Research on the Influence of Near-Fault Round Motion Pulse Characteristics on Seismic Response of Base-Isolated Structures

Yanan Wang¹, Yonghui Liu*, Hairong Wang¹

¹School of Civil Engineering and Architecture, Xi’an Technological University, Xi’an, Shaanxi, 710032, China

*Corresponding author’s e-mail: 1004387826@qq.com

Abstract. The time-frequency distribution of near-fault pulsed ground motion is different from that of ordinary ground motion because of its long period, short duration and high energy acceleration pulse effect, which has a significant influence on the structure with long natural vibration period, such as isolated structure. In this paper, the pulse characteristics of near-fault seismic records and their influence on the seismic response of isolated layer and superstructure are studied by selecting near-fault pulsed seismic records and far-field common seismic records as external excitation. The results show that compared with the far-field ordinary seismic waves, the 3D Hilbert amplitude spectrum of near-fault pulsed seismic waves is distributed in the low frequency region and the middle and late time domain, and the amplitude is also larger. The first natural vibration frequency of the isolated structure is located at the peak of the power spectrum of the near fault pulse wave, which makes the seismic response of the isolated structure in the near fault pulse type seismic record obviously larger than that in the far field common seismic record. The intensity indexes Sa(T₁) and Sd(T₁) of near-fault pulsed ground motion are greater than those of ordinary ground motion. The relationship between them and structural seismic response should be studied in depth.

1. Introduction
Near-fault pulse ground motion is a special long-period ground motion, which has the characteristics of long-period, short-duration, high energy acceleration pulse and directional rupture, which will weaken the shock absorption performance of isolated structures and produce a large potential destructive power to the structures [1]. However, not all near-fault ground motions contain pulses, and the characteristics of those pulseless near-fault ground motions are almost the same as those of the far-field common ground motions [2]. The research of Wu Yingxiong et al. [3] showed that the damping effect of isolated structures under the action of near-field pulsed long-period ground motion was poor, and the displacement of isolated layer significantly increased or even exceeded the displacement tolerance value under rare earthquakes. Du Yongfeng et al. [4] studied the influence of different site types and source mechanisms on the spectrum characteristics of near-fault pulsed ground motion response, indicating that the correlation between ground motion intensity index and structural response varies with different site types and source mechanisms. Jangid [5] discussed the seismic response analysis and optimal design of the base-isolated structure under the action of near-fault ground motion.

Isolation technology has been proved to be an effective passive control technology and has been widely used in engineering structures and post-earthquake reconstruction in high intensity areas.
Compared with the traditional aseismic structure, the foundation isolated structure extends the natural vibration period of the foundation isolated structure by setting the isolation bearing with low horizontal stiffness to form the isolation layer, and is almost insulated from the high-frequency components in the ground vibration, so as to reduce the earthquake effect and ensure the safety and reliability of the superstructure [6]. This article selects normal fault pulse seismic records near and far field seismic record as excitation load, with base isolation structure as the research object, studies the pulse characteristics of near-fault ground motion and the vibration isolation structure of isolation layer and the influence law of seismic responses of the upper structure, ground motion was discussed preliminarily the relationship between the power spectrum and the earthquake response of the structure.

2. Selection of seismic records and spectral analysis

Combined with existing research results [7,8], the selection criteria of near-fault pulsed seismic records were determined as follows:

(1) Determine the magnitude greater than 6 to ensure sufficient earthquake intensity, and determine the source mechanism and corresponding critical fault distance. The source mechanism is unified as a strike-slip fault, and the fault distance Rs≤30km in the near-fault ground motion record is selected from PEER ground motion database.

(2) Using the method suggested by Baker, the pulse index \( I_p \) of each of the above selected near-fault seismic records was calculated, and the pulse index \( I_p \) greater than 0.85 was used to judge that the vibration in the area was a pulse type ground motion.

\[
I_p = \frac{1}{1 + e^{0.23 - 1.4 R_{PGV} + 20.5 R_{Energy}}}
\]

Where, \( R_{PGV} \) is the ratio of the peak velocity of the remaining part to the peak value of the original velocity; \( R_{Energy} \) is the ratio of the energy contained in the residual velocity time history to the energy contained in the original velocity time history;

(3) The spectrum components of the ground motion determined in the first two steps that satisfy the Fourier spectrum are mainly concentrated in 0.1~2Hz; Ground motion records with PGA≥0.05;

According to the above criteria, 11 near-field pulsed long-period ground motions were selected from the Pacific Earthquake Engineering Research Center (PEER). In order to compare the effects of near-fault pulse characteristics on isolated structures, another 11 remote field common seismic records are selected.

