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Seismic hazard analyses for Taipei city including deaggregation, design spectra, and time history with excel applications

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ABSTRACT

Given the difficulty of earthquake forecast, Probabilistic Seismic Hazard Analysis (PSHA) has been a method to best estimate site-specific ground motion or response spectra in earthquake engineering and engineering seismology. In this paper, the first in-depth PSHA study for Taipei, the economic center of Taiwan with a six-million population, was carried out. Unlike the very recent PSHA study for Taiwan, this study includes the follow-up hazard deaggregation, response spectra, and the earthquake motion recommendations. Hazard deaggregation results show that moderate-size and near-source earthquakes are the most probable scenario for this city. Moreover, similar to the findings in a few recent studies, the earthquake risk for Taipei should be relatively high and considering this city's importance, the high risk should not be overlooked and a potential revision of the local technical reference would be needed. In addition to the case study, some innovative Excel applications to PSHA are introduced in this paper. Such spreadsheet applications are applicable to geosciences research as those developed for data reduction or quantitative analysis with Excel's user-friendly nature and wide accessibility.

1. Introduction

Although earthquake prediction is still considered controversial, it has been generally accepted to use seismic hazard analysis for evaluating earthquake risk (Geller et al., 1997). One of the representative seismic hazard assessments is the Cornell–McGuire method (Cornell, 1968; McGuire, 1976, 1978; McGuire and Arabasz, 1990; Merz and Cornell, 1973), or usually known as Probabilistic Seismic Hazard Analysis (PSHA). Not only have a few PSHA case studies been conducted (e.g., Cheng et al., 2007; Stirling et al., 2011), a recent technical reference has prescribed the use of PSHA as part of site-specific earthquake-resistant designs (USNRC, 2007).

The region around Taiwan is known for high seismicity. As a result, local researchers have devoted themselves to a variety of studies aiming to mitigate the inevitable earthquake hazard. The investigations include earthquake early warning (Wang et al., 2012c; Wu et al., 2001), fault investigation (Lin et al., 2008, 2009), and seismic hazard analysis (Cheng et al., 2007; Wang et al., 2012a, 2012b). In the recent PSHA study for Taiwan, two hazard maps in 2% and 10% exceedance probabilities in 50 years were provided. This pioneering work is by all means laudable, but with its setup scope being a large-scale investigation covering the entire region around Taiwan, some important analyses such as hazard deaggregation and response spectra were not followed. However, those follow-ups are of more importance to modern earthquake-resistant designs, compared with seismic hazard itself.

As a result, this study aims to launch the first in-depth PSHA study for Taipei, the economic center of Taiwan with a six-million population. In addition to seismic hazard, the first hazard deaggregation, response spectra, and earthquake time histories are also investigated and recommended. Moreover, the analysis is assisted with Excel calculation and the NGA (Next Generation Attenuation) database. Altogether, the overview of PSHA, the case study, Excel applications to PSHA, the NGA database, result interpretations and discussions are given in this paper.

2. Overview of seismic hazard analysis

2.1. Seismic hazard analysis

Generally speaking, seismic hazard analysis can be considered an exercise to best estimate the site-specific, earthquake-induced ground motion given local seismicity and other geological evidences combined. Among a few methods developed, DSHA (Deterministic Seismic Hazard Analysis) and PSHA are the two representative approaches and both have been prescribed in respective technical references (California Department of Transportation, 2006; USNRC, 2007). It must be noted that other probabilistic methods considering earthquake uncertainties in

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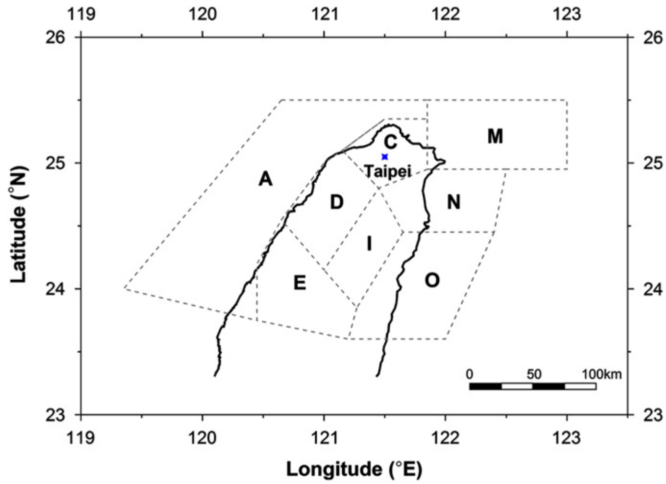

Fig. 1. Seismic sources included in this PSHA study for Taipei (after Cheng et al., 2007).

different manners were also developed (e.g., Wang et al., 2012a). But when PSHA is mentioned, it customarily connects to the Cornell–McGuire method.

However, not a seismic hazard analysis is perfect without challenge. For example, Krinitzsky (2003) considered PSHA being potentially problematic for the use of a logic-tree analysis to "average" the differences in the so-called experts' opinion, or epistemic uncertainty. On the other hand, DSHA is believed not "worse-case" enough for its use of the mean motion when field evidence has pointed out the observed motion occasionally exceeding two, even three, standard deviations above the mean (Bommer, 2003). Klugel (2008) conducted a comprehensive review on PSHA and DSHA, commenting that a robust seismic hazard analysis should be strongly related to the fundamental quality such as transparency, traceability, and verifiability, but not to methodology itself. This perspective is somehow in line with Mualchin (2005): Complicated analysis does not warrant the reliability in results, given the subject (i.e., earthquake) that is highly uncertain with our limited understanding of it.

