REVISED DESIGN EARTHQUAKE MOTION AND THE EFFECTS ON SEISMIC DESIGN OF HIGHWAY BRIDGES

Kataoka Shojiro[1]

Abstract

Strong motion records obtained during the 2011 off Tohoku earthquakes were used, along with the other records, for analyses to revise Level 2 earthquake motion (Type I) for seismic design of highway bridges. This paper introduces the analyses and the perspective of the revision of standard acceleration response spectra, zone factors, and acceleration waveforms for time history response analyses correspond to Level 2 earthquake motion (Type I).

Introduction

Japanese design specifications for highway bridges, which is revised in February 2012 (Japan Road Association, 2012), have required highway bridges to be checked if the bridges satisfy target seismic performances against Level 1 and Level 2 earthquake motions since 1990. 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 performances 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 motion from large-scale plate boundary earthquakes, while Type II from inland shallow earthquakes that 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 given for seismic design using dynamic response analyses. The time history waveforms were produced by spectral fitting using strong motion records as original waveforms.

The 2011 off the Pacific coast of Tohoku earthquake, of which moment magnitude M_w, 9.0 took two days to be determined, is the largest earthquake in recorded history in Japan. More than 2,400 strong motion records (Midorikawa *et al.*, 2012) were obtained during an M9 earthquake for the first time. This paper introduces analyses using the records and the perspective of the revision of the Type I earthquake motion based on the analyses.

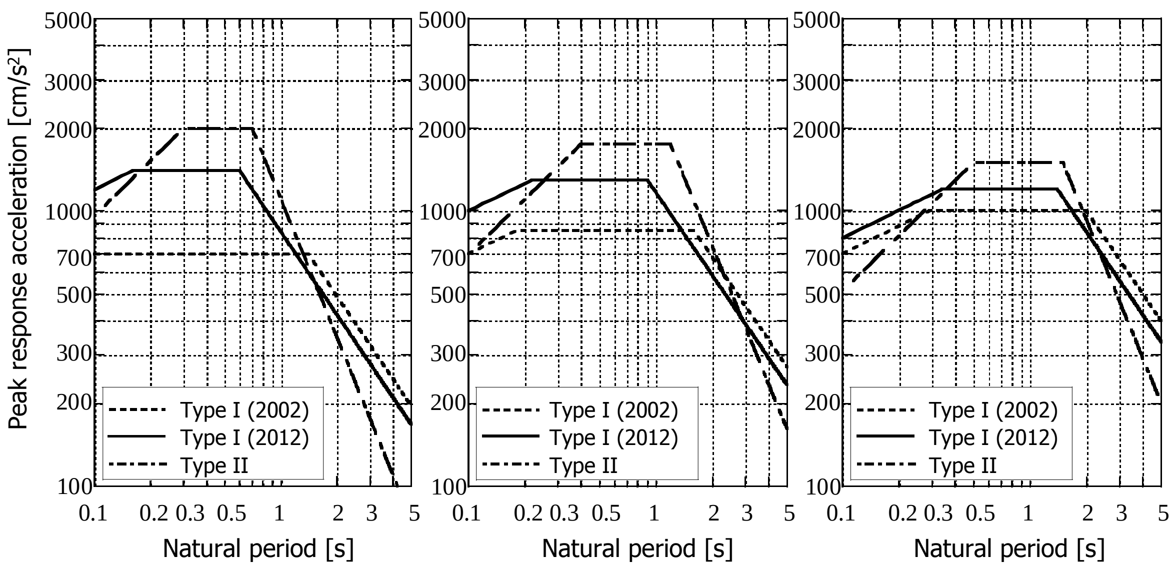
---

[1] Senior Researcher, Earthquake Disaster Prevention Division, National Institute for Land and Infrastructure Management (NILIM)

Revision of Standard Acceleration Response Spectra

Design earthquake motions for highway bridges are set by multiplying zone factor, which will be discussed later, and damping factor to standard acceleration response spectra. Since the critical damping ratio $h = 0.05$ is assumed for the standard response spectra, the damping factor, $c_D = 0.5+1.5/(40h+1)$, is employed for correction of the response spectra when h is not 0.05.

