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Jackson, 1985b

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August 23, 1985
RFW/SAL/DFL/00883/85

Dr. Allan J. Jelacic
Geosciences Team Leader
Geosciences and Technology Division
Office of Geologic Repositories
U.S. Department of Energy
RW-24 (Forrestal), Room 7F-091
Washington, DC 20545

Subject: Assessment of Potential Damage to Underground Facilities from Earthquakes
(TDD #3002-24-08-1001)

Dear Dr. Jelacic:

As requested, we have reviewed the literature in order to provide you with an assessment of potential damage to underground facilities from earthquakes (enclosed). In addition, a list of publications on the topic of subsurface ground motion is included in the references to the enclosure.

The enclosure briefly discusses ground motion at depth, empirical correlations of subsurface damage and ground motion, subsurface design considerations, and the effects of fault displacement. As noted in the enclosure, there have been numerous observations that underground structures suffer less damage than surface structures during strong motion shaking. A large portion of this information, however, is qualitative rather than quantitative. Two very general conclusions are that: 1) mines and tunnels are less susceptible to strong ground motion than surface facilities; 2) ground motion is likely to be lower in the subsurface, particularly if the surface facilities are located on soil.

In addition to the conclusions on potential damage to underground facilities we have attempted to relate these conclusions to the framework of the seismic/tectonic position paper, for the preclosure time. This assessment included listing the types of seismic events, the potential repository subsurface component failure items, and the the types of consequences and risks. Our qualitative conclusions at this time are:

- o the probability of events causing damage is likely to be low - only large ground motions, which are likely to have low probabilities, will cause damage - given what is currently known about the tectonics of the candidate sites, fault displacement probabilities are also likely to be very low (less than 10^{-4} to 10^{-5} per year).

- damage to subsurface facilities from either ground motion or fault displacement is likely to be localized - this may indicate that potential radionuclide release may not be significant because few, if any, canisters would be damaged.

- potential flooding should be investigated, particularly if the mitigative system is adversely affected by the earthquake. The flooding could impact retrievability.

- other systems used in retrievability, such as the shaft, hoist, and transportation systems may be issues for consideration regarding seismic design requirements.

These conclusions should be considered qualitative and non-site specific. Site-specific data and performance assessment models will be needed to make final conclusions regarding potential impact of earthquakes on underground facilities.

In addition to the conclusions above, for the Nevada Project it is recommended that they investigate if it is feasible to estimate shaking at the tunnel sites (such as G Tunnel) from the weapons tests within Yucca Flat and Rainer Mesa. This would be good qualitative evidence to support the occurrence of minimum levels of ground motion below which no damage has been caused to the subsurface support systems.

If you have any questions regarding the above conclusions or the enclosure please contact Jeff Kimball at 963-5233 or myself at 963-5211. This is in partial fulfillment of TDD #3002-24-08-1001.

Sincerely,

ROY F. WESTON INC.

Robert E. Jackson, Manager
Site Assessment

Approved By:

William M. Hewitt

Enclosure

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ASSESSMENT OF POTENTIAL DAMAGE TO UNDERGROUND FACILITIES FROM EARTHQUAKES

The purpose of this short paper is to provide supplemental discussion of the expected effects from earthquakes on underground repository facilities, as summarized in the April 30, 1985 DOE/HQ memorandum from D. Youngberg to A. Jelacic (attached). This discussion is based on a review of a number of publications cited in the text. In addition, a list of publications on the topic of subsurface ground motion is included in the references to this paper. The expected effects of earthquakes on underground facilities can be broadly broken into two categories; ground motion and fault displacement. Each category will be discussed below.

Effects of Ground Motion

There have been numerous observations that underground structures suffer less damage than surface structures during strong motion shaking, as discussed by Stevens (1977), Pratt (1981), McClure (1981), and Dowding and Rozen (1978). A large portion of this information, however, is qualitative rather than quantitative. There may be a number of reasons for these observations: many surface structures are located on soil which tends to accentuate the effects of strong ground motion; ground motion may decrease with depth; and subsurface structures such as mines or caverns are less susceptible to strong motion shaking. The following discussion will concentrate on the seismological observations of subsurface ground motion. However, factors such as the depth below the ground surface, the subsurface openings support and lining systems, strength and other rock characteristics, are extremely important parameters contributing to the structural stability of subsurface structures to seismic shaking.

