Consideration of Near-Field Earthquakes for Design of Nuclear Power Plants in Canada

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Abstract
The potential for damage to Nuclear and other installations due to near-field earthquake events has been of interest to the designers and the licensing authorities. It has been argued that in spite of large acceleration peaks, the damage potential of near-field earthquakes is limited compared with earthquakes generated at far distances (far-field). The present paper examines the characteristics of near-field ground motions presently available. It attempts to identify the important parameters that influence the seismic response of structures and components. The potential for damage to Nuclear facilities due to near-field earthquakes is also assessed. It is shown that because of their characteristics, these earthquakes do not contribute to the seismic response and are not of concern for engineering design. The need for additional research and investigation in this area is addressed.

1.0 Introduction
Most of the strong motion earthquakes recorded in the past were at locations far from the source. These earthquakes are referred to as far-field earthquakes. The nature and characteristics of these earthquake motions have been investigated in detail. Only recently, a small number of strong motion data for locations close to the source became available. These earthquakes were recorded within 10 km from the source and are referred to as near-field earthquakes. Acquisition of near-field earthquake data was facilitated by the installation of seismographic networks close to potential sources in the U.S.A, Canada and other parts of the world. The earthquake records so obtained possess characteristics that require added attention. The present paper examines the characteristics of near-field earthquake records in relation to their impact on the design of nuclear power plants.

2.0 Near-field Earthquake Records
Difficulties are experienced in acquiring near-field ground motion data because of the following reasons:
(a) Seismographic instruments are not always located close to the earthquake source.
(b) Since an earthquake cannot be generated it has to occur in areas where instrument
have been installed. The occurrence of an earthquake is an unusual event.

(c) Commonly, the installed instruments are not suitable for signals from near-field earthquakes. Lack of sensitivity at high frequencies, calibration problems and malfunctioning of instruments can limit confidence in the data recording. Consequently, there is only a limited number of documented near-field strong motion earthquake data available throughout the world. A few examples of these records, together with magnitude, distance and peak acceleration, are given in Table-I. It is noted from the table that the peak acceleration levels exhibit a wide scatter of values. This scatter has caused considerable difficulty in defining reliable attenuation laws.

3.0 Characteristics of Near-Field Earthquakes

Unlike earthquake shocks generated at larger distances, near-field earthquake records possess certain distinguishable characteristics relating to frequency content, shock duration and peak accelerations. Although these characteristics can vary somewhat from one earthquake to another, some common features are being noted as described below:

Frequency Content

The near-field earthquake records show a relatively larger energy content in the high frequency zones. A study of the Fourier amplitude spectrum of near-field records shows that relatively large peaks are located between 10 Hz and 100 Hz. Whereas, for the far-field earthquakes, there is very little or no energy at frequencies above 30 Hz.

This is due to the fact that the high frequency motions that originate at the source attenuate more rapidly than the low frequency motions. Consequently, at shorter distances, away from the source, the ground motion is dominated by the high frequency motions. Whereas, at larger distances, away from the source, the high frequencies motions are being attenuated. As a result, the motions contain little or no frequencies exceeding 30 Hz.

Shock Duration

The duration of shocks for the near-field earthquakes are short compared to the far-field earthquakes. The duration of the predominant ground motions for this far-field earthquake is typically 15 to 30 seconds. For near-field earthquakes, the duration is considerably shorter. The duration of the predominant motion is as low as 2 seconds for some near-field records. The time-history plot of an example near-field earthquake is shown in Figure 1. This was obtained during the Fairfield California earthquake of 1966 at Cholame Shandon, record No.5, in the N-E direction. This earthquake has been documented in EERL report [1]. It is noted from the time-history plots that the predominant motion occurred between 5 to 10 seconds. Beyond 10 seconds, the motion is reduced considerably so as to be of little significance for engineering purposes.

Peak Acceleration

Near-field earthquake records are characterized by large acceleration peaks. The records normally show a limited number of high acceleration spikes preceded or followed by a larger number of smaller sustained peaks. In the case of the
Parkfield earthquake record, shown in Fig.1, only one peak reaches the maximum acceleration of 0.43 g. Other sustained peaks are lower than 0.24 g.

These characteristics, namely the frequency content, duration and peak acceleration values, which influence the response of structures and systems are discussed in the next section of this paper.

