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Research Article

SEISMIC ANALYSIS OF REACTOR BUILDING OF A NPPBASED ON ASCE 4-98 AND RCC-G METHOD

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ABSTRACT

This paper describes the seismic analysis of reactor building of a Nuclear Power Plant including the soil structure interaction analysis for uniform soil. The soil stiffness of the soil below foundation has been computed from two standards ASCE 4-98 and RCC-G and comparison is made. Simplified lumped mass stick model for time history analysis of reactor containment building along with internal structures is made in SAP2000 advanced V 11.0.2. The time history of Kashmir Earthquake on October 8, 2005 is used as input motion. In SSI analysis, the elastic half space theory is used for calculating translational and rotational springs from both RCC-G and ASCE 4-98 Standards. Floor response spectra are generated at various floors of the reactor building using stiffness values computed from both standards and comparison is made. This analysis gives a better understanding of the differences between RCC-G and ASCE 4-98 in terms of SSI which found to be significant. It is found that the RCC-G standard gave more conservative responses so it should be given preference where the soil is sandy and uniform.

INTRODUCTION

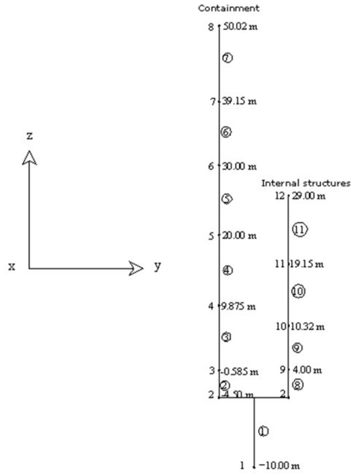
An earthquake of Magnitude 7.6 occurred on October 8, 2005 in Northwest of Pakistan which was the deadliest earthquake in the recent history of the sub-continent resulting in more than eighty thousand casualties, two hundred thousand injured, and more than four million people who have been left homeless. This has jolted all the civil engineers in Pakistan in general and strategic organizations like Pakistan Nuclear Regulatory Authority (PNRA) in particular. PNRA management decided to increase its knowledge and skills in the areas of seismic safety review and analysis and also to start research and development in this key area.

This paper is the outcome of the research in the areas of time history analysis of reactor building including the soil structure interaction effects using the two standards RCC-G [1] appendix A and ASCE 4-98 [2]. FRS developed from these two standards are enveloped for lower and upper stiffness values and compared with each other. The site has sandy soil conditions and has the seismicity potential of Safe Shutdown earthquake of 0.25g. The research in the area of soil structure interaction would be very useful in terms of finding the best standard for the site to compute the soil stiffness values which are conservative and give stringent conditions.

MATHEMATICAL MODEL

Structural Model

A simplified lumped mass stick model is made in SAP2000 advanced V 11.0.2 as shown in fig1.



- Fixed equipments
- The part of the operating load present during normal operations
- Torsion is not taken into account due to quasi-symmetry of structure.

Figure 1 Lumped Mass Stick Model of Reactor Building

The masses are taken into account and are lumped at the main floors such that a) Dead load of the concrete and steel

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structures, b) Fixed equipments, c) The part of the operating load present during normal operations, d) Torsion is not taken into account due to quasi-symmetry of structure.

Modeling of soil and soil structure Interaction

There is a narrow range of variation of dynamic parameters below the foundation base level. For the site, the following values of table 1 are taken into account:

Table 1 Soil Properties of the Site

	Site
Dynamic Shear Modulus (MPa)	600~800
Poison Ratio	0.31
Unit Weight (Kg/m^3)	1980
Internal Damping Ratio %	2

In accordance with the relatively homogeneous characteristics of the subsoil at the site, the ground is linked by using elastic half space modeling of soil with three translational springs and three rotational springs. The SAP2000 link support feature is used for modeling the soil media for these six stiffness values and their respective damping.

The interaction between buildings is not negligible, but for lumped mass stick modeling, containment building is considered as isolated.

Two methods have been adopted for the calculation of springs and their respective damping ratios:

Frequency Dependent Soil Springs using RCC-G approach

The foundations can be considered as shallow and sufficiently rigid, the ground is represented by a spring system linking the nodes representing the structure foundation to the free field reference. SSI analysis is done using impedance function as mentioned in RCCG [1]. Each spring is defined by its rigidity and its reduced damping, which depend upon the model soil structure frequency.

Calculation of Rigidity Coefficient

These are calculated for each earthquake direction, using the following expressions:

$$K_V = G\, r\, F_V \tag{1}$$

$$K_H = G\, r\, F_H \tag{2}$$

$$K_R = G\, r^3\, F_R \tag{3}$$

where

K_H = Soil translational rigidity coefficient in X and Y direction.

