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CAV Seismic Hazard Analysis of Taiwan

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Abstract: Recent studies show that cumulative absolute velocity (CAV) is a ground motion intensity measure that is more indicative of structure damage than PGA. Different than previous PGA-based seismic hazard studies, this paper presents the first CAV seismic hazard assessment for Taiwan, showing two hazard maps in 2% and 10% exceedance probabilities within the next 50 years. The result shows that the seismic hazard in Taiwan is relatively high in terms of CAV. Specifically, the CAV hazard in most areas of Taiwan is greater than 0.318 g-s in 10% exceedance probability with 50 years. In other words, on the basis of 0.318 g-s as the CAV threshold to structure damage, there is a 10% probability that the engineered structures in most areas in Taiwan could be damaged by earthquakes within the next 50 years.

Keywords: CAV; seismic hazard analysis; Taiwan.

1 Introduction

Cumulative absolute velocity, CAV, a relative new ground motion intensity measure proposed in the late 1980s by the Electric Power Research Institute (EPRI 1998). Basically, the CAV intensity measure is energy-oriented, considering the amplitude variation of the whole duration, unlike PGA that only considers the peak amplitude while disregarding the rest of the motion. Fig. 1 shows the schematic diagram illustrating the CAV of a ground motion, and the mathematical expression of CAV is as follows:

$$CAV = \int_0^{t_{\max}} |a(t)| dt \tag{1}$$

where $|a(t)|$ denotes the absolute value of acceleration at time t, and $t_{\max}$ is the duration of ground motion.

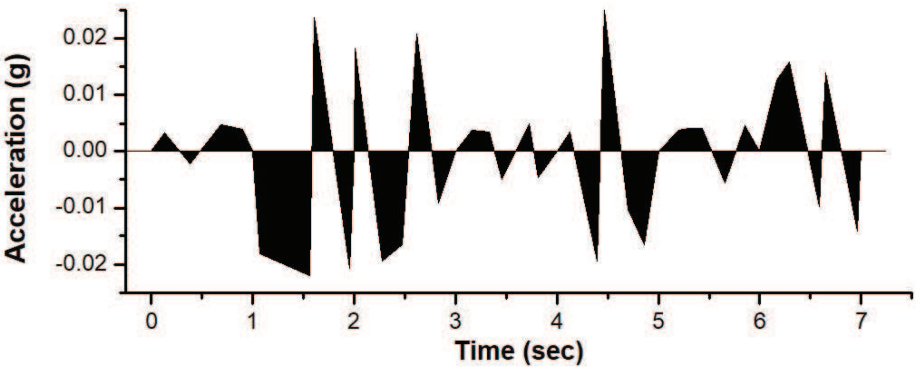

Figure 1. CAV of the ground motion time history: the total of the black areas.

The main reason that CAV has gained more attention should be as follows: the EPRI study (1998) investigated the relationship between structure damage and various ground motion intensity measured, and showed that CAV was more indicative of structure damage than PGA. Then in the following years, different CAV studies were reported, including CAV ground motion prediction equations (GMPEs), the relationship between CAV and PGA, etc. For example, Danciu and Tselentis (2007) proposed CAV GMPEs based on earthquake data from Greece, which are essential to CAV-based seismic hazard analysis; Xu et al. (2016) calibrated a joint distribution model for CAV and PGA based on earthquake data from Taiwan, and provided an application of the joint probability model to CAV-PGA joint seismic hazard analysis; Wang et al. (2018) studied

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the basin effect on site amplification in Taipei areas, which was using CAV as the indicator rather than its predecessors all using PGA as the indicator to study the basin effect.

2 Overview of Probabilistic Seismic Hazard Analysis (PSHA)

PSHA is an approach to estimate the annual rate of a given earthquake ground motion, e.g., Wang et al. (2012) used PSHA and estimated that the annual rate for Taipei to encounter a ground motion with PGA > 0.23 g should be about 0.01 per year. Explicitly, for being a probabilistic analysis, PSHA considers the variability of three variables, namely earthquake magnitude, source-to-site distance, and the error term of GMPEs.

