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Effect of poorly-compacted backfill around embedded foundations on building seismic response

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Abstract. Many building foundations are embedded, however it is not easy to compact the backfill around the foundation especially for the deeply embedded ones. The soil condition around the embedded foundation may affect the seismic response of a building due to the weak contact between the soil and the foundation. In this paper, the response accelerations in the short-period range and at the period of 1 second (in the long-period range) for a seismic design spectrum specified in the IBC design code were compared considering perfect and poor backfills to investigate the effect of backfill compaction around the embedded foundation. An in-house finite-element software (P3DASS) which has the capability of horizontal pseudo-3D seismic analysis with linear soil layers was used to perform the seismic analyses of the structure-soil system with an embedded foundation. Seismic analyses were carried out with 7 bedrock earthquake records provided by the Pacific Earthquake Engineering Research Center (PEER), scaling the peak ground accelerations to 0.1 g. The results indicate that the poor backfill is not detrimental to the seismic response of a building, if the foundation is not embedded deeply in the soft soil. However, it is necessary to perform the seismic analysis for the structure-soil system embedded deeply in the soft soil to check the seismic resonance due to the soft soil layer beneath the foundation, and to compact the backfill as well as possible.

Keywords: response acceleration; backfill; embedded foundation; finite-element software of P3DASS; structure-soil system; soft soil.

1. Introduction

Many buildings are built on embedded foundations with basement slabs rather than on surface foundations. However, the backfill around an embedded foundation is not easily compacted and loose soil is especially hard to densify for deeply embedded foundations. The state of the backfilled soil around an embedded foundation may affect the seismic response of a building due to loss of the contact between the soil and the foundation.

Researchers have studied the effects of the backfill around the foundation and the soil-structure interaction on the seismic response of a structure. Cai and Hu (2010) have examined the vertical vibration of an embedded foundation considering the perfect bond between the foundation and the soil, and Rollins *et al.* (2010) have investigated the dynamic stiffness of the pile cap with three backfill cases to evaluate the dynamic behavior. Rayhani and Naggar (2008) have performed

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centrifuge model tests to investigate the seismic response of a rigid foundation on soft clay and the effects of soil-structure interaction and foundation embedment, and Dicleli *et al.* (2005) and Zhang *et al.* (2008) have studied the effect of soil-structure interaction on the seismic performance of bridges. Also, Gazetas and Tassoulas (1987) have carried out a parametric study to estimate the horizontal stiffnesses of embedded rigid foundations considering perfect and non-uniform contacts with the surrounding soil. In this paper, a study is presented of the seismic response of a building on an embedded foundation taking into account the backfill condition and structure-soil interaction.

The site coefficients Fa and Fv are specified in the International Building Code (IBC) (2009) to represent the amplification factors of the seismic response of a structure due to the soil characteristics of the site with respect to those of a structure on rock with shear wave velocity of 1050 m/s (site class B). Site coefficients Fa and Fv are used in a seismic design spectrum of a building in the short-period range and at the period of 1 second in the long-period range. The site coefficient Fa is estimated by averaging the response spectrum from 0.1 second to 0.5 second and dividing the average by the averaged response of a structure built on rock. Similarly the site coefficient Fv is also estimated by averaging the response between 0.4 second and 2 second as described by Borcherdt (1994).

For the purposes of the study reported in this paper, seismic analyses were performed for a structure-soil system with perfect or poor soil compaction around the embedded foundation to take into account the effect of the backfill. Site-specific analyses were carried out with the specialized in-house software developed for the peudo-3D finite-element seismic analysis using weak and moderate earthquake records. The building was modeled as a single degree of freedom (SDOF) system built on the foundation embedded in the 30 m soil layer proposed by Dobry *et al.* (2000), and the radius and the embedment depth (E) of an equivalent circular foundation and the shear-wave velocity of the soil were taken as variables for the study.

2. Model of a structure-foundation-soil system

The finite-element software for Pseudo 3-Dimensional Dynamic Analysis of Structure-Soil System (P3DASS) used in this study was developed to perform the horizontal seismic analysis of a structure built on a surface or embedded foundation in linear or nonlinear soil by Kim (1987, 2004) using the cylindrical coordination system. P3DASS can solve for multiple seismic responses of a SDOF building system built on layered soil in a single run. The soil around the foundation is assumed to be layered on bedrock or relatively stiffer soil as shown in Fig. 1. The soil layer can be divided into sub-layers for the finite-element analysis, and partitioned into the cylindrical core region under the equivalent circular foundation and the far field outside of the core. An arbitrary shaped foundation can be modeled as an equivalent circular one having the same area or moment of inertia (aspect ratio up to 4 is acceptable for a rectangular shaped foundation; Roesset (1980)). The validity of an equivalent circular foundation in the seismic analysis was verified in references of Kausel (1974), Roesset (1980), Gatetas and Tassoulas (1987) and Kim (1987). A mat foundation and the soil under the foundation in the core region are subdivided into toroidal finite-elements considering the horizontal and vertical displacements around the circumference of a cylinder. The far field is represented by the consistent transmitting boundary matrix developed by Kausel (1974) reproducing an extension of the finite-element mesh from the foundation boundary to infinity. The consistent transmitting boundary can be placed at the edge of a circular foundation for the linear

