Study of Shock Landslide-Type Geomechanical Model Test for Consequent Rock Slope

THE SECOND WORLD LANDSLIDE FORUM

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Abstract

Mountain deformation and fracture as a result of earthquakes is a complicated evolution process. We need to take advantage of geomechanical simulation and shock effects to reproduce the mountain deformation process based on the understanding and conceptual model through geological analysis, in order to verify and disclose the facts. The author has chosen a certain typical landslide-type geomechanical model of consequent rock slope under earthquake effect, and carried out the simulation testing study for the geomechanical mechanism under the vibration conditions. This paper introduces the methods of model preparation, the test plan design and testing methods, and studies the testing results, from the vibration trace and deformation and fracture evolution process, deformation and fracture evolutionary process and vibration acceleration time-history changes, vibration intensity and deformation and fracture evolution of different geological structures, so some useful results and new knowledge are reported.

Keywords

Vibration test • Geomechanical simulation mechanism • Shock landslide-type geomechanical model for rock slopes dip toward excavation • Deformation and fracture evolution of mountains

Introduction

Destabilization is likely to happen to the gently titled external stratified slope, medium titled external or consequent slope with changeable angle, with the deformation and fracture mechanical mechanism generally as sliding-rip type and sliding-bending type, and destruction instability mode generally as consequent slope, consequent-tangential slope or rotating landslide, such as the typical front edge of rock slop dip toward excavation of Diexi Jiaochang of Diexi Seismic Area in Sichuan in 1933, Yiwanshui Landslide in Longling Seismic Area in Yunnan in 1976, some consequent slope at Jueta Mountain of Caoling and Kandou Mountain of Niufen'er Mountain after the Taiwan jiji Earthquake in 1999, as well as landslide in Jiazi Village of Baishui, Hetaoyuan Landslide in Hudiaoxia, Bendiwan Landslide and Wenziping Landslide in Lijiang Seismic Area in Yunnan in 1996, etc. (Wang Lansheng et al. 2000; Wang Sijing 1987). In the Wenchuan Earthquake in Sichuan on May 12, 2008, such series of landslides occurred at the seismic zones, such as Daguangbao Massive Landslide in Anxian County (see Fig. 1), Tangjiashan Landslide in Beichuan, Donghekou Landslide in Qingchuan, Magongwoqian Landslide, Shibangou Landslide, Niujuangou Landslide in Yingxiu of Wenchuan, Hongchungou H5 Landslide, Shaofanggou Landslide, Wenjiagou Landslide in Mianzhu, etc.

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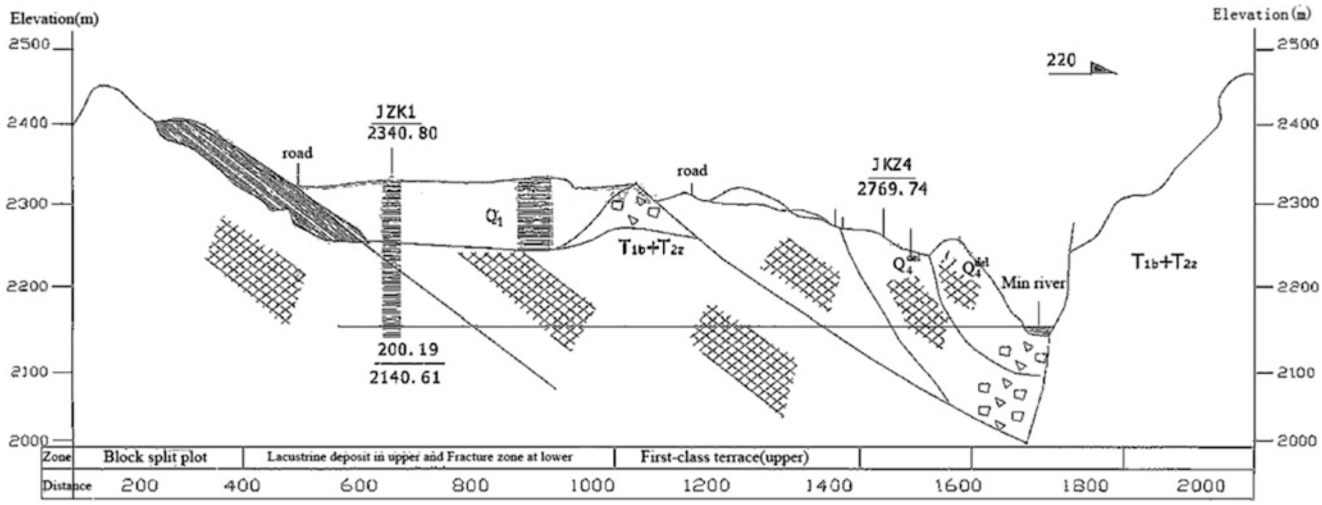

