Idealized curved surface for mimicking slope failure : toward the sequential failure

Chi-Jyun Ko, Chih-Ling Wang, Hock-Kiet Wong & Yih-Chin Tai
Dept. Hydraulic and Ocean Engineering, National Cheng Kung University, 701 Tainan, Taiwan

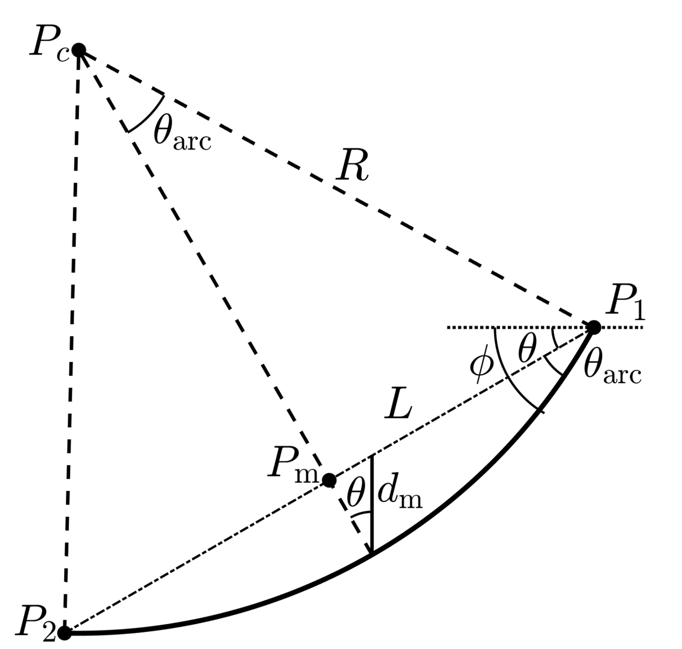
EGU21-10520
EGU General Assembly 2021

ABSTRACT

In Tai et al. (2020), the concept of idealized curved surface (ICS) is proposed to mimic the failure surface, and the application to a large-scale landslide yields good agreement with the satellite image for the post-failure flow paths. The ICS consists of two constant curvatures in the down- slope and cross-slope directions, respectively. Hence, it is convenient to evaluate the stability based on the moment of momentum with respect to the plausible ICS. In this study we are going introduce a new formula for the stability analysis, in which the balance of angular momentum is employed, so that the local failure thickness (above the ICS) and the local ground water level can be taken into account. That is, the depth distribution of the landslide body may also have significant impacts on the slope stability. Motivated by the similarity between landslide and granular avalanches, the periodic sand avalanches on a heap are investigated by means of the snap shots of high-speed camera, where the sand is accumulated up to a specific volume before sliding down. It is found that the first failure takes place near the toe of the avalanching body and the rupture surface develops and moves upwards. The ICS and the associated stability analysis can well explain the initial failure near the toe. This concept can also be applied to the mystery of the Hsiaolin landslide, taking place in southern Taiwan in 2009, where the released volume is up to more than 22 M m³ but the mean slope is around 21 degrees. In spite of a 2D analysis, it can be found that, with a reasonable groundwater level, the first failure could be suspected to develop around the toe part. Therefore, we speculate that the plausible state of the landslide is the rainfall induced rise of groundwater level, inducing the sequential landslides and resulting the resultant large-scale landslide event.

Idealized curved surface

Define P_1 and P_2 on the failure surface can obtain the value of L and θ, and given a d_m, the radius of curvature R can be calculated through the Equation (1).



$$\begin{cases} L = 2R\sin\theta_{arc}, \\ R - d_m\cos\theta = R\cos\theta_{arc}, \end{cases} \qquad (1)$$

Fig 1: Geometric relationship

The stability analysis

When calculating the moment caused by gravity, the length of the moment arm varies with the height of each section of the soil. Therefore, the length of the moment arm of each section needs to be calculated separately to analyze the moment.

$$FS_s = \frac{\sum_{n=1}^{n=p}(W_n R\cos\alpha_n \tan\phi)}{\sum_{n=1}^{n=p}[W_n \sin\alpha_n (R - \frac{h}{2}\cos\alpha_n)]} \qquad (2)$$

When considering the influence of groundwater on the safety factor, Equation (3) does not consider the influence of hydrostatic pressure on the soil.

