Slope stability analysis using Universal Distinct Element Code (UDEC) method

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Abstract. Slope stability analysis was conducted using the Universal Distinct Element Code (UDEC) technique in this research. This technique stimulates the spread of stress waves in the jointed rock mass owing to dynamic loading caused by the blast. Simulation is a vital component of the slope stability analysis, as it generates a model called discontinuum capable of simulating the movement of fragments owing to the burst of production. Besides, the discontinuous codes used in this analysis may duplicate the entire method of fragmentation of the rock from fracture to fragment throw. This discontinuous analysis can also simulate joints and porosity attributes in a rock mass.

1. Introduction

A slope is known as a surface that is higher than one end or side; a falling or rising surface. An earth slope is a layer of a soil mass that is supported, inclined. The collapse of a ground mass under a slope can be called as a slip. This requires the entire mass of soil involved in the failure to move down and out. The slope failure is primarily linked to the gravitational effects and the seed forces inside the soil [1].

Slope stability refers to a method of calculating and evaluating how much stress can be managed before a specific slope fails [2]. The strength of the earth slopes should be evaluated quite carefully, as their failure can contribute to the loss of human lives and the huge financial loss [3]. The calculation of slope stability for geotechnical engineers remains one of the most critical problems [4]. Slope stability analysis is carried out in order to assess the safe design of natural or human-made slopes and the balance conditions. The main purpose of slope evaluation in most engineering applications is to assist to the secure and economical design of earth dams, embankments, excavations, etc. [3].

Study of slope stability is conducted to assess the appropriate structure of natural and human-made slopes and the equilibrium circumstances. Slope is the sliding or fall resistance of the inclined surface to failure. Slope failure may result in death and loss of property. Therefore, the stability of the proposed slopes must be monitored [1].

A thorough understanding of the various techniques and constraints used to check the stability of the slopes is required. There are three types of methods used in slope stability analysis, including the Limit Balance, the Finite Element Method and the Numerical Modelling Approach [1]. In this research,
discontinuum modelling is one of the numerical methods used to assess the stability of the slope of the study area.

1.1 Discontinuum Modelling
Discontinuum modelling is capable to simulate the behaviour of the rock mass correctly. This includes discontinuity response and interactive coupling of slope and hydraulic response to a certain degree makes it ideal for design analysis of rock slopes as long as appropriate field input data are acquired [5]. Universal Distinct Element Code (UDEC) used in the discontinuum modelling was built mainly for advanced two-dimensional geotechnical study of soil, rock, and structural support [6].

1.2 Application of Universal Distinct Element Code (UDEC)
In Rock Mass Model, Universal Distinct Element Code (UDEC) can be defined as a discontinue analysis method where the mechanical behaviour of the discontinuities and also the contact surfaces between the discrete elements must be represented by a numerical model [6]. In UDEC, the displacements and rotations of the discrete element blocks must be considered by the discrete element codes. It will identify new surfaces or contacts automatically during the execution process.

The rock mass model in Universal Distinct Element Code (UDEC), is described as a formation of discrete blocks element that individually influenced by the applied forces or the boundary limitation. This technique allows the finite displacement and rotations of the discrete blocks, and capable to detect new contact surfaces automatically during the process of the simulation [6, 7]. This dynamic behaviour of the numerical analysis is related to the application of the time-stepping algorithm [8].

The time-step size is calculated on the premise that the speeds and accelerations are set in the time-step. The size of the time-step is sufficiently minute to prevent disturbances propagate between one discrete element block to another connected element blocks. This solution approach is similar to an explicit method of finite differences continuum simulation. For rigid blocks, the time-step limitation is governed under the block mass and stiffness of the interface between block elements. Meanwhile, the concept of zone size is used for deformable blocks with additional rigidity of the system, which included the inclusion of intact rock modules and the rigidity of the contacts [8].

1.3 Study Area
The survey area is in Simpang Pulai, Perak, situated at 4°31'44.15"N latitude and 101°9'21.37"E as can be seen in Figure 2. Figure 3 shows the geology maps that shows the Kinta Limestone. This area has huge limestone bodies that are massively fractured and jointed.

**Figure 1.** Site location of survey works for comprehensive study at Simpang Pulai, Perak
2. Methodology

2.1 Conceptual Development of Rock Mass Model

The development of the rock mass model that can be developed into three (3) different perspectives; the joints of the rock mass model, the joint-force displacement model and the constitutive model [9]. Figure 3 shows the basic concept of rock mass modelling.