Fig. 1 Profile of Diexi Jiaochang landslide induced in 1933s earthquake

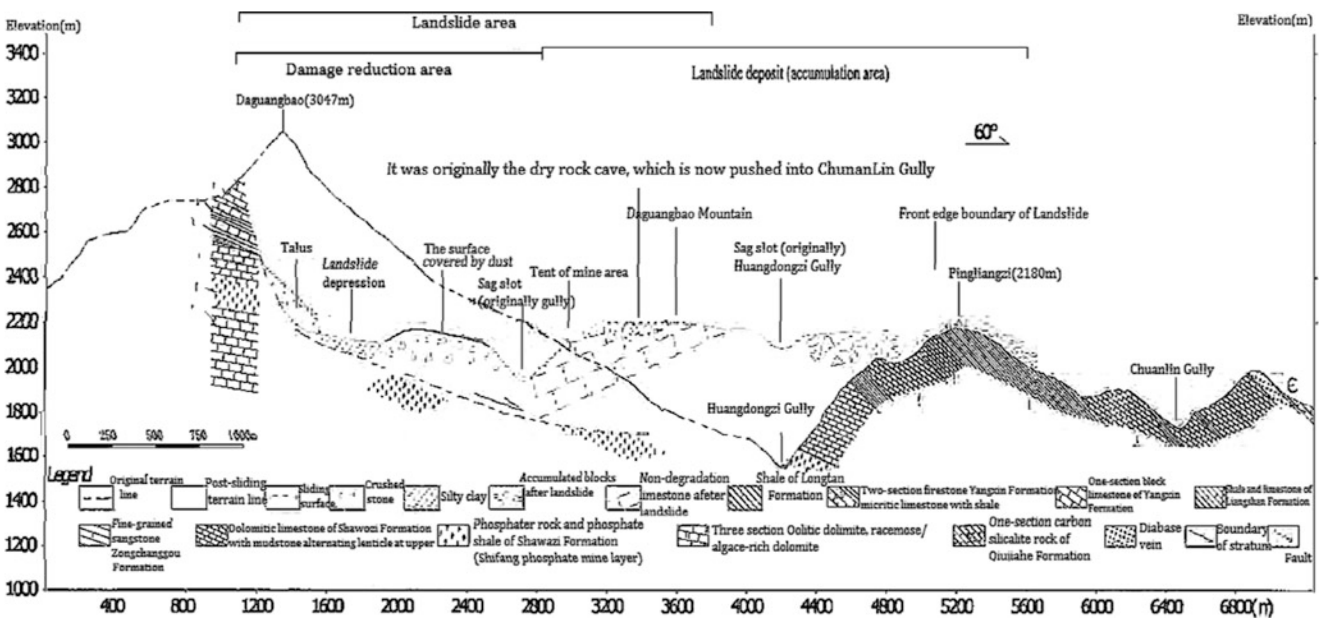

Fig. 2 Profile of Daguangbao landslide induced in 2008s earthquake

Test Model and Test Plan

Model Preparation

Diexi Jiaochang Landslide and Daguangbao Consequent Slope in Anxian are taken as the reference (Figs. 1 and 2). Based on the similarity theory, the geometric similarities between the model and reference, distribution of hard and soft rock mass, difference of parameters are factored into the model.

The model shall be staked by 5 cm long, 5 cm wide and 5 cm thick sandstone blocks at an angle of 10–40° of the stratum for different testing plans. The rock blocks shall be bonded by clay, with gradient of 50–60° (see Pictures 1 and 2). The unit weight, modulus of elasticity, modulus of deformation, Poisson ratio, shearing strength and other physical and mechanical indexes of the blocks basically meet the requirements. See Table 1 for the model parameters. The base is a 10–40° slope of barite powder.

The model is 45 cm long, 38 cm high and 40 cm wide in size, with scale of 1:1,000. The weight of the model shall be controlled between 230 and 250 kg.

The model is directly made within the model cabinet of the vibrating table, with one model of the same size on the left and right sides and one 10 cm wide channel in the middle (see Pictures 1 and 2).

Picture 1 Model of block structure of bonding by the clay

Picture 2 Model of slop dip toward excavation

Test Purpose and Plan

In the testing design, the geological background, the rock mass medium characteristics and structure characteristics of the reference model is analyzed in order to study the forms and characteristics of seismic force deformation and destruction of mountains with synthetic structure. The specific test purpose and plan are as follows:

1. The mode, process and regularity of the deformation and fracture of stratified rock mass under the earthquake effects shall be observed and understood throughout the whole process, particularly the deformation and destruction extent, and earthquake acceleration, vibration frequency, the rock mass structure surface distribution features, bonding force between layers and relativity of slope dip.