2.2. Overview of PSHA

In short, PSHA takes the (aleatory) uncertainties of earthquake magnitude (M), source-to-site distance (D), and wave attenuation into account. The governing expression is as follows (after McGuire, 1976, 1978; McGuire and Arabasz, 1990)

$$\lambda(Y > y^*) = \sum_{i=1}^{N_S} \nu_i \sum_{j=1}^{N_M} \sum_{k=1}^{N_D} \Pr[Y > y^* | m_j, d_k] \times \Pr[M = m_j] \times \Pr[D = d_k] \tag{1}$$

where N_S, N_M, N_D are the number of sources, magnitude bins, and distance bins, respectively; annual earthquake rate ν is governed by the Gutenberg and Richter (1944) as follows:

$$\nu = 10^{a-bm} \tag{2}$$

where a-value and b-value are known as the G–R recurrence parameters. With this G–R relationship, the magnitude density function $\Pr[m_1 \le M < m_2]$ can be estimated by the ratio between the number of earthquakes in a magnitude range prescribed, to the total number of earthquakes (after McGuire, 1976, 1978; McGuire and Arabasz, 1990)

$$\Pr\left(m_1 \le M < m_2 \,|\, m_0 \le m_1,\ m_2 \le m_{max}\right) = \frac{10^{-bm_1} - 10^{-bm_2}}{10^{-bm_0} - 10^{-bm_{max}}} \tag{3}$$

where m_0 and m_{max} are the magnitude threshold and maximum magnitude. Therefore, the four types of underlying parameters (a, b, m_0, m_{max}) are part of PSHA. In addition, other parameters such as the magnitude increment (i.e., m_2 minus m_1), source discretization interval, distance threshold, are also needed although these parameters are more related to the resolution than the accuracy in results. Along with proper source models and attenuations relationships, a PSHA study in the original framework can then be carried out.

Considering that the earthquake randomness is of high aleatory uncertainty and that earthquake forecast is controversial (Geller et al., 1997), PSHA accounting for the earthquake's aleatory uncertainty in such a formula (i.e., Eq. (1)) should be on a logical, defensible basis. To the best of our knowledge, PSHA is in fact more challenged for its follow-up analyses such as logic-tree and deaggregation (Krinitzsky, 1995, 2003), but less to the underlying framework itself (i.e., Eq. (1)) except for those comments of Klugel (2007). Moreover, the recently implemented guideline that prescribes the use of PSHA somehow reflects the general acceptance of this method in the community of earthquake engineering and engineering.

3. Case study for Taipei

Input characterizations are by all means closely related to the accountability in any of an analysis. In this case study, the PSHA inputs are mainly characterized with published sources, and we made our best effort to make the process as transparent as possible, which is one of the underlying qualities contributing to a robust seismic hazard analysis as suggested (Klugel, 2008).

3.1. Source model, distance threshold, and distance function

The source model used here follows the recent PSHA (Cheng et al., 2007) and DSHA (Wang et al., 2012b) studies for Taiwan. Since they were developed with the earthquakes less than 30 km, we used a focal depth of 15 km in the following analysis. We customarily use a 200-km range as the distance threshold, and Fig. 1 shows the seismic sources in this PSHA study for Taipei. To develop the distance probability function, we discretized the source into 0.1 degrees in both latitude and longitude. Note this source model is the only reputable model recently developed for Taiwan, and its development (i.e., area source) is a result of fault ruptures (i.e., line source) and regional seismicity (i.e., point source).

3.2. a-value, b-value, magnitude threshold m_0, maximum magnitude m_{max}, and magnitude increment m_{inc}

Accounting for the recent seismicity in best estimating a-value and b-value, we conducted an in-house calibration with the up-to-date earthquake catalog published and used (Wang et al., 2011, 2012a, 2012b). The maximum magnitudes used here are equal to those in the recent DSHA for Taiwan. We employed the magnitude threshold of 5.0M_w, considering the fact that little damage of engineered structures has been caused by $M_w < 5$ earthquakes in the past couple decades in Taiwan. As for the magnitude increment, we followed a benchmark PSHA example (Kramer, 1996) using ten bins in developing the magnitude density function. As a result, magnitude increment m_{inc} is then equal to $(m_{max} - m_0)/10$. To sum up, the PSHA parameters used in the analysis are summarized in Table 1.

Table 1
Summary of recurrence parameters and maximum magnitudes of each source zone (after Cheng et al., 2007; Wang et al., 2012b).

Source zone	*a*-value	*b*-value	Maximum magnitude (M_w)
A	3.099	0.828	6.5
C	3.727	1.014	7.1
D	5.774	1.334	7.3
E	4.898	1.087	7.3
I	3.492	1.137	6.5
M	5.689	0.803	6.5
N	6.106	1.134	8.0
O	5.036	1.107	8.3

Table 2
Summary of the coefficients (i.e., c_1 to c_5) and model standard deviations (i.e., $\sigma_{\ln Y}$) of the ground motion model used (after Lin et al., 2011).

Period (s)	c_1	c_2	c_3	c_4	c_5	$\sigma_{\ln y}$
PGA	−3.248	0.943	−1.471	0.100	0.648	0.628
0.01	−3.008	0.905	−1.451	0.110	0.638	0.623
0.06	−1.994	0.809	−1.500	0.251	0.518	0.686
0.10	−1.508	0.785	−1.551	0.280	0.500	0.713
0.20	−3.226	0.870	−1.211	0.045	0.708	0.687
0.30	−4.050	0.999	−1.205	0.030	0.788	0.657
0.50	−6.307	1.291	−1.134	0.0042	1.118	0.653
1.0	−9.868	1.691	−1.004	0.0004	1.485	0.677
2.0	−12.806	2.005	−0.975	0.0005	1.528	0.759
3.0	−13.886	2.099	−1.077	0.0004	1.548	0.787
5.0	−14.606	2.160	−1.114	0.0004	1.562	0.820

3.3. Ground motion models

A series of local attenuation equations was used in this study (Lin et al., 2011). They were developed on the basis of Campbell's model (Campbell, 1981), calibrated with a total of 4383 local strong-motion data. Their basic form is as follows:

$$\ln Sa = c_1 + c_2 \times M + c_3 \times \ln\left(D + c_4 \times e^{c_5 \times M}\right) \quad ; \quad \sigma_{\ln Sa} = \sigma^* \tag{4}$$

where Sa denotes spectral acceleration in unit of g; D is the rupture distance from the source to the site. The model standard deviation (σ^*) are summarized in Table 2, as well as the model coefficients (i.e., c_1 to c_5). It is worth noting that this attenuation family is the first, comprehensive series for Taiwan.

