STUDY ON CHARACTERISTICS AND EFFECT OF ASYMMETRY OF PEAK GROUND ACCELERATION

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ABSTRACT :

The asymmetrical characteristics of PGA and its effect on the soil dynamic property are investigated. The effect of asymmetrical characteristics of seismic loads on the soil deformation is pointed out by using the triaxial dynamic tests. The test results indicate the asymmetrical characteristics of PGA have the significant effect and in some cases play the dominant role. Using the records of 287 earthquakes above the magnitude 5 the feature of the symmetry ratio of PGA is described and the its calculation formula is presented。The statistic results indicate that the asymmetrical characteristics of the earthquakes loads are obvious and the asymmetry ratio of PGA is 1.0—3.3, 1.3 on average. The probability of the asymmetry ratio of PGA is 30% for 1.2—1.4 and 60% for 1.1—1.5. The average asymmetry ratio of PGA is 1.4—1.2 from the magnitude 5 to the magnitude 8 and slightly decreases with the increasing of the magnitude.

KEYWORDS: Earthquake wave; Peak asymmetry; Asymmetry ratio of PGA; Soil deformation

1. INTRUDUCTION

Seismic waves possess the asymmetrical characteristics, which can be observed in the records of the earthquakes. Scholars have done some research on asymmetry of ground motion through macroscopic earthquake damages. Shi Zhenliang has studied macroscopic earthquake damages of Xingtai earthquake. He points out that the damage of the housing and bridges is not random, but has predominant directions, which are controlled by seismic origin mechanism. Through his research on main shock and aftershocks of the Tangshan earthquake, Wang Jingming pointed out that ground motion and the collapse of the buildings caused by strong earthquake have certain predominant directions. These results show that the seismic wave has a cdirectional strong asymmetry. Recent studies on near-fault strong ground motion indicate that near-fault ground motion has a strong large pulse characteristic. Through the analysis of structural response under the near-fault ground motion, scholars made a further understanding on earthquake damage characteristics of building structure.

In the strong earthquake, soil and the foundation show strong non-linear response, especially the soft soil layer. Therefore, theoretically, the asymmetry of seismic waves should exert a stronger influence on soil dynamic response. In addition, the current geotechnical engineering basic theory is based on seismic amplitude wave experiments. In a real seismic wave analysis, the equivalent method, which was proposed by Seed in the 1970s, is the most commonly used one. In this method, Seismic waves will be turned to constant amplitude load for calculation. This method doesn't take into consideration of seismic waves' asymmetry and the wave sequence, which may leads to an unreasonable result. [6-9] For example, even in the situation of building load distribution is obviously not balanced as well as the foundation soil transverse distribution is uneven, one cannot work out the heterogeneity of earthquake-induced building settlement, thus cannot get the result which is consistent with the actual earthquake damage. The analysis shows that seismic waves should not be turned to constant amplitude load for calculation in this model [10]. The fundamental issue of soil dynamics and geotechnical seismic study is the soil response under seismic load, so the relationship between the characteristics of ground motion and soil dynamic response should be very close, so should the relationship between seismic wave asymmetry and soil dynamic response. But in this field, there are also two aspects of the work needed to be done: For one thing, the effect of seismic wave asymmetry on soil dynamic response is still not fully understood. For another, even if the evidence, which indicates that seismic wave asymmetry exert a great influence on soil dynamic response, can be found, whether the results are universal is still doubtful, for our understanding and knowledge on the characteristics and laws of ground motion asymmetry is still inadequate at present.

Peak is the fundamental element for seismic load, so this paper will focus on the asymmetrical characteristics of PGA. It will firstly illustrate the great effect of seismic wave asymmetry on soil deformation through experiments, and then focus on the asymmetrical law of PGA. Here, we will select some M>5.0 earthquake records at home and abroad, classify them according to the different magnitude, and statistically analyze the asymmetrical characteristics of PGA, finally deduce its calculation formulas and access the effect of seismic wave asymmetry on soil deformation.

2. EXPERIMENTAL PHENOMENA

In this paper, a series of dynamic triaxial experiments are designed for the study of the effect of asymmetry of PGA on soil deformation. The triaxial apparatus, which is designed by Institute of Engineering Mechanics, China Earthquake Administration and the Harbin Institute of Technology, has a high precision in closed loop control as well as a broadband(0～20Hz). So that it can helps to realize seismic wave input experiment under the control of stress and displacement, and ensure the high precision reconstruction of load amplitudes and waveforms. Soil sample in the test is soft clay from China's Hangzhou Bay region and the Tianjin area. Stress control is adopted in this test, in which, σ3 stands for consolidation stress, kc for consolidation ratio, σd for dynamic stress-peak, γ for bulk density and ω for water content.

