

Wetting-Induced Collapse Characteristics of Silty Sand Matrix from the Kodari Landslide, Nepal

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Abstract: Wetting-induced collapse is a critical but largely unexplored mechanism in slope stability analysis in Nepal. Highways frequently experience rainfall-induced slope failures, yet the role of collapse behavior in these failures remains poorly understood. This study investigates the wetting-induced collapse behavior of the silty sand matrix derived from surface deposits of the Kodari Landslide along the Araniko Highway, Sindhupalchok, Nepal. The landslide-affected zone consists of heterogeneous, highly permeable materials ranging from silty sand (SM) to well-graded gravel (GW), with SM as the dominant soil type, exhibiting high apparent strength under dry conditions but undergoing volumetric collapse and rapid strength reduction during intense rainfall. One-dimensional consolidation and wetting-induced collapse tests were conducted on four representative samples of the reconstituted matrix fraction (<2 mm). Consolidation results indicated an overconsolidated state (OCR ~7.0–9.5), likely linked to desiccation-induced suction in addition to past loading history. Collapse potential ranged from 0.25–1.40% under natural moisture conditions and increased to 7.88% under air-dried conditions, with fines content also appearing to influence collapse sensitivity. These findings suggest that wetting-induced collapse may act as a potential contributing factor to landslide initiation at Kodari, requiring further investigation, while emphasizing the importance of effective drainage for reducing slope-failure risk.

Keywords: *Wetting-induced collapse, Collapse potential, Silty sand matrix, Landslide debris, Nepal Himalaya.*

Introduction

Wetting-induced failure during the monsoon is a frequent hazard in Nepal, causing highway disruption and infrastructure damage (Upreti and Dhital, 1996; Adhikari et al., 2025). Intense and uneven rainfall is a major trigger of landslides, with up to 10% of annual precipitation occurring within a single monsoon day and up to 50% within 10 days (Dahal and Hasegawa, 2008; Dahal, 2012). The Kodari landslide, located along the Barabise–Kodari section of the Araniko Highway, is repeatedly affected by such rainfall. Field observations indicate cracks, small streams, wet zones, and erosional features, suggesting strong hydrogeological influence. Combined with intense rainfall, these conditions may weaken interparticle bonding and promote collapse of loose surface deposits, potentially contributing to slope failure.

Collapsible soils are characterized by low density, high porosity, and metastable structures that can undergo rapid volume reduction upon wetting (Lawton

et al., 1989; Li et al., 2016). Although collapsible soils and their stabilization have been extensively studied worldwide, their role in rainfall-induced slope failure remains largely unexplored in the Nepal Himalaya. Previous studies in Nepal have mainly focused on rainfall characteristics, slope instability, and changes in soil properties and shear strength (Dahal and Hasegawa, 2008; Dahal, 2012; Adhikari et al., 2025), leaving wetting-induced collapse as a potential contributing mechanism largely unexamined.

Bhandari et al. (2025) identified sand and gravel as dominant materials in the Kodari landslide, with fines showing moisture-sensitive behavior. However, engineering parameters related to compressibility and collapse potential remain unexplored. Therefore, this study investigates the wetting-induced collapse behavior of the silty sand matrix, focusing on the effects of initial moisture conditions and fines content, together with its physical and compressibility characteristics.

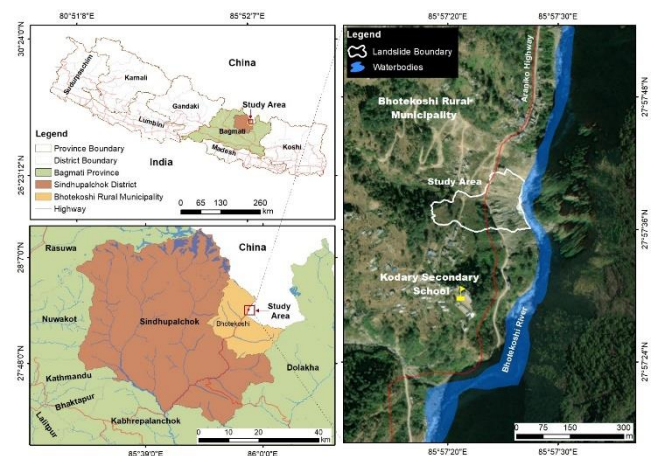


Figure 1, Location map of the Study Area.

Methodology

Field sampling and matrix preparation

Representative surface samples were collected from approximately 50 cm depth across the landslide zone. Tests were performed on the reconstituted matrix fraction (<2 mm), compacted to in-situ dry density under natural moisture and air-dried (~4–5%) conditions.

