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MEMORANDUM FOR: Philip S. Justus, Acting Chief
Geotechnical Branch
Division of Waste Management, NMSS

FROM: Abou-Bakr Ibrahim
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SUBJECT: TRIP REPORT, ENGINEERING CHARACTERIZATION OF SMALL-MAGNITUDE EARTHQUAKES, PALO ALTO, CALIFORNIA

From January 26-30, 1987, I attended the workshop dealing with small magnitude earthquakes, visited the Lawrence Berkeley Laboratory (LBL), Chevron oil Company and the United States Geological Survey in Menle Park. The purposes of these visits were to:

A. participate in the workshop and discuss the issues concerning the selection of a lower-bound magnitude for use in probabilistic seismic hazard assessment,

B. discuss the geophysical program which LBL is conducting at Yucca Mountain,

C. examine the seismic reflection data which Chevron has recently collected in the Hanford area, and

D. discuss the progress of the interpretation of the seismic reflection and refraction data which the USGS has acquired in Yucca Mountain and in the Hanford area.

The following is a summary of activities and observations conducted during my visits.

A. Workshop on Engineering Characterization of Small Magnitude Earthquakes:

In recent years considerable effort has been spent on the probabilistic seismic hazard assessment. In order to describe the seismic hazard in a region, a lower-bound on earthquake magnitude should be defined. A lower-bound on earthquake magnitude defines the limit below which the contribution from smaller events to the ground motion is not considered in the analysis.

The theme of the workshop was to establish a realistic lower-bound earthquake magnitude below which there is high confidence that safety related structures and equipment are not adversely effected. To address the theme of the workshop the following questions were discussed:

1. What are the current seismic design requirements and how do they relate to the ground motion due to small magnitude earthquakes?

2. What is the impact of the lower-bound magnitude cutoff on seismic hazard assessments?

The following papers presented at the workshop tried to address the above mentioned questions.

- Engineering characterization of small magnitude earthquakes, an overview: by Martin W. McCann, Jr.

This paper provided the background and the concerns regarding using the lower-bound earthquakes magnitude (M < 5.5) in seismic hazard analysis. The author indicated that using small magnitude earthquakes in the seismic hazard analysis can lead to an overestimate of the risk due to seismic events. Table 1 provides an estimate of the seismic hazard when lower bound magnitude of 3.5 and 5.0 are used in the hazard calculations. From the table, it is clear that large differences are observed in the probability of exceedence when pga (peak ground acceleration) is below 0.2 g and at higher pga (i.e. greater than 0.20 g) the differences are less.

- Seismological characteristics of small magnitude earthquakes: by Hiroo Kanamori.

The author presented spectral ratios of various large earthquakes showing that the w-square model is a better presentation of the seismic spectrum than the w-cube model. For small earthquakes, using the New Brunswick earthquake data set of 1982, the author again indicated that the data favor the w-square model over the w-cube model in the frequency range of 1 to 20 Hz. The stress drop of intraplate events is approximately a factor of 3 higher than the interplate earthquakes. The author concluded by saying that although the w-square model explains well the average data for earthquakes in the eastern U.S., the actual data exhibits a scatter of at least a factor of 10. This scatter is due to radiation, pattern, site effects, focusing and defocusing, reflection and refraction from crustal discontinues, attenuation and crustal wave guide effects. The author recommended a unified magnitude scale should be used and recommended the use of moment magnitude.

- Engineering characterization of small magnitude earthquakes by: Robert P. Kennedy.

Despite the lack of empirical evidence, the author indicated that he is not aware of any small earthquake magnitudes (M < 5.0) causing any damage to well engineered structures and components. Therefore, he recommended that the lower-bound earthquake magnitude be set at M = 5.0 in estimating the seismic hazard. If lower bound magnitude earthquakes, M < 5.0, have to be considered in the seismic hazard analysis, Kennedy cautioned against aggregating earthquake ground motions from different sources and different earthquake magnitudes all together into a single smooth broad band frequency response spectrum for use in evaluating structures and components. Instead he suggested that these earthquakes should be classified into different categories (disaggregate) depending on frequency content and magnitude, and the spectral acceleration and duration for each category should be identified for the engineers use in evaluating structures and component.

