Evaluation of dispersion of calculated seismic site responses through Round Robin Test in Korea

L'évaluation de dispersion de réponses de site sismiques cqlculées par le Test de Rond de Robin en Corée

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ABSTRACT

One dimensional site response analysis is widely used in practice to estimate the seismic site amplification effects. The site response analysis involves determination of various uncertainties, which include characterization of future seismic event and dynamic soil properties. The accuracy and reliability of the site response analysis depend on how these factors are properly defined. A site response analysis round robin test has been performed in Korea to evaluate the dispersion of the calculated site responses caused by such uncertainties. To simulate the common practice, only the SPT, CPT data, and boring logs were given for three sites. Three input motions representative of the seismic hazard with a return period of 1000 years were given. The participants were then asked to choose a method of analysis and submit the calculated responses. The submitted results showed significant variation. Among the factors influencing the response, the shear wave velocity had the greatest influence on the dispersion, followed by the dynamic curves, and the type of analysis.

RÉSUMÉ

Une analyse de réponse de site dimensionnelle est largement utilisée en pratique pour estimer les effets d'amplification de sites sismiques. L'analyse de réponse de site implique la détermination d'incertitudes différentes, qui incluent la caractérisation d'événement sismique futur et de propriétés de sol dynamiques. L'exacititude et l'intégrité de l'analyse de réponse de site dependent de comment ces facteurs sont correctement defines. Une analyse de réponse de site l'épreuve de rond de Robin a été execute en Corée pour évaluer la dispersion des réponses de site calculées provoquées par de telles incertitudes. Pour simuler la pratique commune, seulement le SPT, les données de CPT et les rodins ennuyeux ont été donnés pour trios sites. On a donné à trois représentant de mouvements de contribution du hasard sismique avec une période de retour de 1000ans. On a alors demandé les participants de choisir une method pour l'analyse et soumettre les réponses calculées. Les résultats soumis ont montré la variation significative. Parmi les facteurs influençant la réponse, la vitesse de signe de tondage avait la plus grande influence sur la dispersion, suivie par les courbes dynamiques, et le type d'analyse.

Keywords : site response analysis, round robin test, shear wave velocity, dynamic curves, dispersion

1 INTRODUCTION

To perform a site response analysis, various soil parameters including density, shear wave velocity (Vs) and dynamic curves (shear modulus reduction and damping curves) need to be determined. In order to perform an effective stress analysis, parameters for the excess pore pressure generation model must be additionally defined. It would be ideal if all parameters for the analysis are determined from field and laboratory tests. However, the dynamic properties are seldom measured and an engineer is most often forced to make assumptions based on limited data. The estimation of the ground vibration at a site is further complicated by difficulty in selecting representative ground motion time history.

This paper documents a site response analysis round robin test (RRT) that has been performed in Korea. The purpose of the RRT was to evaluate the dispersion of the calculated site responses resulting from uncertainties in the soil properties and ground motions.

2 SITE RESPONSE ANALYSIS ROUND ROBIN TEST

16 institutions and individuals participated as 12 teams in the site response analysis RRT organized by the Soil Dynamics Technical Committe of the Korean Geotechnical Society. The participants were given the resistance (N) obtained from the standard penetration test (SPT), Figure 1, and cone tip resistance (qt) measured from cone penetration test (CPT), along with boring logs. The Vs profiles measured from geophysical tests were available at the sites, but intentionally not disclosed. Three input ground motions widely used in Korea were given. The response spectra of the input motions and the seismic design response spectrum are shown in Figure 2.

The participants needed to estimate the shear wave velocity and select appropriate dynamic curves based on the given information. The participating teams were asked to submit the following results: acceleration response spectra, acceleration time histories, PGA profiles, and maximum shear strain profiles.

