# Study on the influence of slope morphology on seismic dynamic response based on numerical simulation

Sizhe Huang[1, *], Le Gao[2]

[1]School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China, 510641

[2]School of Civil Engineering and Water Resources, Qinghai University, Xining, China, 810016

* Corresponding Author Email: 19198261763@163.com

**Abstract.** Geological disasters frequently occur in our country. Multiple earthquakes have caused landslides on slopes, resulting in serious casualties and property losses. Therefore, it is particularly important to study the dynamic response and instability mechanism of slopes under earthquakes of different frequencies. This paper uses numerical simulation methods to establish a slope model, loads sine waves of different frequencies and amplitudes, collects acceleration and displacement dynamic responses of different profiles, and studies the distribution law of slope acceleration and displacement under dynamic action. Finally, the phenomenon of acceleration amplification effect is discovered. The research results of this paper can provide a basis for slope disaster prevention and mitigation and seismic reinforcement measures.

**Keywords:** slope morphology, seismic dynamic response, numerical simulation, Sine wave.

## 1. Introduction

### 1.1. The basis and significance of the topic selection

Our country's terrain is mountainous, including mountains, plateaus and hills, occupying a large part of the country's land area. As a result, our country has a large number of natural slopes, and a large number of geological disasters such as collapses, landslides, and debris flows occur every year. At the same time, as my country implements development strategies such as the development of the western region, the revitalization of the old industrial base in the Northeast, and the rise of the central region, the construction of a large number of infrastructure projects such as hydro-power hubs, highways, railways, and mines will add new artificial slopes.[1] These projects Activities can also reduce the stability of existing natural slopes. Our country is located between the two most active seismic belts in the world, the Pacific seismic belt in the east and the Himalayas-Mediterranean seismic belt in the west. Strong earthquakes are widely distributed. Almost all provinces are threatened by destructive earthquakes, especially in the central and western regions. Earthquake activity is frequent. The seismic activity in recent years shows that seismic activity in my country has become more active. The stability of these slopes related to project safety is directly related to the safety of the project itself. If the slopes of important projects are unstable and damaged, catastrophic secondary disasters may occur, threatening the lives and property of large cities, large enterprises, and people. In some cases, the losses will be huge.[2] The static stability analysis of slopes is relatively mature, but the seismic stability analysis of slopes is still in the exploratory stage, and there is a lack of mature and reliable evaluation methods and standards for reference. Therefore, it is of great practical significance to study the seismic dynamic response and failure mechanism of slopes.

### 1.2. Research status

MK Yegian[3][4] introduced the probabilistic analysis method into the dynamic analysis of dam slopes earlier, proposed the use of probabilistic methods to analyze the risk of dam slopes under earthquake conditions, and estimated the effects of earthquakes on slopes (including dam slopes) permanent displacement . Subsequently, R.V. Halatchev[5] proposed a probabilistic method for the stability analysis of embankments and slopes based on the Sarma solution, taking into account the

horizontal and vertical components of the seismic force, that is, the seismic force can have arbitrary inclination angles. The soil shear strength parameters are assumed to be normally distributed and the Monte-Carlo simulation method is used; the failure probability is determined by the seismic coefficient; the seismic coefficient is regarded as a random variable and applied to open-pit coal mine slope analysis. A SA-Homo ET Al.[6] used the safety factor and the critical displacement of slope failure to propose a three-dimensional stability probabilistic analysis model of slopes and dams under the action of earthquake forces, taking into account the following uncertain factors: laboratory and field measurements The uncertainty of the obtained shear strength parameter values, spatial changes and the relationship between soil parameters. They proposed a non-transcending probabilistic earthquake displacement model based on limit values, and a probabilistic model for three-dimensional dynamic slope stability analysis based on safety factors, and wrote the PTDDSSA computer program.

