A comparison between free-field shear strain profiles using natural and synthetic earthquake motions in a case study

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ABSTRACT

This paper investigates the effect of natural and synthetic earthquake ground motions on free-field shear strain for soils of Site Class C located within Toronto area. The 2015 NBCC seismic hazard de-aggregation for the area of interest indicate that earthquakes with magnitude (M_w) of 6.0 at distances of about 40 km as well as earthquakes with M_w of 7.0 at distances of more than 100 km mostly contribute to uniform hazard spectra. Therefore, site response analysis requires selection of earthquakes that are beyond the available natural records within this region. Alternatively, synthetic motions are recommended. A suite of natural and synthetic ground motions was used in the analyses and the results show that average of responses to natural motions are generally similar to the average of responses to synthetic motions, however, there is more scatter in responses to natural motions and unfavorable response comes from the natural motions.

RÉSUMÉ

Cet article étudie l'effet d'accélérogrammes provenant de séismes d'origine naturelle et synthétique sur la déformation en cisaillement des sols en champs libre pour un site de classe C, situé dans la région de Toronto. Selon la désagrégation de l'aléa sismique du CNBC 2015 pour la zone d'intérêt, les séismes d'une magnitude (M_w) de 6,0 à une distance d'environ 40 km, ainsi que les séismes d'une M_w de 7,0 à une distance de plus de 100 km, sont les contributeurs principaux à la distribution de l'accélération spectrale. Par conséquent, l'analyse de propagation des ondes nécessite la sélection de séismes qui va au-delà des séismes d'origine naturelle disponibles pour cette région. Comme alternative, il est recommandé d'utiliser des accélérogrammes provenant de séismes synthétiques. Une série d'accélérogrammes provenant de séismes naturels et synthétiques a été utilisée dans les analyses et les résultats montrent que la moyenne des réponses découlant de l'utilisation de séismes naturels est généralement similaire à la moyenne des réponses découlant de l'utilisation de séismes synthétiques. Par contre, les résultats provenant de séismes naturels sont plus dispersés et génèrent des réponses défavorables.

1 INTRODUCTION

Natural and synthetic earthquake ground motions in the form of acceleration time histories are available for seismic analysis. Natural ground motions are the actual recorded earthquakes and can be obtained from any ground motion databases around the world, while synthetic motions are those originated either from seismological source models that accounts for path and site effects, or from mathematical simulation of spectrum-compatible accelerograms.

Use of real acceleration time-histories is preferred in some building codes (e.g., UBC, 1997 and IBC, 2000) while synthetic records are recommended for cases where sufficient numbers of suitable natural earthquake records are not available for a region (Bommer and Acevedo, 2004).

Based on Eurocode 8 (2005), both natural and synthetic earthquake motions may be used in time-domain seismic analyses of structures. However, real earthquake motions are preferred because their frequency content is more realistic than the synthetic ones and a proper time correlation exists between horizontal and vertical components of them (Eurocode 8, 2005).

Bommer and Acevedo (2004) recommend use of appropriately selected and scaled real accelerograms as they have a more realistic number of cycles and energy content in relation to synthetic records. They noted that synthetic records are a complement to real records for scenarios that are not covered by existing database of natural earthquakes.

Rota et al. (2011) used natural accelerograms in their seismic site response study in central Italy. For them, using natural records was a priori decided because of the reasons given in Eurocode 8 (2005), as described above. They performed stochastic analyses of subsurface material (i.e., varying soil profile and parameters) and used seven spectrum-compatible natural records in their analyses. Their selected records were available within the magnitude-distance as well as the mechanism of their design earthquake. Their results indicated that the most important source of uncertainty in response is the variability of the input motions.

At any specific probability level, different types of seismic motions contribute to the uniform-hazard spectrum (UHS). Small to moderate seismic motions at close distances are the most important contributor to UHS at short periods, whereas large motions at greater distance are the most influential contributor to UHS at long periods (Reiter, 1990 and McGuire, 1995).

Although it is typically preferable to use recorded ground motions from the same seismological regime as the subject location, such recordings in eastern Canada are few and far apart and they are generally associated with small magnitude earthquakes (Atkinson and Beresnev, 1998). Therefore, synthetic time histories may be the only reliable option to use in an analysis when large magnitude earthquakes are expected to contribute most to the uniform-hazard spectrum (UHS) in this region. There is no historical record of large magnitude earthquakes in eastern Ontario.

This study presents estimation and a comparison of seismic free-field shear strain for a site in southern Ontario, Canada obtained from a series of one-dimensional ground response analyses that considers natural and synthetic earthquake ground motions.

2 METHODOLOGY

To estimate the free-field shear strain at the location of an underground structure at a site located in the Toronto area (Ontario), one-dimensional ground response analyses were carried out using a computer modelling program SHAKE2000 developed based on Schnabel et. al (1972) and Idriss and Sun (1992) models. The program provides an equivalent-linear model that can simulate the dynamic response of a one-dimensional soil column. In this simulation, a soil column or profile is divided into several sublayers. The soil layers in the one-dimensional model are characterized by their total unit weights and dynamic properties including their damping characteristics and small-strain shear modulus (G_{max}) estimated from site specific shear wave velocities.