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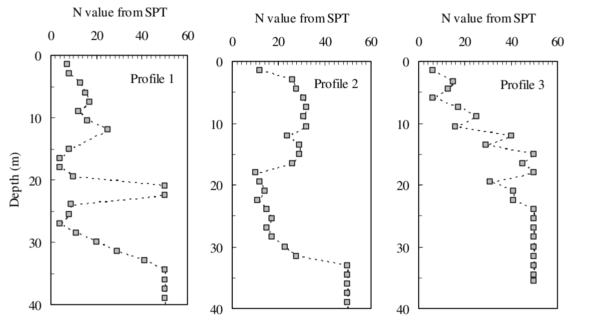

Figure 1. SPT N profiles of selected sites.

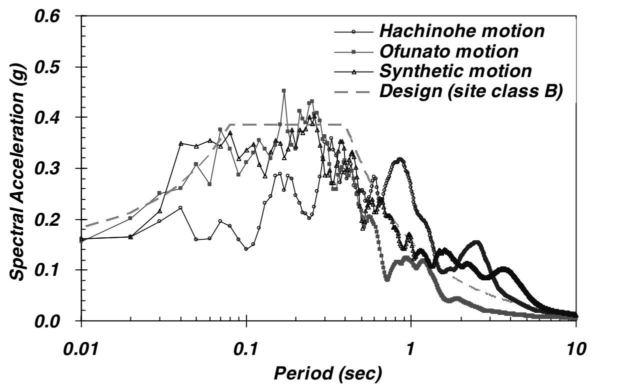

Figure 2. 5% damped acceleration response spectra of the ground motions and design spectrum for an earthquake with a return period of 1000 years.

All of the participating teams were required to perform the equivalent linear analysis as a default, while performing total and effective nonlinear analyses was optional. Among 12 teams, four teams performed total stress nonlinear analysis, while only two teams performed effective stress analysis.

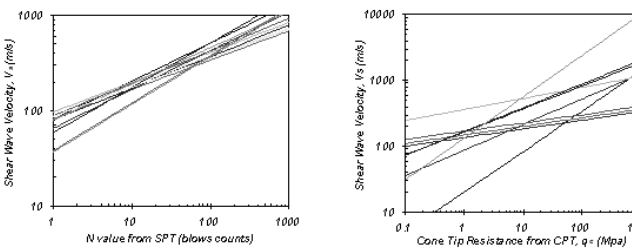

Figure 3. Comparison of selected N vs. Vs and qt vs. Vs relationships

The programs used for performing equivalent linear analyses were SHAKE91 (Idriss and Sun, 1991), ProShake, EERA (Bardet et al., 2000), and DEEPSOIL (Hashash and Park, 2001). Nonlinear analyses were performed using DEEPSOIL (Hashash and Park, 2001), YUSAYUSA (Yoshida et al., 1991), NERA (Bardet et al., 2000), and FLAC 5.0 (Itasca, 2005).

3 SELECTED SOIL PROPERTIES

This section describes the range of Vs profiles and dynamic curves selected by the participants. Other properties that need to be defined to perform a site response analysis, which include the density profile, bedrock properties, and soil column thicknesses will not be discussed in this paper.

3.1 *Shear wave velocity estimation*

The participants used a wide range of empirical relationships to estimate the shear wave velocity profiles. A total of 25 relationships between N and Vs was used, compared to 10 qt vs. Vs relationships. All participants used qt only to estimate the properties of clays. All relationships used are shown in Figure 3. The significant differences between the relationships used can be observed. The discrepancy is especially dramatic for qt vs. Vs equations. While the CPT is known to be more accurate than the SPT, the qt. vs. Vs relationships show lower reliability. Therefore, caution is warranted in estimation of Vs from qt.