The standard acceleration response spectra are set for each soil type as shown in Figure 1. Ground type I, II, and III correspond to stiff, medium, and soft soil conditions, respectively. Type I earthquake motion is based on the ground motion in Tokyo area during the 1923 Kanto earthquake (M_w7.9). They had been introduced into seismic design of highway bridges in 1990, prior to Type II in 1996, and were revised for the first time in 2012 using newer attenuation relationships (Kataoka *et al.*, 2006, 2008) and the strong motion records during the 2011 off Tohoku earthquake as well as the 2003 off Tokachi, Hokkaido, earthquake (M_w8.0). Previous response spectra are larger in soft soil (Ground type III) and smaller in stiff soil (Ground type I) because earthquake motion is usually amplified in soft soil more than stiff soil, while the relationship is reversed in the revised response spectra.



(a) Ground type I (b) Ground Type II (c) Ground Type III

Figure 1 Comparison of standard acceleration response spectra for Level 2 earthquake motions. Type I of Level 2 earthquake motion was revised in 2012.

Figure 2 shows relative amplification factors, i.e. amplification factors of Ground type II and III relative to Ground type I, derived from stochastic analyses of strong motion records. When only high intensity records (SI>40cm/s, which is equivalent to MMI 9 or higher) are used in the analysis, the peak values become smaller and the peak periods become longer compared with the analysis using moderate intensity records. It can be said the relative amplification factors are affected by the intensity of ground motion due to nonlinear response characteristics of soft soil ground.

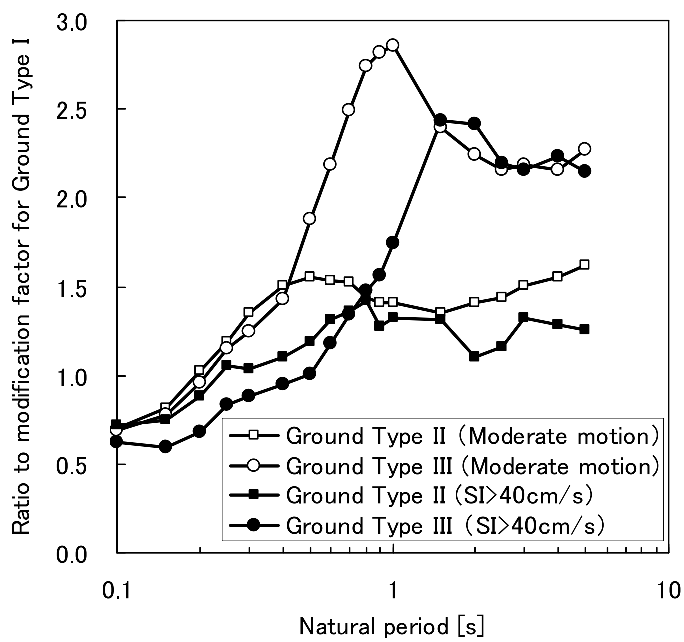


Figure 2 Ground motion amplification factors of Ground type II and III relative to Ground type I. They are affected by the intensity of ground motion due to nonlinear response characteristics of soft soil ground.

Revision of Zone Factors

Zone factors for Type I earthquake motion are also revised along with the standard acceleration response spectra. There had been only three zones, A, B, and C, with zone factors 1.0, 0.85, and 0.7, respectively, and they had been commonly employed for Level 1 and 2 earthquake motions. As shown in Figure 3, zone A was divided into two zones, A1 and A2, as well as zone B into B1 and B2, while zone C was not changed in this revision. Zone factor for Type I earthquake motion, c_{Iz}, was introduced as 1.2 for zones A1 and B1, 1.0 for A2 and B2, and 0.8 for C. Figure 4 presents source regions of major plate boundary earthquakes that are taken into account in the revision. Off the Pacific coast of Hokkaido and Tokai-Tonankai- Nankai-Hyuganada earthquakes are assumed M_w9.0 besides the off Tohoku earthquake. Zones A1 and B1 were set based on the area where ground motion intensity is estimated larger than that in Tokyo area during the 1923 Kanto earthquake. Figure 5 shows the distribution of peak response acceleration with natural period T=0.6s and 3s estimated by the attenuation relationships.

