Management Innovation, and Practice Journal
ISSN 3065-1417
Volume 11 Issue 3
July-September 2023
Impact Factor: 6.85
Enquiry: contact@continentalpub.online
Published by Continental Publication | https://cspjournals.org/index.php/Management

THERMODYNAMIC INSIGHTS INTO EARTHQUAKE-INDUCED STRUCTURAL DAMAGE

Chen Xiu Ling
Information Center, Liaoning Earthquake Agency, Shenyang, Liaoning, China

Abstract: *Earthquakes are recurrent and devastating natural disasters that result from a combination of natural and human factors. They often lead to the collapse of entire regions, endangering lives and causing significant damage to property. Areas prone to earthquakes are predominantly characterized by geological conditions comprising rock aggregates, making earthquake-induced landslides a prevalent and hazardous geological disaster. The complex composition of soil-rock mixed slopes complicates the understanding of their failure mechanisms, particularly in the context of earthquakes, where they pose a substantial threat to human safety. This research delves into the intricate and dynamic process of studying soil-rock mixed slopes under earthquake conditions. Employing the thermodynamic principle as its foundation, this study investigates the behavior of soil-rock mixed slopes during seismic events, offering a crucial technical framework for experimental endeavors while ensuring their feasibility. The research utilizes the FLAC3D program to construct a three-dimensional model, creating a virtual environment that facilitates in-depth experimentation. The simulation experiments with this three-dimensional model enhance the credibility of the collected data. Analyzing the destructive tendencies of soil-rock mixed slopes during earthquakes holds pivotal significance. By gaining insights into their behavior, this research contributes to landslide prevention, reduces the incidence of natural disasters, and lays the experimental groundwork for future investigations into earthquake-soil-rock mixed slopes.*

Keywords: *Earthquake, Soil-Rock Mixed Slopes, Landslide Prevention, Seismic Behavior, Geotechnical Analysis*

1. Introduction

1.1 Background Meaning

Earthquake is one of the most common natural disasters, are usually caused by natural factors or human factors, and is likely to cause the collapse of the severe earthquake zone. Life and property of the state and people to the frequent occurrence of earthquake safety caused serious losses, the geological conditions of the earthquake area, mostly rock aggregate, mixing earthquake-induced landslide slope debris is one of the main types of geological disasters. Due to the uneven material composition of the soil-rock mixed slope, its failure mechanism is not clear. The soil-rock mixed slope will pose a huge threat to people under the action of an earthquake. The research on the damage analysis of the soil-rock mixed slope under the earthquake is particularly important.

It is an extremely complicated dynamic process to study the mixed slope of earth and rock under the action of earthquake. Based on the thermodynamic principle, this paper studies the mixed slope of earth and stone under the action of earthquake, which provides a good technical basis for the experiment and guarantees the possibility of the experiment. The experiment USES FLAC3D program to build a research model, which provides a three-dimensional virtual research environment for the experiment. The simulation experiment with three-dimensional model makes the experimental data more convincing. The study on the destructive analysis of earth-rock mixed slope under the action of earthquake can prevent the slope from landslide, reduce the occurrence of natural disasters, and provide the experimental basis for the related research on the earthquake-earth-rock mixed slope in the future.

1.2 Related Work

At present, many scholars have analyzed the stability of the earth rock mixed slope under earthquake. In order to study the dynamic characteristics of rock slope under earthquake action and the influence of tunnel structure, Niu established a dynamic numerical simulation model of soil slope, and verified the effectiveness of the simulation through shaking table model test [1]. Based on the upper bound limit analysis method, Yin proposed a soil slope collapse model consisting of two rigid blocks and a plastic shear band. Yin analyzed the velocity and force of the three blocks, and obtained the expression of velocity discontinuity according to the principle of incompressibility, and solved the external force work of the block, the internal energy and velocity discontinuity of the plastic shear band [2]. Sun has carried out physical and mechanical tests of air-dried soil accumulation slope mixed accumulation slope, and carried out the generalized rsmd slope centrifuge shaking table model test at the geometric scale of 1:50. He analyzed the under four different earthquake intensities, and carried out dynamic finite difference numerical simulation of centrifugal model test by FLAC software [3]. Liu discusses the initial failure of rock slope in stability analysis of rock slope based on two-phase random media and finite element method [4]. Zhuang used the transparent soil technique to study the soil, and analyzed the soil mass [5]. However, there are some shortcomings in the methods used in the above research. Niu's method is too one-sided and the experimental data is not comprehensive. Yin's method needs too much data to calculate and the calculation process is too complex. The cost of sun's method is too high, the process of data acquisition by Liu's method is too complex, and the experimental data obtained by Zhang's method are wrong.

1.3 Innovation of this Paper

In this paper, the first law of thermodynamics is used to study the destructive analysis of soil rock slope under earthquake action. A soil rock mixed slope model is constructed by FLAC3D program. The dynamic load is used to replace the force brought by seismic wave on the slope. The data in the model are calculated and analyzed according to relevant calculation methods and formulas. FLAC3D program "mixed discretization" can accurately simulate slope shaping destruction and mobility, and the use of dynamic equations of motion can be solved to calculate the numerical value obstacles experimental research.

