# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

## TRIP REPORT

**SUBJECT:** Earthquake Induced Ground Motions
ASCE Continuing Education Seminar
Charge Number 20.01402.158

**DATE/PLACE:** May 17 and 18, 2001
Seattle, Washington

**AUTHOR:** A. Ghosh

**DISTRIBUTION:**

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**PERSONS PRESENT:** This continuing education seminar was attended by 22 people with approximately 40 percent from Seattle and nearby areas.

**BACKGROUND AND PURPOSE OF TRIP:**

The instructor for the seminar was Dr. Praveen K. Malhotra of Factory Mutual Research (FM Global affiliate) of Norwood, MA. The purpose of attending this professional development seminar is to gain basic understanding of the earthquake induced ground motions and design and analysis methods to estimate the response of a structure subjected to an earthquake.

**SUMMARY OF PERTINENT POINTS:**

This seminar was divided into eight sessions. Each session was devoted to one or more broad topics. A brief discussion of each session is given below. A copy of the outline of this seminar is provided in Appendix A.

Session 1: Basic Engineering Seismology

This session covered the basic information on seismology, e.g., structure of the earth, basic plate tectonics, different fault types, earthquake parameters (hypocenter, epicenter, etc.), characteristics of different waves, differences between far-field and near-field records, and different earthquake magnitude scales.

Session 2: Characteristics of Ground Motion

Mainly strong-motion earthquake ground motion was discussed in this session, because engineering applications primarily deal with the strong-motion data. Processing of strong-motion records along with the subjective judgement used in the processing were discussed. Ground motion can be described by amplitude, frequency content, and duration. Development of ground velocity and ground displacement records from the ground acceleration data were also discussed. Ground acceleration records are mostly dominated by the high-frequency part of the motion whereas ground displacement records are mainly controlled by the low-frequency part. Response of very stiff systems (e.g., one or two story buildings) is controlled by peak ground acceleration (PGA). Response of most structures, such as medium to high-rise buildings, bridges, and baseisolated buildings, is controlled by peak ground velocity (PGV). Response of very flexible structures, such as suspension bridges, very tall buildings, and sloshing of liquids in broad tanks, is controlled by peak ground displacement (PGD). The PGA is most accurately measured by the accelerometers while PGD is least accurately estimated from strong-motion earthquake records. Frequency content of ground motion is important because structures respond differently under input motion with different frequencies. Larger earthquakes produce greater low-frequency waves and, consequently, larger ground displacements. Accelerations attenuate faster than velocities which, in turn, decay faster than displacements because accelerations are controlled by high frequency (short wave length) waves that scatter more easily than low frequency (long wave length) waves. As the duration of shaking increases, the number of stress cycles experienced by the structure increases. Therefore, damage to a structure or liquefaction of soil is greatly influenced by the duration of the ground motion.

Session 3: Response Spectrum

Structures and soil deposits can be represented by one or more single-degree of freedom systems. Damping accounts for the loss or dissipation of energy of the structure. Typical damping ratios are 2 percent for steel buildings, 5 percent for concrete buildings and bridges, 20 percent for modern buildings with dampers, and 20 percent for soil deposits. Effect of damping is not generally significant for very rigid or stiff and very flexible systems. Effect of damping is most pronounced for structures with intermediate stiffness. The response spectrum indicates the relative motion of the mass of structure with respect to the foundation motion. Width of various regions of a response spectrum changes from one ground motion to another. The acceleration-deformation spectrum provides the design trade off between force and deformation that can be tolerated by a structure. The structure can be designed very stiff to resist a large amount of force with relatively small deformation (brittle failure). On the other hand, the structure can be designed to resist small forces at the expense of large deformation (ductile failure).

It was also noted that response of a tunnel subjected to earthquake loads is a wave propagation problem. Response spectrum method cannot be used to analyze this problem. One reason is that the mass of a tunnel, unlike the mass of a single-degree of freedom system idealized in the response spectrum method, is undefined.

Session 4: Attenuation Relationships

Due to spreading and loss of energy, earthquake motion (such as, PGA, PGV, PGD, spectral values, and bracketed duration) decreases with increasing distance from the source. Several measures of distance commonly used were discussed. Attenuation relationships for both soil and rock sites are developed by regression analysis of recorded ground motion data to express ground motion parameters (PGA, PGV, spectral values) as functions of magnitude, distance, rupture mechanisms, soil conditions, etc. Spectral values at longer periods (> 2 s) are required for designing very flexible structures and are sensitive to ground displacements. They are difficult to obtain due to low signal-to-noise ratio at longer periods and inability to recover permanent ground displacements from strong-motion records.

Session 5: Deterministic and Probabilistic Seismic Hazard Analyses

Deterministic Seismic Hazard Analysis (DSHA) provides an estimate of worst-case ground motions for a site. Earthquake potential for each identified source is required. Estimates of rupture length, rupture area, and fault displacement can be used to determine the earthquake potential of a given source. Usually the closest distance between the source and the site is used. Attenuation relations suitable for the site are selected. From this analysis, the controlling earthquake(s) (i.e., the earthquake expected to produce the strongest level of shaking at the site) with associated ground shaking parameters (spectral values and duration) are estimated. However, the DSHA provides no information on the likelihood of occurrence of the controlling earthquake or the level of ground motion that may be expected in a given time period.