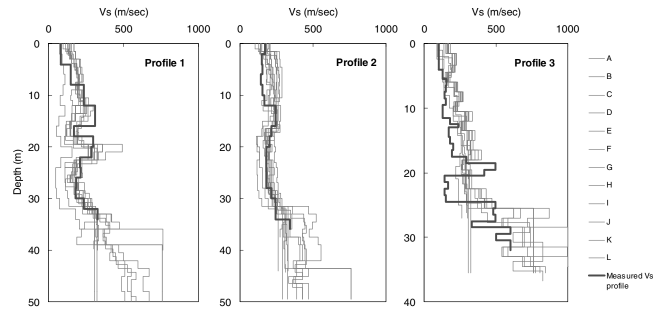

Figure 4. Comparison of estimated and measured Vs profiles

The Vs profiles developed by the participants and the actual measured Vs are compared in Figure 4 (measured profile is shown in thick red lines). All estimated profiles strongly deviated form the measured Vs. Not a single profile matched the measured profile within acceptable range.

3.2 *Dynamic curve estimation*

The range of selected dynamic curves was also quite variable. 8 sets of curves were selected for sands, while 10 sets were selected for silts and clays, as shown in Figure 5 and 6.

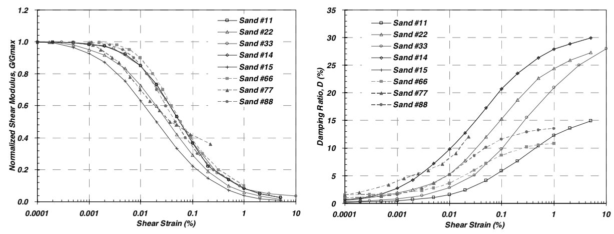

Figure 5. Selected dynamic curves for sands

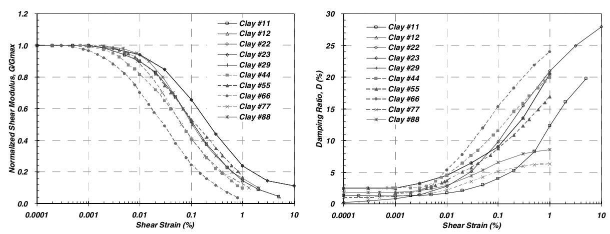

Figure 6. Selected dynamic curves for clays

4 EVALUATION OF CALCULATED OUTPUT

The dispersion of the submitted results and the causes for the dispersion are discussed in this section. Due to the page limit, only a portion of the results are shown.

4.1 *Overall dispersion*

Figure 7 shows the calculated 5% damped surface acceleration response spectra for Profile 1. Shown in Figure 8 are the calculated maximum shear strain and peak ground acceleration (PGA) profiles for Profile 1. Figure 7 and 8 show that there are pronounced discrepancies in the calculated responses. The figures strongly demonstrate that the state-of-practice, which assumes the dynamic properties from boring logs and SPT / CPT results, does not provide reliable estimate of the seismic hazard at a given site.

In the ensuing, possible causes for the observed dispersion are discussed.

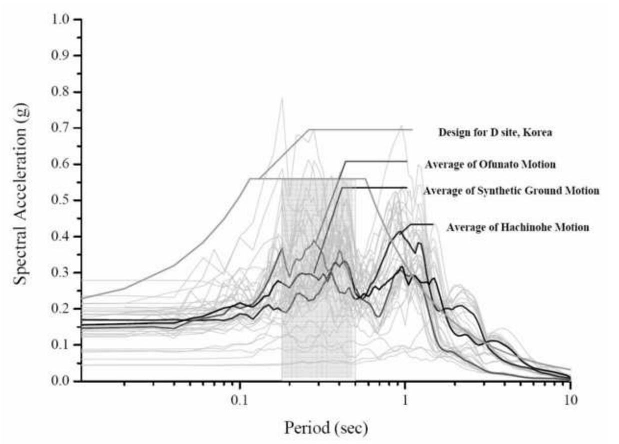

Figure 7. Calculated 5% damped surface acceleration response spectra for Profile 1.

