 m/s². Since the stability outside the plane of the structure is not considered, the z-direction constraint is applied to the beam, and the connection between the beam and the column and the connection between the column and the ground are both rigidly connected. The structural damping model uses Rayleigh damping.^[4] The Rayleigh damping is assuming that the damping matrix is proportional to the mass matrix and the stiffness matrix:

$$C = \beta M + \alpha K \quad (1)$$

α, β In general, the scale factors can be expressed as:

$$\alpha = \omega_1 \omega_2 \beta = 4\pi^2 f_1 f_2 \beta \quad (2)$$

$$\beta = \frac{2\zeta}{\omega_1 + \omega_2} = \frac{2\zeta}{2\pi(f_1 + f_2)} \quad (3)$$

Where ω₁, ω₂ is the circular frequency; f₁, f₂ is the frequency and ζ is the structural damping ratio.

3. The Selection of Seismic Records

It is well known that the determinants affecting seismic response are mainly:^[2] the spectrum, amplitude and duration of ground motion. Below we will analyze the common seismic records in these aspects to select the appropriate ground motion record.

Through seismic record spectrum analysis, three seismic records suitable for the first group of earthquakes in China II site design are selected in the common seismic records: artificial wave, Taft wave and El Centro wave.

How to make the seismic record meet the seismic intensity of 8 degrees (0.3g), it is necessary to adjust the ground motion intensity, mainly to adjust the ground motion amplitude. This method only changes the amplitude

Table 1. The calculation results of structure size and partial PKPM

Layers	Beam Size / mm	Side Column / mm	Center Column / mm	Cycle / s	Earthquake force / kN
1-3 Layers	350X250X8X16	380X300X12X20	450X350X12X20	1.467	277.7
4-6 Layers	350X250X8X14	380X250X12X20	400X300X12X16		

of the ground motion response spectrum without changing the spectral characteristics. The specific adjustment formula is:

$$a'(t) = \frac{A'_{max}}{A_{max}} \cdot a(t) \quad (5)$$

Where $a(t)$, A_{max} represents the seismic acceleration curve and peak value of the original record; $a'(t)$, A'_{max} represents the adjusted seismic acceleration curve and peak value. According to “Code for Seismic Design of Building Structures”,^[3] For the Class II sites and the fortification intensity of 8 degrees (0.3g), under the conditions of frequent and rare earthquakes, the dynamic time-history analysis should adjust the peak acceleration of ground motion to $1.1m/s^2$ and $5.1m/s^2$ respectively.

The determination of the duration can be based on the relevant provisions of the seismic code to select 3-4 times the basic period of the structure, and not less than 10s and ensure that the strongest part of the seismic wave is included in the determined duration. For the above seismic records, the time interval of the record near the peak is selected, and the time interval is 0.02s.

4. Seismic Response Analysis

4.1 Reaction Characteristics under Multiple Earthquakes

The displacement response of the structure under multiple earthquakes can be adjusted to $1.1m/s^2$ by the Formula (3), and then ANSYS dynamic time-history analysis. The structural displacement values and the inter-layer displacement angles are shown in Figure 3 and Figure 4. It can be seen from the figure that the inter-layer displacement values of the structures under different seismic records are different from the displacement values obtained by the PKPM software designed according to the specifications. The artificial wave and El Centro wave ratios are smaller according to the specifications; while the results calculated by Taft wave are larger than those calculated by the norm, and the difference between the average value of the three seismic records and the calculated value is within 20%, which is statistically consistent. The maximum base shear forces of the three seismic records, namely artificial wave, Taft wave and El Centro wave, are 275.3kN, 419.6kN and 271.0kN, respectively. Compared with the value 277.7kN obtained from the mode decomposition reaction spectrum, the ratios are 99%, 151%, and 98% respectively meeting the specification requirements ($\geq 65\%$), and the average value of the three seismic records is 116% to meet the specification requirements ($\geq 85\%$), which shows that the above three seismic records meet the requirements.

