EARTHQUAKE RESPONSE OF HIGHWAY BRIDGES SUBJECTED TO LONG DURATION SEISMIC MOTIONS

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Abstract

Strong motion records obtained during the 2003 off Tokachi, Japan, earthquake (Mw8.0) and the 2010 Maule, Chile, earthquake (Mw8.8) are used to investigate effects of duration of seismic motion on earthquake response of highway bridges. Not much difference was found between the responses excited by the seismic motions from the two earthquakes despite difference of the duration.

Introduction

Current Japanese design specifications (Japan Road Association, 2002) require highway bridges to be checked if the bridges satisfy target seismic performances against Level 1 and Level 2 earthquake motions. Level 1 earthquake motion covers ground motion highly probable to occur during service period of bridges and its target seismic performance is set to have no damage. Level 2 earthquake motion is defined as ground motion with high intensity with less probability to occur during the service period of bridges. The target seismic performance against Level 2 earthquake motion is set to prevent fatal damage for bridges with standard importance and to limit damage for bridges with high importance.

There are two types of Level 2 earthquake motion, i.e. Type I and Type II earthquake motions. Type I represents ground motions from large-scale plate boundary earthquakes, while Type II from inland earthquakes and directly strike the bridges. These design earthquake motions are defined as design acceleration response spectra with damping ratio of 0.05. Time history waveforms are also shown in the design specifications as examples for seismic design using dynamic response analyses. The time history waveforms were produced by spectral fitting using strong motion records as original waveforms; their acceleration response spectra were adjusted to fit to the design spectra by means of a spectral fitting technique.

As for Type I earthquake motion, strong motion records obtained during plate boundary earthquakes of which magnitudes ranging from 7.4 to 8.2 were used as original waveforms. Duration of the example waveforms are up to only 55[s] (duration in this paper will be defined in the next section). Ground motion records with long duration, however, were obtained during the 2003 off Tokachi, Japan, earthquake (Mw8.0) and the 2010 Maule, Chile, earthquake (Mw8.8). Besides, it has been pointed out that super-giant earthquakes, of which magnitudes are as large as 9, may occur in Suruga-Nankai trough, south-western Japan, in the near future – though the 2011 off the Pacific coast of Tohoku earthquake (Mw9.0) had never been imagined.

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In this paper, effects of long duration seismic motions on earthquake response of highway bridges are investigated using the strong motion records from the 2003 off Tokachi and the 2010 Maule earthquakes.

Strong Motion Records and Adjusted Waveforms

Table 1 lists 10 observation stations where strong motion records were obtained by the Department of Geophysics, the University of Chile, during the 2010 Maule earthquake. The digital data were downloaded from its website (http://ssn.dgf.uchile.cl). Locations of these observation stations are shown in Figure 1 with the epicenter and surface projection of the source fault. The strong motion recorded at CCSP (Figure 2) has the largest PGA and the longest duration. In this paper, the duration is defined as the time between first and last moments when amplitudes exceed 50 [cm/s^2]. The durations of NS, EW, and UD components of the strong motion at CCSP are 151[s], 152[s], and 122 [s], respectively.

The acceleration response spectrum of EW component of the strong motion at CCSP was adjusted to target response spectra by spectral fitting. The target response spectra are set as shown in Figure 3. Type I, II, and III grounds are stiff, medium, and soft soil conditions, respectively. Since there was no available information about the soil condition at CCSP, three acceleration waveforms that represent Type I, II, and III grounds were produced as shown in Figure 4; the acceleration response spectra of these waveforms were adjusted to the target response spectra (Figure 3) by spectral fitting. The durations of the waveforms produced here are very close to the duration of the original waveform (152 [s]).

Acceleration response spectra of strong motion recorded during the 2003 off Tokachi earthquake were also adjusted to the same target response spectra by spectral fitting. The strong motion records obtained at UKE (Urakawa-Efue), CKB (Chokubetsu), and TCS (Taikicho-Seika) stations were chosen to represent Type I, II, and III grounds, respectively. The original and adjusted waveforms are shown in Figures 5, 6, and 7. The durations of the adjusted waveforms are 75[s], 78[s], and 96[s], which are more than 50[s] shorter than those produced from the strong motion during the 2010 Maule earthquake.

Analytical Models of Highway Bridges

Analytical model of highway bridges and nonlinear models for plastic hinge section of RC piers and seismic isolation bearings are shown in Figures 8 and 9. Rubber bearings, seismic isolation bearings, and fixed bearings were chosen for Type I, II, and III grounds, respectively. Spread foundation was chosen for Type I ground, while pile foundation was chosen for Type II and II grounds. All three analytical models were designed under the current seismic design specifications and their fundamental natural periods are 1.25[s], 1.15[s], and 0.71[s] for Type I, II, and III grounds, respectively.

Earthquake Response of Highway Bridges

Figure 10 shows hysteretic force-displacement response of the analytical model subjected to the long duration seismic motions produced from the strong motion records obtained during the 2003 off Tokachi and the 2010 Maule earthquakes. The amplitudes of the adjusted waveforms were magnified to 1.2 times for seismic input to check nonlinear response of the model more clearly. We can see that peak response displacements of the bridge models due to the adjusted waveforms from the 2003 off Tokachi earthquake are as large as or larger than those from the 2010 Maule earthquake.

Hysteretic force-displacement response of the seismic isolation bearings, adopted for Type II ground, subjected to the long duration seismic motions from the two earthquakes are compared in Figure 11. The amplitudes of the adjusted waveforms were magnified to 1.2 times for seismic input as well. The peak response displacements of the bearings are not much different and do not exceed 250% shear strain.

