

Article

Mechanical Behavior of Geogrid Flexible Reinforced Soil Wall Subjected to Dynamic Load

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Abstract: The geogrid flexible reinforced soil wall is widely used in engineering practice. However, a more comprehensive understanding of the dynamic behavior of reinforced soil wall is still required for a more reasonable application. In order to explore the mechanical behavior of a geogrid flexible reinforced soil wall, the model test was carried out to investigate the dynamic deformation of geogrid reinforced soil wall subjected to a repeated load. The numerical simulation was also conducted for comparison and extension with regards to the earth pressure and the reinforcement strain. The change rules for the deformation of the wall face, the vertical earth pressure and the reinforcement strain subjected to dynamic load with four frequencies (4, 6, 8 and 10 Hz) and four amplitudes (30–60, 40–80, 50–100 and 60–120 kPa) were obtained. The factors that affect the mechanical behavior of geogrid flexible reinforced soil wall were analyzed. The results show that the dynamic deformation characteristics of reinforced soil wall are affected by the number of vibrations, the amplitude of dynamic load and the frequency of vibration. The maximum lateral displacement of the reinforced soil wall occurs on the third to the fifth layer. With an increase in dynamic load amplitude, the development of dynamic deformation gradually increases, and after a cumulative vibration of 200×10^4 times, the cumulative lateral deformation ratio and the cumulative vertical deformation ratio of the wall face is less than 1%. The vertical earth pressure of geogrid flexible reinforced soil wall increases partially along the length of the reinforcement, and the vertical earth pressure of the third layer is basically unchanged when subjected to a dynamic load. With an increase in vibration number, the change in the reinforcement strain of the third layer is more complex, and the change rules of the reinforcement strain of each layer are different. The reinforcement strain is small, with a maximum value of 0.1%.

Keywords: geogrid flexible reinforced soil wall; mechanical behavior; model test; numerical simulation



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1. Introduction

Reinforced soil improves the strength and deformation performance of the soil by adding reinforcing materials [1,2]. It is widely used in retaining walls and reinforced embankments. In addition, the widely used reinforced materials include geogrid, gabion mesh, fiber and so on [3–6].

The friction and embedding effect between the geogrid and the soil make it possible to form a reinforced soil structure. The reinforced soil structure can effectively improve the strength and internal stability of the soil, so the interaction between the geogrid and the soil is very important for the reinforced soil structure [7–11]. Generally, the interaction along the reinforced soil interface is very complex [12,13]. Eigenbrod et al. [14] studied the mutual friction of the reinforced soil interface through experiments, and concluded that the friction angle of reinforced soil is smaller than the internal friction angle of soil. Ahmad et al. [15]

calculated the bearing capacity of reinforced soil through a new theoretical equation, and analyzed the mechanical properties of geogrid and the distribution of shear stress at the interface between the reinforcement and the soil. Jia et al. [16] established a DEM model to study the influence of shear direction and geogrid characteristics on the interface strength. In addition, there are some scholars who have studied the influence pull-out load has on interactions with a reinforced soil interface [17–19]. For example, the interaction between the geogrid and the soil can be analyzed by pull-out tests [20–24], and the mechanisms of pull-out limit state and anchorage zones can be studied with a large pull-out facility [25,26]. Abdi [27] analyzed the size, distribution and displacement of particles at the interface of reinforcement and soil by pull-out test. Teixeira et al. [28] evaluated the interaction between reinforcements and the soil pull-out test, and the longitudinal and transverse resistances of geogrid ribs were determined.

The tensile mechanical properties of reinforced materials in reinforced soil are basic technical indices of reinforced soil structure design. The stress-strain characteristics of the reinforcement directly affect the lateral displacement, vertical settlement and service life of the reinforcement. Some scholars have carried out research on the tensile mechanical properties of reinforced soil. Yang et al. [29] studied the stress-strain characteristics of four kinds of reinforcement materials, such as geobelt, geotextile, geogrid and geonet under cyclic loading. Masahiro et al. [30] studied the vertical and lateral deformation characteristics of three kinds of geogrids (PET, PP and HDPE) under tensile load. Boisse and Buet-Gautier et al. [31,32] carried out the biaxial tensile test of reinforced soil materials. In addition, many scholars have studied the influence of tensile rate, specimen size and other factors on the tensile test results [33,34]. Perkins [35] established the constitutive relationship of reinforced soil and verified it using a series of tensile tests. However, the mechanical properties of different reinforcements vary greatly, so it is necessary to determine the tensile mechanical properties of specific reinforcements by tensile tests.