2. Related Techniques and Methods for Destructive Analysis of Soil Rock Slope under Earthquake Action

2.1 Thermodynamic Principle

Thermodynamics is a discipline that studies the thermal motion of matter by using the principle of energy conversion [6]. Thermodynamics puts forward the laws that should be followed when energy is transformed from one form to another, and summarizes the thermodynamic theory according to this phenomenon [7]. Thermodynamics mainly embodies the heat phenomenon and its change law of the whole system. While conducting energy conversion, substances must also follow some thermal laws applicable to all phenomena, and then calculate the basic characteristic data of materials according to these thermal laws, and obtain the correlation between materials and other research results [8-9]. The law of energy transfer in thermodynamics is also known as the law of thermal balance. It mainly takes temperature as the basis for the description of the thermal balance of an object, and explains the definition of temperature and the measurement method of temperature. The zeroth law of thermodynamics is widely used in the production of thermometers, and the thermometer used in daily life is made by using the zeroth law of thermodynamics [10]. It mainly embodies the conservation of energy in the process of energy transfer and transformation, which is summarized as the law of conservation of energy. The first law of thermodynamics has a wide range of applications in energy utilization and development. Its relevant expression is:

$$\Delta U = Q + W \quad (1)$$

In formula (1), ΔU is the sum of the increase of internal kinetic energy D and the increase of internal energy N, Q is the heat absorbed by the material from the external system, and W is the work done by the external system to the matter. In the infinitesimal thermodynamic process, V_m is the volume of the material, s S_m is the surface area of the material, k is the heating rate of heat radiation, H is the L-heat flux vector, G is the external normal vector of the surface area of the material, the heat conductivity is r, ρ_0 is the density of the material, x is the vector of the force on the unit volume, v is

the particle velocity, Z is the stress tensor, and ∇ is the gradient operator. The calculus form of the first law of thermodynamics can be expressed as follows:

$$\rho 0 \,(D+N) = \rho 0 \, xv + (xZ)\nabla + \rho 0 k - H\nabla \quad (2)$$

The second law of thermodynamics explains and defines the direction, condition and limit of energy conversion. It means that heat can only be transferred from high energy to low energy, and this phenomenon is irreversible. And the system from the final shape to the initial state must rely on the role of the outside world. In the second law, temperature *t* and entropy *E* are generally used to describe the properties. Entropy is a state function in thermodynamics, which can be divided into two parts: the external entropy supply E_s of the system and the internal entropy production E_p of the system.
Moreover, the total entropy of a system is equal to the sum of the entropy of each part:

$$E = E_s + E_p \quad (3)$$

The supply entropy is the ratio of the heat *Q* absorbed by the system from the outside to the absolute temperature *t* of the system:

$$Es = Q/t \quad (4)$$

In the reversible process, the entropy value is equal to 0. Therefore, and all thermodynamic processes that occur in a system do not have entropy decrease.
The third law of thermodynamics said at absolute zero, the entropy of all perfect crystal of pure substance is zero. Another expression of the third law of any system is impossible to achieve absolute zero by the limited steps. In thermodynamics, the third law is usually used to calculate the coefficient of thermal expansion. For any substance, when its temperature tends to absolute zero, its thermal

expansion coefficient will also tend to zero. Therefore, the expression of the thermal expansion coefficient can be expressed as:

$$\alpha=\frac{1}{V_m}\left(\frac{\partial V_m}{\partial t}\right)_p \qquad (5)$$

According to Max-well's relation, we can get the following conclusions

$$\left(\frac{\partial V_m}{\partial p}\right)_p=-\left(\frac{\partial s}{\partial p}\right)_t \qquad (6)$$

t is the temperature, V_m is the volume, s is the entropy, and p is the pressure.

2.2 Earthquake Action

Earthquake is a natural phenomenon caused by crustal movement. It is easy for earthquake to cause dislocation and fracture of plate boundary and interior, and rupture, bending and other damages of surface mixed rocks, thus leading to instability of rock internal structure and collapse of slope [11-12]. The movement of the earth's crust causes the plates of the earth to collide and squeeze each other, which in turn causes the crust to vibrate and produce seismic waves. Soil movement refers to the vibration of soil surface caused by seismic waves released from the source. The seismic load is different from the conventional load, which generally appears in the form of force, and its magnitude and direction are determined. The seismic load appears in the form of motion, and its magnitude and direction are random [13]. In experiments on seismic studies, researchers usually use amplitude, spectrum characteristics and duration to describe the characteristic parameters of seismic waves. Acceleration of seismic wave can be used to represent the amplitude of directly reflects the intensity of earthquake; spectrum is a curve used to reflect the relationship between amplitude [14-15]. Any material in the environment has its own unique natural vibration period, which will produce different degrees of vibration in the earthquake load, thus causing different degrees of disaster. Therefore, spectral analysis of seismic waves is of great significance for earthquake prevention [16-17]. At present, Fourier spectrum and power spectrum are usually used to analyze the spectrum of seismic waves in experimental research. The duration of seismic waves is also a very important parameter in seismic research experiments. The longer the duration of ground motion is, the more destructive the earthquake will be and the more serious the damage to the environment will be.

The spectrum characteristics of seismic wave can be obtained by analyzing the spectrum of seismic wave in experimental research, and the frequency distribution characteristics of ground motion can be seen intuitively by using the spectrum map, and the energy of earthquake can be linked with the frequency. Seismic waves are not invariable, people cannot determine the characteristics of seismic waves through a single study, and its spectral characteristics are very complex. If scientific methods are used to decompose seismic waves, many sine waves of different frequencies can be obtained. In experimental studies, seismic waves with complex wave-forms are usually decomposed into simple harmonics of different frequencies and amplitudes, and the horizontal and vertical coordinates of frequency and corresponding amplitudes are established. Finally, the relationship curve between frequency and amplitude is called the spectrum diagram of seismic waves. Using this method, the researchers were able to convert a random, complex seismic wave signal into one that varies with frequency. We usually use the Fourier transform and its inverse transform to analyze the correlation of the spectrum of seismic waves and obtain the spectrum diagram of seismic waves.