Four earthquake acceleration records used in the test are the acceleration records from the Beijing Hotel in the Tangshan earthquake (Tangshan wave, the same below), Ninghe wave, Qian'an wave and El-Centro wave, as shown respectively in Figure 1 (a), (b), (c) and (d) below. Earthquake acceleration of the soil will be transformed into the stress of the soil, and the time history of acceleration is consistent with that of stress, so the nature of soil under the stress wave can be represented by that under the acceleration load.

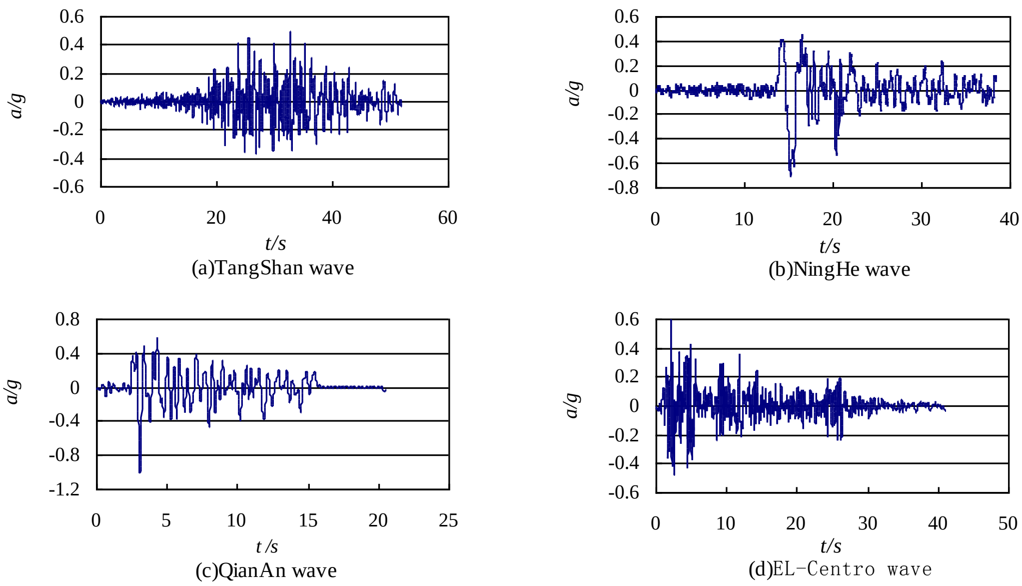
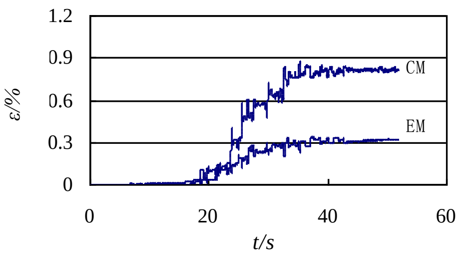


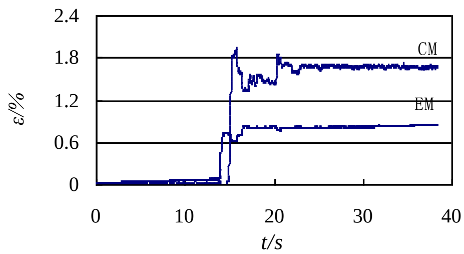
Figure1 Four earthquake acceleration records

These four commonly used earthquake acceleration records are asymmetric, and their peak values in positive and negative direction are respectively 1.33, 1.54, 1.78 and 1.30, with an average of 1.49.