At present, abundant results have been obtained on the dynamic response characteristics of subgrade and pavement under dynamic traffic load. However, as the traffic load is a kind of dynamic load, which is different from seismic load and wave load, the factors that affect the amplitude of traffic load are extremely complex and it is very difficult to accurately determine traffic load [36]. At present, the traffic load model is generally simplified as a steady-state harmonic load (triangular wave load or sine wave load) or a moving random load by considering a dynamic load coefficient [37]. Both theoretical and experimental results show that the dynamic load caused by the train is a one-way pulse mode rather than a two-way sinusoidal mode. Many scholars adopted one-way pulse load, half-sine wave load [38] and sine wave load [39] to reflect the dynamic train load. When the train passes through, the dynamic load of the train on the reinforced soil wall can be regarded as a form of sine wave.

In this paper, the model test of the geogrid flexible reinforced soil wall is carried out by applying a sine wave load to reflect the dynamic train load. Combined with a finite element numerical simulation, the dynamic deformation characteristics of the geogrid flexible reinforced soil wall under dynamic train load are studied. The distribution laws of dynamic deformation, vertical earth pressure and reinforcement strain in reinforced soil retaining walls are analyzed. The factors affecting the mechanical behavior of the walls are considered.

2. Model Test

2.1. Experimental Overview

The test model of the geogrid flexible reinforced soil wall was constructed in a model box. The size of the model box was 3.0 m (length) $\times$ 0.85 m (width) $\times$ 2.0 m (height), which includes: an organic glass observation surface with a size of 3.0 m (length) $\times$ 2.0 m (height); a top surface of 3.0 m (length) $\times$ 0.85 m (width) that was used to apply vertical load; and another front surface of 0.85 m (width) $\times$ 2.0 m (height) that was used to construct the wall face in the reinforced soil wall model. The remaining three surfaces were welded with steel

plates. On the observation surface of plexiglass, the angle steel was welded every 24 cm horizontally as a vertical support to ensure that the plexiglass did not undergo any lateral deformation. The model test chamber is shown in Figure 1. The geogrid flexible reinforced soil wall was 3.0 m in length, 0.8 m in width and 2.0 m in height. The cross section of geogrid flexible reinforced soil wall is shown in Figure 2. The geogrid flexible reinforced soil wall was constructed layer by layer. The number of layers was marked from bottom to top.



Figure 1. A photograph of the model test of geogrid reinforced soil wall.

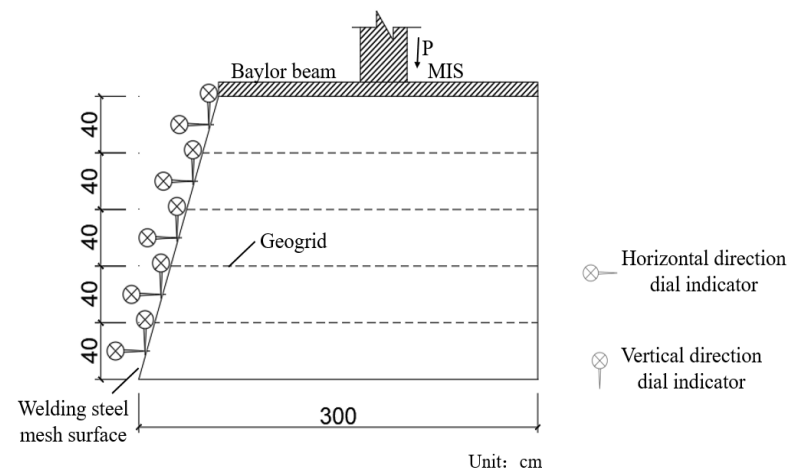


Figure 2. The size and layout of the reinforced soil wall in the model box.

The filling material was derived from weathered argillaceous red sandstone. Red sandstone presents the characteristics of low natural strength, easy disintegration and crushing in water, softening of strength, dehydration and cracking. Based on engineering geological data and indoor geotechnical tests, the main physical and mechanical properties of the filler are shown in Table 1. The reinforced soil wall was filled using five layers inside the model box, and it was compacted at a 95% compaction degree.

Table 1. Basic physical and mechanical parameters of the filling material.

Proportion	Cohesion, kPa	Internal Friction Angle, °	Maximum Dry Density, $\text{g} \times \text{cm}^{-3}$	Optimum Moisture Content, %	Liquid Limit, %	Plastic Limit, %	Plasticity Index
2.74	25	21	1.73	18.1	41.8	25.1	16.7

The wall face of the geogrid flexible reinforced soil wall was formed using geogrid, geomembrane and steel mesh. Specifically, the flexible reinforced soil wall took the steel mesh surface as the wall face skeleton, and the face wall was formed using a geogrid inverted with a geomembrane. The angle between the steel mesh and the horizontal plane could be adjusted according to the actual needs of the project (which is about 73° in this test). Each layer of geogrid was firmly connected to the welded steel mesh surface, and the geotextile was laid inside to prevent leakage of the fill. A lap length of 30~50 cm was set between the adjacent soil geogrid, and they were firmly attached by connected rods. The structural diagram of each layer of the reinforced soil wall is shown in Figure 3. The unidirectional high density polyethylene HDPE geogrid was used. The relevant parameters of the geogrid according to the tensile test, are shown in Table 2, and a photograph of the tensile test is shown in Figure 4. The deformation of the geogrid flexible reinforced soil wall was measured by dial indicators. The horizontal and vertical dial indicators were installed in the center of each layer of the wall panel to investigate the lateral and vertical deformation.