Since the Fourier series of longitudinal multi harmonic component can represent periodic function and Fourier integral can represent aperiodic function, the Fourier integral form of strong earthquake acceleration composed of aperiodic function can be expressed as follows:

$$A(x)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}H(t)e^{-2j\pi xt}dt \quad (7)$$

$A(x)$ can be composed of real number $R[A(x)]$ and imaginary number $I[A(x)]$. After conversion, the formula of Fourier amplitude spectrum can be obtained:

$$A'(x)=|A(x)|=\sqrt{(R[A(x)])^2+(I[A(x)])^2} \quad (8)$$

The power spectrum $G(x)$ can be expressed as:

$$G(x)=\lim_{T\to\infty}\frac{2\pi}{T}|A'(x)|^2 \quad (9)$$

Intensity of production activities has also increased, and people's impact on the natural environment is also more and more profound. All the improper land development for economic construction will cause the destruction of slope body, intensify the reconstruction of slope body, and lead to the deterioration of the stability of slope body.

2.4 FLAC3D Program

FLAC3D program is one of the important methods used to simulate the physical properties of or other materials and to calculate the numerical values of rock and soil mechanics [23]. FLAC3D program is widely used in slope stability evaluation, construction design, valley evolution, tunnel engineering and other fields. The FLAC3D program first calls the motion equation to obtain the new velocity and displacement from the stress and external force, and then obtains the new strain rate and new stress according to the new velocity. FLAC3D program has good data processing function and accurate and effective computing advantages. Based on the principle of finite difference, it USES the "mixing-discrete partition" technology to simulate the mixed soil and stone slope in real life, which can accurately simulate the plastic flow and failure of the slope [24-25].

3. **Data Collection and Experimental Design of Soil Rock Slope**

3.1 Data Collection

According to the subject of this study, the experiment searched and read relevant studies on the destructive analysis of earth-rock mixed slope under earthquake action in the past five years. According to the studies of these scholars, we used FLAC3D program to study the destructive analysis of earth-rock mixed slope under earthquake action based on the principle of thermodynamics. First of all, the experiment set the influencing parameters in the destructive analysis of the soil and stone mixed slope. The experimental parameters include the mixing amount of block stone, lateral limiting pressure and block stone shape of the soil and stone mixed slope. The specific parameter settings are shown in Table 1.

Table 1. Parameters of mixed soil and stone slope

Experimental parameters	Value	Experimental parameters	Value
Stone content	0%	Limiting pressure	100KPa
	10%		200KPa
	20%		300KPa
	30%	Shape of block stone	Crushed stone
	40%		
	50%		Pebble
	60%		

According to the data in Table 1, we can see that the mixture of earth and stone in the slope in this experiment has a mixture of block stone content between 0% and 60%, and the side limit pressure of the slope is 100KPa, 200KPa and 300KPa. The shape of block stone can be divided into two types: gravel and pebble.

3.2 Numerical Calculation of Soil Rock Slope by FLAC3D Program

In this paper, FLAC3D program is used to study the soil rock slope under earthquake action. Firstly, the mesh size L of the model should be determined, and the grid size must be within the range of constraints

$$L \leq [\frac{1}{8} \sim \frac{1}{10}]\lambda \quad (10)$$

$$\lambda = \frac{v}{f} \quad (11)$$

The FLAC3D program can apply loads to the boundary or internal nodes of the model to simulate the tilt response under external or internal dynamics. The dynamic load input allowed in the program includes and concentrated force time history of seismic waves. This kind of research also needs to calculate and analyze the damping of matter. In dynamic problems, it is necessary to use the FLAC3D program. The damping forms involved in FLAC3D dynamic calculation include Rayleigh damping, local damping and hysteretic damping. Rayleigh damping is mainly used in dynamic calculations to weaken the amplitude of the natural vibration mode of the system.

In the calculation process, it is assumed that the damping matrix is U, the mass matrix is V, dynamic problem can be expressed as:

$$a_1 = \pi D \quad (12)$$

$$U = aV_1 + a_2 K \quad (13)$$

The critical damping ratio ϕ_i of any frequency f_i can be expressed as:

$$a_1 + a_2 f_i^2 = 2 f_i \phi_i \quad (14)$$

$$\phi_i = \frac{1}{2}\left(\frac{a_1}{f_i} + a_2 f_i\right) \quad (15)$$

Local damping is the application of damping to the equation of motion (16), where $R_i w$ is the damping, $w_i w$ is the generalized unbalanced force, and v is the generalized velocity:

$Ri\ w + wi\quad w = V\ w\ (dvi\ )\ w$ ⟨ ⟩ (16) ⟨ ⟩ dt ⟨ ⟩ ___ ⟨ ⟩

In the hysteresis damping, the modulus attenuation coefficient η represents the nonlinear characteristics of the soil. The normalized shear stress w' can be obtained from the modulus attenuation curve, θ is the shear stress, η_1 is the normalized tangent modulus:

$dw'\quad d\eta$

$\eta_1 = \quad = \eta + \theta$ (17) $d\theta \quad d^{\theta}$

___

___

(18)

