Ninth Canadian Conference on
Earthquake Engineering
Ottawa, Ontario, Canada
26-29 June 2007

INELASTIC DEMANDS FROM GROUND MOTIONS RECORDED DURING THE 2003 TOKACHI-OKI SUBDUCTION INTERFACE EARTHQUAKE

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ABSTRACT

Ground motions recorded during the 2003 Tokachi-Oki Earthquake in Japan provide the opportunity to systematically evaluate the inelastic displacement demands expected from subduction ground motions. The inelastic displacements for SDOF systems subjected to the Tokachi-oki records are consistently higher than the inelastic displacements from crustal ground motions. The results of the study suggest that current procedures for estimating displacement demands may underestimate the inelastic displacements imposed by subduction ground motions. An adjustment to the C_1 coefficient of the Displacement Modification Method is proposed to account for the additional demands from subduction ground motions.

Introduction

The world's largest earthquakes occur in subduction zones. As the oceanic plate is being subducted, a locked portion of the fault is typically formed and when this locked portion releases, large magnitude megathrust or subduction interface earthquakes occur. These events typically have a magnitude larger than 8.0 and have a longer duration of strong motion than associated with crustal events (Onur *et al.*, 2006). Significant structural damage has been observed up to 200 km away in previous megathrust earthquakes (e.g. 2004 Sumatra, 1985 Mexico, 1964 Alaska). Some examples of megathrust earthquakes include Prince William Sound, Alaska (1964, M=9.2; no strong motion records); Michoacan, Mexico (1985, M=8.0); Valparaiso, Chile (1985, M=8.0); Arequipa, Peru (2001,M=8.4); Tokachi-Oki, Japan (2003, M=8.3); Sumatra, Indonesia (2004, M=9.2; no strong motion records). There are a limited number of strong motion records from the Mexico, Chile and Peru earthquakes while hundreds of records are available from the Tokachi-Oki earthquake.

Increasingly nonlinear static analysis procedures are being used to estimate the inelastic demands imposed by earthquakes. The Displacement Modification Method from FEMA 356 (ASCE, 2000), and recently updated in FEMA 440 (ATC, 2005), is often used to estimate the target displacement. The relationships which modify the elastic spectral displacement were derived from statistical studies using earthquake records exclusively from crustal events. Therefore, the availability of records from the Tokachi-Oki earthquake provides the opportunity to examine the applicability of these relationships, or coefficients, when structures are subjected to long-duration subduction ground motions.

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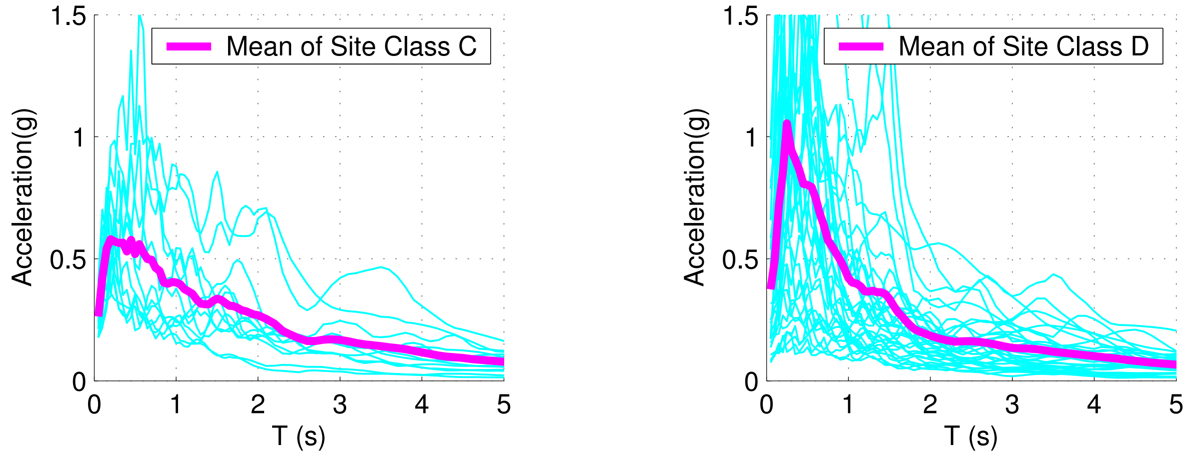

Figure 1. Acceleration spectra of subduction ground motions recorded on site class C and D soils.

Ground Motion Records

In Japan, there are three separate subduction structures due to the triple-junction to the south of Japan where three plates (Eurasia, Philippine, and Pacific) come together. In southwest Japan (Nankai), subduction of the Philippine Plate under the Eurasian Plate is underway, while in northeast Japan (Kuril) Pacific Plate subducts beneath the Eurasian Plate, and at the Izu-Bonin trench, the Pacific Plate is subducting under the Philippine Plate. The ages and the convergence rates of the three subduction zones vary, with Kuril and Izu-Bonin being considerably older than Nankai, and Kuril converging faster than Izu-Bonin and Nankai (Heaton and Kanamori, 1984). The 2003 Tokachi-oki earthquake occurred at a depth of 47 km in the Kuril subduction zone approximately 70 km off the southeast coast of Hokkaido Island.