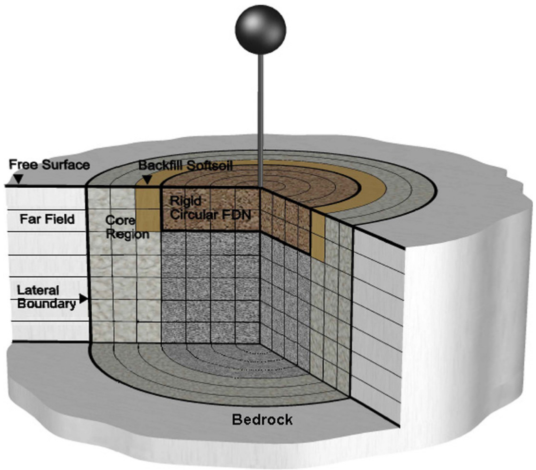

Fig. 1 Pseudo-3D finite-element model

Table 1 Seven weak or moderate earthquake records

No.	EQ. Name		Component		*Max. Acc.* (m/s^2)	Natural period (sec)	Magni-tude	Duration (sec)	Epicenter distance (km)	Site class
1	San Francisco	1957	Golden Gate Park	GGP100	1.098	0.15	5.3	39.72	11.1	B
2	San Fernando	1971	Lake Hughes #9	L09291	1.314	0.10	6.6	34.89	23.1	
3	Coyote Lake	1979	Giroy Valley #1	G01230-2	1.010	0.10	5.7	36.83	12.6	
4	N. Palm Springs	1986	Silent Valley-Poppet F.	SIL000-2	1.363	0.10	6.0	24.00	27.7	
5	Whittier Narrows	1987	Mt. Wilson-CIT	B-MTW000	1.549	0.15	5.3	22.00	18.7	
6	Northridge	1994	Lake Hughes #9	L09000	1.618	0.20	6.7	40.00	44.8	
7			Mt. Wilson-CIT	MTW090	1.314	0.20				

elastic analysis according to Kim and Roesset (2004).

In this study, the 30 m thick (H) soil layer lying on stiff bedrock was considered assuming that it is horizontally layered, homogeneous, elastic, viscous and isotropic. Five shear wave velocities of 100, 180, 360, 760 and 1500 m/s for the soil were considered to classify the site for the seismic analyses. They are the boundary shear wave velocities specified in IBC to classify the site classes. The unit weights of the soil were assumed to be 16, 16, 18, 20 and 26 kN/m^3 depending on the shear wave velocities respectively, and Poisson's ratio of 0.3 and initial damping ratio of 0.05 were also assumed. Furthermore, the foundation was taken as a rigid cylindrical mat foundation with the embedment, while the unit weight of the mat foundation embedded less than 3.3 m was set equal to 23.5 kN/m^3 without a basement and, otherwise, 3.56 kN/m^3 considering the basements of a building. For a surface foundation with a zero embedment, it was assumed to be embedded 1 m for the practical purpose. The seismic design response spectrum of a SDOF system was developed assuming the damping ratio of 0.05.

For the seismic analyses, seven records shown in Table 1 were selected among the 1557 seismic records provided by the Pacific Earthquake Engineering Research Center (PEER) in Berkeley. They were recorded at rock sites having shear-wave velocity of greater than 750 m/s defined by United

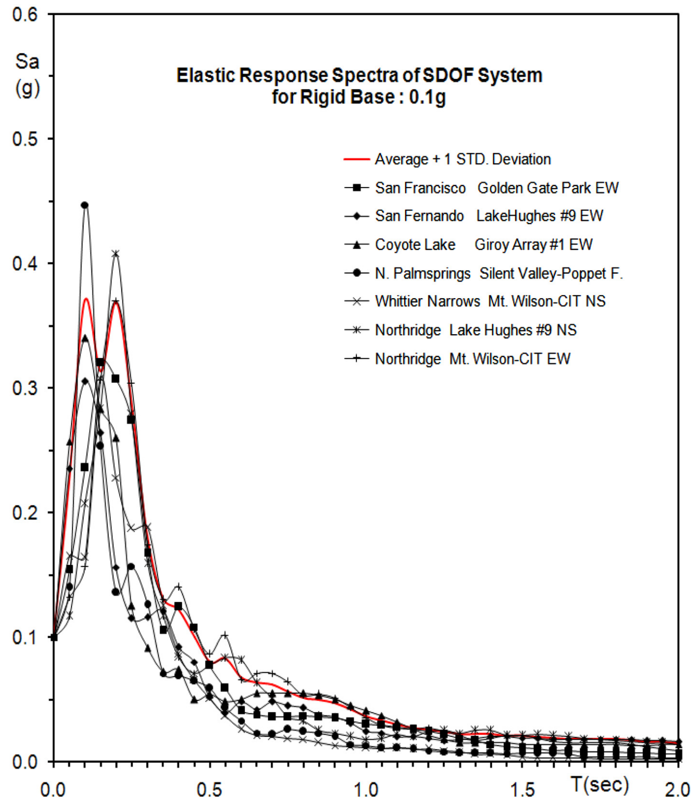

Fig. 2 Response spectra of 7 earthquake records (0.1 g)

States Geology Survey (USGS) or at the site estimated as A (rock) by the Geomatrix site classification system. The peak accelerations of the records were scaled to be 0.1 g for the study, and the corresponding response spectra are plotted in Fig. 2. However, these seismic records were recorded at the outcrop corresponding to the site class B in IBC. So it is necessary to generate the seismic records at the bedrock located at 30 m below the outcrop by the de-convolution process assuming that the shear wave velocity of the site class B is 1050 m/s for the rational seismic analysis of the structure-soil system as discussed by Roesset and Kim (1987).

