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Multistage Consolidated Drained Triaxial Behavior of Shallow Landslide-Prone Soils in Rangamati Sadar, Bangladesh: Implications for Slope Stability and Critical State Analysis

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Abstract: Shallow landslides are a common geo-hazard in the hilly regions of southeastern Bangladesh, particularly in Rangamati Sadar, where slope instability poses significant risks to infrastructure and human settlements. This study investigates the Multistage Consolidated Drained Triaxial behavior of normally consolidated clay and silty sandy soils obtained from shallow landslide-prone zones. A series of drained triaxial tests were conducted under varying effective confining pressures to evaluate stress-strain response, volume change, and critical state behavior. Results reveal stress strengthening characteristics, with maximum deviator stress occurring between 2.6% and 15% axial strain, followed by strain softening or stabilization. The soils exhibited contractive behavior during shearing, stabilizing near peak stress. Shear strength parameters were determined, with cohesion (c') of 23.3 kPa and friction angle (ϕ') of 30°. Critical State Soil Mechanics (CSSM) parameters—λ = 0.396, Γ = 1.84, and M = 0.044—were estimated, although a well-defined single Critical State Line (CSL) could not be established. These findings contribute to the understanding of soil behavior under drained loading conditions and provide valuable input for slope stability analysis and geotechnical design in landslide-prone areas.

Keywords: ***Triaxial test, Landslide, Critical state.***

Introduction

The cohesiveness and internal friction angle of the soil must be accurately calculated while analyzing landslides. In the long-term study, effective parameters are used to assess stability issues with natural slopes. The pore water pressures, which alter with increasing axial stresses, must be measured to evaluate these effective parameters in the lab. The shear strength characteristics of sand can be observed more precisely using the consolidated drained triaxial test (Craig, 2004). During the test, the pore water gets drained which is why excess pore water pressure cannot be developed. The behavior of soil with changing axial strain can be obtained through this drained test. Since it is a consolidated drained test, the sample has been consolidated at 50 kPa, 100 kPa, 200 kPa, 300 kPa, 400 kPa, 600 kPa, 800 kPa and 1200 kPa before shearing took place.

The multi-stage triaxial test is an information-rich testing technique that utilizes a minimum number of specimens and can circumvent the consequences of the variability of specimens often observed from one single-stage triaxial test to the other (Ho and Fredlund, 1982). Since its first practical application in the early 1950s (Taylor, 1951), multi-stage triaxial tests have been successfully used to characterize the strength of various rocks and soils (Goodman, 1974; Kovári and Tisa, 1975); Houston et al., 2008; Mishra and Verma, 2015; Parker et al., 1980; Youn and Tonon, 2010).

Methodology

The triaxial tests are conducted on the undisturbed soil specimens under consolidated undrained test with pore pressure measurement (CU) following the BS 1377-8: 1990 (8) Standard Test Method at laboratory Ground Instrumentation and Engineering Pte Ltd in Singapore.

The total volume change of each specimen was also measured throughout the tests by monitoring the volumes of pore water and confining fluid. Stages I, II, and III are the stages at which the specimens were sheared, which were each applied with effective confining stresses of 50 kPa, 100 kPa, and 200 kPa to determine the Mohr strength envelopes. To minimize the effects of stress anisotropy and strain heterogeneity brought on by the earlier stages, it was decided that each effective confining stress should be twice as great as the one before it (Nambiar et al., 1985).

Results

The basic properties of the samples are listed in Table 1. The sample belongs to five individual boreholes of 0.90 to 4.15 m depth were used for the consolidated drained tests. The basic geotechnical properties and testing details of the analyzed landslide hazard site samples are listed in Tables 1 and 2.

The results of the multistage drained triaxial tests are graphically presented in Figures 1 to 6.

Table 1, Summary of basic geotechnical properties of the soils.

Sample No	Depth(m)	Initial moisture content (w %)	Specific gravity (Gs)	Bulk density (ρ) (Mg/m3)	Initial Dry density (ρ_d) (Mg/m3)	Dry density (ρ_d) (Mg/m3)	Initial void ratio (e_0)	Wet weight of Sample (g)	Dry weight of the sample (g)
CD100	2.13-2.62	22	2.68	2.04	1.67	1.71	0.609	175.6	172.6
CD200	0.9-1.4	28	2.70	1.63	1.28	1.49	1.116	140.5	138.5
CD300	0.9-1.4	33	2.82	1.91	1.43	1.57	0.973	164.3	159.4
CD400	3.65-4.15	25	2.67	2.02	1.76	1.98	0.514	174.4	172.4
CD600	2.13-2.62	30	2.73	1.79	1.38	1.59	0.977	155.7	153.7

Table 2, Drained testing details of natural soils of Rangamati landslide sites.