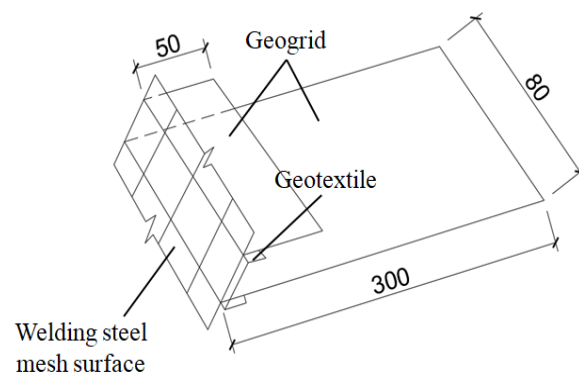


Figure 3. Schematic diagram of each layer of reinforced soil wall.

Table 2. Main physical parameters of geogrid.

Rib Thickness, cm	Maximum Elongation, %	Tensile Force at 2% Elongation, $\text{kN} \times \text{m}^{-1}$	Tensile Force at 5% Elongation, $\text{kN} \times \text{m}^{-1}$	Maximum Tensile Strength, $\text{kN} \times \text{m}^{-1}$
0.27	10.5	25.4	46.0	72.2



Figure 4. A photograph of the tensile test of the geogrid.

2.2. Test Loading Process

The factors affecting the train load were extremely complex, and it was very difficult to determine the traffic load accurately. In order to simplify the calculation, the dynamic

train load could be regarded as a sine wave load or a unidirectional pulse load. In this study, a form of sine wave was adopted to simulate the train load, which could provide an important basis for the safety performance evaluation of geogrid flexible reinforced soil walls.

The MTS servo exciter was used to apply the dynamic train load. The magnitude and speed of the train load could be reflected by the dynamic stress amplitude and frequency of the servo exciter. In this study, the load frequencies applied on top of the reinforced soil walls were 2, 4, 6, 8 and 10 Hz to simulate different train speeds, and the dynamic stress amplitudes were 30–60 kPa, 40–80 kPa, 50–100 kPa and 60–120 kPa, respectively. The amplitude of dynamic stress basically corresponded to the measured dynamic stress of the Daqin Railway line, the Chengkun Railway line, the Baocheng Railway line and the test results of Yang et al. [40], as shown in Table 3.

Table 3. Dynamic stress range of subgrade subjected to dynamic load.

Test Site	Daqin Line	Baocheng Line	Chengkun Line	Yang et al. [40]	This Study
Dynamic load distribution range, kPa	20–110	30–120	40–100	40–100	30–120

The loading method on top of the geogrid flexible reinforced soil walls is shown in Table 4. In order to study the long-term service condition of geogrid flexible reinforced soil walls, the cumulative number of repeated loads on top of the reinforced soil wall reached 200×10^4 times.

Table 4. Loading system of the flexible mesh geogrid reinforced soil wall.

Loading Order	Amplitude, kPa	Frequency, Hz	Loading Times, 10^4 Times	Cumulative Loading Times, 10^4 Times
1	30–60	4	10	10
2		6	10	20
3		8	10	30
4		10	20	50
5	40–80	4	10	60
6		6	10	70
7		8	10	80
8		10	20	100
9	50–100	4	10	110
10		6	10	120
11		8	10	130
12		10	20	150
13	60–120	4	10	160
14		6	10	170
15		8	10	180
16		10	20	200

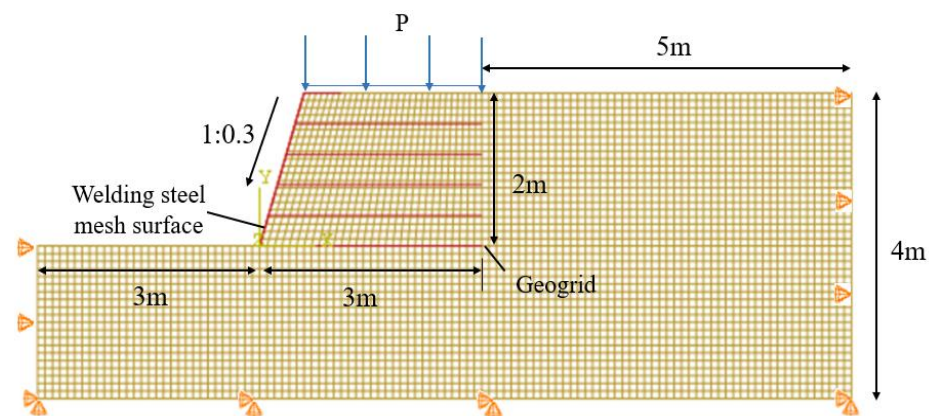
3. Numerical Simulation

The finite element analysis software ABAQUS 2020 was used to establish the geogrid flexible reinforced soil wall according to the size and arrangement of the test model. The angle between the surface wall of the reinforced soil wall and the horizontal plane was about 73° , and the height of the reinforced soil wall was 2 m ($H = 2$ m). The geogrid was used to pack the filler, and a layer of steel mesh was arranged on the surface wall and welded to the geogrid. The reinforced soil wall was divided into five layers, with a height of 40 cm for each layer. The parameters of each material are shown in Table 5.