Figure 1 shows the Fourier spectral curves of the two types of seismic records respectively. It can be seen that the spectrum components of near-fault pulse seismic records are mainly concentrated in the low frequency range of 0.1~1Hz, while the spectrum distribution of ordinary long-period seismic waves without pulse characteristics is relatively wide. Figure 2 for the selected two classes of seismic record 3D Hilbert amplitude spectrum, through the 3D Hilbert amplitude spectrum can visually see the Hilbert energy in the time domain and frequency domain in the plane distribution. the chart shows, near fault type pulse waves are mainly distributed in the time domain of middle and low frequency region, and the far field in the early period of the ordinary seismic wave energy is mainly distributed in the time domain and has a wide distribution in the frequency domain. The amplitude of selected near-fault pulse seismic wave is also larger than that of ordinary seismic wave.
2. Seismic response analysis of base-isolated structures

2.1 Project Overview
The nonlinear finite element analysis model of 5-storey frame base isolation structure is established. Various layers of high of 3.3 m, the structure for seismic fortification category b, design earthquake are grouped into 2 groups, the site category is Class II, characteristic cycle value of 0.4s, 0.2g seismic fortification intensity of 8 degrees. The beam section size is 300mm×500mm, the column section size is 600mm×600mm, and the plate thickness is 120mm. The beams and columns are made of C30 concrete, and the beams and columns are made of HRB400. Floor live load is 2kN/m², roof live load is 0.5kN/m²; The isolation height is 1.6m. An isolation support is arranged at the bottom of each column, and its parameters are shown in Table 1.

| Isolation bearing | Effective diameter | Total-rubber thickness | Pre-yield stiffness | Equivalent stiffness | vertical stiffness | yield strength |
|-------------------|--------------------|------------------------|---------------------|----------------------|-------------------|--------------|
|                   | mm                 | mm                     | KN/m                | 100% Horizontal-shear deformation | 250% horizontal-shear deformation | KN/m | KN |
| LRB600            | 600                | 110                    | 13110               | 1580                 | 1580              | 2800 | 63.0 |
| LRB500            | 500                | 92                     | 10910               | 1270                 | 1010              | 5400 | 40.0 |
2.2 Seismic response analysis of isolated structures

The first three order natural vibration periods of the structure after earthquake are 2.373s, 2.277s and 1.974s, and the elongation coefficient are 2.47, 2.72 and 2.60, respectively. In this way, the excellent period of the site is avoided, and the resonance effect of seismic action and natural vibration of the structure is avoided, which conforms to the characteristics of long period of isolated structure.

In order to compare and study the effect of near-fault pulsed ground motion characteristics on the seismic response of isolated structures, the amplitude of the two selected far-field seismic records was modulated to 400cm/s² and unidirectional input along the Y-axis. The seismic response of the isolated structure is analyzed, and the results are shown in Fig 3 and Fig 4 respectively.

As can be seen from Fig 3, the displacement Angle between the upper layers of the base-isolated structure under the action of near-fault pulsed ground motion varies in a large range, but shows certain regularity. The first and second layers of the structure enter into plastic deformation under ground vibration at 8 degrees (0.2g), while the upper three layers remain within the elastic deformation range. Among them, the displacement Angle between the top layers is the smallest, the displacement Angle between the downward layers gradually increases, and the bottom layer is the largest, even more than 1/50=0.02 of the allowable value of the specification, and the average displacement Angle of the bottom layer is 0.024. The average displacement of the isolation layer is 325mm, and the maximum deformation is 480mm, exceeding the maximum horizontal displacement limit Min (0.55d, 3Tr) =330mm under rare earthquakes. The results show that the damage of the base-isolated structure mainly occurs in the bottom layer and the isolation layer under the near-fault-pulsed ground motion. The pulse characteristics of near-field vibration should be considered in isolation design to strengthen the bottom layer and isolation layer of the structure.

It can be seen from Fig 4, due to the high randomness of ordinary ground motions, the displacement Angle values of isolated layer and superstructure layers vary widely and discreteness greatly under the action of ordinary remote field seismic records. In particular, the graphs of RSN-124-270, RSN-66-5135 and RSN-52-315 have two inflection points, which may be due to the relatively wide distribution range of spectrum components in the seismic record, thus arousing the participation of high-order mode of the structure. The variation of the displacement Angle between layers of the superstructure is similar to that of near-fault pulsed ground motion. However, the displacement Angle between the upper layers and the maximum displacement of the isolation layer are both smaller than the response of the structure under the impulse ground motion of the near fault.
For structural seismic response analysis of cause quantity distribution range wide, and pulse type of structure in the near fault ground motion under the action of earthquake response is significantly greater than the far field common reasons of ground motion, respectively of earthquake acceleration response spectrum, and displacement response spectrum and power spectrum and the relationship between the earthquake response of the base-isolated structure were discussed.

