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Chelungpu Fault, Taiwan, footwall heterogeneity as expressed in true triaxial strength, deformability, and failure micromechanics of core retrieved from two boreholes 40 m apart

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Under the auspices of the Taiwan Chelungpu-fault Drilling Project (TCDP) two scientific boreholes were drilled, 40 m apart, some 2 km east of the surface rupture that occurred during the M_w 7.6 Chi-Chi earthquake in 1999. Both boreholes were substantially deeper than the fault zone that hosted the earthquake ($\sim$1110 m in hole A, and $\sim$1133 m in hole B). Core from immediately below the fault (1252 m in A, and 1286 m in B) was obtained for true triaxial testing. The rocks in both holes are clastic belonging to the Pliocene Chinshui Formation, but differ in grain size (44 μm and hence siltstone in A; 71 μm and hence sandstone in B), and composition (A: 65% quartz, 26% clay, 7% feldspar; B: 73% quartz, 20% calcite, 5% feldspar). Hence in core B quartz is more abundant and calcite has replaced the clay found in core A.

Dry rectangular prismatic specimens (19×19×38 mm) were prepared and subjected to two different lateral principal stresses (σ_2 and σ_3), and then loaded axially (σ_1) until brittle failure. In both rocks four groups of tests were conducted, each for a constant σ_3(10, 40, 60, 100 MPa). Within each group σ_2 was varied from test to test between $\sigma_2 = \sigma_3$ and σ_2 approaching $\sigma_{1(at failure)}$. In both cores rock strength ($\sigma_{1(at failure)}$) for given σ_3 gradually increased with the rise in σ_2 until a peak was reached beyond which it slowly declined, thus demonstrating the considerable effect of σ_2 and the inadequacy of the Mohr criterion. However, the sandstone in B exhibited substantially higher strength throughout the range of stresses used. For example at σ_3/ σ_2

= 10/40 MPa $\sigma_{1(at failure)}$ was A/B = 138/197 MPa, and at σ_3/ σ_2 = 60/180 MPa $\sigma_{1(at failure)}$ was A/B = 285/416 MPa. Integrating all the true triaxial strength data for each rock into a Mogi-modified Nadai strength criterion yielded monotonically increasing power functions: τ_{oct} = 2.86[$(\sigma_2 + \sigma_3)$/2]$^{0.69}$ (r = 0.991) for A, and τ_{oct} = 2.36[$(\sigma_2 + \sigma_3)$/2]$^{0.75}$ (r = 0.993) for B, where τ_{oct} is the octahedral shear stress at failure. Again, a comparison of the two criteria reveals the higher strength of the sandstone.

With respect to deformability, the modulus of elasticity E, and the onset of dilatancy D, exhibited a similar behavior to that of $\sigma_{1(at failure)}$ when subjected to a constant σ_3(gradual increase followed by a decrease with rising $\sigma_2)$. However, on average E in hole A was roughly one half of E in hole B (12 vs. 24 GPa). Thus the sandstone in B is twice as stiff as the siltstone in A. Similarly, for example, D in hole A under σ_3/σ_2= 40/120 MPa is reached at 125 MPa, but D in hole B is 155 MPa, a sign that the sandstone in B is more resilient to the onset of microcracking and faulting.

Upon brittle fracture both rocks developed a through-going fault steeply dipping in the σ_3 direction. Moreover, fracture dip angle steadily increased with rising σ_2 for unchanged σ_3. The range of increase in both rocks was limited to about 10-15˚. Backscatter electron images revealed a major difference in microcracking localized along and preceding the through-going fault. In the siltstone microcracks are sporadic, intergranular, and follow the boundaries between silicate clasts and clay matrix; in the sandstone microcracks are abundant and are both inter- and intra-granular, splitting both quartz grains and calcite cement. Thus, with respect to strength, deformability, and grain-scale failure mechanism, the differences between the two rocks only 40 m apart provide strong evidence of the heterogeneity of the Chelungpu Fault footwall.