Table 2 summarizes residual displacements of the analytical models subjected to the long duration seismic motions. The amplitudes of the adjusted waveforms were magnified to 1.2 times and 1.4 times for seismic input. It was found that the residual displacements vary case by case and that seismic motions with longer duration are not always more severe in terms of the residual displacement.

Conclusions

In this paper, strong motion records obtained during the 2003 off Tokachi earthquake (Mw8.0) and the 2010 Maule earthquake (Mw8.8) are used to investigate effects of duration of seismic motion on earthquake response of highway bridges. We could not find notable difference between the responses, i.e. the peak response displacements of RC piers and seismic isolation bearings and the residual displacement, excited by the seismic motions from the two earthquakes though there are differences of more than 50 [s] between their durations. Further investigations will be carried out using the abundant strong motion records obtained during the 2011 off the Pacific coast of Tohoku earthquake.

References

Japan Road Association (2002): Specifications for highway bridges, Part V: Seismic design.

Table 1 Strong motion records obtained from website of the Department of Geophysics, the University of Chile. Directions of horizontal component of olmu are unknown.

Station code	Place	Location			Sam-pling [Hz]	Number of data	PGA [cm/s^2]		
		Lat. (S)	Lon. (W)	Elev. [m]			NS	EW	UD
ANTU	Campus Antumapu, Santiago	33.569	70.634	640	50	22,779	230.0	265.0	162.3
CCSP	San Pedro, Cancepcion	36.844	73.109	38	100	20,200	633.7	602.3	566.8
CLCH	Cerro Calan, Santiago	33.396	70.537	865	50	22,533	195.3	216.6	103.3
csch	Casablanca	33.321	71.411	260	100	9,000	285.0	322.0	221.0
lach	Colegio Las Americas, Santiago	33.452	70.531	729	100	19,100	304.7	228.7	158.2
melp	Melipilla	33.687	71.214	180	100	9,000	556.1	761.2	377.9
olmu	Olmue	32.994	71.173	173	100	9,000	(244.3)	(346.8)	150.4
ROC1	Cerro El Roble, TilTil	32.976	71.016	2,191	100	60,261	168.4	135.8	113.0
sjch	San Jose de Maipo	33.452	70.531	728	100	18,800	457.4	470.9	234.0
stl	Santa Lucia, santiago	33.440	70.643	614	100	17,900	233.1	330.0	235.7