Table 5. Reinforced slope model material parameters table.

Material	Density, $\text{g} \times \text{cm}^3$	Cohesion, kPa	Internal Friction Angle, °	Elastic Modulus, MPa	Poisson Ratio
Filler	1.8	25	21	35	0.3
Steel mesh	2.2	—	—	100	0.3
Geogrid	2.5	—	—	1400	0.33

In order to eliminate the influence of boundary effect, the size of the reinforced soil wall was enlarged. The geogrid flexible reinforced soil wall was enlarged by 3 m on the left side and 5 m on the right side. The lower part of the reinforced soil wall was increased by 2 m. The horizontal displacement on the left and right sides of the model was limited, as were the horizontal and vertical displacement at the bottom. The quadrilateral high-order algorithm was adopted to simulate the filler, and the element type CPE4 was used for the meshing. The side length of the quadrilateral was set to 0.1 m. The element type T2D2 was used to simulate the geogrid and steel mesh, and the length was set to 0.1 m. The filler, geogrid and steel mesh were divided into 3880, 163 and 21 units, respectively. The model was divided into 4064 units. The finite element model of the reinforced soil wall is shown in Figure 5. The loading process was consistent with that in the model test.

**Figure 5.** Finite element model of the reinforced soil wall.

4. Results and Analysis

4.1. Dynamic Deformation

The curve of cumulative lateral deformation and vertical deformation (settlement) of the geogrid flexible reinforced soil wall with the vibration number of the train load in the model box test is shown in Figure 6. The curve of the cumulative lateral deformation of the wall face along the height of the reinforced soil wall in the model box test is shown in Figure 7.

It is seen that the cumulative lateral deformation and vertical deformation (settlement) are significantly affected by the number of vibrations and the amplitude of the dynamic stress. When the dynamic stress amplitude increases, the cumulative lateral deformation and vertical deformation (settlement) of the wall present a certain degree of mutation. Due to the effects of the steel mesh surface and the geogrid, the cumulative lateral deformation is less than the cumulative vertical deformation (settlement) under the same amplitude and vibration time. When the number of vibrations increases, the cumulative lateral deformation changes little, and the cumulative vertical deformation (settlement) changes greatly. Under the same dynamic stress amplitude, when the vibration frequency changes, the cumulative lateral deformation and vertical deformation (settlement) do not change significantly.

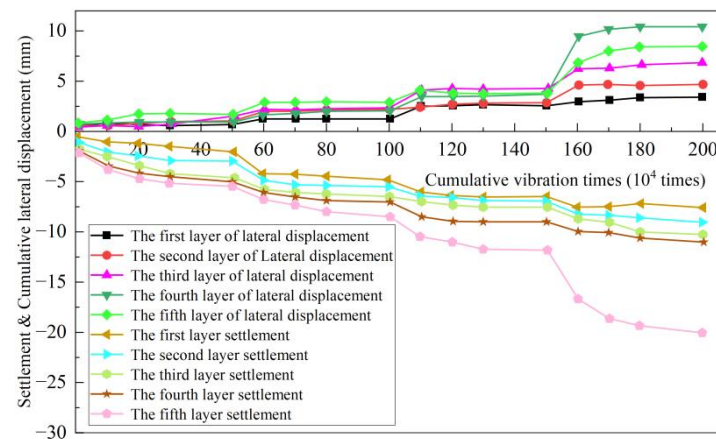


Figure 6. The cumulative lateral and vertical deformation of wall in model test.

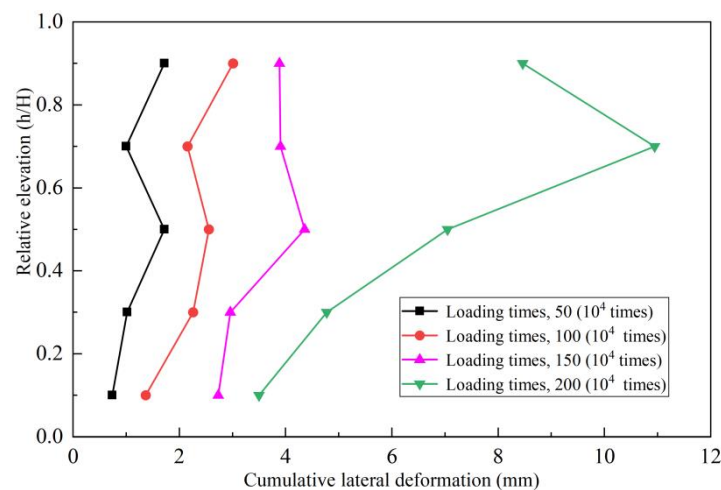


Figure 7. The cumulative lateral deformation curve of the wall with the height of the wall.