Once the soil properties were assigned to each layer, a series of acceleration time histories should be applied as input ground motions to simulate the dynamic response of the soil column.

Subsurface material information, dynamic properties of soils and the selection of earthquake acceleration time series are presented in the following sections.

3 SOILS DYNAMIC PROPERTIES

3.1 Soil Profile

Two representative soil profiles A and B (Figure 1) were used in the site response analysis to estimate the free-field shear strain. The subsurface soils for these profiles were determined based on the geotechnical boreholes which encountered asphalt with thickness of about 260 to 300 mm at the ground surface underlain by cohesionless sandy silt and cohesive clayey silt fill material with varying thickness of about 1.5 to 3 m which in turn underlain by mostly compact to very dense non-cohesive glacial till (i.e., Toronto Transit Commission (TTC) Soil Group 3N) deposits. Very dense cohesionless deposits of silty sand/sandy silt (i.e., TTC Soil Group 4) were also encountered at various depths.

The unit weights of 22 kN/m^3 and 21 kN/m^3 were used for TTC Group 3N and TTC Group 4, respectively.

Stabilized groundwater depth for Profiles A and B was about 4.2 m and 4.6 m below ground surface, respectively.

Bedrock elevation was not confirmed through borehole drilling or rock coring, however, based on a review of existing subsurface information from Ontario Ministry of Energy Northern Development and Mines the soft bedrock surface is estimated to be at a depth of about 146 m below ground surface. Two bedrock depth scenarios were considered for the analyses, as the depth to the bedrock was not confirmed during the site investigation. Soil profiles A and B with source motion (i.e., bedrock of Site Class C) located at 146 m below grade were modelled as shown in Figure 1. Figure 2 shows the same profiles with the bedrock located at a shallower depth of about 70 m below grade.

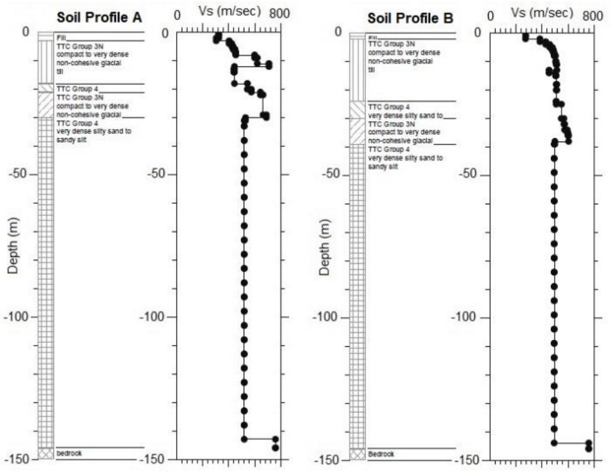

Figure 1. Soil profiles A and B with deep bedrock.

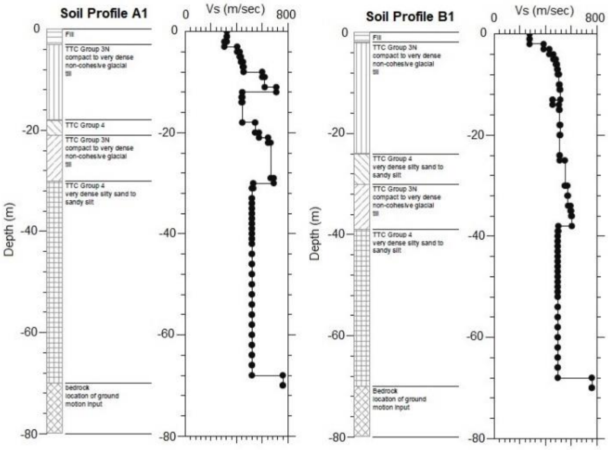

Figure 2. Soil profiles A and B with shallow bedrock.

3.2 Shear Wave Velocity

A site-specific shear wave velocity measurement was carried out using vertical seismic profiling (VSP) method to estimate the G_{max} for the subsurface material. The site-specific shear wave velocities of the subsurface soil deposits, obtained through VSP tests at two representative profiles, are presented in Figures 1 and 2. Based on the seismic site classification methodology outlined in the 2015 National Building Code of Canada (NBCC, 2015), average shear wave velocities within the upper 30 m (V_{s30}) below ground surface were used to classify the Site Class for this study. The VSP tests were carried out to depths of about

38 m and 45 m, respectively, at the location of the profiles using the existing boreholes. The average VSP shear velocity of top 30 m at the location of profiles A and B was estimated to be 542 and 497 m/sec, respectively, indicating of Site Class C (i.e., 360 m/sec < V_s < 760 m/sec in accordance with the 2015 NBCC).