Seismic analyses of the structure-soil system were carried out in the frequency domain from 0 to 30 Hz for the structures having the fundamental periods between 0 and 2 second with the period interval of 0.1 second.

3. Response acceleration of a building built on a perfectly backfilled foundation

Seismic analyses to estimate the response acceleration of the structure-soil system were performed for a building built on an embedded foundation assuming perfect backfill. The response acceleration in the short-period range of *Aa* was estimated by averaging the response spectrum which represent the mean plus one standard deviation response spectra of seven earthquakes from 0.1 second to 0.5 second, and that at the period of 1 second of *Av* was also estimated by averaging the response

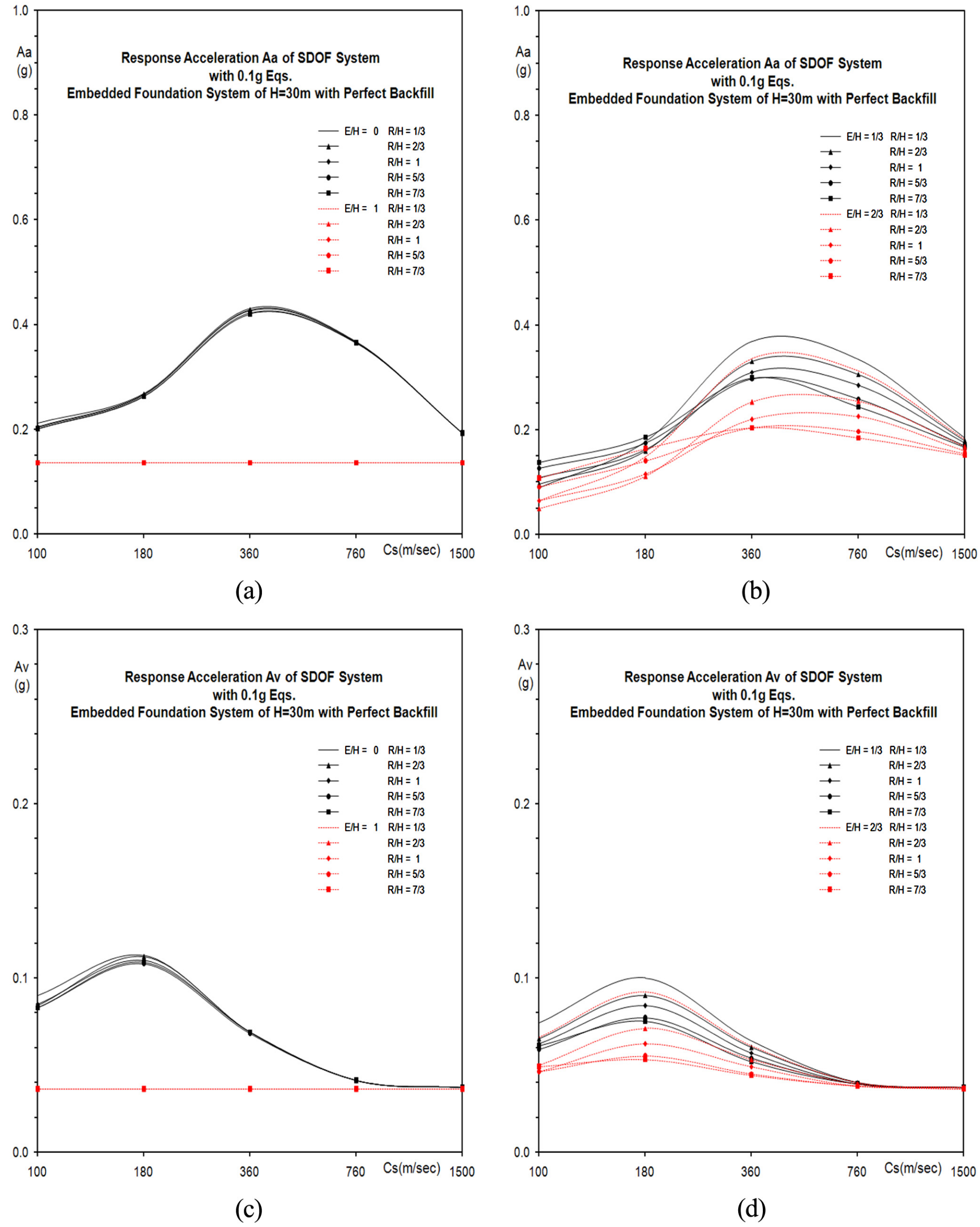

Fig. 3 Response accelerations of *Aa* and *Av* with perfect backfill: (a) *Aa* in the case of *E*/*H*=0 and 1, (b) *Aa* in the case of *E*/*H*=1/3 and 2/3, (c) *Av* in the case of *E*/*H*=0 and 1 and (d) *Av* in the case of *E*/*H*=1/3 and 2/3

spectrum from 0.4 second to 2.0 second, applying the same method utilized to estimate the site coefficients *Fa* and *Fv*.