Unlike such a comprehensive model, first of its kind, a few PGA attenuation relationships have been developed for Taiwan, and utilized in recent seismic hazard studies (Cheng et al., 2007; Wang et al., 2012b). To account for the epistemic uncertainty in the PGA model, a total of three models were used to develop the PGA hazard curve. The other two models are expressed as follows (Cheng et al., 2007; Wu et al. 2001)

$$\ln(PGA) = -3.25 + 1.075 \times M - 1.723 \times \ln\left(D + 0.156e^{0.62391M}\right); \quad \sigma_{\ln PGA} = 0.577 \tag{5}$$

$$\ln(PGA) = 2.303 \times 0.00215 + 0.581M - \log\left(D + 0.00871 \times 10^{0.5M}\right) - 0.00414D\sigma_{\ln PGA} = 0.79 \tag{6}$$

On the other hand, without further knowledge in judging the relative model goodness for the site, we used an equal weight (i.e., 1/3) in the logic-tree analysis.

4. Overview of the in-house computation tool

Because of the advantages in Excel (Wang and Huang, 2012; Wang et al., 2012b), we made an attempt to apply it to PSHA calculation. A companion DSHA study has introduced some algorithms and Excel applications, which were applied to this PSHA tool development along with innovative PSHA-specific algorithms for hazard deaggregation and logic-tree analysis. Fig. 2, for example, shows the interface of this tool in hazard-curve calculations for two problems (i.e., the case study and benchmark example). Some more details about the Excel-based tool are also summarized in this section.

4.1. Logic-tree calculation

An efficient logic-tree analysis can be performed in a single Excel workbook (i.e., file) with Excel's copy-and-paste functionality extended to the worksheet. For example, a *n*-branch logic-tree analysis can be performed on *n* worksheets in Excel, and the programmed worksheet can be easily generated through copy-and-paste in advance. Next, as respective inputs are filled in the worksheet, the logic-tree analysis can be conveniently performed in a single workbook. Basically, the underlying reason making this exercise possible is because the subroutine created in Excel is executable in any of a worksheet when it is programmed to be "public."

4.2. Hazard deaggregation

Deaggregation is part of PSHA for analyzing hazard contributions from certain sizes and locations. The hazard deaggregation can help to determine the most probable earthquake scenarios and accordingly, proper earthquake time histories can be suggested. Table 3 shows an example of a deaggregation table recommended by the same technical reference introduced (USNRC, 2007), and it is followed in this study.

In this version of Excel PSHA, deaggregation can be performed at six default hazard rates as follows: 0.1, 0.01, 0.0021, 0.001, 0.0004, and 0.0001 per year. Note that the annual rates of 0.0021 and 0.0004 are the two customary hazard levels equivalent to 10% and 2% exceedance probabilities within 50 years. Such a conversion is in use of the Poisson process recommended (Kramer, 1996).

4.3. Program structure

Although the underlying PSHA algorithms (Eqs. (1–3)) are by no means complicated, the tool development became tedious with the designs of user-friendly operations and instant graphing. This version of Excel PSHA consists of more than ten macros working collectively from formatting, to computing, to graphing. Each macro's description is summarized in Table 4.

Note that macros "Distance" and "Calculate HZ" are project-specific subroutines. The script inside possibly needs to be changed when this tool is used for another project with new ground motion models and distance types selected. To the best of our knowledge, the operation procedure is similar to Fortran-based PSHA tools (e.g., SEISRISK III) that are considered generic because those are applicable to different projects, although in-house source-code modifications are needed during the input-changing process for accommodating specific information in a specific project.

4.4. Program verification

Before using, Excel PSHA was subject to verification with a benchmark PSHA example (Kramer, 1996). The validation report is given in the Appendix. With the seismic hazard calculated by Excel PSHA being nearly identical to those given in the benchmark example, the in-house tool is considered verified and ready for use.

