Proc. of the 6th Intl. Symposium on Reliability Engineering and Risk Management (6ISRERM)
31 May – 1 June 2018, Singapore
Editor(s) Xudong Qian, Sze Dai Pang, Ghim Ping Raymond Ong, Kok-Kwang Phoon

The Worst-Case Scenario-Based Seismic Hazard Maps in Guangdong Province, China

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Guangdong province including the Pearl River Delta (PRD) region is one of the major economic centers in China, which accounts for 11% of the total GDP in China. Although this region is located in low-to-moderate seismicity regions, seismic risk should be an important concern due to its strong economy, dense population and numerous buildings. Based on historical documentation, this region has experienced several noticeable earthquakes, including the 1918 Shantou Earthquake with a moment magnitude of 7.3. Therefore, it is necessary to accurately account for the seismic hazard, especially its maximum shaking intensities that could occur in this region. In this study, historical earthquake catalogue and recent earthquake events are first compiled. Then the worst-case scenario affecting this region is identified. Finally, under this deterministic earthquake scenario, the corresponding hazard maps, including peak ground acceleration (PGA) and spectral acceleration at 0.3 second ($S_a(0.3s)$) maps, are generated based on ground motion prediction equations with or without local site conditions. The resultant hazard maps are key components for further conducting seismic risk evaluation analyses in this region.

Keywords: Guangdong province, PRD region, seismic hazard, earthquakes, OpenQuake.

1. Introduction

Evaluation of seismic hazard for metropolitan areas especially in Asia has become increasingly important due to the concentration of exposures resulting from their dense population and rapid economic growth. For instance, the 2015 Gorkha Nepal earthquake with a moment magnitude (M_w) of 7.8, caused a catastrophe with more than 8,500 deaths and about USD 10 billion economic loss (Goda et al. 2015). Recently, seismic hazard analyses of metropolitan areas such as Metro Manila, Singapore, and Istanbul have been conducted by several researchers (e.g., Miura et al. 2008, Bal et al. 2010, Du and Pan 2017).

Guangdong province including the Pearl River Delta (PRD) region is an area where the seismic hazard should be well studied. Covering a territory of about 20,600 square kilometers, the PRD region comprises the urban districts of Hong Kong, Shenzhen, Dongguan, Macau, and Guangzhou, and is home to over 100 million inhabitants. The region is one of China's main economic centers, with an estimated GDP of USD 690 billion. Guangdong province generates 11% of China GDP (largest provincial economy for 26 consecutive years), and realizes 26% of

China's international trade. It has 9 cities (out of 21 prefecture-level cities in Guangdong) including 2 of the 4 Tier-1 cities of China - Guangzhou and Shenzhen.

Although the PRD area is generally classified as a low-to-moderate seismicity zone, the seismic risk cannot be neglected. In the seismic design code of China (2010), the bedrock peak ground acceleration (PGA) values for major cities in PRD area are classified as in the range of 0.1-0.2 g for a return period of 475 years (10% probability of exceedance in 50 years). More importantly, as shown in Figure 1, a large portion of Guangdong province lies over the various periods of sediments which consist of clay, silts, and sand layers. The time-average shear wave velocity in the top 30 m (V_{s30}) map estimated by U.S. Geological Survey (USGS) is shown in Figure 2, from which it can be seen that the center part of the PRD region has V_{s30} values lower than 300 m/s, classified as ground types C and D based on Eurocode 8 (2004). Therefore, significant site effects could be expected in PRD area.

The aim of this paper is to identify the worst-case earthquake scenario in Guangdong province, and generate seismic hazard maps under the earthquake scenario considered.

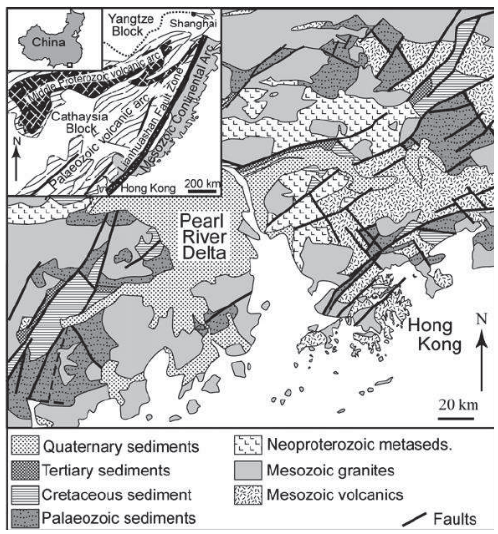

Figure 1. Geological map of the PRD region (Shaw et al. 2010).