Mean plus one standard deviation elastic response spectra for the site shear wave velocities of 100, 180, 360, 760 and 1500 m/s were calculated to estimate the response accelerations of *Aa* and *Av* for the cases of the radii of an equivalent circular foundation of 10, 20, 30, 50 and 70 m and the

Table 2 Mean+*SD* of *Aa* and *Av* for 5 different cases of *R*/*H* (Perfect backfill) (unit : g)

Shear wave velocity (m/s)	*R*/*H*	*Aa*				*Av*			
		E/*H*				*E*/*H*			
		0	1/3	2/3	1	0	1/3	2/3	1
100	1/3	0.211	0.089	0.065	0.136	0.09	0.074	0.066	0.036
	2/3	0.204	0.096	0.05	0.136	0.084	0.065	0.05	0.036
	1	0.203	0.109	0.064	0.136	0.085	0.062	0.046	0.036
	5/3	0.201	0.127	0.091	0.136	0.083	0.059	0.046	0.036
	7/3	0.2	0.138	0.107	0.136	0.083	0.061	0.049	0.036
	Mean+*SD*	**0.208**	**0.132**	**0.098**	**0.136**	**0.088**	**0.07**	**0.06**	**0.036**
180	1/3	0.268	0.178	0.149	0.136	0.113	0.1	0.092	0.036
	2/3	0.266	0.159	0.111	0.136	0.112	0.09	0.071	0.036
	1	0.265	0.162	0.115	0.136	0.11	0.084	0.062	0.036
	5/3	0.263	0.175	0.14	0.136	0.083	0.059	0.046	0.036
	7/3	0.263	0.186	0.163	0.136	0.083	0.061	0.049	0.036
	Mean+*SD*	**0.267**	**0.183**	**0.158**	**0.136**	**0.116**	**0.097**	**0.083**	**0.036**
360	1/3	0.431	0.369	0.336	0.136	0.069	0.064	0.061	0.036
	2/3	0.427	0.331	0.253	0.136	0.069	0.06	0.053	0.036
	1	0.426	0.31	0.22	0.136	0.069	0.057	0.049	0.036
	5/3	0.422	0.297	0.204	0.136	0.068	0.054	0.045	0.036
	7/3	0.42	0.298	0.204	0.136	0.069	0.052	0.044	0.036
	Mean+*SD*	**0.43**	**0.351**	**0.299**	**0.136**	**0.069**	**0.062**	**0.057**	**0.036**
760	1/3	0.367	0.335	0.312	0.136	0.041	0.04	0.04	0.036
	2/3	0.366	0.306	0.254	0.136	0.041	0.04	0.039	0.036
	1	0.366	0.285	0.225	0.136	0.041	0.039	0.038	0.036
	5/3	0.365	0.259	0.197	0.136	0.041	0.039	0.038	0.036
	7/3	0.364	0.244	0.185	0.136	0.041	0.039	0.038	0.036
	Mean+*SD*	**0.367**	**0.322**	**0.285**	**0.136**	**0.041**	**0.04**	**0.039**	**0.036**
1500	1/3	0.192	0.185	0.181	0.136	0.037	0.037	0.037	0.036
	2/3	0.192	0.179	0.168	0.136	0.037	0.037	0.037	0.036
	1	0.192	0.175	0.16	0.136	0.037	0.037	0.037	0.036
	5/3	0.192	0.169	0.154	0.136	0.037	0.037	0.036	0.036
	7/3	0.192	0.166	0.151	0.136	0.037	0.037	0.036	0.036
	Mean+*SD*	**0.192**	**0.182**	**0.175**	**0.136**	**0.037**	**0.037**	**0.037**	**0.036**

embedment depths of the foundation of 0, 10, 20 and 30 m. For the sake of convenience, the foundation radii were normalized by the soil layer depth of 30 m as 1/3, 2/3, 1, 5/3 and 7/3, and the foundation embedment depths were also normalized as 0, 1/3, 2/3 and 1.

The variations of response accelerations of *Aa* and *Av* are also shown in Fig. 3 with the shear wave velocity for different values of the embedment ratio (*E*/*H*) and the foundation radius ratio (*R*/*H*). The response accelerations of *Aa* and *Av* are almost independent on the foundation radius (size)

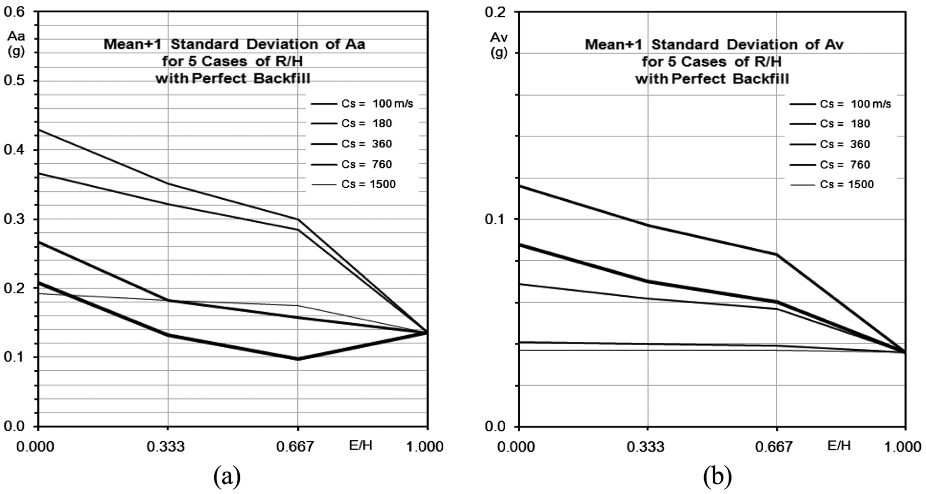

Fig. 4 Mean+*SD* of *Aa* and *Av* for 5 cases of *R*/*H* with perfect backfill: (a) Mean+*SD* of *Aa* and (b) Mean+*SD* of *Av*