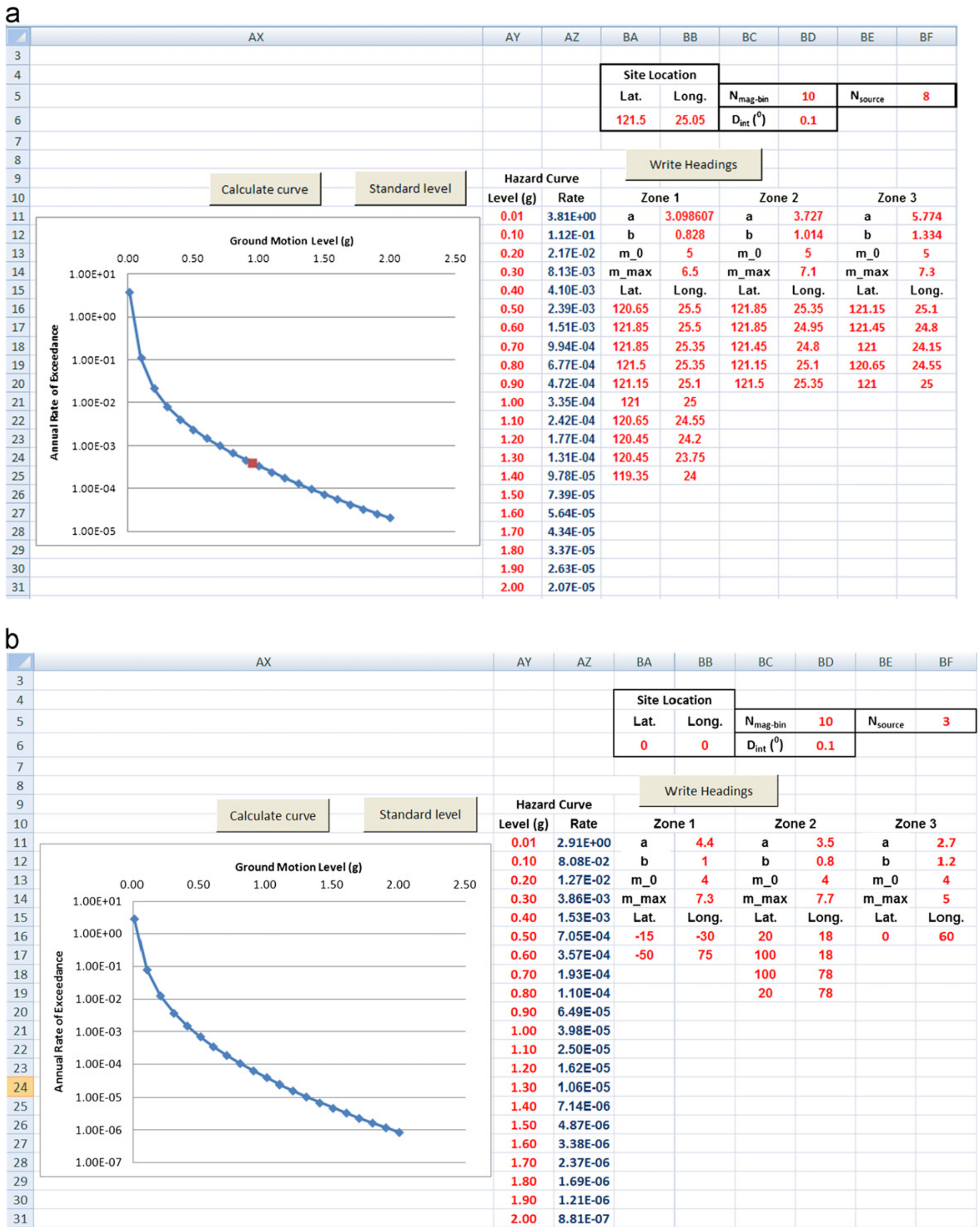

Fig. 2. Interface of the in-house tool: (a) for the case study for Taipei, and (b) for the benchmark example (Kramer, 1996). Note that the screenshot of the input spreadsheet for the case study (Fig. 2a) is cropped in the right-hand side.

4.5. Remarks on the difference in tools

A comment about compiling/running computer codes on different platforms is worthwhile to be given here. Take most, non-commercial Fortran-based tools as an example, the.exe program is generated with a compiler and the.txt source-code file. It is indeed less user-friendly since the every program modification and execution needs to go to a few different files. On the other hand, the platform such as Excel VBA or Matlab is an integrated tool with inputs, outputs, and in-house source codes contained in the same file. In other words, such a program is readily and equally "compile-able" and "run-able" with one file, which "should" be more user-friendly to operate. (User-friendliness is a subjective sense and spreadsheet calculation, for example, might not be user-friendly to everyone.)

5. NGA earthquake time-history database

After the site-specific response spectra and hazard deaggregation are evaluated, Excel PSHA cannot go on with providing suitable earthquake time histories, but neither can other PSHA tools, to the best of our knowledge. In this study, we resort to the NGA database managed by the Pacific Earthquake Engineering Research Center, or PEER (2011). The resource contains over 3000 earthquake motions collected from North America, Taiwan, etc… Note this tool also provides spectra matching and scaling while the searching is in progress.

Given a target spectra, magnitude range and distance range, the matched motions are immediately summarized and ranked as the searching is complete. Any of those time histories is ready for download if interested. In this study, six of the best matched motions are altogether recommended for the study site, aiming to have this type of uncertainty under consideration when such inputs are needed (e.g., in site amplification analysis). Note this study does not limit to those earthquakes around the study site, but mainly based on how well the response spectrum of the time history matches the target spectrum.

6. Results

Fig. 3 shows the PGA hazard curve for the geographical center of Taipei at 121.5°E and 20.05°N from a logic-tree analysis with three probable attenuation relationships. The mean rate for PGA > 0.23 g is calculated at 0.004 per year, and the seismic hazards at 10% and 2% exceedance probabilities within 50 years are corresponding to PGAs in 0.30 g and 0.55 g, respectively. It is worth noting that the seismic hazard calculated is comparable to the recent PSHA study (Cheng et al., 2007).

Fig. 4 shows the respective PGA hazard deaggregation at the two hazard levels. It was found that 90% of hazards are contributed by moderate earthquakes (i.e., 5.0–6.0M_w) occurring relatively close to the site (i.e., 0–50 km).

Table 3
The deaggregation table recommended by the technical reference (USNRC, 2007).

Distance range of bins (km)	Magnitude range of bins					
	0–5	5–5.5	5.5–6	6–6.5	6.5–7	> 7
0–15						
15–25						
25–50						
50–100						
100–200						
200–300						
> 300						

Along with other spectral accelerations, Fig. 5 shows the two response spectra for Taipei, and Figs. 6 and 7 show those time histories from the NGA database satisfactorily matching the target spectra and hazard deaggregation calculated. Table 5 summarizes those time histories recommended. It must be noted that those are considered half-space motions, because the ground motion models used in seismic hazard evaluation intend to simulate wave propagation within rock.

