Arch action in granular media placing along an oblique plane across an undercut pit examined by computer simulations

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The arch action and its mechanism of granular slopes placing on the oblique plane with supporting portion along their toes were examined through a series of three-dimensional numerical models based on discontinuous deformation analyses. Deformable blocks were discretized into elements. Distinct boundary interaction between the rigid plate and the granular media was solely friction. The boundary conditions of model slopes were varied with two different conditions of the smoothness of side constraints and the amount of surcharge applied on the top of slopes. The development of arch action represented by trajectories of principal stresses at a certain distance away from the pit can be observed above the undercut area.

1. Introduction: This study aims to examine the load transfer mechanisms of slopes sitting on the rigid plane with undercut pit along their toes by using distinct element method for discontinuum modeling, which can be extended to engineering application of cut-and-fill sequences for supporting earth slope as a new mining technique. Investigations of arch action parallel to the gravity direction that appeared in silos, tunnels, underground conduits/pipes (e.g. [1]) and those that are normal to the gravity direction which materialized in retaining walls stabilized by drilled shafts have been already studied in the past (e.g. [2]). Therefore, the arch action slanting to the gravity direction needs further exploration.

2. Background: Khosravi et al. [3] investigated the possible modes of slope failure due to excavation at the toe of slope through a series of simple model tests of humid sand placed on an inclining rigid plate. Though removals of propped portions of sand at the toe of slope did not cause the collapse of sand mass due to arch action over the pillars, arching effect cannot be maintained once excessive removals were made. Likewise, different failure modes were observed in accordance with boundary and loading conditions. The case of slope model with side supports and surcharge are selected and considered in this study to illustrate trajectories of the major principal stresses by computer simulations (see Fig. 1).

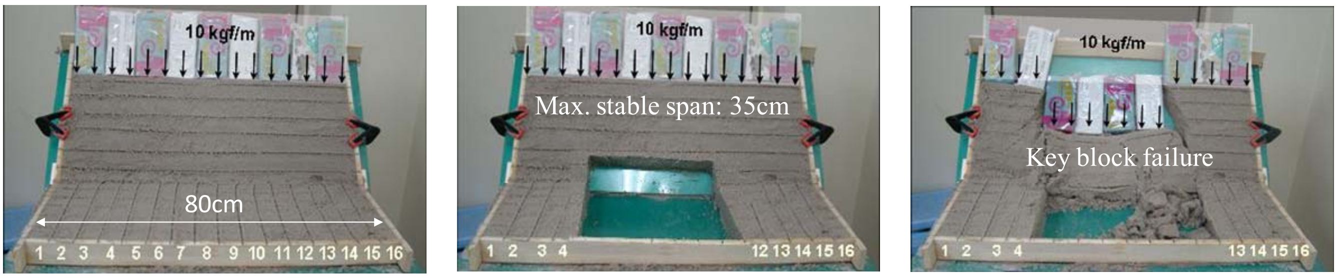

Fig. 1 Slope model with side supports and surcharge for the humid sand with friction angle ϕ'=38^{o} and cohesion c′=8 kPa

3. Numerical models: According to [3], geometry of slope is described by slope width W=80 cm, toe length L_T=30 cm, thickness H=5 cm, slope length L_S=35 cm and slope angle α=50^{o}. Fig. 2 shows the slope model which is comprised of 25,632 tetrahedral elements laterally confined by side supports. For illustration, the assigned material properties are listed in Table 1 with the damping ratio 60% assigned to the sand and the friction angle 38^{o} assigned to the interface between the sand and the rigid oblique plate. The software 3DEC®, a three-dimensional numerical program based on the distinct element method for discontinuum modeling, was employed in this study. Two numerical models were varied by different conditions explained in Table 2. Case A represents a slope with smooth side supports without the external traction. In contrast, Case B represents a slope with fully rough side supports with the external traction applied on the top of the sand and parallel to the oblique plane.