Ren Ziming[7] used Flac3D software to construct model slopes with different heights, slopes, and slope shapes, and applied seismic waves to study the dynamic response characteristics of the slope. Research results show that under the action of seismic loads, the stability of slopes decreases with the increase of slope height and slope. In addition, the results also show that concave slopes are more stable, while convex slopes are less stable. Qiu Rendong[8] and others studied the dynamic response law of slopes through numerical simulation and found that the response (velocity, acceleration, displacement) of the slope under seismic load became more severe as the slope height increased, and as the slope height increased, As the slope increases, the response decreases. Yan Zhixin[9] and others used FLAC3D software to establish a numerical model of the slope and conducted research and analysis. Research results show that under earthquake action, the shear strain increment of the slope first appears slightly above the slope foot and gradually expands to the surroundings. As the input wave duration increases, the growth amplitude of the shear strain increment also increases. Zhou Hongyan[10] established a numerical model based on typical disaster slopes in the Yushu earthquake in Qinghai, studied the dynamic response characteristics of the slope under earthquake action, and came to the following conclusion: when the slope is subjected to horizontal loads, The response acceleration shows obvious elevation amplification effect and surface trend effect, in which the maximum acceleration amplification coefficient appears at the top of the slope. Cai Hancheng[11] studied the response rules of horizontal and vertical acceleration of slopes in different directions through numerical simulation. The study showed that the slope has an amplification effect on the horizontal seismic acceleration in the horizontal and vertical directions, while the vertical acceleration is There are amplification effects in both directions as well. In addition, the slope causes high-frequency filtering and low-frequency amplification of the input wave in the vertical direction. Zhou Xingtao[12] and others used Flac3D to study the impact of topography and landforms on seismic waves. The research results show that when the slope height is low and the slope shape is a single-sided slope, under the action of natural seismic waves and simple harmonics, the peak acceleration has an amplification effect both along the elevation direction and along the slope direction.

The article used numerical simulation methods to build a valley slope model and load sine waves of different frequencies to study the dynamic response of slope acceleration and displacement.

## 2. Introduction to research methods

FLAC3D software studies the dynamic response of slopes usually based on numerical simulation methods. FLAC3D has powerful three-dimensional modeling capabilities and can accurately simulate complex geological structures and underground engineering systems. It allows users to create realistic three-dimensional models, including strata, rock masses, slopes, tunnels, etc., to more accurately analyze and predict the behavior of underground engineering. At the same time, it supports coupled analysis of multiple physical fields, including mechanics, thermodynamics, fluid mechanics, etc. This means that the effects of different physical processes on engineering behavior can be considered simultaneously, providing more comprehensive simulation and analysis capabilities.

It can also simulate the nonlinear behavior of various materials, such as elastic-plasticity, fracture, viscoplasticity of rocks, etc. This allows it to more realistically reflect the actual response of materials when simulating engineering problems such as earthquakes, slope stability, and tunnel excavation. In addition, it can provide the setting of a variety of boundary conditions, including fixed boundaries, free boundaries, stress boundaries, etc., and can flexibly set boundary conditions according to the needs of specific problems to simulate various situations in actual projects. Finally, it has powerful visualization and post-processing capabilities to present simulation results in an intuitive and understandable way. Users can analyze and display simulation results by drawing maps, cross-sections, animations, etc. to better understand and explain engineering behavior.

## 3. Analysis of slope dynamic response characteristics

### 3.1. Numerical Model Establishment and Parameter Configuration

Slope is a geological body with complex characteristics such as heterogeneity, discontinuity, and non linearity. It is affected by various factors such as strati graphic lithological conditions, rock mass structure type, geological structure, and slope height, slope, and slope type. Taking these factors into account makes the numerical simulation problem very complex. Therefore, in this article, the slope is simplified as a homogeneous, continuous elastic-plastic body. The model selected in this article is as follows: a homogeneous soil slope with a slope height of 50 meters, a slope length of 140 meters, and a slope angle of 60 degrees. The model diagram is shown in Figure 1. In order to ensure accurate propagation of seismic waves in the model slope, the maximum grid size used is 1 meter. Elastomer-plastic model and Mohr-Coulomb failure criterion are adopted. Displacement constraints are imposed on both sides of the model slope to limit the displacement in the horizontal direction, and free field boundary conditions are applied during dynamic calculations. Displacement constraints are imposed on the bottom of the model to limit the displacement in the horizontal and vertical directions, and viscous boundary conditions are applied during dynamic calculations. Local damping is adopted with a damping coefficient of 0.1571. First, the model is calculated to an equilibrium state under the action of gravity, and then dynamic calculations are performed. Since a viscous boundary condition is applied at the bottom of the model, in the dynamic calculation, the acceleration time history input to the bottom of the model needs to be converted into a velocity time history, and then the velocity time history is converted into a stress time history, and finally the viscous boundary conditions are applied superior.

