Soil Dynamics and Earthquake Engineering 99 (2017) 150–156

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Earthquake probability in Taipei based on non-local model with limited local observation: Maximum likelihood estimation

J.P. Wang[a], Yun Xu[a], Yih-Min Wu[b,c,*]

[a] Dept. Civil & Environmental Eng., Hong Kong University of Science and Technology, Hong Kong
[b] Dept. Geosciences, National Taiwan University, Taiwan
[c] Institute of Earth Sciences, Academia Sinica, Taiwan

ARTICLE INFO

Keywords:
Maximum likelihood estimation
Empirical model adjustment
Sanchiao fault in Taipei

ABSTRACT

Many earthquake empirical models were developed based on the statistics in the past. However, it is commonly seen that a non-local model was applied to a local study without any adjustment. In this paper, a new algorithm using maximum likelihood estimation (MLE) to adjust a non-local model for local applications was presented, including a case study assessing the probability of major earthquake occurrences in Taipei. Specifically, considering the fault length of 36 km and slip rate of 2 mm/yr, it suggests the Sanchiao (or Shanchiao) fault could induce a major earthquake with magnitude M_w 7.14 ± 0.17, based on a non-local model integrated with limited local data using the MLE algorithms.

1. Introduction

Given our imperfect understandings and natural randomness, many earthquake empirical models were developed with earthquake statistics of the past [1–6]. For example, Wu and Kanamori proposed a relationship between PD3 and PGV (maximum ground displacement in the first three seconds and peak ground velocity) that became a key empirical relationship to on-site earthquake early warning [1]. Similarly, several empirical models between earthquake magnitude and different fault characteristics (e.g., fault length) were developed [2,3], which are useful to earthquake potential assessment for a mapped fault [7,35]. Moreover, ground motion prediction equations that are essential to seismic hazard analysis are usually an empirical model [4–6]. For instance, Lin et al. developed a series of local ground motion models based on the data in Taiwan [6], which were essential to seismic hazard assessments for the region [8].

From the examples above, we can see that earthquake empirical models play an important role in earthquake study, considering that earthquake analytical models are still difficult to be reliably developed (mainly owing to nature randomness and our imperfect understanding). However, from model development to application, the following question is often asked and encountered: Are non-local empirical models suitable for local applications?

A possible solution to this epistemic uncertainty is to develop a local empirical model from scratch, then applying it to any local applications. However, for an earthquake study, the data are usually very limited owing to the long return period of major earthquakes, making it difficult to develop a local empirical model with a representative sample size. As a matter of fact, in the highly-cited study by Wells and Coppersmith [2], the proposed models were developed with data from several regions based on a more representative sample size, with the presumption that the data belong to the same population regardless of locations.

On the other hand, although the local data are too limited to develop a local model, they should be utilized in a local application considering the higher data relevancy. As a result, for a local application it is logical to integrate local data with non-local models based on a robust algorithm, as maximum likelihood estimation (MLE) that was commonly utilized in different applications and studies under such situation [9–15]. As a result, the motivation of the study is also aiming to use MLE to integrate a non-local model with limited local data, then applying the newly adjusted model to the target problem for evaluating major earthquake probabilities in Taipei, the most important city in Taiwan.

The paper in the following is organized as follows: The geological background of the study area is given in Section 2; an earthquake empirical model between earthquake magnitude, fault length, and slip rate is detailed in Section 3; the overviews of MLE, the algorithm developed, and the model application are given in Section 4, followed by the discussions over several issues, such as earthquake randomness and epistemic uncertainty, that are also related to the study.

* Corresponding author.
E-mail address: drymwu@ntu.edu.tw (Y.-M. Wu).

http://dx.doi.org/10.1016/j.soildyn.2017.05.009
Received 11 March 2015; Received in revised form 16 February 2017; Accepted 5 May 2017
Available online 17 May 2017
0267-7261/

2. The Sanchiao fault in Taipei

Taiwan is known for high seismicity owing to its location close to the boundary of three tectonic plates in the west of the Pacific Ocean. On average, there are around 2000 earthquakes above M_L 3.0 occurring in the region, and a catastrophic event, like the M_w 7.6 Chi-Chi earthquake in 1999, could be able to recur in decades [16]. Consequently, a variety of earthquake studies focused on the study region were conducted and reported, from seismic hazard analyses [8], to earthquake early warning [17,18], to earthquake statistics study [19,20], among others [21–26].

Taipei, the most important city in Taiwan, is therefore quite susceptible and vulnerable to earthquake hazard, not to mention the consequence should be more severe if a major earthquake occurs in the city (with a six-million population). As a result, the local community has been continuously studying the potentials of major earthquakes that could recur/occur around the city. For example, by examining the sediment sequences from deep boreholes along the Sanchiao fault in Taipei, the study concluded that the fault should have induced at least three major earthquakes with magnitude around M_w 7.0 in a period of 2600 years in early Holocene [21]. Besides, by studying the so-called neo-tectonic structures in the field, the researchers considered the Sanchiao fault is capable of inducing a major earthquake with magnitude above M_w 6.5 [22]; then with a Bayesian calculation, a study suggested that the return periods of the Sanchiao earthquake could be around 550–750 years [23]. Therefore, from the studies above it should be understood that the Sanchiao fault is the major concern to the (seismic) safety of the city. Fig. 1 shows the location of the fault in north Taiwan, and the geological background of the area.