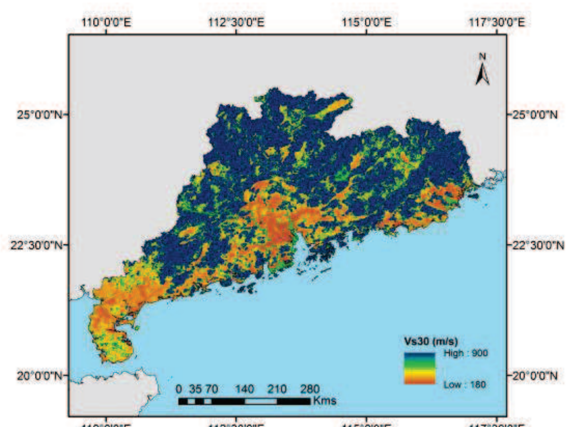

Figure 2. The V_{s30} map of Guangdong province obtained from USGS (2017).

2. Geology and Regional Seismology of Guangdong Province

2.1 *Plate tectonics and faulting*

Since this region is not located at the edge of the plates, earthquakes and volcanoes are less frequent, and geologically such a region is referred to as a passive continental margin. The PRD area is located near the south-eastern margin of the Eurasian Plate, which is situated about 500-700 km away from the nearest plate boundary of the Philippines Ocean Plate. It is generally agreed that the PRD area is located in low-to-moderate seismicity zone, and a devastating large-size earthquake is less likely to occur in this region.

Guangdong Engineering Earthquake Resistance Research Institute (GEERRI 2010) described the regional fault zones in detail in Figure 3. The active faults are shown in red lines in this figure. In the PRD area, the main faults consist of three parts (GEERRI 2010): (i) dominant northeast (NE) trending faults; (ii) east of northeast (ENE) trending faults; and (iii) northwest (NW) trending faults. The NE trending faults are especially in the offshore region. Among these fault classes, the faults striking NE are more likely to create strike-slip moment and therefore have a higher possibility to generate large earthquakes. Historical large earthquakes occurred mostly near Shantou and Nanao, including the magnitude 7.3 Shantou earthquake in 1918, where the NW striking faults intersect the ENE trending faults to extend up to nearly 200 - 600 km intermittently on the surface (GEO 2015), as is shown in Figure 3.

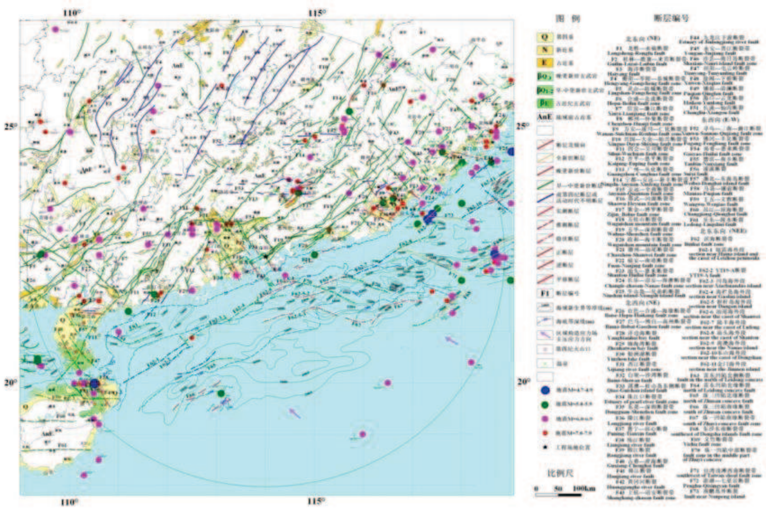

Figure 3. Tectonic structure of PRD Region (GEERRI 2010). In this plot, the thin lines denote the active faults within the PRD region, and the points denote the historical earthquakes with various magnitude size.