K_V= Soil translational rigidity coefficient in Z
K_R = Soil rotational rigidity coefficient in X, Y direction.
G = Dynamic Shear Modulus
r = Radius of foundation equivalent circle
F_V, F_H, F_R= Dimensionless coefficients, which are expressed as function of transmission coefficient by eqns. (4, 5 and 6):

$$F_V = \frac{f_{V1}}{f_{V1}^2 + f_{V2}^2} \tag{4}$$

$$F_H = \frac{f_{H1}}{f_{H1}^2 + f_{H2}^2} \tag{5}$$

$$F_R = \frac{f_{R1}}{f_{R1}^2 + f_{R2}^2} \tag{6}$$

The values of f_{v1}, f_{v2}, f_{H1}, f_{H2}, f_{R1}, f_{R2} are mentioned in tables of Ref [1] as the function of Poison Ratio and Transmission Coefficient α given in eqn. (7):

$$\alpha = \omega_i r \left(\frac{\rho}{G}\right)^{0.5} \tag{7}$$

ω_i = Fundamental ground–structure pulsation determined using preliminary modal calculation,
ρ = ground density

The transmission coefficient tables were compiled by G. DELEUZE, based on the following assumptions: a) Ground is semi-infinite, elastic, homogeneous and isotropic solid, delimited by a plane, b) Ground reaction beneath the foundation is linear, c) Geometrical damping corresponds to wave radiation through the ground.

Calculation of Reduced Damping

The reduced damping corresponds to wave radiation through the ground. For each spring, it is the sum of: a) Internal structural damping equal to 0.05 for all modes and grounds, b) Half of the geometrical damping which is calculated for each component of earthquake movement, each mode and each type of ground spring as the function of Poison Ratio and Transmission Coefficient α and expressed as eqns. (8, 9 and 10):

$$\eta_V = -\frac{f_{V2}}{2 f_{V1}} \tag{8}$$

$$\eta_H = -\frac{f_{H2}}{2 f_{H1}} \tag{9}$$

$$\eta_R = -\frac{f_{R2}}{2 f_{R1}} \tag{10}$$

Frequency Independent Soil Springs using ASCE 4-98 approach

The soil below the foundation is relatively uniform to a depth equal to the largest foundation dimension, frequency-independent soil spring and dashpot constants, as shown in table 2.

where

I_t= Polar moment of Inertia

$$B_\psi = 3(1-\nu) I_O / 8 \rho R^3$$

I_o= Total mass moment of inertia of structure and basemat about the rocking axis at the base;

Table 2 Lumped Representation of Structure-Foundation Interaction [2]

Motion	Equivalent Spring Constant	Equivalent Damping Coefficient
Horizontal	$k_X = k_Y = \frac{32(1-v)GR}{7-8v}$	$c_X = c_Y = 0.576 k_X R\sqrt{\rho / G}$
Vertical	$k_Z = \frac{4GR}{1-v}$	$c_Z = 0.85 k_Z R\sqrt{\rho / G}$
Rocking (X and Y)	$k_\psi = \frac{8GR^3}{3(1-v)}$	$c_\psi = \frac{0.30}{1+B_\psi} k_\psi R\sqrt{\rho / G}$
Torsion	$k_t = \frac{16GR^3}{3}$	$c_t = \frac{\sqrt{k_t I_t}}{1+2I_t / \rho R^3}$

Time History Input Motion

For time history analysis of NPP at site; time history of Kashmirearthquake (October 8, 2005) is used. This time history was recorded at Nilore, Islamabad with peak acceleration of 0.1122g, 0.127g and 0.147g in X, Y and Z direction respectively as shown in fig 2.

Analysis is performed for the Safe Shutdown Earthquake, hence the time histories are scaled to 0.25g in X and Y direction and 0.167g in Z direction to apply on the structural model. The generated FRS is smoothened and broadened by 15% as per Ref [3].Use of appropriate site-dependent free-field earthquake motions and selection of realistic massless springs at the base of the structure are the only modeling assumptions required to include site and foundation properties in the earthquake analysis of most structural systems [4]. Therefore site has its own statistically independent time history and massless springs to generate realistic results.

RESULTS AND DISCUSSION

Comparison of soil Stiffness values calculated from RCC-G and ASCE 4-98

The soil stiffness values calculated from the formulas given in ASCE 4-98 are average 6 % higher than from the calculated from RCC-G standard.

These differences are due to the methodology in calculating the stiffness values adopted by the standards.

