A STUDY OF RAILFALL PATTERN AGAINST CYCLIC SLOPE MOVEMENT IN BHUTAN

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1. Introduction

Bhutan as a part of Himalayan region with rugged mountain and fragile geology, landslide has been prominent and devastating natural disasters. Slope failures are more prominent in cut slopes. The failures are mostly recurrent, and it happens in rainy season (June-September). It is estimated that over 90% of the Bhutan's landslides are direct result of monsoon rain. Thus, it is claimed rain induced slope failure is most common geo-environmental hazard in Bhutan. However, there are limited scientific research done on Bhutan's condition to support the statement. The objective of this study is to find correlation between recurrent slope movement and rainfall pattern considering geology using relationship between landslide records and some underground water indexes.

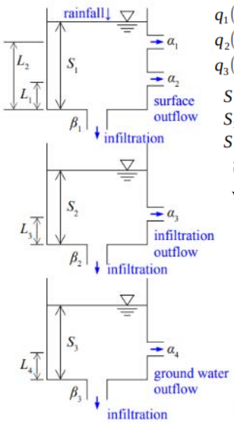
2. Landslide records and rainfall data

In this study, slope failure occurrence data are used from the inventory maintained with the Department of Surface Transport, Bhutan. The landslide inventory is available only from 2019. All landslides are located along the road cut slope. A minimum of 16 representative landslides are selected for the study. Hourly rainfall data of 43 rain gauge stations were obtained from National Center for Hydrology and Meteorology of Bhutan, mainly from 2017. The density of rainfall observation is approximately one per 417 km^2. Due to absence of rainfall observation stations at landslide locations, rainfall data from the nearest stations are used. The average distance is 11km, minimum and maximum distance are 1.5 km and 23.5 km respectively.

3. Underground water indexes

We adopted three indexes to explain the occurrence of landslides. First is Soil Water Index (*SWI*), which is adopted by Japanese Meteorology Agency (JMA) for alerting sediment disasters due to short time heavy rain. Second is Parallel Tank Index (*PTI*), which is proposed by our laboratory to express time lag effects of layer boundary sliding caused by long term rain. Last one is Effective Rainfall (E_{eff}), which we can select influence period of rainfall by using half reduction period, *T*.

SWI is expressed by three layer tanks model as show in Fig.1, developed by Ishihara[(1)]. The parameters are adopted for granite regions are used for all over Japan by JMA. The SWI is the summation of water level of the three tanks. PTI is constituted of parallel tanks[(2)] as shown in Fig.2, the left tank shows retention water of ground. When the water level is over L_1 of left tank height, the rainfall recharge right tank as ground water level that reduces effective stress between layer boundaries. The right tank water level is PTI. When different parameters adopt for this model, it enables to explain both steep slope failure due to short time heavy rain and layer boundary slide due to long term rain. In this study, we tried with three parameters set[(3)] such as long, medium and short as shown in Fig. 2.



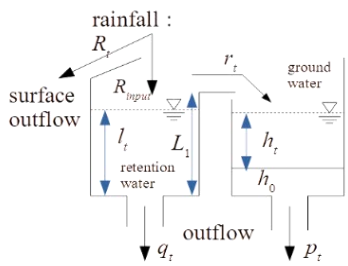
$$q_1(t)=\alpha_1|S_1(t)-L_1|+\alpha_2|S_1(t)-L_2|$$
$$q_2(t)=\alpha_3|S_2(t)-L_3|$$
$$q_3(t)=\alpha_4|S_3(t)-L_4|$$
$$S_1(t+\Delta t)=(1-\beta_1\Delta t)\cdot S_1(t)-q_1(t)\cdot\Delta t+R(t+\Delta t)$$
$$S_2(t+\Delta t)=(1-\beta_2\Delta t)\cdot S_2(t)-q_2(t)\cdot\Delta t+\beta_1\cdot S_1(t)\cdot\Delta t$$
$$S_1(t+\Delta t)=(1-\beta_3\Delta t)\cdot S_3(t)-q_3(t)\cdot\Delta t+\beta_2\cdot S_2(t)\cdot\Delta t$$