3.3 Shear Modulus and Damping Ratio

Soil nonlinearity and damping increase with cyclic shear strain and shear modulus (G) decreases with cyclic shear strain during shaking periods for all soil types. Degradation relationships for the normalized material shear modulus (G/G_{max}) and damping ratio (Figures 3 and 4) obtained from site-specific geotechnical laboratory testing for non-cohesive glacial till (i.e., TTC Soil Group 3N) and silty sand/sandy silt (i.e., TTC Soil Group 4) were used in the analyses. These relationships were derived from resonant column testing for shear strains less than 0.1 % and from cyclic triaxial testing for shear strains larger than 0.1%.

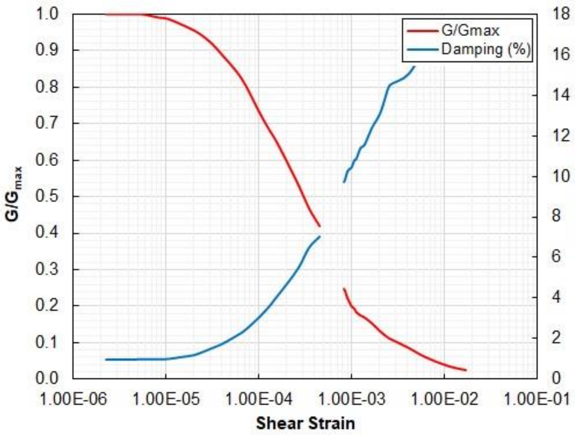

Figure 3. Variation of G/G_{max} and damping ratio with shear strain for non-cohesive glacial till TTC Group 3N.

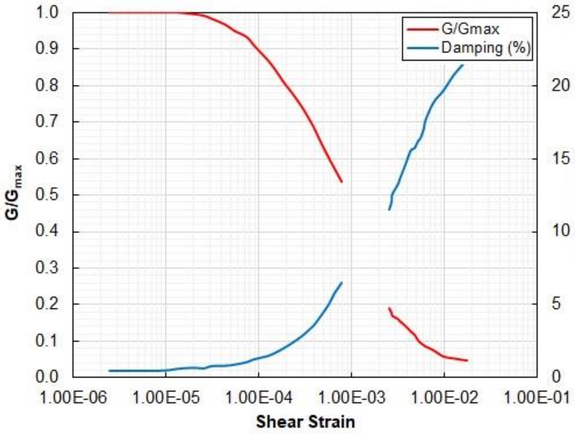

Figure 4. Variation of G/G_{max} and damping ratio with shear strain for silty sand/sandy silt TTC Group 4.

4 SELECTION OF INPUT GROUND MOTIONS

4.1 Design Earthquake

For the design of modern and critical transportation tunnels, seismic ground motions with 2 % probability of exceedance in 50 years is recommended (Federal Highway Administration -FHWA-NHI-10-034-2009). The 2015 National Building Code of Canada (NBCC) seismic hazard values (i.e., design spectral values) for seismic events with 2 % probability of exceedance in 50 years were used as the overall target for ground motion selection and scaling.

To assess what types of earthquake event as a function magnitude and distance contribute most to the hazard of the study area, the seismic hazard deaggregation was obtained from Natural Resources Canada (NRCan).

The deaggregation plots show that the high frequency motions are coming from events of moderate magnitude (M_w) of about 6.0 at distances close to the site (~40 Km). By contrast, longer period motions are controlled by large events (M_w ~7.0) in more active seismic zones at regional distances (~100-200 km). The deaggregation analysis results were considered in selection of acceleration time histories.

Based on National Earthquake Hazards Reduction Program (NEHRP, 2009), '*a suite of not less than seven appropriate ground motions shall be used in the analyses. Appropriate ground motion acceleration histories shall be obtained from records of events having magnitudes, fault distances, and source mechanisms that are consistent with those that control the risk-targeted maximum considered earthquake. If a sufficient number of appropriate recorded ground motion records is not available, appropriate simulated or modified ground motion records are permitted to be used as part of the total number required.*' NBCC (2015) suggests that a minimum of eleven (11) records of ground motions be used for scaling to target the spectrum.

Since there was an insufficient number of recorded natural earthquakes from eastern Canada or eastern North America within the range of design earthquake (i.e., M_w of 5.5 to 7.5 recorded on Site Class C at distance of 40 to 210 km) in this study, additional series of recorded ground motions from western North America as well as synthetically generated acceleration earthquake time histories were considered for the dynamic analyses.

The outputs from the 5 percent damped response spectra of the base bedrock for different seismic events were compared to the specified design spectrum of 5 percent damped for "Very dense soil and soft rock" (Site Class C) as outlined in the NBCC 2015. The eleven selected seismic events were scaled to match a target spectrum for the seismic Site Class Type C.