Location	**Sample no.**	**Depth (m)**	**Sand (%)**	**Silt & Clay (%)**	**Specific gravity (G_s)**	**LL (%)**	**PL (%)**	**PI (%)**	**Classification**
Ghagra Cant.	BH3 S2	2.13-2.62	13.04	86.96	2.68	28.01	20.69	7.32	CL-MLS, Silty Clay with Sand
T.V. Bhabon	BH5 S1	0.90-1.40	68.08	31.92	2.70	-	-	-	SC S Clayey fine-medium Sand
D.C. Bhabon	BH7 S2	2.13-2.62	55.52	44.48	2.82	32.5	19	13.5	SM S Silty Fine-medium Sand
Sukkur Stadium	BH8 S2	2.13-2.62	77.42	22.58	2.73				SM S Silty Fine-medium Sand
Monoghor Master Bari	BH9 S3	3.65-4.15	44.84	55.16	2.67	37.2	16.12	21.08	CL-ML S Sandy Silty Clay

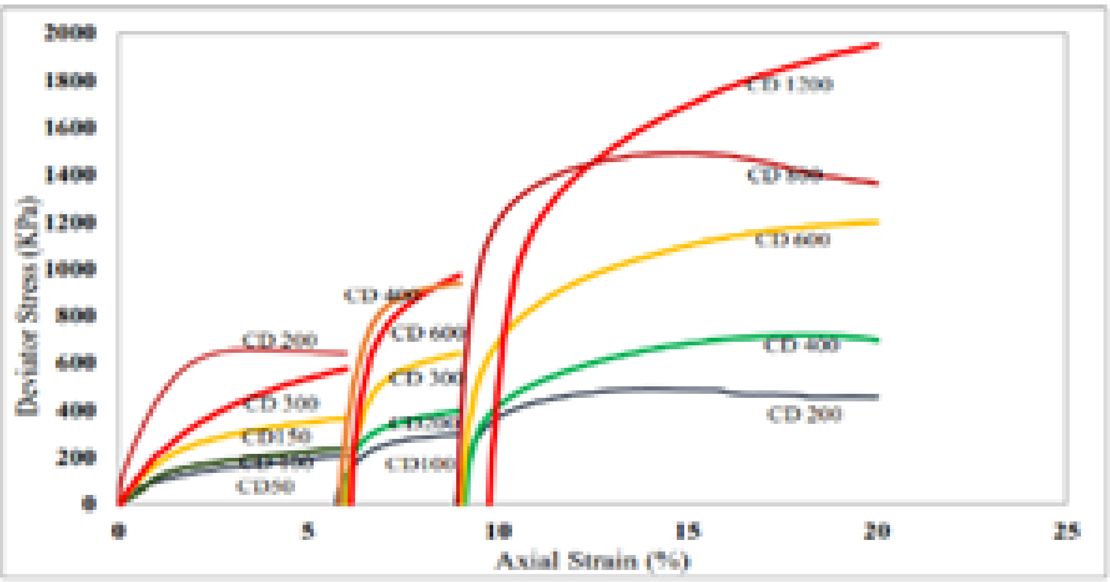

Figure 1, Deviator stress versus axial strain curves of different soil samples.

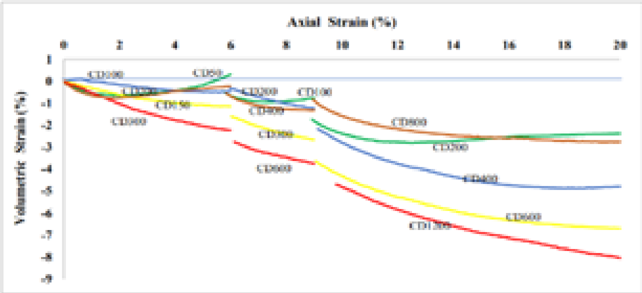

Figure 2, Volumetric strain versus axial strain curves of different soil samples.