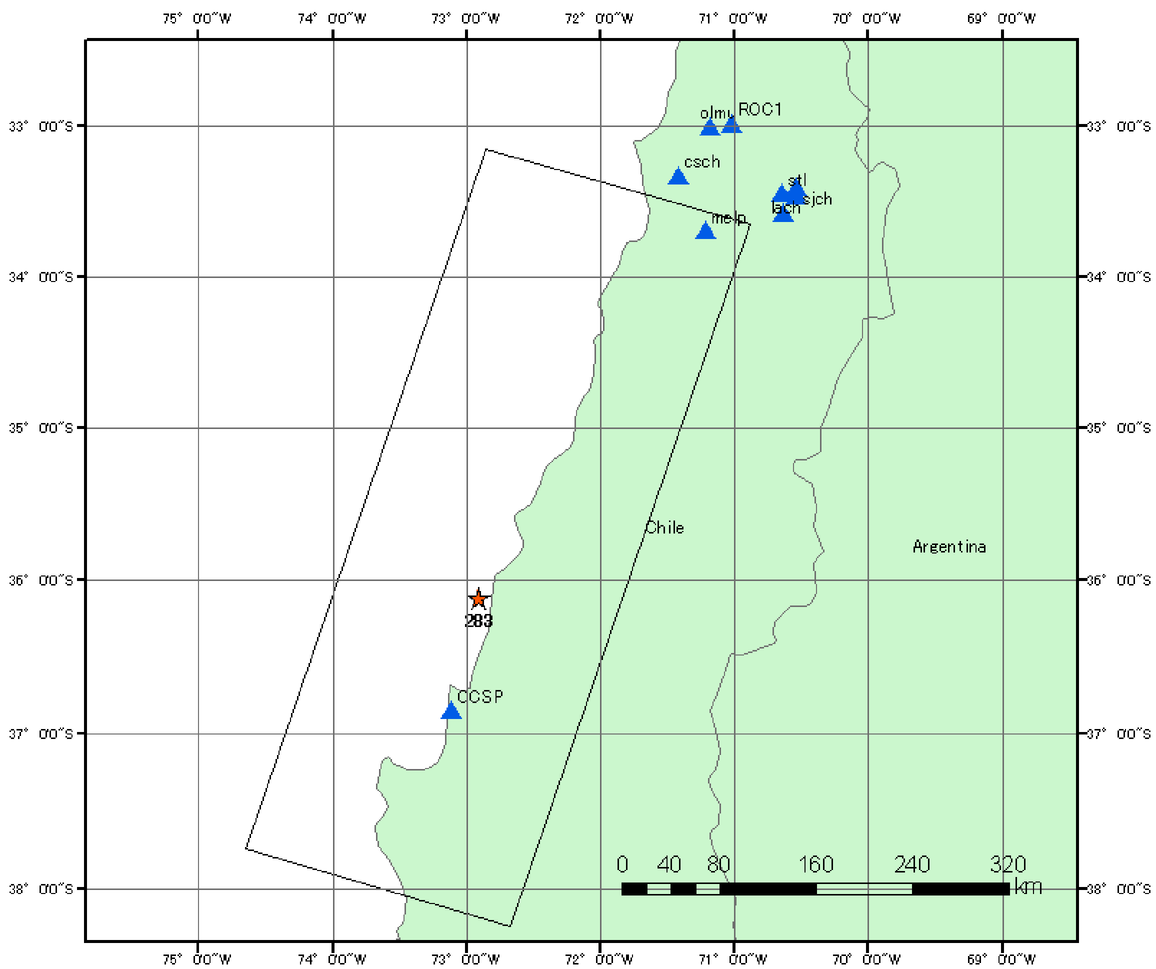
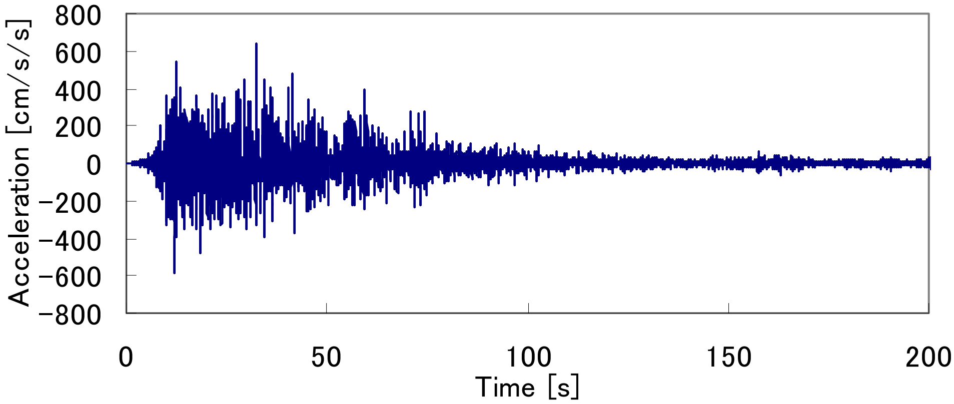
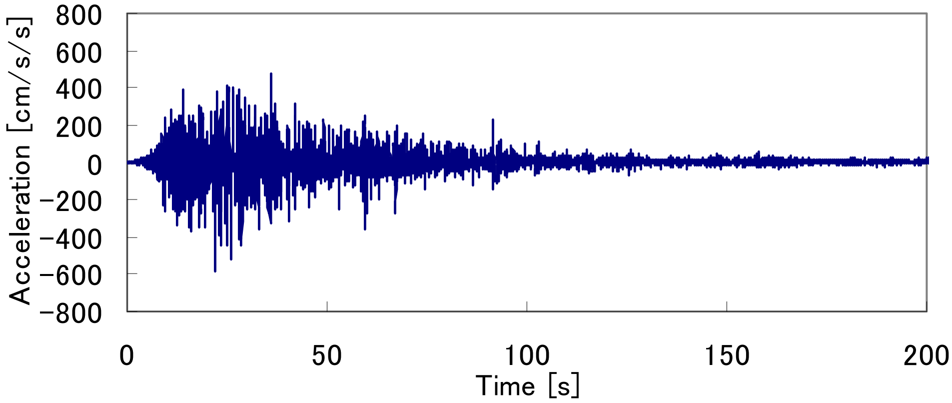


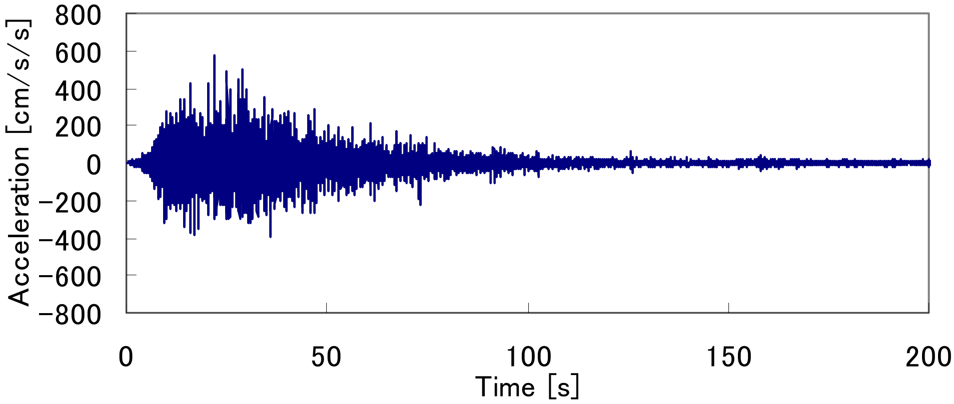
Figure 1 Locations of observation stations of which strong motion records obtained during the 2010 Maule earthquake are available from website of the Department of Geophysics, the University of Chile.



(a) NS component (duration: 151[s])



(b) EW component (duration: 152[s])



(c) UD component (duration: 122[s])

Figure 2 Strong motion recorded at CCSP during the 2010 Maule earthquake.