- Equipment response in linear and non-linear nuclear power plant structures. Small magnitude versus design type motions by: C. A. Cornell and Robert T. Sewell.

The authors discussed the effect of small magnitude earthquakes M < 5.5 on the linear and non-linear structures and equipment response. Small magnitude earthquakes are characterized by a narrow band ground response spectra in comparison with the wide band design basis spectra such as R. G. 1.60. Based on the earthquakes ground response spectra, the authors classified small magnitude earthquakes into 3 categories, type A, B, and C. Type A are these earthquakes with predominantly low frequency contents in the range of 2-6 Hz; type B are these with intermede frequency contents in the 4-10 Hz, while type C are characterized by frequency contents greater than 10 Hz. Small magnitude earthquakes in California are of type A and B while earthquakes in the eastern U.S. are of type C.

The authors concluded:

1. Small magnitude earthquakes of type A may be as effective as large magnitude earthquakes in causing structural and equipment damage,

2. Small magnitude earthquakes of type B may be as severe as large magnitude earthquakes except with respect to low frequency structures and equipment in the frequency range around 3 Hz, and

3. Small magnitude earthquakes of type C are less severe than the large magnitude earthquakes with respect to all structures and most equipment, including higher frequency (> 9 Hz) equipment in low frequency structures. In some cases, type C earthquakes may be more severe than large earthquakes for high frequency equipment in high frequency structures.

- Seismic Experience in Power and industrial Facilities as it relates to small magnitude earthquakes by: Sam W. Swan and Nancy G. Horstman.

In this paper, the authors presented their observations of seismic damage to power and industrial facilities. Their observations are based on 15 earthquakes ranging in magnitude from 5.3 to 8.1. The authors visited 50 sites to examine the effects of the earthquakes to structures or equipment installation of any type. The data base for the damage is examined against:

a. Peak ground acceleration,
b. Earthquake magnitude (Richter Scale), and
c. Modified Mercalli intensity (MMI),

The authors observation lead to the following conclusions:

1. Seismic effects correlate well with MMI,

2. Seismic effects correlate moderately well with peak horizontal ground acceleration, but generally not with Richter magnitude, and

3. For MMI < VIII no damage is observed.

Relating MMI = VIII to magnitude, the authors concluded that detailed investigations of small earthquakes below 5.0 on the Richter Scale are normally not considered worthwhile.

- Effects of the Northern Ohio Earthquake on the Perry Nuclear Power Plant by: John D. Stevenson.

The author discussed the Leroy, Ohio earthquake which occurred on January 31, 1986 at distance of about 10 miles from the Perry Nuclear Power Plant in Ohio. This earthquake is characterized by strong motion high frequency content which exceeded the OBE of the plant. The author indicated that although the earthquake is characterized by such high frequency, the energy content of the event is less than the design basis R.G. 1.60. He indicated that the earthquake has only 3.25%, 1.75% and 1.94% of the energy of R.G. 1.60 for the N-S, E-W and vertical components.

The author concluded that such events with short duration and high frequency are not expected to cause damage to well engineered structures and equipment. But, he indicated the need for new methods to be developed which should properly characterize the damage potential of such events.

The meeting ended with the recommendations that magnitude 5 should be used as a lower bound magnitude. If magnitudes less than 5 are to be used the following information should be provided:

1. The duration of these small magnitude events,

2. The response spectra of these events, and

3. These events should be disaggregated into categories with roughly similar frequency content and magnitude and a unified magnitude scale should be given.

