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Test on dynamic performance of silt-concrete structure system under cyclic loading with different frequency

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ABSTRACT

In order to study the dynamic response of the soil-structure system and the contact performance between soil and structure under cyclic loading, a Suspensory Ring Test Apparatus was designed by the authors, and a series of tests had been carried out. The physical properties of the test silt were that ρ=1.59g/cm^3, ω_P=14.26%, ω_L=21.77%. In the paper, The Suspensory Ring Test Apparatus was introduced firstly. Then, the test data were analyzed in two aspects, that was (1) the damage mechanism of the soil-structure system, (2) the factors which affected on contact performance between silt and concrete structure under cyclic loading, such as moisture content, loading frequency, roughness, and so on. Finally, some conclusions were also proposed.

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1. Introduction

Soil and Structure Interaction (SSI) is very important to study the dynamic response and damage of underground structure, where the description of contact performance between soil and structure is a key problem. Now, there have been many research fruits on the aspect. For example, Potyondyj (1961), as a pioneer, studied the Skin friction performance between various soils and construction materials using direct shear apparatus. Yoshini and Kishida (1981) designed a ring torsion apparatus for evaluating friction between soils and metal surfaces. Desai et al. (1985) discussed the mechanical properties of Soil-structure interface under cyclic loading. Zhang and Zhang (2003) designed an apparatus called TH-20t Cyclic Shear Apparatus for Soil-structure Interface, and many experimental studies have been carried out using this apparatus. Westgate and DeJong (2006) researched the evolution of sand-structure interface response during monotonic shear using particle image velocimetry. Zhang et al. (2008) developed a 3D soil-structure interface test apparatus. Li and Li (2010) developed a test apparatus which was patient of unrestricted deformation of soil in interface area along shear direction. Cai et al. (2010) and Li et al. (2012) improved their test apparatus to research the contact performance between soil and structure respectively. We know that the mechanical performance of material is affected by loading velocity, so, we think loading frequency maybe affect the mechanical performance of material, due to the earthquake includes many different frequency waves. But the literatures about the influence of loading frequency on contact performance between soil and structure are very few. At the same time, these above research did not considering the soil's deformation during test. In order to study the dynamic performance of soil and structure system comprehensively, based on DYS-200-1-05 shaking table system, we designed a Suspensory Ring Test Apparatus (Li et al., 2013). Using the apparatus, the dynamic performance of silt and concrete structure system was researched, and some conclusions were proposed in this paper.

2. Suspensory Ring Test Apparatus

The suspensory ring test apparatus was designed by reforming the DYS-200-1-05 shaking table system. Fig. 1 is its Skeleton drawing. The DYS-200-1-05 shaking table system include the output power system which provide

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the horizontal force and the table system to fix the test structure, where the low frequency can reach 0.5Hz, the vibration displacement can arrive 40mm, and the maximum vertical loading is 100kg. The table system is connected to the output power system with connector and dynamic force sensor. During testing, the structure board was fixed on the table, the suspensory ring container was hanged above the structure slab, and the contact area between soil and structure would be not changed due to the size of structure slab was larger than the diameter of the container. The suspensory ring container was made of latex film around with several aluminum ring, thus the soil can horizontal deform in test. The diameter of two containers was 150mm and 100mm respectively, and the aluminum ring's size was 3mm×5mm (thickness×height) with 5mm space. The displacement sensor 1 (DIS1) was located on the structure board, the displacement sensor 2 (DIS2) lied on the lowest aluminum ring contact the structure, and the displacement sensor 3 (DIS3) lied on the aluminum ring near the lowest one, parallel to the interface between soil and structure. Then, the two shear deformation SD1=DIS1-DIS2 and SD2=DIS2-DIS3 stand for the shear deformation on contact interface between soil and structure and that on soil body respectively. The vertical external force can be input on the top of the soil with additional weight. The dynamic force sensor was a MCL-Z force sensor, used to record the force history along the interface.