![Figure 3. Basic concept of rock mass modelling.](image)

These three components are important in identifying the attributes of the rock mass and also the fragmentation of the discrete blocks. This study also indicated the difference between a constitutive model and joint model. The joint model controls the behaviour of the rock mass joints while the constitutive model governs the behaviour of the intact rock with joints. The effects of these models on rock mass are [9]:

Figure 2. Geological map of the site area
i. The rock mass will fail in a flexible behaviour under high confinement,
ii. The rock mass will fail in a brittle manner under low confinement,
iii. The elastic waves are transmitted without any distortion.

2.2 Fully Dynamic Simulation of Rock Mass Model
The importance of initial state conditions of the rock mass model has been discussed by (Raffaldi, M. J. et al. [9]. The development of the static model is very important before dynamic loadings. The study explained the steps required to develop a static numerical model as shown in Figure 4:

![Figure 4. Basic steps to develop a static numerical model.](image)

As the static numerical model already completed, several further steps need to be considered to produce a dynamic numerical model as can be seen in Figure 5:

![Figure 5. Basic steps to develop a dynamic numerical model.](image)
2.3 Evaluation of Wave Transmission
The wave transmission within the simulated model must be accurately achieved to ensure numerical accuracy. This matter can be solved by assigning all the element sizes which are small enough concerning the wavelength of the input wave [9].

2.4 Attenuation of Blast Induced Vibration (Mechanical Damping)
The behaviour of blast-induced vibration is attenuated over distance. The reduction of blast magnitude over distance is influenced by two factors consist of material damping and geometrical spreading [10]. The damping ratio is declared as an important parameter in numerical modelling [9].

The study described the mechanical damping as a reduction of wave amplitude due to the energy dissipation when the wave propagates through matter. The damping ratio in numerical analysis is really important to prevent the oscillation of waves through rock mass without any attenuation which can affect the result of the numerical analysis.

2.5 Application of Dynamic Boundary Conditions
The condition of the dynamic boundary is an important aspect to consider as it involved the behavior of the waves at the artificial boundaries. In a static analysis, the stress boundary condition can be assigned at a distance where the waves are allowed to propagate back to virtually undisturbed condition. Nevertheless, in dynamic analysis, this condition boundaries cause the propagation of the waves to be reversed back into the model.

The size of the dynamic numerical model will be larger due to the increasing distance between the boundaries that acted as a material damping for energy dissipation and the region of interest. Hence, it is necessary for geomechanical modelling to develop artificial boundaries which purposely to attenuate the propagation and reflection of waves [9].

2.6 Application of Dynamic Loading
Dynamic loading in Universal Distinct Element Code (UDEC) or any other numerical approach is related to the transient load conditions. The dynamic loadings in numerical simulation can be transient stress, displacement or velocity which assigned at the selected boundary of the model [9].

For a problem related to the stability of the excavation due to dynamic loadings from the nearby blasting, a stress time-history which showing the borehole pressure from a detonating might be considered to an internal boundary within the simulated model [9].

3. Results and Analysis
3.1 Effect of Blast Vibration on Slope Stability
Quarry slope stability can be managed by structure, rock mass strength, or both. Berm/ inter amp heights and rock strengths will control rock mass failure. The strength and structure of rock mass are key factors that influence overall stability, especially in large quarry or open pits. Overall stability is always checked through the rock mass for the possibility of deep-seated failure, and the slice method is typically the preferred device. It is becoming more popular to apply numerical analyses; however, more data is needed than the simpler methods of limiting equilibrium and calibration of input parameters. Calibration is possible only in a quarry that has been in operation for some time and has a background of recorded failures and movement conditions. Because of this, the use of computational methods is not common in early design phases. Maximum equilibrium slope stability analyses will be performed when simple failure modes are required, as well as the more sophisticated numerical methods. Study of this analysis using separate methods of elements (UDEC) is carried out when the strength of the rock mass influences the stability. The quarry has an average angle of slope between 28º to 40º and a height of 179 meters from sea level with berm or an inter-ramp angle between 35º to 45º. The main rock in this quarry domain are limestone and dolomite. Figure 6 show the geometry of the wall and Figure 7 shows the cross section of the wall (A-B).
Discontinuities have been expressly implemented in the UDEC model to provide greater freedom of movement. The assumed spacing reflects a compromise between the real spacing and computational requirements; however, it has maintained their relative consistency and the overall aspect ratio of blocks. Numerical models containing safety estimation factor are obtained by simultaneously decreasing the intensity of both the material and joint properties when tracking the movement of selected points on the wall by UDEC modelling. The properties obtained by downgrading are gained by dividing by a metric the stiffness and the friction angle tangent for all materials and joints. Although wall movements are tracked by UDEC modelling, the model is then permitted to balance downgraded properties and the process is continued until conditions of equilibrium can no longer be achieved. A plot of the displacements tracked against the factor of downgrading shows where the wall is unstable. The magnitude of the downgrading factor at the point of instability can be demonstrated as a safety factor.

