# A summary of fault displacement analysis for bridge design in central Taiwan

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**ABSTRACT**

A relatively new approach domestically for seismic hazard assessment termed "Probabilistic Fault Displacement Hazard Analysis" (PFDHA) is outlined and applied to a freeway design project in central Taiwan. The project site is located in Taichung City, central Taiwan. Served as part of freeway link system in east Taichung City, the north-south project section will connect existing freeway and provincial road, satisfying the demand of a much sufficient transportation network in the east of the city. The total length of the project is approximately 11 km. Two active faults, Sanyi Fault and Chelungpu Fault, inevitably intersect with the route at certain sections. Giving that these faults are classified as active fault, the fault rupture hazard of these sections are assessed as references for the seismic design of a bridge that will cross Sanyi Fault. Comparing with well-known Probabilistic Seismic Hazard Analysis (PSHA) which has been used for assessing ground shaking hazards, PFDHA is established to evaluate fault rupture hazard, and had been widely used in California, USA. In addition, a deterministic method for assessing the displacement will also be performed as a comparison with PFDHA. The one with higher predicted displacement will be incorporated in the seismic design of the bridge. The result indicates that, the highest predicted displacement came from deterministic method and it is 1.08m. Consequently, a steel deck box girder bridge is designed conservatively according to this displacement. However, the result from PFDHA further provides a clearer picture in terms of evaluating the reoccurrence of certain displacement from a given source to the site of interesting which is valuable.

**Keywords:** Fault Displacement Hazard, PFDHA, Seismic Hazard Analysis, Active Fault

## 1 INTRODUCTION

In order to facilitate the development of transportation network in the mountainous area of Taichung City, this project was firstly launched in 1998. Subjected to further environmental assessment and modification of the route in the following one and half decades, the feasibility study of this project was completed in 2013.

To meet the need of connecting national freeway 1 and provincial road 74 in the east of the city, this 11 km long north-south direction freeway inevitably intersects two main active fault of category I (active within past 10,000 yrs) in central Taiwan. Considering that the intersections locate in regions of high density population area, it is less likely to perform more flexible embankment and cut methods in each crossing with the ruptures. Subsequently, a bridge (Bridge No. 5) with the concept of seismic design based on assessment of fault displacement is required.

According to data published by Central Geological Survey (CGS, 2012), Chelungpu Fault is a reverse fault and the total length is above 70km. Chelungpu Fault also caused 1999 Chi-Chi Earthquake which resulted in significant impact.

On the other hand, Sanyi Fault is also a reverse fault and the length is more than 30km. The evidence of activity comes from field observation where a holocene gravel layer had been disturbed by the fault rupture.

As for the topography and lithology, the project area approximate coincides with the boundary between Taichung basin and western foothills, whereas it is mainly alluvium in the west and sedimentary rocks of late Tertiary to Quaternary in the east. Fig. 1 shows the Geological map of project area.

