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Study on Early Warning of Landslides by Using Rainfall Parameters

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1. Historical Landslide Event in Taiwan

In Fig.1 (a), the 36-hour accumulated rainfall curve can be used as the landslide early warning curve in the Siaolin village (sliding surface 86.2 m deep).

In Fig.1 (b), the 24-hour accumulated rainfall curve can be used as the landslide early warning curve in the Tuchang tribe (sliding surface 20-30 m deep).

In Fig.1 (c), the 12-hour accumulated rainfall curve can be used as the landslide early warning curve in Houtong (sliding surface 10 m deep).

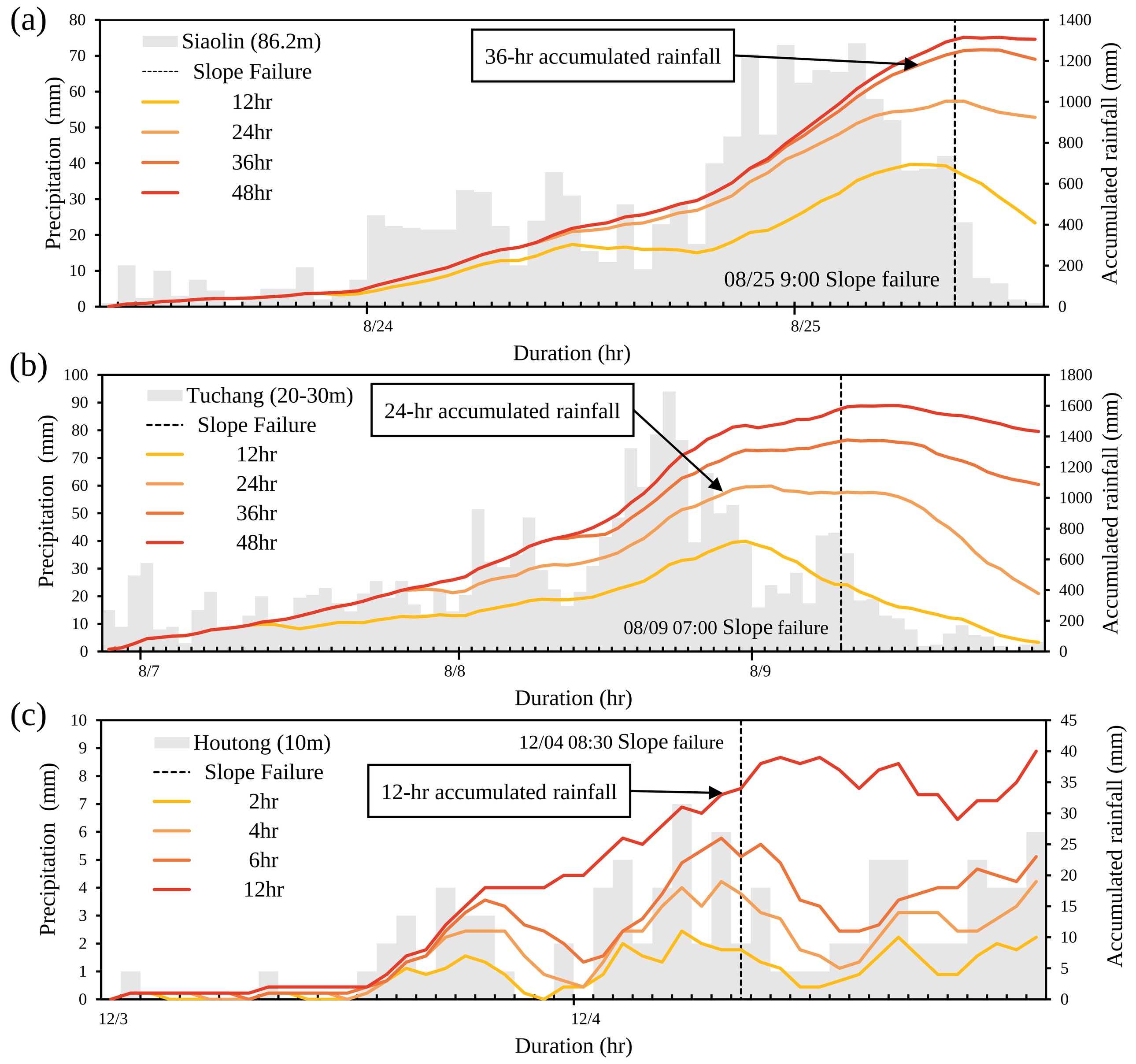

Fig.1 Landslide in (a) Siaolin (b) Tuchang (c) Houtong.

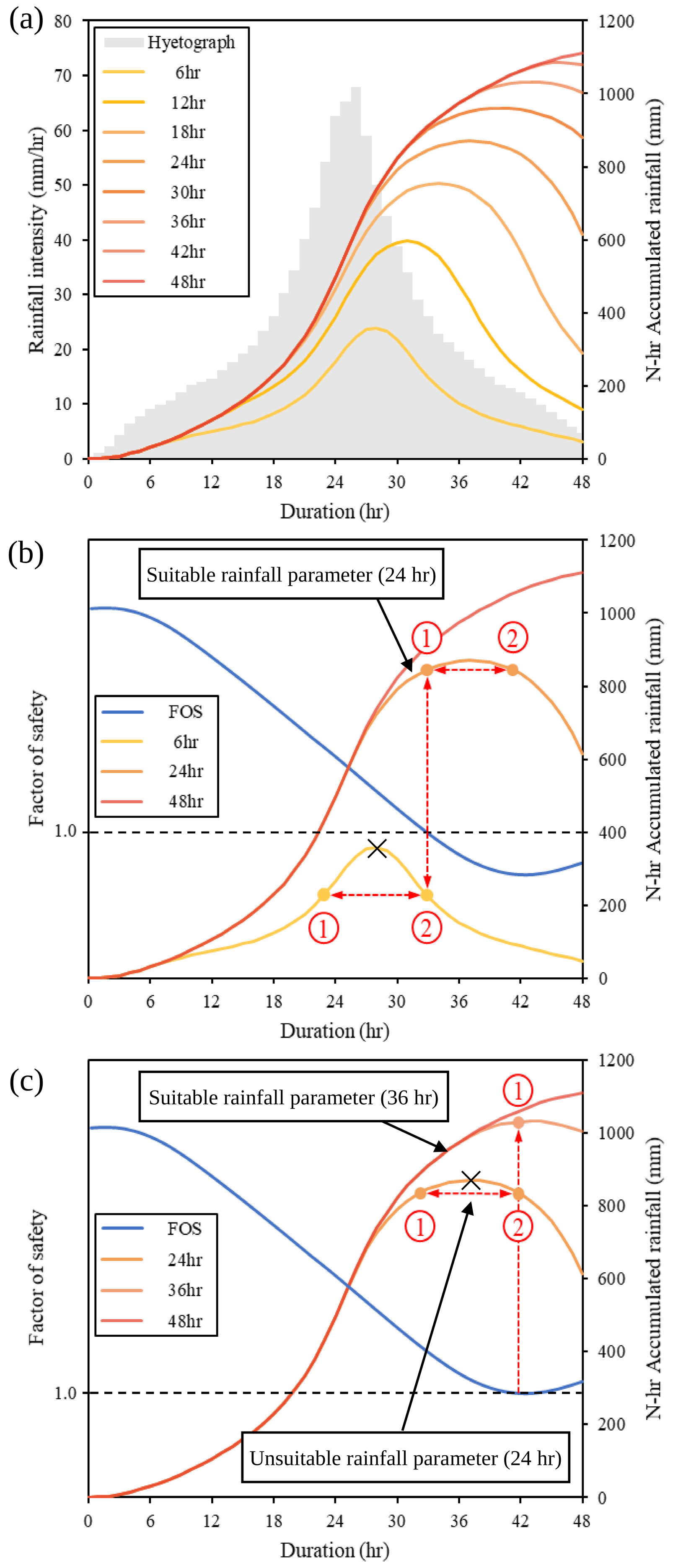

Fig. 2 Introductions of rainfall parameters under the same rainfall event.