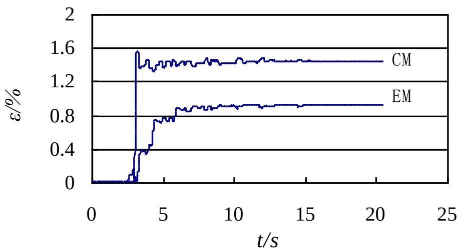
To study the impact of the peak asymmetry of the seismic waves, the experiments on two clay samples of the same conditions are conducted with two equivalent and reverse dynamic stress time histories originated from the same earthquake wave. In the experiment, when dynamic load peak applied, the piston is in the lowest position, known as CM experiment; The piston is in the highest position, known as EM experiment. The strain comparison of the soil samples in CM and EM experiments is shown in Figure 2.The axial dynamic stress time histories adopted in Figure 2 (a), (b), (c) and (d) are relative to four acceleration records in Figure 1. Seen from Figure 2, in every CM and EM test, the strain developments are different, so are the residual strain. In the four tests, CM's residual strain value is 156%, 120%, 56% and 50% higher than that of EM, with an average of 96 percent. Therefore, asymmetry of ground motion, especially peak asymmetry, has a great effect on soil deformation, and in some cases plays the dominant role.



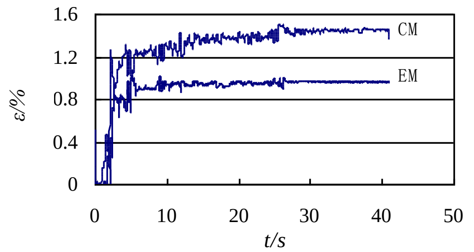
(a)TangShan wave input, σ_3=130kPa, k_c=1.5, σ_d=50kPa, γ=17.8 kN·m^{-3}, ω=40.0%



(b)NingHe wave input, σ_3=100kPa, k_c=1.3, σ_d=70kPa, γ=17.8 kN·m^{-3}, ω=39.5%



(c)QianAn wave input, σ_3=100kPa, k_c=1.3, σ_d=100kPaγ=19.2 kN m^{-3}, ω=30.7%



(d) El-Centro wave input, σ_3=50kPa, k_c=1.5, σ_d=60kPa, γ=18.1kN m^{-3}, ω=24.7%

Figure2 Comparison of the strain histories of cohesive soils by CM and EM tests

Although the four tests indicate the ground motion asymmetry's great effect on soil deformation, only a limited number of earthquake waves can be used in them, therefore, whether the results have universal significance depends on people's understanding on ground motion asymmetry, in which there are no research results we can draw, and which is to be discussed in this paper.

3. ASYMMETRY OF PEAK GROUND ACCELERATION

3.1 Data Sources

In order to understand the asymmetry of PGA, this paper adopts statistical method for analyzing the real earthquake records. In this paper, all acceleration records are selected in free sites, including the 287 earthquakes in 11 countries such as China, the United States, India, Canada, Turkey, Mexico etc. In order that the earthquake records have certain representativeness, one record is selected for every earthquake at least, and two records are selected for some bigger ones, sum to 332 records. M<5.0 earthquakes, whose destructiveness is not strong, are not mentioned here. So are M>8.0 earthquakes, whose records are rare. All the selected records cover the major earthquake, the moderate earthquake, the near-fault earthquake, the far-field earthquake and the earthquakes under the different soil condition. According to the different magnitudes, they are divided into 5.0～5.5、5.5～6.0、6.0～6.5、6.5～7.0、7.0～7.5、7.5～8.0, shown in Table 1. Because of the space limits, the specific records are omitted here.

Table 1 Grouping of earthquake records

Magnitude	5.0≤M<5.5	5.5≤M<6.0	6.0≤M<6.5	6.5≤M<7.0	7.0≤M<7.5	7.5≤M<8.0
Total	95	71	57	40	42	27

3.2 Asymmetry Ratio of PGA and Its Feature

In these earthquake records, some PGA are positive, some are negative. The absolute values of PGA are used here. The ratio of PGA and the PGA in the opposite direction are used as a parameter for ground motion asymmetry characteristics, which is defined as asymmetry ratio of PGA, R_A in short.

Figure 3 shows the distribution of the asymmetry ratio of PGA. Seen from the figure, the asymmetry ratio of PGA is 1.0—3.3, 1.3 on average, among which, the possibility of the asymmetry ratio of PGA below 1.05 is 13%, and the one above 1.05 is 87%. This shows that most positive and negative values of PGA present a notable characteristic of asymmetry.

In addition, we can see that the average values of the asymmetry ratio of PGA for different magnitude are 1.37, 1.29, 1.34, 1.28, 1.25, 1.24, and the general trend is that the asymmetry ratio of PGA decreases with the increasing of the magnitude.