SWI: $S_1+S_2+S_3$

Where:
$\alpha_1, \alpha_2, \alpha_3$: coefficient of outflow
L_1, L_2, L_3, L_4: Hight of reservoir
S_1, S_2, S_3: current water level
$\beta_1, \beta_2, \beta_3$: coefficient of infiltration flow
R: Rainfall

	1st tank	2nd tank	3rd tank
outflow hight(mm)	L1=15 L2=60	L3=15	L4=15
coefficient of outflow (1/hr)	α1=0.10 α2=0.15	α3=0.05	α4=0.01
coefficient of infiltration (1/hr)	β1=0.12	β2=0.05	β3=0.01

Fig. 1: Three tank model developed by Ishihara.



$$R_{input}=R_t\exp(\alpha R_t)$$
$$q_t=\beta l_t^{0.5}$$
$$p_t=\gamma h_t^{0.5}$$

when $l_t-L_1>0$, $r_t=l_t-L_1$ and h_t += r_t

Parameters			
	Long	**Med.**	**Short**
L_1	100	30	10
α	-0.01	-0.005	-0.0035
β	0.02	0.1	2
γ	0.2	0.25	0.35

Fig. 2: Parallel Tank model setup

Effective rainfall is developed by Yano, 1990[(4)], to predict landslide in Japan. This index can consider antecedent rainfall effect by using weighed factor as shown in equation 1.

$$R_{eff}=\sum_{i=0}^{n}0.5^{(\frac{i}{T})}R_i \quad \text{.....................} \ (1)$$

where R_{eff}: effective rainfall, *T*: half reduction period (usually,72hr or 1.5hr), *i*: hourly count, R_i: input rainfall. For n, there is no explicit rule, but n=10T and T=72 hours are adopted in this Study. This index seems to express long term rain effect mainly.

Keywords: Bhutan, landslide, rainfall pattern, geology, Soil Water Index, Parallel Tank Index.
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4. Relationship between occurrence date and each index

For example, Table 1 shows landslide occurrence date time at Boxcut landslide in 2020. As shown in Table 1, most of recurrent landslides are occurred among rainy season, June to September. Table 2 shows annual repetitive times for each landslide location. A total of 680 repetitive landslide recorded from 16 landslide locations over a span of 4 years. The relationships between hourly rainfall and each index are shown in Fig.3 (a)-(d). The black lines show dry season, no landslide period, and blue lines show rainy season relationship. The polygon indicates occurrence time of recurrent landslides. When the landslide occurrence is higher horizontal value than black line, the index can express or predict occurrence of landslide.

Table 1: Landslide occurrence at Boxcut in the year 2020

Sl. No.	Regional Office	Type of Disaster	Occurance Date	Occurance time	Max Rain (mm)
1	Sarpang	land slide	02/06/2020	22:00:00	11.3
2	Sarpang	land slide	11/06/2020	14:00:00	14.8
3	Sarpang	land slide	22/06/2020	23:00:00	12.5
4	Sarpang	land slide	24/06/2020	21:00:00	13.3
5	Sarpang	Landslide	01/07/2020	20:00:00	20.3
6	Sarpang	land slide	08/07/2020	09:00:00	19.3
7	Sarpang	land slide	11/07/2020	18:00:00	17.5
8	Sarpang	land slide	17/07/2020	03:00:00	15.5
9	Sarpang	landslide	12/08/2020	03:00:00	13.3
10	Sarpang	landslide	20/08/2020	18:00:00	14.8
11	Sarpang	landslide	22/08/2020	19:00:00	25.8
12	Sarpang	landslide	28/08/2020	21:00:00	14
13	Sarpang	land slide	10/09/2020	21:00:00	10.5
14	Sarpang	land slide	23/09/2020	01:00:00	12.5

Table 2: Record of repetitive landslide occurrence at 16 locations.