There were 48 records available within 150km of the epicenter from the Kyoshin Network (K-Net) and the Kiban-Kyoshin Network (Kik-Net). These were recorded on NEHRP site class C, D and E sites, although, due to the limited number of motions on site class E, only the results from site classes C and D have been included in this study. (It should be noted that shear wave velocities were not available for all sites to a depth of 30m, and therefore, to calculate the average shear wave velocity for this range, the last known value was used to extrapolate the results to 30m. This is a conservative assumption as typically the shear wave velocity increases with depth and therefore the actual average shear wave velocity would be somewhat larger than this value.) Table 1 summarizes the properties of each ground motion with an epicentral distance between 71 and 152 km. While epicentral distance is not the ideal parameter for determining the distance with subduction sources, it provides a reasonable distance parameter which is easily obtained. However, it must be noted that epicentral distances cannot be directly compared between different subduction zones due to the differences in the width and dip angle of the fault. Further study is required to determine the applicability of the results from this study to other subduction zones.

The ground motions range in peak ground acceleration from 66 cm/s^2 (~0.07 g) to 969 cm/s^2 (~1.0 g), and have a range of peak ground displacements of 5.7 cm to 54.7 cm. Since, in this study, the concern is in calculating ratios of displacement demands from different systems (e.g. EPP vs. Elastic) for strengths normalized to the intensity of the ground motion, the variability in seismic demands apparent in Table 1 for sites of similar distance and site class is not of significant concern. Fig. 1 shows the pseudo-acceleration spectra for the subduction ground motions. The mean spectral accelerations and displacements of the subduction ground motions are significantly higher than the mean values of crustal ground motions (Mattman, 2006). This increased level of demand, combined with the additional number of loading cycles, will affect the inelastic displacement demands of the SDOF systems considered in this study. This increased level of demand is a combination of the larger magnitude of the subduction event as well as the increased long period frequency content of the subduction ground motions (CREW, 2005).

Table 1. Summary of Tokachi-Oki ground motions with epicentral distance between 71 and 152km.

Station Name	Station Code	Distance (km)	Component (EW)			Component (NS)			NEHRP Site Class*
			PGA (cm/s^2)	PGV (cm/s)	PGD (cm)	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)	
ERIMOMISAKI, K-Net	HKD112	71	113.5	11.1	6.1	141.7	12.1	5.9	D
MEGURO, K-Net	HKD113	74	205.1	16.1	5.8	156.2	13.5	7.7	C
ERIMO, K-Net	HKD111	81	66.0	12.0	8.6	66.9	13.7	8.7	D
HIROO, K-Net	HKD100	84	969.0	49.3	14.1	809.5	40.7	8.5	D
SAMANI, K-Net	HKD110	102	174.9	28.3	13.1	215.8	39.1	20.2	D
TAIKI, K-Net	HKD098	103	345.5	91.4	31.5	365.3	75.3	38.7	C
SAMANI, Kik-Net	HDKH07	104	197.0	39.7	20.3	169.5	27.2	15.1	C
TAIKI, Kik-Net	TKCH08	109	499.0	45.5	15.4	415.6	22.6	6.1	D
URAKAWA, K-Net	HKD109	117	238.5	33.0	12.8	184.5	35.6	15.3	D
URAHORO, K-Net	HKD091	119	374.4	61.3	20.3	391.8	54.0	18.9	E
CHOKUBETSU, K-Net	HKD086	120	800.5	102.8	54.7	732.7	65.2	24.8	D
TOYOKORO, Kik-Net	TKCH07	123	404.4	76.4	21.9	365.8	93.4	33.9	D
NAKASATSUNAI, K-Net	HKD096	128	199.0	33.9	16.0	176.9	24.2	10.5	C
SHIRANUKA, K-Net	HKD085	131	277.6	47.1	22.8	257.0	39.2	17.8	E
SHIRANUKA-S, Kik-Net	KSRH09	134	387.2	69.0	33.9	368.5	43.1	18.5	D
KUSHIRO, K-Net	HKD077	136	410.4	44.1	11.3	314.3	35.6	11.8	D
MITSUISHI, K-Net	HKD108	136	165.8	15.9	7.8	161.2	20.7	11.4	D
IKEDA, K-Net	HKD092	138	608.9	53.1	15.5	436.3	49.4	26.0	D
OBIHIRO, K-Net	HKD095	146	190.6	36.1	19.4	148.4	37.1	27.2	C
AKAN, K-Net	HKD084	148	353.8	40.5	19.4	352.3	35.6	20.4	C
NOYA, K-Net	HKD107	148	75.5	16.0	9.6	103.3	24.2	7.4	D
AKAN-S, Kik-Net	KSRH02	148	405.2	40.8	20.3	373.6	40.1	18.7	D
MEMURO, Kik-Net	TKCH06	149	144.3	39.2	20.6	163.5	31.1	17.9	D
TSURUI-S, Kik-Net	KSRH07	152	493.8	40.8	19.9	338.6	36.4	17.9	D

*Average shear wave velocity was extrapolated for some sites.