In the dynamic problem, in addition to the calculation of material damping, it is also necessary to set the boundary conditions. The boundary will reflect the seismic wave and affect the result of dynamic analysis. Therefore, the static boundary and free boundary conditions provided by FLAC3D program can be used to reduce the influence of wave reflection on the analysis results. The static boundary is to set free dampers in the normal and tangential directions of the model to achieve the absorption of the incident wave. v_1, v_2 Are used to represent the normal and tangential velocity components on the model boundary, ρ is the density of the material, S_1, S_2 are the wave velocities of P wave and S wave respectively. Under the boundary conditions, the normal and tangential viscous forces provided by the damper are as follows:

$F1 = a1\ (\rho Si\ )v1$ (19)

(20)

Finally, according to the formula transformation, the normal stress θ_0 and shear stress θ, ω are the amplification factors introduced by the energy loss caused by the external propagation of input wave, and the value range is [1,2]:

$\theta o = \omega\rho(\ S1)v1$ (21) $\theta = \omega\rho(\ S2)v2$ (22)

4. Destructive Analysis of Soil Rock Slope under Earthquake Action

4.1 Dynamic Shear Modulus and Damping Ratio of Soil Rock Mixed Slope

(1)Effect of rock mass content on dynamic shear modulus and damping ratio

Experiments under different confining pressures for earth-rock mixture slope analysis, calculation and statistics of the different dosage of earth-rock mixture slope in the stone of 0% to 60% of the cases of mixed quantity of earth-rock mixture slope stone and dynamic shear modulus and damping ratio, the relationship between statistic results are shown in Table 2.

Table 2. Data changes of dynamic shear modulus and damping ratio in different lump stone content

	Dynamic shear modulus			Damping ratio		
	100KPa	200KPa	300KPa	100KPa	200KPa	300KPa
0%	25	35	40	2.15	1.95	1.9
10%	27	37	47	2	1.9	1.85
20%	50	90	120	1.9	1.8	1.7
30%	75	100	150	1.75	1.7	1.45
40%	90	146	170	1.6	1.5	1.4
50%	93	167	210	1.5	1.45	1.25
60%	97	200	275	1.4	1.25	1.2

According to the data in Table 2, we can see that the dynamic shear modulus of the soil rock mixed slope increases, while the damping ratio of the soil rock mixed slope decreases with. In order to better observe the influence of rock mass content on dynamic shear modulus and damping ratio of soil rock mixed slope, we convert the data in the table into the form of graph for analysis, and the final results are shown in Figure 1.

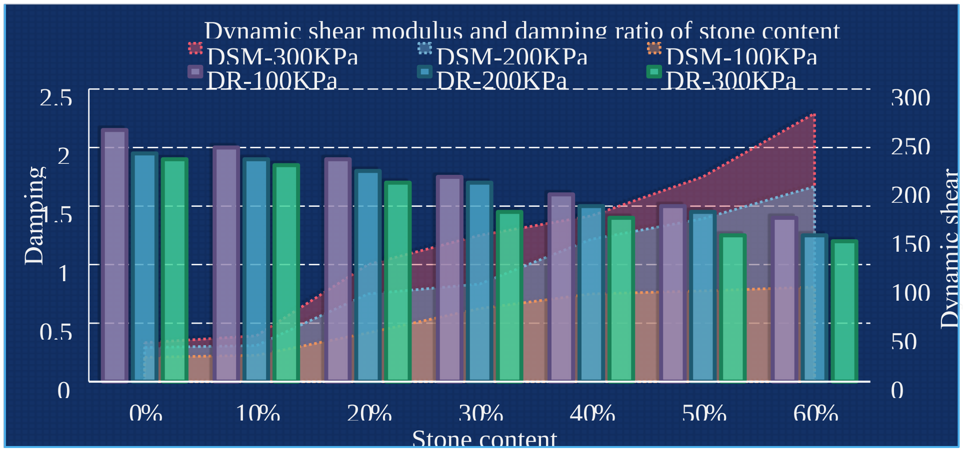

Figure 1. Changes of dynamic shear modulus and damping ratio in different of rock

According to the data in Figure.1, it can be seen that the dynamic shear modulus and damping ratio of the mixed slope with soil and stone are the smallest and the largest when the mass stone content is 0%. The slopes with different lateral limiting pressures are 25KPa, 35KPa and 40KPa respectively, and the damping ratios are 2.15, 1.95 and 1.9 respectively. With the increase of the mixture of soil and stone, the slope increase gradually. When the mixture of block and stone is between 40% and 60%, the increase of dynamic shear modulus of the slope with lateral pressure of 100KPa increases, while that of 300KPa decreases and tends to be stable.

(2)Influence of rock shape on dynamic shear modulus and damping ratio

The mixed slope of earth and stone with gravel and pebble in the experiment was tested, and the dynamic shear modulus under the lateral limiting pressure of 100KPa, 200KPa and 300KPa was calculated and calculated respectively. The final statistical results are shown in Table 3.

Table 3. Influence of block stone shape on shear modulus

	Crushed stone			Pebble		
	100KPa	200KPa	300KPa	100KPa	200KPa	300KPa
0%	24	35	48	27	37	45
10%	25	30	49	31	32	47
20%	48	97	115	56	95	113
30%	77	122	150	85	119	147
40%	86	125	180	91	140	170
50%	90	174	205	97	172	220
60%	95	196	250	99	200	280

According to the data in Table 3 and the dynamic shear modulus of pebble is basically greater than that of gravel. In order to analyze the dynamic shear modulus changes of different stone shapes for observation, and the final result is shown in Figure 2.