Ground Motion at Depth

In July of 1983, a workshop was convened to discuss the site-specific effects of soil and rock on ground motion (U.S.G.S. Open File Report 83-845). As discussed by numerous researchers at this workshop, soil sites, particularly shallow soil sites, (less than about 60 to 100 feet) will amplify recorded strong motion. For a high-level-waste repository this observation means that surface facilities located on soil, are likely to have significantly higher ground motion than that expected in the subsurface rock. It is not known whether the same conclusion would hold true if the surface facilities were located on bedrock. Unfortunately, very little earthquake data exists to quantify the reduction of ground motion in rock. Iwasaki et al. (1977) recorded 10 earthquakes at three depth levels in sandstone and siltstone. In general, the ground motion was reduced at depth compared to the surface.

In contrast to earthquake data, a large amount of information on downhole ground motion is available from underground nuclear tests (Vortman and Long, 1982a, 1982b). On the average the peak vector acceleration at a depth of 350 meters is reduced by a factor of 2 relative to that at the surface. Reduction of peak velocity and displacement is less. All three parameters show strong effects of the geology at the point of measurements. There is some question about whether this data is applicable to earthquake ground motions because these measurements are relatively close to the nuclear tests where the source effect differences compared to an earthquake are most significant. Until the question is fully resolved, this data will be of limited use.

Empirical Correlations of Damage and Ground Motion

Other qualitative assessments of earthquake effects on underground openings may be made based on empirical correlations developed from performance data on damage or lack of damage to rock tunnels and openings, and peak ground motion parameters of earthquakes. As stated by Owen and Scholl (1981) the following conclusions may be drawn.

- Little damage occurred in rock tunnels for ground surface accelerations below 0.4g and ground surface velocities below 28 inches per second. Dowding and Rozen (1978) found that there was no damage in either lined or unlined tunnels for ground surface accelerations up to 0.19g and ground surface velocities up to 8 inches per second. For ground surface accelerations between 0.19g and 0.4g, they found a few cases of minor damage, such as falling of loose stones and cracking of brick or concrete linings,

- Severe damage and collapse of tunnels from shaking occurred only under extreme conditions. Dowding and Rozen (1978) observed that no collapse occurred for ground surface accelerations up to 0.5g (ground surface velocities up to 36 inches per second). Severe damage to the lining or portals from strong shaking was usually associated with marginal construction, such as brick or plain concrete liners and the lack of grout between wood lagging and the overbreak. Poor soil or incompetent rock also seemed to contribute to the susceptibility of tunnels to damage.

These conclusions should be used qualitatively because they are dependent on a number of assumptions including the use of a specific attenuation relationship to assess ground motion at the tunnel sites. If a different attenuation relationship were used, the results may be different. There also was no attempt to correlate damages with the duration of strong shaking. Additionally, the performance data for the tunnels and openings represented a wide variety of construction methods and support systems which may not be applicable to an individual site. Finally, there may be combinations of structure and rock characteristics not included in the data set surveyed which are more susceptible to ground motion damage.

Design Considerations

With respect to the design of a large underground opening in a seismic zone, Hendron and Fernandez (1983) discuss dynamic and static considerations for underground chambers. They state that the primary objective of a support system for a large underground opening is to provide temporary and permanent stability of the roof and walls of the opening under static loading and earthquake effects. Suggested steps include:

- determine the magnitude of the static load to be supported

- determine the magnitude of the dynamic load

- analyze the potential support alternatives to identify the most critical loading conditions for each type of support.

One conclusion that Hendron and Fernandez (1983) draw is that rock bolt support systems have the advantage of being more flexible in accommodating unexpected loading conditions likely to develop in a chamber. In addition, their support capacity is less sensitive to the construction process. Their article should be consulted for the full details of the discussion.

In summary, observations suggest that mines and tunnels are less susceptible to strong ground motion than surface facilities. Ground motion is likely to be lower in the subsurface, particularly if the surface facilities are located on soil.

Effects of Fault Displacement

As discussed by Owen and Scholl (1981) and Duke and Leeds (1959), severe tunnel or mine damage appears to be inevitable when the tunnel or mine is crossed by a fault which slips during an earthquake. Relative to a high level waste repository, these observations suggest that it will be extremely important to; 1) determine if active faults exist in the subsurface at the site; 2) determine the likelihood of movement for both the preclosure and postclosure time frames; 3) determine the significance of potential fault displacements. The impacts of displacements could include radionuclide exposure risk, safety hazard to personnel and subsurface structures and equipment, and plans to continue operation if an event were to take place.