Geotechnical characterization

Index properties, Atterberg limits, and dry density were determined according to Indian Standards (IS). Direct

shear tests were conducted at 0.25 mm/min under drained conditions with normal stresses of 50, 100, and 200 kPa to determine shear strength parameters (c , ϕ).

Consolidation and collapse testing

Standard oedometer tests were carried out on four representative samples (S1K1, S2K1, S6K1, and S11K1) up to a maximum vertical stress of 800 kPa. Compression index (C_c) and recompression index (C_r) were determined via Eq. (1)

$$C_c = \frac{e_1 - e_2}{\log\left(\frac{\sigma'_2}{\sigma'_1}\right)} \quad (1)$$

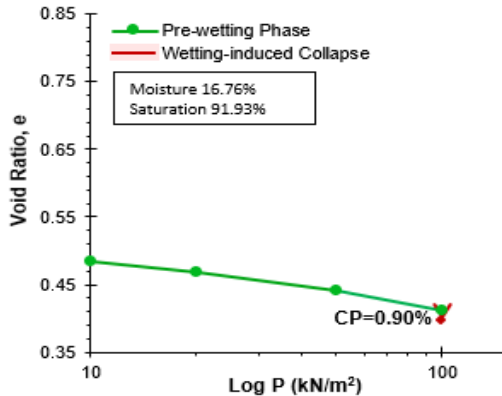
$$CP(\%) = \frac{\Delta h}{h_0} \times 100 \quad (2)$$

Table 1, Summary of consolidation characteristics of the silty sand matrix from Kodari Landslide.

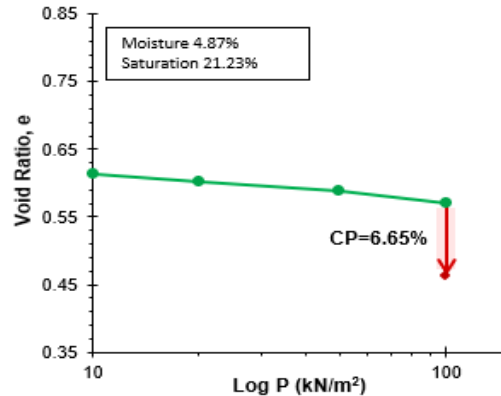
Sample No	Init. Moisture (%)	Init. Saturation (%)	Dry Density (g/cm ³)	Init. Void Ratio (e ₀)	C _c	C _r	P _c (kN/m ²)
S1K1	16.53	93.74	1.820	0.473	0.108	0.033	70.00
S2K1	21.60	98.92	1.691	0.585	0.113	0.033	75.00
S6K1	13.01	50.72	1.588	0.688	0.120	0.035	95.00
S11K1	11.41	45.43	1.602	0.673	0.117	0.034	95.00