A number of PSHA case studies for different cities and regions were reported (e.g., Wang et al. 2012). In addition, the USNRC (United States Nuclear Regulatory Commission) implemented a new earthquake-resistant design guideline for NPP (nuclear power plant) construction, in which the design parameters have to be obtained from PSHA (USNRC, 2007). With those applications, it shows that currently PSHA is a commonly accepted method for seismic hazard estimation and preparedness.

Nevertheless, it is noted that every PSHA study in the literature is PGA- or SA-based (spectral acceleration), although the EPRI study has shown PGA was less indicative of structure damage than CAV. As a result, this study aims to conduct the first CAV-based PSHA for Taiwan, estimating the annual rate of a given level of CAV exceedance in the region.

3 Input Data

The main input data of a conventional PGA-based PSHA include seismic source models, earthquake catalogs, and PGA-based GMPEs. Similarly, those data are also needed, except PGA GMPEs, for conducting a CAV PSHA. In short, the PGA GMPE will be substituted by a CAV GMPE for conducting a CAV PSHA, with the rest remaining the same, including the process of computation.

3.1 Source model

Figure 2 shows the seismic source model in Taiwan that was used in this study. This source model is the most recent one developed and used for (PGA-based) PSHA in Taiwan (Wang et al. 2016). Accordingly, the regions of Taiwan were characterized with more than 40 seismic sources.

3.2 Earthquake catalogs

Earthquake catalogs are needed for PSHA to calibrate the a- and b-value of the Gutenberg-Richter law and the maximum earthquake magnitude for each seismic source. The earthquake catalog used in this study contains more than 60,000 earthquake events around Taiwan from years 1978 to 2017. Note that the cutoff magnitude of the catalog is M_L 3.0 (local magnitude).

3.3 CAV GMPE

Two CAV GMPEs from the literature were used in this study. The first one was developed based on earthquake data from Taiwan (Xu et al. 2016), referred to as the Xu-2016 model hereafter, and the second was developed with data from Greece (Danciu and Tselentis 2007), referred to as the Danciu-2007 model. Note that although the Xu-2016 model developed using earthquake data from Taiwan seems more suitable for this study, its functional form is rather simple as those developed in earlier days (Cornell et al. 1979), which did not consider fault mechanism and site condition as the Danciu-2007 model. As a result, both were used in this study to somehow complement each other, and as other PSHA studies, we conducted a logic-tree analysis to resolve this epistemic uncertainty.

3.4 A-value, b-values and maximum magnitude

Derived from the earthquake catalog based on the Gutenberg-Richter recurrence law, the respective a- and b-value for each of the seismic source are summarized in Table 1. Similarly, the maximum magnitude assigned for each source is also given in Table 1 based on the earthquake catalog. Specifically, following the suggestion of Vilanva et al. (2007), the maximum magnitude was regarded as the largest one in the catalog plus 0.5.

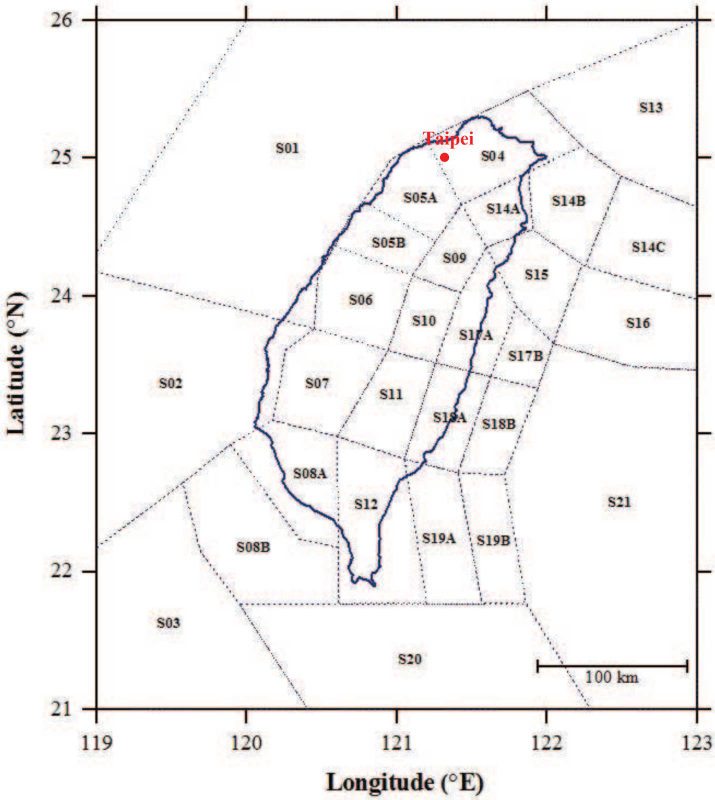

Figure 2. Seismic source models of Taiwan.