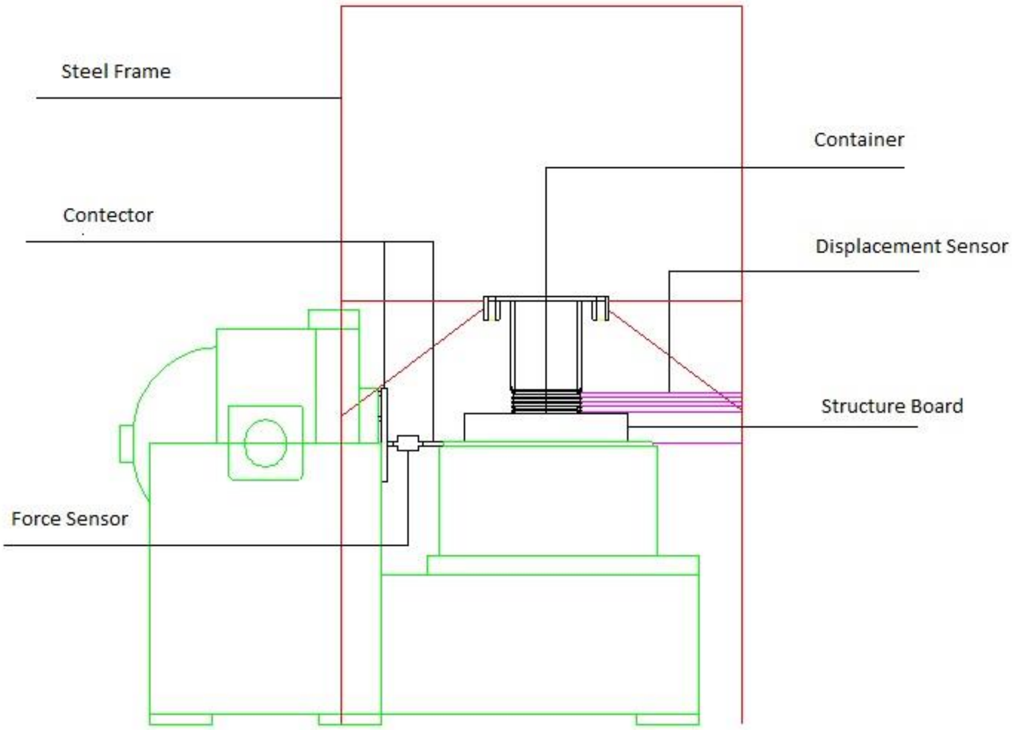

Fig. 1. Skeleton drawing.

The apparatus' features and applications include the following aspects. Firstly, the vertical force on the interface was constant, and the horizontal force paralleled to the interface can be carried out by different frequency. Secondly, the shear distortion of the test soil was considered, thereby, the relationship between destroy of soil-structure system and that of soil can be studied in test. Thirdly, the influence of some factors including the load frequency and velocity on the contact performance between soil and structure can be researched.

Fig. 2 is the relation between loading frequency and ratio of force to displacement in different assembling stage, where there is nothing on the shaking table at stage I, the structure board has been fixed on the shaking table at stage II, and the container has been hanged above the structure board at stage III. As shown in Fig. 2, the ratio of force to displacement at stage II is consistent with that at stage III, thus, the friction is very low between the container and the structure board, and the incremental force could only be caused by the soil in container during test. So, the shear force along the interface is $SF=F_{III}-F_{II}$.

3. Overview of the Experiments

In order to study the response of the soil-structure system and the contact performance between soil and structure under cyclic loading systematically, a series of tests had been carried out by using the suspensory ring test apparatus designed by the authors. The test soil was silt, whose physical properties were that ρ_d=1.59g/cm^3, w_P=14.26%, w_L=21.77%, c=6.26kPa, and φ=34.96°. One of the test structures was a plain concrete board (STR1), the other was concrete board covered with reinforcing net of 20mm with the diameter of 2.0mm (STR2). Table 1 shows the test cases.