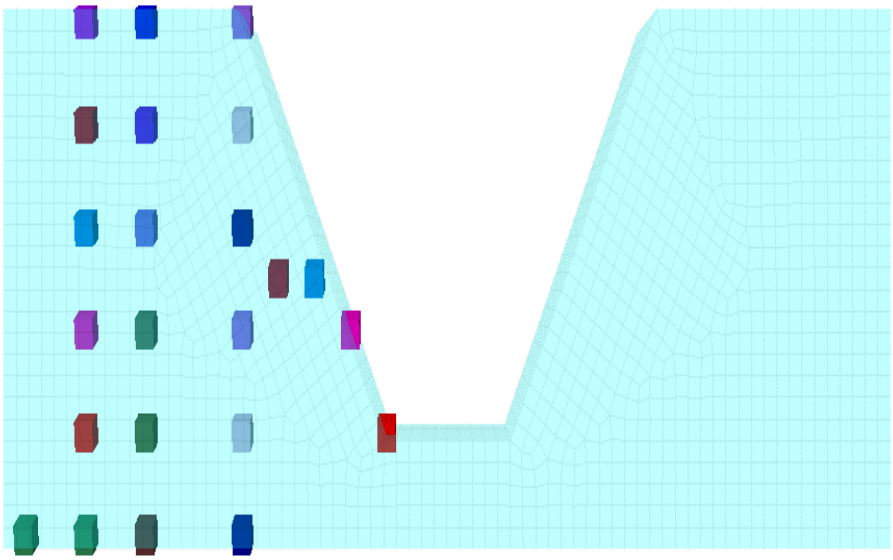


**Figure 1.** Calculation Model

### 3.2. Seismic Wave Loading

Figure 2-6 shows the time history of sine waves with different frequencies as inputs.