in the case of a surface foundation on soft soil ($E/H = 0$) or a rigid foundation on bedrock ($E/H = 1$), indicating that *Aa* and *Av* can be estimated independently of the foundation size. However the foundation size affects some of the response accelerations of the embedded foundations with the embedment ratio (E/H) of 1/3 and 2/3, if the foundation radius is larger than 20 m (in the cases of R/H of 2/3, 1, 5/3 and 7/3). In the case of E/H of 2/3 and R/H of 1/3 (foundation radius of 10 m and embedment depth of 20 m), *Aa* values with the shear wave velocities of 360 and 760 m/s deviate somewhat from those with the other shear wave velocities as shown in Fig. 3(b), and *Av* values with the shear wave velocity of 180 m/s also deviate from those with the other shear wave velocities as shown in Fig. 3(d). This is because the motion of a small foundation was amplified by 3-4 earthquakes in the short-period range from 0.15 second to 0.4 second due to the soft soil beneath the foundation having a small shear wave velocity. Practically it can be concluded that the response accelerations of *Aa* and *Av* are almost independent on the foundation size because only a small building built on the soft soil with the foundation radius smaller than 10 m ($R/H = 1/3$) has approximately 50% greater response acceleration.

So, mean plus one standard deviation response accelerations representing the response accelerations of 5 different foundation radii were calculated to investigate the variation of the response accelerations associated with the embedment ratio and the shear wave velocity as shown in Table 2.

The variation of mean plus one standard deviation response accelerations of *Aa* and *Av* in terms of the embedment ratio and the shear wave velocity are shown in Fig. 4 considering the perfect backfill. The response accelerations generally decrease as the embedment ratio increases. While the response accelerations with the stiffer soil decrease gradually as the embedment ratio becomes large, however those with the softer soil show a somewhat drastic change.

4. Response acceleration of a building built on a poorly backfilled foundation

Seismic analyses of a building built on an embedded foundation resting on the elastic soil site were performed with the seven earthquake records to find the elastic response spectra considering

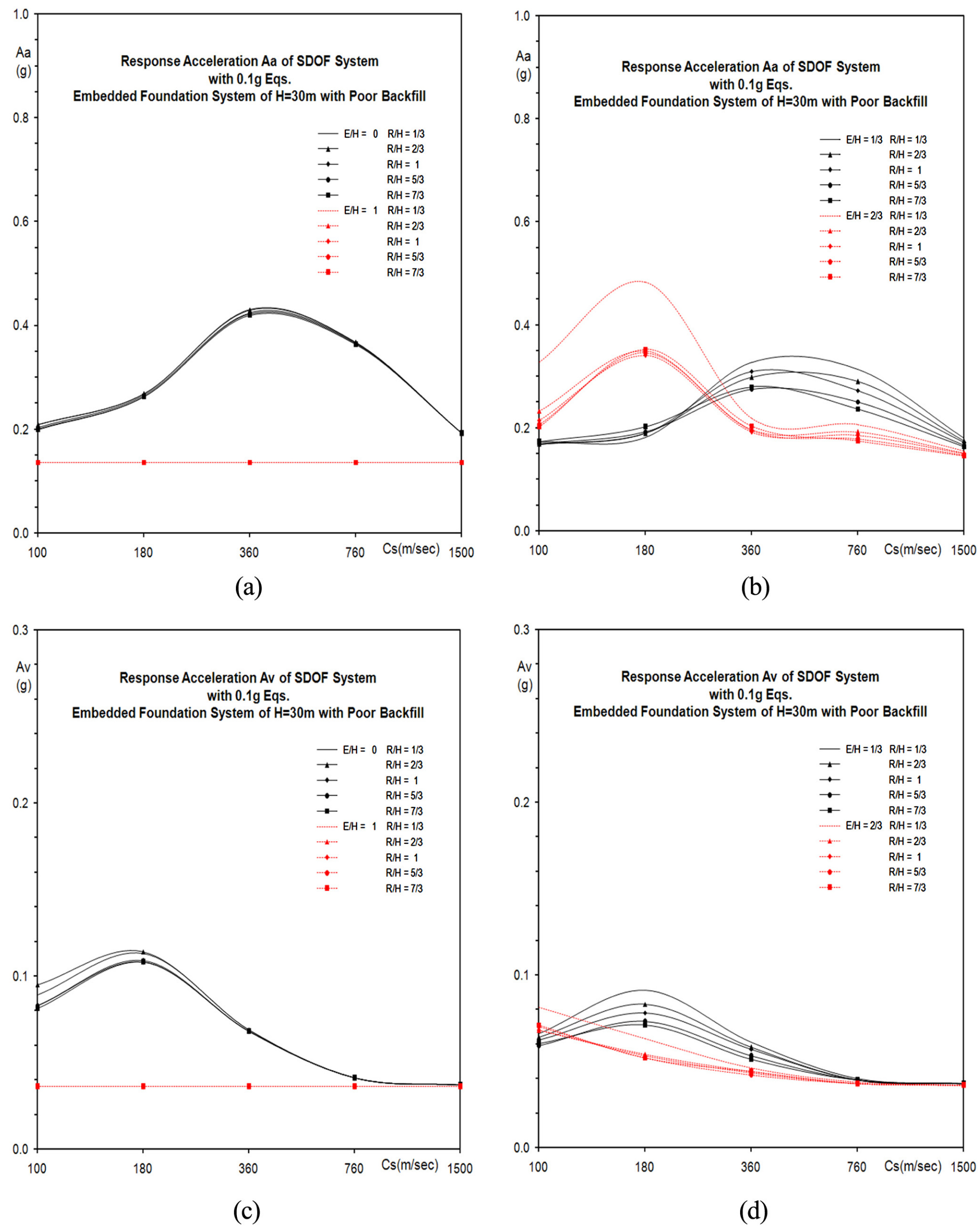

Fig. 5 Response accelerations of *Aa* and *Av* with poor backfill: (a) *Aa* in the case of *E*/*H*=0 and 1, (b) *Aa* in the case of *E*/*H*=1/3 and 2/3, (c) *Av* in the case of *E*/*H*=0 and 1 and (d) *Av* in the case of *E*/*H*=1/3 and 2/3