2. Rainfall Parameters

By accumulating rainfall over different durations, various N-hour accumulated rainfall curves can be obtained from a single rainfall event, as illustrated in Fig.2 (a). To facilitate comparison between these curves and the temporal variation of the factor of safety (FS), this study defines the accumulation duration as the **rainfall parameter** and the resulting curve as the **rainfall parameter curve**.

When selecting a rainfall parameter curve based on the time FS drops below 1.0, two outcomes may occur: (1) As shown in Fig.2 (b), using the 6-hour curve, the threshold might be exceeded before actual failure, causing false alarms, making the 6-hour curve unsuitable for early warning.

(2) In contrast, the 24-hour (or longer) rainfall parameter curve rises after failure, so the first threshold exceedance usually matches the actual failure time. It offers a more accurate and reliable basis for early warning.

In some cases, as shown in Fig.2 (C), when FS = 1.0 co-occurs with the minimum FS, choosing a suitable rainfall parameter curve is more limited. In such situations, a longer duration, like a 36-hour curve, may be appropriate.

Rainfall parameter curves with longer values inherently encompass the characteristics of shorter ones. The minimum FS time can also be considered the latest possible time of failure. **Thus, this study uses the time of FS minimum to select the most suitable rainfall parameter curve and ToF to define the rainfall threshold.**

