An Approach to Evaluate Effective Ground Motion for Nuclear Power Plant

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Abstract

Many past observations suggest that large peak values of recorded (or instrumented) earthquake ground motion do not always relate to damage of well designed structures. Concept of the effective peak acceleration has been introduced by several experts to define the maximum input ground motion rationally instead of instrumented peak acceleration for a design purpose. In this paper, a new approach, which is based on the *filtering effect* of embedded large rigid foundation, is introduced to estimate the effective peak acceleration. The *filtering effect* is explained by a fact that the rigid foundation behaves as if it constrains spatial variation of both amplitudes and phases of the impinging ground excitation. Many accelerograms recorded at different major earthquakes in Japan and the United States were processed, and resulting effective peak values were examined. Besides, relating current researches and a design approach to define the input ground motion, employed in Japanese nuclear power industries, are briefly described.

1. Introduction

One of current issues for seismic design of nuclear power plant is how to estimate the reasonable input ground motion as an design earthquake. There have known been well that destructiveness of earthquake ground motion depends on both amplitude and duration of the motion. Amplitude of ground motion is generally represented by a peak value of the motion. However many past observations suggest that large peak values of recorded (or instrumented) earthquake ground motion do not always relate to damages of well designed structure. Concept of the effective peak acceleration (EPA) has been introduced by several experts to define a maximum input ground motion rationally instead of instrumented peak acceleration for a design purpose, especially in the United States.[1].

While in Japan, there have been few researches on this specific topic.[2], [3] However, many relating researches have been conducted for many years and a different design approach was introduced to define the rational ground motion, i.e. the peak ground velocity instead of the peak ground acceleration.[4], [5]

In this paper, a different approach, which is based on the *filtering effect* of an embedded large rigid foundation, is introduced to estimate the effective ground motion. The *filtering effect* is explained by a fact that the rigid foundation behaves as if it constrains spatial variation of both amplitudes and phases of the impinging ground excitation.[6], [7] Many records have shown that earthquake ground motions measured at large rigid foundations have less intensity in high frequency components than those at near free-field.[8], [9], [10]

2. Current Status

Although there have occurred several destructive earthquakes with many smaller ones and many strong motion records have been obtained for last two decades in Japan, there have been only a few records, which have unusually high spikes. This is considered probably due to following reasons :

1) Most large destructive earthquakes have occurred in the oceans not very close to the land recently, such as Tokachi-oki Earthquake 1968 (M=7.9), Miyagiken-oki Earthquake 1978 (M=7.4) and Nihonkai-chubu Earthquake 1983 (M=7.7). Whereas there have been several island earthquakes, which caused relatively minor damages, however, they have occurred in remote mountain areas, such as Ohitaken-chubu Earthquake 1975 (M=6.4) and most recent Naganoken-seibu Earthquake 1984 (M=6.9). Therefore nearest stations of strong motion recorder located not very close to the sources. Besides many sources of those earthquakes placed generally in deeper areas than those of west coast of the United States.
2) Geological conditions also influence on the earthquake ground motion. Most of Japanese land are covered with deep alluvial deposits except mountain areas, and many strong motion accelerographs locate on the deposits. High spikes of earthquake excitation tend to diminish as they penetrate through the deposits.
3) There have been installed many strong motion accelerographs (SMAC) all over Japan, however, frequency characteristics of those accelerographs differ considerably from those of the SMA type recorders employed in the United States. This is illustrated in Fig. 1, which shows frequency characteristics of the most widely used SMAC-B2 and SMAC-B types, shared more than 60 percent of total accelerograms, along with the SMA-1 type for comparison. From the figure, acceleration amplitudes measured by the SMAC-B2 and the SMAC-B drop substantially on high frequency range of greater than 7 Hz and 10 Hz, respectively, while those by the SMA-1 drop on much higher frequency range. Therefore high frequency spikes appear less on the SMAC-B2 or -B records than on the SMA-1 records.