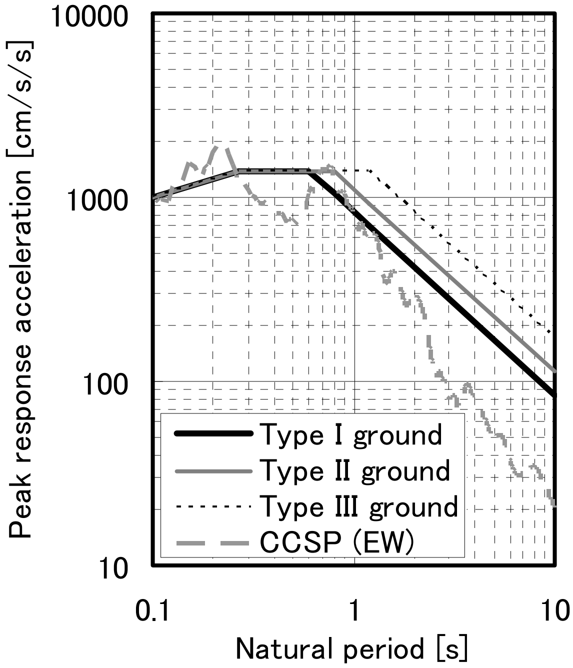
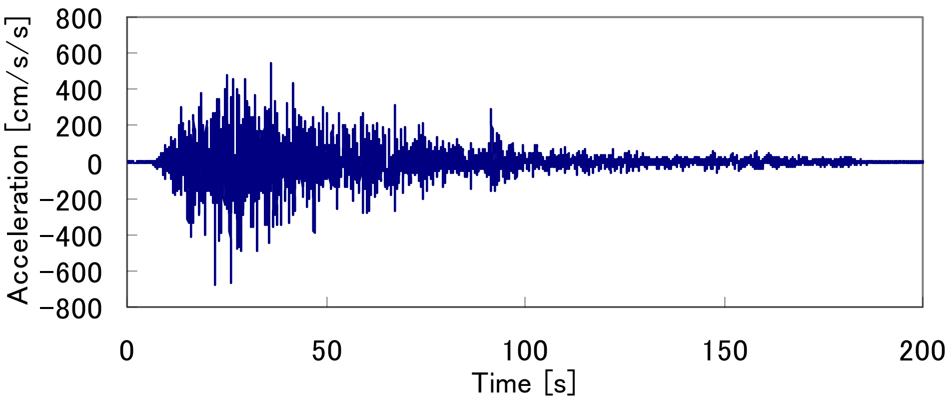
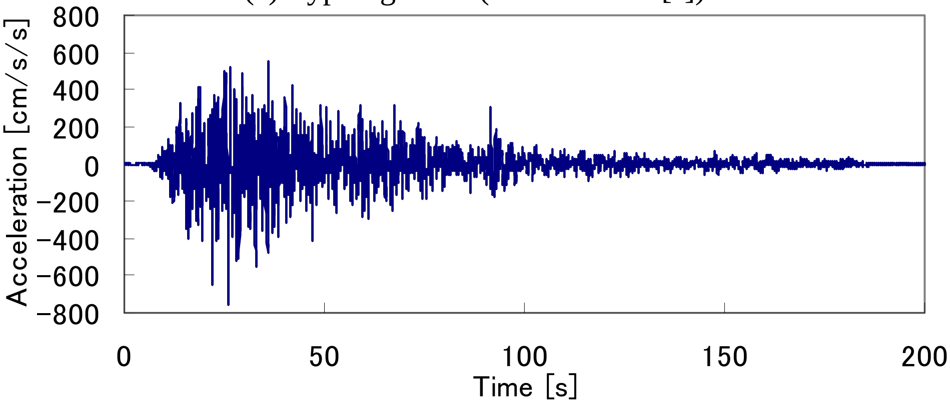


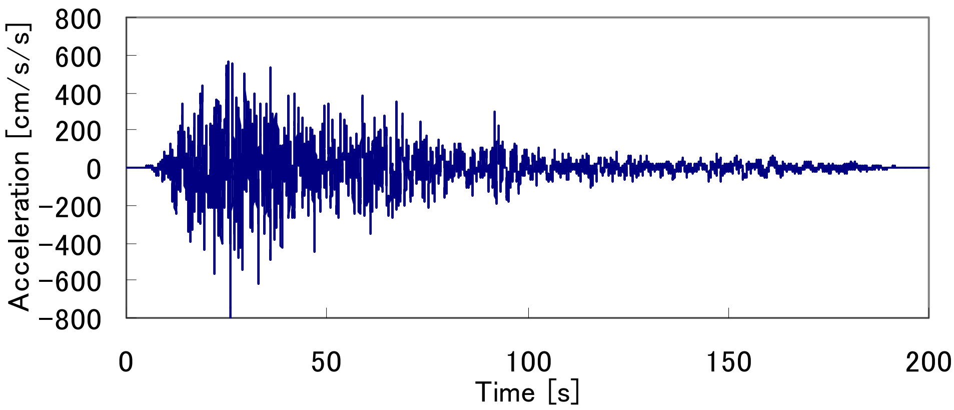
Figure 3 Target acceleration response spectra for spectral fitting of the strong motion records. Type I, II, and III grounds correspond to stiff, medium, and soft soil conditions, respectively. The peak levels of the target response spectra are 1,400 [cm/s^2]. The acceleration response spectrum of EW component of the strong motion at CCSP is also shown.