$$FS_s = \frac{\sum_{n=1}^{n=p}((W_n\cos\alpha_n - u_n\Delta L_n)R\tan\phi)}{\sum_{n=1}^{n=p}[W_n \sin\alpha_n (R - \frac{h}{2}\cos\alpha_n)]} \qquad (3)$$

Experiment

- Two glass plates are used as the wall, the distance between the two is 2 cm.
- The same weight of sand was added each time to supply sand.
- A high-speed camera was used to record 100 shots per second

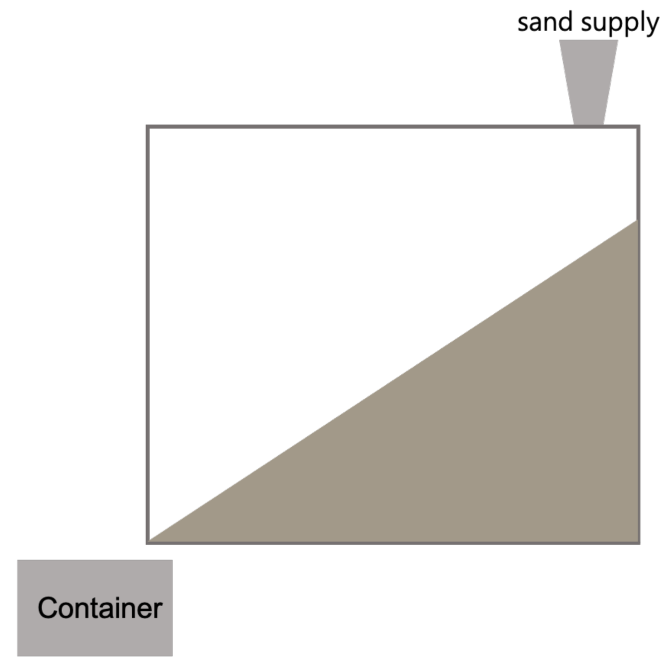


Fig 2: Experimental schematic

Analysis of the landslide process

- During the landslide, the changes of surface changed.
- Most of the soil was concentrated on the slope at the beginning.
- It gradually showed symmetrical as the landslide occurred.

- The failure surface (orange line) is established by using an ideal curved surface.
- When the landslide occurs, the area covered by the orange line is the landslide mass.
- The white area is the amount of landslide at the same time.

