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Simulation analysis of wave phenomenon of high-rise building under earthquake

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Abstract

Since the beginning of the 21st century, China's high-rise buildings have developed rapidly, a large amount of high-rise building seismic simulation data are accumulated. Data analysis shows that the structural model has a significant time delay of displacement response from the bottom to the top under the excitation of ground motion. Further analysis shows that the continuous distribution of the vertical rod mass causes the input excitation to be transmitted at a finite speed and in a wave form from the bottom to the top of the model. In this paper, the main building of China International Trade Center 3A is used as an example. Two types of models are used to simulate and analyze the time delay of seismic displacement response of super high-rise buildings. Among them, the first type of model is the synchronous excitation of each point and the discrete floor particle system model, and the second type of model is the asynchronous excitation of each point and the discrete floor particle system model. The analysis results show that the calculation results of the first type of model have no displacement response time delay, and the calculation results of the second type of model can reflect the displacement response time delay to some extent. Therefore, for the seismic response of super high-rise buildings, it is not appropriate to use the traditional dynamic equations based on the first type of model to solve the problem, and the influence of wave effects should be considered.

Keywords: Simulation, high-rise building, wave phenomenon

1. Introduction

At present, international high-rise buildings are getting taller and taller. The main building of the China World Trade Center Phase III project in Beijing has a height of 330m, and Beijing CITIC Tower has reached a height of 528m. The seismic analysis of high-rise structures, especially super high-rise structures, is particularly important. When calculating the seismic dynamic response of a structure according to the current dynamic time history analysis method, it is assumed that the ground motion response of each layer of the structure is synchronous, that is, the seismic response of each layer of the high-rise structure is simultaneously with the ground motion of the base layer, that is, It takes no time to propagate through the structure, and it is simultaneous. This is the assumption of Newton's classical mechanics. However, after a careful examination of the response of the structural earthquake, it was found that each layer of the high-rise building generates a chain reaction from bottom to top in the form of shear waves at the bottom of the structure, and there will be a time delay effect between adjacent two floors.

Todorovska and Trifunac used measured records of seismic waves on different floors of a 7-story building to show that the propagation speed of seismic waves in the building in the east-west direction is: 201m / s (ground and floor 2), 183ms / s (layer 2 ~ 4) 111m / s (between floors 4 ~ top floors); in the north-south direction (east side building): 252m / s (ground and floors 2), and 186m / s (between floors 4 ~ top floors), each in other buildings The results of layer ground motion records are similar.

However, the current theory of structural dynamics does not integrate the research results of wave dynamics well. It is still considered that the equivalent earthquake action is acting on all layers of the structure simultaneously and instantaneously, which is inappropriate. At the same time, in engineering practice, the propagation delay effect of this seismic wave in the structure is ignored. For simple and low-rise buildings, it is possible, but for super high-rise buildings above 300m, it takes an average of 3 ~ 4s for the seismic wave to propagate from the bottom to the top of the structure. The effect is quite significant, and it is not appropriate to continue to use the traditional input equation of ground motion.

2. Delayed fluctuation model considering ground motion propagation

According to whether the propagation process of seismic waves in the structure is considered, the structural dynamics equation and the wave dynamics equation are different. The traditional structural dynamics equation can be expressed by

$$[M_{11}][\ddot{x}_1]+[C_{11}][\dot{x}_1]+[K_{11}][x_1]=[F_1] \tag{1}$$

Where,, $\ddot{x}_1$、 $\dot{x}_1$、 x_1, are the relative acceleration, velocity and displacement vectors of degrees of freedom at the unsupported position, and, M_{11}、 C_{11}、 K_{11} are the mass, damping, and stiffness matrices of degrees of freedom at the unsupported position, and F_1 are input ground motions.

After considering the seismic propagation process, the structural wave dynamic equilibrium equation is as follows:

$$\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix}+\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix}+\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}=\begin{bmatrix} 0 \\ F_2 \end{bmatrix} \tag{2}$$

Where, $\ddot{x}_1$、 $\dot{x}_1$、 x_1,, are absolute acceleration, velocity and displacement vectors of degrees of freedom at unsupported positions,,, M_{11}、 C_{11}、 K_{11} are mass, damping and stiffness matrices of degrees of freedom at unsupported positions, and, $\ddot{x}_2$、 $\dot{x}_2$、 x_2 are absolute acceleration, velocity, and displacement of degrees of freedom at supported positions The vectors,, M_{22} 、 C_{22} 、 K_{22} , are the mass, damping and stiffness matrices of the degrees of freedom at the support. To F_2 restrain the reaction.