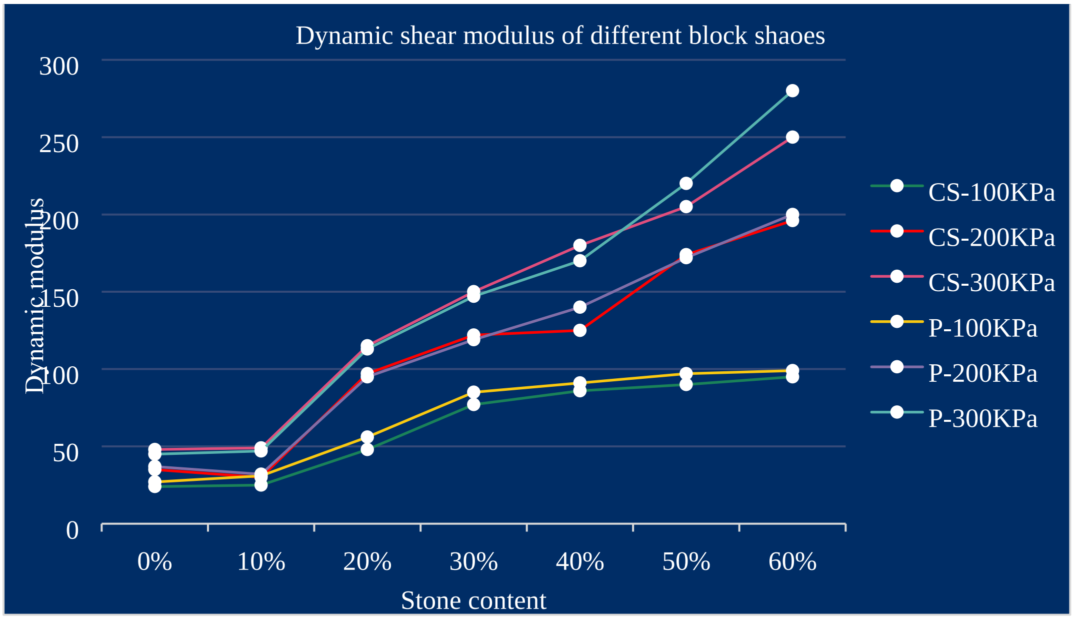

Figure 2. Dynamic shear modulus changes of different rock shapes

According to the data in Figure 2, we can see that the block stone is in the shape of gravel and the dynamic shear modulus of pebble shape of the amount of block stone. The dynamic shear modulus of gravel with confining pressure of 100KPa is always less than that of pebble. The 200KPa of pebble when the content of block stone is 20% ~ 30% and 50%, and it is smaller than that of pebble in other cases. The dynamic shear modulus of gravel with lateral confined pressure of 300kPa is always greater than that of pebble before the content of block stone is 40%, and the gravel is less than that of pebble when the content of block stone is 50% ~ 60%.

For the soil rock mixed slope with different stone contents, the damping of gravel and pebble with lateral limit pressure of 100KPa, 200KPa and 300kPa is shown in Table 4.

Table 4. Effect of block shape on damping ratio

	Crushed stone			Pebble		
	100KPa	200KPa	300KPa	100KPa	200KPa	300KPa
0%	2.15	2	1.97	2.17	2.1	2
10%	2.01	1.95	1.8	2	1.98	1.83
20%	1.86	1.75	1.7	1.85	1.77	1.72
30%	1.72	1.6	1.5	1.74	1.62	1.53
40%	1.57	1.5	1.45	1.58	1.53	1.44
50%	1.43	1.4	1.3	1.44	1.42	1.31
60%	1.28	1.25	1.2	1.29	1.27	1.22

According to the data in Table 4, we can see that although the damping ratio of the soil rock mixed slope with different shapes of block stone the amount of block stone, the damping ratio of gravel and pebble slope under limited pressure on the same side has little difference. Transform the data in the table into the form of graph, and the final result is shown in Figure 3.

