Response Analysis of A Heat-absorbing Tower under Near-field Earthquake

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Abstract. In order to better study the impact of near-field vibration pulse effects on high-rise structures, a random point source method and an equivalent velocity pulse superposition method were used to generate 26 multi-environmental near-field vibration samples with pulse effects for 7-degree fortification. Through the finite element modeling and analysis, the vibration type of the light and heat tower structure is obtained, and the seismic response of the heat absorption tower is analyzed by the generated random ground motion, and the mean value and variance of the structure dynamic amplification factor, base shear force and displacement angle are obtained. Coefficient of variation. The results show that the random seismic response of the structure shows an obvious discrete type, the dispersion of the acceleration amplification factor increases with the height of the tower, the displacement response increases with the height of the tower, and the steel structure on the top of the tower has a significant whiplash effect.

1. Introduction

Due to the complex propagation path of the earthquake and the uncertainty of the plate motion, it becomes a random event, and the earthquake ground motion is called a random process [1]. Liu Zhangjun [2] applied the probability model of non-stationary ground motion to analyze the random seismic response and seismic reliability of the gravity dam. Bai Guoliang [3] et al. designed a 1:18 scale ratio model of a steel-reinforced concrete tower composite structure prototype using solar power, and carried out a seismic shaking table test of model structure simulation to study the seismic performance of the structure.

In order to embody the randomness of ground motion in the research, this paper uses a random point source combined with an equivalent velocity pulse [5] to generate random ground motion samples. At the same time, the finite element model of the photothermal tower was established. Based on the test results in literature [4], the basic vibration modes of the structure were compared, and the mean, standard deviation and coefficient of variation of the main response were analyzed.

2. Random near-field vibration generation

2.1. Random point source model

In point source random simulation, the source is regarded as a point source, irrespective of the geometry of the source body, and the seismic wave is generated by a series of randomly distributed
ruptures in phase [5]. According to the seismic wave propagation path shown in the figure below, Boore [6] believes that the Fourier amplitude spectrum of ground motion can be expressed as:

$$ Y(M_o, R, f) = E(M_o, f) \times P(R, f) \times G(f) \times I(f) $$  \hspace{1cm} (1)

In the stochastic simulation method, the source is expressed by general formula (2).

$$ E(M_o, f) = \frac{R_m \times F_S \times PRTITN}{4\pi \times \rho \times \beta^3} \times M_e \times S(f, f) $$  \hspace{1cm} (2)

In the formula, $R_m$ is radiation pattern coefficient, usually valued 0.55; $F_S$ is free surface magnification factor, usually valued 2.0; PRTITN is horizontal component coefficient, usually valued 0.707; $\rho$ is the density of the medium at the source, unit $g/cm^3$; $\beta$ is the shear wave velocity of the medium at the source, unit $km/s$; $S(f, f)$ is Source spectrum shape function. This paper uses the shape function of the classic $\omega^2$ source model.

Path effect is generally considered to be composed of two parts: geometric diffusion $G(R)$ and hysterelastic attenuation $A_n(R, f)$:

$$ P(R, f) = G(R) \times A_n(R, f) $$  \hspace{1cm} (3)

In this paper, the three-segment geometric diffusion relationship given by Atkinson in 1992 [7] (as shown in equation (4)):

$$ G(R) = \begin{cases} 
\frac{1}{R} & , \quad -R < 70km \\
\frac{1}{70} & , \quad -70km \leq R \leq 130km \\
\frac{1}{70\sqrt{R}} & , \quad -R \geq 130km 
\end{cases} $$  \hspace{1cm} (4)

The hysteresis elastic attenuation $A_n(R, f)$ is generally expressed by formula (5).

$$ A_n(R, f) = e^{-\frac{\pi f R}{Q(f) \beta}} $$  \hspace{1cm} (5)

In the formula, $f$ is the frequency, the unit is Hz; $R$ is the epicentral distance, the unit is $km$; $Q(f)$ is the quality factor, dimensionless.

The impact of the site on seismic waves is also relatively complex. It is generally believed that the site impact includes the two parts of the site's amplification effect $A(f)$ and attenuation, which can be expressed in the form of equation (6).

$$ G(f) = A(f) \times D(f) $$  \hspace{1cm} (6)

$A(f)$ is used to describe the amplification effect of near-surface soft bedrock and $D(f)$ is the high-frequency filter function of the propagation medium:

$$ D(f) = \left[1 + \left(\frac{f}{f_w}\right)^8\right]^{-1/2} $$  \hspace{1cm} (7)

Or

$$ D(f) = e^{-\frac{f}{\kappa}} $$  \hspace{1cm} (8)

Coefficients of different spectrum types:

$$ I(f) = (2\pi f)^\lambda $$  \hspace{1cm} (9)

For $\lambda = \sqrt{-1}, n = \begin{cases} 0, & \text{displacement} \\
1, & \text{velocity} \\
2, & \text{acceleration} \end{cases}$
It can be seen from the above introduction to the principles and procedures of the random point source simulation method that the core of ground motion simulation is to obtain an accurate Fourier amplitude spectrum, and its calculation accuracy depends on the model and parameters used.