Write the absolute displacement vector as a motion expression relative to the ground.

$$x_1 = u + B_1 x_g \ , \quad x_2 = B_2 x_g \quad , (3)$$

Where: is the seismic ground motion displacement vector, is the displacement vector caused by the support moving acceleration, and is the seismic ground motion acceleration.

Expand equation (2):

$$M_{11}\ddot{u} + M_{11}B_1\ddot{x}_g + M_{12}B_2\ddot{x}_g + C_{11}\dot{u} + C_{11}B_1\dot{x}_g + C_{12}B_2\dot{x}_g + K_{11}u + K_{11}B_1x_g + K_{12}B_2x_g = 0 \quad (4)$$

$$M_{21}\ddot{u} + M_{21}B_1\ddot{x}_g + M_{22}B_2\ddot{x}_g + C_{21}\dot{u} + C_{21}B_1\dot{x}_g + C_{22}B_2\dot{x}_g + K_{21}u + K_{21}B_1x_g + K_{22}B_2x_g = F_2 \quad (5)$$

Considering Rayleigh damping, $C = \alpha M + \beta K$, and, and finally derived:

$$M_{11}\ddot{u} + C_{11}\dot{u} + K_{11}u = -M_{11}B_1\ddot{x}_g - \alpha M_{11}B_1\dot{x}_g = -M_{11}B_1(\ddot{x}_g + \alpha\dot{x}_g) \quad (6)$$

The above formula is a wave equation that considers the process of seismic wave propagation. At this time, the displacement of the support is excitation, and the absolute displacement of the structure is basically unknown.

3. Analysis of the wave effect of a super high-rise building

The main building of the China World Trade Center Phase III project (hereinafter referred to as the main building of China World Trade Center Phase III) is an over-limit high-rise building with a total height of about 330m, 3 floors underground, and 74 floors above the ground. The first floor is about 55.3m × 55.3m in plan and office floor. The floor height is 4.25m, and the hotel floor height is 3.60m. The tube-in-tube structure is adopted, and the inner tube is a steel concrete core tube body, and the core tube is provided with a steel plate shear wall below 16 floors. The outer cylinder is a steel concrete frame column cylinder. Between the inner and outer cylinders, there are two outrigger truss layers on the 28th and 56th floors. The outer cylinders are provided with three two on the 6-8th, 28-30, and 55-57 floors. The height of the layered waist truss is equipped with a five-story hat truss on the top. The waist truss and outrigger truss are both steel structures. The hat truss is a steel concrete structure.

Figure 1 is a model diagram when dynamic calculation is performed using ABAQUS software, and Figure 2 is the input artificial seismic wave time history. The top-level displacement response time-history curve of the upper layer under the excitation of artificial seismic waves propagated by the seismic wave in the structure shown in Fig. 3 is shown. The curve in Figure 4 clearly shows that the structural responses of the layers are synchronized without time delay. The curve in Figure 6 visually shows the linear change in the displacement response delay.

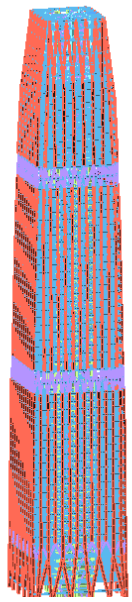


Figure 1a 3D axial side view of the structure

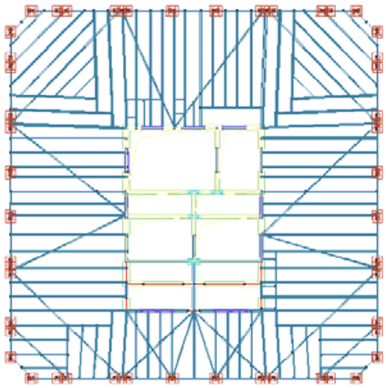
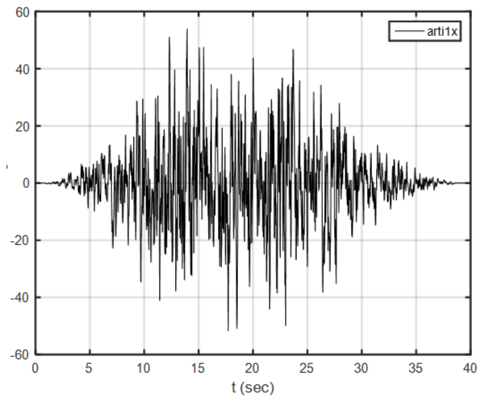
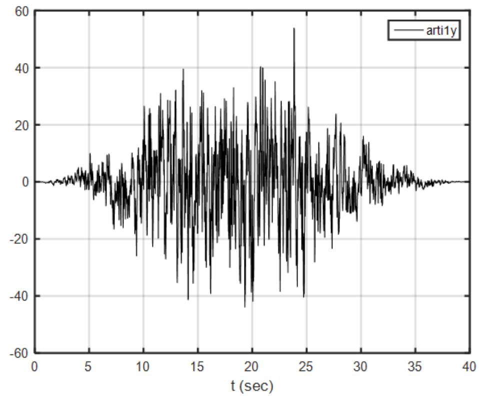