4.2 Fundamental Period

Natural and synthetic motions were scaled in time domain to cover a scenario period range that significantly contribute to the dynamic response of the soil column. At the location of the buried structure, overburden thickness is about 146 m and the underside of the structure is located at a depth of about 25 m below ground surface. Considering that the underground structure is constrained by the surrounding soil and is unlikely that it could move to any significant extent independently of the soil, a period range covering fundamental period of the soil column is used as target. Fundamental period of the soil column (T_s) is defined as $4H_s/V_s$, where H_s is height of soil column and V_s is weighted average of shear wave velocity over height of soil column. Selected period range between 0.15 to 2.0 times of the T were chosen as recommended by NBCC (2015). Two types of soil column with shallow and deep bedrock were used in the analysis which result in fundamental period of 0.5 sec to 1.1 sec, respectively. Therefore, a scenario period range of 0.05 to 2 sec were used as target.

As recommended by NBCC (2015) for the selection of natural ground motions compatible with the source mechanisms or seismic hazard level, only time histories with the scaling factor between 0.5 to 4 were selected. However, for the selection of synthetic ground motions simulated time histories with the scaling factor between 0.5 to 2 were selected, which is within the range of NBCC.

Acceleration time histories associated with each scaled response spectrum were selected and scaled for use as the sources of input ground motion for the dynamic analyses. The type of input ground motion was considered as “outcrop” in the ground response analysis model.

4.3 Eastern North America

The recorded ground motions were selected from Pacific Earthquake Engineering Research Center (PEER) ground motion database. A suite of three ground motions were selected from Central & Eastern North-America (PEER-NGA EAST).

Figure 5 presents the scaled spectra for the eastern North America records that match the target spectrum with a scenario period range of 0.05 to 2 seconds. As it is shown in Figure 5, the matching spectra are higher than target for periods lower than 0.4 and lower for periods higher than 1.

Table 1 presents information on the selected ground motions from Central & Eastern North-America (NGA EAST) based on the matching spectra presented in Figure 5.

Table 1. Summary of selected ground motions from PEER database for Central & Eastern North-America (NGA EAST)

RSN[1]	Earthquake Name	M_w[2]	R_{rup}[3] (km)	V_{s30} (m/sec)	SF[4]
64	Saguenay_1988-11-25	5.85	192	822	3.1
8529	Mineral_2011-08-23	5.74	124	430	2.1
10058	Sparks_2011-11-06	5.68	43	606	4.0

[1] RSN: Record Sequence Number
[2] M_w: Moment magnitude in Richter scale
[3] R_{rup}: Closest distance to rupture plane
[4] SF: Scale Factor

4.4 Western North America

To achieve large period of target spectrum, four records from western North-America that have focal mechanism of thrust (reverse)/strike-slip were selected to simulate focal mechanism of eastern Canadian earthquakes (Bent et al, 2003). Figure 6 presents the scaled spectra for the western North America records that match the large period of the target spectrum with a scenario period range of 0.8 to 5 seconds. Information on the selected ground motions from Western North-America, Shallow Crustal Earthquakes in Active Tectonic Regimes (PEER - NGA WEST), based on the matching spectra presented in Figure 6 are presented in Table 2.

Table 2. Summary of selected ground motions from PEER database for Western North-America, Shallow Crustal Earthquakes in Active Tectonic Regimes (NGA WEST)

RSN[1]	Earthquake Name	M_w[2]	R_{rup}[3] (km)	V_{s30} (m/sec)	SF[4]
4002	San Simeon_ CA	6.52	187	376	1.88
4017	San Simeon_ CA	6.52	159	515	1.48
1769	Hector Mine	7.13	196	460	1.86
1804	Hector Mine	7.13	173	400	2.43

[1] RSN: Record Sequence Number
[2] M_w: Moment magnitude in Richter scale
[3] R_{rup}: Closest distance to rupture plane
[4] SF: Scale Factor

4.5 Synthetic Ground Motions

The synthetic acceleration time histories were selected for Site Class C from SEIMOTOOLBOX developed by Atkinson and Beresnev (1998). They indicated that the uniform hazard spectrum (UHS) corresponding to a 2 percent probability of exceedance in 50 years for eastern Canadian sites could be approximated using an earthquake event of moment magnitude (M_w) equal to 6.0 to represent the short-period hazard, plus an earthquake event of moment magnitude (M_w) equal to 7.0 to represent long-period hazard. The distance from the source is dependent on the seismicity rates at each location. Figure 7 presents the scaled spectra for the synthetic events that match the target spectrum within the desired scenario period range of 0.05 to 2 seconds. Table 3 presents information on selected synthetic motions used in this study.