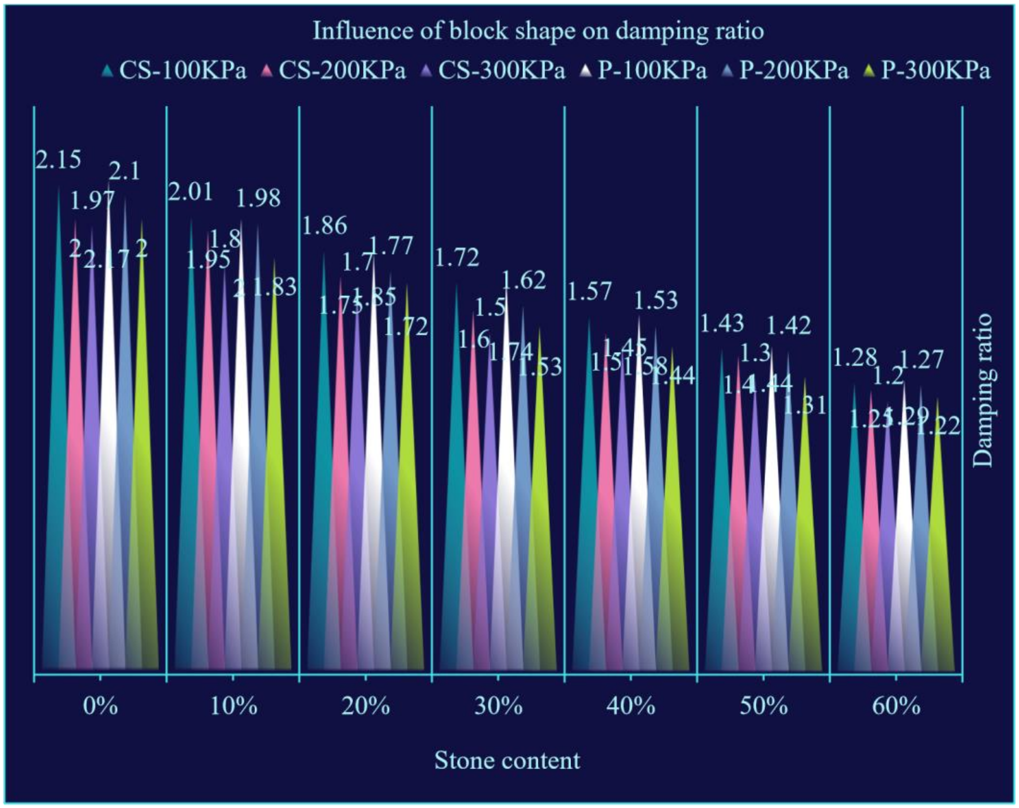

Figure 3. The influence of block shape on damping ratio

According to the data in Figure 3, it can be seen that the damping ratio of earth-stone mixed slope mixed with different block stone shapes is basically the same under different lateral limiting pressures. Therefore, it can be seen that the shape of block stone has little influence on the damping ratio of earth-stone mixed slope. The damping ratio of the soil and stone mixed slope with the lateral limiting pressure of 300KPa is lower than that of the other two cases and the damping ratio of the soil and stone mixed slope with the greater the proportion of block and stone is smaller.

4.2 Shear Strength Analysis of Soil Rock Slope

(1)Shear strength parameters of soil rock slope

Experiment according to the turning point of earth-rock mixture slope sliding surface of slope can be divided into five parts, respectively for the five part Numbers from 1 to 5, use the formula to calculate shear strength parameters of each part of the slope indicator of internal friction angle (angle) and cohesion, and bulk density of slope, sliding the weight M, maximum and minimum horizontal thrust and the destruction of the slope length L, finally the results as shown in table 5.

Table 5. Shear strength parameters of soil and rock mixed slope

	angle	Cohesion	Bulk density	M	Max	Min	L
1	47.93	16.18	35	8.65	76	43	1.41
2	43.82	13.31	27	9.26	82	51	1.32
3	44.31	16.43	31	10.13	75	46	1.49
4	45.12	14.47	26	7.84	81	50	1.53

5	47.91	15.92	33	9.47	73	45	1.46

According to the data in Table 5, we can get the basic parameter values and the shear strength index parameter values of the measured part of the earth-rock mixed slope in the experiment. According to the data in the table, we can see that the bulk density of the five parts of the soil and stone mixed slope is the first part, and its cohesion is also the largest among the five parts. The data was converted into graphs for analysis, and the final result was shown in Figure 4.

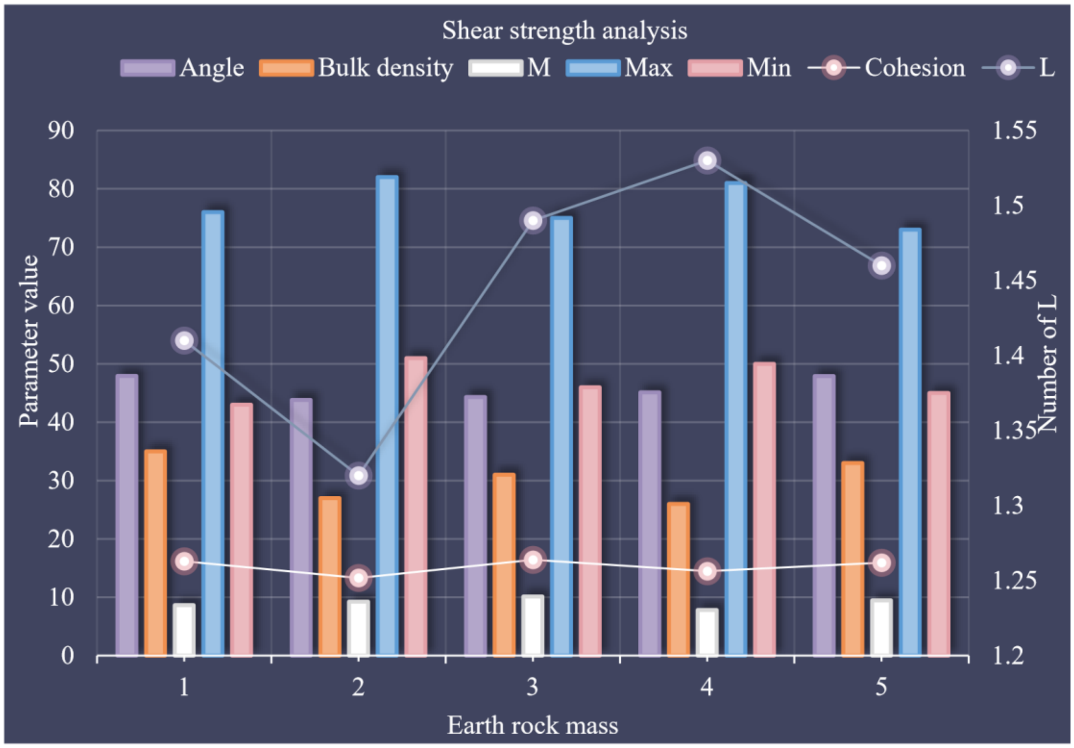

Figure 4. Shear strength analysis of soil rock slope

The largest internal friction angle of the five sod-stone mixtures is in the first part, whose internal friction angle is 47.93°. Meanwhile, the cohesion and bulk density of this part are also the largest among the five parts, whose cohesion is 16.18KPa and bulk density is 35KN/m3. Among the five parts, the largest sliding weight is the third part, whose sliding weight is 10.13KN. In the second part, the values of maximum horizontal thrust and minimum horizontal thrust are the largest among the five parts, but the internal friction angle, cohesion and length of the failure surface are the smallest among the five parts.