Thus there have been only a few researches on this specific subject of the effective ground motion vs. the recorded ground motion. A recent research done by Watabe and Tohdo[2)] proposed an approach to evaluate the effective peak acceleration from the recorded accelerogram based on the spectrum intensity (SI) introduced by Housner. In the method, first, estimate the cut-off level of accelerogram (A_t), above which the recorded accelerogram is clipped, so that the resulting clipped accelerogram produces 90 percent of the spectrum intensity of the original accelerogram. Then evaluate the EPA from an equation : $EPA = A_t\,(100/90)$.

An another research done by Kameda and Ohsawa[3)] introduced a method, which gave emphases not only to the maximum response of a system, but also to the duration of the input ground motion, since damages of structure depend on these two factors. Their proposed parameter is called a "Equivalent Ground Acceleration (A_e)", instead of the EPA, which is evaluated by a peak ground acceleration (A_p) and a reduction factor (C_e) as $A_e = C_e \cdot A_p$.

Whereas, many other relating researches have also been conducted for years, since the seismic safety of structures depends on the reasonable evaluation of input ground motion for design.

A recent trend of rational design practice performed in Japan is an increasing use of the peak ground velocity instead of introducing the effective peak ground acceleration to define input ground motion . This is mainly due to a following fact that the velocity ground motion, which is calculated by integrating the recorded accelerogram, and it's peak value are considered to be more closely correlated and stable indicators to show damage potential of input ground motion than the peak value of the recorded accelerogram, which sometimes has unusually high spikes.[5)]

In *the Guideline for Evaluation of Basic Design Earthquake Ground Motion* [4] published by Atomic Energy Commission of Japan, standard design response spectra are proposed based on accumulated informations of accelerograms obtained on rock sites to define the input ground motion for nuclear power facilities.[5], [11] Shapes of response spectra depend on magnitudes and epicentral distances of earthquakes and control points of the spectra are described by the velocity response values and the corresponding period. And the peak velocity amplitude, instead of the effective peak acceleration, of the design ground motion is evaluated at the plant site by using Kanai's empirical equation, which depends on the magnitude of earthquake and the focal distance.

A similar practice of using the peak ground velocity is also allowed being applied to define design amplitude of the input ground motion for other structures such as high-rised buildings.

3. Evaluation of EPA Based on Filtering Effect of Embedded Foundation

Most researches on the EPA have been concentrated mainly on the structural response and the damage potential of earthquake ground motion. Authors agree with the basic ideas behind those researches. However in this paper a different approach is employed to evaluate another engineering meaning of the earthquake ground motion: the input motion is affected by the size, the rigidity and the embedment of foundation and it differs from the free-field ground motion.

The approach is based on the *filtering effect* of foundation. Several studies on earthquake records have shown that earthquake motions measured on large rigid foundations have less intensity in higher frequency components than those on near free-fields[6],[8],[9]. This phenomenon is called the *filtering effect* (or kinematic interaction) of the rigid foundation, which behaves as if it constrains spatial variation on both amplitudes and phases of the impinging ground excitation. Frequency components of the input motion become smaller, when their wave lengths are relatively short compared with dimension of the foundation, therefore the rigid foundation behaves as a kind of low-pass filter for the free-field ground motion. Consequently, large high frequency components appeared on recorded accelerograms are expected to diminish substantially, and peak values of the effective foundation input motion would be smaller than those of the free-field motion.

A mathematical model of seismic response analysis of structure is illustrated on Fig. 2 by two calculation steps[7]. The first step is an estimation of the foundation input motion from the free-field ground motion by applying the proposed low-pass filter, which represents the *filtering effect* of foundation. The second step is an earthqauke response analysis of the lumped mass system, which includes the dynamic interaction effects, by using the foundation input motion as an input load. Thus the foundation input motion can be considered as an effective input motion to calculate the structural response. In this paper, the foundation input motion are estimated for an embedded foundation of large nuclear power plant by various earthquake records and their peak values are compared with original peak values.