2.2 *Data collection and historical earthquakes*

For the present study, the search parameters for earthquake events are mostly from and within the coordinates 15°N to 27°N and 105°E to 125°E. Since no single catalogue source is complete on its own, the catalogues are compiled from various available sources and also from reports of historical earthquakes. Also, different sources have different time-span of data available in their archives and to overcome the gap and missing earthquakes, different sources are combined. The sources from which the catalogues are derived are China

Earthquake Administration, Guangdong Engineering Earthquake Resistance Research Institute, and Seismological Bureau of Guangdong Province.

As a standard, the earthquake information in each catalogue consists of date, time, coordinates of the earthquake epicentre, depth, and magnitude, though in some catalogues additional information is present. The combined earthquake catalogue covers the time from year 1067 up to 31 July 2016 inclusive. The catalogues consist of different types of earthquakes (e.g., M_w, M_s, and M_L), and the empirical relationships proposed by Wells and Coppersmith (1994) are used for the conversion from different magnitudes to M_w. The overall seismicity plot of the study area with respect to different magnitude bins is shown in Figure 4.

Extensive seismicity analyses indicate that the 1918 strike-slip Shantou event (M_w=7.3) can be identified as the worst-case earthquake scenario, due to its capability of producing larger stronger motions in this area. Therefore, the next step is to determine the credible ground motion intensity map subjected to this scenario, which will be illustrated in next section.

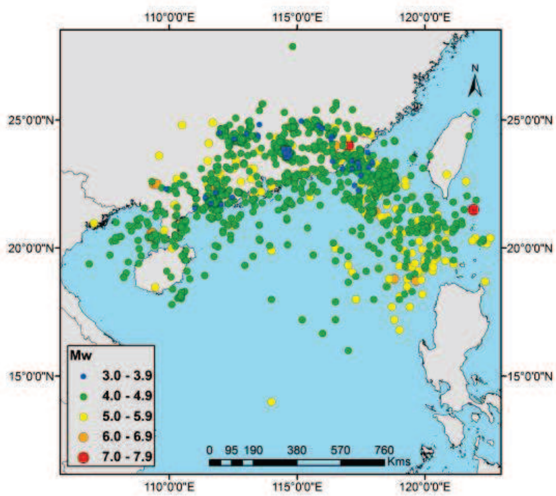

Figure 4. Historical earthquake events collected in this study. The empirical relationships proposed by Wells and Coppersmith (1994) were used to covert the different magnitude types (i.e., M_s, and M_L) into M_w.

Table 1. Source parameters used for the deterministic earthquake scenario

M_w	Depth (km)	Strike (º)	Dip (º)
7.3	10	44	60
Epicenter (lat)	Epicenter (long)	Upper Depth (km)	Lower Depth (km)
23.613	116.828	2	17

3 Generation of Ground Motion Intensity Maps

3.1 *OpenQuake software*

OpenQuake is an open-source developed, and accessible software for earthquake hazard and risk modelling developed by the Global Earthquake Model (GEM) community (Pagani et al. 2014). To run the hazard engine implemented in OpenQuake, three kinds of input parameters are needed: (i), seismic source parameters for source modelling; (ii), a set of ground motion prediction equations; and (iii) geological information such as V_{s30} map to quantify the site amplification effect. In this study, the source parameters for the 1918 Shantou earthquake are listed in Table 1. The globally applicable NGA-West2 ground motion prediction equation developed by Chiou and Youngs (2014) is used to predict the surface response spectrum, and the V_{s30} map shown in Figure 2 is used to account for the site effects.

3.2 *Ground motion intensity maps*

Accordingly, seismic hazard analysis is performed based on the OpenQuake engine. Figure 5 (a) (b) show the median prediction maps of PGA and $S_a(0.3s)$ at rock sites (V_{s30}=760 m/s), respectively. The highest PGA and $S_a(0.3s)$ values are 1.543 g and 5.436 g, respectively. As expected, the higher intensity values can be observed at the neighboring region of the fault area, such as Shantou, Jieyang, and Chaozhou cities.