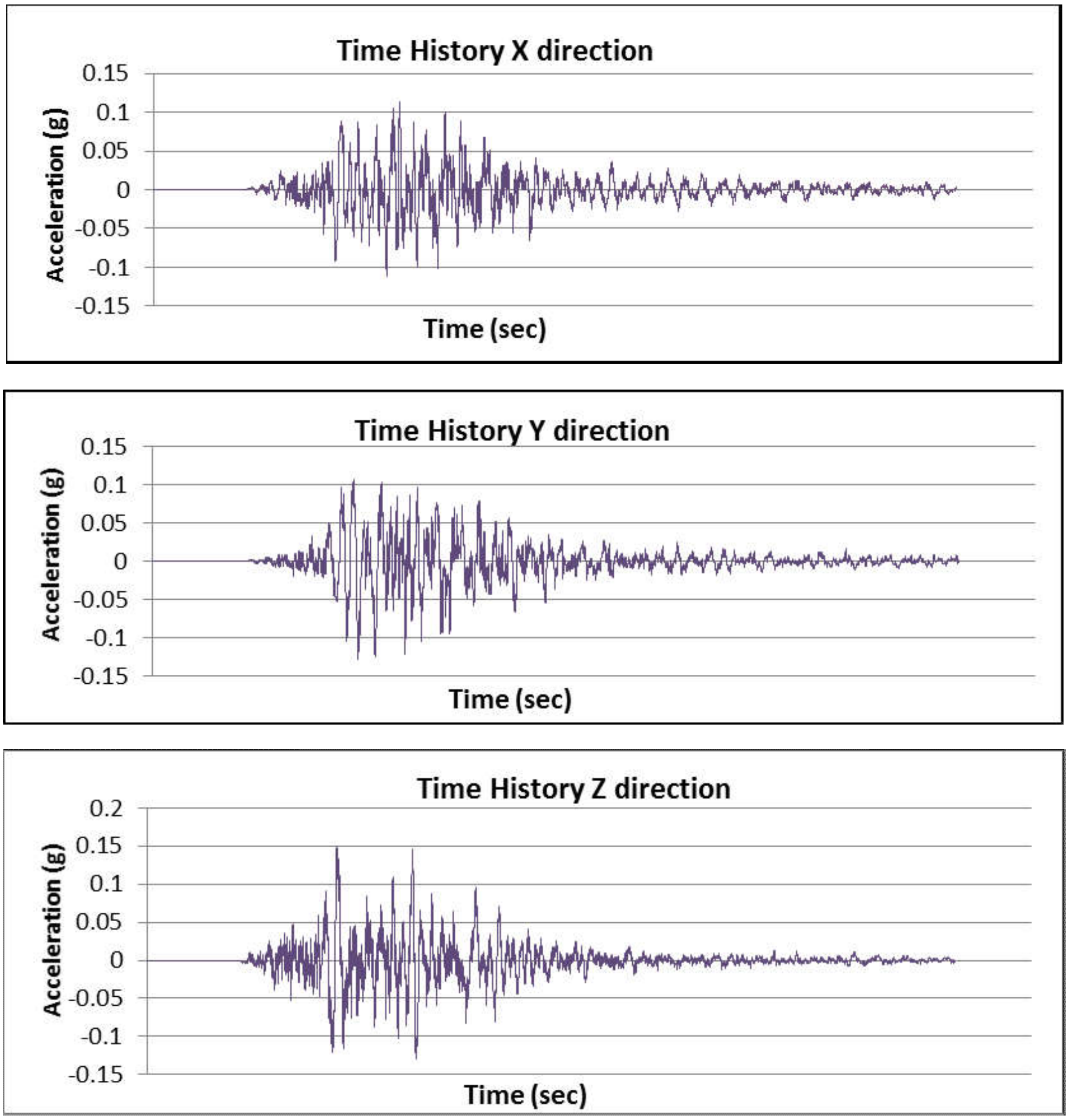

Figure 2 Time histories record

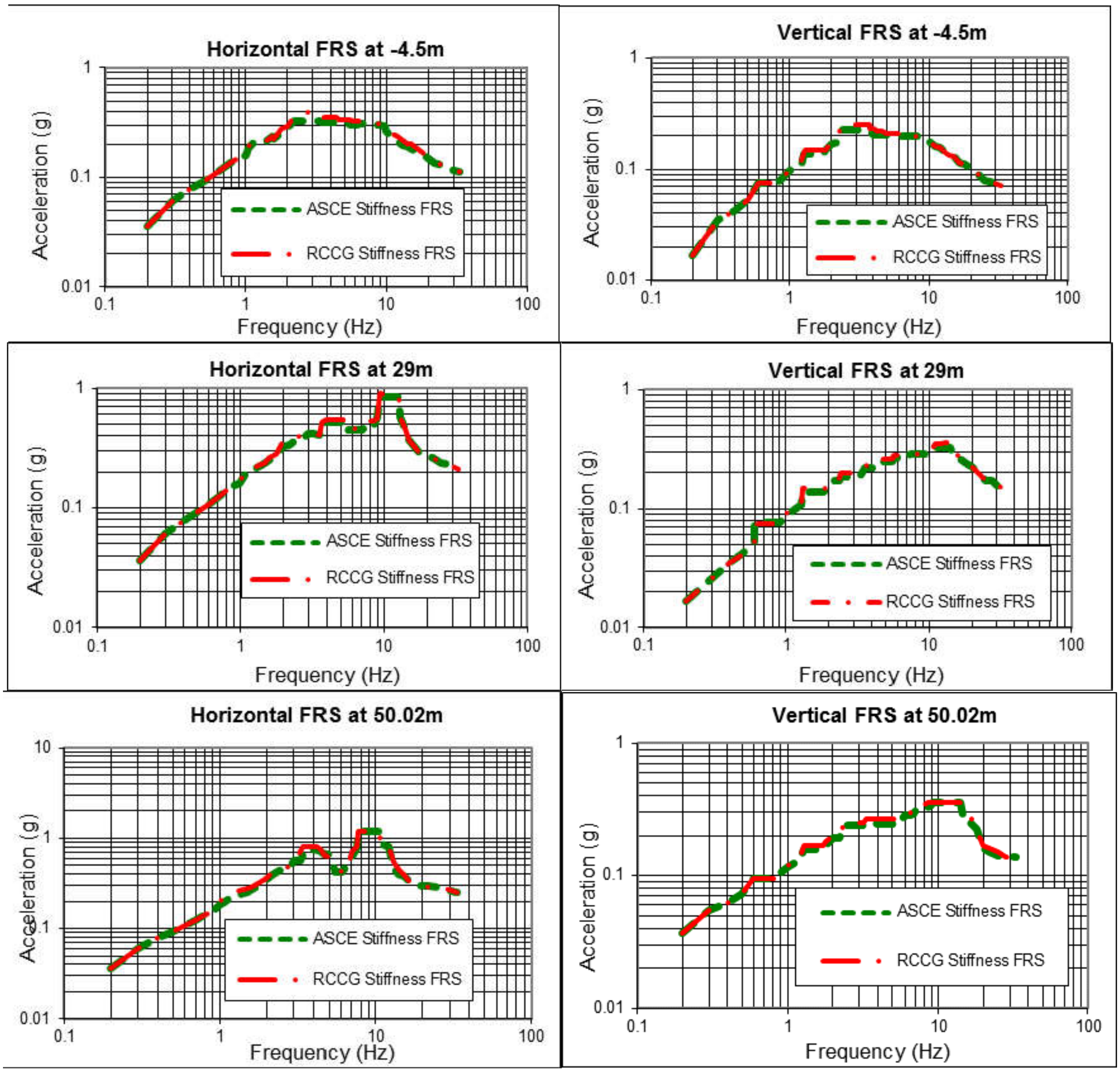

Figure 3 FRS at different heights of the structure in Horizontal and vertical direction

In RCC-G, soil stiffness is calculated by taking into account the frequency dependent characteristics; so stiffness values are more realistic as compared to frequency independent ASCE 4-98.

Comparison of Floor Response Spectra with RCC-G and ASCE 4-98

In Fig. 3, the floor response spectra (FRS) have been developed from both standards for different floors of the structure (containment and internal structures). It has been shown that FRS from RCC-G gave slightly higher values of responses as compared to ASCE 4-98 particularly near the fundamental natural frequencies between 4 to 10 Hz. It is due to the fact that soil stiffness values calculated from RCC-G are lower than the ASCE 4-98 standard. The site has sandy soil conditions and these differences are pronounced when compared to the differences in case of rocky foundations as computed [5, 6, 7, 8, 9].

CONCLUSIONS

1. The soil stiffness values using half space modeling of soil media by ASCE 4-98 standard are higher (about 6%) than the same values calculated from the RCC-G standards in case of sandy and uniform soil.
2. It has been shown that the floor response spectra (FRS) of containment of the Nuclear Power Plant (Design according to RCC-G Standard) are little higher in response than the FRS calculated from stiffness values of ASCE 4-98 standard. It is suggested that design from RCC-G would be more stringent than ASCE 4-98 and therefore it would be given preference when in case of sandy and uniform soil.

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