Table 1 Assigned physical properties for the numerical models

Material properties	Rigid plate	Sand
Young's modulus (MPa)	30000	10
Poisson's ratio	0.2	0.2
Bulk density (kg/m^3)	2,800	1,077

Table 2 Parametric study for the numerical models

Cases	Side friction angle	Traction (N/m)
A	0	0
B	38^{o}	98

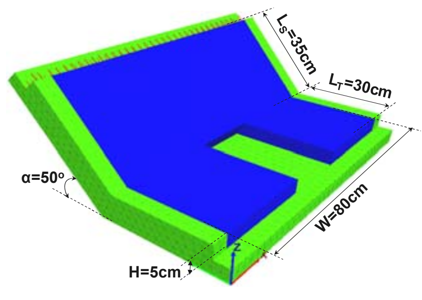

Fig. 2 Slope model with side supports and surcharge

Keywords Arc action, Computer simulation, Physical model test, Slope stability, Numerical analysis, Granular media
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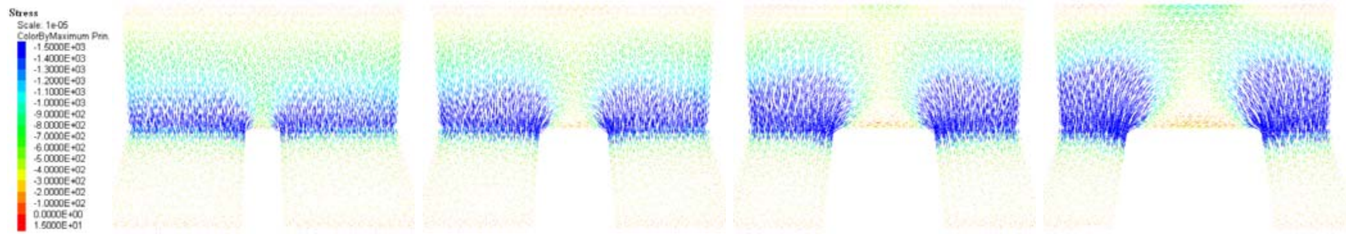
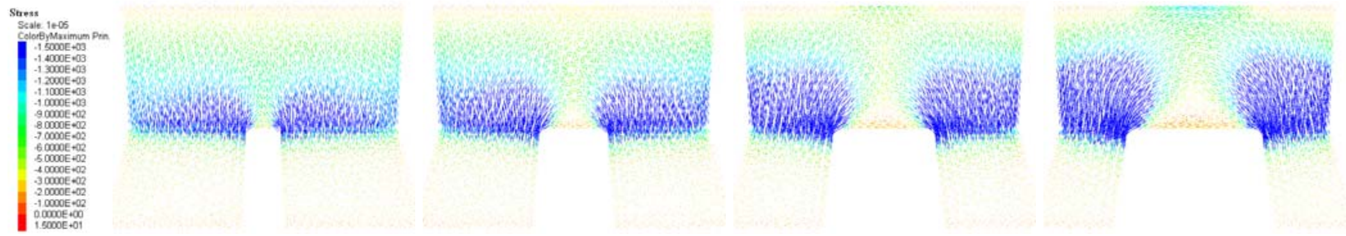


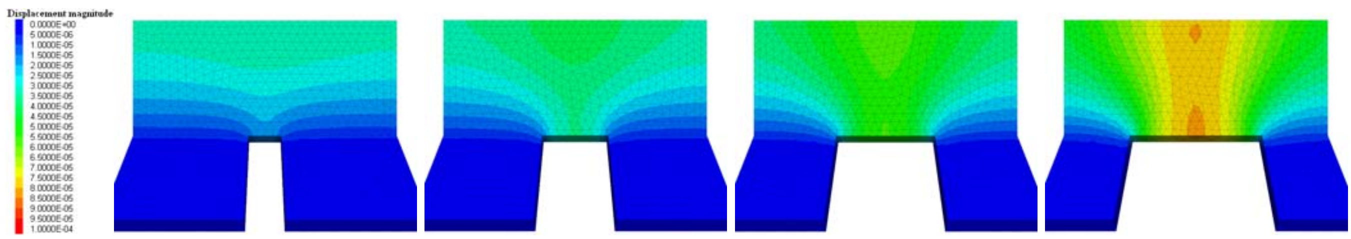
Case A: 10-cm excavation 20-cm excavation 30-cm excavation 40-cm excavation