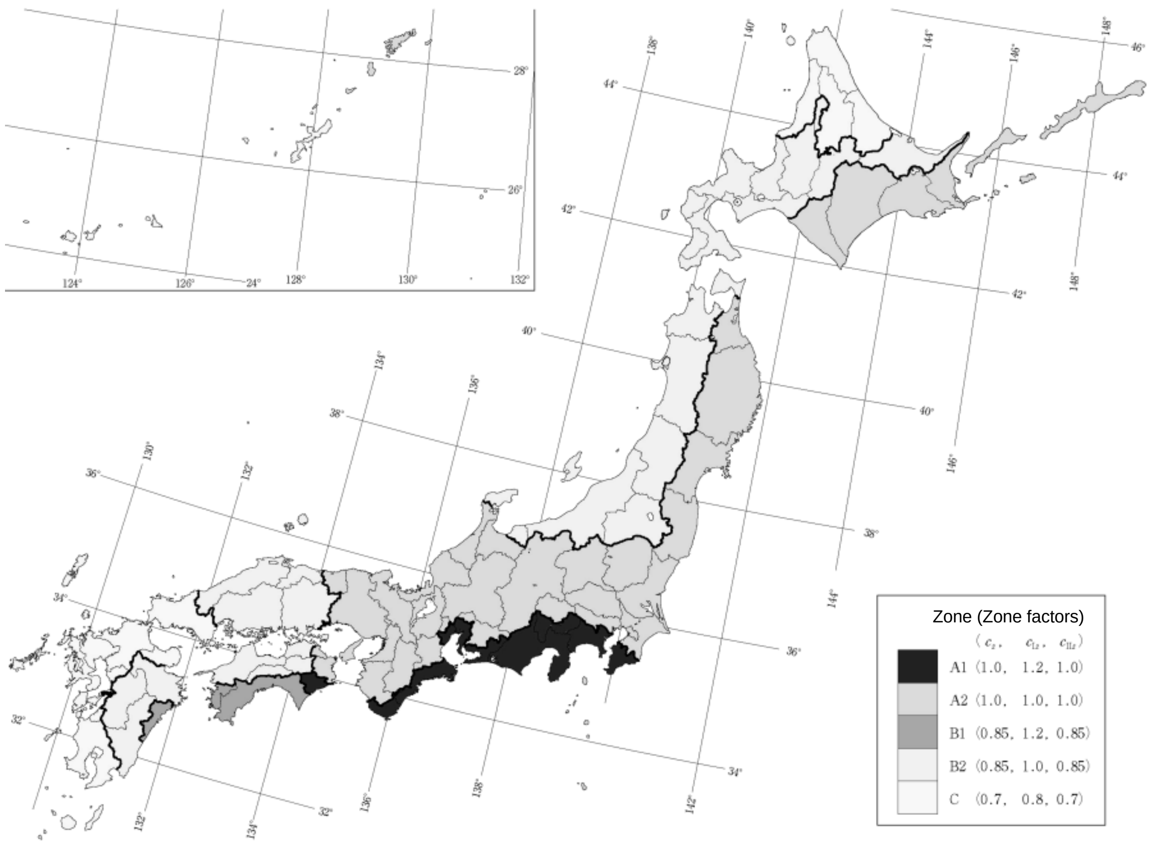


Figure 3 Map showing zones A1, A2, B1, B2 and C. Zone factor c_{Iz} corresponds to Type I of Level 2 earthquake motion.