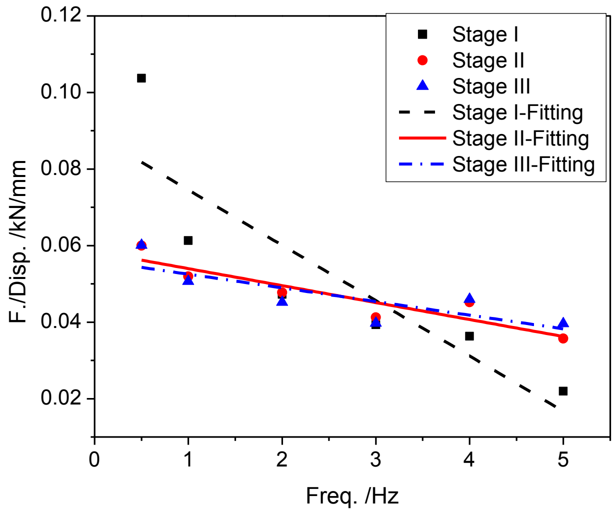

Fig. 2. Relation between loading frequency and ratio of force to displacement.

Table 1. Test cases.

Loading Freq. (Hz)	Moisture content (%)					
	14.3	8.1	7.1	6.3	5.4	4.1
0.5	√	√				
1.0	√	√		√		
1.5	√	√		√		
2.0	√	√	√	√	√	√
2.5	√	√	√	√	√	
3.0	√	√	√	√	√	√
3.5			√		√	√
4.0	√		√	√	√	√
5.0	√		√	√	√	√
6.0			√		√	√

4. Analysis of Test Results

4.1. Mechanism of silt-structure system

Fig. 3 is a typical record curves under 0.5Hz loading, where the moisture content of silt is 14.3%. Fig. 4 is the shear deformation curve deduced from Fig. 3. From Fig. 3, we find that the increasing of the displacements is slower than that of shear force along the interface between soil and structure. Fig. 4 indicates that the shear deformation on the interface between soil and structure is different to that on soil, the shear deformation on the interface increases fast with the increasing in shear force until the destruction, but, the shear deformation on the soil is basically unchanged. Finally, the damage of the silt-structure system is taken place on the interface between soil and structure. But, the other test data represent that the shear deformation on the soil can be larger than that on the interface when the loading frequency reached a certain value, we will talk about it in the following.

As shown in Fig. 5, the SD2/SD1 is related to the moisture content of soil and the loading frequency, which indicate that the SD2/SD1 increase and then decrease with the increasing in loading frequency, and the peak value of SD2/SD1 increase with the increasing in moisture content of soil. Because SD1 and SD1 stand for the shear deformation on contact interface between soil and structure and that on soil body respectively, the system damaged will be found in soil when SD2/SD1>1.0.

Fig. 6 is a typical hysteresis loop, where the moisture content of silt is 14.3%. Fig. 6 presents that the development of the deformation can be divided into three phases. First, the size of hysteresis loop is very small, and its long axis is almost horizontal, where the shear force and shear deformation are all low. Second, the shear force increases quickly, and the long axis of hysteresis loop turns into vertical direction. Third, the shear deformation is larger and larger with the increasing in shear force, and the size of hysteresis loop also become large to a value, and its long axis is going to horizon again. So, the damage of the soil-structure system will be occurred between the second phase and the third phase, and that the energy dissipation may be used to study the contact performance because of the hysteresis loop represents the energy dissipation during deformation under cyclic loading. Fig. 7 is a typical relationship between energy dissipation and number of loading cycle which also indicate that the development of deformation of the soil-structure system includes three phases. Fig. 8 shows that the monocycle energy will decrease and the number of cycle will increase with the increasing in loading frequency to cause the soil-structure system damaged. So, the total energy dissipation will be employed in order to eliminate the influence of the number of cycle in the following study.

