Proceedings of the 8th International Congress on Archaeology, Computer Graphics, Cultural Heritage and Innovation 'ARQUEOLÓGICA 2.0' in Valencia (Spain), Sept. 5 – 7, 2016

SURVEYING DAMAGE TO HISTORIC BUILDINGS IN MEINONG EARTHQUAKE

Ren-Zuo Wang[a,*], Heng-Chen Chang[b], Meng-Chieh Lee[c]

[a] Associate Research Fellow, National Center for Research on Earthquake Engineering, Taipei, Taiwan. rzwang@ncree.org.tw

[b] Research Assistant, National Center for Research on Earthquake Engineering, Taipei, Taiwan. sis81818@hotmail.com

[c] Associate Professor, Department of interior design, National Taichung University of Science and Technology, Taichung, Taiwan. MCJL@nutc.edu.tw

Abstract:

In this paper, according to survey damage to historic building in Meinong earthquake, five damage models for Chinese temple, the state temple of the Martial God are proposed. These temples were built during 1600s. These five damage models are separation of column from wall (*M1*), roof damage (*M3*) wall cracks (*M5*), surface peeling (*M6*), and Tilt column (*M8*). Taiwan free field strong earthquake network is used to analyze seismic data from three free field stations. These stations are close to the state temple of the Martial God. Due to forward directivity effect, the stations' maximum ground acceleration amplitude is dependent of distance between epicenter and station. Modal analysis using finite element method (FEM) is used to detect weak positions of Martial God temple. Weak positions of numerical results are close to site failure positions of Martial God temple.

Key words: Meinong earthquake, Chinese temple, damage model, free field strong earthquake network, FEM.

1. Introduction

Taiwan is located in Circum-Pacific seismic zone. According to statistics data of earthquake records, Taiwan may occur a strong earthquake per 15-year to 20-year. It is possible to have large disasters under region with intense and frequent seismic activities. Economic losses and casualties cause by natural disasters. In addition, cultural heritages and historic buildings may be destroyed. Intense typhoon occurrence can be predicted, but intense earthquake occurrence can't be predicted. On February 6, 2016, an earthquake with a moment magnitude of 6.6 in southern of Taiwan caused by some cultural heritages damage. It seems to be a problem with maintained Taiwan's cultural heritages and historic buildings under seismic.

In Taiwan, few researchers are to study seismic resisting capability of historic buildings. When time passing, structures' earthquake-resisting capacity of monuments is less than modern architectures. On the other hand, the materials of early construction are mostly timbers and bricks. Timbers are hard to prevent deterioration than other materials. Bricks are also broken away when some earthquakes occurs. Moreover, in Taiwan's building codes, there are not enough articles to provide information of structures' earthquake-resisting capacity of monuments. Although many researchers in Taiwan have provided technologies of seismic disaster prevention for general buildings, but in terms of historical buildings, there are short of analytical techniques to introduce more new technology, such as measurement and assessment of seismic evaluation and early warning system.

This earthquake caused some cultural heritages damage especially close to epicenter. Therefore, we choose 30 historic monuments (Table 1) to survey damage models and conduct disaster data collection.

Table 1 Number of monument survey sites

3 Level Historic Monuments of Taiwan	*Amount*
National Historic Monuments	12
County Historic Sites	17
Historic Buildings	1

2. Damage Models of historic monuments

In Meinong earthquake, the wood structure and the brick mixed constructions have severely damaged. In Taiwan, historic monuments have three types such as national historic monuments, county historic sites and historic buildings. In this paper, damage models of historic monuments are classified as nine damage models (see Table 2). Most of historic monuments are Chinese temples. They are traditional wooden frame type (Chuang *et al*. 2006). One of them is the state temple of the Martial God. Figure 1 shows damage models of the

* Corresponding Author: Ren-Zuo Wang, rzwang@ncree.org.tw

This work is licensed under a Creative Commons 4.0 International License (CC BY-NC-ND 4.0)

state temple of the Martial God. They are separation of column from wall (M1), roof damage (M3) wall cracks (M5), surface peeling (M6), and tilt column (M8).

Table 2 Damage models of 3 level historic monuments

Damage models		*Number of monument sites*		
		National Historic Monuments	*County Historic Sites*	*Historic Buildings*
M1	Separation of column from wall	10	6	1
M2	Tilt wall	5	3	None
M3	Roof damage	7	3	None
M4	Separation of beam from Wall or column	4	14	1
M5	Wall cracks	18	12	2
M6	Surface peeling	5	6	None
M7	Separation of dowel from wall	2	4	1
M8	Tilt column	3	1	None
M9	Land subsidence	None	2	None

The damage events of *M1* at the state temple of the Martial God are the most damage in these five damage Models. The maximum displacement of gap between column and wall is 5 cm.