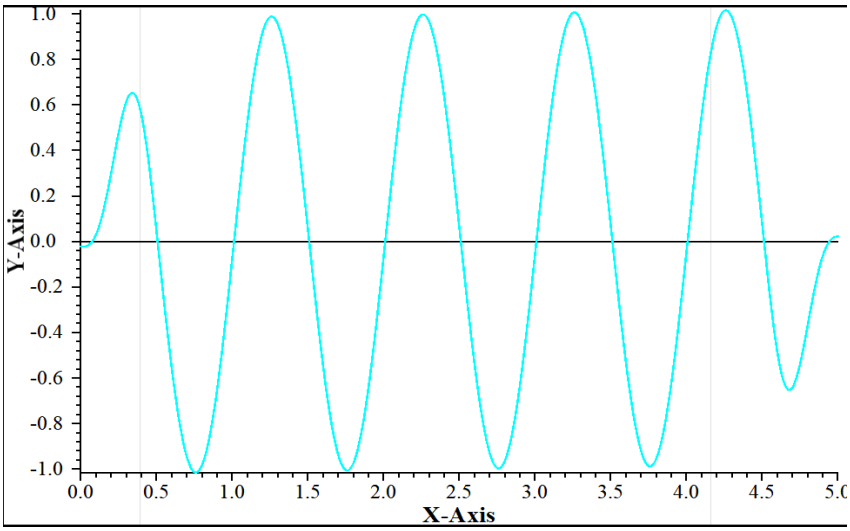



**Figure 2.** 1Hz Seismic Wave Loading

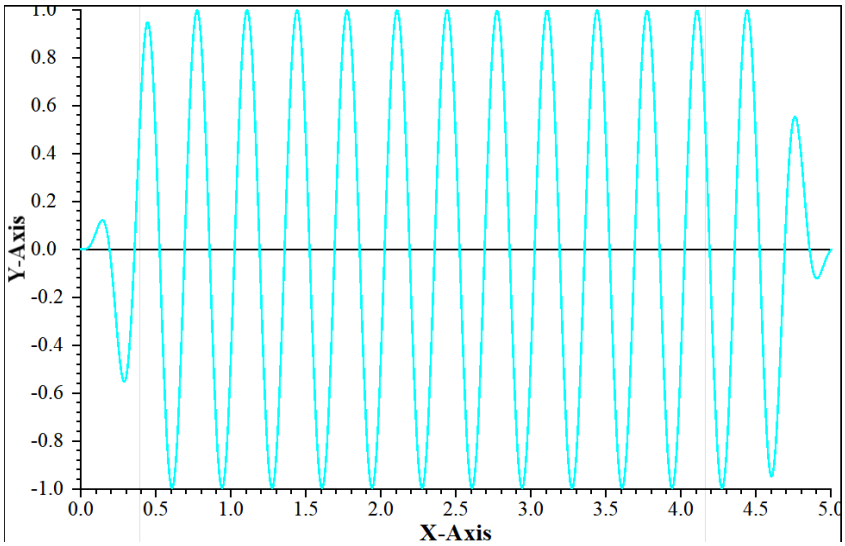



**Figure 3.** 3Hz Seismic Wave Loading

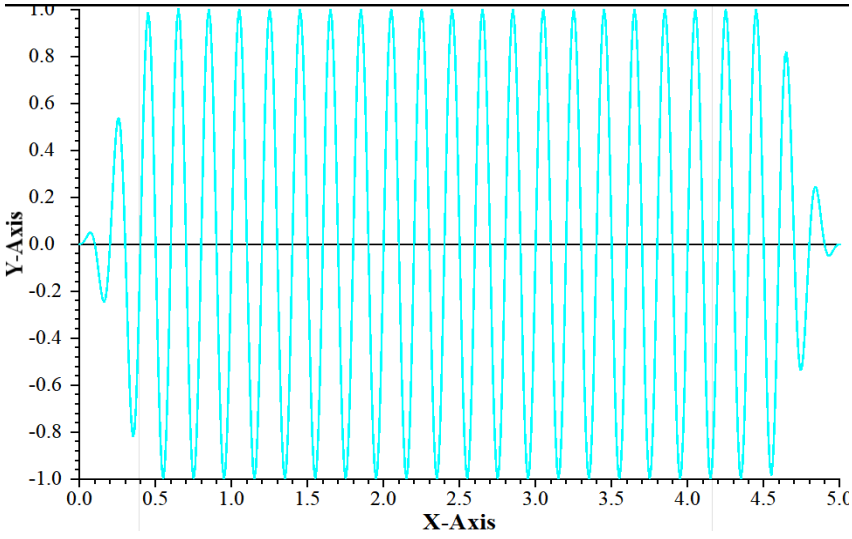



**Figure 4.** 5Hz Seismic Wave Loading

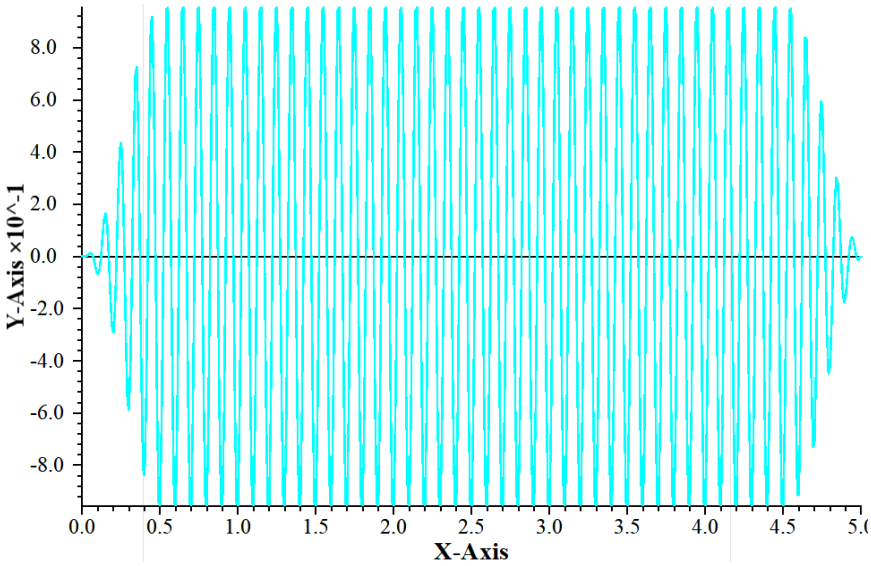



**Figure 5.** 10Hz Seismic Wave Loading

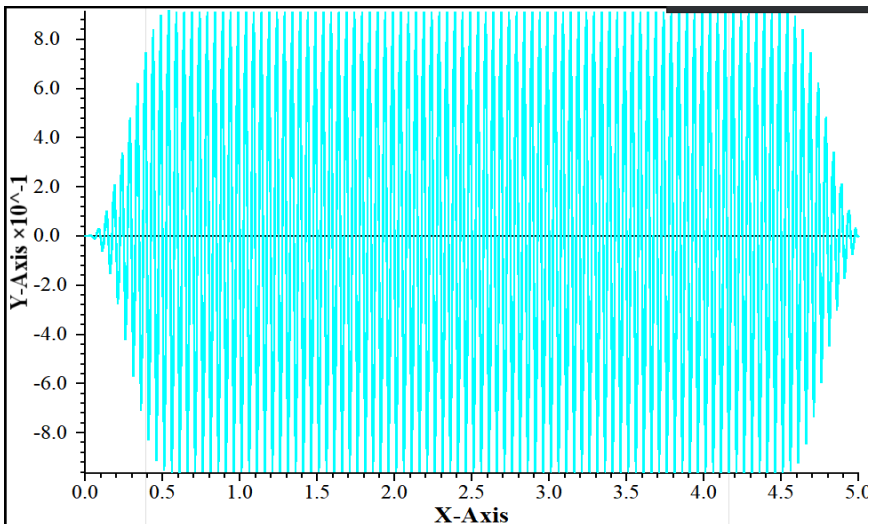



**Figure 6.** 20Hz Seismic Wave Loading

## 4. Result analysis

To facilitate a more comprehensive exploration of slope behavior in response to seismic events, this paper introduces the notion of an acceleration amplification factor for precise quantitative analysis. Referred to as the Peak Ground Acceleration (PGA), Peak Ground Displacement (PGD), these factors is defined by equation (1)(2):

$$PGA_i = \frac{a_i^{\max}}{a_o} \tag{1}$$

$$PGD_i = \frac{d_i^{\max}}{d_0} \tag{2}$$

Within the equation, $a_i^{max}$ $and$ $d_i^{max}$ respectively signifies the peak acceleration,displacement observed at detection point i, while $a_0$ and $d_0$ respectively denotes the peak acceleration,displacement and recorded at the incident point.

In order to study the effect of seismic wave frequency on slope acceleration and displacement, the frequencies of 1 Hz, 3 Hz, 5 Hz, 10 Hz, and 20 Hz were taken for study, and the calculation results were plotted as Figures 3 to 8.

# 5. Acceleration responses

## 5.1. A1 Monitoring profile

Figures 7 and 8 show the variation of the A1 monitoring profile with the frequency of seismic waves.For the A1 monitoring profile,when the frequency of local seismic waves is 1 to 3Hz,PGA first increases and then decreases with increasing altitude,reaching its maximum value at A1-2, then decreases, and reaches its minimum value at A1-5.Under the influence of 5-20Hz seismic waves, the PGA of the slope first decreases with the increase of elevation,reaches its minimum value at A1-5,and finally increases at A1-6.

