QUANTITATIVE DETERMINATION OF THE PEDRO MIGUEL FAULTS SLIP DISPLACEMENT AND SLIP KINEMATICS FOR DESIGN OF THE

PANAMA CANAL EXPANSION PROJECTS BORINQUEN DAM

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As part of the seismic hazard investigation component for the Panama Canal Expansion Projects design studies, we completed detailed paleoseismic investigations of

the Pedro Miguel fault. The fault not only poses a shaking hazard to the Panama Canal, it also crosses through the proposed footprint of Borinquen Dam, a critical part

of the expansion program. Borinquen Dam is composed of four discrete dam segments, totaling nearly 5 km in length. It will contain the new 6.7 km long approach

channel to the new Pacific Lock, preserving the Gatn Lake water elevation at 10.6 meters above the current Miraflores Lake. Our studies of the fault involved over 55

geologically logged trenches, including three locations where we excavated the fault in 3-D to determine earthquake recurrence, displacement magnitudes and fault slip

kinematics. The Pedro Miguel fault poses a significant hazard to the project. We were able to determine that it has had three surface-rupturing earthquakes in the last

1500 years, with the last event almost certainly occurring on May 2, 1621 AD. These three events all had 2-3 meters of right-slip displacement, with 8.1 meters

cumulative. The fault exploits weak, low-angle, west-dipping bedding planes of the La Boca Formation to rupture through to the surface as a series of north-stepping,

en-echelon, west-dipping fault petals that roll over near the surface to almost horizontal. The challenge for the dams design will be to correctly understand the specific

geology of the fault-crossing location to be able to predict the fault rupture kinematics, and then to use deformation modeling to understand how that rupture will transfer into the dams earthen structure.

RUPTURE POTENTIAL OF THE LEFT ABUTMENT FAULT, SAN VICENTE DAM, SAN DIEGO COUNTY, CALIFORNIA

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During original construction of San Vicente Dam in the 1940s, a fault was identified in the left abutment of the proposed dam as a 6 inch-wide gouge zone in early

Cretaceous Santiago Peak metamorphosed volcanic rock. The fault was briefly studied by J. Buwalda of Caltech and deemed not a concern, as the fault had little

geomorphic expression. However, as part of the geologic investigations to raise San Vicente Dam, we have conducted new, detailed studies of this fault to assess its

rupture potential and possible hazard to the dam. The fault is NW-striking, and horizontal striae are preserved in the gouge on slikensided surfaces. Because this fault

aligns with other strike slip faults in southern California, it was considered plausible that the fault may accommodate minor localized slip related to the current stress

regime along the Pacific - North American plate boundary.

We conducted extensive field mapping, trenching, and thin section analysis of the Left Abutment fault. The fault juxtaposes two domains of metamorphic volcanic

rocks, and mapping of the fault into a granitic pluton shows 9.5 feet of left-lateral separation of the pluton contact. This sense of slip is opposite of that expected from

the current stress regime. To assess whether the fault has been active since emplacement of the pluton, we cleared off the soil cover into the pluton and determined: 1)

there is no significant offset of the granite itself, and 2) the fault dies into the pluton. Analysis of thin sections across shear surfaces indicates that most or all "gouge" is

pedogenic clay and confirms the absence of young shearing and grain-size reduction.

Our observations from the fieldwork and thin section analysis indicate that the Left Abutment fault is not active and does not pose a concern for raising the level

of San Vicente Dam. Our trenching and mapping show that the observed displacement on the fault resulted from minor crustal adjustments related to the emplacement

of a Cretaceous pluton, its subsequent uplift and consequent stream incision, and is therefore not a rooted seismogenic fault.

PALEOSEISMIC ASSESSMENT OF THE VILARI‖ SEGMENT OF THE MANTEIGAS-BRAGAN‖ FAULT IN NORTHEASTERN PORTUGAL

FOR THE PROPOSED SABOR RIVER DAM

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We studied the late Quaternary activity of the Manteigas-Bragança fault as part of the seismic hazard characterization for the proposed Sabor Dam in NE Portugal. This

fault, which is a major, 250 km-long, NNE-striking, sinistral strike-slip structure, has no historical seismicity for large earthquakes, although it may have generated

moderate (M5+) earthquakes in 1751 and 1858. Evidence of continued left horizontal displacement is shown by the presence of Cenozoic pull-apart basins as well as

late Quaternary stream deflections. To investigate its recent slip history, a number of trenches were excavated at three sites along the Vilariça segment, north and south

of the Douro River. At one site, the Vale Meão winery, the occurrence of at least two and probably three events in the past 14.5 ka was determined, suggesting an

average return period of about 5-7 ka. All three events appear to have occurred as a cluster in the interval between 14.5-11 ka, suggesting a return period of less than 2

ka between events within the cluster. In the same area, a small offset rill suggests 2-2.5 m of slip in the most recent event and about 6.1 m after incision below a ~16 ka

alluvial fill event along the Douro River. At another site along the Vilari硍River alluvial plain, northeast of the Vale Me ▪ site, several trenches were excavated in late

Pleistocene and Holocene alluvium, and exposed the fault displacing channel deposits dated to between 18 and 23 ka. In a succession of closely-spaced parallel cuts

and trenches, the channel riser was traced into and across the fault to resolve ~6.5 m of displacement after 18 ka and ~9 m of slip after ~23 ka. These observations yield

a slip rate of 0.3-0.5 mm/yr, which is consistent with earlier estimates. Combining the information on timing at Vale Me ▪ winery and displacement at Vilari硍argues

for earthquakes in the M7+ range, with co-seismic displacements of 2-3 m. This demonstrates that there are potential seismic sources in Portugal that are not associated

with the 1755 Lisbon earthquake or the Tagus Valley, and although rare, large events on the Vilari硍fault could be quite destructive for the region and for proposed and existing dams.

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