FAULT GROUND RUPTURE BENEATH A NUCLEAR REACTOR

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SUMMARY

The possibility of fault ground rupture beneath the 20 year-old Vallecitos Nuclear Reactor led to its shutdown followed by 5 years of investigations and hearings. The theoretical behavior of a hypothetical fault in soil beneath a heavy structure was an important factor in the NRC licensing board's decision to permit restart. The Vallecitos case raises some fundamental questions on the role of technical predictions in safety evaluation.

CHANGING PERCEPTION OF FAULT RISK

The possibility of active geological fault movement directly beneath the foundation of a nuclear reactor has been a major safety issue since the birth of the nuclear power industry twenty-five years ago. One of the first major safety-related setbacks to the industry was the failure of the Pacific Gas and Electric Company's efforts to build a 300-Mw plant north of San Francisco at Bodega Bay. In that case, the AEC staff rejected PG&E's license application because there was strong evidence of past faulting which had evidently caused a few inches of displacement some time in the past 30,000 years. The AEC staff, in a precedent-making decision, considered PG&E's attempt to structurally accommodate potential fault movement unprecedented and unprovable. Other well known western U.S. cases where possible future fault ground rupture (as opposed to ground shaking, which is an issue not considered here) became an issue are nuclear sites at Malibu, San Onofre, Pt. Arena, Davenport, and Montezuma; also, the Auburn Dam, and the proposed LNG facilities near Santa Barbara.

Many engineers used to think that once you got away from the principal well known faults like the San Andreas, you were on reasonably safe ground, and that concern over faults was an example of public hypersensitivity. However, geologists are discovering more and more faults, and standards of acceptable risks have tightened. If one selected a nuclear site by throwing a dart at a map of California, the odds are about 10^{-4} per year that the selected site would be traversed by an active fault. My interpretation of the latest NRC risk guidelines is that this is 10 or 100 times higher than acceptable. Of course, the most dangerous sites are those with clear evidence of underlying active faults, and if these are eliminated, the residual risk is lower than 10^{-4} per year. However, a reliable geological test is still needed to assure that one's site is 10 to 100 times less risky than a randomly selected site.

THE CASE OF VALLECITOS

In the case of GE's test reactor (GETR) at Vallecitos, California, the issue of fault hazard was raised in 1977, twenty years after the reactor was placed in operation. Following the release of a U.S. Geological Survey map indicating the presence of a fault 200 feet from GETR, the facility was shut down by NRC order,

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and the owner was obliged to demonstrate that the reactor was safe. I have discussed the history of GE's 5-year campaign to restart the reactor fully elsewhere (2).

GE's arguments in defense of the plant rested on several assertions as to geological conditions and structural capacity. Faults, if indeed they did exist near the site (a disputed issue) apparently were at least some distance away from the structure. What were the odds of a fault migrating or an undetected fault beneath the structure (Figure 1)? Would fault movement beneath the reactor cause a structural loading condition as in Figure 2? Or would the presence of the reactor structure deflect or disperse the fault deformation as in Figure 3? As it turned out, the issue of fault movement (Figure 2 vs. Figure 3) was of crucial licensing importance. Agreement between GE and the NRC staff that the response would be as in Figure 3, not as in Figure 2, was a substantial factor in the NRC decision, handed down in mid-1983, to permit restart of the reactor.

ANALYZING FAULT DEFORMATION

Realistic assessment of the characteristics of gross deformation of geological materials such as the dense clays and sands underlying GETR is a difficult task. Weak comparisons can be made with past performance such as the well publicized case of fault deflection around a bank vault in the Guatemala earthquake of 1976. Some experimental laboratory techniques, such as centrifuge modelling, are available (4). Usual state-of-the-art analytical techniques such as finite element modelling lose predictive capability when deformations greatly exceed the elastic limit. For the purposes of this analysis, we adopted the traditional limit equilibrium approach used in soil mechanics stability analyses and addressed the problem as illustrated in Figure 4.