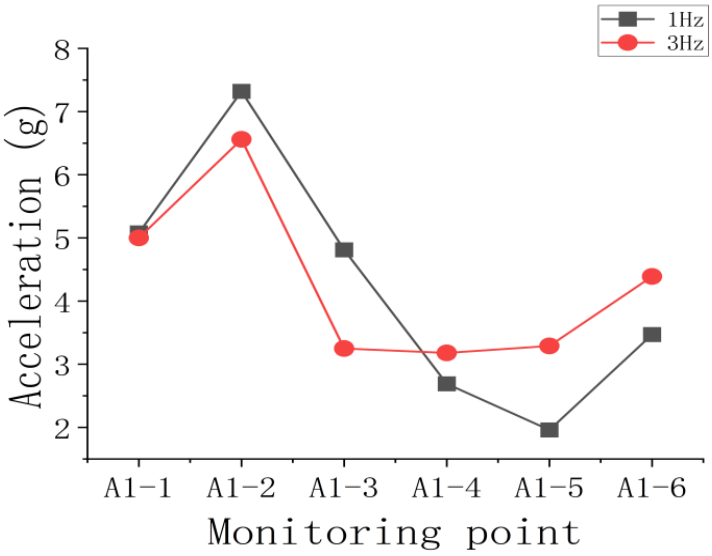



**Figure 7.** A1 monitoring profile with the frequency of seismic waves when frequency range from 1Hz to 3Hz

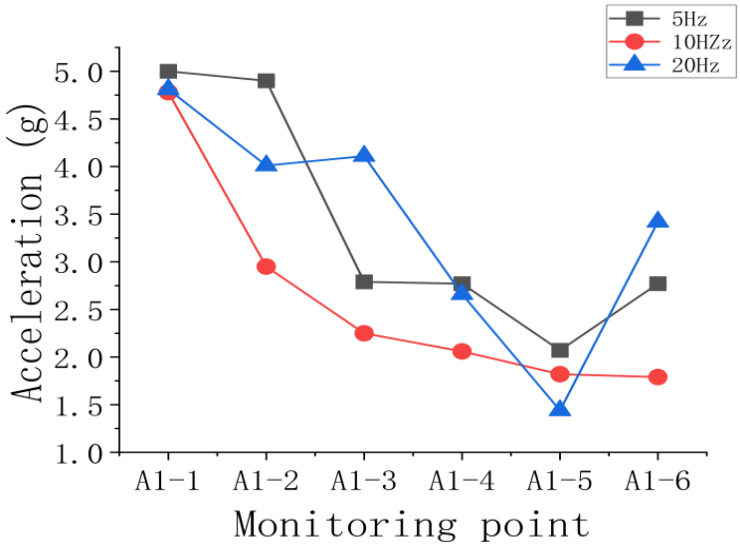



**Figure 8.** A1 monitoring profile with the frequency of seismic waves when frequency range from 5Hz to 20Hz

## 5.2. A2 Monitoring profile

Figure 9 shows the variation of the A2 monitoring profile with the frequency of the seismic wave.For the A2 monitoring profile, when the frequency of local seismic waves is between 1 and 20Hz, PGA first increases with altitude, reaches its maximum value at A2-2,then decreases, reaches its minimum value at A2-5,and finally increases again at A2-6.