3. Slope model

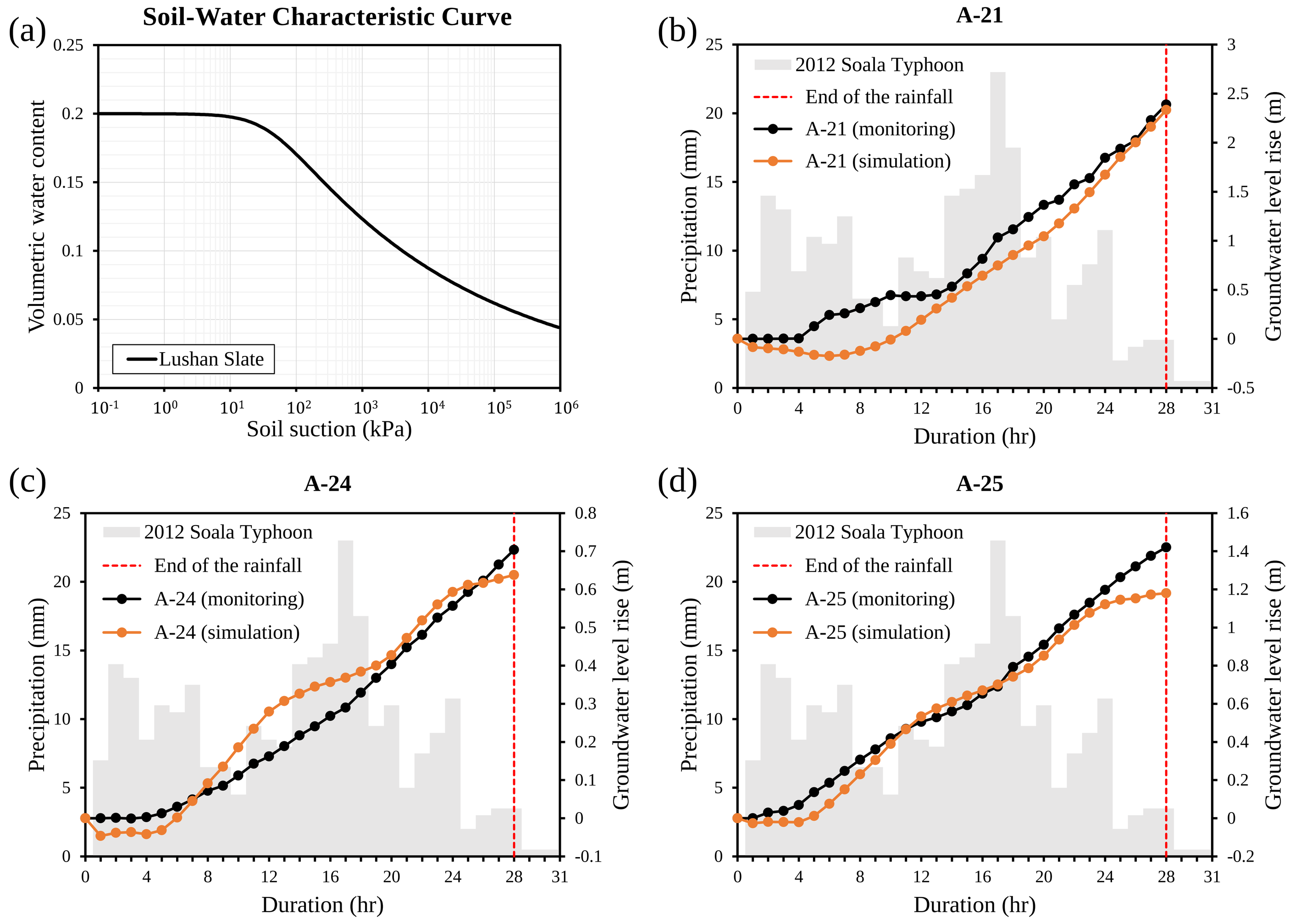

Fig.3 Results for the VG parameters back calculation. (a) SWCC curve for Lushan slate. (b)(c)(d) the comparisons between monitoring and simulation A-21, A-24, and A-25.