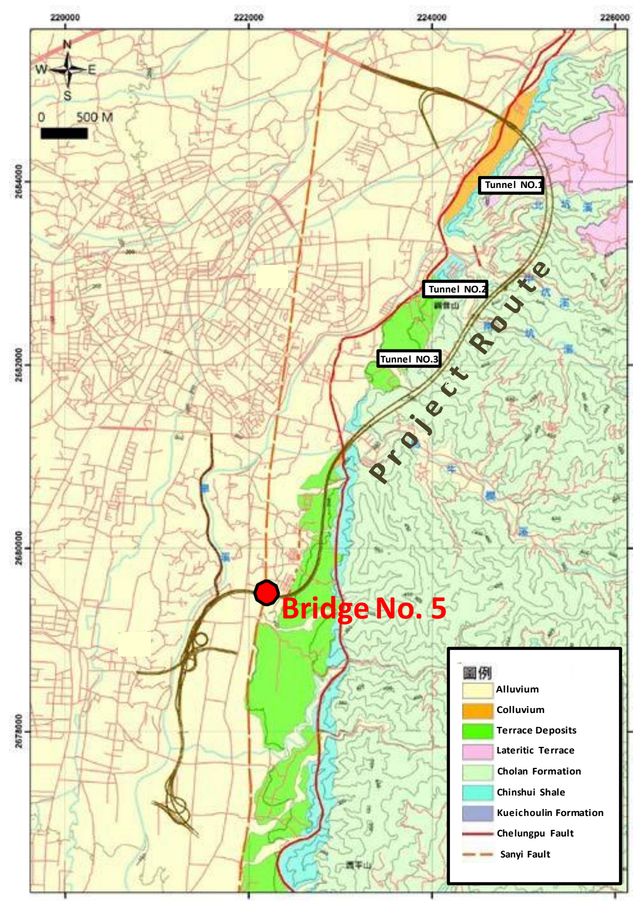


Fig. 1. Geological map of project area

## 2 METHODOLOGY

Generally there are two approaches in a PFDHA, including "earthquake magnitude approach" and "fault displacement approach", where the first one allows the calculation of fault displacement away from the primary fault trace, and the second one calculates fault displacement hazard based on fault-specific information regarding past displacements along the primary fault trace. In this study, an earthquake magnitude approach was performed. Besides, a deterministic method which utilizes parameters as well as empirical equations to compute displacement in a given earthquake magnitude was performed as well. The result of two approaches will be compared, the higher displacement obtained will be considered in bridge design. The basic idea of earthquake approach is briefly elaborated as follows.

The earthquake magnitude approach is based on the methodology for probabilistic seismic hazard analysis (PSHA), which relates the occurrence of displacement on a feature to the occurrence of earthquakes in the site region. Generally the form of the PFDHA expresses the annual rate of earthquakes in which a displacement parameter D, exceeds a specified level, *d* at site. This rate of exceedance, *v(d)* can be related to displacement and produce hazard curve. The following expression shows the idea of obtaining *v(d)* (Youngs et al., 2003):

$$v(d) = \sum_n N_n(m_0)\int_{m_0}^{m_u} f_n(m)\left[\int_0^{\infty} f_n(r|m)P_n(D > d|m,r)dr\right]dm \quad (1)$$

Where Nn ($m_0$) is the rate of all earthquakes on source n above a minimum magnitude, $f_n(m)$ is the probability density function of earthquake magnitude between $m_0$ and maximum earthquake $m_u$ that source can proved, $m_u$ is calculated based on equation suggested by Wells and Coppersmith (1994) or Yen and Ma (2011), with both related magnitude with parameters of fault geometry, and $m_0$ is assigned as 4.5; $f_n(r|m)$ is the conditional probability density function for distance r from site to an earthquake of magnitude m occurring on source n, and was described as suggested by Youngs and Coppersmith (1984) where the magnitude of earthquakes and their occurring frequencies were related; Pn(D> d|m, r) is the conditional probability that, given an earthquake of magnitude m at distance r from site, the displacement will exceed level d. Fig. 2 shows the geometric framework of PFDHA. In this figure, the site location is represented as coordinates *x* and *y*, and dimension of scale *z*, together with the closest distance from the site to the fault *r*, the rupture length *L*.

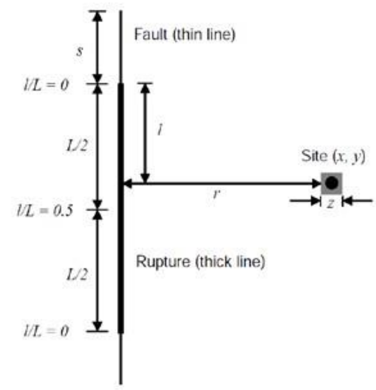


Fig. 2. Definition of PFDHA variables of earthquake magnitude approach

The term Pn(D> d|m, r) addresses the likelihood and amount of displacement at a site owing to an earthquake.

$$P_n(D > d|m,r) = P_n(Slip|m,r)P_n(D > d|m,r,Slip) \quad (2)$$

Where Pn(Slip|m,r) is the conditional probability that some amount of displacement occurs at the site as a result of the earthquake of magnitude m on source n with distance of r, and was described as magnitude versus probability that suggested by both Wells and Coppersmith (1994), Moss and Ross (2011). Considering that not every earthquake could lead to displacement which is different from PSHA, the term Pn(D> d|m, r, Slip) defines the condition probability of the amount of fault displacement given that slip occurs at site, including log-linear regressions between average displacement on the primary fault and magnitude (Petersen et al., 2011; Moss and Ross, 2011;

Wells and Coppersmith, 1994). The concept of acquiring input parameters needed for the terms are further elaborated in Fig. 3.