Probabilistic Seismic Hazard Analysis (PSHA) provides a more complete information of the seismic hazard at a site from various earthquake sources by addressing uncertainties in size, distance, rate of occurrence, and attenuation relationships. Smaller earthquakes from a given source are more frequent than larger earthquakes. The recurrence law can be applied to a region or a source. In PSHA, earthquake sources are identified along with the probability distribution of distance from the source to the site. Recurrence relationship for each seismic zone and likelihood of earthquakes of different magnitudes are established. The suitable attenuation relationships are selected along with the associated uncertainties. Based on the information, ground motion parameters with a certain probability of exceedance within a specified time period that is, the Seismic Hazard Curve, is estimated. The Uniform Hazard Response Spectrum represents aggregate effects of seismic hazard from several different sources and may not correspond to anyone specific event. Different segments of a uniform hazard spectrum are controlled by different seismic events. It has the same probability of exceedance for all natural periods. It can be developed from ground motion parameters. Spectral shapes are different in West Coast and in East Coast due to differences in attenuation relationships. Strong-motion duration can be estimated from the magnitude and distance of seismic sources controlling the hazard at the site. Hazard de-aggregation can be used to determine the controlling earthquake(s).

Session 6: Spectrum-Compatible Ground Motion Histories

Although response spectrum method is sufficient for most code-based designs, histories of ground motion may be required for nonlinear analysis of structures especially for complex structures, and to analyze liquefaction potential, slope stability, and local site effects. Ground motion time histories should be consistent with the target response spectrum with duration appropriate for the sources affecting the site. If possible, recorded time histories with little or no modification should be used. Previously recorded ground motions can be scaled and stretched to achieve compatibility with a site-specific design spectrum. Amplitude scaling by a factor $\alpha$ should be limited to $0.25 < \alpha < 4$. PGV, PGV, and PGD change by the factor $\alpha$ along with change in bracketed duration. On the other hand, stretching the time scale of the acceleration history by a factor $\beta$ should be limited to $0.75 < \beta < 1.25$ and should not be used to change the duration alone. Although PGA remains unaffected by stretching, PGV and bracketed duration change by $\beta$, and PGD changes by $\beta^2$. It is better to match some records to the acceleration- and velocity-sensitive regions and other records to the velocity- and displacement-sensitive regions. For time histories at other orthogonal directions, it is recommended that the stretching factor should be kept same as that of the first direction and the scaling factor should be selected to match the smooth spectrum of the component with the design spectrum at the effective period of the system. Additionally, synthetic time histories may be developed from recorded motion to achieve a closer match with the design spectrum using computer programs.

Session 7: Effects of Local Soil Conditions

A few hundred feet of soil can change the characteristics of seismic motions more than thousands of feet of travel of the seismic waves through the rock. Soils can be treated as liner-elastic for only very low-level of ground shaking. The frequency-domain analysis can be only used for liner systems to estimate the motion at the soil (free) surface from the input ground motion at the bedrock. The soil mass acts as a filter that modifies the amplitude and phase characteristics of each frequency. De-amplification of the motion occurs at higher frequencies. Computer program SHAKE can be used to determine the transfer function from the bed rock to the free surface using a frequency-domain analysis. Both amplitude and duration increase at the free surface compared with the bedrock motion.

Session 8: Soil-Structure Interactions and Directivity Effects

Actual foundation motion will be different from the free surface motion due to soil-structure interaction. Higher frequencies are filtered out. Resulting motion of the foundation will have torsional and rocking components, even for purely horizontal foundation input motion. Ground accelerations are affected more by soil-structure interaction than velocities and displacements. Additionally, the response of a stiff system is more affected by the soil-structure interaction. Moreover, soil-structure interaction changes the system damping due to radiation effects and nonlinear soil behavior (hysteretic effects). Consequently, the flexibility of the system and, consequently, its natural period, increases.

Fault rupture travels at a velocity nearly same as the shear wave velocity. Sites located in the direction of fault rupture, the seismic energy arrives almost simultaneously leading to larger velocities and displacements with shorter duration. Directivity effects are more pronounced for strike-slip faulting. Higher velocities lead to a wider acceleration-sensitive region of the spectrum. Additionally, higher spectral accelerations will be developed at longer periods.

## IMPRESSION/CONCLUSIONS:

The course is quite informative and extremely useful. However, a lot of subjects were covered in two days which make it difficult to discuss some topics in sufficient details. A three-day course with more example problems would have been more effective.

## PROBLEMS ENCOUNTERED:

None

## PENDING ACTIONS:

None

## SIGNATURES:

A Ghosh
Amitava Ghosh
Principal Engineer

May 29, 2001
Date

**CONCURRENCE SIGNATURES:**

for A.H. Chowdhury
Manager, MGFE Element

5/30/2001
Date

Budhi Sagar
Technical Director

5/30/2001
Date

**Appendix A**

*Outline of the Seminar on*

# Earthquake Induced Ground Motions