Table 1 Model material parameter table

Sandstone		Clay		
Density (g/cm^3)	Deformation modulus (10^4 MPa)	Density (g/cm^3)	C (kpa)	ϕ(°)
2.68	0.95	2.7	40~60	6~13

2. The vibration amplitude, trace, dip of stratum, gradient of slope surface, bonding strength as well as initial vibration direction are changed, and the fracture process shall be observed and recorded. The digital camera and video camera shall be used for recording before, during and after each vibration, respectively.

Analysis of Testing Results

Analysis of Vibration Trace and Deformation and Fracture Evolution Process

According to the images collected by the video camera during the test, the motion trace of the vibrating table shall be drawn (as shown in Fig. 3a), and the relationship between the appearance, evolution and vibration trace status shall be observed during the vibration (as shown in Fig. 3a, b). Moreover, the displacement curves of a certain deformation and fracture characteristic point of the model shall be drawn (as shown in Fig. 3c).

Take the consequent slope model vibration instability evolution process with the stratum dip of 30° and gradient of 60° as an example. The amplitude is 5 cm, and the elliptic vibration trace is shown in the chart. The points A1–A3 are deformation and fracture deflection points, the corresponding deformation and fracture status is shown in Fig. 3b, and the movement displacement curve of the corresponding deformation fracture point is shown in Fig. 3c.

Figure 3 shows that the deformation and fracture of the mountain generally appeared at the deflection point of the vibration movement trace, i.e. deflection point of changing the movement direction. As seen from the trace image and deformation sign, when the motion direction of the vibrating table changes to the rightward movement from leftward, the inertia force of the model movement is generally identical with the free surface direction as it is opposite the model movement direction, which may trigger the sliding-rupture deformation and fracture. And when the movement acceleration direction is changed from upward to downward movement, the vertical restricted strength of the rock masses is reduced under the reduced gravity, which facilitates the tension of structural surface and rock mass displacement, so that the rock blocks with smaller strength will be likely to

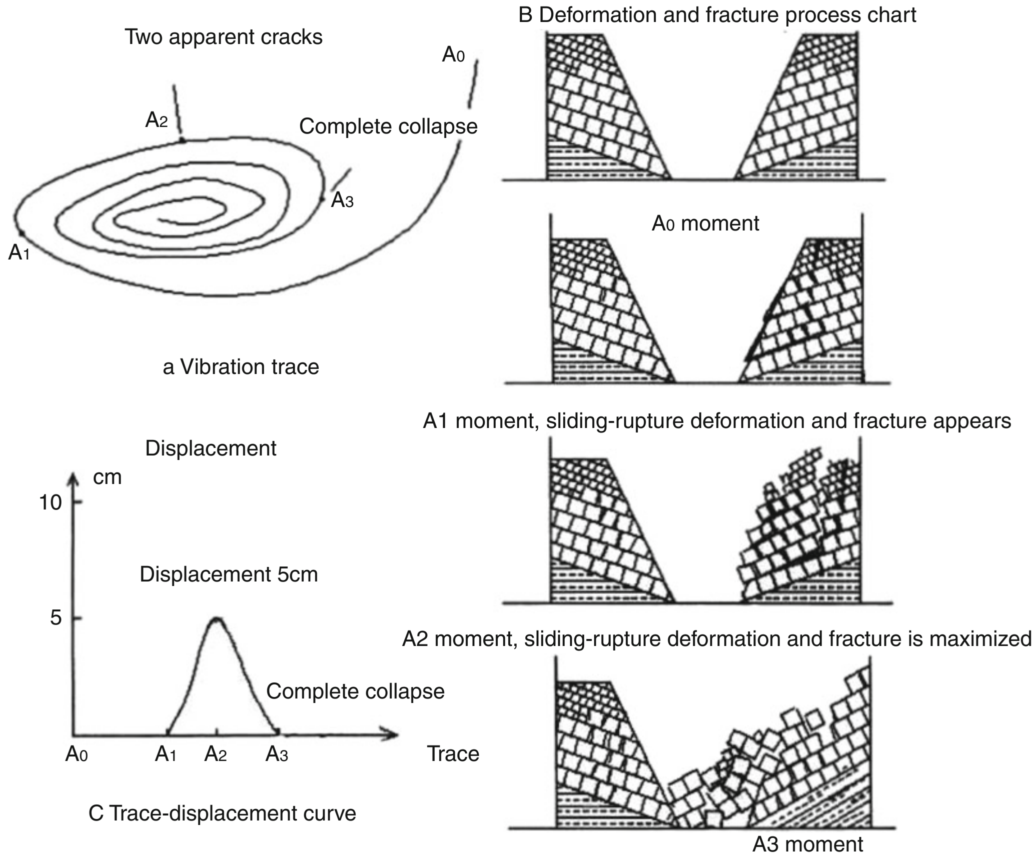

Fig. 3 Contrast diagram of shock instability evolution process for consequent slope model

separate from the intact mass, and sliding-rupture deformation, facture or instability will be caused, and trigger effects will come out. When the displacement is accumulated to a certain critical value, a certain through face will be formed, and landslide will be caused.

