True Triaxial Strength and Deformability of the Siltstone Overlying the Chelungpu-fault (Chi-Chi earthquake); Taiwan

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Abstract

We have conducted true triaxial compression tests (in which σ_1 is monotonically raised to failure while holding σ_2 and σ_3 constant) to determine strength, deformability, and other mechanical properties of the fine-grained (70 μm), quartz- (70%) and clay-rich (20%), Pleistocene siltstone just above the Chelungpu fault, intercepted by the TCDP (Taiwan Chelungpu-fault Drilling Project) borehole at 1111 m depth. The fault zone is considered the host of the 1999 Chi-Chi earthquake. Specimens (19×19×38 mm^3 rectangular prisms) were instrumented with strain gages and a strain-gaged beam for recording strains in all three directions.. Five groups of tests were conducted, each for a constant σ_3 (10, 25, 40, 60, 100 MPa). Within each group σ_2 was varied from test to test between $\sigma_2 = \sigma_3$ and σ_2 approaching $\sigma_{1(\text{at failure})}$. Contrary to the Mohr criterion assumption, for each σ_3 a consistent pattern was observed of gradually increasing strength with the rise of σ_2 until a peak was reached followed by a gradual decline, with $\sigma_{1(\text{at failure})}$ always higher than the conventional-triaxial strength (at $\sigma_2 = \sigma_3$). Strength variation with σ_2 for a given σ_3 is best fitted by a second order polynomial. For example, for σ_3 = 60 MPa, the true triaxial strength is $\sigma_{1(\text{at failure})}$ (MPa) = $237 + 1.65\sigma_2 - 0.004\sigma_2^2$ (r = 0.900). The maximum strength of 400 MPa is achieved at σ_2 = 206 MPa, which is 25% higher than the 320 MPa at $\sigma_2 = \sigma_3$ = 60 MPa. Integrating all the true triaxial strength data into a Mogi-modified Nadai strength criterion yields a monotonically increasing power function $\tau_{oct} = 2.32[(\sigma_2 + \sigma_3)/2]^{0.75}$ (r = 0.995), where τ_{oct} is the octahedral shear stress at failure. The modulus of elasticity, and the onset of dilatancy, exhibited a similar behavior to that of $\sigma_{1(\text{at failure})}$ when subjected to a constant σ_3 (gradual increase followed by a decrease with rising σ_2). Upon failure the siltstone developed a shear through-going fracture dipping steeply in the σ_3 direction. Moreover, the

fracture dip angle steadily increased with rising σ_2 for unchanged σ_3, between 59° and 77°. The trend of the dependence of fracture dip on the deviatoric stress state is generally consistent with the prediction of rock failure based on localization of deformation (Rudnicki and Rice, 1975). SEM inspection of tested specimens revealed only sporadic microcrack localization adjacent to and predating the through-going shear fracture, unlike the pervasive microcrack accumulation within a shear band observed in crystalline rocks tested under similar conditions.