Table 1. Summary of a-value, b-value and maximum magnitude for each seismic source.

Area	a-value	b-value	Mmax	Area	a-value	b-value	Mmax
S01	4.42	1.20	5.64	**S13**	4.08	0.83	7.79
S02	3.83	1.03	6.05	**S14A**	4.20	0.88	7.16
S03	4.37	1.08	6.11	**S14B**	5.15	0.99	7.35
S04	4.56	1.18	6.25	**S14C**	5.04	1.00	8.10
S05A	4.45	1.25	5.33	**S15**	5.5	1.10	7.62
S05B	5.25	1.33	5.95	**S16**	4.65	0.84	7.46
S06	3.6	0.81	8.10	**S17A**	4.77	0.91	7.81
S07	4.43	0.96	7.02	**S17B**	4.67	1.07	7.13
S08A	3.93	0.94	7.31	**S18A**	4.84	1.00	7.04
S08B	4.34	1.00	7.92	**S18B**	4.42	0.98	7.78
S09	4.39	1.07	7.02	**S19A**	4.45	0.90	8.05
S10	3.76	0.87	7.46	**S19B**	4.09	0.91	6.32
S11	5.14	1.18	7.04	**S20**	4.66	0.96	7.87
S12	4.57	0.97	6.94	**S21**	4.15	0.84	7.94

4 Results

Figure 3 shows the CAV hazard curve for the center of Taipei with the input data above. It shows, for example, that at this location, the annual rate for the site to encounter an earthquake ground motion with CAV greater than 0.975 g-s is equal to 0.0021 per year. Considering the occurrence of such a rare event within a given period of time follows the Poisson stochastic process (Kramer 1996), its occurrence probability within the next 50 years is equal to 10%.

The same analysis was iterated for different locations in Taiwan for constructing the hazard maps in 10% occurrence probability within 50 years (Fig. 4), as well as in 2% occurrence probability in 50 years (Fig. 5). It shows that central Taiwan is of higher seismic hazard in terms of CAV, in relative to the rest areas of Taiwan.

5 Discussion

How can we evaluate the seismic risk based on the CAV hazard map? To answer the question, we have to find out the CAV threshold value to structure damage. Summarized by Campbell and Bozorgnia (2012), a panel convened by EPRI suggested the CAV threshold value to structure damage is about 0.318 g-s; in other words, an earthquake ground motion with its CAV greater than 0.318 g-s would be very likely to cause structure damage. Note that this threshold is based on the experience from the U.S., given no such local study has been conducted.

From the hazard map in Figs. 4 and 5, it shows that some locations have a CAV seismic hazard greater than 0.318 g-s with a 2% occurrence probability within the next 50 years. In other words, there would a 2% probability for the structures in the areas to be damaged by earthquakes. Even worse, some locations have a CAV seismic hazard exceeding this level with a 10% occurrence probability in 50 years, which infers than the probability that the structures at the locations would be damaged by earthquakes within the next 50 years is 10%.