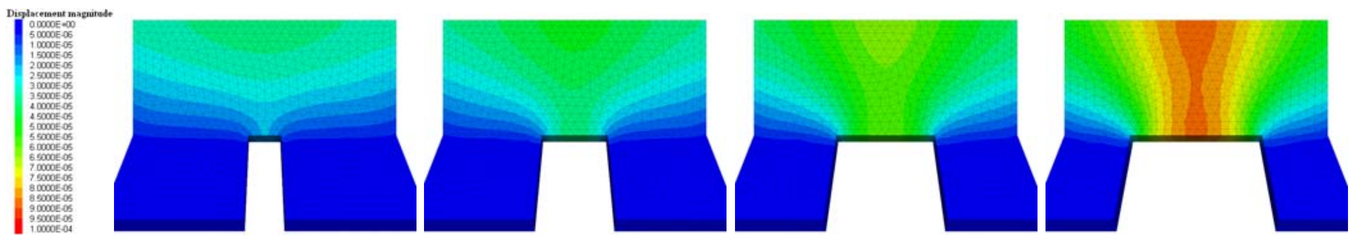
Case B: 10-cm excavation 20-cm excavation 30-cm excavation 40-cm excavation

Fig. 3 Trajectories of principal stresses in the middle layer of the slope in corresponding to the widen excavation widths

4. Illustrations of results: After the completion of the numerical model calculations, a number of results, graphically presented, aid in to understand of the load transfer mechanism of slope sitting on the oblique plane with propping portion along its toe. The major principal stress trajectories are crucial indicators of the passive aching occurrence. Therefore, the major principal stress trajectories are plotted in Fig. 3 by using a cutting plane placed at the middle of the slope thickness. The major principal stress trajectories are formed an arch-like shape in both Case A and Case B when made an excavation at the toe. The arch-like shape, formed by the trajectories, becomes wider and higher when the excavation at the toe is expanded. The lower magnitude of major principal stress locates beneath the arch. The side friction along the rigid plate and the sand, as well as loading conditions, considerably affect to the displacement magnitude on the slope face. Fig. 4 shows the contours of displacement magnitude on the slope face. Large displacements occurred near the center line of the slope particular for Case B which could describe a key block failure observed in the physical model test. Because the downward motions of sand toward the inner interval of excavation indicated that the slope is being pushed inward, it can be realized that the lateral compression would be greater than the inclined compression to sufficiently initiate the arch action in passive condition.



Case A: 10-cm excavation 20-cm excavation 30-cm excavation 40-cm excavation



Case B: 10-cm excavation 20-cm excavation 30-cm excavation 40-cm excavation

Fig. 4 Contours of displacement magnitude on the slope face in corresponding to the widen excavation widths

5. Conclusion: The simulations confirmed that, load from the slope is dominantly supported by two propping portions at the toe of the slope. Stress pattern being reduced from the middle during the excavation stage, increases downward pressure toward the pillars of an arch. Therefore, arch action is formed over the pit and steers the weight away from the central plane of the slope. The results confirmed the assumption about curved arches in a passive condition and could be employed to describe load transfer mechanisms and failure criteria under more complex situations in mining applications.

References: [1] K. Terzaghi, Stress distribution in dry and saturated sand above a yielding trap-door. in *The 1st ICSMFE*. pp.307-311, 1936. [2] L. Robert & Z. Sanping, Numerical study of soil arching mechanism in drilled shafts for slope stabilization. *Soils and Foundations* 42(2), pp.83-92, 2002. [3] M.H. Khosravi, T. Pipatpongsa, C. Leelasukseree & P. Wattanachai, Failure mechanisms in arched excavation of sloped earth using model test. in *Geo-Kanto2009*. pp.241-246, 2009.