In consideration of the limited understanding of the nature of earthquake in present technology, the application of logic tree for determining input parameters is essential. These inputs normally comprise parameters needed for evaluating earthquake magnitude (e.g. fault plane geometry, fault length) or slip rates. In Fig. 4 and 5, the logic tree applied in this study is illustrated.

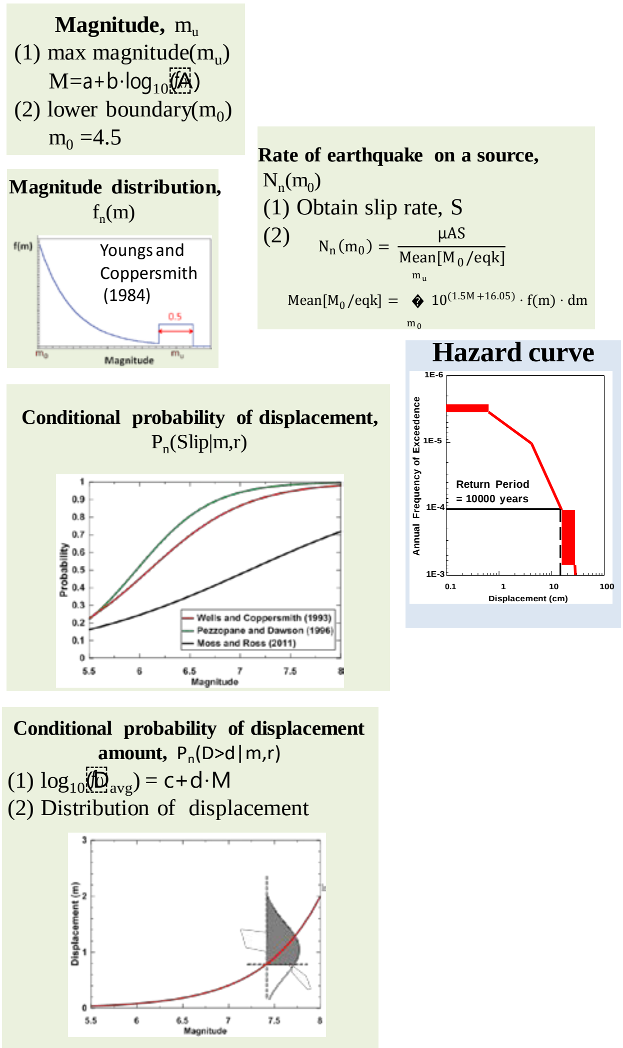


Fig. 3. Flowchart of earthquake magnitude approach

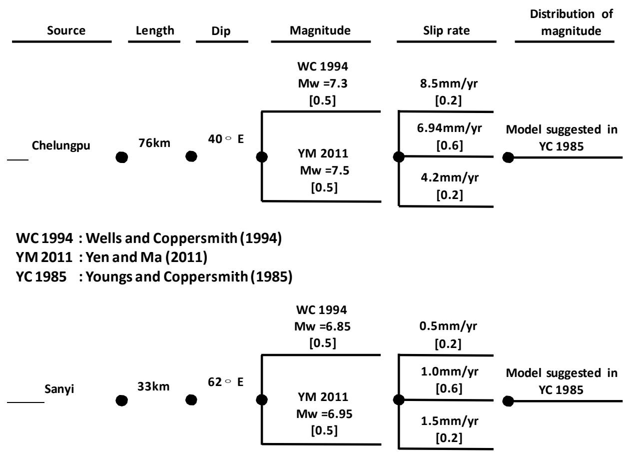


Fig. 4. Logic tree in earthquake magnitude approach (1/2)

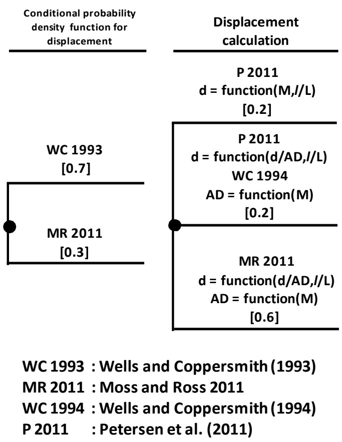


Fig. 5. Logic tree in earthquake magnitude approach (2/2)

Among these inputs in logic tree, the slip rate of Sanyi Fault was obtained through fault trenching in the vicinity of the fault line. A fault trenching observation enables the understanding of past seismic events and evaluation of the activity. The result suggests that it could be 0.88mm/yr.