7. Discussions

7.1. Local earthquake-resistant designs and suggestions

Currently, the local earthquake safety design for Taipei is governed by a deterministic PGA in 0.23 g (R.O.C. Construction and Planning Agency, 2005), and based on this PSHA case study, it is approximately a 250-year return period for such a design value. Indeed, with little information such as the consequences at failure, it is difficult to judge whether using a 250-year return period in design is adequate or not. But considering Taipei a metropolitan city, where any failure of natural earth systems or engineered structures could lead to a severe consequence, designing the structure only capable of holding against a 250-year hazard seems inadequate, compared to some benchmark acceptable risks (Whipple, 1986). Therefore, the suggestion made to the

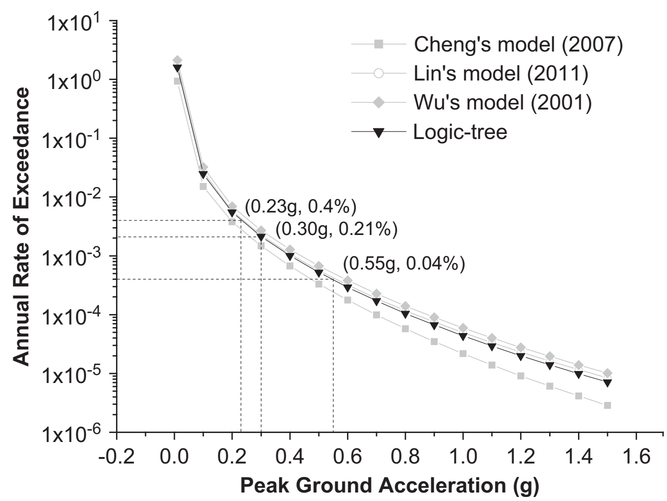

Fig. 3. PGA seismic hazard curve for the geographical center of Taipei located at 121.5°E and 20.05°N with the in-house Excel tool.

Table 4
Summary of macros in Excel PSHA.

Name of macro	Description	Notes
Standard level	Automatically fill the default series of ground motion values	–
Write heading	Write headings on the spreadsheet	–
Is-cross	Determine whether two lines cross each other or not	–
Is-inside	Determine whether a point is inside of a polygon or not	–
Magnitude function	Develop magnitude probability density function	–
Distance	Compute source-to-site distance	Users' implementation needed
Discretize line source	Discretize a line source	–
Discretize area source	Discretize an area source	–
Distance function	Develop distance probability density function	–
Calculate HZ	Calculate the annual rate for a given ground motion level	Users' implementation needed
Calculate HZ curve	Calculate hazard curves	–
HZ interpolate	Interpolate a corresponding ground motion level from hazard curves	–
Deaggregation	Perform deaggregation and 3-D instant graphing	–
Hazard map	Develop a seismic hazard map	–

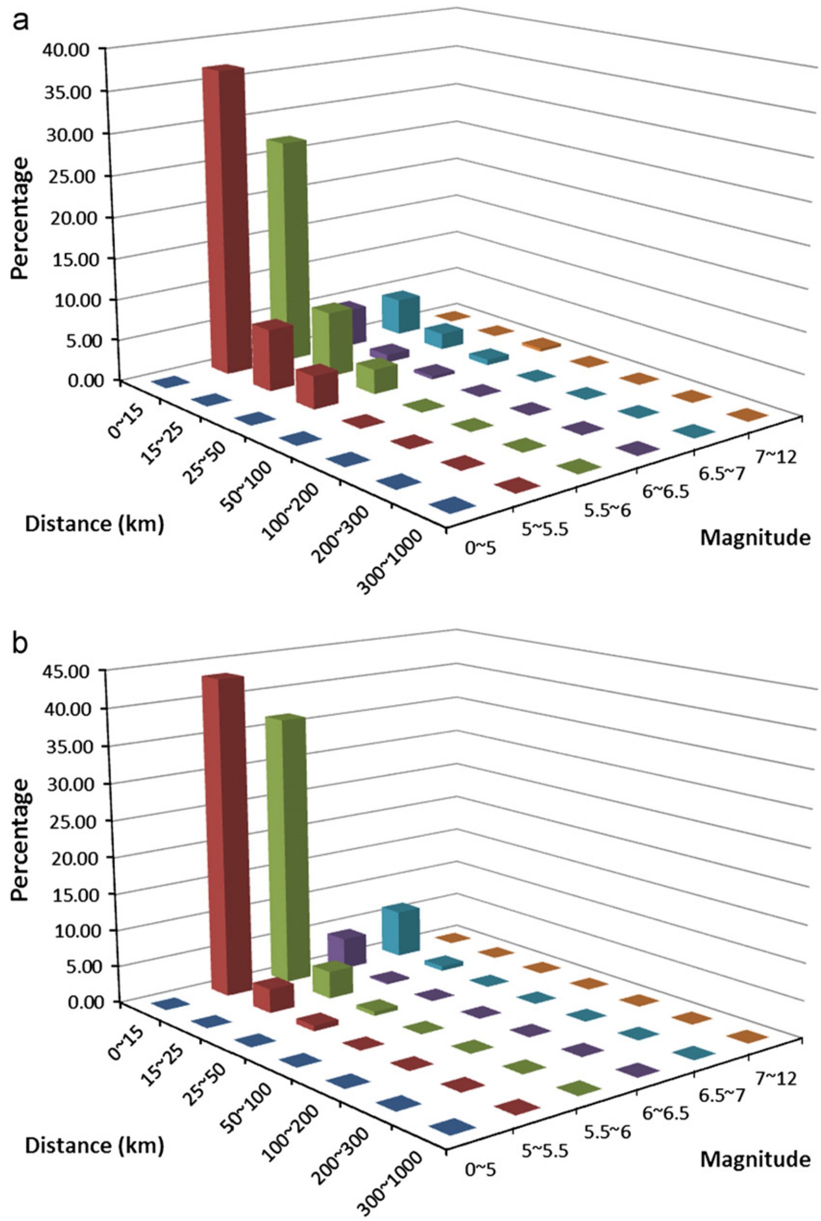

Fig. 4. Hazard deaggregation for Taipei at two customary hazard levels: (a) 10% exceedance probability in 50 years, and (b) 2% exceedance probability in 50 years.

local administration is that the earthquake risk in Taipei should not be overlooked, and characterizing the acceptable risk for this metropolitan city might be a good starting point, followed by earthquake hazard assessments and decision making.