In roof damages (*M3*), different roof positions have different kind of damages. Figure 1 shows grave collapse from eaves in the state temple of the Martial God and the beam supporting the roof was broken.

In Fig.1, M5 is wall cracks at the top of door. This type of cracks is occurred at the corner of beams and door. *M6* is the surface peeling of stone wall next to the gate. It didn't affect the structure stability. *M8* occurs at the stairs and the column almost separated from its original position.

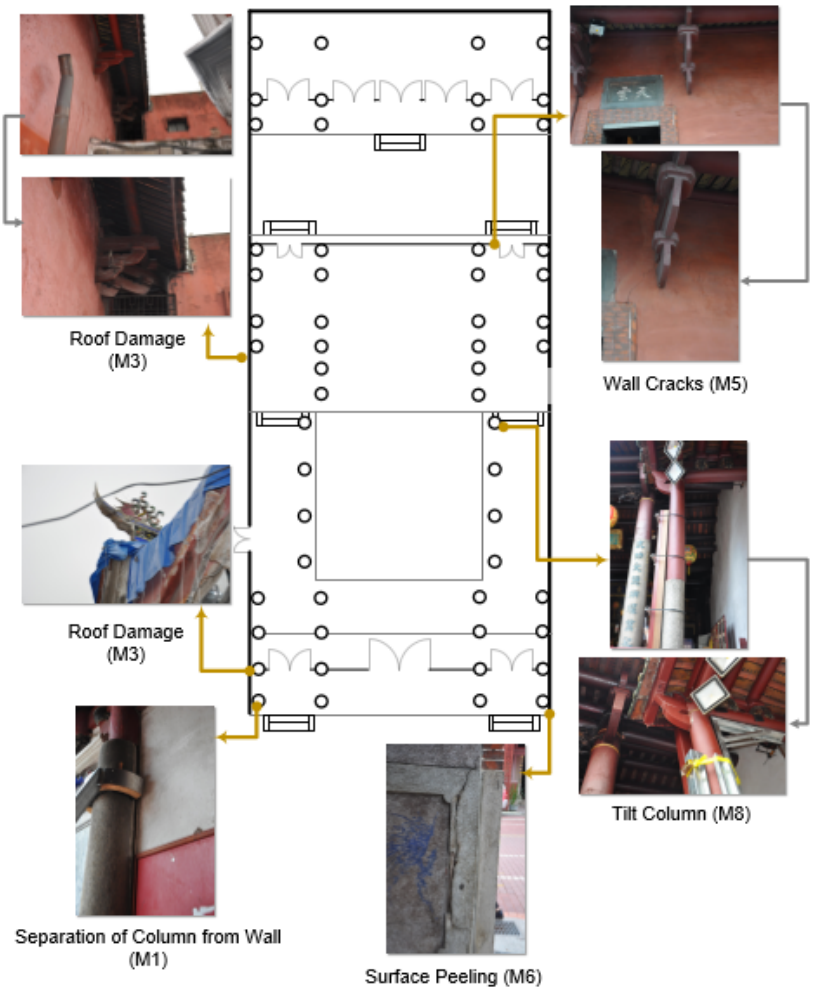

Figure 1: Damage Models of the State Temple of the Martial God.

This work is licensed under a Creative Commons 4.0 International License (CC BY-NC-ND 4.0)

3. Strong Motion Observation Stations

According to CWB's free field strong earthquake network, three free field stations are close to the state temple of the Martial God. These three stations are CHY067, CHY085, and CHY097 (as Fig. 2). Table 3 shows more information of these free field stations. They are including GPS, distances between stations and epicentre, impulse per mass, maximum ground acceleration, and first frequency for three components. Figure 3 shows the earthquake response spectrum at CHY085. CHY085 is the closest station from the state temple of the Martial God. Figure 4 shows acceleration time histories at CHY085 for Z, NS and EW components. The impulse per mass of earthquake can be computed as:

$$J = \int \mathbf{F} dt = \int m\mathbf{a} dt \qquad (1)$$

$$\frac{J}{m} = \int \mathbf{a} dt = \int |a| dt \qquad (2)$$

Where

J = impulse, $\mathbf{F}$ = force vector, m = mass, $\mathbf{a}$ = acceleration vector, a = acceleration.

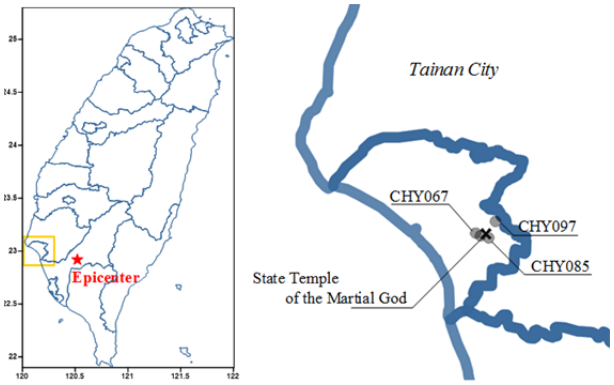

Figure 2: Positions of the state temple of the Martial God and three free filed stations.