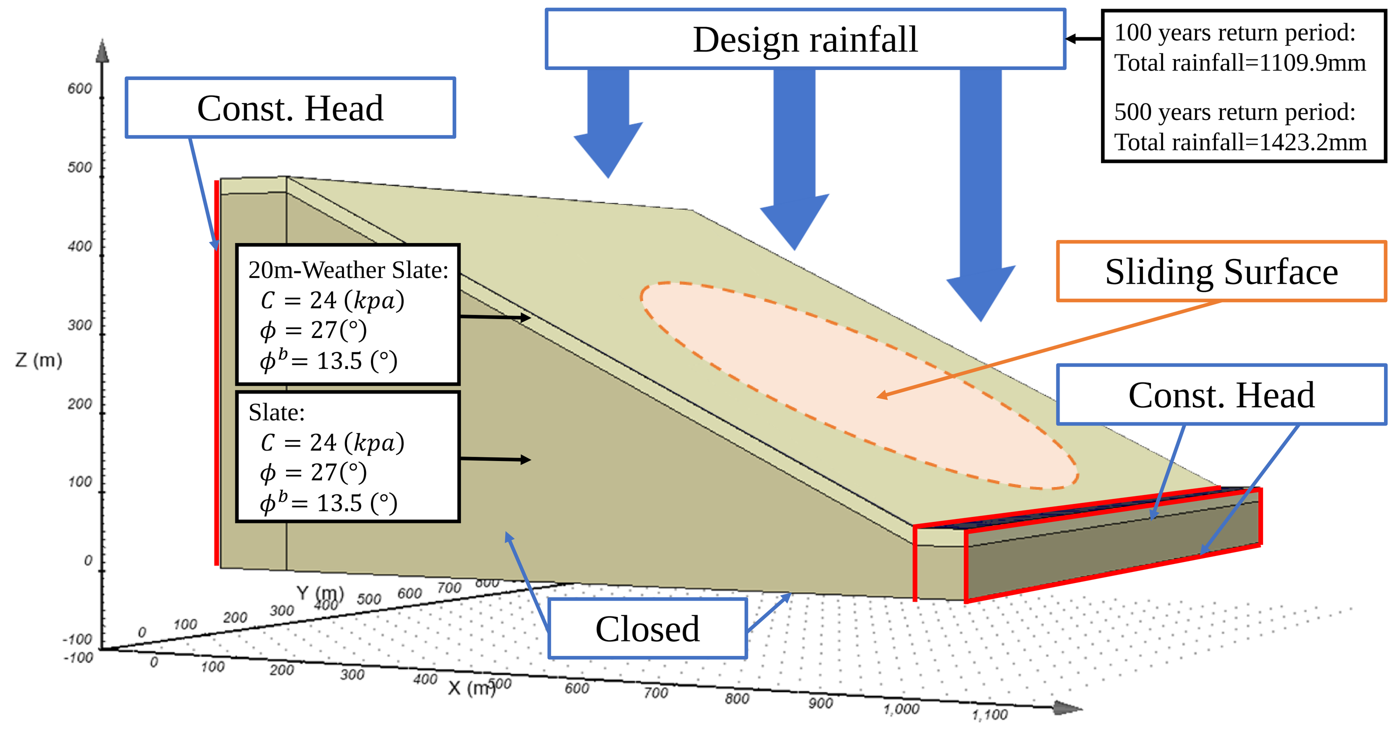

Fig.4 Simple slope model for FS calculation.

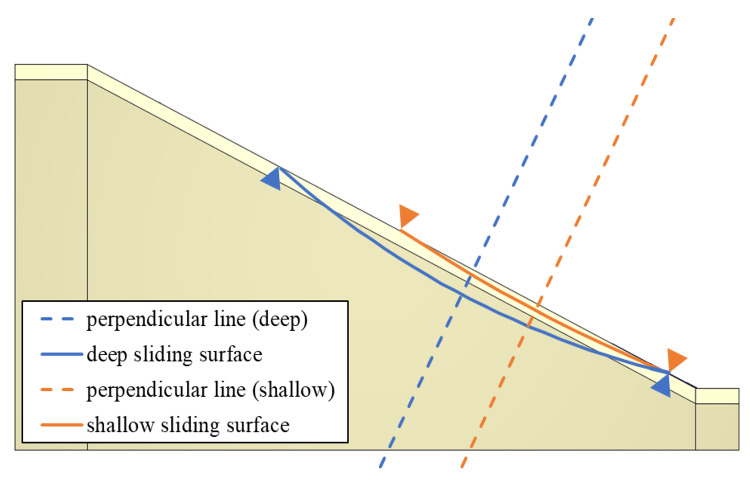

Fig.5 The positions for the sliding surface.

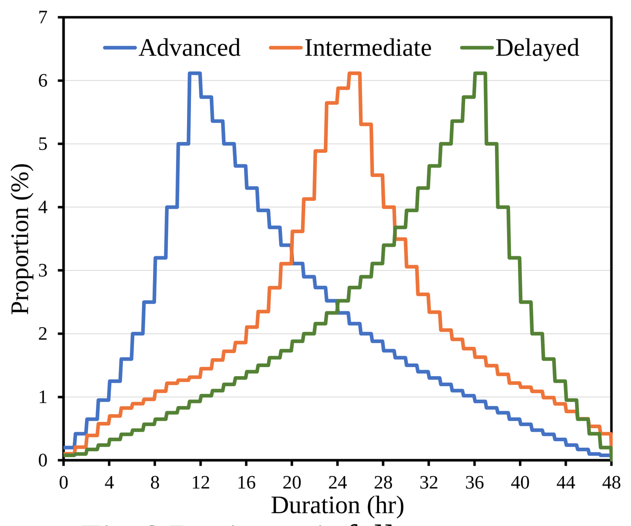

Fig.6 Design rainfall patterns.

