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Evaluation of seismic slope stability through rock mass classification and Newmark's model along North Western Himalayas

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1 Introduction

- Historically, Jammu and Kashmir region of the Himalayas have faced several earthquakes of which, 2005 Kashmir quake Magnitude > 7.6 is major event; resulting in 80000 fatalities, economic losses worth billion's and initiated more than 2900 seismically induced landslides over an area of 4000km^2 **(Basharat et al., 2016)**.
- Landslide which is primarily triggered by seismic activity, rainfall and slope undercut, addition of earthquake strong motion results in short lived, cyclic changes in hill slopes.
- Slope stability in these seismically active regions is a pressing concern in geotechnical engineering, especially when it comes to young and dynamic rugged mountainous terrains like Himalayas.

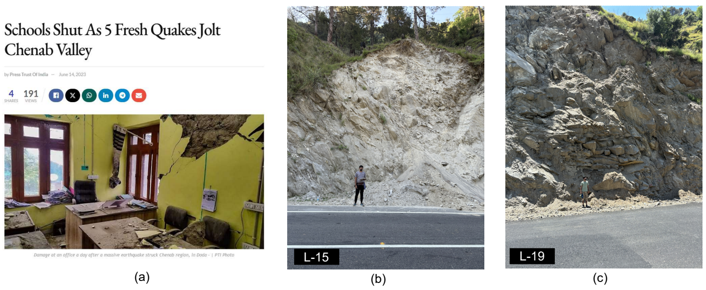

Fig1: (a) Effect of EQ-2023 (PTI,2023), (b)&(c) critical slope Failure along location 15 & 19

2 Study Area

- The study area is located along NH-244, a national highway between Batote to Doda-Kishtwar border a stretch of 80 km, classified as IV & V seismic zones with MSK scale of VIII & IX intensities respectively **(IS: 1893, 2016)**.
- The rock mass of the study area is formed by Salkhala formation of Lesser Himalayan succession partially covered by a thin layer of colluvium soil and landslide debris.
- Located in the tectonically dynamic NW Himalayas, the area is highly susceptible to landslides and slope failures, especially during seismic events and monsoon periods.

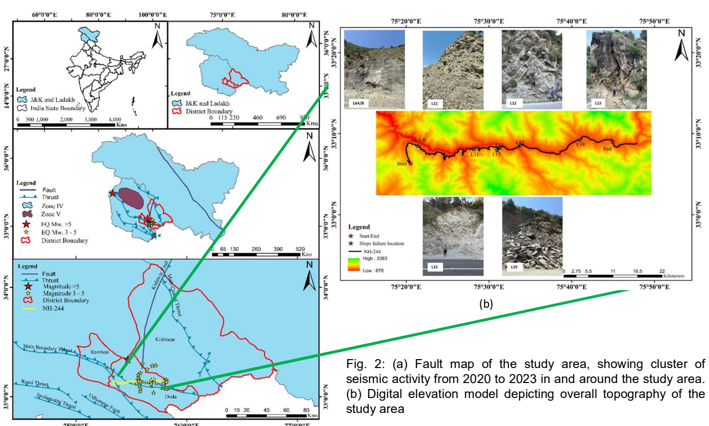

Fig. 2: (a) Fault map of the study area, showing cluster of seismic activity from 2020 to 2023 in and around the study area. (b) Digital elevation model depicting overall topography of the study area

3 Methodology

- A detailed geotechnical and geological field was carried out in seven critical locations prone to slope failure.

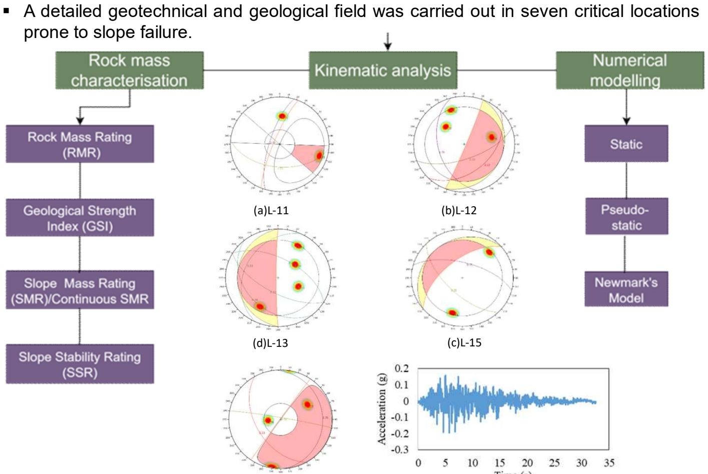

Fig. 3: (a-e) Stereographic projections of studied cut slopes along NH-244,(f) Generated Synthetic Seismic Time VS Acceleration earthquake data for Mw 7.6