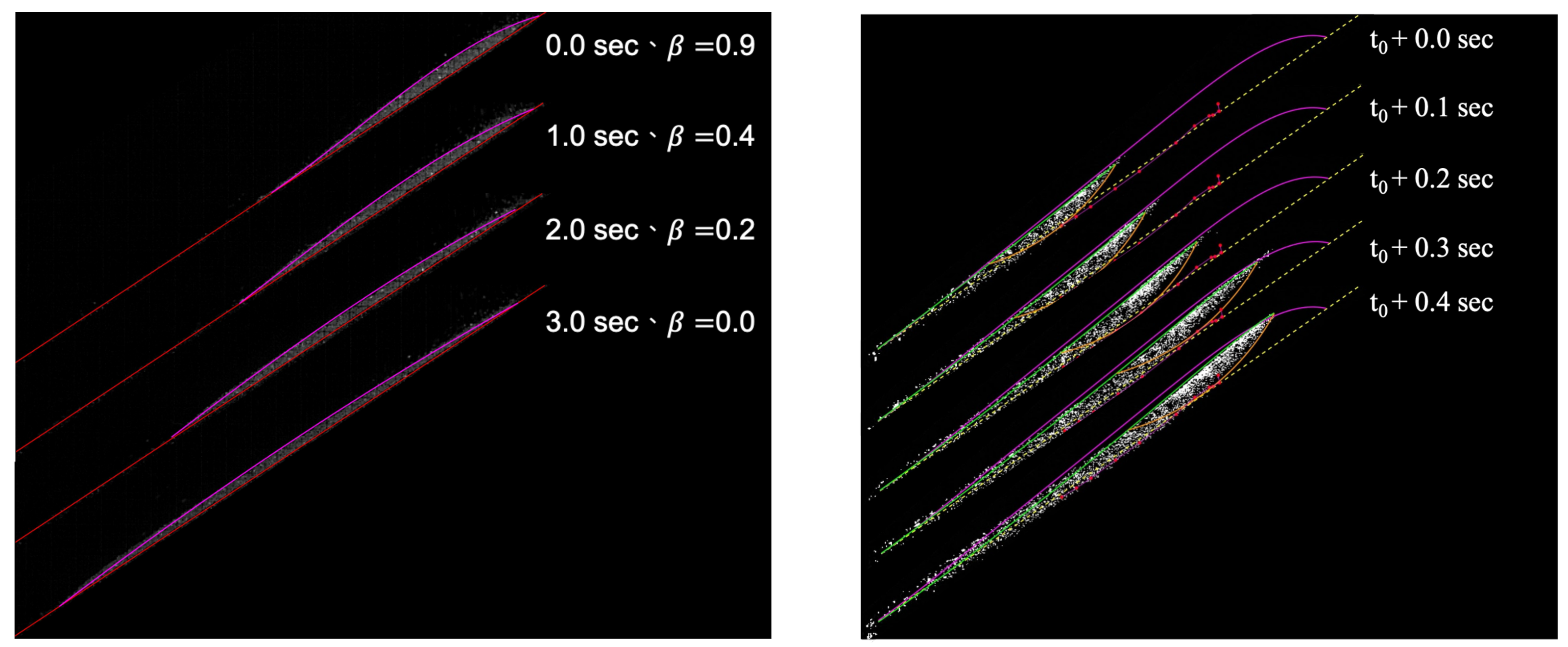


Fig 3: Left : different shape factors and safety factors. Right: shape factors and the surface.

Safety Factor and Shape Factor

$$h^* = h_0\left(1 - \left(\frac{x - x_0}{R}\right)^2\right) \times \left(\beta\left(\frac{x - x_0}{R}\right) + 1\right) \qquad (4)$$

- When the shape factor is 0, it represents the symmetrical shape of the slope.
- The shape factor on the below figure is 0.9.
- Different shape factors will also affect the safety factor.