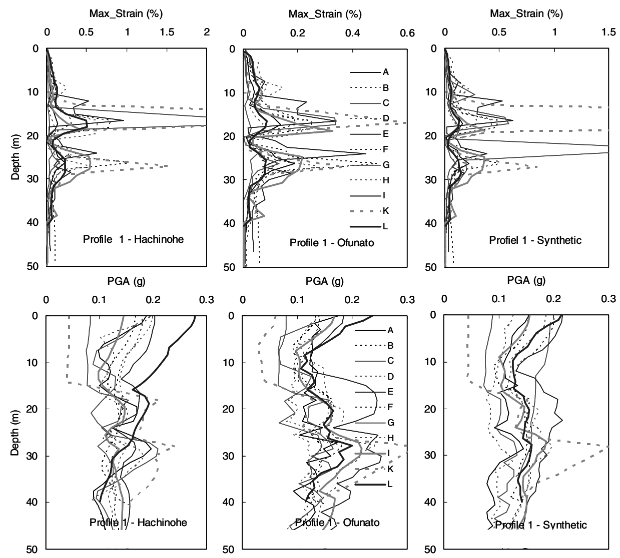

Figure 8. Calculated maximum shear strain and peak ground acceleration profiles for Profile 1.

4.2 *Influence of input ground motion*

Also shown in Figure 7 are the averaged response spectra of three input ground motions. Although the overall dispersion of the calculated response spectra is significant, the averaged spectra show much lower variation. Figure 9 compares the range of calculated PGA for Profile 1. Again, although PGA shows strong variation among the participating teams, the averaged PGAs of three ground motions are very similar.

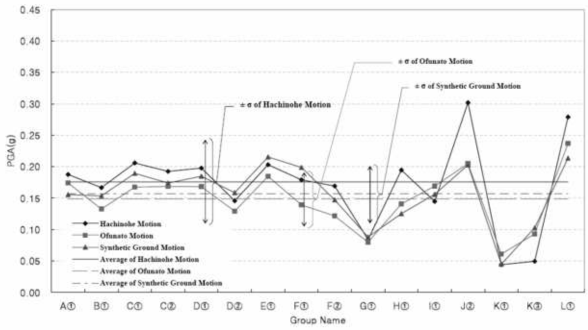

Figure 9. Range of calculated surface PGA for Profile 1.

4.3 *Influence of shear wave velocity*

It was not possible to determine the influence of a particular dynamic property on the dispersion of the response based on the submitted results only. To evaluate the effect of dynamic properties, additional analyses were performed. In this section, the effect of the shear wave velocity is evaluated. The shear wave velocity profiles selected are shown in Figure 10.

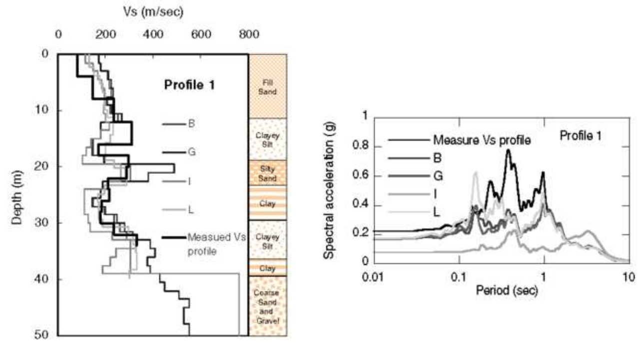

Figure 10. Range of calculated surface PGA for Profile 1.

Among twelve profiles submitted by the participants, a total of four profiles were selected. They represent the lower, upper, and mean profiles. In addition to the estimated profiles, the measured Vs profile (shown in thick line in Figure 10) was used as the reference profile. Identical dynamic curves were used for all analyses, such that the response is only dependent on the Vs profile. Seed and Idriss (1970) mean curves were used for sands while Vucetic and Dobry (1991) PI = 15 curves were used for clays and silts. Figure 10 shows the range of the calculated acceleration response spectra. All calculated response clearly deviated from the reference analysis, which used the measured Vs profile. The variation is truly disturbing, and again highlights the inappropriateness of using SPT / CPT to estimate the Vs.