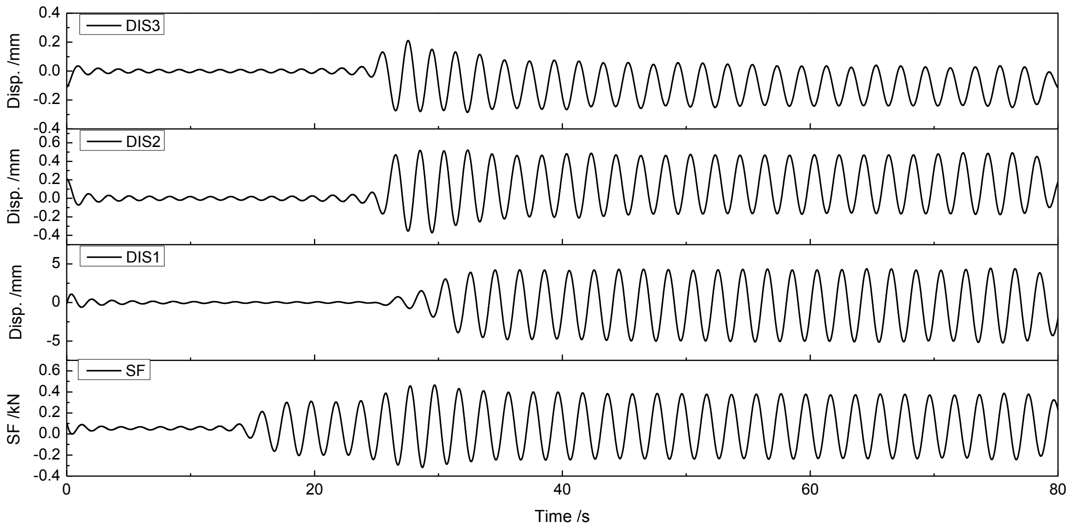

Fig. 3. Typical record curves.

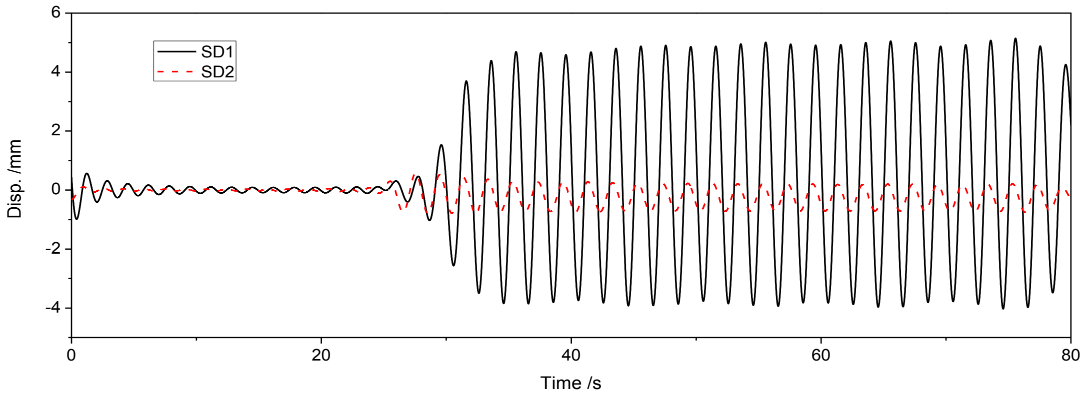

Fig. 4. History curve of shear deformation.

4.2. Influence of moisture content and loading frequency

Fig. 9 presents the relation between the total energy dissipation and the moisture content, and Fig. 10 is the relation between the total energy dissipation and the loading frequency. The two figures indicate that the total energy dissipation causing the system to damage will decrease with the increasing in moisture content and the loading frequency, which can be fitted with formula of $y=ax^b$ respectively. From Fig. 9 and 10, we also find that the relations among the total energy dissipation, moisture content, and loading frequency were coupling.

4.3. Influence of contact size and roughness on interface

Table 2 shows the total energy dissipation on different case under different loading frequency, including contact diameter with 150mm, 100mm, and different roughness of STR1, STR2. From Table 2, we find that the total energy dissipation on different cases all decrease with the increasing in loading frequency, the total energy dissipation on large contact size case are larger than that on small contact size case, and the influence of roughness are also obvious which present that the total energy dissipation on STR2 are less than that on STR1.