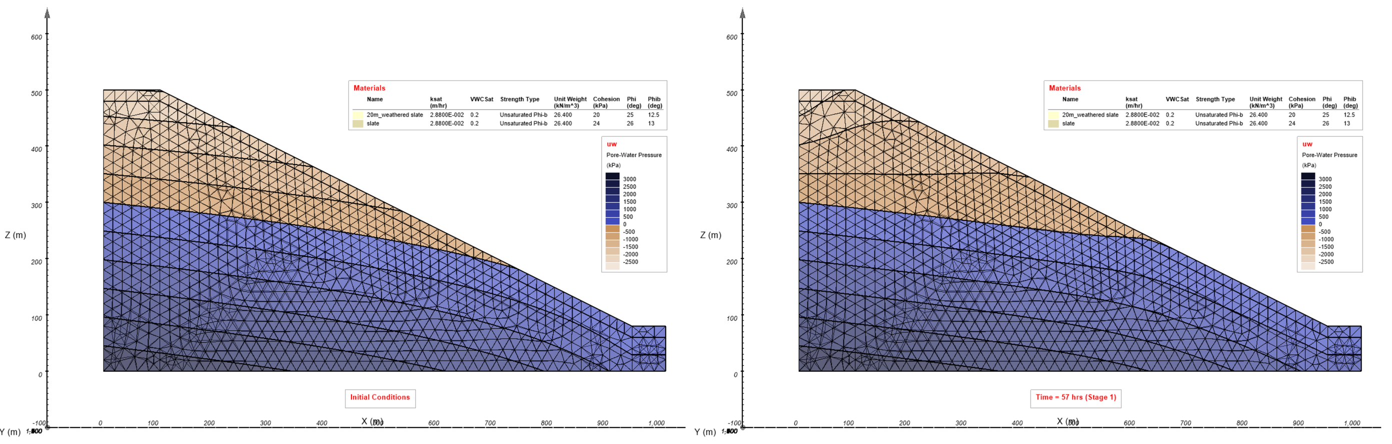

Fig.7 (a) Initial groundwater condition. (b) Groundwater level rise after design rainfall.

4. Result

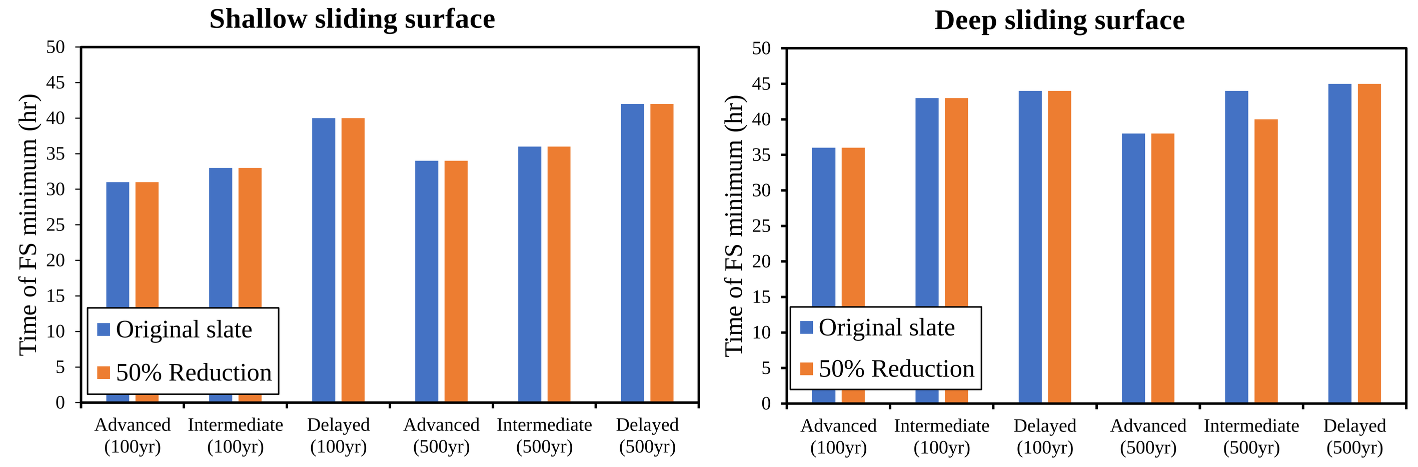

Fig.8 Effect of mechanical parameters at the time of minimum FS.