7.2. *A robust seismic hazard analysis*

Given the recent discussions on seismic hazard analysis (e.g., Bommer, 2002, 2003; Krinitzsky, 2002, 2003), it seems that not a method is perfect without challenge (Mualchin, 2005). As suggested (Klugel, 2008), no matter what method is employed, transparency, traceability, and verifiability are the key to a robust seismic hazard assessment. With that in mind, the key assumptions and parameters made use in a seismic hazard analysis should be clearly documented and being traceable, followed by a repeatable result.

Applying it to the two PSHA studies for Taiwan, although with different scopes, this study is more qualified as a robust analysis than its counterpart. For example, the information about the computational tool, recurrence parameters, magnitude threshold,

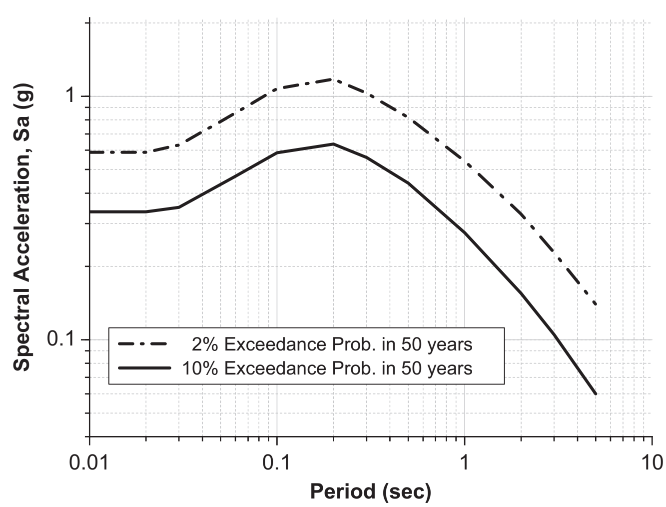

Fig. 5. Response spectra for Taipei in 2% and 10% exceedance probabilities within 50 years.

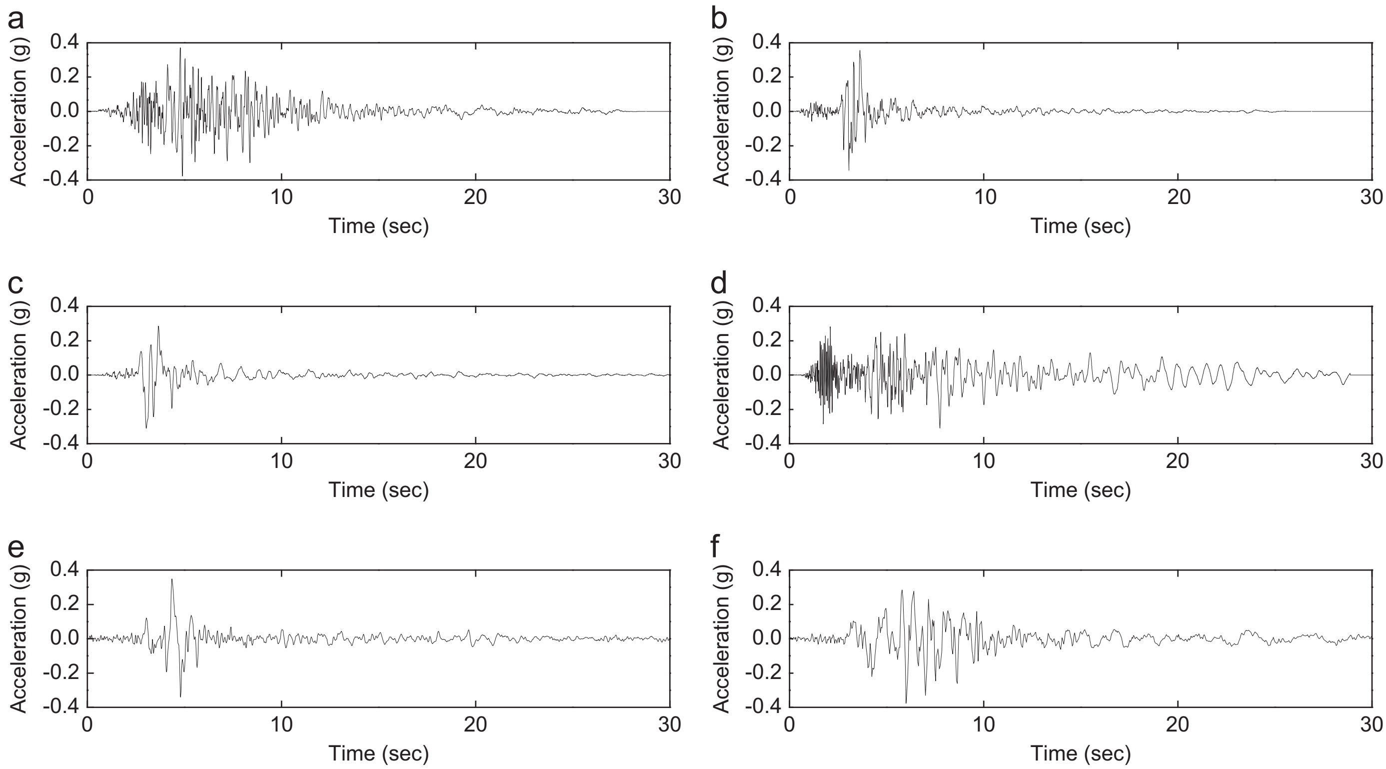

Fig. 6. Recommended earthquake time histories for Taipei corresponding to the 10%-in-50-year seismic hazard.