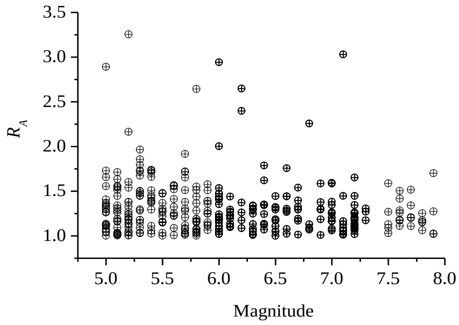
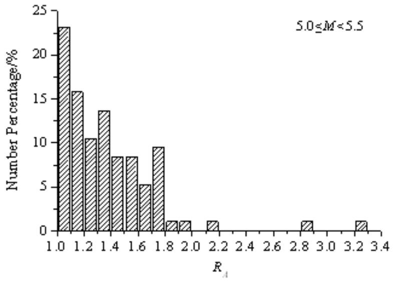
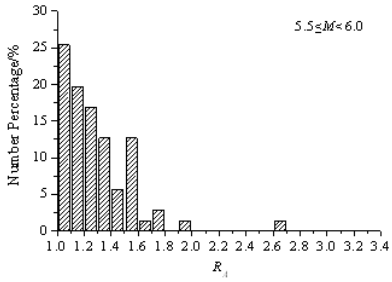


Figure3 Distribution of the asymmetry ratio of PGA

Figure 4 is the interval distribution of the number of the asymmetry ratio of PGA for the different magnitude, which shows the distribution probability of the asymmetry ratio of PGA in different intervals. As shown in Figure 4, if the average values of the asymmetry ratio of PGA for different magnitude (1.37, 1.29, 1.34, 1.28, 1.25, 1.24) are regarded as intermediate value respectively, for the records of the six earthquakes, the possibility of the asymmetry ratio of PGA less than intermediate value is respectively 58%, 62%, 63%, 43%, 66% and 59%, the one more than intermediate value is respectively 42%, 38%, 37%, 57%, 34% and 41%, and the possibility of the asymmetry ratios of PGA more than 1.5 is respectively 27%, 20% , 12%, 10%, 10% and 15%.





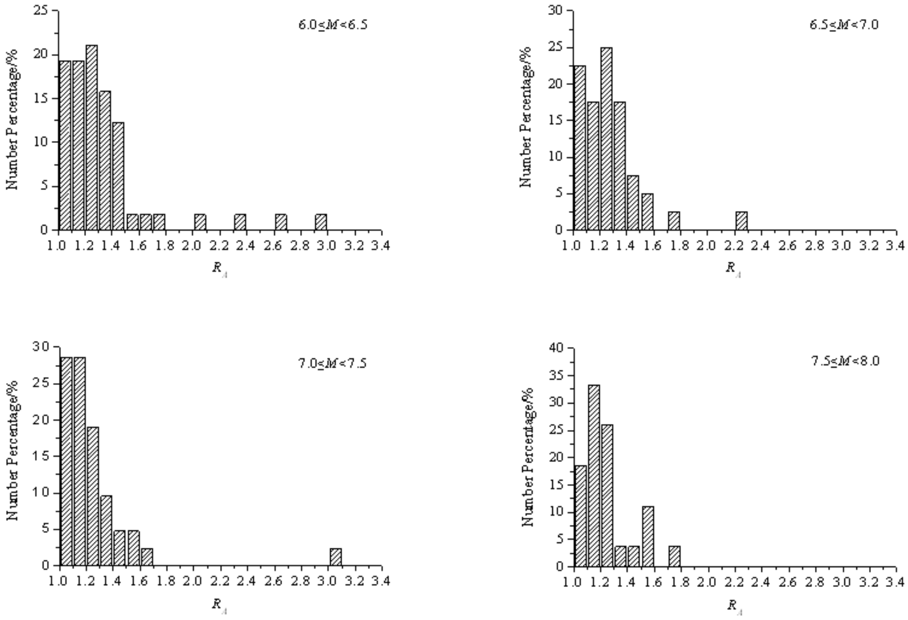


Figure4 Interval distribution of the number of the asymmetry ratio of PGA for the different magnitude

Figure 5 is the interval distribution of the number of the asymmetry ratio of PGA for all data. If the average value of the asymmetry ratio of PGA of the six earthquakes (1.3) is regarded as intermediate value, the asymmetry ratio of PGA for the different magnitude is in partial distribution. For the records of the six earthquakes, the possibility of the asymmetry ratio of PGA is 18% for 1.2-1.3, 13% for 1.3-1.4, 38% for 1.1-1.3, 20% for 1.3-1.5, 61% for 1.0-1.3, 29% for 1.3-1.6, which indicates that the possibility of the asymmetry ratio of PGA for 1.0-1.3 is higher than that above 1.3.
In addition, seen from Figure 5, the possibility of the asymmetry ratio of PGA is 31% for 1.2-1.4, 60% for 1.1-1.5, that is, the possibility of the asymmetry ratio of PGA is about one-third for 1.2-1.4, about two-thirds for 1.1-1.5.