Relationship to Seismotectonic Position Paper

As presently planned, the conceptual approach to seismotectonic assessments for licensing a repository (discussed in the annotated outline of the seismic/tectonic position paper) includes both the preclosure and postclosure evaluations of tectonic event impacts on subsurface facilities. Each site will have to develop a framework or logic diagram to address a variety of tectonic issues which may impact the subsurface facilities. The general framework is likely to be:

- Event identification and assessment of likelihood
- Types of damage and/or failure modes of subsurface structures and components
- Expected impacts of damage and failure of components (such as radionuclide releases)
- Consequences (injuries, deaths, exposures)

For example the following text outlines some of the issues which may need resolution, or investigation, in determining the impacts on subsurface facilities of tectonic events for the preclosure time frame (postclosure consideration were not developed at this time). This list is not meant to be exhaustive, but outlines some of the issues likely to be included.

Preclosure Tectonic Events - Subsurface Facilities

Types of Events

- earthquake ground motion in the subsurface
- earthquake fault displacement
- induced seismicity (includes weapons testing)
- probability and uncertainty analysis of each phenomena

Potential Repository Component Failure Items

- shaft liners
- shaft and borehole seals
- headframe and associated hoist system equipment
- pumps
- underground openings and drifts
- waste canisters (number and types of failure)
- ventilation systems
- other suspended utilities such as wiring and compressed air pipes

Types of Consequences and Risk

- flooding of repository
- loss of retrievability
- radionuclide releases and exposures
- injuries and deaths

For the preclosure, relating the list above to the previous discussion on potential damage to underground facilities one can qualitatively conclude that:

- the probability of events causing damage is likely to be low - only large ground motions, which are likely to be low probabilities will cause damage - given what is currently known about the tectonics of the candidate sites, fault displacement probabilities are also likely to be very low (less than 10^{-4} to 10^{-5} per year).

- damage to subsurface facilities from either ground motion or fault displacement is likely to be localized - this may indicate that potential radionuclide release may not be significant because few if any canisters would be damaged.

- potential flooding should be investigated particularly if the mitigative system is adversely affected by the earthquake. The flooding could impact retrievability.

- other systems used in retrievability, such as the shaft (at, for example the soil/rock interface if it exists) hoist, and transporter systems may be issues for consideration regarding seismic design requirements.

These conclusions should be considered qualitative and non-site specific. Site specific data and performance assessment models will be needed to make final conclusions regarding potential impact of earthquakes on underground facilities. In addition to the conclusions above, it is recommended for the Nevada Project that they investigate if it is feasible to estimate shaking at the tunnel sites (such as G Tunnel) from the weapons tests within Yucca Flat and Rainer Mesa. This would be good qualitative evidence supporting levels of ground motion below which no damage is caused to the subsurface support systems.

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DOE F 1325.8
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United States Government — Department of Energy

memorandum

DATE: APR 30 1985

REPLY TO ATTN OF: RW-24

SUBJECT: Assessment of Potential Damage to Underground Facilities from Earthquakes

TO: Allan Jelacic

A review of several publications that documented the damage or non-damage to underground facilities due to earthquakes was accomplished. The sources of data included experiences of earthquake damage to tunnels, mines and wells. General conclusions developed from the data suggest some criteria for siting an underground repository:

1. A repository should not be located in the immediate vicinity of active faults.

   o In mines and tunnels, large displacements have occurred primarily along pre-existing faults and fractures.

   o Severe damage was inevitable when underground structures were intersected by a fault that slipped.

THIS COULD HURT US!

2. Proper seismic design can reduce susceptibility of a repository to damage from shaking.

   o Severe damage from shaking was usually associated with marginal construction or incompetent rock.

3. The seismic criteria for siting and design of an underground repository can be less restrictive than the seismic criteria for the design of surface facilities.

   o Tunnels, wells and shafts are less susceptible to damage than surface facilities.

   o The intensity of shaking below ground is commonly less severe than on the ground surface and generally decreased with depth.

   o More damage has been reported in shallow, near surface tunnels than in deep mines.

Dan Youngberg

Dan Youngberg
Geologist