(a) Type I ground (duration: 149[s])

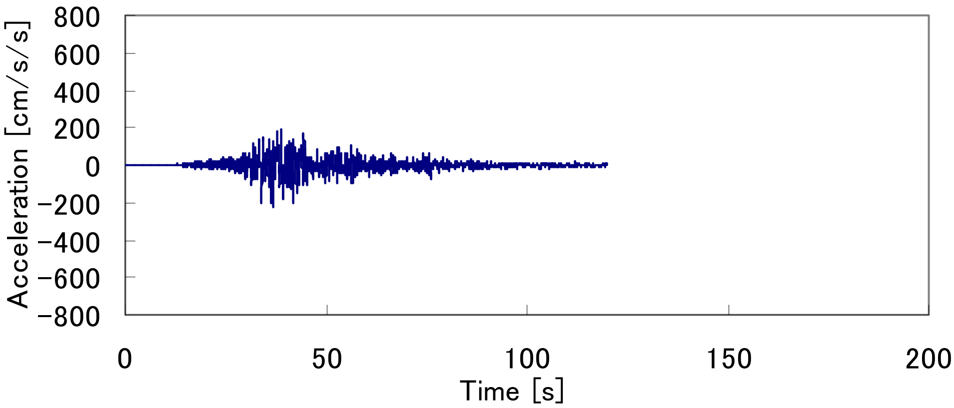


(b) Type II ground (duration: 152[s])

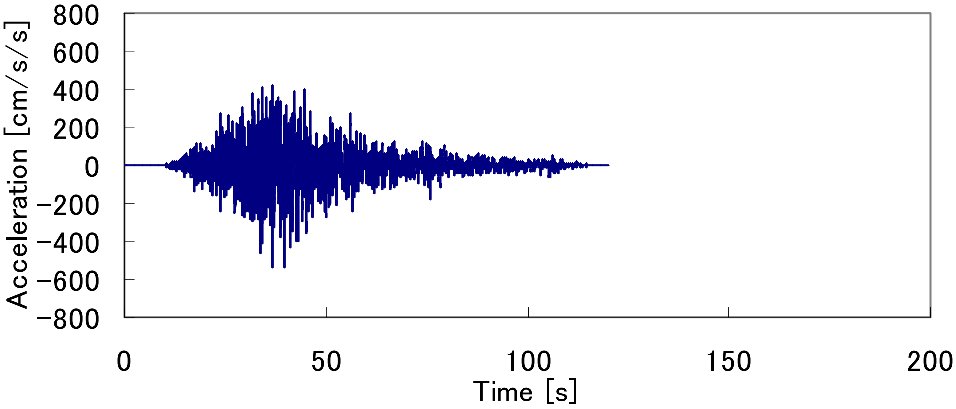


(c) Type III ground (duration: 152[s])

Figure 4 Acceleration waveforms produced by spectral fitting from EW component of the strong motion at CCSP. The acceleration response spectra of these waveforms were adjusted to the target spectra shown in Figure 3.

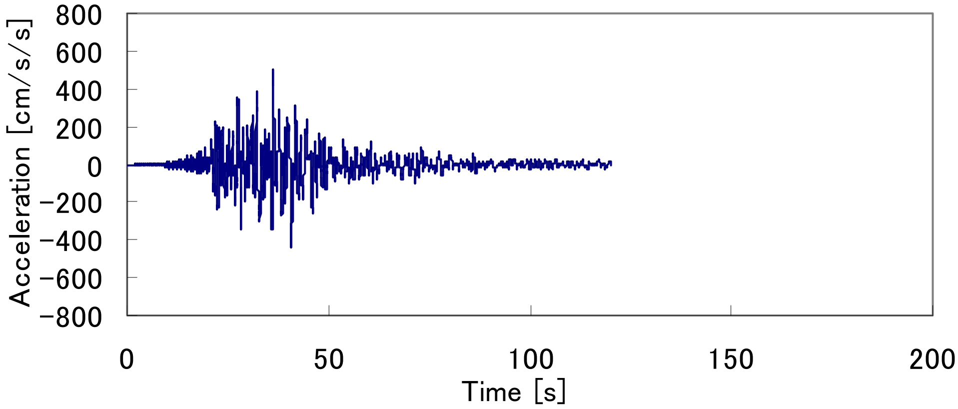


(a) Original waveform (duration: 46[s])

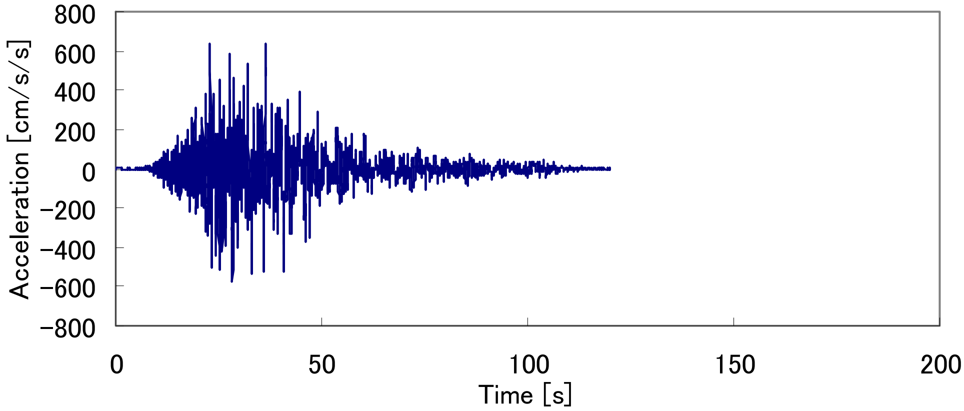


(b) Adjusted waveform (duration: 75[s])

Figure 5 Original (a) and adjusted (b) waveforms for Type I ground. The original strong motion is observed during the 2003 off Tokachi earthquake at UKE (Urakawa-Efue) station. Adjusted waveform was produced by spectral fitting