The proposed low-pass filter considered in the analysis represents the S-H type of earthquake wave penetrating into the embedded foundation straight upward as shown in Fig.3, even though other types of wave and foundation exist. The filter is a partially revised form of Ishii's proposed filter as,[10]

$$H(f) = \sin\{\pi(f/f_o)\}/\{\pi(f/f_o)\} \qquad \cdots\; 0 \leqq f \leqq 0.603\,f_o \qquad (1)$$

$$= 0.5 \qquad \cdots\; 0.603\,f_o \leqq f$$

$$f_o = Vs/4H \qquad (2)$$

where H is a depth of embedment of the foundation and Vs is a shear wave velocity of surrounding soil. In the analyses, $H=20\ m$ and $Vs=500\ m/sec.$ are assumed as a standard large plant model, and then $f_0=6.25\ Hz.$ Frequency characteristics of the filter is shown in Fig.4.

Earthquake records employed in the analysis consists of fifty-nine accelerograms observed at thirteen different earthquakes, such as El Centro 1940, Tokachi-oki 1965, Imperial Valley 1979, and most recent Nihonkai-chubu 1983, as shown in Table 1.

Results of calculation are illustrated on Fig. 5. On the figure, amplitude ratios of peak values between the filtered accelerograms(EPA) and the original accelerograms are shown for a distance parameter between the source of earthquake and the observation station with four different levels of earthquake magnitude. As shown, amplitude ratios of peak value scatter on the range of greater than 0.5, since amplitude ratios of the employed filter is greater than 0.5. Though there are no clear-cut phenomena, it seems that peak amplitudes tend to reduce less as the magnitude of earthquake becomes larger, while they tend to reduce more as the distance becomes longer. And following few facts can be suggested from the results :

(1) Amplitude ratios of peak value scatter around 0.8, therefore, the effective foundation input motion of large nuclear power plant can be reduced to about 80 percent of the free-field motion.

(2) Far field earthquake ground motions employed in the analysis have relatively high frequency components compared with near field motions, probably due to local ground conditions of the observation site. This is well illustrated on earthquake records of Tokachi-oki and Imperial Valley, as shown in Fig. 6. This does not imply a generally recognized fact that near field ground motions have greater high frequency components than far field ground motions.

Acknowledgement

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Table-1. List of Earthquakes

Name	Date	M	No 1)
El Centro	1940/5/19	7.0	2
Kern County	1952/7/21	7.4	2
Golden Gate	1957/3/22	5.3	2
Kushiro	1962/4/23	7.0	2
Matsushiro	1966/4 & 5	~5.0	4
Park Field	1966/6/28	6.1	1
Tokachi-oki	1968/5/16	7.9	6
Tokachi-oki (After Shock)	1968/6/12	7.2	6
Hiroo	1970/1/21	6.7	2
San Fernando	1971/2/9	6.6	4
Imperial Valley	1979/10/15	6.5	14
Coalinga, California	1983/5/2	6.7	6
Nihonkai-chubu	1983/5/26	7 7	8