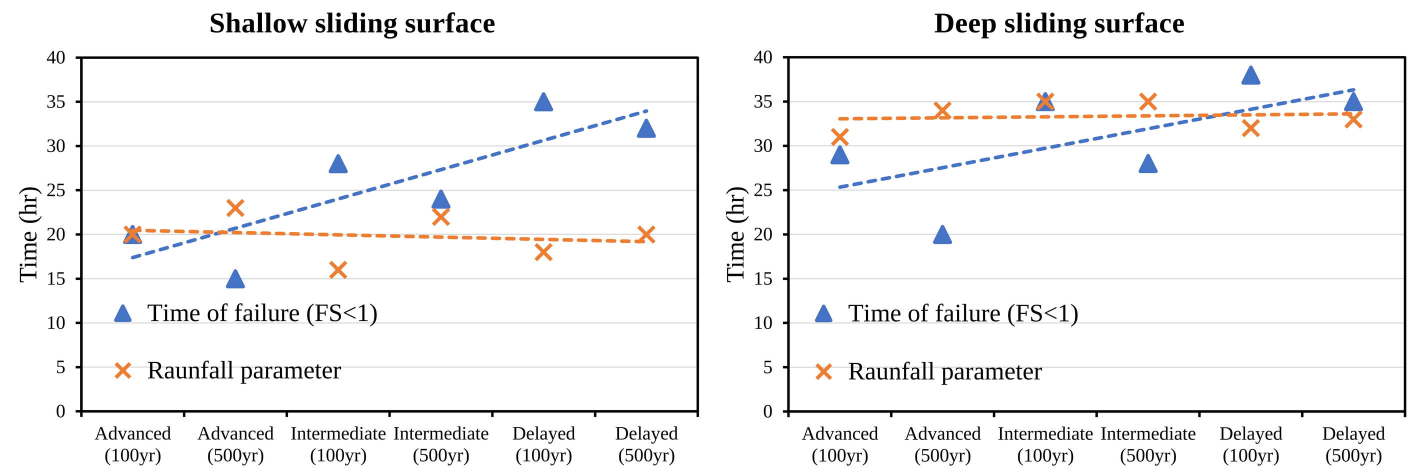

Fig.9 ToF vs. rainfall parameter adopted in shallow and deep sliding surface.