the structure-soil interaction, but ignoring the backfill around an embedded foundation. The 50 cm thickness soil around the foundation was assumed as a soft soil having no stiffness to simulate the poor backfill around the embedded foundation. Response accelerations of *Aa* for the site shear wave velocities of 100, 180, 360 and 1500 m/s were estimated by averaging the response spectra which represent the mean plus one standard deviation ones of seven earthquakes from 0.1 second to 0.5 second. Response accelerations of *Av* were also estimated by averaging the response spectra from

Table 3 Mean+*SD* of *Aa* and *Av* for 5 different cases of *R*/*H* (Poor backfill) (unit : g)

Shear wave velocity (m/s)	*R*/*H*	*Aa*				*Av*			
		E/*H*				*E*/*H*			
		0	1/3	2/3	1	0	1/3	2/3	1
100	1/3	0.208	0.173	0.328	0.136	0.089	0.066	0.081	0.036
	2/3	0.208	0.169	0.233	0.136	0.095	0.064	0.068	0.036
	1	0.203	0.168	0.214	0.136	0.083	0.062	0.068	0.036
	5/3	0.201	0.169	0.206	0.136	0.083	0.059	0.07	0.036
	7/3	0.199	0.173	0.202	0.136	0.081	0.06	0.071	0.036
	Mean+*SD*	**0.208**	**0.173**	**0.289**	**0.136**	**0.092**	**0.065**	**0.077**	**0.036**
180	1/3	0.268	0.182	0.483	0.136	0.113	0.091	0.063	0.036
	2/3	0.268	0.19	0.349	0.136	0.114	0.083	0.054	0.036
	1	0.265	0.19	0.341	0.136	0.108	0.078	0.053	0.036
	5/3	0.263	0.193	0.346	0.136	0.109	0.073	0.052	0.036
	7/3	0.262	0.202	0.353	0.136	0.108	0.071	0.052	0.036
	Mean+*SD*	**0.268**	**0.199**	**0.435**	**0.136**	**0.113**	**0.087**	**0.059**	**0.036**
360	1/3	0.431	0.327	0.219	0.136	0.069	0.061	0.046	0.036
	2/3	0.429	0.298	0.197	0.136	0.069	0.058	0.044	0.036
	1	0.424	0.31	0.192	0.136	0.068	0.057	0.043	0.036
	5/3	0.422	0.275	0.196	0.136	0.068	0.053	0.042	0.036
	7/3	0.419	0.28	0.204	0.136	0.068	0.051	0.044	0.036
	Mean+*SD*	**0.43**	**0.319**	**0.212**	**0.136**	**0.069**	**0.06**	**0.045**	**0.036**
760	1/3	0.367	0.314	0.207	0.136	0.041	0.04	0.038	0.036
	2/3	0.367	0.29	0.192	0.136	0.041	0.039	0.038	0.036
	1	0.366	0.273	0.186	0.136	0.041	0.039	0.037	0.036
	5/3	0.365	0.251	0.179	0.136	0.041	0.039	0.037	0.036
	7/3	0.363	0.237	0.175	0.136	0.041	0.039	0.037	0.036
	Mean+*SD*	**0.367**	**0.304**	**0.2**	**0.136**	**0.041**	**0.04**	**0.038**	**0.036**
1500	1/3	0.192	0.18	0.155	0.136	0.037	0.037	0.036	0.036
	2/3	0.192	0.175	0.151	0.136	0.037	0.037	0.036	0.036
	1	0.192	0.172	0.15	0.136	0.037	0.037	0.036	0.036
	5/3	0.192	0.167	0.147	0.136	0.037	0.037	0.036	0.036
	7/3	0.192	0.164	0.146	0.136	0.037	0.037	0.036	0.036
	Mean+*SD*	**0.192**	**0.178**	**0.153**	**0.136**	**0.037**	**0.037**	**0.036**	**0.036**

0.4 second to 2.0 second.

Mean plus one standard deviation elastic response accelerations of *Aa* and *Av* for the site shear wave velocities of 100, 180, 360, 760 and 1500 m/s are estimated considering the poor backfill around the embedded foundation with the foundation radius ratio of 1/3, 2/3, 1, 5/3 and 7/3 and the embedment ratio of 0, 1/3, 2/3 and 1. The variations of *Aa* and *Av* in terms of the shear wave velocity are also shown in Fig. 5 for the different values of *E*/*H* and *R*/*H*. Response accelerations of

