Geo-engineering Characteristics and Performance Analysis of the Landslide Mitigation Measures Implemented in the Rohingya Camps in Bangladesh

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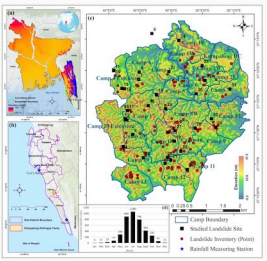
BACKGROUND

- Landslides frequently occur in the Chittagong Hill Tracts of Bangladesh during the monsoon season, causing significant loss of life and property damage.
- Since 2017, the influx of nearly a million Rohingya refugees fleeing Myanmar has worsened the situation. Settling in the Kutupalong Rohingya Camps (KRC), an area with undulated topography and fragile lithology, the refugees have caused deforestation and slope cutting.

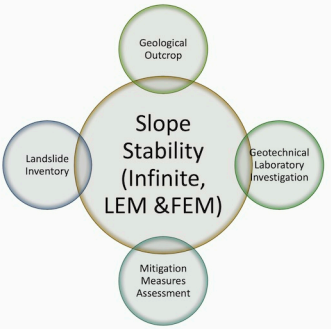
- These activities, combined with the area's geological characteristics, have significantly increased landslide occurrences.



3 KEY QUESTIONS

1. What are the geological and soil characteristics of the KRC area contributing to landslides?
2. How effective are the implemented landslide mitigation measures in the KRC?
3. What are the primary factors influencing the stability of slopes in the KRC?

METHODS



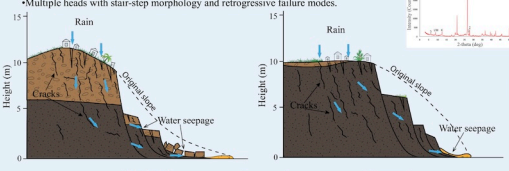
RESULTS

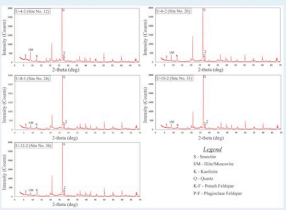
Geological Observations

❑ **Stratigraphy**:
- Upper cohesive soil and lower non-cohesive sandstone layers.
- Composed of Pliocene to Pleistocene DupiTila, Girujan clay, and Tipam Formations.

❑ **Slope Characteristics**:
- Heights >15 m, steepness 40°-70°.
- Presence of numerous polygonal tension cracks and fissures.

❑ **Landslide Types**:
- Predominantly slide and slump types.
- Multiple heads with stair-step morphology and retrogressive failure modes.



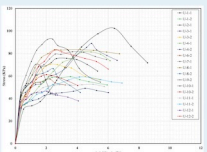


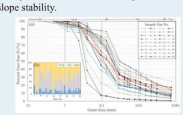
Geo-engineering Properties

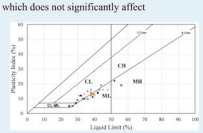
❑ **Upper Soil Layer**:
- Bulk density: 1.49-1.97 g/cm³.
- Liquid limit: 25-48%.
- Plasticity index: 5-16%.
- Undrained shear strength: 23-46 kPa.
- Exhibits strain-softening behavior under stress.

❑ **Lower Sandstone Layer**:
- Bulk density: 1.44-1.94 g/cm³.
- Internal friction angle: 34°-40°.
- Cohesion: 0.5-13 kPa.

❑ **Mineralogical Composition**:
- X-ray diffraction shows low clay mineral content, which does not significantly affect slope stability.







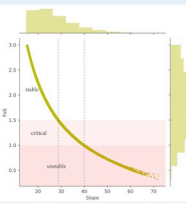
Mitigation Measures Assessment

❑ **Implemented Measures**:
- Structural: Concrete retaining walls, Reinforced terrace slope and Geo/sand bag covering slope.
- Non-Structural/Nature-Based: Slope reforestation and reworking.

ANALYSIS & FINDINGS

Lithology	Unit weight (kN/m³)	Cohesion (kPa)	Internal friction angle (deg.)
Upper Soil	17.3 ± 0.34	10.67 ± 2.15	33.23 ± 1.97
Sandstone	16.38 ± 0.69	6.32 ± 1.85	37.6 ± 1.93

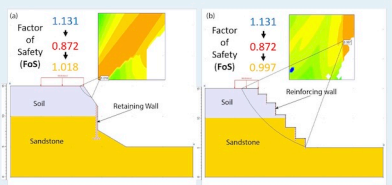
❑ **Slope Stability Analysis**:
- Infinite slope, Limit Equilibrium (LEM) and Finite element (FEM) analysis were carried out.
- Slopes **<40°** are **stable**; **>40°** are **unstable**
- Effective overburden loads due to Rohingya settlement reduce the slopes factor of safety, hence its stability
- Hill cutting of slope also reduce the stability.



❑ **Effectiveness**:
- Structural measures provide marginal protection, though some failures have caused fatalities
- Concrete retaining walls are more effective in reducing landslides.
- Slope reforestation helps control soil erosion.

❑ **Critical Factors**:
- Cohesion and friction angle of lower sandstone.
- Cohesion of upper soil layers

Mitigation measure type	Slope angle	Loading (kN/m²)	Factor of Safety (FoS)	
			Before	After
Reinforced Terrace Slope	50°	100	0.98	1.129
	55°	50	0.98	1.122
		100	0.87	0.997
Concrete Retaining Wall	50°	100	0.98	1.102
	55°	50	0.98	1.355
		100	0.87	1.018
Geo/Sandbag Cover	50°	100	0.98	1.065
	55°	50	0.98	1.153
		100	0.87	1.014

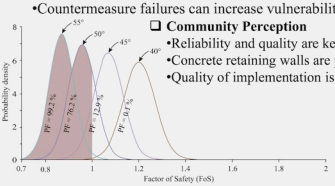


DISCUSSIONS & CONCLUSIONS

❑ **Stability Analysis**
- GIS-based analysis underestimates safety factors.
- LEM and FEM results are similar with semicircular slip surfaces.
- Slopes >40° are unstable.

❑ **Mitigation Measures**
- Structural measures provide minimal stability improvement.
- Some slopes failed despite measures.
- Countermeasure failures can increase vulnerability.

❑ **Community Perception**
- Reliability and quality are key concerns.
- Concrete retaining walls are preferred.
- Quality of implementation is questioned.



❑ **Geotechnical Parameters**
- Cohesion and friction of sandstone and soil are critical.
- Variations in shear strength affect failure probability.

❑ **Recommendations**
- Use a mix of structural and non-structural measures.
- Include afforestation, bioengineering, and early warning systems.
- Consider relocation or resettlement options.

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ACKNOWLEDGEMENT

This research was funded by the Royal Society (CHL\R1\180288) through the UK Government's GCRF. The authors thank the RRRC, Cox's Bazar, for permitting fieldwork in the Kutupalong Rohingya Camp.