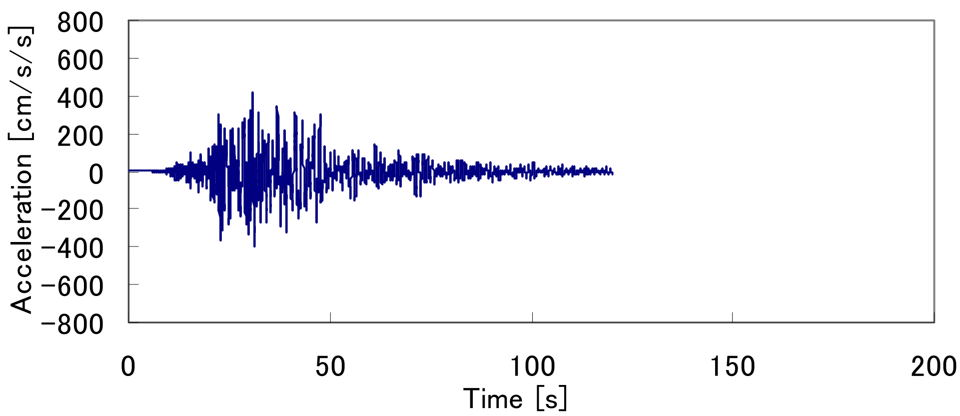


(a) Original waveform (duration: 68[s])

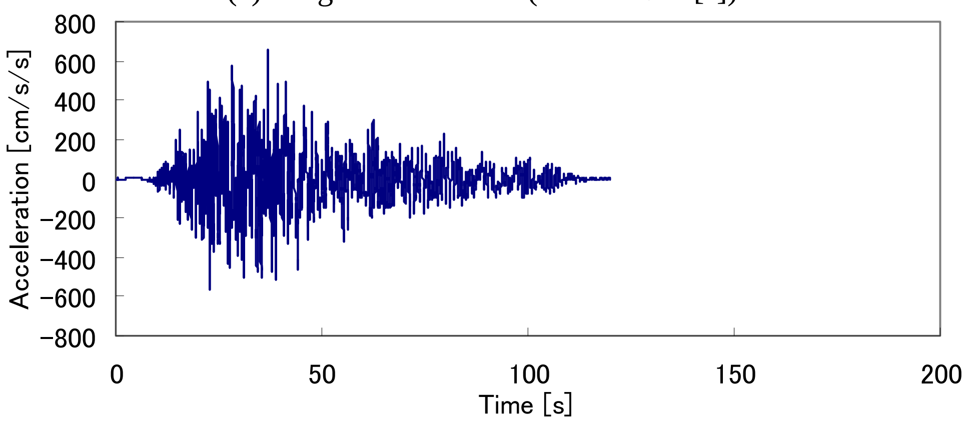


(b) Adjusted waveform (duration: 78[s])

Figure 6 Original (a) and adjusted (b) waveforms for Type II ground. The original strong motion is observed during the 2003 off Tokachi earthquake at CKB (Chokubetsu) station. Adjusted waveform was produced by spectral fitting



(a) Original waveform (duration: 71[s])



(b) Adjusted waveform (duration: 96[s])

Figure 7 Original (a) and adjusted (b) waveforms for Type III ground. The original strong motion is observed during the 2003 off Tokachi earthquake at Taikicho-Seika (TCS) station. Adjusted waveform was produced by spectral fitting