1) Number of Records

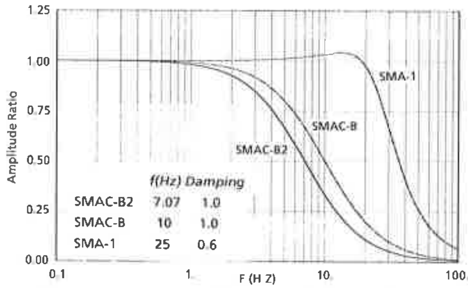


Fig. 1 Frequency Characteristics of Strong Motion Accelerographs

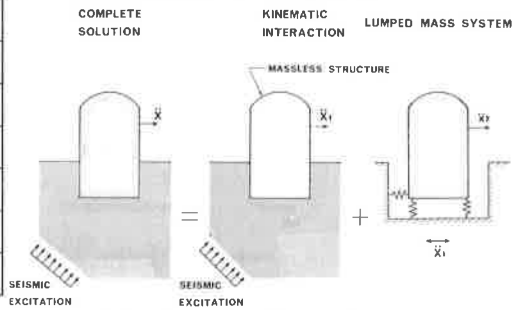


Fig. 2 Mathematical Model of Seismic Response Analysis

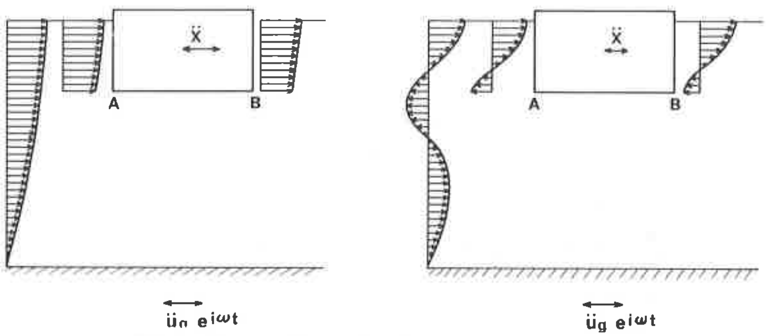


Fig. 3 Filtering Effect of Embedded Foundation

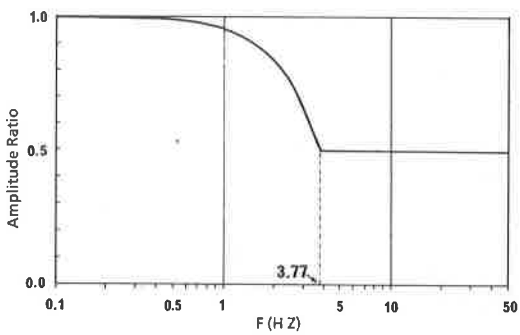


Fig. 4 Frequency Characteristics of Low-Pass Filter

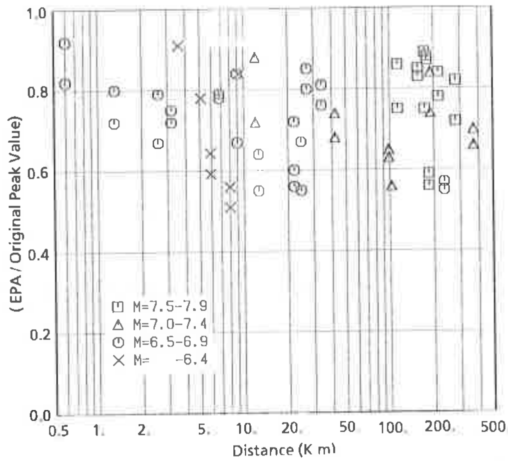
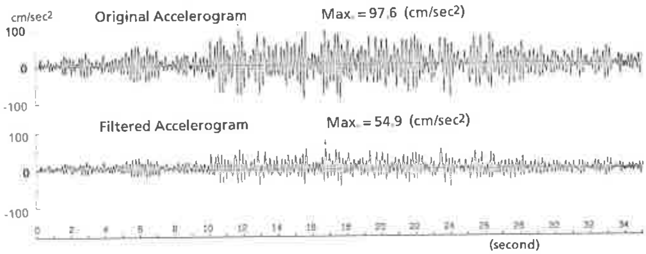
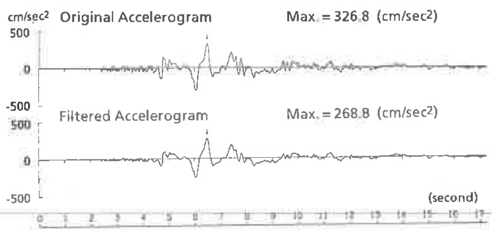


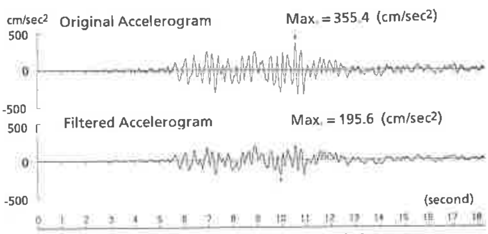
Fig. 5 Amplitude Ratios of EPA and Original Peak Value



(a) After Shock of Tokachi-oki Earthquake, June 12, 1968
(E-W Component Measured at Miyako)



(b) Imperial Valley Earthquake, October 15, 1979
(140° Component Measured at Array 7, 0.6 km from Source)



(C) Imperial Valley Earthquake, October 15, 1979
(140° Component Measured at Array 11, 12.6 km from Source)

Fig. 6 Original and Filtered Accelerograms