The overall seismic performance analysis of the web light-gauge steel joist structure

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Abstract. The WEB Light-Gauge Steel has the advantages of superior seismic performance, low cost, efficient construction speed and so on, and can better deal with the emergency under the rapid construction and put into use. In this paper, ABAQUS finite element program is used to analyse the time history of two-story buildings with extremely light steel structure. The displacement time history curve, acceleration time history curve is successively compared with the opening and depth as the reference variables. It is concluded that the depth of the room has a significant effect on the overall seismic stiffness of the structure, and the selection of the length-width ratio of the plane form of the structure should be considered in the seismic analysis.

1. Introduction
Code for seismic design of building structures (gb50011-2010) (2016 edition) is based on the probabilistic limit state design method, which defines the two-stage design principle of "small earthquakes are not bad, big earthquakes are not bad". Elastic-plastic time history analysis of the structure of directly by the motion equation of the structure, it is concluded that seismic response all the time during the whole process of the structure of the internal force and deformation condition, as well as the structure begins to produce cracks and eventually achieve the yield process, find the concentration of stress and plastic deformation area, yield mechanism, weak parts of the structure are obtained and possible failure mode of structure[1]. In this chapter, the time history analysis of the multi-storey extremely light steel keel system residence under the action of horizontal earthquake is carried out, and the seismic performance of the structure system is deeply explored, so that this system residence can be well promoted and applied in our country[2,3].

2. Selection and input of seismic waves
In the time history analysis, the determination of the input seismic wave is the result of time history analysis, which can not only reflect the maximum earthquake effect that the structure is likely to suffer, but also satisfy the premise of seismic design based on safety and function. The ground motion of earthquake is a non-stationary random vibration with wide frequency band, which is affected by many factors. The influence of different seismic waves on the structure is also very different. Therefore, it is necessary to adjust the maximum acceleration peak of the input seismic wave according to the seismic cracking and related requirements of the proposed site[4].

In this paper, the representative el-centro wave, tangshan wave and tianjin wave of 1940 were selected to study the seismic performance of the residence with extremely light steel keel system. Table
1 lists the main parameters of the selected seismic wave. In this paper, the duration of the earthquake is 20 seconds and the time step is 0.02s.

| Seismic wave   | Peak acceleration | The duration of the seismic wave |
|----------------|-------------------|----------------------------------|
| EL-Centro      | 341.7 cm/s²       | 20s                              |
| Tangshan wave  | 55.49 cm/s²       | 20s                              |
| Tianjin wave   | 67.7 cm/s²        | 20s                              |

After the structure enters the elastic-plastic stage under earthquake excitation, the energy dissipation of seismic wave absorbed by each structure is different due to the different duration of seismic wave, which affects the relevant seismic response of the structure. In engineering, the duration of ground motion is often determined according to the amplitude of ground motion or the relative amount of energy.

### 3. The finite element analysis process of the housing of the WEB Light-Gauge Steel

#### 3.1. Specimen design and grouping

This test consists of 6 different sizes of two floors of extremely light steel keel housing, which is divided into two groups. The two-storey extremely light steel keel house takes into account the 110mm thickness of the upper and lower concrete floors. In the modeling, the connection mode between the concrete floor slab and the upper and lower beams adopts the Tie command in ABAQUS finite element software to select the main surface and the slave surface in turn. Under the influence of seismic waves such as el-cent wave, tangshan wave and tianjin wave, the difference of natural vibration period, displacement time-history curve and acceleration time-history curve of each structure of the residence with extremely light steel keel under the excitation effect of seismic waves such as el-cent wave, tangshan wave and tianjin wave was studied. Table 2 lists the time Numbers and research contents.

| The serial number | group | Specimen parameters (width × depth) | The research content |
|-------------------|-------|-------------------------------------|---------------------|
| 1                 |       | 3.6m × 3.9m                         | The specimens of this group all adopt the same width and different depth. The influence of different depth on the structural stiffness of specimens with the same seismic wave is studied. |
| 2                 | Group 1| 3.6m × 4.2m                         |                     |
| 3                 |       | 3.6m × 4.5m                         |                     |
| 4                 |       | 3.0m × 3.9m                         | The specimens of this group all adopt the same depth and different width. The influence of different depth on the structural stiffness of specimens with the same seismic wave is studied. |
| 5                 | Group 2| 3.3m × 3.9m                         |                     |
| 6                 |       | 3.6m × 3.9m                         |                     |