Sl. No.	Name of Landslide	Number of Occurance				Total in 4 years.
		2019	2020	2021	2022	
1	Toribari	13	4	9	9	35
2	Bawanijhora	12		1	32	45
3	Laptshakha			4	7	11
4	Sonambja	4	2	5	30	41
5	Lamalameyni		7	9	13	29
6	Aieslip	9	31	2	49	91
7	Boxcut	10	36	23	50	119
8	Balukhola	3	18	2	21	44
9	Ganteypani		7	5	6	18
10	Laylang		17	22	62	101
11	Waterfall		5	5	19	29
12	Kurigongrizomsa	5	12	8	2	27
13	Faderi		24		8	32
14	Reotala	6	9	8	5	28
15	Aadagangchu	4	3	7	3	17
16	Tekizampa		2	4	7	13
					Total	680

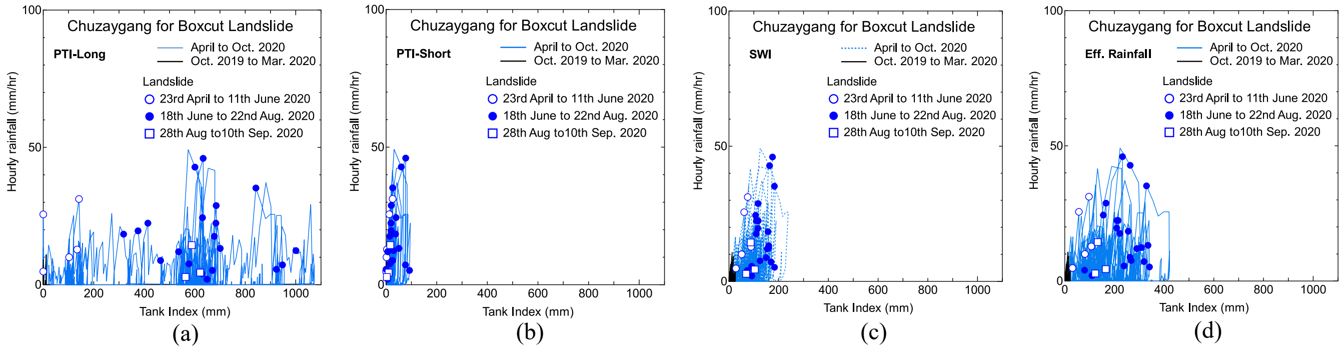

Fig. 3: Relationship between hourly rainfall and tank index for Boxcut landslide for year 2020.

From the comparison of prediction possibility, most applicable model or parameters for each landslide is shown in Table 3. The threshold value in Table 3 shows boundary for alert at the present, but too small value of 20 maybe not appropriate prediction.

The landslides which PTI using long term rainfall parameters was best model are 8 of 9, it is revealed that the recurrent landslide in Bhutan has same mechanism to layer boundary slide. Since the Effective rainfall can consider longest period compared with other index, 3 of 9 landslides also are applicable. However, SWI cannot explain the recurrent landslide, because SWI consider intermediate of long and short term rainfall feature.

Table 3: Summary of relationship between landslide occurrence and rainfall pattern.

Sl. No	Landslide Name	Model	Threshold	Geology
1	Aieslip	PTI-Long	70	Colluvium overlaying weathered phyllite.
2	Balukhola	PTI-Med.	100	Weathered phyllite with bands of conglomerate and quartzite.
3	Boxcut	PTI-Long	70	Weathered phyllite interbedded with thin laminated quartzite.
4	Lamalamaney	PTI-Long	200	Weathered sandstone and shale.
5	Sonambja	PTI-Long	100	Highly fractured conglomeratic quartzite.
		Eff.	70	
6	Toribari	PTI-Med.	100	Weathered carbonaceous phyllite interbedded with thin layers of quartzite.
		Eff.	150	
7	Laylang	PTI-Long	20	Dolomite, limestone, with minor quartzite and phyllite.
		Eff.	70	
8	Tekizampa	PTI-Long	100	Biotite Gneiss, and mica schist.
		Eff.	80	
9	Reotala	Eff.	20	Graphitic phyllite and Quartzite.

5. Conclusion

Comparison of underground water indexes and landslides occurrence date was performed. From the results, it was found that most of Bhutan's recurrent landslides has same feature with layer boundary slide. The repetitive landslide in Bhutan is more prevalent at the geology consist of phyllite.

As next step, we will specify more applicable parameters suit for geological features and consider about effective counter measure method by using rigid plastic analysis such as Janbu method.

Reference:

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