Figure 1b Plan view of the fifth layer structure



(a) X direction



（b） Y direction

Figure 2 Waveform of artificial wave

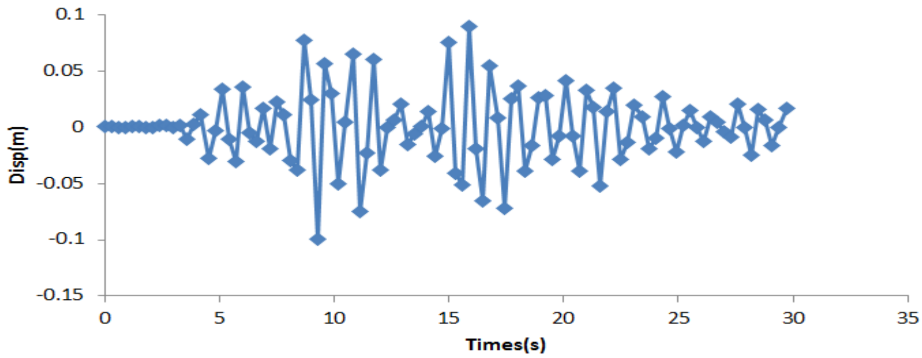


Figure 3 Displacement response of the top layer under artificial wave excitation

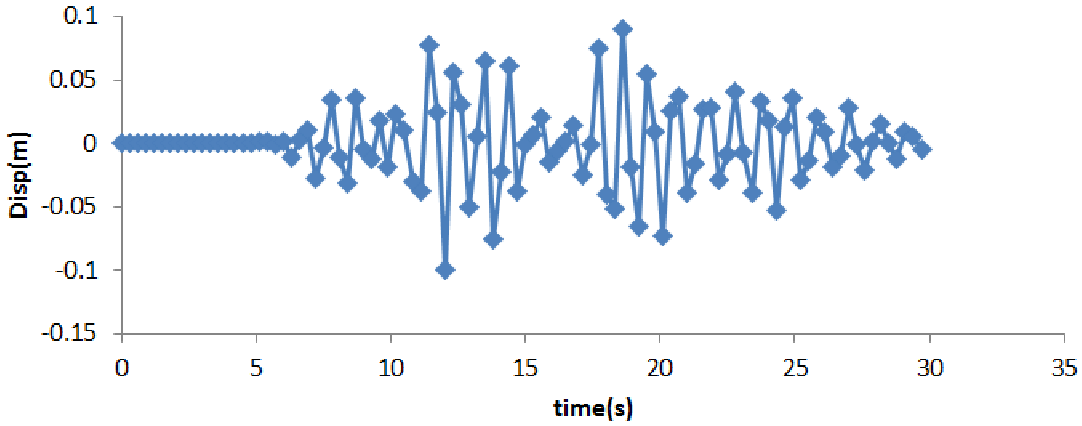


Figure 4 Displacement response of the top layer under artificial wave excitation

4. Conclusions and recommendations

First, the chain-by-layer transfer method of the structure's response to each layer of the structure is analyzed in the traditional structural dynamics equations under the action of the underlying earthquake, and then the time-delay characteristics of seismic waves propagating through the structure are analyzed from the perspective of structural wave dynamics. The analysis results show that the calculation results of the first type of model have no displacement response time lag, and the calculation results of the second type of model can reflect the displacement response time lag to some extent. Therefore, for the seismic response of super high-rise buildings, it is not appropriate to use the traditional dynamic equations based on the first type of model to solve the problem, and the influence of wave effects should be considered.

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