Table 3. Summary of selected synthetic motions from Atkinson SEISMOTOOLBOX database

Earthquake Name	M_w[1]	Fdist[2] (km)	Azimuth	V_{s30} (m/sec)	SF[4]
east6c2acc28	6	26.3	218.0	C	0.8
east6c2acc32	6	25.6	46.7	C	0.7
east6c2acc43	6	24.8	29.1	C	0.9
east7c2acc3	7	41.6	304.4	C	0.6
east7c2acc45	7	98.6	157.7	C	1.1

[1] M_w: Moment magnitude in Richter scale
[2] Fdist: Closest distance to fault
[3] C: Site Class C

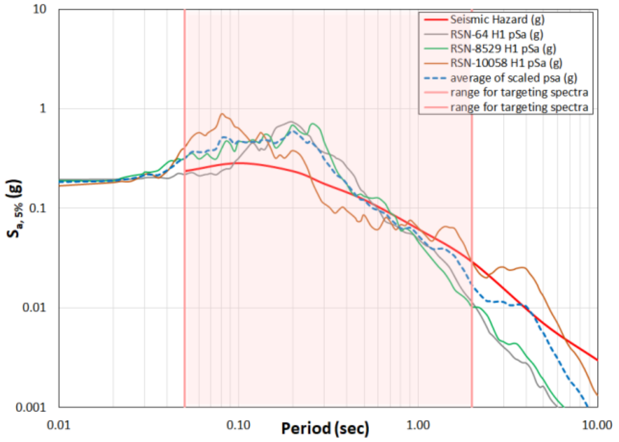

Figure 5. Scaled response spectra for selected ground motions from NGA EAST and target design spectrum

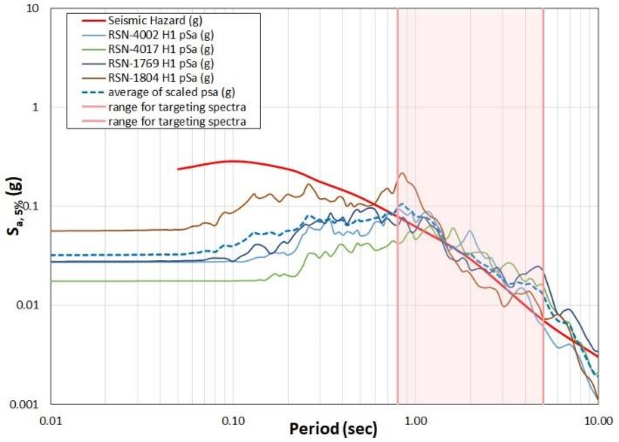

Figure 6. Scaled response spectra for selected ground motions from NGA WEST and target design spectrum

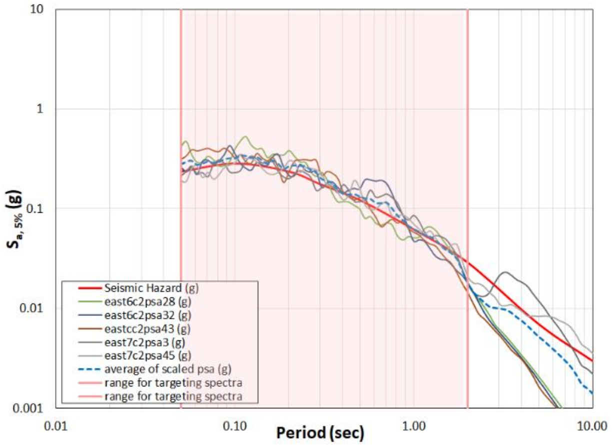

Figure 7. Scaled response spectra for Atkinson synthetic motions and target design spectrum

4.6 Ground Motions Comparison

Three representatives of the scaled acceleration time histories (i.e. one natural record from NGA EAST, one natural record from NGA WEST and one synthetic motion from SEISMOTOOLBOX) used in this study are presented in Figure 8 along with their simplified Arias Intensity/Power, which is a measure of earthquake intensity that captures the potential destructiveness of an earthquake. Strong duration of NGA East RSN-64 is approximately 42 sec whereas for NGA West RSN-1804 and synthetic east6c2acc28 strong motion last for about 30 and 5 sec, respectively.

Arias Intensity of NGA East RSN-64 was more than 40% higher than the Arias Intensity of NGA West RSN-1804 and synthetic east6c2acc28. It is noted that Arias Intensity is function of the integration of squared acceleration (i.e., power) which is more related with the destructiveness of a dynamic event or its energy dissipation than its maximum acceleration. Strong motion duration was considered for calculation of Arias Intensity.

A quick comparison between these ground motions indicates that there is an expectation that the NGA east motions may result in higher responses, as the duration of these motions are higher than the other two representatives. Longer duration of dynamic loading (i.e., more cycles) could results in deformation accumulation in soil as it experiences oscillations and cycles of going non-linear. Although equivalent linear analysis was used in this study, soil non-linearity was implicitly included by using the stiffness and damping degradation curves. Higher non-linearity results in higher shear strain responses.

