Paleoseismology of Surface Ruptures:

Research Tool or Standard of Practice?

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In the AEG News (Vol. 47, No. 4, p19), Jeffrey R. Keaton and David H. McCormack (here abbreviated KM) argue that "it is ... not reasonable for guidelines to require that developers determine recency of faulting and recurrence of prehistoric earthquakes as part of the process of demonstrating that their buildings do not straddle active fault traces" and "it is ... not reasonable for guidelines to require that developers investigate off-site locations as part of the process of demonstrating that these buildings do not straddle active fault traces. ." We disagree, in part.

The discussion that KM have started is significant because of the evolving importance of fault rupture hazards in site development in the Pacific Northwest. The increasingly common recognition that Washington and Oregon face surface fault rupture threats is a new paradigm that is only just beginning to face the consulting community (Yeats and Weaver, 2004).

This conversation is important because the State of Washington, faced with the presence of active faults with potential for surface rupture, must develop guidelines influencing development, as the States of California and Utah have done. The new paradigm is a result of a campaign led by the U.S. Geological Survey (USGS) to identify surface fault traces using aeromagnetic surveys followed by a new system of laser swath aerial mapping (LiDAR) providing a bare-earth digital elevation model of areas covered by forest (Haugerud et al., 2003; Yeats and Weaver, 2004). This program has identified several faults impacting development in urban areas in the Puget Sound region. Some of the LiDAR scarps have been excavated, yielding evidence for multiple earthquakes during the Holocene. The most recent documentation of Holocene coseismic deformation was found in two trenches on the site of a proposed regional wastewater treatment plant in southern Snohomish County (Sherrod et al., 2005). It was this site that the KM paper referred to in the conclusions section, and which appears to have served as the basis for their opinion that paleoseismological studies are unreasonable for a development project. In the case of this project, we disagree.

Paleoseismology is defined as "...the investigation of individual earthquakes decades, centuries, or millennia after their occurrence" (Yeats et al., 1997). Its use by the USGS in the Puget Sound region is instructive as to why it is, or should be, a necessary part of consulting practice. Prior to LiDAR, the area was known to have been struck by a large crustal earthquake on the Seattle fault about 1,000 years ago. Trench excavations on a strand of that fault on Bainbridge Island provided evidence for three and possibly four earthquakes on the Seattle fault system between 2,500 and 1,000 years ago (Nelson et al., 2003). Subsequent trenching, coring of turbidite deposits in Lake Washington (Karlin et al., 2004), and coring in the Snohomish River delta (Johnson and Bourgeois, 2001) have shown that the recurrence interval of earthquakes in the Seattle area is measured in centuries rather than millennia.

Is this important for local government, the bank issuing construction loans, the company insuring the property, the developer, and the general public to know? If an earthquake occurred only once in several thousand years, as was thought to be the case for the Seattle fault, the probability of another event during the life of the project is much lower than if the recurrence interval is measured in centuries. The paleoseismological input to the decision to proceed with the project can be translated into probabilistic estimates of potential losses from a surface-rupturing earthquake.

Does surface rupture matter? The losses from the 1989 Loma Prieta and 1994 Northridge earthquakes were due to factors other than surface rupture. However, the California sample is not representative. Losses due to surface rupture were very large in the 1999 Koçaeli, Turkey, and 1999 Chi-Chi, Taiwan, earthquakes. An illustration from Yeats and Gath (2004, their Fig. 3.3) shows the surface trace of the Chelungpu fault in Fengyuan City, Taiwan; the destruction of buildings was nearly total along the fault trace and in the adjacent hanging wall close to the fault. The fault had been mapped prior to the earthquake. If an Alquist-Priolo-type zone had been in place prior to development, hundreds of lives could have been saved. In California, the probability of an earthquake on the surface-rupturing Hayward-Rodgers Creek fault in the next 30 years is very high. The San Jacinto and San Andreas faults in southern California pose comparable hazards to urban areas.

Why require geologic studies? For desert regions of Iran, the evidence is clear: the 1968 Dasht-e-Bayaz earthquake on a strike-slip fault and the 1978 Tabas earthquake on a reverse fault were accompanied by surface ruptures on secondary faults as well as the principal displacement zones. These faults might not be visible in forested areas on LiDAR or aeromagnetic surveys but would be mapped by trench excavations. For this reason, it is critical to excavate and describe in detail trenches along the entire footprint of a building that is part of a critical facility. As for residences and apartment buildings: would you like to find out someday that an active fault extends beneath your foundation?