The deterministic method in this project incorporates parameters of earthquake magnitude, faulting mechanism, distance, as well as the empirical equations relating these parameters to the displacement. The empirical equations adopted in this project were suggested by Petersen et al. (2011), Moss and Ross (2011), and Wells and Coppersmith (1994). The magnitude input for Chelungpu Fault is 7.3, 7.5 and 7.6 respectively. As for Sanyi Fault, it is 6.85 and 6.95 respectively.

## 3 RESULT AND DISCUSSION

According to the Seismic Design Specifications and Commentary of Buildings (Ministry of the Interior, 2011), scenarios of design earthquake (475yrs reoccurrence period) and maximum considered earthquake (2,500yrs reoccurrence period) should be considered. The displacement hazard curve obtained from PFDHA is shown in Fig. 6. For Chelungpu Fault, the displacement of 475 yrs design earthquake (the

Mean annual frequency of exeedence is 0.0021) is about 1cm, and the displacement of 2,500yrs maximum earthquake is about 200cm; as for Sanyi fault, the displacement of 475 yrs design earthquake is far less than 1cm, and the displacement of 2,500yrs maximum earthquake is approximately 1cm (Table 1)

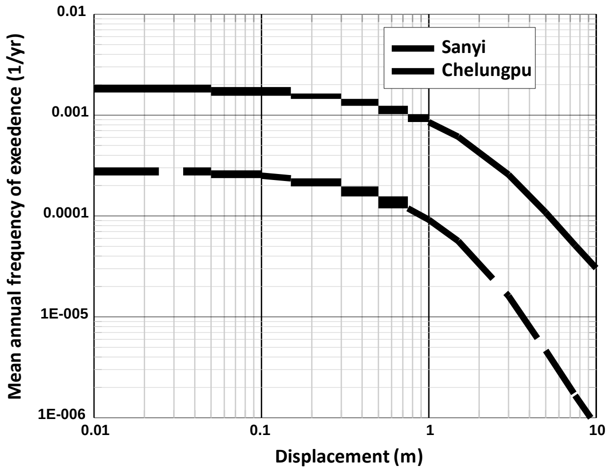


Fig. 6. Displacement hazard curve for Chelungpu Fault and Sanyi Fault

Table 1. Result of probabilistic method

| Fault | Earthquake considered | |
|---|---|---|
| | Design | Maximum |
| Chelungpu | 1cm | 200cm |
| Sanyi | <<1cm | 1cm |

As for the result of deterministic method, the displacement for Chelungpu Fault ranges between 1.41 and 3.02m; as for Sanyi Fault, it ranges between 0.79 and 1.08m (Table 2).

Table 2. Result of deterministic method

| Fault | Result | |
|---|---|---|
| | Magnitude input | Displacement (m) |
| Chelungpu | 7.3 | 1.41-1.76 |
| | 7.5 | 1.64-2.52 |
| | 7.6 | 1.76-3.02 |
| Sanyi | 6.85 | 0.79-1.01 |
| | 6.95 | 0.94-1.08 |

The analysis suggests that, the displacement of Sanyi Fault obtained from deterministic method is higher (1.08m) than it is in PFDHA (1cm). Thus the result from deterministic method was further taken into consideration of subsequent seismic design of a steel deck box girder bridge that crosses Sanyi Fault, which is set to be 1.1m.

Meanwhile, aside from only obtaining the amount of displacement from a given source (as it is in deterministic method), a PFDHA further provides a chance to evaluate the likelihood of a certain displacement from the source to happen. To summarize the findings in this study, it is concluded that the expected frequency for considered displacement (1.1m) to take place is relatively low and the design is well-considered.

## 4. CONCLUSION

To evaluate the possible displacement of a bridge that crosses active fault in a freeway of central Taiwan, a PFDHA was performed. Two alternative methods were included in the assessment, including PFDHA and deterministic method. The maximum displacement obtained from these methods is 1.08m, and was taken into consideration of bridge design.

## ACKNOWLEDGEMENTS

We would like to show our gratitude for the support from the employer, Freeway Bureau, MOTC during the implementation of this study.

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