Displacement Modification Method

The Displacement Modification Method in FEMA 440 consists of modifying the elastic spectral displacement to account for the nonlinear behaviour of the structure. The goal of the procedure is to determine the target displacement (δ_t) at which the seismic capacity of the structure will be assessed. The target displacement is given by:

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \tag{1}$$

where S_a is the spectral acceleration at the effective period, T_e; C_0 is the coefficient to relate the spectral displacement from the equivalent SDOF system to the roof displacement of a multiple degree of freedom system; C_1 is the coefficient which relates the maximum displacement of an elastic perfectly-plastic (EPP) SDOF system to the equivalent linear elastic system; C_2 represents the effect of the hysteretic shape, strength, and stiffness degradation; and g is the acceleration due to gravity. The current study focuses on the inelastic displacement demands for SDOF systems; hence, coefficients C_1 and C_2 are of particular interest. FEMA 440 recommends the following expressions to estimate C_1 and C_2:

$$C_1 = 1 + \left(\frac{R-1}{aT_e^2} \right) \quad (2)$$

$$C_2 = 1 + \frac{1}{800} \left(\frac{R-1}{T} \right)^2 \quad (3)$$

where $R = mS_a/F_y$, m is the mass, and F_y is the yield strength of the structure. The coefficient a can be taken as 130, 90, 60 for site classes B, C and D, respectively. Eq. 2 was derived based on the analyses conducted by several researchers using crustal ground motions (e.g. Ruiz-Garcia and Miranda 2003, Ramirez *et al* 2002, Chopra and Chintanapakdee 2004). For periods less than 0.2s, C_1 is limited to the value calculated for T_e equal to 0.2s, and for periods greater than 1.0s C_1 is equal to 1.0. These conditions are imposed on C_1 since the inelastic displacements were found to be comparable to the elastic displacements for periods larger than 1.0s (so-called "equal-displacement rule"), and for periods shorter than 0.2s the effects of soil-structure interaction are expected to influence the amplification of the elastic response. C_2 is also capped for periods below 0.2s, and for periods greater than 0.7s is equal to 1.0. Eq. 3 suggests that the hysteretic shape and stiffness degradation has very little impact on the displacement demands for an inelastic system, particularly for periods greater than 0.7s. The current study will focus on the assessment of the C_1 and C_2 coefficients for regions affected by subduction ground motions.

Inelastic Displacement Demands

Elastic-Perfectly Plastic Systems

Single-Degree-of-Freedom (SDOF) analyses were conducted using the 48 subduction ground motions described above. The models used had 2 hysteretic behaviours, either 50 or 70 periods of vibration and 9 relative strength values (R). The two hysteretic behaviours consisted of an elastic perfectly-plastic (EPP) and stiffness degrading model similar to a modified Clough (Clough, 1966; Mahin and Lin, 1983). The results of these analyses are discussed below. The results from other strength and stiffness degrading hysteretic models are presented elsewhere (Mattman, 2006).

The first model used for analysis was the elastic-perfectly-plastic (EPP) hysteretic model which was used with 70 periods of vibration (0.05s to 2.0s in increments of 0.05s and 2.1s to 5.0s in increments of 0.1s). The inelastic displacement of the EPP system was recorded and compared to the elastic spectral displacement similar to the research conducted by Ruiz-Garcia and Miranda (2003) and others (Krawinkler *et al.*, 2003, Chopra and Chintanapakdee, 2004, Miranda, 2000). The mean of the ratio of the maximum inelastic displacement to the elastic spectral displacement is shown in Fig. 2 for the 12 site class C and 32 site class D ground motions.

The inelastic displacement of the SDOF systems are significantly higher than the elastic displacement in the short period range for both site class C and D ground motions. The inelastic displacement ratios exceed a factor of three for short periods. These high levels of inelastic displacement ratios are of concern, but are mitigated by two different factors. First, structures with very short periods have very small elastic spectral displacements and thus the absolute inelastic displacements experienced by the structure may still be within tolerable limits. Second, many structures which have very short periods have a response that is greatly affected by the interaction between the surrounding soil and the structure. If the effects of soil-structure interaction are included in the analysis, the inelastic displacements calculated will be reduced (ATC, 2005).

As the period increases, the inelastic displacement ratios decrease and approach a value of 1.0 which indicates that the inelastic displacement is the same as the elastic displacement. Above this point the so-called "equal displacement rule" provides a good approximation of the inelastic displacement. As noted above, the C_1 coefficient from FEMA 440, has a value of 1.0 for periods of vibration greater than 1.0s. The mean inelastic displacement ratios for the subduction records approach unity at periods greater than 3.0s for relative strength values, *R*, greater than 2.0. In fact, it can be seen that the equal displacement approximation would underestimate the mean response by approximately 25% for a ductile system with *R* equal to 4 and a 2.3s period of vibration. Fig. 2 shows that the transition to the use of the equal displacement rule happens at short periods for $R = 1.5$ and $R = 2.0$, but happens between approximately 3.0s and 3.5s for the other relative strength values used in this study.