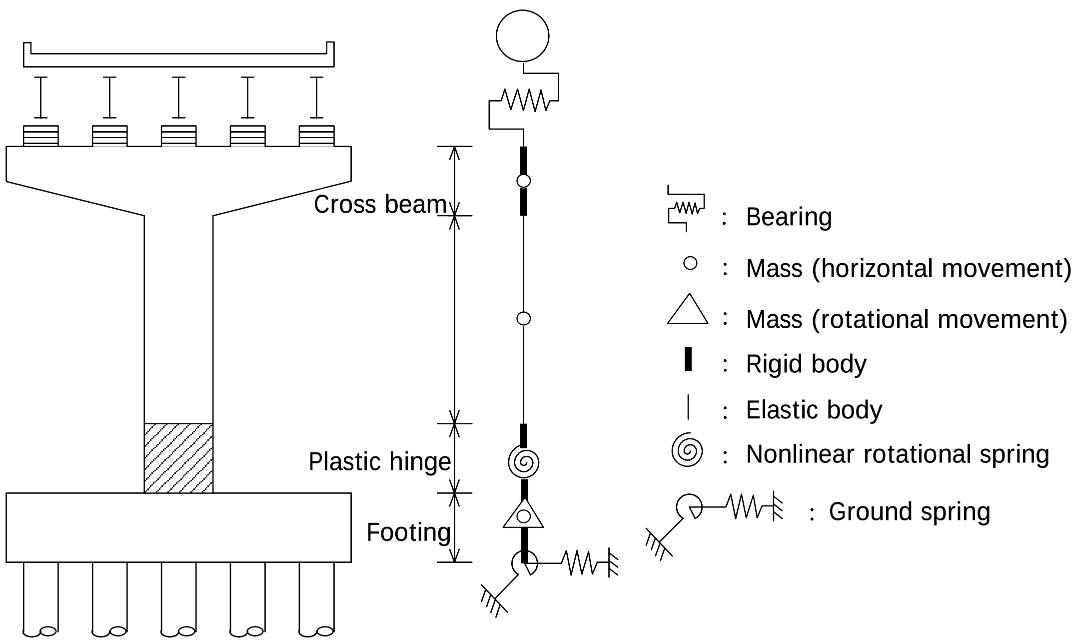
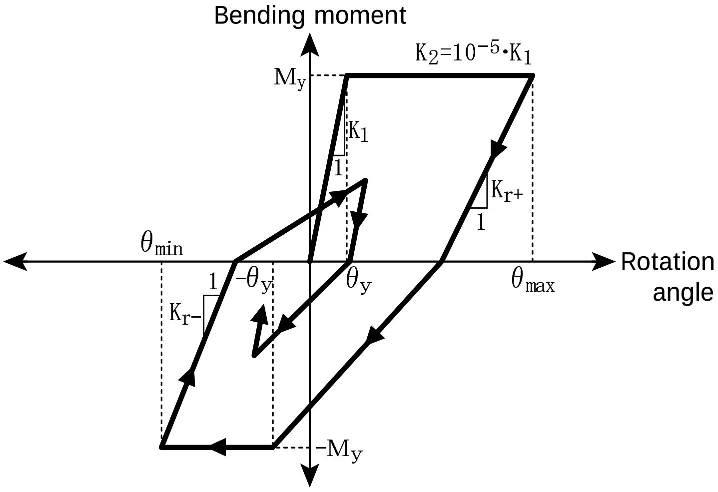
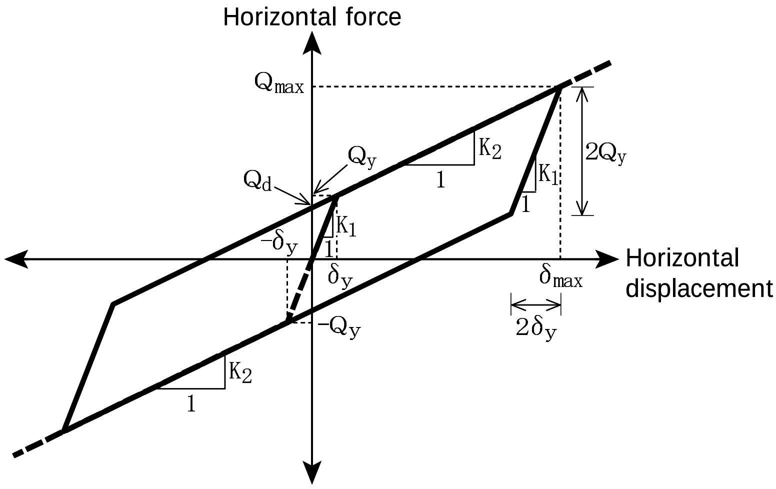


Figure 8 Analytical model of highway bridges. Rubber bearings, seismic isolation bearings, and fixed bearings were chosen for Type I, II, and III grounds, respectively.