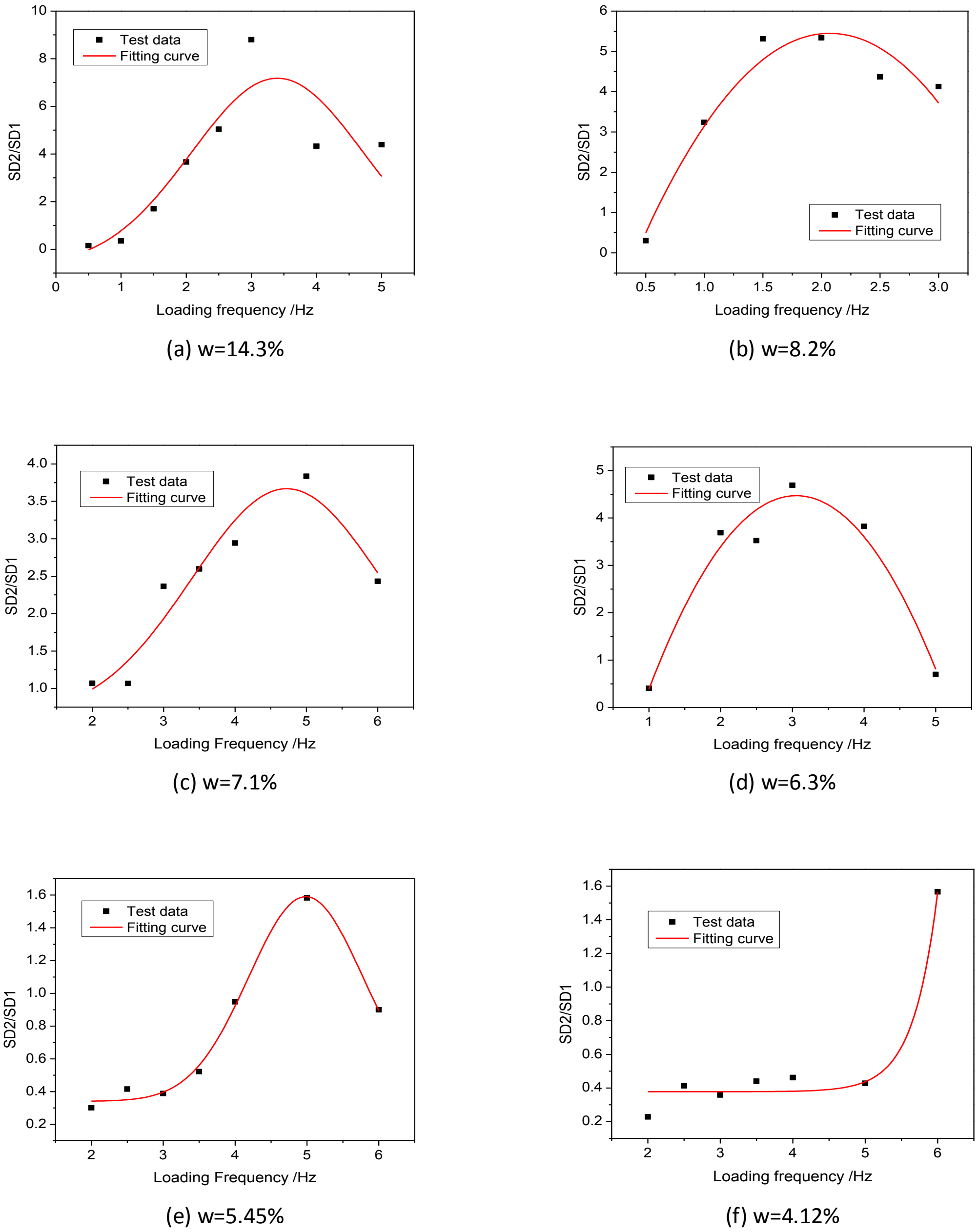

Fig. 5. Relationship curve between SD2/SD1 and loading frequency.