From engineering perspectives, studies like seismic hazard assessment and earthquake probability evaluation were also reported for the study area. For example, Wang et al. [8] conducted a detailed probabilistic seismic hazard analysis (PSHA) for the city, and suggested 12 earthquake time histories that properly matched the hazard levels for the site's performance-based, earthquake-resistant designs. On the other hand, considering the basin topography could amplify ground shakings, Solokov et al. [24] studied and quantified the basin effect in Taipei by cross checking ground motion records (i.e., time histories) inside and outside the basin. As to earthquake probability evaluation, statistical studies on the earthquake records of the past were also reported, aiming to estimate earthquake probabilities for some preparedness work from the historical data and trend [19,20].

As shown in Fig. 1, the mapped length of the Sanchiao fault in Taipei is commonly considered at 36 km, which have been adopted in several applications [7,23]. In addition, the slip rate of the fault was considered around 2 mm per year [7,23]. For other properties (such as rupture area and displacement) that are not as essential as length and slip rate to this study present herein, refer to the investigation report [23] for more details.

3. Empirical relationship between earthquake magnitude, fault length, and slip rate

Mainly based on the data from North America with a sample size of 43, Anderson et al. [3] proposed the following empirical model between earthquake magnitude, fault length and slip rate:

$$M_w = 5.12 + 1.16\log(L) - 0.2\log(S) + e \ ; \quad \sigma_e = 0.26 \tag{1}$$

where M_w is earthquake moment magnitude, L is fault length in km, S is slip rate in mm/yr, and e is error term or model error. Note that the standard deviation of e was characterized as 0.26 from the level of sample scattering, and based on regression theory it is a random variable following the normal distribution with mean value = 0 [27]. Also note that the empirical model showing a positive correlation between earthquake magnitude and fault length should be rational, since a longer active fault should more possibly trigger a more extensive rupture or displacement, leading to more energy release and causing a bigger earthquake. On the other hand, it is also rational that the magnitude should be negatively correlated with slip rate, considering the possibility that a creep movement could release less strain energy over time, then ending up with a more brittle and explosive failure at critical points.

This model developed by Anderson et al. [3] can be considered a continuous work of the highly-cited study (with more than 4500

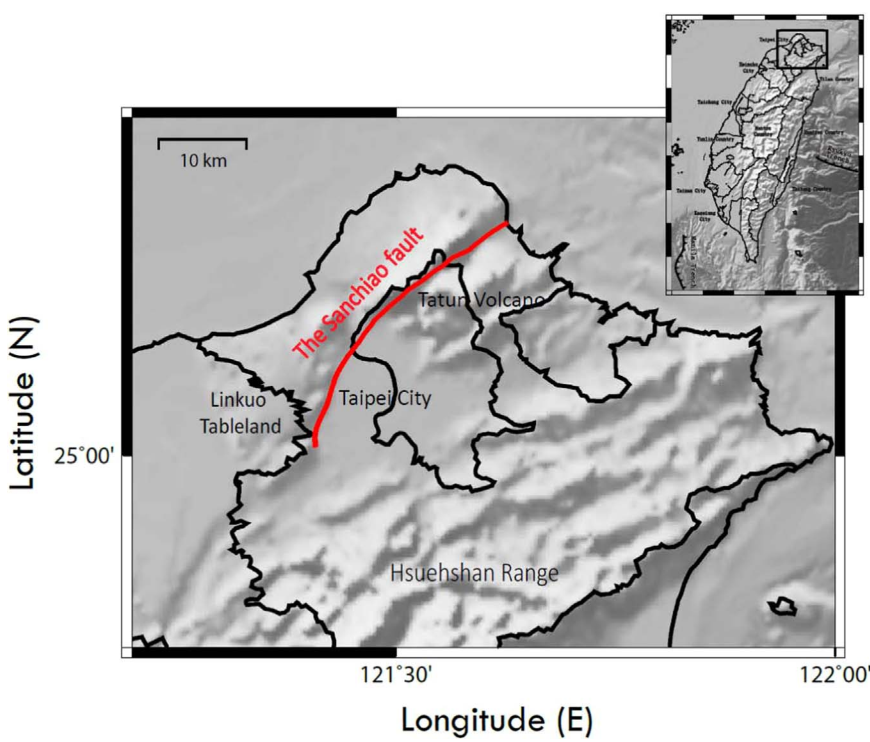

Fig. 1. Location of the Sanchiao fault in north Taiwan and the geological background of the study area.