4.3 Sensitivity Analysis of Shear Strength Index

On the basis of experimental numerical calculation, this study carried out repeated calculations and two tests on the internal friction Angle and cohesion of the soil-rock mixture slope, calculated the safety factor of the slope under different cohesion Angle and internal friction Angle of the soil-rock mixture slope, and analyzed the sensitivity of the internal friction Angle and cohesion of the soil-rock mixture slope according to the calculation results. The cohesion and internal friction Angle of the corresponding safety factor of the soil-rock mixture slope are shown in Table 6.

Table 6. Safety factor analysis of soil rock mixed slope

	13KPa	14KPa	15KPa	16KPa	17KPa	normal
42°	0.95	0.975	1	1.025	1.05	1.05

43°	0.975	1	1.025	1.05	1.075	1.05
44°	1	1.025	1.05	1.075	1.1	1.05
45°	1.025	1.05	1.075	1.1	1.125	1.05
46°	1.05	1.075	1.1	1.125	1.15	1.05
47°	1.075	1.1	1.125	1.15	1.175	1.05

According to the data in Table 6, we can see that the normal value of the safety factor of the earth-rock mixed slope calculated in the experiment should be 1.05. The safety factor of soil and rock mixed slope increases with the increase of the angle of internal friction under different cohesion. In order to better analyze the sensitivity of the two parameters. The final result is shown in Figure 5.

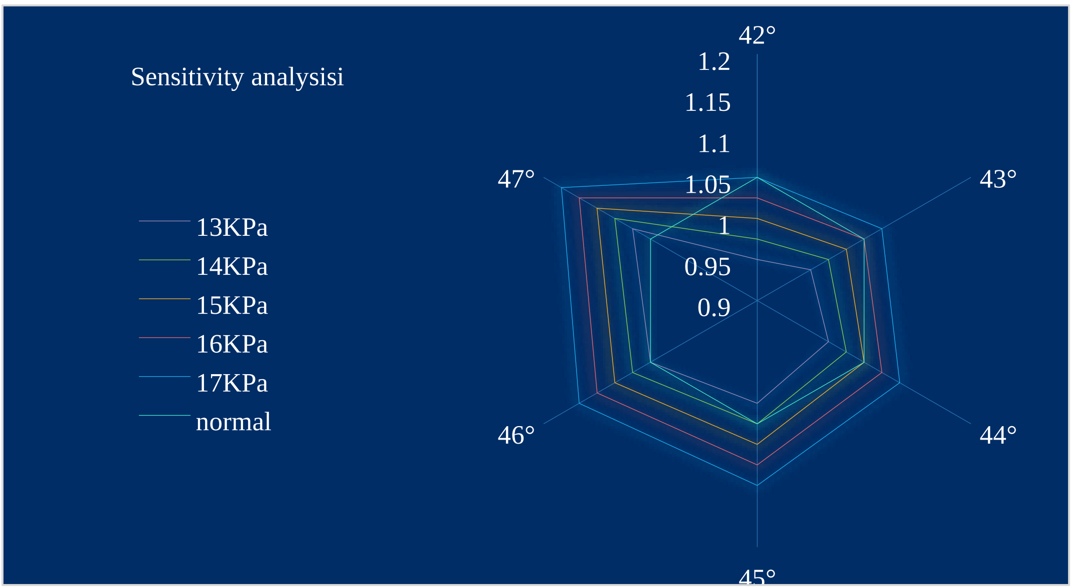

Figure 5. Sensitivity analysis of internal friction angle and cohesion of soil rock mixed slope

According to the data in Figure 5, we can see that the horizontal line in the picture represents the curve when the safety factor of soil rock slope is 1.05. The trend of the data, we can see that the cohesion and internal friction angle of the soil rock mixed slope have obvious influence on the safety factor of the soil rock mixed slope. The greater the cohesion, the higher the safety factor; the greater the internal friction angle, the higher the safety factor. The safety factor of the soil rock mixed slope can reach 1.05.

5. Conclusions

The phenomenon of soil and rock mixed slope landslide caused by earthquake has become one of the main geological disasters that threaten people's life and property safety. Earth-rock mixture slope is easy to cause the slope break under seismic action, the phenomenon such as landslide, but because of earth-rock mixture material composition is the heterogeneity of slope, the slope failure mechanism and the characteristics and other related exists obvious difference, so the related characteristics of earth-rock mixture slope research become the focus of attention.

In this paper, the destructive analysis of the mixed slope under earthquake action is studied based on thermodynamic principle. The experiment provides the knowledge support for this research through the first law of thermodynamics. This study has a certain understanding of the basic concepts of earthquake and soil-rock mixture slope, and then uses FLAC3D program to design a three-dimensional model of soil-rock mixture slope, which takes the action of seismic wave instead of slope dynamic load, and analyzes the soil-rock mixture slope under different rock drop volume and different confining pressure conditions according to experimental data and conditions. The shear strength index of soil-rock mixture slope and its relation with safety factor are analyzed.