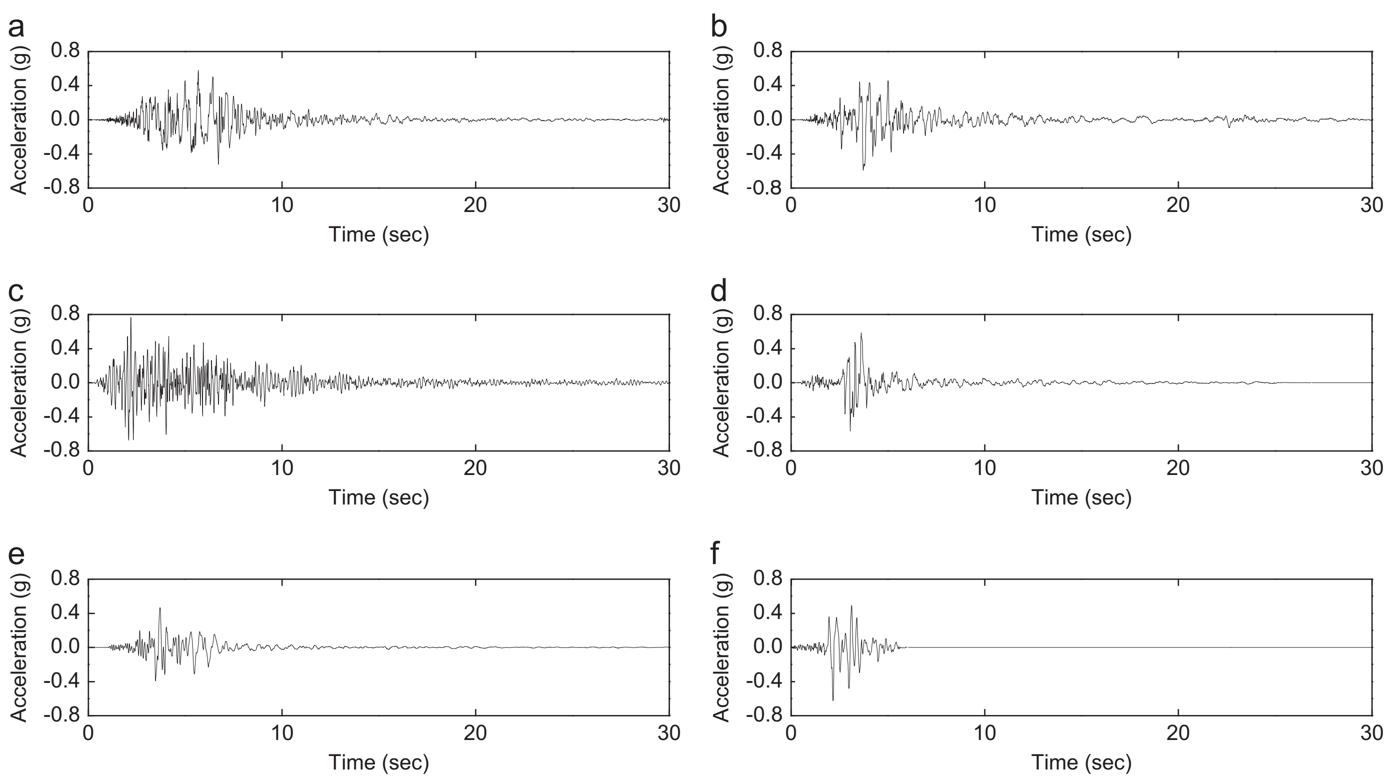

Fig. 7. Recommended earthquake time histories for Taipei corresponding to the 2%-in-50-year seismic hazard.

distance threshold, branch weights of the logic tree, etc… is not traceable inside of that counterpart PSHA study. In contrast, the seismic hazard analysis given here is on a transparent and repeatable basis; in terms of inputs, they are properly supported and documented; in terms of calculation, either the reputable resource is used or the in-house computation is verified.

Table 5
Summary of the earthquake records recommended for Taipei, according to the site-specific response spectra and hazard deaggregation with the use of the NGA database.

Event	Year	Moment magnitude (M_w)	Rupture distance (km)	Station	Fault mechanism
2% exceedance prob. in 50 yr					
Westmorland	1981	5.90	6.5	Westmorland Fire	Strike-Slip
Chalfant Valley-01	1986	5.77	6.4	Zack Brothers Ranch	Strike-Slip
Whittier Narrows-01	1987	5.99	14.7	Whittier Narrows Dam	Reverse-Oblique
Coyote Lake	1979	5.74	9.0	Gilroy Array	Strike-Slip
Yountville	2000	5.00	11.4	Napa Fire	Strike-Slip
Northridge-06	1994	5.28	13.0	Rinaldi Receiving	Reverse
10% exceedance prob. in 50 yr					
Westmorland	1981	5.90	7.8	Salton Sea Refuge	Strike-Slip
Coyote Lake	1979	5.74	9.0	Gilroy Array	Strike-Slip
Mt. Lewis	1986	5.60	13.5	Halls Valley	Strike-Slip
Hollister-04	1986	5.45	14.1	Hollister Diff Array	Strike-Slip
Imperial Valley-07	1994	5.01	11.2	El Centro Array	Strike-Slip
Upland	1990	5.63	7.3	Pomona	Strike-Slip

Table 6
Summary of PSHA programs (after Bender and Perkins, 1987; Danciu et al., 2010; Field et al., 2003; McGuire 1976, 1978; Ordaz, 1991; Risk Engineering Inc., 2005; Thomas et al., 2010).

Software name	Tool accessibility*	Open-sourced codes	Computer language
CRISIS	A-u-R	Yes	Visual Basic
EQRM	A-u-R	Yes	Python
Frisk88M	C-A	–	Fortran
EZ-FRISK	C-A	–	Fortran
MOCAHAZ	A-u-R	No	Matlab
MRS	A-u-R	No	C
NSHM	A-u-R	Yes	Fortran, C
OHAZ	A-u-R	No	Java
OpenSHA	A-u-R	Yes	Java
SEISRISK III	A-u-R	Yes	Fortran
SEISHAZ	C-A	–	Fortran
Excel PSHA	A-u-R	Yes	Excel VBA

* A-u-R: available upon request; C-A: commercially available.