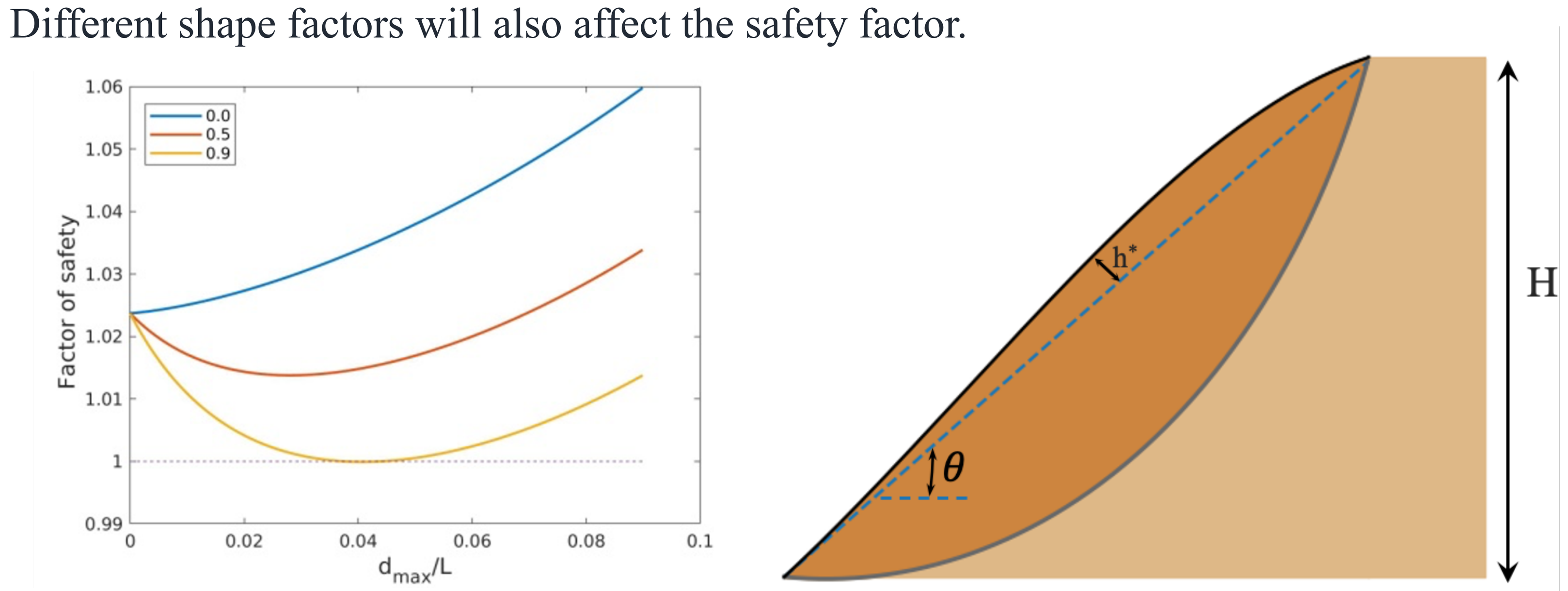


Fig 4: Left : different shape factors and safety factors. Right: shape factors and the surface

Safety Factor and Groundwater

- Equation (5) to assume the possible groundwater distribution.
- Assume the soil under the groundwater is in a saturated state.
- The safety factor of the slope decreases as the groundwater level rises.

$$W = W_0\left(1 - \left(\frac{r}{L_x}\right)^2\right) \qquad (5)$$

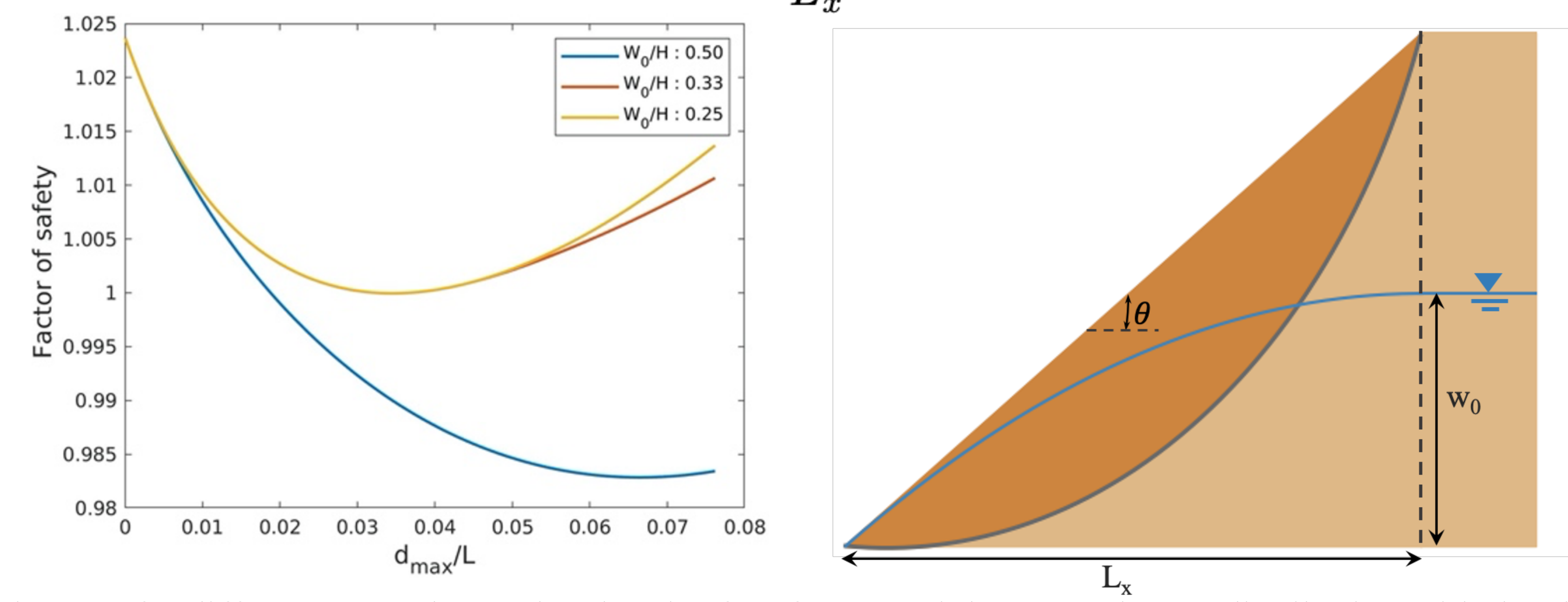


Fig 5: Left : different groundwater level and safety factors. Right: groundwater distribution with the slope.