The cumulative lateral deformation value changes abruptly after 150×10^4 times. Before the cumulative vibration of 150×10^4 times, the values of cumulative lateral deformation of the third and the fifth layer of the reinforced soil wall are close, and both reach the maximum value. After 150×10^4 times of cumulative vibration, the maximum cumulative lateral deformation occurs on the fourth layer of the wall face, and the wall face appears to bulge in the middle. After 170×10^4 times of cumulative vibration, the cumulative lateral deformation tends to be stable. When the cumulative vibration is 200×10^4 times, the maximum cumulative lateral deformation is approximately 10.5 mm. It is defined that the maximum lateral deformation ratio is determined as a ratio of the maximum lateral deformation to the total height of the reinforced soil wall. It is seen that the maximum lateral deformation ratio is less than 0.4%.

The maximum cumulative vertical deformation occurs on the fifth layer. When the cumulative vibration is 150×10^4 times, the cumulative vertical deformation value also changes abruptly. After 170×10^4 times of cumulative vibration, the cumulative vertical deformation changes little, and there is no stable trend. When the cumulative vibration is 200×10^4 times, the maximum cumulative vertical deformation is approximately 20 mm, and the maximum vertical deformation ratio is approximately 1%.

The curves of the cumulative lateral deformation and vertical deformation (settlement) of the reinforced soil wall, with the vibration number of the train load based on numerical simulation, are shown in Figure 8. The curve of the cumulative lateral deformation of the wall with the height of the wall is shown in Figure 9.

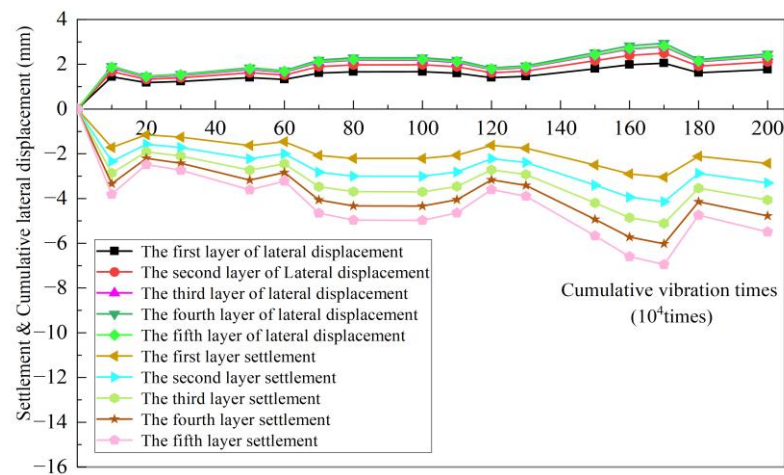


Figure 8. The cumulative lateral and vertical deformation of wall in numerical simulation.

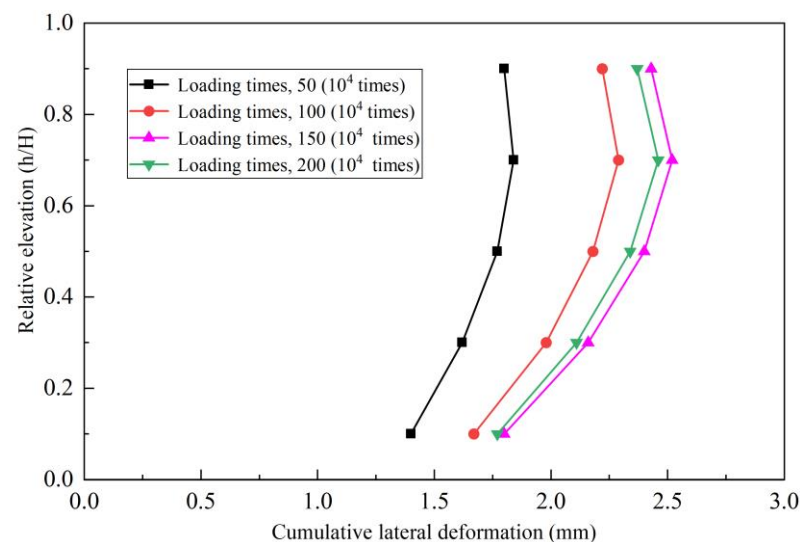


Figure 9. The cumulative lateral deformation curve along the height of the wall.