7.3. Epistemic uncertainty

Epistemic uncertainty in PSHA is basically owing to the different opinions over the underlying inputs. For example, when two ground motion models are considered suitable, both will be used with respective weight, say 50% to 50% or 70% to 30%, to account for the so-called epistemic uncertainty. However, this logical method triggers equally logical challenges. Firstly and obviously, it is the weight. By Krinitzsky's definition (1995, 2003), such 70% to 30% weighting, for example, is a meaningless number because it cannot be supported scientifically. Take the recent PSHA study for Taiwan as an example, Wang et al. (2012a) pointed out that the intention of using logic-tree analysis is understandable, but without any support to the weights, that logic-tree analysis is indeed egocentric (Krinitzsky, 1995), and not being traceable (Klugel, 2008).

With two sides of equally logical opinions, we are in a neutral position toward the use of logic-tree on one condition: When the logic-tree calculation is part of a PSHA, its detail needs to be supported to some degree. For instance, the PGA hazard curve shown in this study is the combination of three local ground motion models. Without further knowledge judging their relative model goodness for the site, an equal weight was adopted in the computation.

7.4. Summary of existing PSHA tools

Reviewing the technical reports (Danciu et al., 2010; Thomas et al., 2010), we summarize those up-to-date PSHA tools in Table 6 for readers' reference. (In our belief, there should be more PSHA tools available although they are not included in the review.) Not only do the tools vary in the underlying computer language adopted, but they were developed in a different way to fulfill the respective setup objectives. In our humble opinion they are equally valuable especially for those non-commercial tools, unless they are proved to be fundamentally flawed.

8. Conclusions

This paper summarizes an in-depth PSHA study for Taipei with the calculation in Excel. In addition to seismic hazard curves, the first hazard deaggregation, response spectra, and suitable earthquake time histories from the NGA database are given in this paper. As pointed out by other assessments, this study comes as little surprise that Taipei is subject to high earthquake hazard. As a result, the local administration should conduct more investigation ensuring the risk to be acceptable in the current earthquake safety designs. In terms of computation innovations, some Excel applications are also introduced in this paper, which might be applicable to other geosciences research.

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Appendix. Program verification report for Excel PSHA

Fig. A1 shows the setup of a benchmark PSHA example with three sources. Note this example is not in a latitude/longitude system, but directly in a km-km layout. The ground motion model used in this benchmark calculation is as follows (Cornell et al., 1979)

$$\ln PGA = 6.74 + 0.859M - 1.8\ln(D+25) \quad ; \quad \sigma_{\ln PGA} = 0.57 \qquad (A.1)$$

For this example, Excel PSHA calculates the annual rates for PGA > 0.01 g at 1.953, 1.000, and 0.004 for the line, area, and point sources, respectively. The rates are reasonably close to 1.923, 1.106, and 0.005 provided in the referred example. Fig. A2 shows the two hazard curves in comparison. (Note the making of Fig. A2 was to scan the referred example as the underlying layer, then adding the in-house curve on top of it in the computer.) The matching is found less agreeable in large PGA levels, but we strongly believe that such a disagreement is a result of the

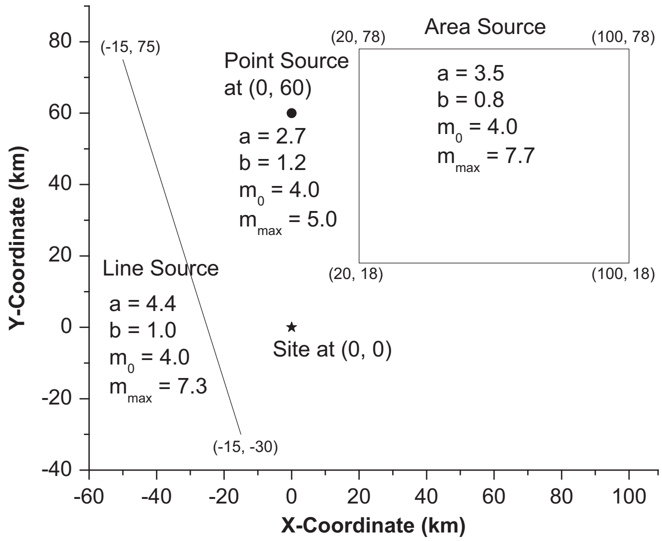

Fig. A1. Setup of the benchmark PSHA example with the three sources (after Kramer, 1996).

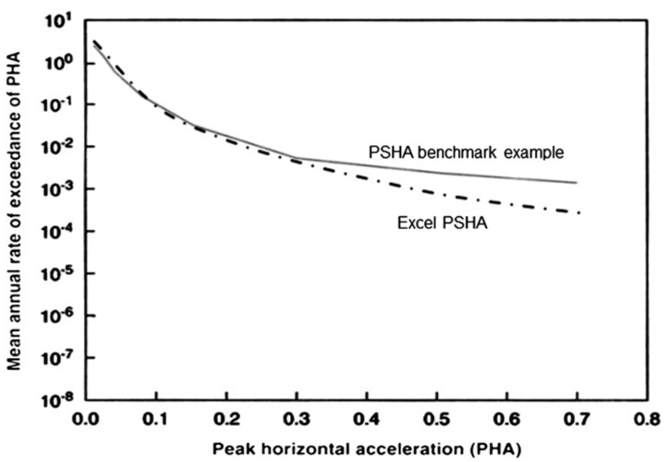

Fig. A2. Hazard curves in comparison: The one through Excel PSHA was processed on top of the chart scanned from the benchmark example (after Kramer, 1996).

improper making of the referred figure, after our calculations after calculations.

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