Acceleration response spectra from near-fault pulsed seismograms and far-field normal seismograms are shown in Fig 5. It can be seen that the Sa(T1) of the near-fault pulsed seismogram shown in Fig 5(a), which is often used as an indicator of ground motion intensity, is 25 times that of the far-field normal seismogram shown in Fig 5(b). From the whole acceleration response spectrum, the amplitude of near-fault pulsed ground motion in each period is greater than that of far-field common ground motion. This shows that the influence of the isolated structure on the near-fault pulsed earthquake is greater than that of the far-field common ground vibration.

It can be seen from the displacement response spectra of the two types of seismic records shown in Fig 6 that Sd(T1), which is mostly used to represent the ground motion intensity index, is 37.5 times as large in each seismic record of the near-fault pulse type shown in Fig 6(a) as that of the far-field normal seismic record shown in Fig 6(b). In terms of the displacement response spectrum as a whole, the amplitude of the near-fault pulsed ground motion is much greater than that of the far-field common ground motion. This makes the seismic response of pulsed ground motion to the structure greater than that of the far-field common ground motion.
Fig 6. Displacement response spectrum of ground motion

From the far field shown in Fig 7 normal seismic record power spectrum can be seen: structure of the Y direction of the first three order natural frequency of vibration are not be inside the main frequency of the ground motion, but compared with Fig 7(b), and the structure in Fig 7(a) the first natural frequency (NF) of vibration on avoiding the vibration energy distribution of spectrum, the second and third natural frequency (NF) of vibration is concentrated in a small amount of ground motion energy spectrum, this leads to structure shown in Fig 7(a) response under the seismic record is less than the Fig 7(b). Due to the strong randomness of ground motion, the structural response to the same type of ground motion will vary to a certain extent.

Fig 7. Power spectrum of far-field ordinary ground motion

As can be seen from the power spectrum of near-fault pulse seismic record shown in Fig 8, the spectrum components of ground motion are mainly concentrated in the low frequency range of 0~1.5Hz. However, compared with Fig 8 (a), the spectrum components of seismic record in Fig 8 (b) are mainly concentrated in individual frequency points in the range of 0~1.5Hz. In addition, the first natural frequency (NF) of the structure coincides with the peak of the seismic record power spectrum shown in Fig 8(a), while in Fig 7(b) there is a certain degree of deviation. Therefore, the response of the structure in the seismic record shown in Fig 8 (a) is greater than that shown in Fig 7(b). Moreover, the power spectrum amplitude of the near-fault pulsed ground motion is about 2.5 times that of the far-field common ground motion. Further comparison with Fig 7(a) shows that the first natural frequency of the structure is located in the main frequency segment of the seismic record as shown in Fig 8. This is also the reason why the seismic response of the structure under the seismic record shown in Fig 8 is significantly greater than that shown in Fig 7.
4. conclusion
This paper analyzes the RC frame base isolation structure in normal fault type pulse ground motion near and far field seismic response under earthquake ground motion, the near fault type pulse seismic pulse characteristics on the influence of the structure, and the relationship between the ground motion acceleration response spectrum, displacement response spectrum and its power spectrum with the seismic response of the base-isolated structure is discussed, and the conclusions are as follows:

(1) For isolated structures, the existing criteria for selecting near-fault pulsed seismic records are reasonable qualitatively, but they still need to be related to the seismic response of structures and further studied quantitatively.

(2) The pulse characteristics of the near-fault pulsed ground motion have a significant impact on the isolated structure. The amplitudes of acceleration response spectrum and displacement response spectrum of the ground motion are much larger than those of the far-field ordinary ground motion, and the intensity indexes $Sa(T_1)$ and $Sd(T_1)$ of the ground motion are 25 and 37.5 times that of the far-field ordinary ground motion, respectively. The displacement response of the isolated structure is obviously greater than that of the far-field seismic records under the impulse ground motion of the near fault.

(3) The y-direction first frequency cycle of the isolated structure basically avoids the frequency band with relatively concentrated energy distribution of common ground vibration in the far field, and the second and third natural vibration frequencies are only in the frequency band with a small concentration of ground vibration energy. The first natural vibration frequency of the isolated structure is located at the peak of the power spectrum of the near-fault pulsed ground motion, which makes the seismic response of the structure significantly larger.

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