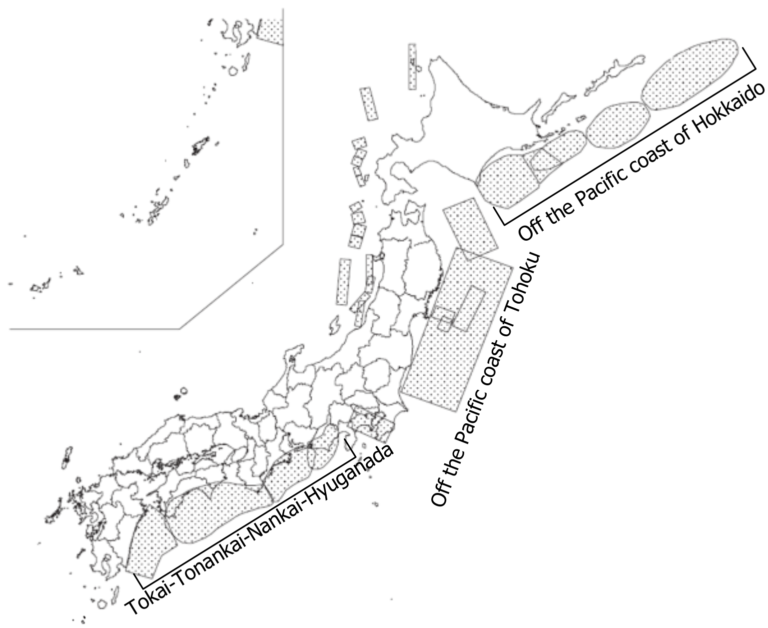
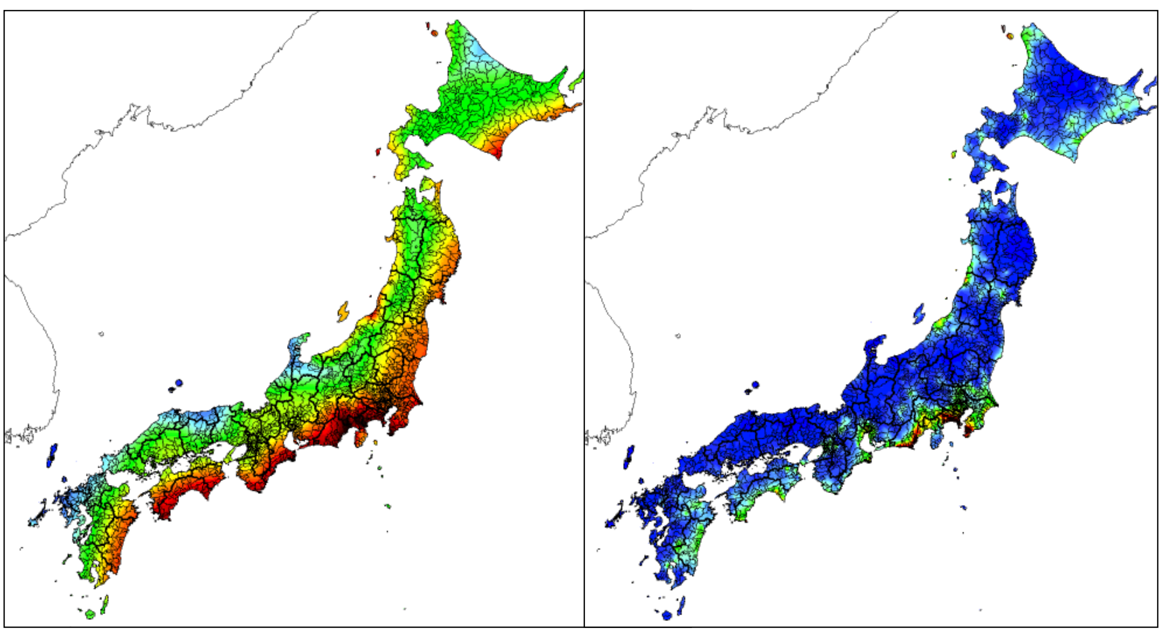