4.4 *Influence of dynamic curves*

In this section, the effect of dynamic curves is evaluated. The shear wave velocity is fixed to the measured Vs Profile 1. The matrix of selected sets of dynamic curves is summarized in Table 1. For sands, the upper and lower curves proposed by Seed and Idriss (1970) were used. For clays and silts, the curves by Sun et al. (1988) and Vucetic and Dobry (1991) were used. Lower plasticity curves were used for silts, while higher plasticity curves were used for clays.

Table 1. Matrix of selected sets of dynamic curves

	Sand		Clay and Silt			
	Seed and Idriss		Sun et al.		Vucetic & Dobry	
	Upper	Lower	PI= 5-10	PI= 20-40	PI=15	PI=30
#1	○		○	○		
#2	○				○	○
#3	○		○			○
#4	○			○	○	
#5		○	○	○		
#6		○			○	○
#7		○	○			○
#8		○		○	○	

Figure 11 shows the calculated range of responses for various combinations of dynamic curves. The effect of the dynamic curve is very dramatic. The overall shape of the response is more consistent than when the Vs profiles were varied. However, the selected dynamic curves influence the overall magnitude of the response.

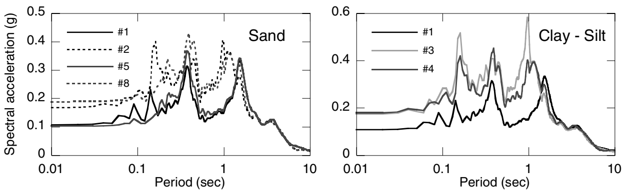

Figure 11. Effect of dynamic curves on the calculated surface response spectra for Profile 1.

4.5 *Influence of type of analysis*

The effect of type of analysis on the calculated RRS (response spectral ratio) is shown in Figure 12 for Profile 1 and 2. RRS represents the ratio of the total stress nonlinear analysis to the equivalent linear analyses. The PGAs from the equivalent linear analyses were similar or slightly larger than nonlinear analyses (up to 20%). At other frequencies, the responses were similar. Overall, the effect of the type of analysis (equivalent linear vs. total stress nonlinear) was not as dramatic as the effect of the shear wave velocity or the dynamic curves.

5 CONCLUSIONS

A site response analysis round robin test (RRT) was performed in Korea to evaluate the dispersion of the calculated responses due to the uncertainties in the soil properties, ground motion, and type of analysis.

The submitted results showed significant variation. Additional analyses were performed to identify which factor had the most critical influence on the dispersion of the calculated response. Results showed that the shear wave velocity profile had the greatest influence on the dispersion, followed by the dynamic curves, and the type of analysis. It is therefore concluded that accurate estimate of the shear wave velocity profile is of primary importance for evaluating the site amplification effects. The dynamic curves, also it had slightly lower impact than the shear wave velocity profile, also had an important influence on the propagated motion.

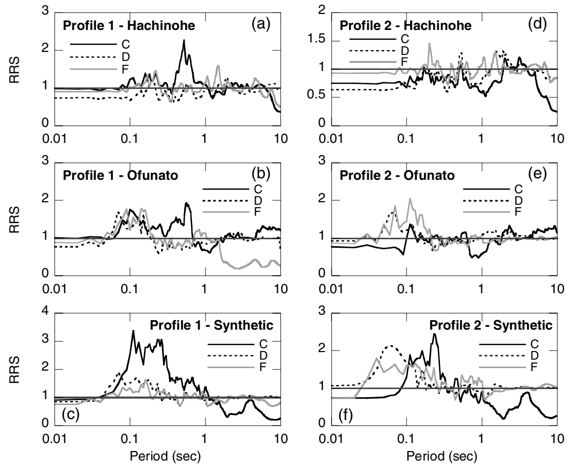

Figure 12. Comparison of total stress nonlinear and equivalent linear analyses.

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