Although this study has been very successful, but there are still some defects. First of all, in order to concretely reflect the effect of the first law of thermodynamics in the experiment, it will be improved in the follow-up experiment. Secondly, the research objects and relevant data selected in the experiment are insufficient, so it is necessary to continue to study other characteristics of earth-rock mixed slope in subsequent experiments. Finally, the research methods used in this paper are not compared with other methods, which cannot reflect the advantages of this method.

References

Niu J, Jiang X, Yang H, et al. Study on dynamic response characteristics of rock slope with small spacing tunnel under earthquakes. Journal of Natural Disasters, 2017, 26(5):130-139.

Yin Xiaojun, Wang Lanmin. Upper bound solution of soil slope stability under coupling effect of rainfall and earthquake. Journal of Donghua University (English Edition), 2019, 160 (04): 36-42.

Sun Z, Kong L, Guo A, et al. Experimental and numerical investigations of the seismic response of a rock-soil mixture deposit slope. Environmental Geology, 2019, 78(24):1-14.

Liu Y, Xiao H, Yao K, et al. Rock soil slope stability analysis by two phase random media and finite elements. Geoscience frontier, 2018, 009 (006): 1649-1655.

Zhuang Wei, Li, Xuanming. Application of transparent soil model test in the study of soil rock interface sliding mechanism. Journal of mountain science, 2019, 16 (04): 214-222.

Feireisl E. Relative entropies in thermodynamics of complete fluid systems. Discrete & Continuous Dynamical Systems - Series A (DCDS-A), 2017, 32(9):3059-3080.

Pettit L D, Bruckenstein S. The Thermodynamics of Ion Association in Solution. I. An Extension of the Denison-Ramsey Equations. Journal of the American Chemical Society, 2018, 88(21):4783-4789.

Arneodo A, Audit B, Bacry E, et al. Thermodynamics of fractal signals based on wavelet analysis: application to fully developed turbulence data and DNA sequences. Physica A Statal Mechanics & Its Applications, 2017, 254(1):24-45.

Nagata I. Thermodynamics of Alcohol Hydrocarbon Mixtures. Ztschrift Fr Physikalische Chemie, 2017, 2520(1):305-311.

Matjaž Bončina, Vesnaver G, Chaires J B, et al. Unraveling the Thermodynamics of the Folding and Interconversion of Human Telomere G-Quadruplexes. Angew Chem Int Ed Engl, 2016, 55(35):10340-10344.

Zhu J, Huang M, Li B, et al. Under the action of earthquake, the application of single layer shell structure stability dynamic with piezoelectric friction damper. World Information on Earthquake Engineering, 2017, 33(2):135-141.

Ye J, Zhu N. Redundancy of single-layer dome under earthquake action based on response sensitivity. International Journal of Steel Structures, 2016, 16(1):125-138.

Li Wan. An analysis of the effects of caves in different positions behind the tunnel lining under the action of an earthquake. National Defense Transportation Engineering and technology, 2016, 014 (001): 37-40.

Rathje E M, Faraj F, Russell S, et al. Empirical Relationships for Frequency Content Parameters of Earthquake Ground Motions. Earthquake Spectra, 2016, 20(1):119-144.

Catalli F, Rinaldi A P, Gischig V, et al. The importance of earthquake interactions for injection-induced seismicity: Retrospective modeling of the Basel Enhanced Geothermal System. Geophysical Research Letters, 2016, 43(10):4992-4999.

Barkat A, Ali A, Rehman K, et al. Thermal IR satellite data application for earthquake research in Pakistan. Journal of Geodynamics, 2018, 116(MAY):13-22.

Leveque R J, Waagan K, González, Frank I, et al. Generating Random Earthquake Events for Probabilistic Tsunami Hazard Assessment. Pure & Applied Geophysics, 2016, 173(12):3671-3692. [18] Rawat S, Gupta A K. Analysis of a Nailed Soil Slope Using Limit Equilibrium and Finite Element Methods. International Journal of Geosynthetics & Ground Engineering, 2016, 2(4):34-35.

Peranic J, Arbanas Z. Impact of the wetting process on the hydro-mechanical behavior of unsaturated residual soil from flysch rock mass: preliminary results. Bulletin of engineering geology and the environment, 2020, 79(2):985-998.

Zhuang W, Chi L, Ming D. Model tests on sliding mechanism of soil-rock slopes based on transparent soil technology. Chinese Journal of Geotechnical Engineering, 2019, 41(339):135-136. [21] Song D, Chen Z, Chao H, et al. Numerical study on seismic response of a rock slope with discontinuities based on the time-frequency joint analysis method. Soil Dynamics and Earthquake Engineering, 2020, 133(Jun.):1-13.

Teng W, Ga Z. Failure behavior of soil-rock mixture slopes based on centrifuge model test. Journal of Mountainence, 2019, 16(008):1928-1942.

Yan Zhixin, Long Zhe, Zhou Xiaoliang, et al. Numerical analysis of anchoring parameters for bolt in rock slope anchored interface shear action under earthquake. Acta coal Sinica, 2017, 042 (010): 2537-2544.

Cao Riyue, Cao Yue. FLAC3D numerical analysis of a tunnel under different lateral pressure coefficients. Journal of Taiyuan University of science and technology, 2016, 37 (3): 243-247. [25] Zhang Y. Study on dynamic response laws of Rock Slope Blasting Based on FLAC3D. Renmin Changjiang River, 2019, 050 (003): 198-204.