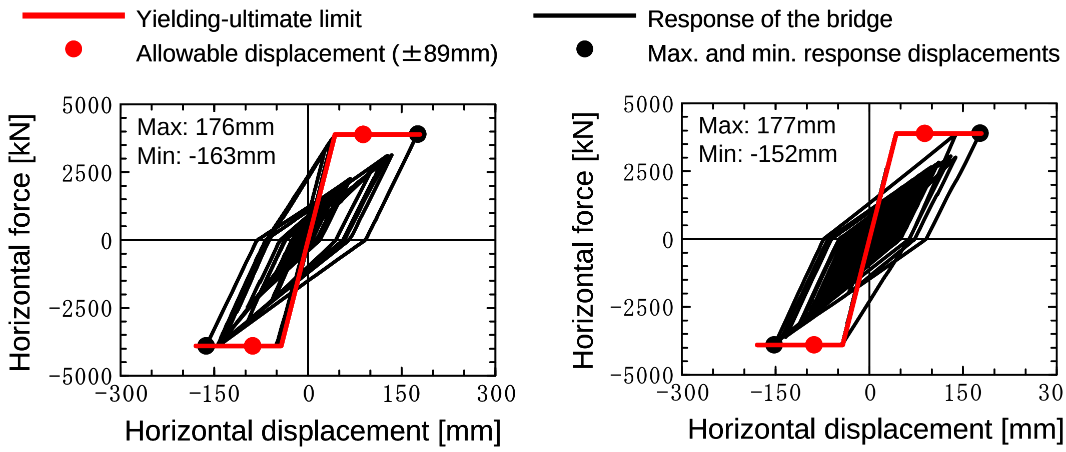


(a) Plastic hinge section of RC piers

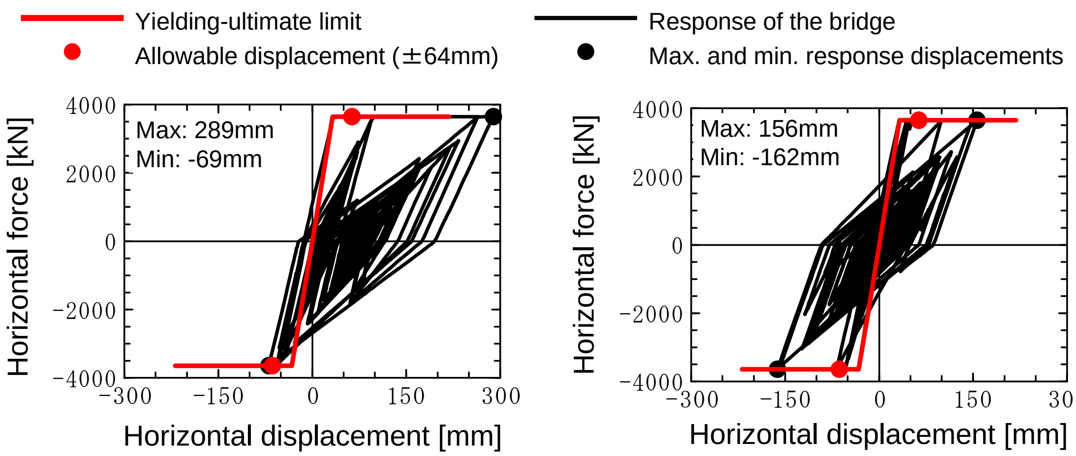


(b) Seismic isolation bearings

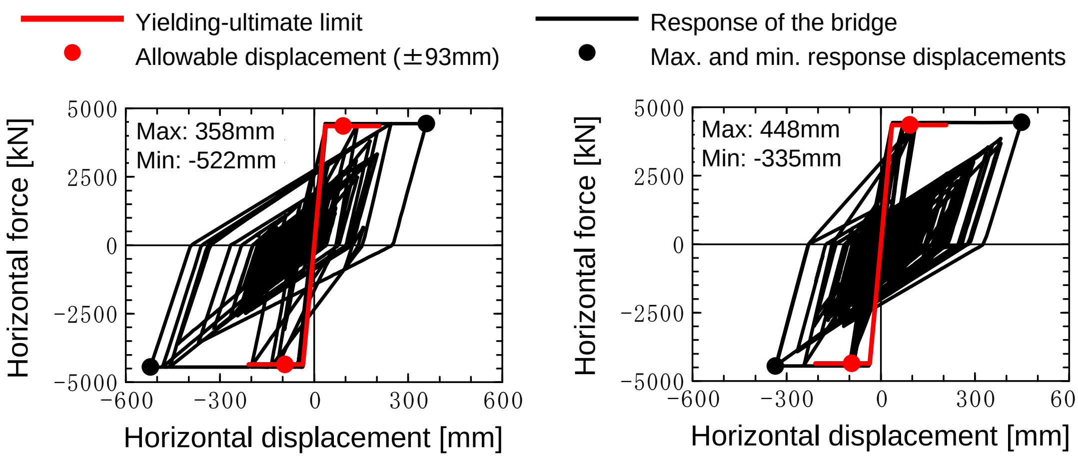
Figure 9 Nonlinear models for: (a) Plastic hinge section of RC piers; (b) Seismic isolation bearings. Seismic isolation bearings are adopted for the highway bridge on Type II ground.



(a) Type I ground (left: UKE-Tokachi, right: CCSP-Maule)



(b) Type II ground (left: CKB-Tokachi, right: CCSP-Maule)



(c) Type III ground (left: TCS-Tokachi, right: CCSP-Maule)

Figure 10 Hysteretic force-displacement response of the analytical model subjected to the long duration seismic waves produced from the strong motion records obtained during the 2003 off Tokachi and the 2010 Maule earthquakes. The amplitudes of the adjusted waveforms were magnified to 1.2 times for seismic input.

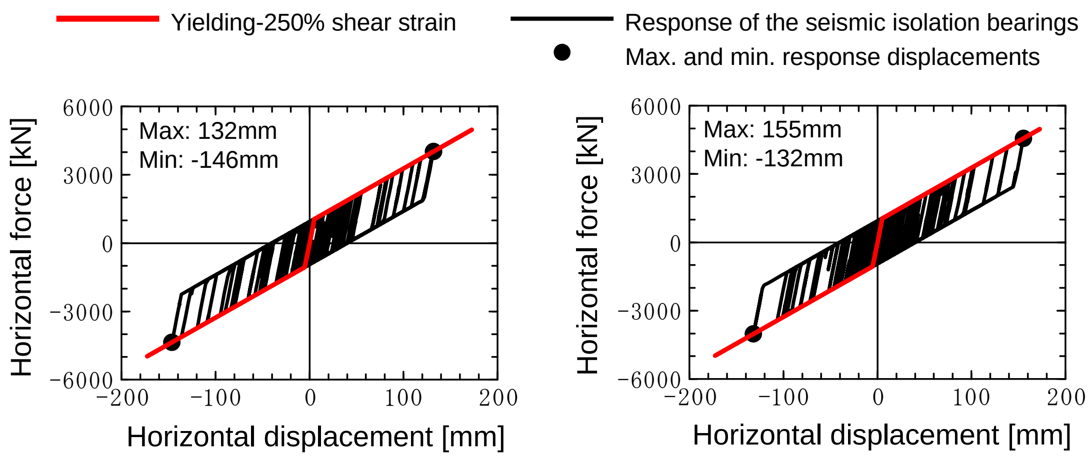


Figure 11 Hysteretic force-displacement response of the seismic isolation bearings, adopted for Type II ground, subjected to the long duration seismic waves. The amplitudes of the adjusted waveforms were magnified to 1.2 times for seismic input.

Table 2 Residual displacements of the analytical models subjected to the long duration seismic motions. The amplitudes of the adjusted waveforms were magnified to 1.2 times and 1.4 times for seismic input.

Ground	Fundamental natural period	Strong motion record	Residual displacement [mm]	
			1.2 times	1.4 times
Type I	1.25 [s]	UKE-Tokachi	11	34
		CCSP-Maule	17	39
Type II	1.15 [s]	CKB-Tokachi	73	82
		CCSP-Maule	1	2
Type III	0.71 [s]	TCS-Tokachi	57	156
		CCSP-Maule	100	57