Table 3: Information for Taiwan strong motion observation stations.

Free Field Stations	*Epiceteral Distance (km)*	*Impulse per Mass (cm/s)*			*Max. Ground Acceleration Amplitude (gal)*		
		Z	*NS*	*EW*	*Z*	*NS*	*EW*
CHY067	34.67	399	528	707	78	147	208
CHY085	33.31	310	487	572	90	163	232
CHY097	33.13	257	455	545	48	125	127

In Table 3, the impulses per mass at CHY067 are large than other station impulses. Due to resonance effect caused by topographic effect, the maximum ground acceleration and impulse per mass are at CHY085 station in EW direction. Since forward directivity effect by fault, PGA in this area is more than 200 gal (Lee *et al.* 2001).

In Fig. 5, modal analysis using FEM is proposed. Site weak positions (WPs) of FEM such as roof M3, M5 and M8 in Figs. 1 and 5 are close to site positions of the state temple of the Martial God.

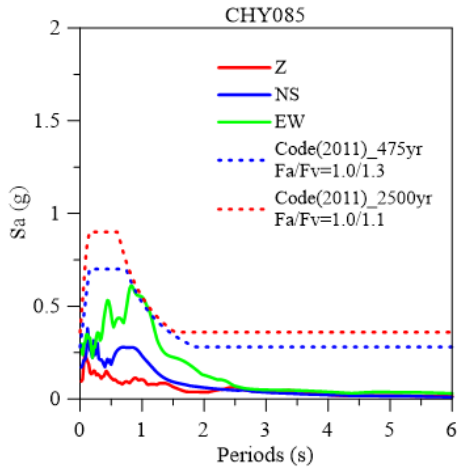

Figure 3: earthquake response spectrum at CHY085.

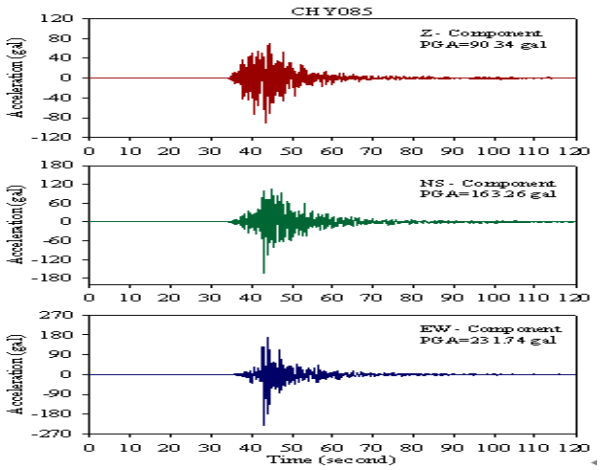

Figure 4: Acceleration signal at CHY085.

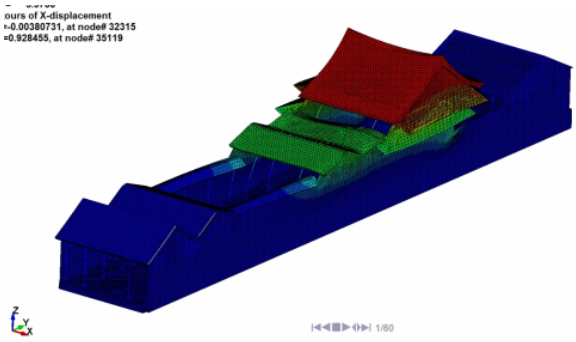

Figure 5: Finite element analysis of state temple of the Martial God in X direction.

4. Conclusion

Five damage models for wood and brick mixed constructions are proposed. Damage model relationships with strong motion observation stations are established. Modal analysis using FEM is used to find the weak positions (WPs) of the Martial God temple. WPs of FEM analysis are close to site positions of Martial God temple such as roof M3, M5 and M8 in Fig. 1.

This work is licensed under a Creative Commons 4.0 International License (CC BY-NC-ND 4.0)

References

Central Whether Bureau, Geophysical Database Management System. Message posted to ftp://gdms.cwb.gov.tw/

CHUANG, T.F., CHEN, C.Y., LIN, Y.Y., and CHEN J.W., 2006. Numerical analysis for the behavior of traditional wooden frame under earthquake excitation-Illustrated by Yu-shan-Kuan. *MingDao Journal,* **2**(2), pp. 69-105 (in Chinese).

LEE, C.T., CHENG, C.T., LIAO, C.W., and TSAI, Y.B., 2001. Site classification of Taiwan free-field strong-motion stations. *Bulletin of the Seismological Society of America*, **91** (5), pp. 1283–1297.

This work is licensed under a Creative Commons 4.0 International License (CC BY-NC-ND 4.0)