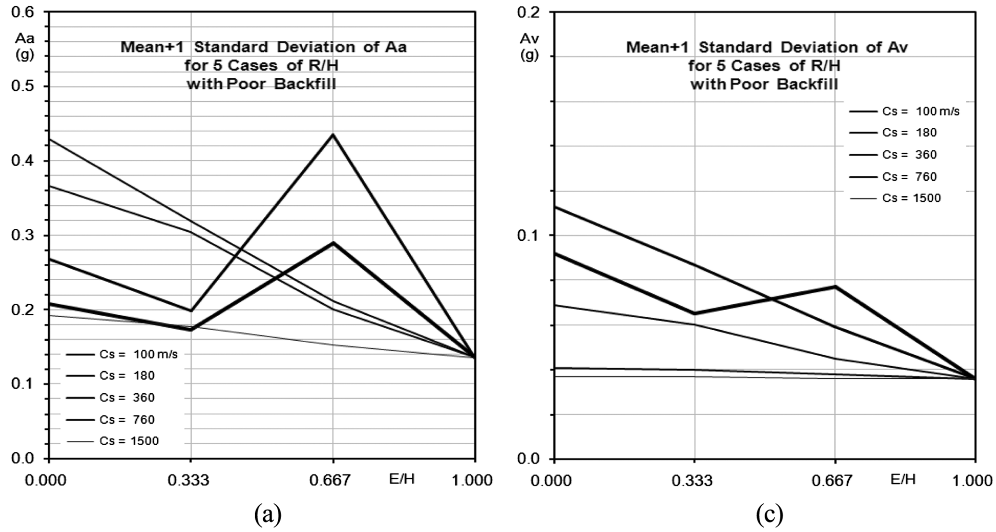

Fig. 6 Mean+*SD* of *Aa* and *Av* for 5 cases of *R*/*H* with poor backfill: (a) Mean+*SD* of *Aa* and (b) Mean+*SD* of *Av*

Aa and *Av* are also almost independent on the foundation radius in the case of a surface foundation on soft soil or a rigid foundation on bedrock similar to the case of the perfect backfill. However, the foundation size affects some of the response accelerations of the embedded foundation with the embedment ratio of 2/3 and the foundation radius ratio of 1/3 (embedment depth of 20 m and foundation radius of 10 m). *Aa* values with the shear wave velocities of 360 and 760 m/s deviate noticeably from those with the other shear wave velocities as shown in Fig. 5(b), and *Av* values with the shear wave velocity of 180 m/s also deviate a little bit from those with the other shear wave velocities as shown in Fig. 5(d).

The response accelerations of the SDOF system with the poorly backfilled foundation are almost independent on the foundation size practically as with perfectly backfilled systems. So, the response accelerations of mean plus one standard deviation representing the response accelerations of 5 different foundation radii were calculated to investigate the variation of the response accelerations associated with the embedment ratios and the shear wave velocities as shown in Table 3.

The variation of mean plus one standard deviation response accelerations of *Aa* and *Av* in terms of the embedment ratio and the shear wave velocity are shown in Fig. 6 considering the poor backfill. The response accelerations with the shear wave velocities larger than 360 m/s decrease as the embedment ratio increases, but these are amplified when the foundation is embedded deeply in the soft soil having a shear wave velocity of less than 180 m/s. Also, the response accelerations decrease as the shear wave velocity of the soil increases, except in the case of soft soil.

5. Backfill effect on response acceleration of a building

The effects of the backfill were investigated comparing the seismic analysis results of a building built on the embedded foundation. The seismic analyses were performed modeling the building as a SDOF system and taking into account the condition of the compacted soil around the embedded foundation.

