Permeability and strength of core samples from the Taiwan Chelungpu-fault Drilling Project: Hydromechanical constraints on earthquake rupture

USGS NEHRP External Grant# 05HQGR0065
Final Technical Report

Teng-fong Wong
State University of New York at Stony Brook
Department of Geosciences
Stony Brook, NY 11794-2100
Phone: (631) 632 8212; Fax: (631) 632 8240; e-mail: Teng-fong.Wong@stonybrook.edu;

Key words: laboratory studies, fault dynamics, source characteristics, seismotectonics

Investigations Undertaken

In Taiwan an international project to drill into the Chelungpu fault was initiated in January 2004. The M_w7.6 Chi-Chi earthquake ruptured this thrust fault system in 1999, resulting in significant casualty and damage. The surface break of the Chi-Chi earthquake extended over 100 km, with scarps as high as 8 m in some locations. At Takeng two vertical holes to depths of about 2 km have been drilled through the northern portion of Chelungpu fault. These holes penetrated the Chelungpu fault core at a depth of ~1100 m, and another major thrust fault (believed to be the Sani) was encountered at a depth of ~1800 m. Cores from hole A are available to international scientists for earthquake physics studies.

The first phase of the current project focuses on the measurements of the permeability of TCDP core samples as function of pressure and the brittle failure behavior. Preliminary measurements of the frictional strength were also conducted. Experiments have been completed in the Stony Brook laboratory on TCDP cores (primarily shaly siltstone and sandstone) retrieved from several depths. Since the amount of core materials is somewhat limited, we have been coordinating our efforts with other laboratories interested in this scientific component, in particular Dr. David Lockner of USGS Menlo Park. His laboratory has obtained hydromechanical data on samples from near the fault core at depths of 1111 m and 1151 m. Formation rock types vary from shales to mudstones to graywacke.

Results

Several preliminary conclusions can be drawn from the data on country rock samples acquired at the Stony Brook lab.

- The shaly siltstone samples are associated with beddings that dip preferentially at ~30^o. The principal stresses for the samples cored horizontally simulated those in a thrust faulting regime, and the failure mode in these samples was characterized by almost planar shear faults that were aligned along the dip of the bedding, demonstrating that bedding anisotropy has dominant control over the style of faulting.

- Interconnected porosities were determined to be 4-5%. Possibly due to their high clay content our samples were mechanically weak, with strengths only ~ 1/2 of those of a clean quartz arenite such as Tennessee sandstone (with 6% porosity). However, the frictional strengths are quite normal, in that the friction coefficient of a fractured sample under wet condition is comparable to Byerlee's law.
- The shaly siltstone shows significant water weakening, and dilatancy observed prior to brittle failure was relatively small. Presence of water resulted in ~30% reduction in the strengths of the saturated samples relative to the corresponding dry samples cored in either directions. If further experiments confirm these trends, the data would provide important hydromechanical constraints and impact our analysis of the tectonics and development of pore pressure excess, as well as borehole breakout and inference of the stress states.
- While elastic moduli of the saturated samples are comparable to those inferred from seismic data, they are sensitively dependent on bedding and presence of water. Although elastic heterogeneity was considered to be very important in the inversion of geodetic data for resolving details of the fault geometry, elastic anisotropy and its implication seem not to have been analyzed.
- The permeability was relatively low, with values in the range of 10^{-17}-10^{-19} m^2 at effective pressures of 5-40 MPa. Permeability for flow across bedding was lower than that parallel to bedding by one order of magnitude. Such permeability anisotropy seems not to be considered in fault models on thermal pressurization. Our permeability values are appreciably lower than previous measurements by other groups that use argon instead of water, and in light of recent findings that the presence of water would modify the pore geometry of shaly material and reduce the permeability our study underscores the necessity of such systematic measurements on core samples from active fault zones even though the relatively complicated experiments sometimes require weeks to complete.

The complementary data from the Menlo Park laboratory show that notwithstanding their high clay contents the fault core samples contain sufficient quartz and other hard grains to sustain moderate to high frictional strength. The northern segment of the Chi-Chi earthquake which slid on the Chelungpu fault showed an unusual combination of suppressed high frequency seismic radiation and large total slip, leading to the suggestion that deformation was enhanced by high transient pore fluid pressure. If confirmed by more comprehensive measurements, these preliminary observations of low permeability, high frictional strength and high storativity indicate that this section of the Chelungpu fault would be a good candidate for thermally-induced fluid pressurization and dynamic weakening during the Chi-Chi earthquake.

The data summarized above were presented on May 19-20, 2005 in Taiwan as invited speakers in the International TCDP workshop: [1] Wong, T.-f., N. Chen, W. Zhu and S. R. Song, *Hydromechanical properties of TCDP core samples: Preliminary country rock data and implications for development of pore pressure excess and fault weakening*; [2] Lockner, D., C. Morrow, S. R. Song, S. Tembe, T.-f. Wong, *Preliminary measurements of permeability and shear strength of Chelungpu fault core samples*.

Non-technical Summary

In January 2004 a project was initiated in Taiwan to drill into the Chelungpu fault that ruptured during the M_w7.6 Chi-Chi earthquake in 1999. Two vertical holes have been drilled through the northern portion of Chelungpu fault at Takeng. Core samples are available for scientific studies related to earthquake physics. While the overall objectives of the Taiwan Chelungpu-fault Drilling Project (TCDP) and San Andreas Fault Observatory at Depth (SAFOD) are rather similar, the Chelungpu and San Andreas fault systems are associated with very different tectonic settings, styles of faulting and earthquake cycles. This project was undertaken to conduct laboratory studies on hydromechanical properties of TCDP core samples in parallel with current efforts to study SAFOD samples, aiming to derive synergistic understanding of important questions on earthquake mechanics that remain unresolved. Detailed seismological and geodetic measurements indicate that the Chi-Chi earthquake may involve dynamic weakening. Our preliminary observations of low permeability, high frictional strength and high storativity indicate that this section of the Chelungpu fault would be a good candidate for thermally-induced fluid pressurization and dynamic weakening during the Chi-Chi earthquake.