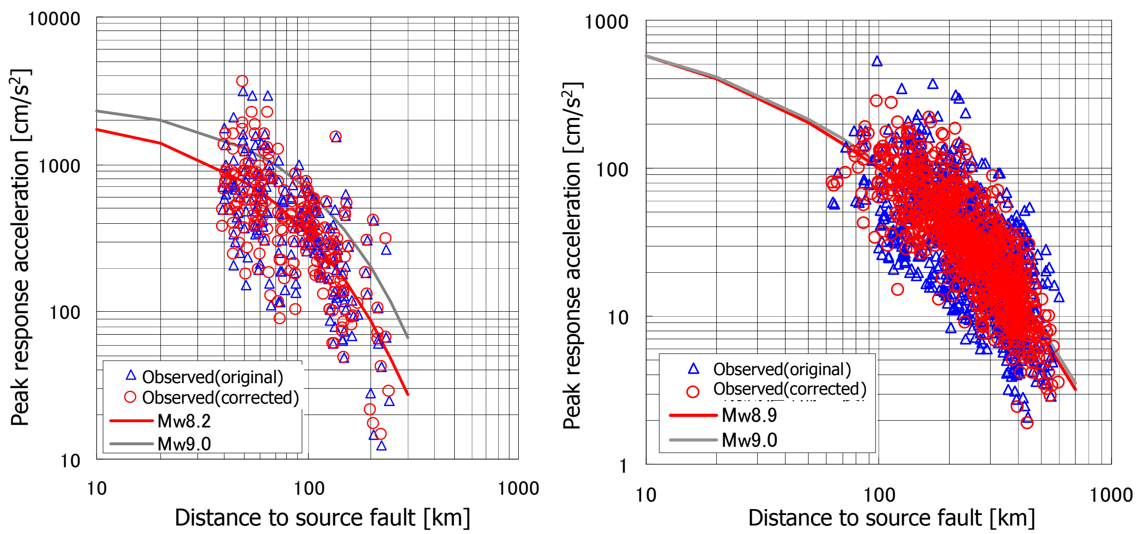
Figure 4 Source regions of major plate boundary earthquakes that are taken into account in the revision of the zone factor c_{Iz}.



(a) T = 0.6s (b) T = 3s

Figure 5 Source regions of major plate boundary earthquakes that are taken into account in the revision of the zone factor c_{Iz}.

Figure 6 compares peak response acceleration of the observed ground motion with the attenuation relationships. Two kinds of observed values are plotted in the figure; original and corrected (site amplification characteristics are removed) ones. It can be seen that the attenuation relationships overestimate the ground motion intensity when M_w is set to 9.0. The attenuation relationships were found to have least misfit with the corrected peak response acceleration when M_w was set to 8.2 and 8.9 for T=0.6s and 3s, respectively. This result shows that intensity of short period ground motion saturates around M_w8.2. Thus, M_w8.3 and 9.0 were assumed for T=0.6s and 3s, respectively, when the distribution of peak response acceleration (Figure 5) were estimated by the attenuation relationships.

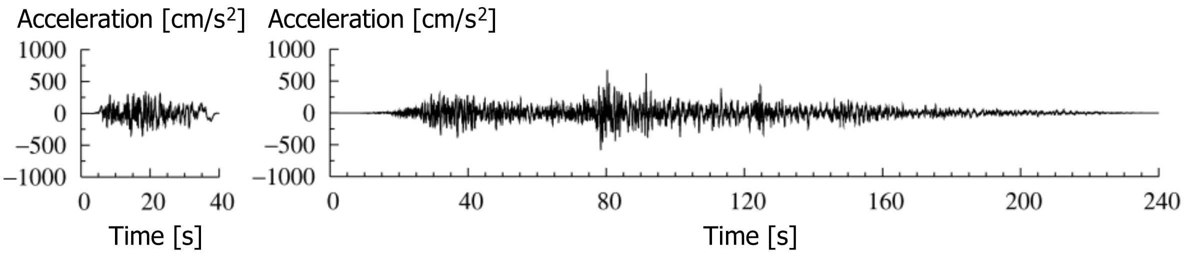


(a) T = 0.6s (b) T = 3s

Figure 6 Original and corrected observed peak response acceleration compared with the attenuation relationships.