We considered the hypothetical fault to be suitably modelled by a simple Rankine passive failure wedge. For appropriate soil strength parameters (the subgrade included stiff clays and dense gravels, so a variety of parameters were tried), a total passive resistance (A) can be calculated for various failure plane inclinations (C) and points of origin (B). The reactor structure is treated as a rigid surcharge that may be wholly lifted or tilted by the failed wedge, depending on the location of the intersection of the failure plane with the base of the reactor.

The objective is to determine whether there is some origin of failure plane (B) for which the thrust (A) is a minimum with the failure plane (C) intersecting the base of the reactor. The method of solution is a simple computer trial and error solution of the Rankine condition in which (B) and (C) are varied and (A) computed. The result in the case of GETR was that the preferred failure plane (i.e., the failure plane with the minimum thrust (A)) always avoided the reactor foundation, i.e., surfaced on the near or far side of the foundation. This result was unique to the conditions at GETR. Obviously, the presence of shallow rock which constrained the depth of (B), or, conversely, a larger reactor dimension or lower structural weight, could lead to a different result. As it was, for certain cases the thrust (A) for failures bypassing the reactor was only slightly greater (a few percent) than the thrust for certain planes intersecting the foundation. Clearly, under those circumstances the actual behavior of the ground might well be more complex than suggested by the simple Rankine model, as suggested in Figure 3. Nonetheless, it seems most unlikely that the condition of concern, the cantilever condition of Figure 2, would develop. The NRC staff concurred with this finding.

WHAT LEVEL OF CERTAINTY?

My use of the phrase "seems most unlikely" will doubtless raise discomforting thoughts in the minds of some readers, as it did in the NRC hearings. How certain do the results of such an analysis have to be? The theoretical outcome described here was an important element in GE's overall argument and in the NRC's decision. I say "element" rather than "link" because the overall case contained many geological, geotechnical, structural, and failure-scenario redundancies. Naturally, the NRC licensing board, consisting of three judges--two scientists and one lawyer--wanted to know how certain the fault-deflection prediction was ("Did faults always break ground in the street, avoiding buildings?" asked one judge). This raises the important issue of how one deals with the uncertainty in a particular sub-argument which is a significant but not necessary essential element in the overall presentation of safety assurance. In a recent book (1), Blockley argues that model uncertainty, unlike load or resistance uncertainty, cannot be logically assigned a probability. If this is true, the probable goodness of this or other such elements of the technical argument cannot be quantified. How, then, do we quantify the level of assurance attained? The question remains to be answered by advocates of probabilistic risk analysis. In the case of Vallecitos, attempts were made to quantify the risk of faulting (3). However, the licensing board's decision was not in the end based on any numerical standard. The resolution was procedural, not rational. It was the absence of any counter-argument from either NRC staff or intervenor witnesses that convinced the licensing board that the theoretical results leading to the dismissal of the "cantilever case" were reasonably assured. This comes as no surprise to a lawyer, but it may run against the engineering sensibility. It suggests that successful technical cases are built less on rationality or on facts than on assertions that nobody troubles to oppose.

REFERENCES

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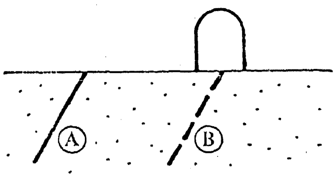

Figure 1. Known Ⓐ and hypothetical Ⓑ faults at GETR

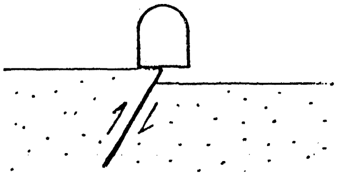

Figure 2. Hypothetical "cantilever" loading due to fault movement

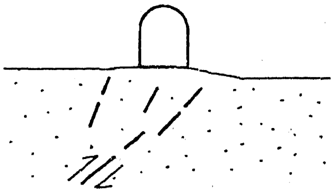

Figure 3. Alternative subgrade deformation due to fault movement

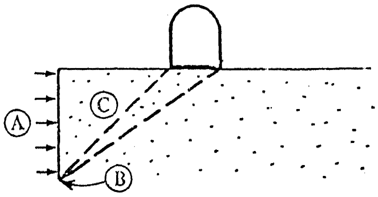

Figure 4. Soil failure model for studying fault movement