Figure 6 (a) (b) show the median prediction maps of PGA and $S_a(0.3s)$ by considering the realistic site conditions in PRD area, respectively. It can be seen that the hazard intensities in Figure 6 are consistently higher than those shown in Figure 5. This is not surprising due to the significant site amplification effects. Besides, the PGA and $S_a(0.3s)$ values at the PRD area are generally smaller than 0.02 g and 0.05 g, respectively.

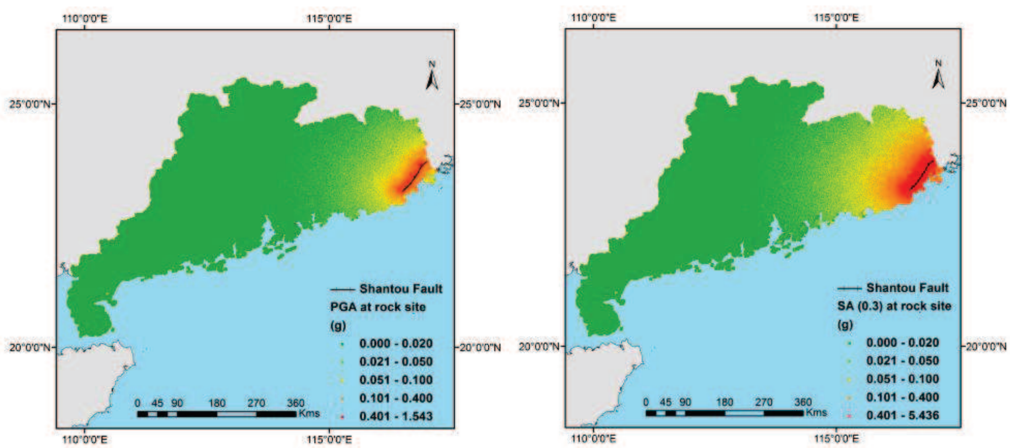

Figure 5. Generated (a) PGA and (b) $S_a(0.3s)$ maps at rock sties of Guangdong province for the 1918 Shantou (M_w=7.3) earthquake event.

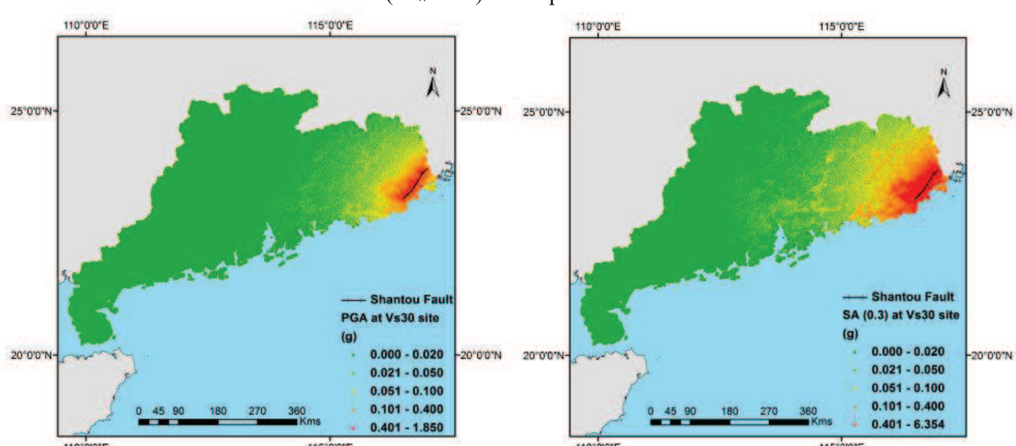

Figure 6. Generated surface (a) PGA and (b) $S_a(0.3s)$ maps considering the realistic site condition of Guangdong province for the 1918 Shantou (M_w=7.3) earthquake event.

4 Conclusion

This paper identified the worst-case earthquake scenario affecting Guangdong province, and presented the PGA and S_a(0.3s) hazard maps under the 1918 Shantou M_w=7.3 scenario. It is anticipated that the high seismic hazard (PGA>0.2 g) is mostly occurred at the eastern part of this province, whereas the seismic hazard for the PRD area is generally small (PGA<0.05 g). Besides, it is observed that the site effect at the PRD area is significant. The results can be further used to address the seismic risk as well as its impact on this area.

Acknowledgments

The authors acknowledge financial supports provided by the Sino-Singapore International Joint Research Institute for this work.

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