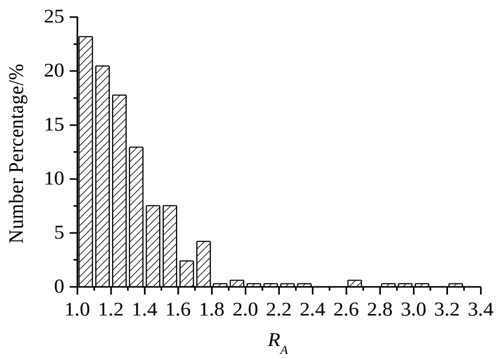


Figure5 Interval percentage distribution of number of asymmetry ratio for all PGA data

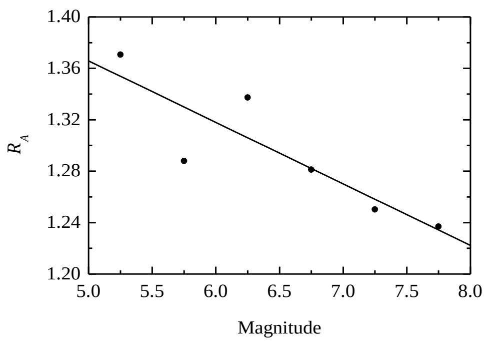


Figure6 Fitting curve of relationship between asymmetry ratio of PGA and magnitude

3.3 Calculation Formula for the Asymmetry Ratio of PGA

On the basis of statistical results of the average values of the asymmetry ratio of PGA for the different magnitude, the fitting formula for the asymmetry ratio of PGA is proposed here:

$$R_A = 1.60512 - 0.04786M \tag{1}$$

In this formula, R_A stands for the asymmetry ratio of PGA, M for the magnitude.
Figure 6 is the comparison between the statistical results and the fitting formula, and their developing trends are generally consistent. Generally speaking, the asymmetry ratio of PGA varies from 1.2 to 1.4, 1.3 on average, and it decreases with the increasing of the magnitude.
According to the change law of the asymmetry ratio of PGA proposed in this paper, the predominant directions of damage of the buildings and bridges which have been investigated have some universal significance. Meanwhile, in the dynamic triaxial experiments with two equivalent and reverse dynamic stress time histories originated from the same earthquake wave, the difference of soil deformation also has a certain universal significance. Besides, through the change law and the experimental results of the asymmetry ratio of PGA of this paper, the main range of the soil deformation difference is preliminarily estimated to be 50% -150%, and the 100% difference should be a result with an average significance.

4. CONCLUSION

(1) Asymmetrical characteristics of seismic loads have a significant effect on the soil deformation, especially the asymmetrical characteristics of PGA, which in some cases plays the dominant role.
(2) The asymmetrical characteristics of PGA can be described by the asymmetry ratio of PGA, and its statistical results have their regularity.
(3) The asymmetrical characteristics of PGA are obvious, and the asymmetry ratio of PGA varies from 1.0 to 3.3, 1.3 on average.
(4) The probability of the asymmetry ratio of PGA is one-third for 1.2－1.4 and two-thirds for 1.1－1.5.
(5) The average asymmetry ratio of PGA is 1.4－1.2 from the magnitude 5 to the magnitude 8 and slightly decreases with the increasing of the magnitude.
(6) The predominant directions of damage of the buildings and bridges that have been investigated are consistent with the results of this paper, further illustrate this is a universal phenomenon.
Although the strong ground motion discussed in the paper has a universal significance, it is not a near-fault ground motion. Judging from the current understanding, the asymmetrical characteristics of peak of near-fault ground motion acceleration should be stronger. But with the limited data, the statistically significant results are still difficult to obtain. In addition, the paper discusses only the asymmetrical characteristics of PGA. But in fact, besides PGA, there are also some pulses with relatively large amplitude in the earthquake time history. Combined with PGA, they control the dynamic response of soil elements. The asymmetry of this combination and its effect on soil need further investigation.

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