4 Results & Discussion

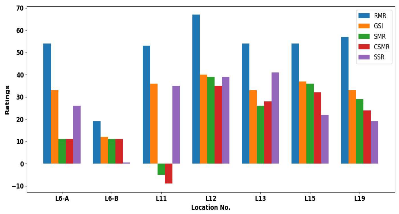

Fig. 4: Outcomes obtained by different methods

- The study finds that even with fair-to-good rock quality (RMR & GSI), slopes can be unstable due to slope geometry, joint orientation, groundwater, and seismic effects, with SMR/CSMR showing kinematic controls as the main cause.
- LEM shows two critical slip surfaces under static conditions, while applying a seismic coefficient in pseudo-static analysis greatly reduces FoS, leading to overall slope instability dominated by base failure.

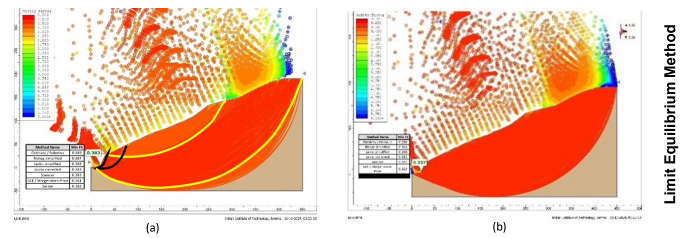

Fig. 5: The critical failure surface of slope L6-B (a) Static condition & (b) Pseudo – static condition

Newmark's analysis:

- A simplified approach by **Newmark, (1965)** provides a quantitative estimate of earthquake induced slope movement. The method offers insight into seismic displacement based driven failure leading to unrecoverable deformations.

Fig. 6: Heat map illustrating spatial distribution of cumulative seismic-induced displacement across slope locations.

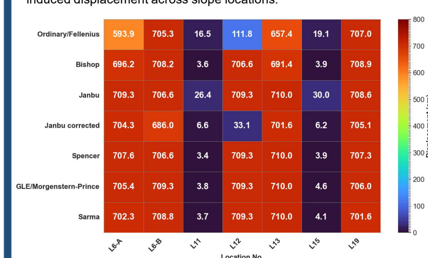

Table 1: Comparison of Factor of Safety (FoS) under static and pseudo-static (seismic) conditions for various slope sections.

Location No.	Factor of safety	
	Static	Pseudo-static
L6A	0.916	0.711
L6B	0.381	0.329
L11	1.188	0.869
L12	0.987	0.832
L13	0.663	0.56
L15	1.129	0.88
L19	0.793	0.643

Based on California Geological Survey Guidelines (CDMG,1997):

- **0 - 10 cm** – unlikely to correspond to serious landslide movement.
- **10 - 100 cm** – Slope deformations may be sufficient to cause serious ground cracking or enough strength loss to result in continuing post-seismic failure.
- **>100 cm** – damaging landslide movement and slopes should be considered unstable.

5 Conclusion

- RMR_{basic} indicates , rock mass quality varying from very good to poor and based on GSI assessment, five slopes exhibited a blocky/disturbed/seamy structural with fair to very poor condition which are at high risk of failure and requires immediate stabilization measures.
- Based on SMR and CSMR ranged from unstable to completely unstable while SSR indicating unstable for all the slopes.
- Based on Kinematic and SMR analyses, complex failure occurs mainly in highly fractured limestone and planar failure in micaceous schist, phyllitic schist, schist and phyllite rock types with major discontinuity along foliation.
- As per IS 14243: Part 2 (1995) both static and pseudo-static conditions indicates the slopes are unstable.
- From Newmark analysis all the slopes are very unstable and prone to failure under seismic acceleration where maximum slopes exhibited slip surface passing through toe region and shear strain are predominately concentrated near toe of the slopes.

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