Sample: S1K1

a) Natural Specimen

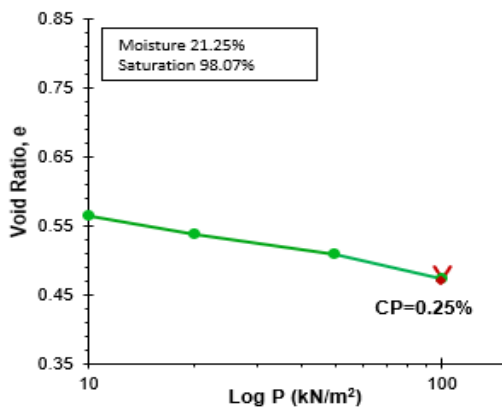


b) Air-dried Specimen



Sample: S2K1

c) Natural Specimen



d) Air-dried Specimen

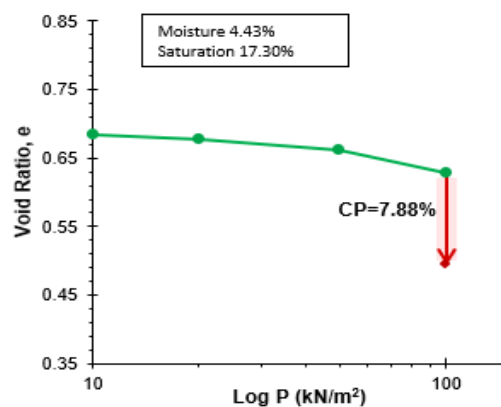
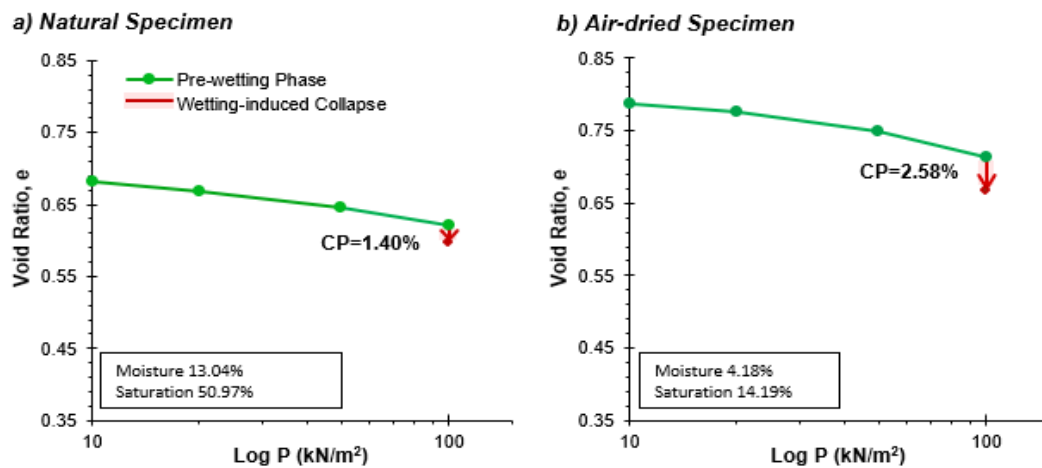


Figure 2, Wetting-induced collapse behavior at 100 kN/m² vertical stress for samples S1K1 (a, b) and S2K1 (c, d) under natural and air-dried conditions, respectively.

Sample: S6K1



Sample: S11K1

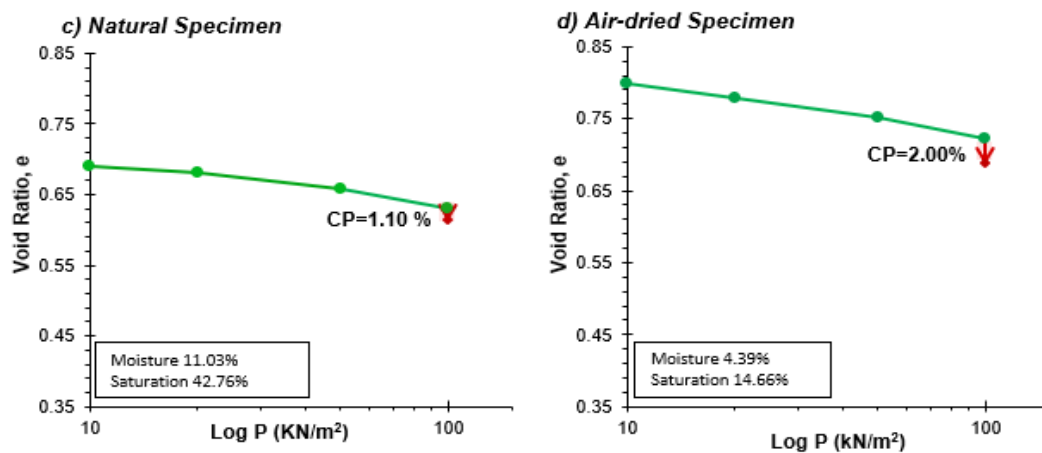


Figure 3, Wetting-induced collapse behavior at 100 kN/m² vertical stress for samples S6K1 (a, b) and S11K1 (c, d) under natural and air-dried conditions, respectively.

Results and discussion

Soil classification and compressibility

The matrix deposits are classified as SM and SP-SM, predominantly non-plastic, with cohesion of 0.00–2.92 kPa and friction angles of 28.09°–31.78°. Compression indices (C_c) range from 0.108–0.120, while preconsolidation pressures (P_c) of 70–95 kPa yield apparent OCR values of 7.0–9.5.

Collapse potential and failure mechanism

As shown in Figure 2 and 3, collapse potential (CP) under natural moisture remains low (0.25–1.40%), indicating limited immediate collapse hazard. However, air-drying increases CP significantly, reaching 7.88% in the high-fines specimen (S2K1). Low moisture and silty fines form a metastable structure supported by apparent matric suction. During monsoon rainfall, loss of apparent suction causes collapse, reduces soil confinement, and may increase pore-water pressure, promoting progressive shear failure.

Conclusion

The Kodari Landslide surface matrix is dominated by permeable, non-plastic silty sand (SM) with moderate compressibility ($C_c = 0.108$ – 0.120). The high OCR (7.0–9.5) reflects apparent overconsolidation caused by desiccation and matric suction. Collapse potential increases from 0.25–1.40% under natural moisture to 7.88% when dry. Wetting-induced collapse may contribute to shallow slope failures, highlighting the need for effective surface and subsurface drainage.

Acknowledgement

The authors sincerely acknowledge Geotech Solutions International Pvt. Ltd. for providing laboratory facilities and technical support throughout this study.

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