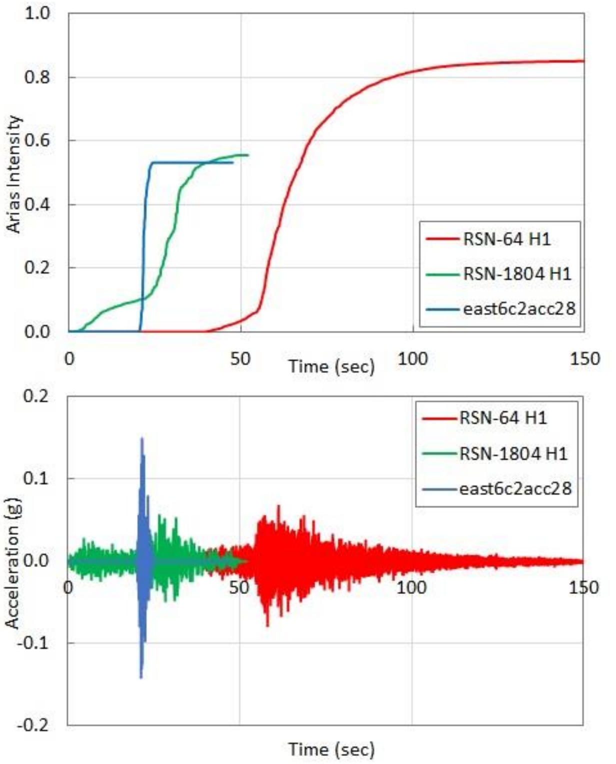

Figure 8. Comparison of scaled acceleration time histories and their associated simplified Arias Intensities/Power

5 RESULTS AND DISCUSSION

The results of the one-dimensional ground response analyses are shown in terms of the maximum free-field shear strain distributions versus elevation for each input ground motion in Figures 9 to 12. An average shear strain was also estimated based on the response of the input ground motions shown on each figure.

5.1 Deep Bedrock

Responses to natural and synthetic ground motions are presented in separate plots in Figures 9 and 10 for two soil profiles A and B, respectively, with the bedrock located about 146 m below ground surface.

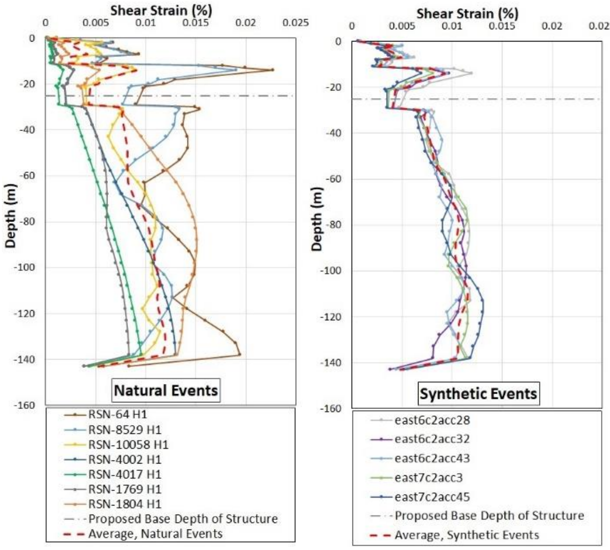

Figure 9. Free field shear strain versus elevation for Profile A with deep bedrock

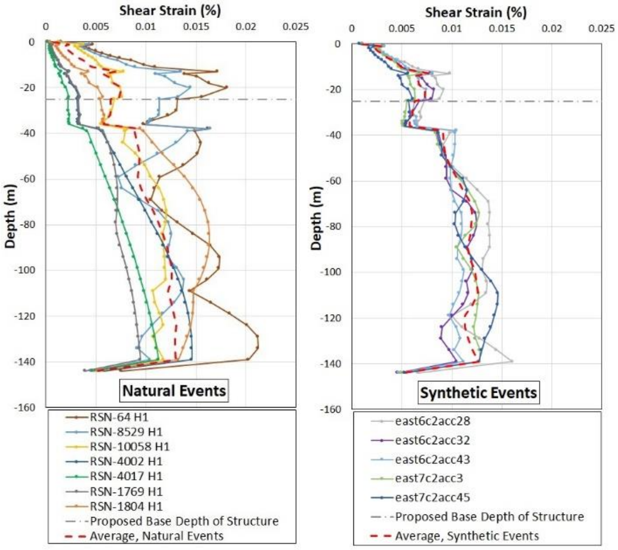

Figure 10. Free field shear strain versus elevation for Profile B with deep bedrock

The results of analyses for Profile A with deep bedrock indicate that the local maximum free-field shear strain above the proposed base of underground structure is estimated to be about 0.023% at approximate depth of 14 m below ground surface induced by the NGA EAST RSN-64.

The results of analysis for Profile B with deep bedrock indicate that the local maximum free-field shear strain above the proposed base of underground structure is estimated to be about 0.018% at approximate depth of 20 m below ground surface induced by the NGA East RSN-64. Table 4 summarizes the maximum and average shear strain responses.

For both soil profiles with deep bedrock, the NGA West motions resulted in lower free field shear strains while the NGA East motions resulted in higher values. The shear strains as the result of the synthetic motions are within the values of natural earthquakes. The average of responses to natural motions were generally similar to the average of responses to synthetic motions. However, the average response may not necessarily reflect the soil non-linearity due to the level of energy and random nature of natural earthquakes.

Table 4. Summary of local maximum shear strain responses for soil profiles A and B.