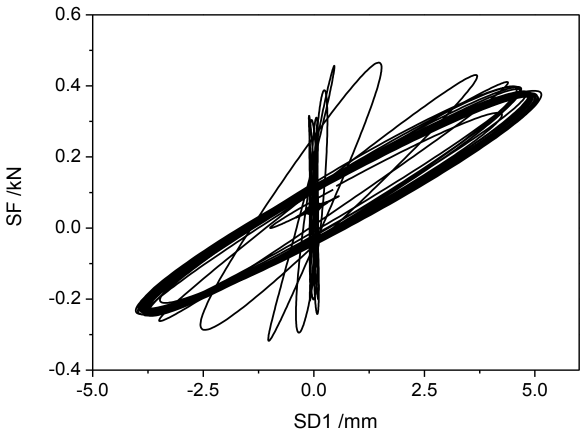

Fig. 6. Typical hysteresis loops.

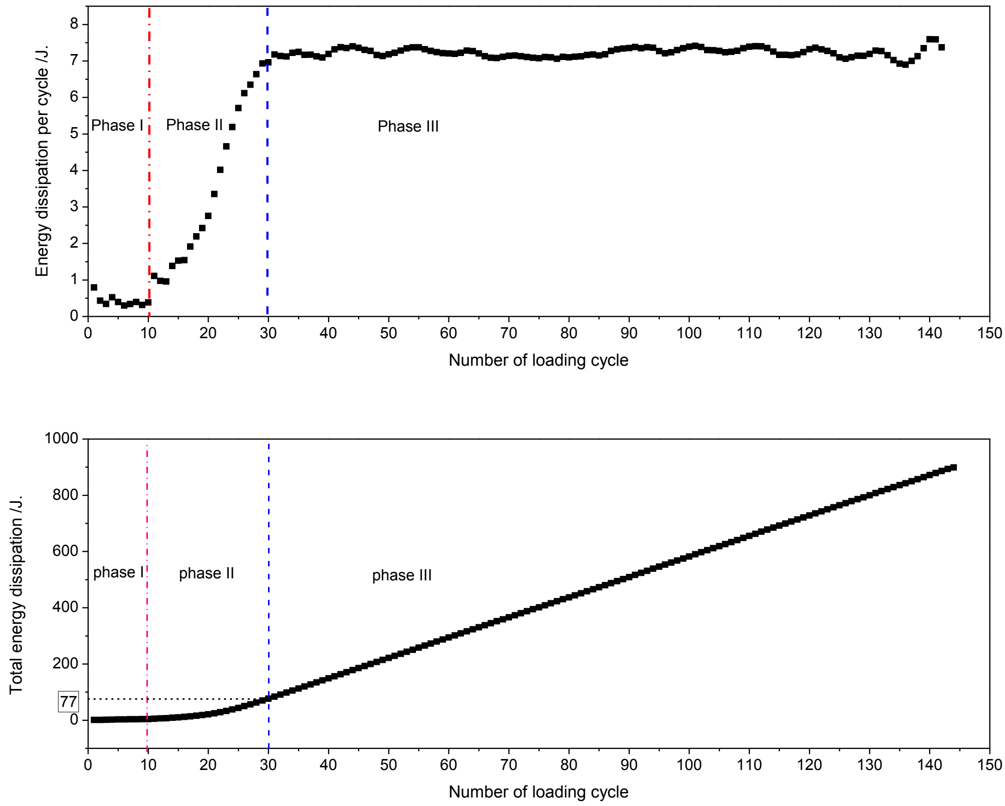

Fig. 7. Relationship between energy dissipation and loading cycle.