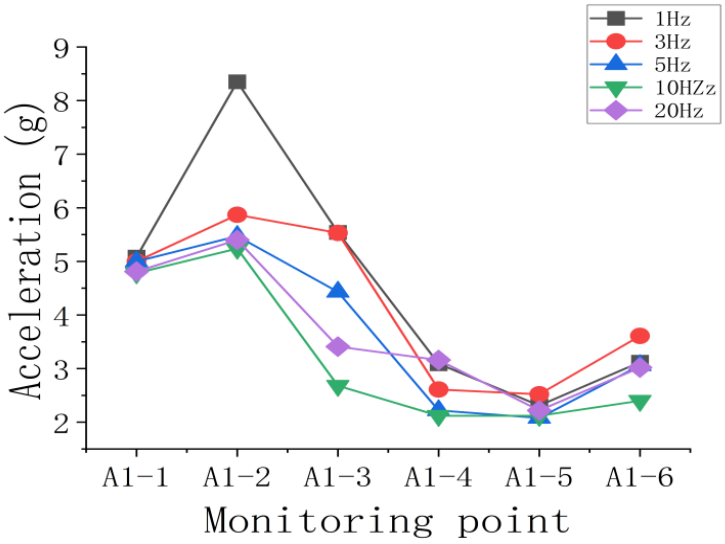



**Figure 9.** A2 monitoring profile with the frequency of seismic waves when frequency range from 1Hz to 20Hz

## 6. Displacement responses

### 6.1. D1 Monitoring profile

Figures 10 and 11 show the variation of the D1 monitoring profile with the frequency of seismic waves. For the D1 monitoring profile, when the frequency of local seismic waves is between 1 and 3Hz, PGD first increases and then decreases with the increase of altitude, reaching its maximum value at D1-2, then decreases and then increases again. Under the influence of 5Hz seismic waves, PGD first increases with altitude, reaches its maximum value at D1-3, then decreases and then increases. When the seismic wave frequency is 10-20Hz, PGD first decreases and then increases with altitude, reaching its maximum value at D1-1.Specifically, when a 1 Hz sine wave is loaded, the displacement of monitoring point D1-2 is 545, and the displacement of monitoring point D1-4 is 20.1. When a 3 Hz sine wave is loaded, the displacement of monitoring point D1-2 is 137, and the acceleration of monitoring point D1-3 is 4.7. When a 5Hz sine wave is loaded, the displacement of monitoring point D1-3 is 15.1, and the displacement of monitoring point D1-5 is 1.1.