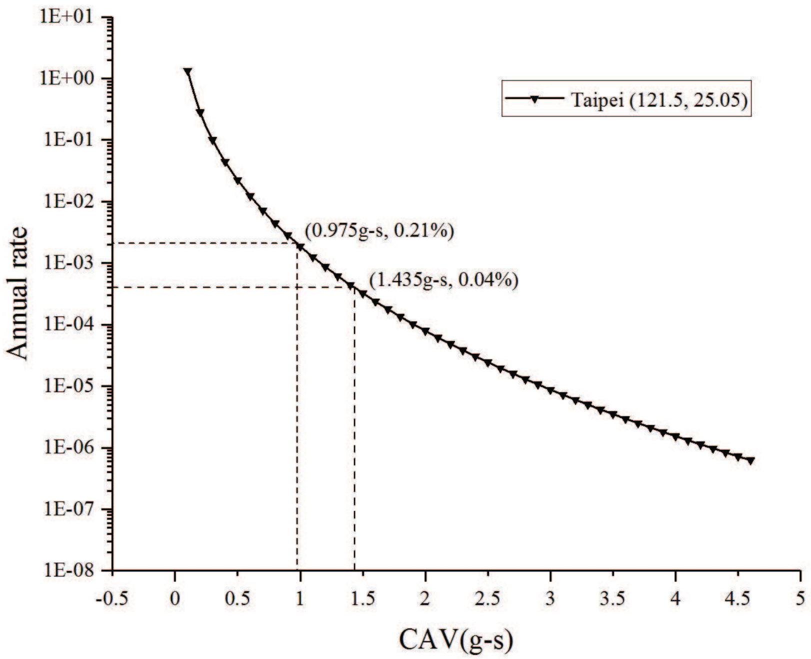

Figure 3. The hazard curve for Taipei.

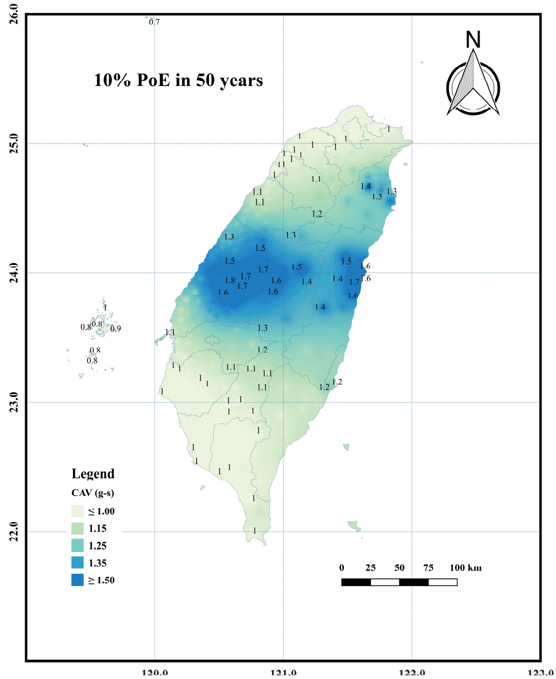

Figure 4. The CAV hazard map of Taiwan in 10% occurrence probability within 50 years.

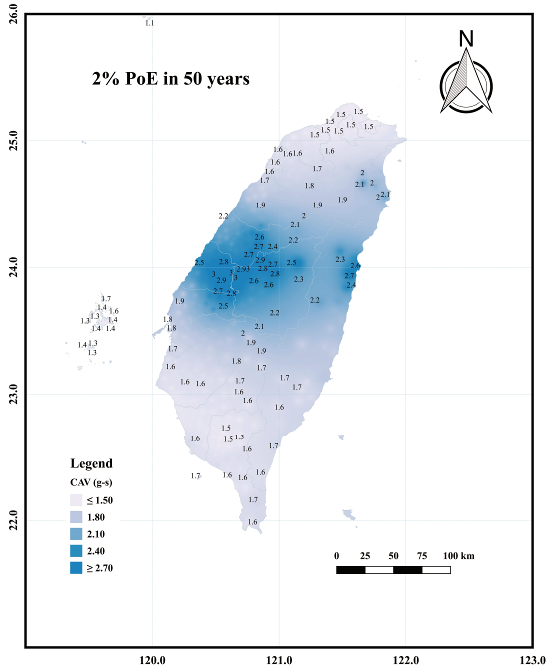

Figure 5. The CAV hazard map of Taiwan in 2% occurrence probability within 50 years.

6 Conclusions

Recent studies have shown that CAV is a ground motion intensity measure that is more related to structure damage than PGA, and the scope of this study is to investigate the CAV seismic hazard in Taiwan, on the basis of the PSHA approach.

With the main input data, i.e., seismic source model, earthquake catalog, CAV GMPES, from the literature, two CAV seismic hazard maps for Taiwan were presented, which are at the risk levels in 2% and 10% occurrence probabilities within the next 50 years. The CAV hazard maps can be used for evaluating the possibility of structure damages owing to earthquakes, considering the CAV threshold value to structure damage that was considered at 0.318 g-s from previous studies. Furthermore, it is suggested to the local government thinking of retrofitting the buildings located at the areas of high CAV seismic hazard.

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