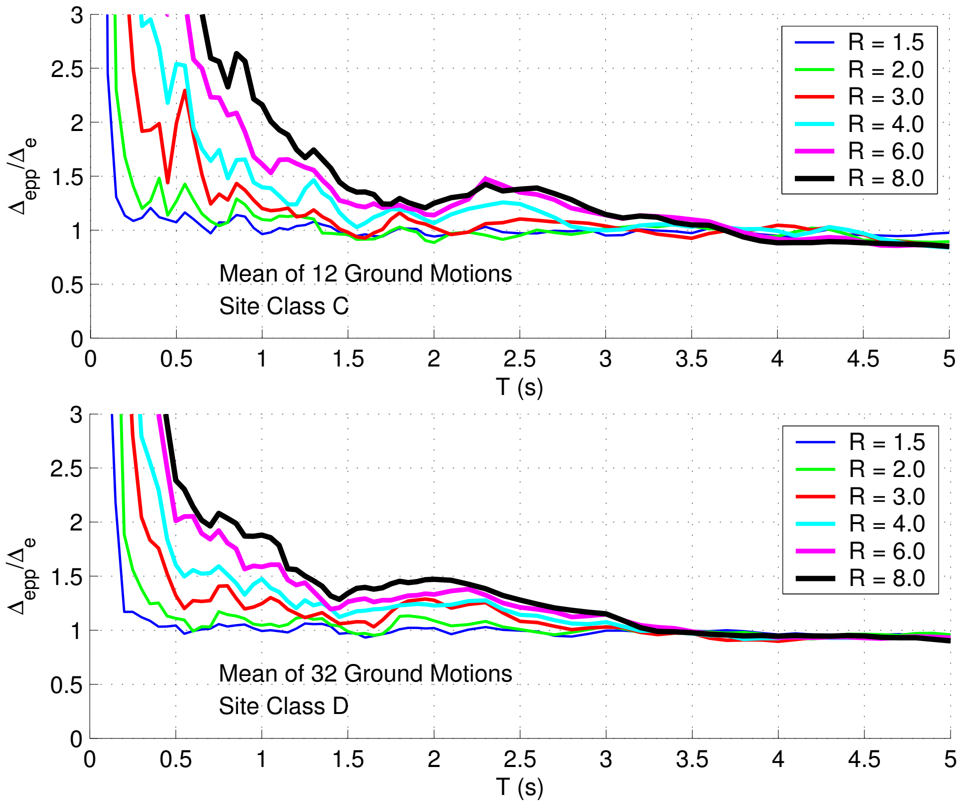

Figure 2. Mean inelastic displacement ratios for EPP hysteretic model for subduction ground motions.

Stiffness Degrading Systems

The second model considered contains stiffness degradation within the hysteretic model to account for the effect of damage on the structure through repeated loading. The model utilized is a peak-oriented stiffness degrading model similar to the Modified Clough model (Mahin and Lin, 1983, Clough, 1966). The C_2 coefficient in FEMA 440 is intended to incorporate the increased inelastic displacements that result from stiffness degradation and strength degradation that happens between cycles. Therefore, when examining the inelastic displacements of the stiffness degrading model, they should be compared with the inelastic displacements of the equivalent EPP system. Thus, the mean ratio of the inelastic displacement of the stiffness degrading system to the inelastic displacement of the EPP system is presented in Fig. 3 for the subduction ground motions. The effect of the stiffness degradation is significant for short period structures (i.e. T<0.2s). The maximum value of this ratio for site class C and D is at $T = 0.05s$, the shortest period of analysis, and for the strongest system with $R = 1.5$. However, if the shortest periods are removed, the increases in the inelastic displacement from the EPP to the stiffness degrading model are small. For periods greater than 1.0s and 0.55s for site class C and D respectively, the inelastic displacements from the EPP system are in fact greater than or equal to that of the stiffness degrading system.

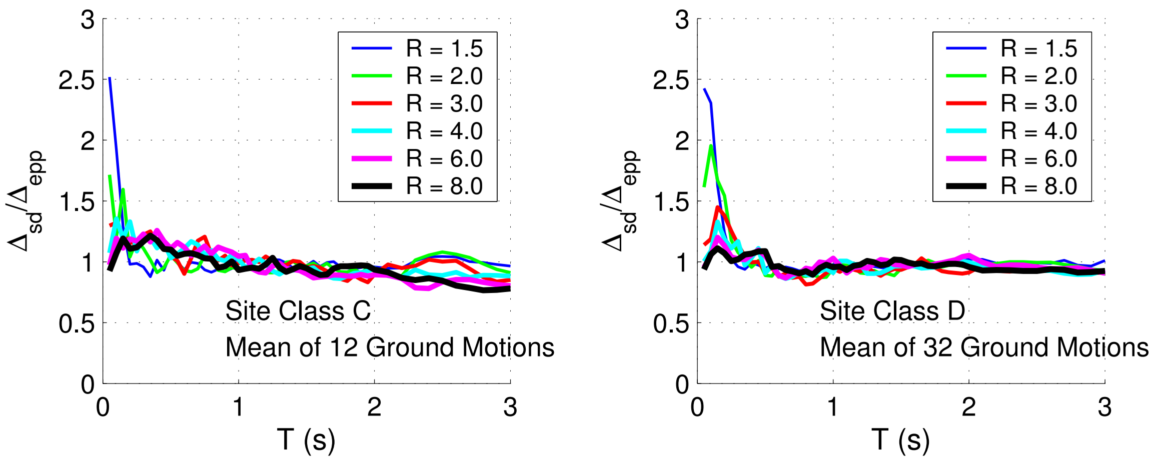

Figure 3. Mean inelastic displacement to EPP ratios for stiffness degrading hysteretic model for subduction ground motions.