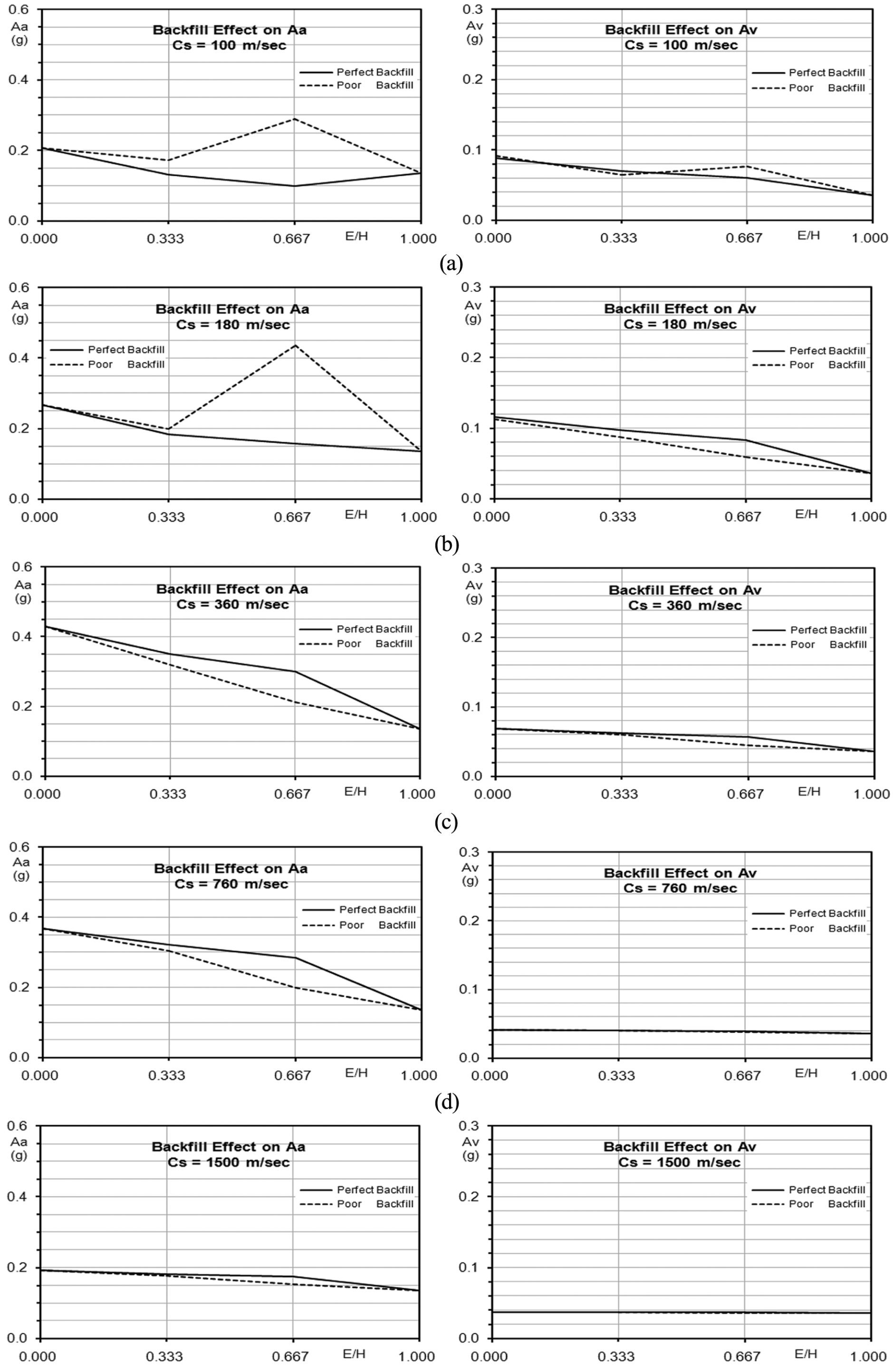

Fig. 7 Backfill effect on the response acceleration of *Aa* and *Av*: (a) *Cs*=100 m/s, (b) *Cs*=180 m/s, (c) *Cs*=360 m/s, (d) *Cs*=760 m/s and (e) *Cs*=1500 m/s

The response accelerations of *Aa* and *Av* with perfect or poor compaction around the embedded foundation were compared in Fig. 7 to understand the backfill effect for the shear wave velocities of 100, 180, 360, 760 and 1500 m/s. The response accelerations of *Aa* with the shear wave velocities of 100 and 180 m/s shown in Figs. 7(a) and (b) indicate that the response acceleration with the poor backfill around the foundation is amplified almost 3 times when the embedment ratio (E/H) is 2/3. This is due to the response amplification at the fundamental frequency of the soft soil layer beneath the mat foundation in the short-period range by some earthquakes. The response accelerations of *Aa* for the shear wave velocities of 360 and 760 m/s shown in Figs. 7(c) and (d) indicate that the poor backfill reduces the response more than 30% with the embedment ratio of 2/3 due to the shallow soil layer beneath the foundation. For the embedment ratios other than 2/3, the effect of backfill is negligible and can be ignored.

The response acceleration of *Av* with shear wave velocity of 100 m/s shown in Fig. 7(a) indicates that the response difference between perfect and poor backfill is not as large as the amplification of the response acceleration of *Aa*, and the effect of the backfill is not significant. In the cases of the shear wave velocities of 180 and 360 m/s, the response accelerations of *Av* with the poor backfill are somewhat lower than those with the perfect backfill as shown in Figs. 7(b) and (c) indicating that poor backfill is not always harmful to the seismic response of a building. The condition of the backfill has a small effect on the response acceleration of *Av* with the stiff soil or the rock having the shear wave velocity of 760 or 1500 m/s as shown in Figs. 7(d) and (e) and the backfill effect is insignificant.

The effect of poor backfill around the foundation is helpful to the seismic response of a building built on the embedded foundation, if the foundation is embedded in stiff soil having the shear wave velocity of larger than 360 m/s. Also, the poor backfill does not adversely affect the seismic response of a building even with the foundation embedded in the soft soil, if the foundation is not embedded deeply so that the earthquake amplifies the response of a building in the fundamental frequency of the soft soil layer beneath the foundation. Thus, it is necessary to perform the seismic analysis for a structure-soil system to check the seismic amplification due to the soft soil layer beneath the foundation only when the foundation is embedded deeply in the soft soil, and to compact the backfill around the foundation as well as possible.

6. Conclusions

In this paper, the response accelerations of *Aa* and *Av* which are the seismic accelerations in the short-period range and at the period of 1 second in the long-period range specified in the IBC design code were compared to investigate the effect of soil compaction around the embedded foundation considering perfect and poor backfills.

The seismic analyses of the structure-soil system with the embedded foundation were performed using an in-house finite-element software P3DASS which has the capability of horizontal pseudo-3D seismic analysis with linear soil layers. A 30 m thick soil resting on the bedrock was assumed to be homogeneous, elastic, viscous and isotropic. Equivalent circular rigid foundations with radii of 10, 20, 30, 50 and 70 m were considered to be embedded 0, 10, 20 and 30 m in the soil. Seismic analyses were performed with 7 bedrock earthquake records provided by PEER, scaling the peak ground accelerations to 0.1 g, and then de-convoluting them into the bedrock ones.

The results of the study show that the condition of the backfill around the foundation does not affect significantly the response of a building, if the foundation is not embedded deeply in soft soil with soft soil extending beneath the foundation. Poor backfill can be somewhat helpful if the foundation is embedded in stiff soil, and does not penalize the seismic response, if the foundation is not embedded deeply in soft soil. However, poor backfill around the foundation deeply embedded in soft soil amplifies the response acceleration almost 3 times. So, it is necessary to perform the seismic analysis for a structure-soil system to check the seismic resonance due to the soft soil layer beneath the foundation, and to compact the backfill as well as possible.

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