Sequential failure

- It is possible that the first damage occurred around the slope site, resulting in a large-scale landslide.
- Each time increase the ideal failure surface length by 10 meters to calculate the safety factor at different maximum landslide depths.
- Obtain the idealized curved surface where the minimum safety factor.

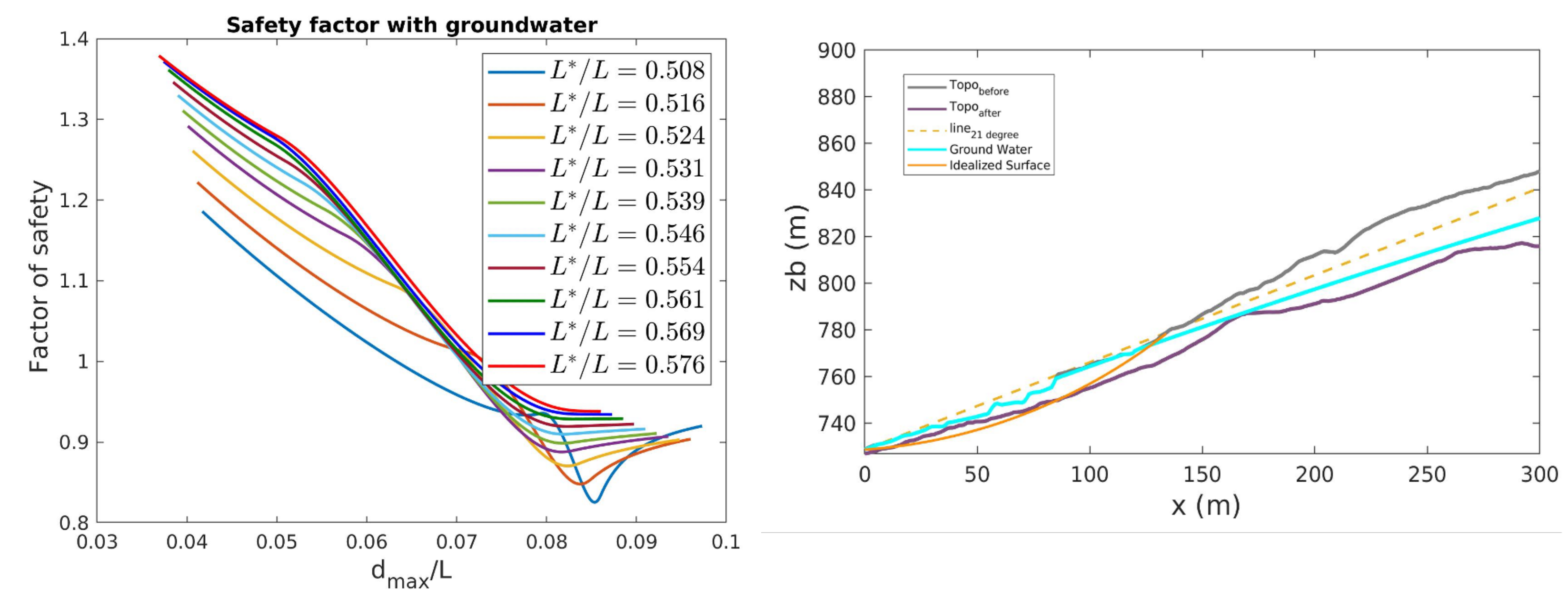


Fig 6: Left : Safety factor of partial landslide. Right : Section of partial landslide on the Hsiaolin event.

Conclusion

- Observed from the sandpile experiment, the change of the surface during the landslide.
- Destruction from the slope site when a landslide occurs.
- The distribution of the slope surface will affect the safety factor.
- Slope site damage may lead to large-scale landslide.

References

[1] Yih-Chin Tai, Chi-Jyun Ko, Kun-Ding Li, Yu-Chen Wu, Chih-Yu Kuo, Rou-Fei Chen, and Ching-Weei Lin. An idealized landslide failure surface and its impacts on the trav- eling paths. *Frontiers in Earth Science*, 8:313, 2020.
[2] Alan W Bishop. The use of the slip circle in the stability analysis of slopes. *Geotech- nique*, 5(1):7–17, 1955.
[3] Braja M Das and Nagaratnam Sivakugan. *Fundamentals of geotechnical engineering*. Cengage Learning, 2016.