Comparison with Crustal Ground Motions

The EPP model above was also analyzed with 40 ground motions recorded from crustal sources (20 from site class C and 20 from site class D). These ground motions, used in the development of the FEMA 440 recommendations (ATC, 2005), were recorded during the following California earthquakes: San Fernando, Imperial Valley, Morgan Hill, Palm Springs, Whittier Narrows, Loma Prieta, Landers, and Northridge. Further details on the crustal ground motions can be found in Mattman (2006). When the mean inelastic displacement ratios for the crustal ground motions were examined, the transition to "equal displacement" region was observed at a period of approximately 1.2s for site class C and 1.4s for site class D (Mattman, 2006). The mean inelastic displacement ratios for the subduction ground motions can be considerably higher than those observed for the same system subjected to the crustal ground motions. Since the inelastic displacement ratios are higher for the subduction records, it is logical that the equal displacement rule would become applicable at a higher period of vibration.

Ruiz-Garcia and Miranda (2003) observed an increase in inelastic displacement ratios with larger magnitude earthquake ground motions for short periods of vibration. While the inelastic displacement ratios of the subduction records are generally higher than those from the crustal records for all periods of vibration, the larger inelastic displacement ratios at the shorter periods may be the result of the larger magnitude of the Tokachi-Oki Earthquake compared with that of the crustal earthquakes. The larger inelastic displacement ratios in the analyses with higher periods of vibration may be due to either the richer long period content found in subduction records (CREW, 2005) or an extension of the effect of the higher magnitude event. Since most large magnitude (M_w>8) earthquakes result from subduction sources, it is unclear, but not necessarily significant, whether the increase in the inelastic displacement ratio is due to a magnitude dependence or a source dependence.

The mean inelastic displacement ratios of the subduction ground motions has been divided by the mean inelastic displacement of the crustal ground motions and shown in Fig. 4. The effect of the subduction ground motions, whether through the enriched long period content or simply magnitude effects, increases the inelastic displacement ratios when compared to those from crustal ground motions. The mean ratio of the subduction records is up to 3 times higher than that from the crustal records for periods less than 1.0s. For periods greater than 1.0s, the mean inelastic displacement ratio is still significantly higher than the crustal inelastic displacement ratio although the effect is more pronounced in the site class C records than in the site class D records. The effect of the subduction ground motions is more prominent as the strength of the system decreases (i.e. R increases) as the inelastic displacement ratios for the $R = 8$ system are much larger when subjected to the subduction ground motions whereas for the $R = 1.5$ systems, the effect is negligible for period of vibration greater than approximately 0.25s.

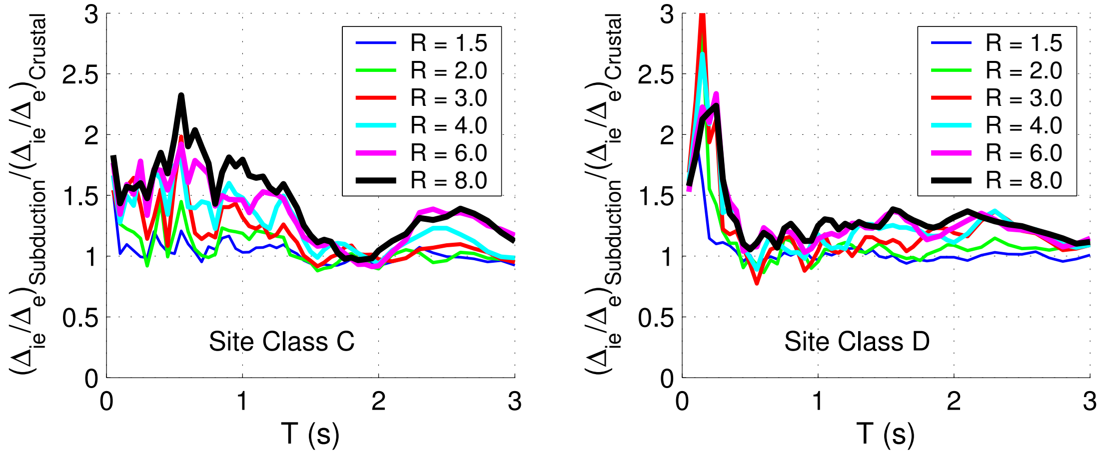

Figure 4. Ratio of the mean inelastic displacement ratios for subduction ground motions to the mean inelastic displacement ratios for crustal ground motions.

Comparison with C_1 and C_2 from FEMA 440

The impact of the subduction ground motions can be also be observed in Fig. 5 which compares the inelastic displacement ratios of the subduction records with the corresponding values of the C_1 coefficient found in FEMA 440. Recall that the C_1 coefficient is intended to capture the increased displacements associated with inelastic behaviour and does not include the effects of strength or stiffness degradation. For periods of vibration less than 0.5s, the C_1 coefficient does a poor job of capturing the inelastic displacement ratios of the EPP systems using the subduction ground motion set. This underestimation is somewhat mitigated by the effects of soil-structure interaction which must be considered in accordance of FEMA 440. While the C_1 coefficient does a better job of predicting the response for periods larger than 0.5s, there is still significant underestimation, particularly for the site class C ground motions. For a ductile system with R = 4, C_1 underestimates the inelastic displacement by factors of 2.5 and 3 at a period of 0.2s, and by factors of 1.4 and 1.5 at a period of 1.0s for site classes C and D, respectively. Since C_1 is equal to unity for periods greater than 1.0s (the start of the "equal displacement" region for crustal ground motions), the ratio plotted in Fig. 5 for $T > 1.0s$ represents the inelastic displacement ratio for these systems. The underestimations of the mean inelastic displacement ratios by the FEMA 440 C_1 factor will result in an unconservative estimate of the inelastic demand for regions affected by subduction ground motions similar to those considered in this study.