Does the discovery of an active fault make the property a no-go zone? Not necessarily. Yeats and Gath (2004) described a case history from a housing development in Moorpark, California, where trenching had disclosed extensive deformation of Quaternary gravels by folding and faulting. Without a detailed geological investigation that allowed a quantitative assessment of past displacement events, and the use of those events to model a potential future deformation, the project was stalled in regulatory limbo. However, trenching of the youngest gravels, at least 50,000 years old, showed that maximum displacement on faults was six inches, and in most places it was one inch or less. Although these displacements could have resulted from more than one earthquake, the worst-case scenario of a single earthquake was assumed. The structural engineer was able to incorporate these displacements into the foundation design, and the project moved forward.

In most cases, such detailed information is not important because avoidance is the best mitigation. However, the best approach is to collect all of the data available in a trench excavation as though it was going to be the last trench. You just never know what might be important.

The final question raised by KM is requiring the developer to trench off-site if the development site does not contain geologic materials of Holocene age that could be used to determine the age of most recent fault rupture. This is always a difficult problem. What property owner in their right mind would want to allow you to come over and dig a trench across their property, and take the risk of allowing you to prove that they (and your client) have an active fault running through their property. In private land development projects, it is virtually impossible. The consultant is therefore left to develop the best possible approach to making a hazard determination using public record reports from nearby projects, and supplemented by using the tool (trenching, coring, CPT, geophysics, etc.) that gains the most useful data on the client's available land. Ultimately it comes down to experience and judgment. In the California experience, it is expected that the intensity of the investigation be scaled in relation to the degree of the hazard and the importance of the project.

> *"The scope of the investigation is dependent not only on the complexity and economics of a project, but also on the level of risk acceptable for the proposed structure or development. A more detailed investigation should be made for hospitals, high-rise buildings, and other critical or sensitive structures than for low occupancy structures such as wood-frame dwellings that are comparatively safe."*
> *CGS SP-42, Appendix C, pg. 28.*

However, the development project cited by KM was not a small private development project. Instead it was a multi-million dollar wastewater treatment facility serving millions of citizens, with numerous intake pipelines, a long discharge tunnel beneath urbanized areas, and the numerous structures and components that make up a modern treatment plant. Failure of the facility is simply not an option, especially a failure that might require months to repair. In addition, the project was embroiled in extensive public debate. For a project this large and this critical, involving large amounts of public money, the paying public does have a right to expect that the government agency has thoroughly explored the hazards and calculated the risks, and honestly presented them to the public for their assessment and eventual concurrence. Yes, it is fair, indeed obligatory, for the project consultants to advise their clients that if the data are not available at the project site, they should be willing to look elsewhere, especially for such a geographically extensive project that simply cannot be allowed to go offline for very long. Indeed, the ability or inability to adequately address seismic risk at the site should probably have been a considered factor in the site selection process.

Paleoseismology is no longer the state of the art, practiced only behind the ivory curtain in academic research institutions. Indeed dozens of companies now employ geologists who have a "Paleoseismology of the XYZ fault" as a title for their MS thesis. Recognition of paleoseismic events in trench stratigraphy is not trivial, but not rocket science either. Understanding the event chronology of a fault allows the consultant to make recommendations to their clients that are based on data, rather than simply opinion or computer hazard models. It helps to communicate the hazard. "This fault has had at least three earthquakes in the last 8,000 years, but the last one looks like it was only 500 years ago" is better than simply "This is an active fault and you need to stay away from it." Of course there is the typical geological uncertainty of missed earthquakes in the first example, but there is still some higher probability that it will be a long time indeed before the next earthquake happens across your client's property.

So how will the standard of care be defined? It will be defined by today's practitioners, by tomorrow's practitioners, by the needs of the clients, by the demands of the regulatory agencies, by discussions such as this one in professional newsletters, and eventually by the courts. As more and more geological consultants practicing in the Northwest begin to appreciate that active faults are here to stay, the standard of practice will evolve quickly. Yes, paleoseismic awareness in trench exposures is still relatively uncommon and above the current standard of practice for most projects. But so was taking core borings 50 years ago. So was checking for pesticide residue only 20 years ago. So was even believing that Washington had a surface fault hazard only 10 years ago. The standard of practice has consistently evolved into the collection of more and better data. It will do so here as well. It has already started.

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