#### 3.2. modal analysis

The purpose of modal analysis is to calculate the dynamic characteristics of the structure. The feature value extraction method of Lanczos provided by ABAQUS/Standard [5] was used to conduct modal analysis on 6 groups of houses with extremely light steel keel system, and the first 20 order mode and natural vibration period of each sample were obtained, as shown in table 3. The circular frequencies of the first two orders of each specimen were recorded, which were substituted into equation (2) to deduce two damping parameters, mass parameters and stiffness parameters of the structure [6], which were substituted into Modal dynamica in ABAQUS 6-12 for analysis.
In Rayleigh damping, it is assumed that the damping matrix can be represented as a linear combination of the mass matrix and the stiffness matrix, i.e

\[ c = \alpha m + \beta k \]  

(1)

In the calculation, the vibration mode of the structure is firstly decomposed, and the natural vibration period (or circular frequency) and the mode mode are obtained. Then, the two main modes of the structure in the calculated vibration direction are found out from the mode mode. The period (circular frequency \( \omega_1 \) and \( \omega_2 \)) is assumed to be (or \( \omega_1 \) and \( \omega_2 \)).

\[ \alpha = \frac{4\pi^2}{T_1 + T_2} = \frac{2\omega_1 \omega_2}{\omega_1 + \omega_2} \]

\[ \beta = \frac{2T_1^2 \omega_2}{\pi(T_1 + T_2)} = \frac{2\xi}{\omega_1 + \omega_2} \]  

(2)

Table 3. Natural vibration period and mode characteristics.

| structure type | grouping  | Natural vibration period (s) | Natural vibration period (s) |
|---------------|-----------|-------------------------------|-------------------------------|
|               |           | The first vibration mode       | The second mode               |
| 1 the specimens | Group 1   | 0.4238                        | 0.3943                        |
| 2 the specimens | Group 1   | 0.4394                        | 0.3898                        |
| 3 the specimens | Group 1   | 0.4716                        | 0.4021                        |
| 4 the specimens | Group 1   | 0.3929                        | 0.3570                        |
| 5 the specimens | Group 1   | 0.4073                        | 0.3750                        |
| 6 the specimens | Group 1   | 0.4238                        | 0.3943                        |

| structure type | grouping  | Natural vibration period (s) | Natural vibration period (s) |
|---------------|-----------|-------------------------------|-------------------------------|
|               |           | The first vibration mode       | The second mode               |
| 1 the specimens | Group 1   | Plane X translation           | Plane X translation           |
| 2 the specimens | Group 1   | Plane X translation           | Plane X translation           |
| 3 the specimens | Group 1   | Plane X translation           | Plane X translation           |
| 4 the specimens | Group 1   | Plane X translation           | Plane X translation           |
| 5 the specimens | Group 1   | Plane X translation           | Plane X translation           |
| 6 the specimens | Group 1   | Plane X translation           | Plane X translation           |

It can be seen from table 3 that the main mode of vibration of the two-story extremely light steel structure system is the overall lateral displacement deformation, the second-order mode is the overall
longitudinal displacement deformation, and the third-order mode is the local structure torsion deformation. It can be seen from the first set of data that, under the condition of the same width, the natural vibration period of the structure significantly increases with the increase of the depth. For every increase of 0.3m in the depth, the natural vibration period of the structure increases by 5.2%. According to the second group of data, under the condition of the same depth, the natural vibration period of the structure also increases significantly with the increase of the open space. For every 0.3m increase of the open space, the natural vibration period increases by 3.72%.