Soil Profile	Corresponding Motion	Shear Strain (%)	Elevation (m)
A	RSN-64 H1	0.023	149.0
	east6c2acc28	0.012	149.0
	Natural Events	0.009*	149.0
	Synthetic Events	0.009*	149.0
	All Events	0.009*	149.0
B	RSN-64 H1	0.018	143.0
	east6c2acc28	0.01	151.0
	Natural Events	0.008*	143.0
	Synthetic Events	0.008*	151.5
	All Events	0.008*	151.5

* Local maximum shear strain from *average* of responses.

5.2 Shallow Bedrock

Responses to natural and synthetic ground motions are shown in separate charts in Figures 11 and 12 for two soil profiles A and B, respectively, with bedrock assumed to be located at about 70 m below ground surface (shallow).

The results of analysis for Profile A with shallow bedrock indicate that the local maximum free-field shear strain above the proposed base of underground structure is estimated to be about 0.024% at approximate depth of 14 m below ground surface induced by the NGA EAST RSN-64.

The results of analysis for Profile B with shallow bedrock indicate that the local maximum free-field shear strain above the proposed base of underground structure is estimated to be about 0.019% at approximate depth of about 20 m induced by the NGA EAST RSN-64. Table 5 summarizes the maximum and average shear strain responses.

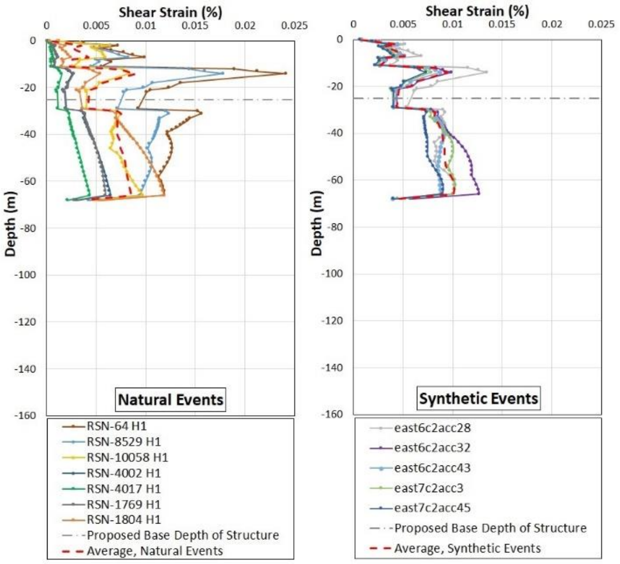

Figure 11. Free field shear strain versus elevation for Profile A with shallow bedrock

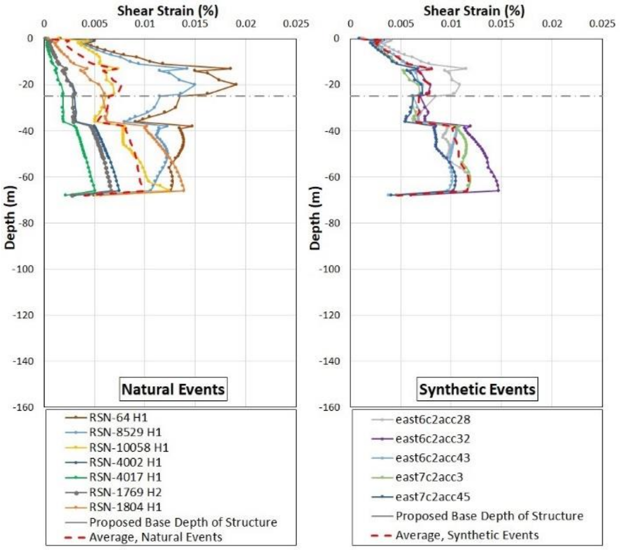

Figure 12. Free field shear strain versus elevation for soil profile B with shallow bedrock

For both soil profiles with shallow bedrock, the NGA West motions resulted in lower free field shear strains while the NGA East motions resulted in higher values. The shear strains as the result of the synthetic motions are within the values of natural earthquakes. The average of responses to synthetic motions were reasonably similar to the average of responses to natural motions. However, the average response may not necessarily reflect the soil non-linearity due to level of energy and random nature of natural earthquakes.

Table 5. Summary of local maximum shear strain responses for soil profiles A and B.

Soil Profile	Corresponding Motion	Shear Strain (%)	Elevation (m)
A	RSN-64 H1	0.024	149.0
	east6c2acc28	0.013	149.0
	Natural Events	0.009*	151.5
	Synthetic Events	0.009*	149.0
	All Events	0.009*	149.0
B	RSN-64 H1	0.019	143.0
	east6c2acc28	0.012	151.0
	Natural Events	0.008*	143.0
	Synthetic Events	0.008*	151.5
	All Events	0.008*	151.5

* Local maximum shear strain from *average* of responses.