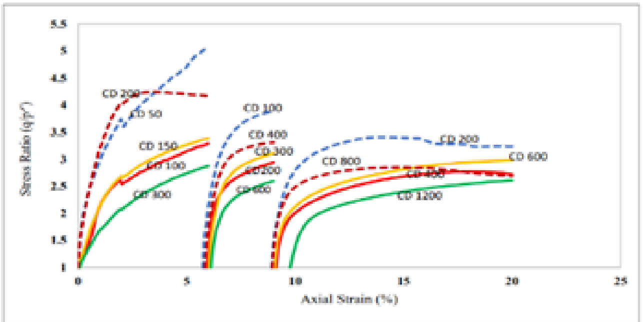

Figure 3, Stress ratio versus axial strain curves of the soil.

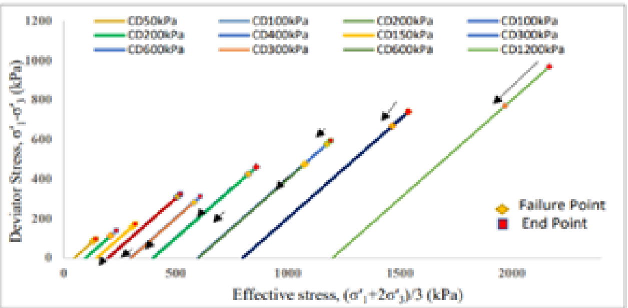

Figure 4, Effective stress path of the samples

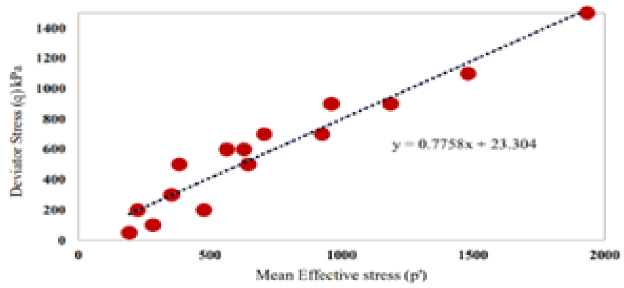

Figure 5, Failure surface of the tested samples.

Conclusion

The consolidated drained multistage triaxial tests carried out on normally consolidated clayey and silty sandy soils from landslide-prone zones provided valuable insights into their stress–strain and volume change behaviors. The soil exhibited predominantly stress-hardening response, with maximum deviator stress occurring within an axial strain range of 2.6% to 15%, beyond which stress equilibrium or reduction was observed. The results confirmed that deviator stress increases with higher effective consolidation pressures, while volume change curves indicated a contraction behavior that stabilized after reaching peak stress.

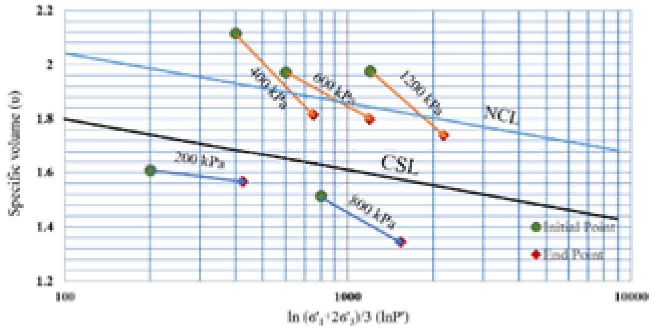

Figure 6, Specific volume (υ) versus mean effective stress values for different soil samples

Table 3, Comparison of the obtained critical state parameters of Rangamati soil with some typical soils [Hossain (2001), Allman and Atkinson (1992), Khatun, et al., (2023]]

Soil	λ	Γ	M
London Clay	0.16	2.45	0.89
Tropical clay, Dhaka	0.06	1.83	0.95-0.96
River Sand (Coarse-grained)	0.16	2.99	1.28
Rangamati Sandy Soil	0.046	1.73	1.84
Rangamati Soil (Medium to fine Sand)	0.396	1.84	0.044

The effective stress paths showed linear trends inclined with the horizontal, with closely positioned failure and endpoint states, further signifying the hardening characteristics of the soils. The shear strength parameters derived from the tests indicated a cohesion of 23.3 kPa and a friction angle of 30°. Failure modes varied across stages, with bulging observed predominantly at higher strains, while only limited samples exhibited distinct shear planes.

In the critical state framework, the soils demonstrated difficulty in defining a unique critical state line; however, key parameters were estimated as $\lambda = 0.396$, $\Gamma = 1.84$, and $M = 0.044$. Overall, the study highlights that the drained multistage testing approach is effective in capturing the shear strength and deformation characteristics of soils with relatively stable structures and low volume change tendencies at failure. These findings contribute to a better understanding of soil behavior in landslide-prone areas and provide essential parameters for slope stability analysis and geotechnical design.

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