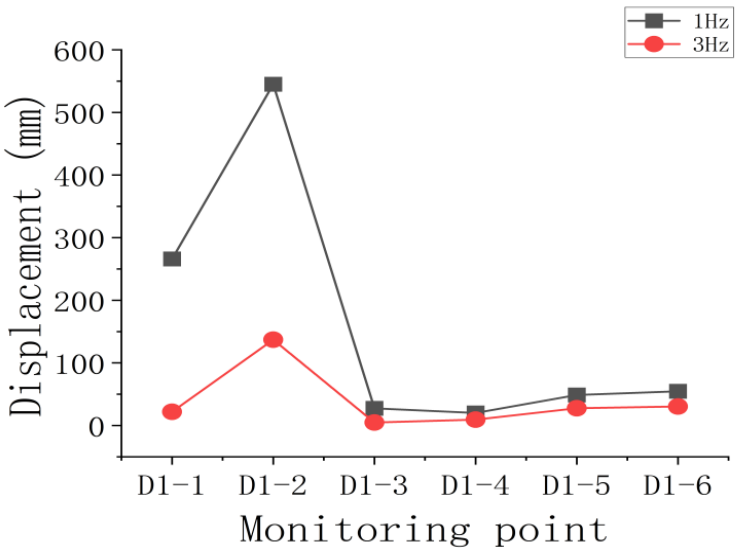



**Figure 10.** D1 monitoring profile with the frequency of seismic waves when frequency range from 1Hz to 3Hz

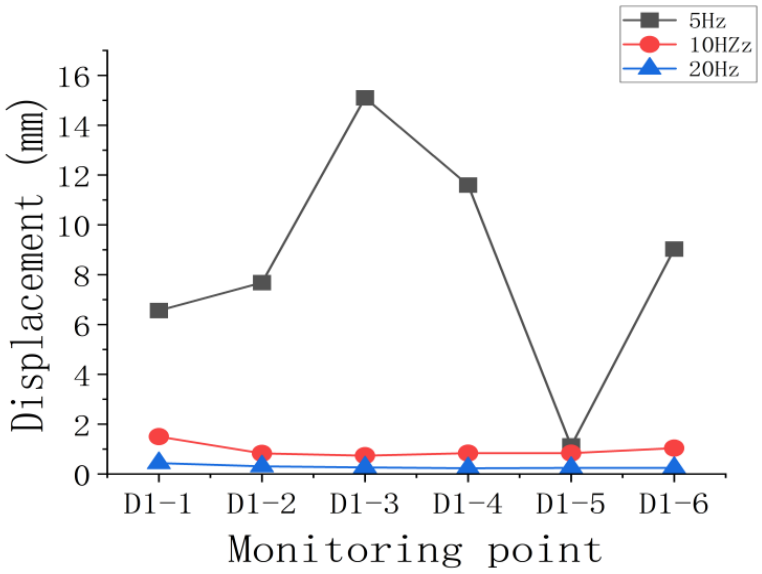



**Figure 11.** D1 monitoring profile with the frequency of seismic waves when frequency range from 5Hz to 20Hz

### 6.2. D2 Monitoring profile

Figure 12 shows the variation of the D2 monitoring profile with the frequency of seismic waves. For the D2 monitoring profile, when the frequency of local seismic waves is 1-3Hz, PGD first increases with altitude, reaches its maximum value at D2-2, and then decreases. When the frequency of the local seismic wave is 5-20Hz, PGD roughly shows a trend of first increasing, then decreasing, and then increasing with the increase of altitude, reaching its maximum value at D2-2.

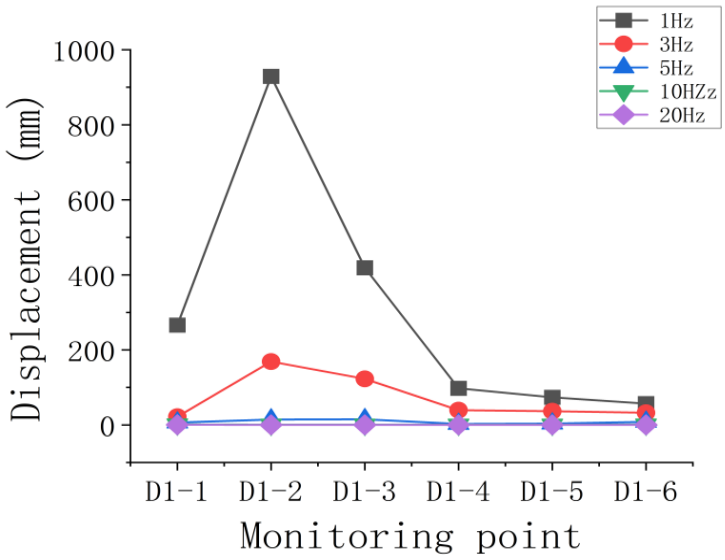



**Figure 12.** D2 monitoring profile with the frequency of seismic waves when frequency range from 1Hz to 20Hz

## 7. Conclusions

(1) The peak ground acceleration (PGA) and peak ground displacement (PDA) of the slope generally show a trend of first increasing, then decreasing, and then increasing or first decreasing and then increasing with the increase of elevation, reaching the minimum value near the top of the slope. It should be noted that there will be a sudden increase at the top of the slope, showing a significant top amplification effect.

(2) Under the action of seismic waves with the same altitude, frequency, and amplitude, the closer the monitoring point is to the center of the slope, the greater the PGA. In addition, for the same monitoring point, when the frequency of local seismic waves increases, PGA actually shows a decreasing trend.

(3) Under the action of seismic waves with the same altitude, frequency, and amplitude, the closer the monitoring point is to the center of the slope, the greater the PGA. For the same monitoring point, when the frequency of local seismic waves increases from 1Hz to 5Hz, there is a particularly significant decrease in PDA. When the frequency of local seismic waves increases from 5Hz to 20Hz, the decrease in PDA decreases significantly and slows down.

This study systematically investigated how the frequency of seismic waves under seismic activity affects the PGA and PGD of slopes, revealing the complexity, regularity, and predictability of slope responses. Future research should verify and deepen the understanding of these mechanisms through physical deduction and numerical experiments, and interpret the underlying mechanisms of these phenomena through theoretical and practical approaches. At the same time, it should also evaluate the impact of different slope shapes to improve the accuracy and practicality of the model, which can provide better guidance for slope design and earthquake preparedness.

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