DAMAGE BEHAVIOUR OF TAIWANESE TRADITIONAL DIEH-DOU TIMBER FRAME

Sok Yee Yeo¹, Min-Fu Hsu², Kohei Komatsu³, Yu-Lin Chung⁴, Wen-Shao Chang⁵

ABSTRACT: Based on the shaking table experiments conducted on two different structural forms (Symmetric and Asymmetric form), the damage pattern of the traditional Dieh-Dou timber structure was studied. Using the 1999 Chi-Chi earthquake time history (TCU 084), roof loads of 17, 26 and 35kN were applied to the specimens under uni-directional excitation mode. Results showed that structural damage for both structural forms generally occur from 480 gal onwards. When friction between the mortise-tenon connections could no longer withstand the large seismic force, amplified rocking and torsion intensity lead to inelastic deformation. Damage pattern all begins from the bottom Dou members, spreading from the front and subsequently moving upwards to the upper Dou, horizontal Gong and traverse Shu members. More structural strengthening is recommended on the bottom Dou and front section members for future post-seismic repair.

KEYWORDS: Dieh-Dou timber structure, bracket system, shaking table experiment, rocking, torsion

1 INTRODUCTION
Bracket system and heavy roof are unique characteristics of traditional oriental timber frame. Of which, ‘Chuan-Dou’ and ‘Dieh-Dou’ frames are the two main types commonly found in Taiwan. But in this study, focus will be placed primarily on the Dieh-Dou frame. Although the 1999 Chi-Chi earthquake had destroyed or severely damaged many valuable traditional timber-frame historic timber buildings in Taiwan, to-date, not much research was done on the structural performance of the Dieh-Dou timber frame [1-4]. Thus, the Taiwanese engineers are still debating over the optimal evaluation method for the Dieh-Dou frame. However, before a proper structural evaluation can be established, a detail understanding of the damage pattern should be made. Hence in this paper, the damage trend of the Dieh-Dou timber frame when subjected to seismic force will be discussed.

2 EXPERIMENT
To understand the dynamic behaviour of traditional Dieh-Dou timber structure under different combination of structural forms and roof loads, two semi full-scale China Fir specimens of different structural forms (symmetric and asymmetric specimens, Figure 1) were mounted and tested on the shaking table of National Centre for Research on Earthquake Engineering (NCREE) in Taipei.

Using the 1999 Chi-Chi earthquake time history (TCU 084), roof loads of 17, 26 and 35kN were applied to the specimens under uni-directional excitation mode. Test levels of 20, 42, 60, 80 and 100% each representing 160, 336, 480, 640 and 800 gal respectively. System identifications were carried out between every test to monitor the integrity of the entire structures. When visible fractures were observed after a test, active reinforcement was carried out to reinstate as much of its structural stiffness as possible for the next test. The parameters used for this study are mainly roof load, PGA and rotation.

¹ Sok Yee Yeo, Department of Architecture, National Cheng Kung University, No. 1 University Road, Tainan city, Taiwan. Email: yanzyeo@gmail.com
² Min-Fu Hsu, National Cheng Kung University, Taiwan.
³ Kohei Komatsu, Kyoto University, Japan.
⁴ Yu-Lin Chung, National Kaohsiung University of Applied Sciences, Taiwan.
⁵ Wen-Shao Chang, University of Bath, U.K.
3 RESULTS AND DISCUSSION

3.1 Damage pattern for both systems

Results shown that structure damage for both structural forms generally occur from 480 gal (60%) onwards. The damage pattern all begin from the bottom Dou members and subsequently spreading from the front section and extending upwards to the members and traverse tie members (Shu), as shown in Figure 2.

3.2 Effects of rotation and torsion on the global structure movement

Before the 480gal-testing, the dowels of the bottom Dou members were pulled out slightly from the sill beam mainly due to the rocking caused by high frequency shaking. But the behaviour was relatively within elastic range, hence no visible crack was observed when the Dou members return in-place. From on-site observation and video records, initial crack first began from 480gal onwards. Forward thrust caused by the adjoining horizontal Gong members against the mortise region of the Dou led to horizontal shearing. Also, uneven distribution of inertia force and torsion (caused by uneven movement of the top and bottom parallel structures) became too great for the bottom Dou dowels to resist and hence the entire Dou was pulled out from the beam (Figure 3).

Under such circumstances, inelastic deformation occurred as the returning force was unable to let the Dou return to its original position; the Dou was thus sheared vertically by its own dowels and horizontally by the Gong member. Under 640gal and 800gal testing, intense rocking and torsion also caused the rest of the members above bottom Dou to be lifted up together and when it returned back, the high impact downwards force not only caused more vertical shearing on the bottom Dou, but also on the Gong members and adjoining traverse Shu members. Similar damage trend were repeated all the way to the middle tier members.

3.3 Design of the structure with relation to overall structural stability

Increasing roof loads amplify the seismic force with increasing seismic input [1] were observed in both structural forms. From on-site observation and measured rotation, the “forward” force is found to be much stronger than the “backward” force from 480 gal onwards. Thus this might account for the front complex members being pulled out at first instance and more damage occurrences at the front than at the back for both structural forms. Another possible reason could be due to the lesser surface contact at the front as compared to the back where the contact surface of bottom back Dou is wider thus giving rise to higher rotational rigidity (Figure 4).

4 CONCLUSIONS

In this paper, the damage pattern of traditional Dieh-Dou timber structure under different combination of structural forms and roof loads was studied. The following conclusions can be made:

1. When friction between the mortise-tenon connections could no longer withstand the large seismic force, amplified rocking and torsion intensity lead to inelastic deformation.
2. Damage pattern all begins from the bottom Dou members and subsequently spreading upwards to the upper Dou, horizontal Gong members and traverse Shu members. Front section is more prone to damage than back section due to lesser surface contact. Hence more structural strengthening is recommended on the bottom Dou and front section members for future repair.

REFERENCES