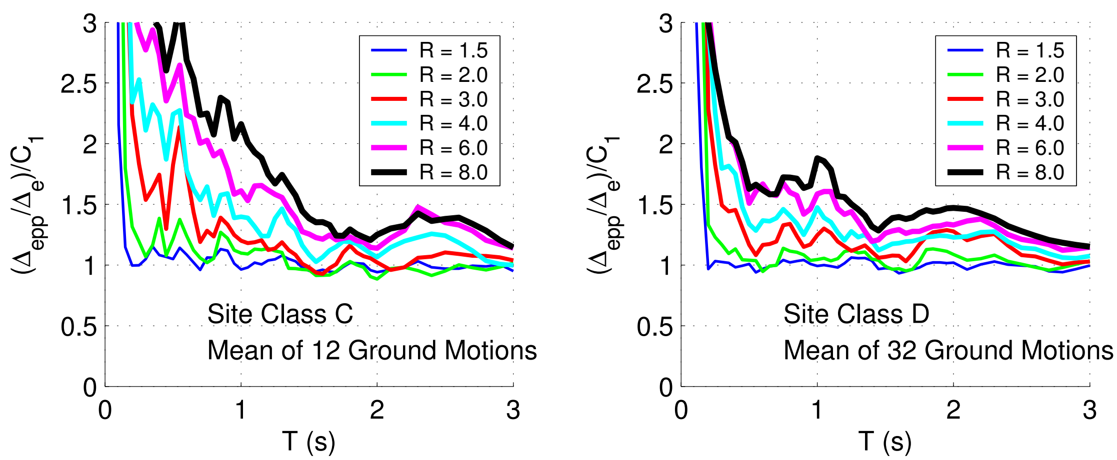

Figure 5. Ratio of inelastic displacement ratio for subduction ground motions from Figure 2 to C_1.

To determine the degree to which the increased displacements from stiffness degradation are captured by the C_2 coefficient in FEMA 440, the mean ratio of the inelastic displacement from the stiffness degrading systems to the inelastic displacement of the EPP model was divided by the value of C_2 (Fig. 6). The C_2 coefficient from FEMA 440 provides a conservative estimate of this ratio with the exception of systems with low *R* values in the very short period range as the C_2 coefficient is small for lower *R* values and thus doesn't capture the increased displacement observed in Fig. 3. As discussed above, discrepancies in the short period range are not of significant concern due to other mitigating factors, and hence, the FEMA 440 C_2 coefficient can be considered appropriate for subduction ground motions.

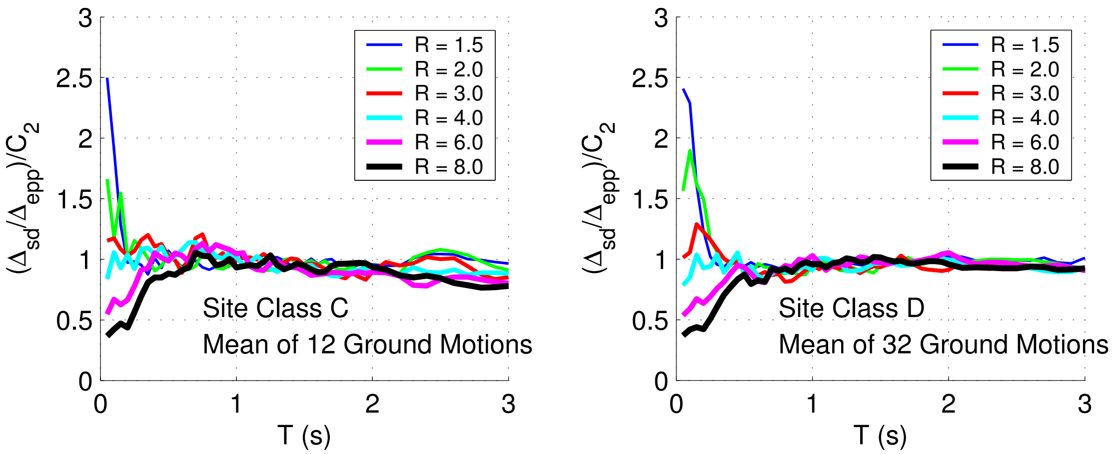

Figure 6. Ratio of increased displacement from stiffness degradation from subduction ground motions to C_2 in FEMA 440.

C_1 Coefficient for Subduction Ground Motions

As it was observed in Fig. 4, the inelastic displacement ratios of the EPP systems subjected to the subduction ground motions were greater than those of the same systems subjected to the crustal ground motions. Fig. 5 illustrates that the inelastic displacement ratios of the EPP systems were not well captured by the C_1 coefficient in FEMA 440 and therefore to achieve better predictions of the target displacement, an improvement of the C_1 coefficient has been calculated. By examining the results presented in Fig. 5, it was felt that a linear approximation could be made to the data to determine a correction factor to the current C_1 coefficient in FEMA 440 for regions affected by subduction ground motions. Therefore, this linear approximation was constructed from a period of 0.5s to the point where the values of $(\Delta_{epp}/\Delta_e)/C_1$ were consistently less than 1.05 (i.e. Δ_{epp}/Δ_e was never more than 5% greater than C_1). A least squares linear regression was performed to determine the slope and the intercept of the correction factor. The resulting equation for the improved C_1 coefficient is shown in Eq. 4 and plotted in Fig. 7. Table 2 and Table 3 show the coefficients for site class C and D for various values of relative strength *R*.