It is seen that the cumulative lateral deformation and cumulative vertical deformation (settlement) are significantly affected by the number of vibrations and the amplitude of dynamic stress and vibration frequency. With the increase in vibration times and dynamic stress amplitude, the cumulative lateral deformation and cumulative vertical deformation (settlement) change regularly. The change in cumulative lateral deformation is not so obvious, while the change in cumulative vertical deformation (settlement) is significant. Under the same amplitude and vibration times, the cumulative lateral deformation is less than the cumulative vertical deformation (settlement). Under the same dynamic stress amplitude, when the vibration frequency changes, the cumulative lateral deformation and vertical deformation (settlement) also change significantly.

The maximum cumulative lateral deformation appears on the fourth layer. As the height increases, the cumulative lateral deformation increases first, then decreases. The phenomenon of bulging along the wall face appears in the middle, which is consistent with the result of the model test. The maximum value of cumulative vertical deformation appears on the fifth layer. Thus, the cumulative lateral deformation and vertical deformation do not present a stable trend.

When the number of train load vibration reaches 130×10^4 times, both the cumulative lateral deformation and the vertical deformation present an obvious increment. When the cumulative vibration is 170×10^4 times, the cumulative lateral deformation and vertical

deformation reach their maximum value. The maximum cumulative lateral deformation is approximately 3 mm, and the deformation ratio, approximately 0.1%. The maximum cumulative vertical deformation is approximately 7 mm, and the deformation ratio is less than 0.4%.

The following conclusions can be drawn based on the model test and the numerical simulation:

1. As a flexible structure, the dynamic deformation of the geogrid flexible reinforced soil wall is relatively small after 200×10^4 times of vibration. Both the cumulative lateral deformation ratio and the cumulative vertical deformation (settlement) ratio are less than or equal to 1%.
2. When the dynamic stress amplitude increases, the cumulative lateral deformation and vertical deformation (settlement) present a certain degree mutation. Under the dynamic stress level of 60–120 kPa, when the cumulative vibration reaches 150×10^4 times, both the cumulative lateral deformation and the vertical deformation suddenly change again.
3. Due to the function of steel mesh and geogrid, under the same amplitude and vibration time, the cumulative vertical deformation is greater than the cumulative lateral deformation, and the vertical deformation (settlement) of the fifth layer (top surface) is greater than the maximum lateral deformation. Before the cumulative vibration reaches 150×10^4 times, the cumulative lateral deformation of the wall face at 0.5 H (i.e., the third layer, $H = 0.5$ m) and 0.9 H (i.e., the fifth layer) is close. When the cumulative number of vibrations reaches 170×10^4 times, the changes in both the cumulative lateral deformation and the vertical deformation of each layer tends to be gentle, and the cumulative lateral deformation at the height of 0.7 H (i.e., the fourth layer) is the largest. The maximum cumulative lateral displacement occurs on the third, the fourth, or the fifth layer.
4. During the test, the vertical displacement (settlement) of the fifth layer (top surface) of the reinforced soil wall is greater than that of other layers. This is mainly because the closer to the loading position, the greater the absolute vertical displacement (settlement) will be.
5. With an increase in the amplitude of the dynamic train load, the development of dynamic deformation gradually increases. The initial growth is slow, and then it gradually accelerates.
6. The main factors affecting the dynamic deformation characteristics of geogrid flexible reinforced soil walls include the amplitude of dynamic load, the vibration frequency, and so on.

4.2. Vertical Earth Pressure

The curve of the vertical earth pressure in the middle of the third layer of the geogrid flexible reinforced soil wall with the vibration time of the dynamic train load is shown in Figure 10. The vertical earth pressure distribution in the middle of each layer of the reinforced soil wall after cumulative vibration of 200×10^4 times is shown in Figure 11. From these, the following conclusions have been drawn:

1. With an increase in the vibration times, the vertical earth pressure distribution trend of the third layer of the reinforced soil wall is basically the same, and the vertical earth pressure value is almost unchanged. It shows that the effect of vertical earth pressure is not significantly affected by the vibration frequency and the loading times.
2. With an increase in distance from the wall face, the vertical earth pressure of the first layer of the geogrid flexible reinforced soil wall decreases first, then increases. Within a horizontal distance of 0.5 m to the wall face, the vertical earth pressure gradually decreases. The vertical earth pressure increases gradually when the distance from the wall face is more than 0.5 m.
3. With an increase in distance from the wall face, the vertical earth pressure of the second, third and fourth layers of the geogrid reinforced soil wall gradually increases,

and the increase ratio gradually slows. With an increase in height, the increment of vertical earth pressure decreases. Within a horizontal distance of 3.0 m to the wall face, the vertical earth pressures of the second, third and fourth layers of the reinforced soil wall increase by 4.3 kPa, 2.8 kPa and 2.0 kPa, respectively.

4. On the third layer of the reinforced soil wall, the vertical earth pressure increases rapidly with an increase in the height of the overlying soil. The vertical earth pressure behind the wall face is approximately 15 kPa, which is mainly due to the flexible adjustment of the geogrid and steel mesh. Subsequently, the vertical earth pressure in the reinforced soil is adjusted.
5. With an increase in the horizontal distance to the wall face, the vertical earth pressure of the fifth layer of the reinforced soil wall is basically unchanged, although the distance from the fifth layer to the top surface is only 0.2 m. The effect of the geogrid is not strong, so the vertical earth pressure remains stable.

