An Assessment on the Functional Effects of the Existing Preventive Structures during Landslides

Fan F. S1, Chen G. Q1, Li Y. G2 and Zheng L3

1Department of Civil and Structural Engineering, Japan Kyushu University, Fukuoka, Japan
2School of Civil Engineering, Central South University, Changsha, China
3School of Economics, Sichuan University, Chengdu, China

Abstract

In recent years, many landslide prone slopes were identified in Japan and preventive structures were implemented against them. But the property damage and life loss were still caused by landslide despite of existing preventive structures. So the validity of existed structures should be investigated. The discontinuous deformation analysis (DDA) is considered as an appropriate numerical tool to resolve this problem since it can reproduce the process of landslide movement after failure. In this paper, both landslide with or without preventive structures is simulated to assess the validity of preventive structures by using DDA. Moreover, different cases are carried out to determine the appropriate position of the building according to the change trend of impact force. Results show that the assessment is acceptable and believable, the calculated impact forces on the building at different locations can be used to future preventive design.

Keywords: Landslide, preventive structures, functional effects, DDA

1. INTRODUCTION

Landslide is identified as the second most natural hazard by the United Nations Development Program (UNEP). Estimated by Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in 2002, 113,557 landslide prone slopes were identified in the whole country, and the preventive structures had been made for 20,600 slopes among them (Osanai et al., 2010). However, how to evaluate the functional effects of a preventive structure still remains unsolved problem in the plan of preventive structure designs. Also, the functional effects of some existing preventive structures are doubted since some landslides still led to damages despite of the existing structures recently. Thus, it is necessary to assess the functional effects of the existing preventive structures during landslides.

In this study, an approach is proposed by applying DDA (Shi and Goodman, 1984) to verify if the existed structures are effective or not against the landslide. The DDA method uses a finite element type of mesh but where all the elements are real isolated blocks, bounded by pre-existing discontinuities (Shi,1988). The approach has been used to assess the validity of the preventive structure on the Ura landslide, where a landslide occurred in October, 2010. On the right part of the landslide, this area is reinforced area. The preventive structure was set in the reinforced area for protecting the house. Although this landslide and reinforced area are all failure, the breakdown strength of reinforced area decreased according to the field investigation and estimate. So it is important to assess if the preventive structure is effective using DDA method. Results show that the assessment is believable and acceptable.

2. GEOLOGICAL CONDITION OF THE URA LANDSLIDE

A heavy rainfall occurred in Amami-oshima Island (Japan) on 18-21 October, 2010, has triggered 55 landslides. The maximum rainfall is greater than 100 mm and accumulation rainfall exceed 400 mm during the period of rainfall. The rainfall monitoring result of Ura area is shown in the figure 1. The landslide which is the object of study in the following paper is destroyed when the accumulation rainfall a maximum value. One of the landslides located in Ura area, is selected as the object of study in this paper. As shown in figure 2 and 3, since it was identified as a landslide prone slope, part of this area was reinforced before this rainstorm event. However, landslide still occurred in this slope after...
the rainfall. It caused one building was fully damaged, two
were half damaged, and the national highway nearby was
totally disrupted. On the right part of the landslide, this
area is reinforced area. The preventive structure was set in
the reinforced area for protecting the house. Although this
landslide and reinforced area are failure, the breakdown
strength of reinforced area decreased according to the field
investigation and estimate.

The Ura landslide is deep seated landslide which length is
80m and width is 50m in the sliding area. The total volume
of the landslide is about 20 thousand m³ and the maximum
sliding depth is greater than 10 m. Before the failure of
landslide, the inclination angle of landslide is about 35
degree. According to the investigation and research after
disasters, the geological structure and sliding surface,
fracture zone were proved. The bedrock of shale (Mesozoic
cretaceous) bed is watertight and it is observed that the
water burst appeared in the top of

landslide. The landslide body is mainly the highly
weathered sandstone and shale. The failure surface is
located on the bottom of upper deposit.

In the middle of sliding surface, the bedrock of shale bed
is watertight and it is observed that the water flow from
this layer to the toe of the landslide after the landslide
occurred. So it has groundwater flow in the layer of shale
could be concluded. As it shown in the figure 2, the
landslide has two sliding direction of main direction and
impact direction. On the left of this landslide, there are
some small creep deformation areas and slump areas.
Besides, the deep sliding failure of landslide is
investigating according to the displacement monitoring
of ground. There are some cracks on the landslide
boundary because of the failure of the landslide.

3. ASSESSING THE FUNCTIONAL
   EFFECTS OF EXISTED PREVENTIVE
   STRUCTURES

3.1 Analytical validation of DDA

The analytical validation of DDA should be proved
before using this numerical simulation method. Block
displacement as a function of time has been studied by
many researchers (Wyllie and Mah, 2004), since a well-
known analytical solution for displacement of a point
mass is readily available. For a plane inclined \( \alpha \) with
friction angle \( \phi \) (figure 4), the analytic solution for the
displacement \( d \) at time \( t \) of a rigid block starting from
rest is
The physical model shown in figure 4 consists of two blocks. The bottom wedge with inclined plane is fixed and only the upper cuboid is allowed to slide under the pure gravity. The top block size is 1m*1m. The mechanical properties and computational parameters are: Density 2000 kg/m$^3$, Young’s modulus 50 GPa, poisson’s ratio 0.2, penalty spring stiffness 500 GPa and the slope of inclined plane 24°.