$$\begin{aligned}
\mathbf{C_{1sub}} &= \mathbf{C_1\beta = \left(1+\left[\frac{R-1}{aT^2}\right]\right)\left(b-\frac{c(0.5s)}{R}\right)} \quad \textbf{for } \mathbf{0.2s \leq \mathit{T} \leq 0.5s} \\
\mathbf{C_{1sub}} &= \mathbf{C_1\beta = \left(1+\left[\frac{R-1}{aT^2}\right]\right)\left(b-\frac{cT}{R}\right)} \quad \textbf{for } \mathbf{0.5s \leq \mathit{T} \leq 1.0s} \\
\mathbf{C_{1sub}} &= \mathbf{C_1\beta = 1.0\left(b-\frac{cT}{R}\right) \geq 1.0} \quad \textbf{for } \mathbf{\mathit{T} \geq 1.0s}
\end{aligned} \tag{4}$$

Table 2. Coefficients of β in $C_{1\ sub}$ coefficient for site class C.

	R						
Coefficient	**≤2**	**3**	**4**	**5**	**6**	**7**	**8**
b	1	1.4	1.6	1.8	2.0	2.1	2.4
c	0	0.42	0.65	1.1	1.6	2.1	3.1

Table 3. Coefficients of β in $C_{1\ sub}$ coefficient for site class D.

	R						
Coefficient	**≤2**	**3**	**4**	**5**	**6**	**7**	**8**
b	1	1.3	1.5	1.6	1.7	1.8	1.9
c	0	0.36	0.61	0.87	1.3	1.8	2.2

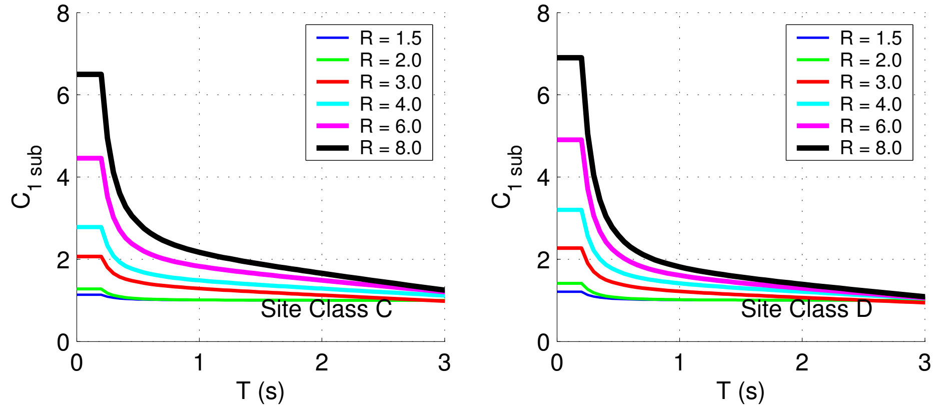

Figure 7. $C_{1\ sub}$ coefficient.

The $C_{1\ sub}$ coefficient incorporates a correction factor, β, which increases the C_1 coefficient in FEMA 440. β accounts for the increased inelastic displacement ratios of the EPP systems that were subjected to the subduction ground motions. Since the lowest period considered in the regression to determine β was 0.5s, the value of this factor remains constant for periods smaller than this period. The values determined using FEMA 440 and the $C_{1\ sub}$ coefficient are presented in Fig. 8 for a relative strength value of 4 on both site class C and D soils. The $C_{1\ sub}$ coefficient is much larger than the C_1 coefficient from FEMA 440 at short periods, but the difference between the two equations decreases as the period of vibration of the system increases until they meet at a period greater than 3.0s. Aside from the increased value of the coefficient, the increased period at which the inelastic displacements become equal to the elastic displacements is significantly larger than for the original coefficient. In FEMA 440, the C_1 coefficient is taken as 1.0 for all periods greater than 1.0s while the $C_{1\ sub}$ reaches 1.0 between $T = 1.0s$ and $T = 3.8s$.

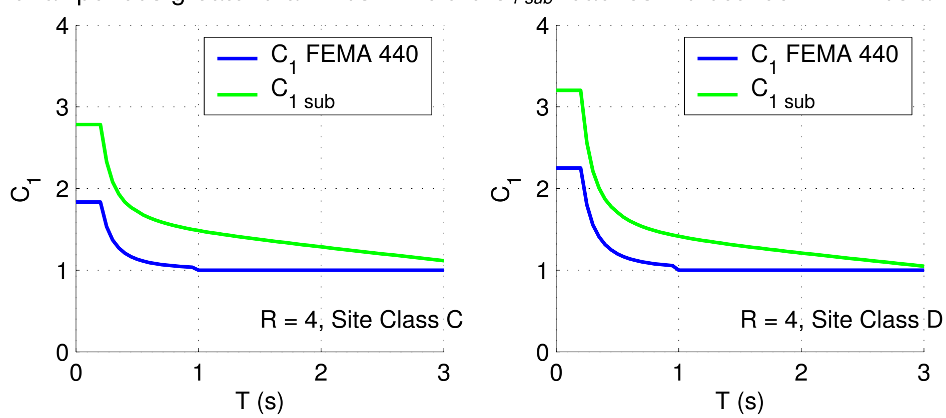

Figure 8. Comparison of C_1 coefficient from FEMA 440 and $C_{1\ sub}$ coefficient.