4.0 Seismic Response due to Near-field Earthquakes

For the design of nuclear power plants in Canada potentially large earthquake events originating far away from the site are considered. In many situations, the possibility of a smaller earthquake event (Magnitude 4 to 5) occurring at a shorter distance from the site is postulated. It is of interest to know the response of the nuclear power plant structures and systems due to such near-field earthquakes. The seismic responses due to a near-field earthquake are governed by the following phenomena:

Blast Effect

The shock type motions for near-field earthquakes are similar in nature to ground motions generated by underground explosions. The ground motions due to such blasts are dominated by high frequencies and persist for short periods of time only. Tests on full-scale structures due to blast effects have been reported by Smith et al. [2]. It has been observed that the severity of structural responses due to the blast effects are several orders of magnitude lower than the responses due to earthquakes. Bleiweis et al. [3] reported blast tests on an Experimental Gas Cooled Reactor at Oak-Ridge, Tennessee. The peak free field ground acceleration was as high as 1 g, while that measured in the reactor building was 0.5 g at 60 Hz-100 Hz (rigid body) and only 0.05 g under free natural vibration at about 7.5 Hz. It is this free vibration response that is of engineering significance.

Travelling Wave Effect

When subjected to earthquake ground motions, heavy and large structures tend to respond differently than small recording stations. Due to the travelling wave effects, structures with larger foundation size filter out the high frequency motion. This was demonstrated during 1971 San Fernando earthquake for the Hollywood Storage Building and the adjacent P.E. lot, for which recorded earthquake motions are available. A comparison of the 5 percent damped response spectrum at these two locations is shown in Fig.2. A substantial reduction in the response spectrum at high frequencies is noted for the Hollywood Storage Building basement as compared with the response at the P.E. lot (free-field).

This difference has been explained on the basis of the travelling wave effect by Morgan et al. [4]. This occurs due to the delay in arrival of a seismic wave travelling from one part of the foundation slab to the other. As a result, the motion is averaged out over the total area of the foundation slab. This averaging process filters out the high frequencies, resulting in a reduction of the effective responses. The extent of the reduction is dependent on a parameter defined by the width of the foundation divided by the wave velocity. The travelling wave effect also generates a torsional input to the structure. For symmetrical structures with no translational-to-torsional coupling, the effect of torsional input is

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small. Therefore, nuclear power plant structures with large foundation slabs can show considerable reduction in effective responses due to travelling waves. For a near-field earthquake with relatively large high frequency contents, the effect of filtration can be very significant.

**Effect of Nonlinearities**

During actual earthquake motions, soil behaves in a non-linear manner. A simplified analytical method which assumes that the soil behaves in a linear elastic manner produces conservative estimates of the seismic responses. Studies have been performed by Lee and Charman [5], including the hysteresis behaviour of soil and the travelling wave effects. It was shown that the nonlinear effect can account for a considerable reduction of responses. Other nonlinear effects, such as uplift and slipping of the foundation slab, can also cause a reduction in effective seismic input. Investigation by Wolf [6] shows that substantial reduction in response spectra at high frequencies can be obtained due to these effects at high seismic input levels.

5.0 Effective Acceleration Levels

The peak acceleration from the earthquake ground motion is an important parameter used in the design of Nuclear Power Plants. In Canada, the normalized design response spectra are given in CSA Standard CAN3-N289.3 [7]. These normalized spectra are scaled to the appropriate effective acceleration levels to be used for seismic design purposes. The peak acceleration from a near-field earthquake is not considered a good parameter to be used for scaling purposes. As stated in Section 3.0, large acceleration spikes with high frequencies for near-field records do not represent a high damage potential of the ground motion. This peak value, therefore, is not significant for design purposes. It is, therefore, necessary to define an effective acceleration level at a lower but sustained value. This effective acceleration value, instead of the peak acceleration value from a near-field earthquake, would be more suitable to be used for design purposes.

6.0 Need for Future Investigation

At present, there is only a limited number of near-field ground motions. More data are needed to understand the nature of earthquake motions generated close to the source. For this purpose, strong-motion seismographs with good high frequency recording capabilities need to be installed in seismically active areas. These data should be acquired and processed quickly for use in research. An international data bank would be ideal for that purpose.

At present, errors are introduced in the record at high frequencies due to the digitization process and base line corrections. To eliminate these errors, the digitization intervals should be refined and the routine for base line correction should be improved.

Records of responses of actual structures during earthquakes are very valuable. Attempts should be made to acquire more data from measurements at Nuclear Power Plants and other actual structures.

Further investigative work is needed to determine the seismic response of
Nuclear Power Plant structures subjected to near-field earthquakes. The effect of travelling waves with different wave types is to be studied. The influence of non-linear geometric effects (e.g. uplift and slippage) have beneficial effects on structural response. These effects need to be investigated in relation to the near-field earthquake responses and the effective acceleration levels to be used for design purposes (see Sec. 5.0).

References

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<tr>
<th>Earthquake</th>
<th>Magnitude</th>
<th>Distance (km)</th>
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<td>5.6</td>
<td>9.0</td>
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<td>6.4</td>
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<td>Gazli,U.S.S.R.,1981</td>
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FIG. 1 Parkfield California Earthquake
June 1966, Cholame Shandon
Record No. 5

FIG. 2 Response Spectrum for San Fernando Earthquake at Hollywood Storage Building