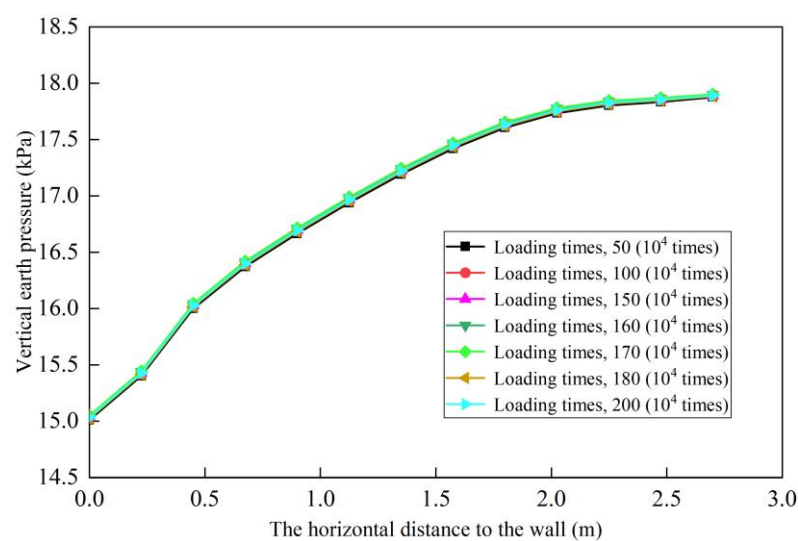


Figure 10. The curve of vertical earth pressure of the third layer.

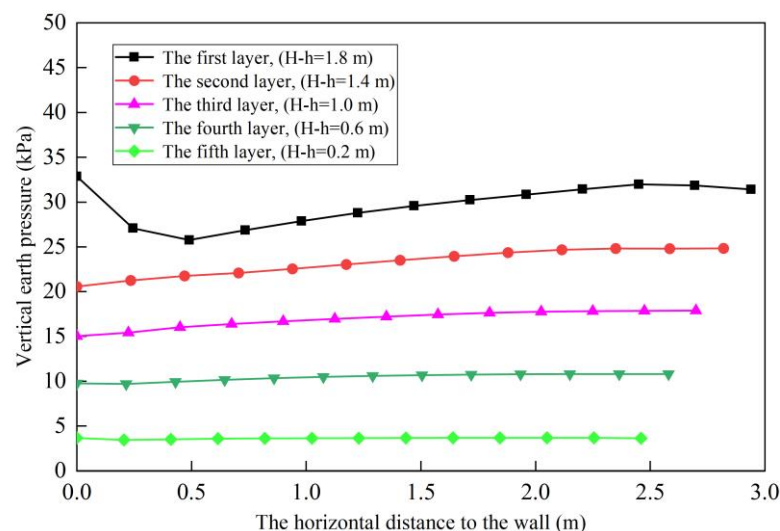


Figure 11. Distribution of vertical earth pressure behind the reinforced soil wall.

4.3. Reinforcement Strain

The curve of the reinforcement strain of the third layer versus the vibration time is shown in Figure 12. The distribution of the reinforcement strain after a cumulative vibration of 200×10^4 times is shown in Figure 13.

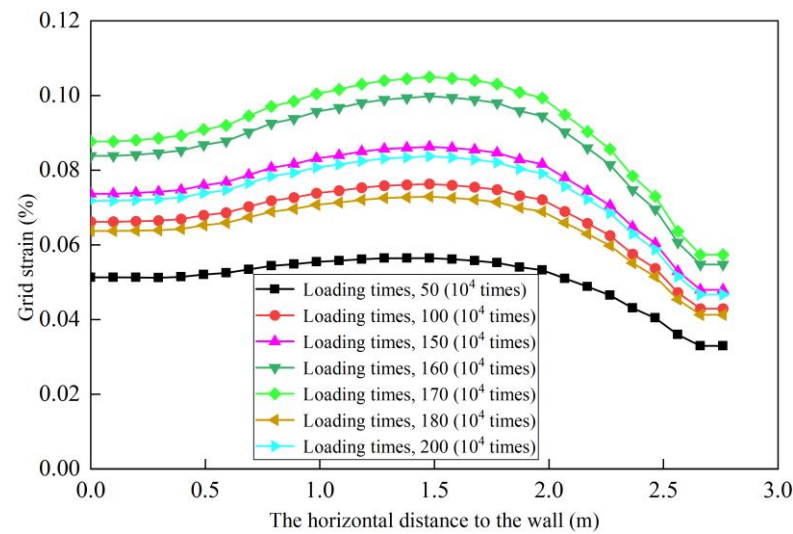


Figure 12. Reinforcement strain of the third layer.