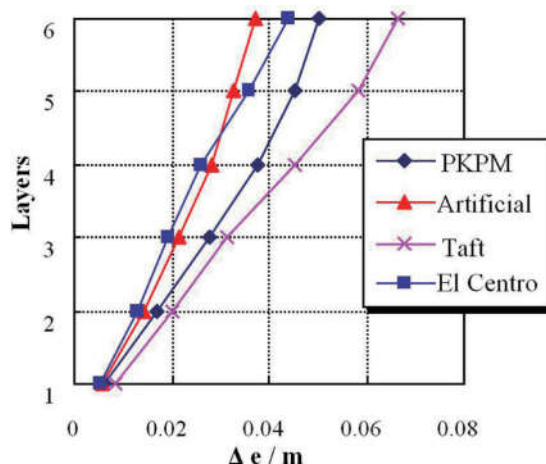


Figure 3. The displacement of the structure under multiple earthquakes

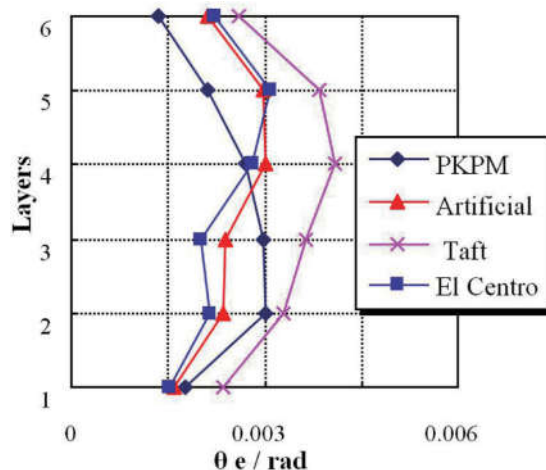


Figure 4. The displacement angle of the structure under multiple earthquakes

4.2 Reaction Characteristics under Rare Earthquakes

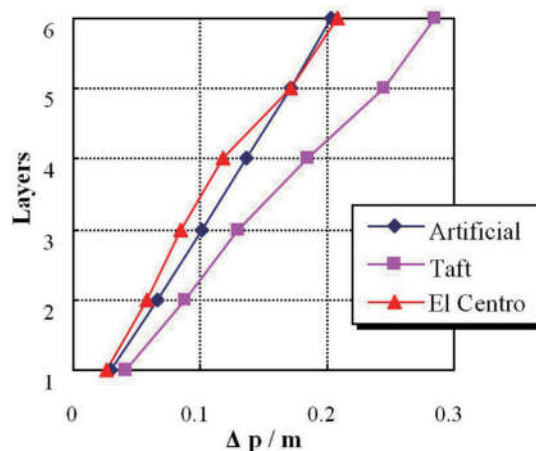


Figure 5. The displacement of the structure under rare earthquakes

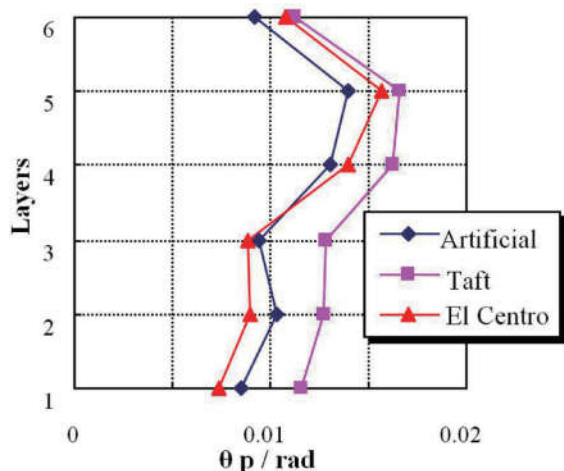


Figure 6. The displacement angle of the structure under rare earthquakes

The displacement response of the structure under rare earthquakes can be adjusted to 5.1m/s^2 by the Formula (3), and the ANSYS dynamic analysis is performed. It is shown that the displacement of the structure and the displacement angle between the layers under rare earthquake conditions are shown in Figure 5 and Figure 6. It can be seen from the figure that the interlayer displacement value of the structure under different seismic records is smaller than the standard steel frame structure displacement angle limit of 0.02, and the larger displacement of the structure appears in the fifth layer, which shows that the weak layer of the structure appears on the fifth layer, where a large plastic deformation occurs; at the same time, the vertex displacement response curves of the structure under different seismic records are also shown in Figure 7.

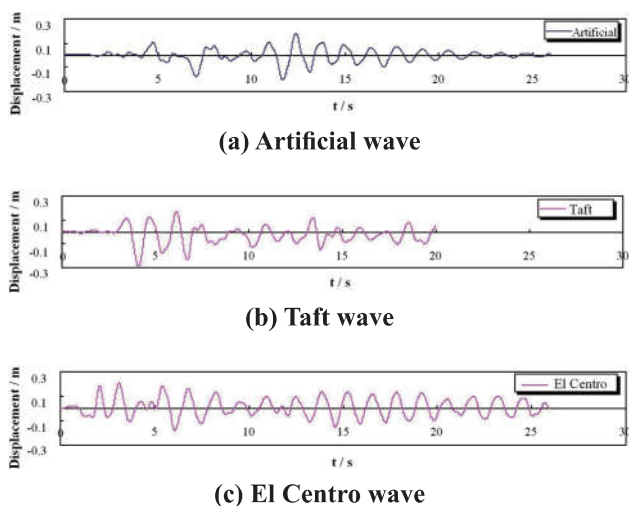


Figure 7. Structural vertex displacement response curves

5. Conclusion

Through the dynamic time-history analysis of the three-span six-layer steel frame structure under multiple encounters and rare earthquake conditions, the following conclusions can be drawn:

(1) There are some differences between the inter-layer displacement values of the structures under multiple earthquakes and the results of PKPM. It can be seen that the structural displacements obtained by the specific seismic records and the base shear forces of the structures are different, which also reached a statistically consistent within 20%.^[2]

(2) When the floor yield strength coefficient of the frame structure is uniform, the structural weak layer always appears on the bottom layer.^[4] The dynamic time history analysis of the above-mentioned structures under different earthquakes and rare earthquakes shows that the maximum plastic deformation of the structure always appears in the fifth layer of the structure, indicating that the weak layer of the design appears in the fifth layer;

(3) The maximum interlayer displacement angle of the structure under rare earthquake intensity is smaller than the elastoplastic displacement angle limit of the seismic code. The design meets the fortification requirements of large earthquakes mentioned in the specification.

Based on the above analysis, it can be considered that the structure can meet the fortification conditions of China's "no damage in small earthquakes, no collapse under strong earthquakes", if the stiffness of the 4-6 layer structure can be properly adjusted, the energy consumption of the structure can be better utilized and the seismic level of the structure can be improved.

References

- [1] Guoqiang Li. Steel structure design of multi-tall buildings[M]. Beijing: China Building Industry Press, 2004. (in Chinese)
- [2] Standards of the People's Republic of China. Code for seismic design of buildings (GB50011-2010)[S]. Beijing: China Building Industry Press, 2010. (in Chinese)
- [3] Bo Zhang, Hetai Sheng. ANSYS finite element numerical analysis principle and engineering application[M]. Beijing: Tsinghua University Press, 2005. (in Chinese)
- [4] Guoqiang Li, Jie Li, Xiaozu Su. Seismic design of building structures[M]. Beijing: China Building Industry Press, 2002. (in Chinese)