In this study, the stabilization of wall/slope using the UDEC model was analyzed based on the combination of discontinuity survey at Area 6 and Area 7 as shown in Figure 8. The parameters of rock
strength in the UDEC modelling was referred on Hoek-Brown Classification and Criterion, Mohr – Coulomb Fit as well as rock mass parameters as shown in Table 1.

**Table 1. The parameters of rock strength**

| Category                                      | Value       |
|-----------------------------------------------|-------------|
| **Hoek-Brown Classification**                 |             |
| Intact Uniaxial Compressive Strength          | 69.5 MPa    |
| Geological Strength Index for rock mass, GSI | 65          |
| Hoek-Brown constant for intact rock pieces, m | 9           |
| Disturbance factor                            | 1           |
| **Hoek-Brown Criterion**                      |             |
| Hoek-Brown constant for rock mass, mb         | 0.739       |
| Hoek-Brown constant, s                        | 0.0029      |
| Hoek-Brown constant, a                        | 0.502       |
| **Mohr-Coulomb Fit**                          |             |
| Cohesion                                      | 2.709 MPa   |
| Friction Angle                                | 23.90 deg   |
| **Rock Mass Parameters**                      |             |
| Tensile Strength                              | -0.275 MPa  |
| Uniaxial Compressive Strength                 | 3.718 MPa   |
| Global Strength                               | 8.328 MPa   |
| Modulus of Deformation                        | 9884.68 MPa |
| Spacing                                       | 12 m        |

Figure 9 shows no sign of rock mass disruption, suggesting that the slope is stable. It means that, for the most part, the wall’s action is straight with some movement on the vertical joint set in the limestone. In the slope displacement plot versus the downgrading element, this is evident. Rock mass loss is a result of a factor of 2.1 downgrading the strength parameters. At the top of the slope, there is a pocket of stress cracks. Figure 10 displays vectors of velocity and indicators of plastics in the unstable area. The downgrading factor versus the displacement plot in Figure 10 clearly shows the point at which red colour indicates instability. Figure 11 shows the UDEC modelling result of displacement effect due to vibration-induced based on time/year.
Figure 9. Indicator of the plastic boundary (Please note, the analysis above represents the analysis above the upper part of quarry door/cave)

Figure 10. Indicator of velocity vectors and plastic boundary at the start of instability (RED COLOR) Please note, the analysis above represent the analysis above the upper part of quarry door/cave)
Figure 11. Shows the UDEC modelling result of the displacement effect due to vibration induced based on time/year.

The results of critical failure surface analysis through the rock mass shown by the UDEC model show that the wall is relatively stable, and the safety factor expected to be less than 2.2. The indicated moderate stability with respect to deep-seated failure modes can be explained by the fact that slope toe is situated in the fracture zone, in other words, to the fact that the failure mechanism, in this case, is a failure by rock mass, except for release structures at the top of the cave door. Figure 12 shows the results of the final analysis of the UDEC. From the UDEC modelling, the plastic indicators at the lower part of the wedge and toppling “columns” do not represent rotational slip but are simply an indication of a “kink” band. This band is where the columns are mounted and therefore the rock is damaged by crushing.
4. Conclusion

In this study, Universal Distinct Element Code (UDEC) method was applied to analyze the slope stability of the study area. This method stimulates the stress wave propagation in a jointed rock mass due to dynamic loadings induced by blasting. The stabilization of the wall/slope using the UDEC model was analyzed based on the combination of the discontinuity survey at Area 6 and Area 7 of the study area. The results of the study of critical failures by rock mass shown by UDEC model demonstrate that the wall is moderately stable, and that the safety factor is estimated to be less than 2.2. The medium stability indicated for deep-seated failure modes is that the failure mechanism, in this case, because the failure mechanism, in this situation, is failure by rock mass, except for the trigger structures at the top of the slope or at the top of the cave entrance. From the UDEC modelling results, it has been shown that the slope is stable without any suggestion of damage to the rock mass. Failure by rock mass resulted from the reduction of the intensity parameters by a factor of 2.1. There is a stress cracks zone at the top of the slope. As a conclusion, discontinuous modelling using Universal Distinct Element Code (UDEC) method is proficient to analyze the slope stability of the study area. The discontinuous codes used in this analysis can duplicate the whole process of rock fragmentation from fracture to fragment throw. This discontinuous analysis also can simulate joints and porosity attributes in a rock mass.

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