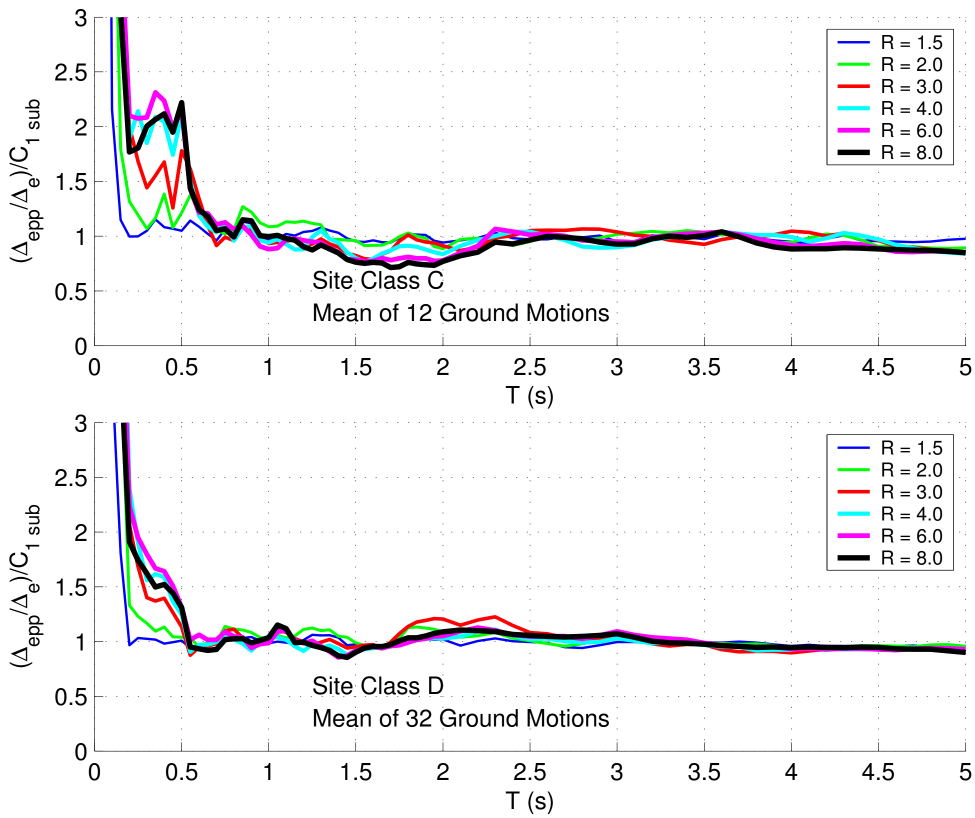

Figure 9. Mean ratio of the inelastic displacement of EPP systems subjected to subduction ground motions to the $C_{1\ sub}$ coefficient.

The improved C_1 coefficient from Eq. 1 was then compared to the inelastic displacement ratios of the subduction ground motions (Fig. 9). When compared with Fig. 5, it is clear that the relatively simple correction factor results in a considerably better estimation of the inelastic displacement ratio for the subduction ground motions. Only a minor underestimation occurs for a few relative strength values for periods greater than 0.75s for site class C and 0.5s for site class D. The mean inelastic displacement ratios then increase for periods less than these periods with significant underestimations for *R* equal 3 or greater. Furthermore, the dramatic improvement is evident by the sudden decrease in the ratio of the inelastic displacement ratios to the $C_{1\ sub}$ coefficient from before 0.5s, where the regression was stopped, to periods greater than 3.0s where the ratio is very close to one or less than one for all *T* and *R*.

Conclusions

The analysis of SDOF systems subjected to 48 subduction ground motions from the 2003 Tokachi-Oki Earthquake has illustrated the effect of the earthquake source on the inelastic response of structures. When the EPP systems were analyzed, the mean inelastic displacement ratio of the subduction records is up to 3 times higher than that from crustal records for periods less than 1.0s. Furthermore, the inelastic displacements of the EPP system approach the elastic displacements at much longer periods as a result of the greater inelastic displacement ratios. It was also noted that the effect of the subduction ground motions is more pronounced as the strength of the system decreases (i.e. *R* increases). A correction factor was developed to reduce the error induced by utilizing the C_1 coefficient from FEMA 440 for inelastic displacement predictions using subduction ground motions. Due to the good correlation between the subduction and crustal results for the stiffness degrading model, and a direct comparison of these ratios to the C_2 coefficient, it was concluded that the C_2 coefficient in FEMA 440 provides reasonable results and is appropriate for use with stiffness degrading systems and subduction ground motions.

This study made use of the largest subduction interface ground motion dataset available to date. However, the scarcity of data from other subduction zones makes it challenging to generalize the results presented here. There is a clear need for further investigation of the inelastic response of structures to subduction interface type earthquakes. Future work will include comparison of these results with the limited number of subduction interface records available from other subduction zones around the world.

Acknowledgments

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for providing funding for this research and the National Research Institute for Earth Science and Disaster Prevention (NIED) for providing the ground motions used in this study from their Kyoshin and Kiban-Kyoshin Seismograph networks (www.k-net.bosai.go.jp and www.kik-net.bosai.go.jp). Input from Garry Rogers of the Pacific Geosciences Centre during the course of this study was greatly appreciated.

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