5.3 Sensitivity Analysis

To investigate the effect of scenario period range for the PEER-NGA EAST on free-field shear strain responses, sensitivity analyses were performed on Profile A. As described in Section 4.3, the matching spectra are higher than the target spectra for a period range between 0.05 sec to 0.4 sec (Figure 5). This range of period is not close to the fundamental period for this profile (i.e., 1.1 sec) but affects the shear strain values. As shown in Figure 13, the NGA East spectra were re-matched with the target spectrum within this new period range to find a new scaling factor for these earthquakes (i.e., lower scaling factor).

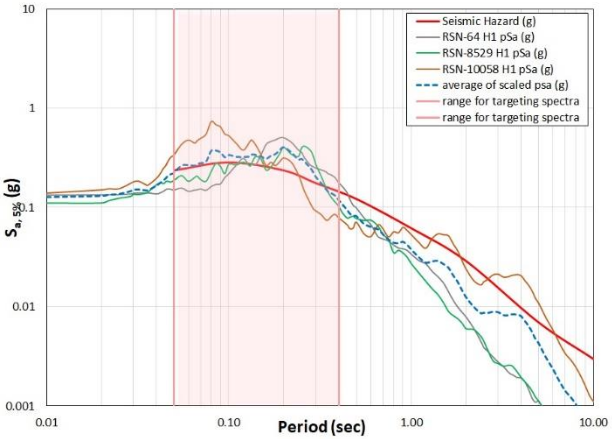

Figure 13. Scaled response spectra for selected ground motions from NGA EAST and target design spectrum (0.05 sec < T_s < 0.4 sec)

The results of the analyses using the re-scaled earthquakes are shown in Figure 14 along with the previous analysis for the same profile. As expected, the shear strains are lower in the new analysis with reduced scaling factor, which affects the entire range of period of spectra from 0.05 to 2 sec. To better understand, the effect of high frequency contents (i.e., periods lower than 0.4 sec) of the NGA East on the free field in this case, a cut off frequency of 2.5 Hz was considered in the analysis and it was observed that the free field shear strains would further decrease by removing the high frequency contents.

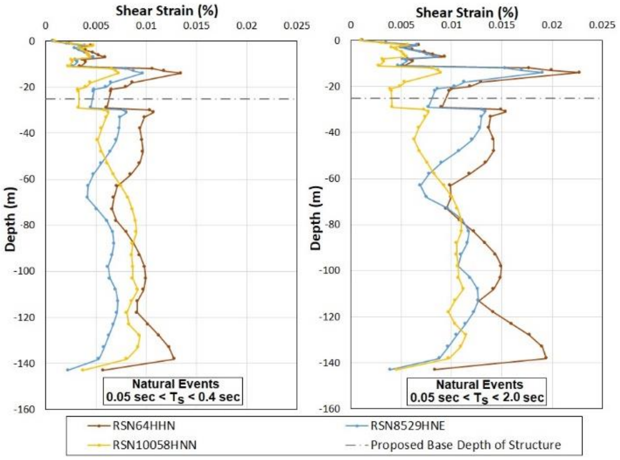

Figure 14. Free field shear strain versus depth for Profile A using NGA East matched with target spectrum for different period ranges)

This result indicates that the maximum shear strain value (Figure 14) obtained from the re-scaled spectra for the NGA East motions are close to the maximum shear strain value obtained from the synthetic motion as presented in Figure 9.

6 CONCLUSIONS

The effect of natural and synthetic earthquake ground motions on free-field shear strain was investigated in a case study. Results of free-field shear strain analysis for soils of Site Class C assuming two different depths (i.e., shallow and deep) for the location of bedrock of Class C were presented.

The results showed that maximum responses correspond to the NGA EAST ground motions. For both shallow and deep bedrock scenarios, the NGA West motions resulted in lower free field shear strains while the NGA East motions resulted in higher values. The shear strains as the result of the synthetic motions are within the values of natural earthquakes. The average of responses to natural motions were reasonably similar to the average of responses to synthetic motions for both soil profiles. This indicates that the synthetic motions are very useful when sufficient natural earthquake records are not available. However, the average response may not necessarily reflect the soil non-linearity due to level of energy and random nature of natural earthquakes. It is important to ensure that the natural earthquakes spectra are matching with the target spectrum within the desirable periods to avoid any overestimation.

Some codes (e.g., Eurocode 8) state that the average shear strains can be used instead of the most unfavorable ones (i.e., maximum free field shear strains) only if the specified minimum number of records (e.g., seven records as per Eurocode 8) are used in the analyses. In this study, although seven natural records were used, it was shown that the shear strains obtained from the natural earthquakes are scattered while the NGA EAST motion resulted in the most unfavorable response. The authors suggest that since the unfavorable response corresponds to a natural event that may reflect the soil non-linearity, the unfavorable response should be used for the design. The sensitivity analysis indicated that the maximum free field shear strain corresponding to an NGA EAST motion reduced to a value slightly higher than the maximum value obtained from the synthetic motions when the NGA EAST spectra were rescaled to better match the target spectrum in the lower period range.

In case that unfavorable response corresponds to a synthetic event, it may be more reasonable to use the average response instead of the unfavorable one.

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