The test also shows that the vibration of the elliptic orbit has greatest impact on the slope deformation and fracture, followed by horizontal vibration trace and inclined vibration trace. The vertical vibration trace has no obvious deformation or fracture. Generally, the damage and instability appears in the 2nd or 3rd recycle movement, and that is to say, the damage and instability movement of the first deflection point after the first peak acceleration and a circulation direction changes will stop after the 4th to 6th movement cycle trace.

Analysis of Deformation and Fracture Evolutionary Process and Vibration Acceleration Time-History Variance

Comparing the deformation and fracture process and vibration trace with acceleration time-history, the results show that when the vibration level acceleration is less than 0.4 g, the stratum structure rocky slope produces only overall vibration, without noticeable damages. For the consequent slope, when the vibration level acceleration is greater than 0.4 g (equivalent to the design basic earthquake acceleration value at the seismic intensity of Magnitude 9), deformation and fracture will begin to appear and the extent of damage is associated with amplitude, the initial motion direction, vibration trace, rock structural strength and other factors. The damage extent deteriorates gradually with the increase in the vibration acceleration. As the vibration level acceleration is close to 0.8 g (equivalent to the design basic earthquake acceleration value at the seismic intensity of Magnitude 10), the consequent slope will show the extensive overall instability. The shear-tension and pull-tension will further extend to a deep extent, and the layers become staggered and displaced obviously, which is mainly represented by sliding-rupture deformation and cracking, and the slope with low structural strength will cause landslide (see Picture 3). The slope with strong rock mass structure strength will be subject to milder damages, but it will cause deep shear-tension and pull-tension fractures (see Picture 4) and some interlayer displacement or sliding.

The deformation and fracture process also shows that when rock structure of the model has certain bonding

Picture 3 Third level sliding face destabilization occurs on the consequent slope

Picture 5 Polished surface and scrapes cinch marks clearly shown on the top slickenside

Picture 4 Tension crack and sinking zone occur at the trailing edge of the consequent slope

Picture 6 Gliding or tension crack and fracture of consequent slope

strength, only deformation fracture accumulated displacement is produced in the 1st peak acceleration of the vibration acceleration time-history process, and pull-tension and shear-tension cracks (see Picture 4) will appear. When the displacement is accumulated to a certain level, once again, the direction of the acceleration changes from up to down and instability damage will be generated.

In a vibration, deformation and fracture extent of the mountain is proportional to vibration duration. The accumulated displacement of the mountain deformation and fracture displacement is also proportional to the vibration duration, i.e. the longer the vibration is, the larger the generated displacement will be, and thus sliding damage will be likely to occur to the rock masses of the slope.

Analysis of Vibration Intensity and Deformation and Fracture Evolution of Different Geological Structures of the Mountain

The above test results show that:

1. Relationship with amplitude, the pull-tension cracks occur in the slope and back edge at the horizontal amplitude of 2.5 cm. When the horizontal level is 3.5 cm, obviously pull-tension and shear-tension cracks will occur (see Picture 4), and apparent tension cracks and settlement zones occur at the back (see Picture 5). When the horizontal amplitude is 5 cm, shear-tension and pull-tension cracks extend to the deep extent, the layers become staggered and displaced obviously, and sliding-rupture deformation and cracking will occur (see Picture 6). The slopes with small structural strength will be causing the landslide.

2. Compared with the relationship of initial motion orientation, both in consequent slope and countertendency slope, the indication and extent of deformation and fracture in right side slope are singly than left side (see Picture 3). Generally, the right side slope becomes unstable while the left slope is only subject to slope deformation and fracture.
3. The deformation and fracture of the inclined external stratified slope is controlled by the structural surface, which will cause serious shear-tension and pull-tension cracks at the moment of vibration starting and gradually extend to the deep extent (see Picture 4). Meanwhile, layers become staggered and cause accumulated displacement, which shows obvious sliding-rupture fracture and becomes unstable as a result of landslides.
4. The steeper the outward tilted dip of the stratum, the more obvious sliding-rupture deformation and fracture will be, and the starting acceleration will be small.

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