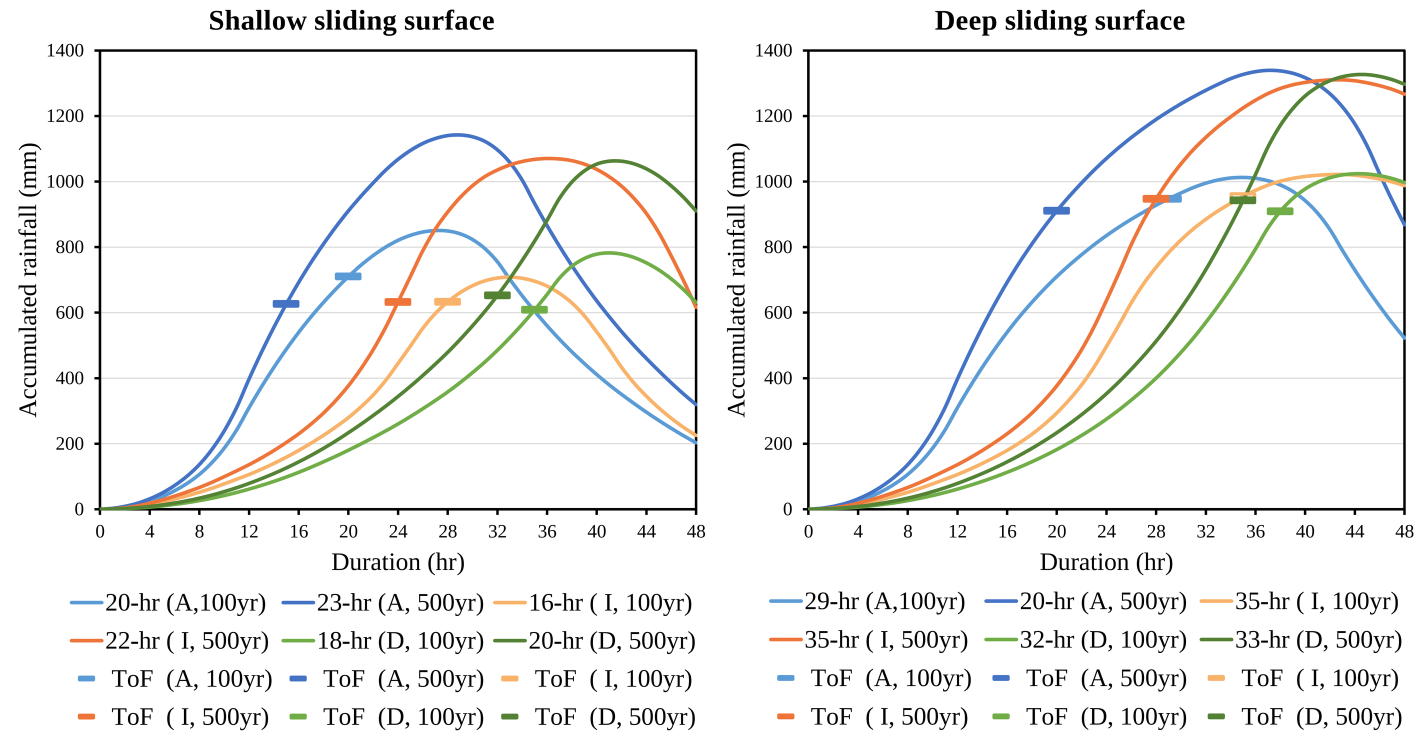

Fig.10 The most suitable rainfall parameter and acc. rainfall under each rainfall condition.

Table 1 The appropriate rainfall parameters under different rainfall and slope conditions.

		Shallow Sliding Surface			Deep sliding surface		
Rainfall type	Returned Period (yr)	Rainfall Parameter (hr)	Time of Failure (hr)	Acc. Rainfall (mm)	Rainfall Parameter (hr)	Time of Failure (hr)	Acc. Rainfall (mm)
Advanced	100	20	20	709.941	31	29	974.763
	500	23	15	625.986	34	20	910.341
Intermediate	100	16	28	632.509	35	35	954.753
	500	22	24	632.162	35	28	946.967
Delayed	100	18	35	608.447	32	38	909.008
	500	20	32	652.252	33	35	942.095

Table 2 The most suitable rainfall parameter and rainfall threshold for early warning.

		Shallow Sliding Surface			Deep sliding surface		
Rainfall type	Returned Period (yr)	Rainfall Parameter (hr)	Acc. Rainfall (mm)	Rainfall Threshold (mm)	Rainfall Parameter (hr)	Acc. Rainfall (mm)	Rainfall Threshold (mm)
Advanced	100	Max: 23	709.941	Min: 626 (mm/23hr)	Max: 35	974.763	Min: 911 (mm/35hr)
	500		625.986			910.341	
Intermediate	100		716.510			954.753	
	500		635.105			946.967	
Delayed	100		675.263			919.885	
	500		687.974			944.658	

5. Conclusion

1. The time of FS minimum can be use to determine the most suitable rainfall parameter in each slope conditions.
2. Although the time of failure varies under different rainfall conditions, the resulting optimal rainfall parameters remain relatively consistent.
3. Using the most suitable rainfall parameter for each case can yield similar accumulated rainfall at the time of failure.
4. Deeper sliding surfaces are more suitable for adopting larger rainfall parameters, corresponding to higher rainfall threshold values.
5. Shallower sliding surfaces should adopt smaller rainfall parameters and lower threshold values for the landslide early warning.