A comparison between the DDA results and the analytical solutions from Eq. (1) is shown in figure 6. The DDA results show a satisfactory agreement with the time-dependent displacement functions predicted by the analytical solutions. DDA is capable of capturing the essential aspects of the displacement over the sliding distance. It can be concluded that the obtained results are more than accurate enough for most practical geomechanical simulations.

$$d = \frac{1}{2} g (\sin \alpha - \tan \phi \cos \alpha) t^2$$  

(1)

Figure 6. Displacement versus time for a cuboid block sliding on an inclined plane.

3.2 Approach of assessing the functional effects of existed preventive structures

To assess the functional effects of existed preventive structure against the landslide, the following procedures are carried out: (1) reproduction of the landslide event by DDA simulation so as to determine the friction angle; (2) two scenarios is investigated by DDA simulations. The one is the case with the preventive structure, and the other is the case without any preventive structure. By comparing the impact forces on existed building, the functional effects of the existing preventive structure can be discussed and assessed; (3) different cases are carried out to determine the appropriate position of the building according to the change trend of impact force, which is useful for the improvement of the existing structures and future design of engineering project.

3.2.1 Determination of the geotechnical parameters

Figure 7 shows the DDA model of the site along the direction which the landslide impacted on the building at the toe of slope. The parameters from field investigation are shown in Table 1. Three parameters, cohesion, friction angle and tension strength are used in DDA simulation (table 1). For the simulation of actual situation, the strength reduction method is used to find the critical friction angle when landslide occurs. That is to say, the friction angle is reduced from 0% to 90%, and the critical friction angle will be taken when the reasonable simulation results are obtained.

Using strength reduction method, a friction angle equaled 70% of origin value could be determined as the friction angle when landslide occurred as shown in figure 8, which presents a similar accumulation shape with the real situation.

3.2.2 DDA simulation of the landslide with preventive structure

To assess the validity of existed preventive structure, the same parameters were used to investigate the movement behaviors of the case that there was no reinforcement. Figure 9 shows the DDA model along the pre-estimated landslide prone direction. Results show that if there was no reinforcement, the building would be fully overburdened by the deposition mass in figure 10. Besides, the impact forces of each floor of the building are calculated without preventive structure, the result is shown in figure 12. In this case, a friction angle equaled 70% of origin value could be determined as the friction angle when landslide occurred without preventive structure.
A friction angle of origin value could be determined as the friction angle when landslide occurred with preventive structure. Moreover, the impact forces of each floor of the building are calculated, the result is shown in figure 11. In this case, the functional assessment was represented by the impact force of debris mass on the structure too. Figure 11 and figure 12 shown that the impact force of case without reinforcement is 2 times larger than the case with it. It also indicates that the preventive structure is partly effective.

### Table 1 Geotechnical parameters in Ura site

<table>
<thead>
<tr>
<th>Item</th>
<th>Density (kg/m³)</th>
<th>Young's Modulus (MPa)</th>
<th>Poisson's Ratio</th>
<th>Cohesion (MPa)</th>
<th>Friction Angle (°)</th>
<th>Tension (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>2000</td>
<td>0.25</td>
<td>20</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>700</td>
<td>0.3</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 10. DDA results without reinforcement using 70% original strength.

For future design of engineering projects, the proper distance from the projects to the landslide needs to be determined. Therefore, the impact force on the building vs the runout distance of the landslide seems to be important. To calculate the impact force alone the movement process, a case without the house is firstly simulated to reproduce the movement of the deposition mass as figure 13 shows. In this case, we can calculate the impact force of blocks in different time and runout distance.

### 3.2.3 Relationship between the runout distance and the impact force

The maximum displacement of the block is approximately 50m away from the toe of the slope. Amount of blocks accumulated at about 30m away from the toe of the landslide. Thus the following cases are...
carried out through changing the house: those are 3m, 13m, 23m and 33m away from the toe of the slope separately. Their impact force on each floor of the building is calculated. Thus the impact force on each floor vs the runout distance of the landslide can be determined. Figure 14 shows the maximum impact force on each floor vs the runout distance of the landslide.

From figure 14, it can be seen that the impact force decreases sharply in the range of 15m runout distance, and becomes flat after the runout distance of 20m. Especially when the distance is larger than 30m, the impact force becomes very small. Therefore, it is suggested to build engineering project 30m far away from the toe of the slope in the future.

From figure 14, it can be seen that the impact force decreases sharply in the range of 15m runout distance, and becomes flat after the runout distance of 20m. Especially when the distance is larger than 30m, the impact force becomes very small. Therefore, it is suggested to build engineering project 30m far away from the toe of the slope in the future.

**REFERENCES**