B. <u>Lawrence Berkely Laboratory visit</u>:

The purpose of my visit was to discuss with the University of California staff the geophysical activities which they will be conducting at Yucca Mountain. I had the chance to talk with Prof. T. V. McEvilly, the director of the LBL, about the different geophysical programs they are conducting in California and Nevada.

One of the programs they are planning to implement at Yucca Mountain is the fracture detection and characterization using shear wave tomography VSP. This technique has been successfully used in geothermal environments.

The idea behind the technique is to identify the anisotropy in shear wave propagation observed in the far offset VSP data which can be correlated to the nature and distribution of fractures in the rock mass. Also, we discussed processed seismic reflection lines which clearly identified detachment faulting in California. In Yucca Mountain we have similar geological features which may be present and may be identified using the same technique.

C. <u>Chevron Oil Company visit</u>:

I visited the Western Region Exploration Department of Chevron in San Ramon, California. The purpose of the visit was to discuss with the staff the seismic reflection activities Chevron is conducting in the Hanford area of Washington. I had the opportunity to examine two sets of seismic reflection data. The first set of data identified the reflection from the top and bottom of the basalt. The estimated thickness of the basalt from the reflection data is supported by magnetotelluric measurements. They other set of data was preliminarily processed and did not clearly identify the reflection signal from the top of the basalt. The staff indicated that more processing and state-of-the-art static correction may be needed before any reflection can be seen in the section. Chevron's staff indicated that they will be willing to discuss the status of this line around March 1987. From my conversation with the staff I got the impression that unless a large source of energy is used and a well designed experiment is carried out it will be hard to obtain reliable reflection data in the Hanford area.

D. <u>USGS, Mento Park visit</u>:

I visited the USGS office to discuss with the staff the final interpretation of the long refraction line shot at BWIP and future geophysical work at Yucca Mountain.

This long refraction line which is 260 km-long trends approximately N 50° E. The interpretation of the data indicates the upper to mid crustal layer has a velocity ranging from 5.0 to 6.8 km/sec, the lower crustal velocity is 7.5 km/sec. The upper crust which consists of the Columbia River Basalt and underlying sediments range in thickness from 5-12 km.

The Columbia River Basalt varies in thickness and ranges from 3 to 6 km, and has its maximum thickness near the center of the Columbia Plateau. This basalt formation is interbeded by low velocity layers. Also the staff indicated that continental rifting beneath the Columbia Plateau may have taken place during the Eocene period.

Informally, I discussed with the staff the interpretation of the seismic and gravity studies west of Yucca Mountain. The interpretation from the refraction data indicates that the volcanic rocks have a maximum thickness of about 3200 m in Crater Flat. On the east side of Bare Mountain the staff identified a fault which exposed Paleozoic rocks into Crater Flat. Also I had the opportunity to discuss the future plans regarding seismic reflection and refraction surveys at Yucca Mountain. I examined a map which indicated where a test survey will be conducted. If the outcome of the test survey is successful a long refraction-reflection survey will be conducted in the the Yucca Mountain area. The comment I have regarding the test survey area is that it is located about 20 miles south from the Yucca Mountain. I discussed with the staff the possibility of conducting the test closer to Yucca Mountain area.

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Table 1

Results of Seismic Hazard Calculations - Point Source Example[1]

Case	Magnitude Limits Lower	Upper	b-Value	Peak Ground Acceleration (g) 0.05	0.10	0.20	0.30	0.50
1	3.5	6.5	0.90	1.56-3	4.77-4	1.28-4	5.52-5	1.64-5
2	5.0	6.5	0.90	2.84-4	2.12-4	1.00-4	5.02-5	1.60-5
3	3.5	6.5	1.30	1.05-3	2.13-4	3.54-5	1.18-5	2.71-6
4	5.0	6.5	1.30	7.29-5	5.15-5	2.12-5	9.46-6	2.55-6

1 Rate of earthquake occurrences for events of 3.5 and greater was set to the same value for both b-value cases.

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DATE: 87/02/ FEB 20 1987

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