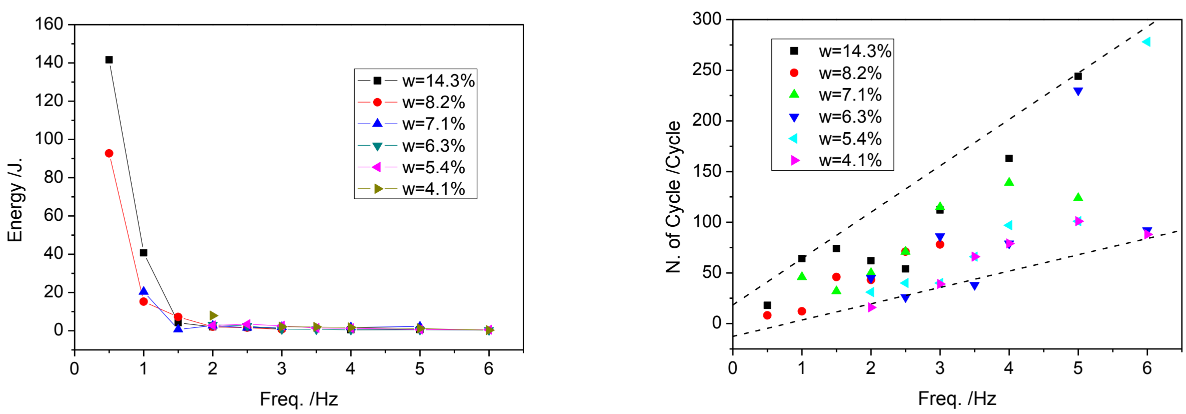

Fig. 8. Monocycle Energy and Number of Cycle while the system damaged.

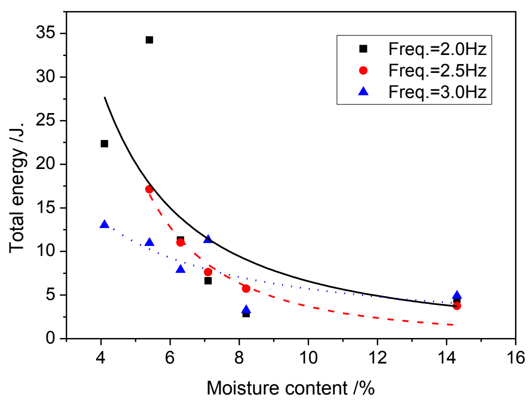

Fig. 9. Total energy versus Moisture content.

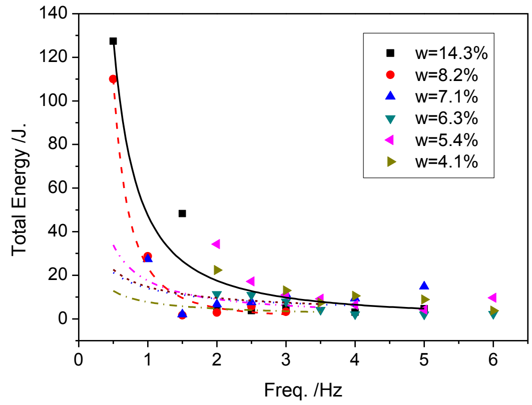

Fig. 10. Total energy versus loading frequency.

Table 2. Total energy dissipation on different cases.

Case Freq. /Hz	D=150mm and STR1	D=100mm and STR1	D=150mm and STR2
2.0	11.31	3.71	3.24
2.5	11.03	2.29	6.59
3.0	7.90	1.49	14.56
3.5	4.15	0.79	2.61
4.0	2.11	1.84	4.44
5.0	1.97	1.49	1.85
6.0	2.24	0.97	2.18

5. Conclusions

In this paper, the dynamic response of the soil-structure system and the contact performance between silt and structure under cyclic loading was studied, using a Suspensory Ring Test Apparatus designed by the authors, where the physical properties of the test silt were that ρ=1.59g/cm^3, ω_P=14.26%, ω_L=21.77%. Firstly, the Suspensory Ring Test Apparatus was introduced. Then, the test data are analyzed and some conclusions were gained. (1) The increasing of the displacements is slower than that of shear force along the interface between soil and structure. (2) The damage position of the soil-structure system was different when the loading frequency and moisture content were different. (3) The factors affected on contact performance between silt and concrete structure under cyclic loading were studied, such as moisture content, loading frequency, contact size, and roughness.

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