3.3. Time history analysis results

3.3.1. Results of displacement - time history curve of column top layer.

| Seismic wave   | 1 the specimens | Group 1 | 3 the specimens |
|----------------|----------------|---------|-----------------|
| EL-Centro      |                |         |                 |
| Time s         | 2.2            | 2.2     | 2.2             |
| The extreme mm | -14.1035       | -13.5818| -14.8501        |
| Tangshan wave  |                |         |                 |
| Time s         | 13.2           | 13.2    | 13.2            |
| The extreme mm | -2.4511        | -2.3705 | -2.5524         |
| Tianjin wave   |                |         |                 |
| Time s         | 7.6            | 7.6     | 7.6             |
| The extreme mm | 4.1748         | 4.0684  | 4.3463          |

It can be seen from table 4 that in the direction of seismic wave input, the influence on the structure in this direction is far greater than the other two directions. In general, for two-layer structures, the greater the influence of seismic action is with the increase of space depth. In case of multiple earthquakes, the maximum displacement increases by 5.03% for every 0.3m increase in the depth of the structure with the same width. At the same depth, the maximum displacement increases by 16.89% for every 0.3m increase in the structural width. The seismic wave is input in the x-direction of the structure. For the structure, the effect of the increase of depth on the structure is much greater than that of the increase of width.
3.3.2. Top - level acceleration - time curve of the structure.

Table 5. Structure vertex acceleration value and happen moments(X-scale).

| Seismic wave | 1 the specimens | Group 1 | 2 the specimens | Group 2 | 3 the specimens |
|--------------|-----------------|---------|-----------------|---------|-----------------|
| EL-Centro    |                 |         |                 |         |                 |
| Tangshan wave| 4.3419          | 2.2     | 4.3177          | 2.2     | 4.4797          |
| Tianjin wave | 0.3461          | 13.2    | 0.3449          | 13.2    | 0.3582          |
|              | -0.2016         | 7.6     | -0.2005         | 7.6     | -0.2038         |

| Seismic wave | 4 the specimens | Group 2 | 5 the specimens | Group 2 | 6 the specimens |
|--------------|-----------------|---------|-----------------|---------|-----------------|
| EL-Centro    |                 |         |                 |         |                 |
| Tangshan wave| 3.9683          | 2.2     | 4.1541          | 2.2     | 4.3419          |
| Tianjin wave | 0.3146          | 13.2    | 0.3306          | 13.2    | 0.3461          |
|              | -0.1950         | 7.6     | -0.1976         | 7.6     | -0.2016         |

It can be seen from table 5 that the acceleration value of the structure in the input direction of seismic wave is one order of magnitude larger than that of the other two directions. This direction is greatly affected by the earthquake. Under the condition of the same width, the maximum acceleration value of the structure increases by 3.08% for every 0.3m increase in the depth of the specimen. Under the same depth of penetration, the maximum acceleration of the structure increases by 8.61% for each 0.3m increase of the width.

4. Conclusion

This chapter firstly introduces the selection and input of seismic response equation and seismic wave in the basic theory of earthquake, and emphatically introduces the requirements for the maximum value of seismic wave acceleration time-history curve used for time history analysis in the code for building seismic design in China (gb50011-2010) (2016 edition) and the specific adjustment method. Then, under the action of the typical el-centro wave, tangshan wave and tianjin wave, the time history analysis of the two groups of 6 incomparately lightweight steel structures was conducted. The following conclusions were obtained through comparative study:

1) the overall use of The WEB Light-Gauge Steel structure galvanized steel plate, and in the analysis all consider the rigid connection, so the overall stiffness of the structure is large, the structure of the natural vibration period is small, has enough stiffness, seismic performance is better, suitable for building in the seismic fortification intensity of 6 degrees, 7 degrees, 8 degrees.

2) Compared with the square steel pipe, the guide rail in the top four directions has a certain constraint effect on each other. Therefore, under the action of seismic excitation, the maximum displacement point of the structure is mostly found in the middle of the square steel pipe and the v-shaped joint of the square steel pipe. Make the square steel tube buckle and deform. Therefore, strengthen the strength of the square steel pipe, strengthen the connection between the square steel pipe and the v-shaped connector. It is of great significance to the seismic performance of the whole structure.

Acknowledgments

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