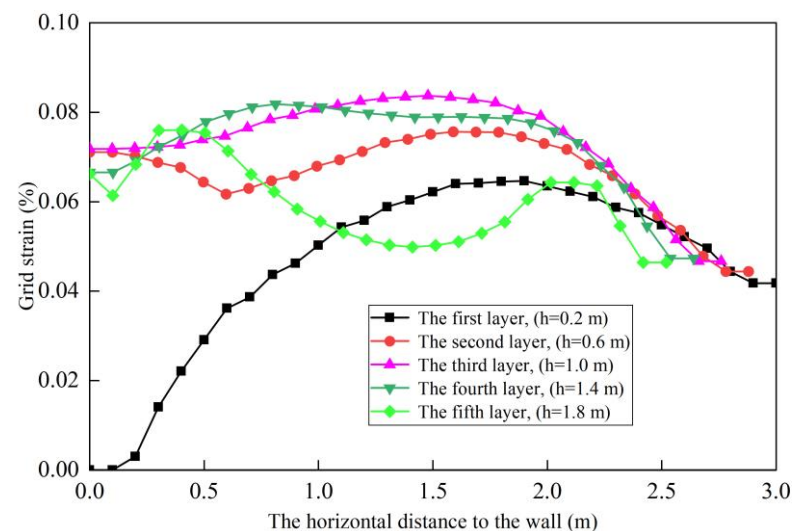


Figure 13. Distribution of reinforcement strain of the geogrid.

It was seen that with the increase in the vibration time, the change trend of the reinforcement strain of the third layer increases first, then decreases. With the increase in dynamic stress amplitude, the strain of the geogrid increases. Under the same dynamic stress amplitude (60–120 kPa), when the cumulative vibration number increases from 160×10^4 times to 200×10^4 times, the change in the reinforcement strain of the third layer is large, and the change law is complex, indicating that the reinforcement strain presents a significant correlation to the dynamic stress amplitude, vibration time and vibration frequency.

After a cumulative vibration time of 200×10^4 , with the increase in the distance from the wall face, the variation law of the reinforcement strain is different. The strain of the geogrid changes under the function of dynamic train load. Combined with the change law of vertical earth pressure, it is seen that the geogrid plays a favorable role of a flexible deformation characteristic. The maximum strain of the geogrid reinforcement is about 0.1%, and there is a high safety reserve for the geogrid.

5. Discussion

When the reinforced soil works under the condition of small strain amplitude, the reinforced soil presents a characteristic of approximate elastomer. When the amplitude of

dynamic load increases, the reinforced soil structure will be changed, which will cause a residual deformation or a strength loss in the reinforced soil. The dynamic characteristics of reinforced soil at a large strain amplitude are different to that of a small strain amplitude.

It is seen that the dynamic deformation characteristics of reinforced soil wall are affected by factors including the dynamic load amplitude, the vibration time and the filling density. In addition, the initial density, humidity, reinforcement degree, initial stress state, engineering characteristics of filling soil and other factors of reinforced soil will also affect the dynamic deformation characteristics. With the increase in dynamic load amplitude, the number of vibrations for achieving stable deformation increases, and the deformation value also increases. The development of dynamic deformation increases with the increase in vibration duration, the initial growth is slow, and then it gradually becomes faster.

When the dynamic load is small (small amplitude or short duration), the reinforced soil structure experiences only slight damage, and the deformation of the reinforced soil is mainly caused by the vertical displacement of the soil particles. When the strength of dynamic load exceeds the yield dynamic strength, the deformation increases obviously, and the influence of deformation of the reinforced soil increases gradually. When the ultimate dynamic strength is reached, the deformation of the reinforcement increases rapidly, which means that the reinforcement may be pulled out or broken.

6. Conclusions

1. When the dynamic stress amplitude increases, the cumulative lateral deformation and vertical deformation (settlement) of the wall face presents a certain degree of mutation. The main factors affecting the dynamic deformation characteristics of flexible geogrid include vibration frequency, dynamic load amplitude, the number of vibrations, and so on. As a flexible structure, the dynamic deformation of the geogrid flexible reinforced soil wall is relatively small after a cumulative vibration time of 200×10^4 . The cumulative lateral deformation ratio and the cumulative vertical deformation ratio of the wall face are less than 1%.
2. With the increase in dynamic load amplitude, the development of dynamic deformation gradually increases. The initial growth is slow, then it gradually becomes faster. Under the same amplitude and vibration time, the vertical deformation is greater than the lateral deformation. The maximum cumulative lateral deformation occurs in the third, fourth, or fifth layers. The maximum cumulative vertical deformation appears in the fifth layer (top layer).
3. The response of vertical earth pressure is not significantly affected by the vibration time or vibration frequency, but the response of reinforcement strain of the geogrid is sensitive to vibration time, dynamic stress amplitude and vibration frequency.

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