Acceleration Waveforms for Time History Response Analysis

Acceleration waveforms were produced by spectral fitting using strong motion records from the 2003 off Tokachi and the 2011 off Tohoku earthquakes as original waveforms for seismic design using time history response analyses. Figure 7 compares acceleration waveforms before and after the revision; a strong motion record during the 1968 Hyuganada earthquake (*M*7.5) obtained at Itajimabashi bridge was used as an original waveform for Figure 7 (a), while SND (Sendai Office of River and National Highway) record obtained during the 2011 off Tohoku earthquake was used for Figure 7 (b), which shows very long duration of strong motion characterized by the giant earthquake. Recent development of computers helps us to use such long duration input without difficulty.



(a) Before revision (b) After revision (SND)

Figure 7 Comparison of acceleration waveforms prepared for time history response analysis. These examples correspond to Ground type II.

Though a number of strong motion records had been obtained during the 2003 off Tokachi and the 2011 off Tohoku earthquakes, only three acceleration waveforms were prepared for each Ground type. Figure 8 explains how those three waveforms were chosen. For example, eight candidate waveforms were prepared for Ground type II and a series of nonlinear time history response analyses of an SDOF system was carried out. Figure 8 shows nonlinear response spectra obtained from the analyses. The largest and second largest spectra correspond to SND and ABK records, respectively. CKB record, of which result was fifth among the eight candidates but the largest of three records from the 2003 off Tokachi earthquake, was chosen for diversity of phase characteristics. Note that the average of nonlinear response spectra of the three chosen waveforms is larger than that of the eight candidate waveforms as shown in Figure 8.

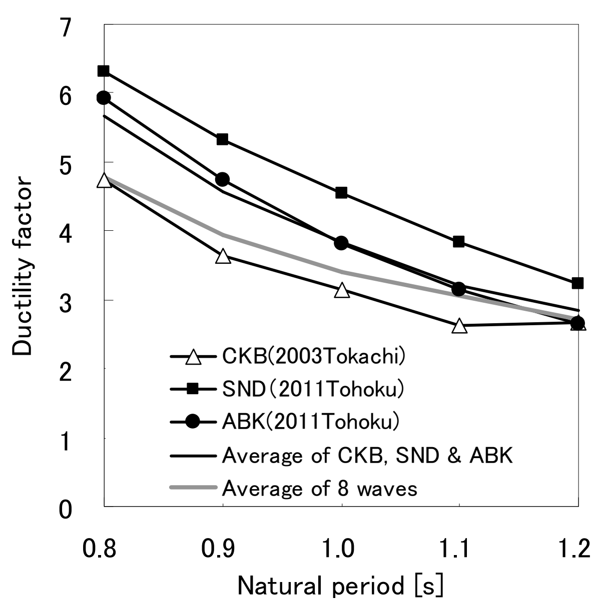


Figure 8 Nonlinear response spectra obtained from series of time history analyses using 8 acceleration waveforms of which response spectra were adjusted to the standard acceleration response spectra for Type I earthquake motion, Ground type II.

Conclusions

In this paper, background of the revision of design earthquake motion for highway bridges was presented. Strong motion records obtained during giant earthquakes that rarely occur played a key role in the analyses for setting up the basis of the revision. Investigation and research on giant earthquakes, not only occur at plate boundaries but also super-long active faults, have been eagerly conducted; the design earthquake motion for public works must follow up the latest results.

References

Japan Road Association (2012): Specifications for highway bridges, Part V: Seismic design.

Kataoka, S., Satoh, T., Matsumoto, S. and Kusakabe, T. (2006): Attenuation relationships of ground motion intensity using short period level as a variable, *Proc. JSCE*, A, Vol. 62, No. 4, pp. 740-757.

Kataoka, S., Matsumoto, S., Kusakabe, T. and Toyama, N. (2008): Attenuation relationships and amplification map for ground motion in rather-long period range, *Proc. JSCE*, A, Vol. 64, No. 4, pp. 721-738.

Midorikawa, S., Miura, H. and Atsumi, T. (2012): Strong motion records from the 2011 off the Pacific coast of Tohoku earthquake, *International Symposium on Engineering Lessons Learned from the Giant Earthquake*, pp. 297-304.