2.2. Random near-field vibration synthesis

According to the method in [4], the low-frequency pulse component less than 1 Hz and the high-frequency component greater than 1 Hz are simulated separately, and then the two are superimposed to generate a time that contains multiple frequency components and can reflect the characteristics of near-field pulsed ground motion Cheng. Specific steps are as follows:

(1) First, the point source model is used to simulate the high-frequency components, and the amplitude of the part with the adjusted frequency less than 1 Hz is set to zero.

(2) Then, according to the statistical formula and actual needs, the equivalent speed pulse model is used to simulate the low-frequency pulse-type speed time history, and the derivative is obtained to obtain the equivalent acceleration time history.

(3) Then the simulated low-frequency pulse time history is translated. For the speed peak, the arrival time of the low-frequency pulse and the high-frequency time history can be regarded as the same time. Adjust and synthesize new speed pulse time course, and get the corresponding acceleration time course through integration.

(4) Finally, in the time domain, the resulting pulse acceleration time history is superimposed on the high frequency time history after low frequency zero adjustment. The figure below shows the simulated acceleration time history and its power spectrum compared with the far-field power spectrum.

3. Finite element modeling and random response analysis

3.1. Finite element modeling

The structure of the heat absorption tower adopts a mixed structure system with a large concentrated mass at the top, which is very unfavorable for the lateral resistance of the structure [8].

The tower body is a long, thin and flexible structure, and the structure is approximately symmetrical. The natural frequencies of each order in two directions are close. The first 3 order vibration mode diagrams of the structure are listed here, as shown in Figure 1, and other vibration modes.

![Figure 1. The first three modes of the structure](image)

By comparing with the test results, it is found that the results of the first-order horizontal, second-order horizontal and first-order vertical are similar, and the vibration pattern diagram is also consistent with the test results.

3.2. Random response analysis

In this paper, 26 random ground motions with probabilistic characteristics are generated based on 7-degree frequent earthquakes, in which the design basic acceleration is 0.1 g and the duration is T=30 s.
The average value of peak acceleration of ground motion \( \ddot{a}_{\text{max}} = 35 \text{ cm/s}^2 \), earthquake impact coefficient \( \alpha_{\text{max}} = 0.12 \), characteristic period \( T_E = 0.40 \text{ s} \). In this paper, the far-field vibration generated by the random point source method and the near-field random ground motion generated based on this method are analyzed and compared. The figure below shows the comparison between the selected seismic wave and its average response spectrum and standard response spectrum.

![Figure 2](image)

Figure 2 (a) time-history comparison of acceleration; (b) velocity time-history comparison;

The peak acceleration is adjusted to 0.035 g in accordance with the peak acceleration used in the 7-degree frequent encounter time history analysis, and the time history analysis is performed on the structure.

3.2.1. Acceleration response

Figure 3(a) (b) is a sample of the acceleration time history of the top of the concrete in the X direction and the acceleration time history of the top of the steel structure under typical random ground motions. It can be seen that the acceleration generated by the near-field pulsed ground motion is significantly larger than the acceleration generated by the far-field vibration. Figure 3(c) (d) is the distribution diagram of the acceleration amplification coefficient along the height of the structure under the action of 26 samples in the far field and near field vibrations. No matter the near field or far field vibrations, the average acceleration amplification factor increases with the height of the structure, the model mainly the first vibration mode, showing bending deformation, the standard deviation increases with the height of the floor, indicating that its dispersion also increases with the height of the structure, and it can be seen that in the upper steel structure part, the dispersion is greater.

![Figure 3](image)

Figure 3 comparison of acceleration responses in the far field (left) and near field (right)

3.2.2. Displacement response

Figure 4 shows the maximum displacement response of each layer of the tower structure under the action of 26 selected far-field and near-field random ground motions. At the connection position of structural concrete and steel structure, a sudden change in stiffness occurs. The maximum displacement angle in the far field under a 7-degree earthquake is 1/1428 and the maximum displacement angle in the near field is 1/667.
From the above analysis, it can be seen that the response of the near-field pulsed ground motion to the structure is greater than that of the far-field non-pulse ground motion, indicating that the damage caused by the near-field vibration is far greater than that of the far field, and it needs to be paid more attention.

4. Conclusion
A finite element model was established and verified based on the test results. Using random point source method and equivalent velocity pulses, 26 non-stationary far-field and near-field pulsed ground motion acceleration samples were synthesized and used as random ground motion input to finite element simulation analysis.

(1) According to the comparison of the dynamic response obtained by the seismic simulation of the structure of the light-heat tower finite element under the effect of the random earthquake in the far field and the near field, it can be seen that the pulse effect of the near-field vibration will increase the impact on the high-rise structure and make the structure subject to the more severe damage also illustrates the importance and urgency of the near-field vibration research.

(2) Analyze the mean and standard deviation of key seismic responses such as acceleration amplification factor and maximum displacement angle of each response at a typical moment. The analysis results show that the random seismic response of the structure exhibits obvious random fluctuations.

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