Status Investigation and Damage Analysis of the Dougong under the External Eaves of the Main Hall of Chuzu Temple in the Shaolin Temple Complex

Ziyin Yao,[a,#] Yilin Que,[b,#] Xiaolin Yang,[c,#] Qicheng Teng,[d] Zherui Li,[a] Xiaolan Zhang,[a] Weizhen Cai,[a] Hongyi Lv,[c] Tongyu Hou,[a] Yifan Liu,[a] and Zeli Que [a,]*

Chuzu Temple is one of the buildings in the historical architectural complex in "The Center of Heaven and Earth" in Dengfeng County. It is more than 800 years old. Currently, various kinds of damage can be found in the Chuzu Temple main hall. For more applicable conservation and renovation of the building, the status of the dougong (斗拱) under the external eaves of the Chuzu Temple main hall was investigated. Additionally, the existing types of damage and their causes were statistically analyzed to provide a practical reference for structural performance evaluations and protection reinforcement of the extant structure. According to the investigation results, 50.8% of the dougong members under the external eaves of the main hall had different types of damage. The main types of damage included detachment, plucking, holes, cracking, crushing, separation, and missing parts. The main causes were mechanical damage, bioerosion, and material degradation. Additionally, the study revealed that *Larix* sp., *Ulmus* sp., *Quercus* sp., and *Populus* sp. were the wood species used in the restoration to replace the antiquated wood.

Keywords: Chuzu Temple; Dougong; Conservation; Restoration

Contact information: a: College of Materials Science and Engineering, Nanjing Forestry University, Nanjing, 210037 China; b: High School Affiliated to Nanjing Normal University, Nanjing, 210037 China; c: School of Architecture, Zhengzhou University, Zhengzhou, 450001 China; d: Baoguosi Ancient Architecture Museum, Ningbo, 315033 China; # these authors contributed equally to this work
** Corresponding author: zelique@njfu.edu.cn*

INTRODUCTION

Ancient architecture is the crystallization of the wisdom of ancient artisans, and it has indispensable value in many areas, such as history and art. Ancient Chinese architecture is dominated by wooden structures, and one of its typical structural features is the use of a dougong between a beam and the top of a column (Li 2017). The dougong (known as puzuo in the Song Dynasty) is a unique structural element of interlocking wooden brackets and is one of the most important elements in traditional Chinese architecture. It is a structure installed under the eaves of ancient buildings or between girders that consists of two members, namely dous (斗, wooden block) and gongs (拱, bow-shaped brackets). Its main job is to transfer roof loads to the column frames and improve the seismic performance of buildings; additionally, it has architectural aesthetic functions (Ma 2003; Zhou *et al.* 2014). According to the location of dougong members in a building, they can be divided into two categories, *i.e.* inside eaves and external eaves dougong. Inside eaves dougong are found under the inside eaves of a building, and external eaves dougong are found under the external eaves of a building. The dougong is of vital importance for the timber frame structure of traditional Chinese buildings because of its unique functions (Que *et al*. 2015). The integrity of a dougong has considerable influence on the overall structure of a building (Tong and Liu 2018).

The concept of heritage conservation has been spreading, and increasing attention has been paid to the real-time monitoring, renovation, and protection of ancient buildings. An appropriate scientific renovation and reinforcement scheme should be based on an accurate understanding of the current status of a building. Therefore, site surveys have become an important part of the ancient building protection process (Chen *et al*. 2012; Zhang 2012; Chun *et al*. 2013).

The goal of this work was to contribute to a sufficient and reliable reference basis for the structural performance evaluation and restoration of the extant structure. The existing types of damage and their causes were analyzed. Information about the materials and their wood species (Cheng 1992; Kisternaya and Kozlov 2007; Yin *et al*. 2010; Mertz *et al*. 2014; Dong *et al*. 2017) was supplemented.

EXPERIMENTAL

Study Site

Chuzu Temple is located at the foot of Wurufeng Peak in the northwest of the Shaolin Temple complex (Guo 2009) in Dengfeng County. The overall scale of Chuzu Temple is not large. It is approximately 75 m long from north to south and 35 m wide from east to west. The main hall of Chuzu Temple (Fig. 1) is the main building in the nunnery. It uses a single-eave xieshan roof. According to records, Chuzu Temple was founded during the reign of Emperor Xiaowen of the Northern Wei Dynasty (A.D. 471 to 499), and was rebuilt during the Northern Song Dynasty in the seventh year of Xuanhe (A.D. 1125), only 25 years after publication of the treaty *Yingzao Fashi* by Li Jie (Wang 2003). The main original members and structural features have been retained after many restoration processes during the Jin, Yuan, Ming, and Qing dynasties (Qi 1979).

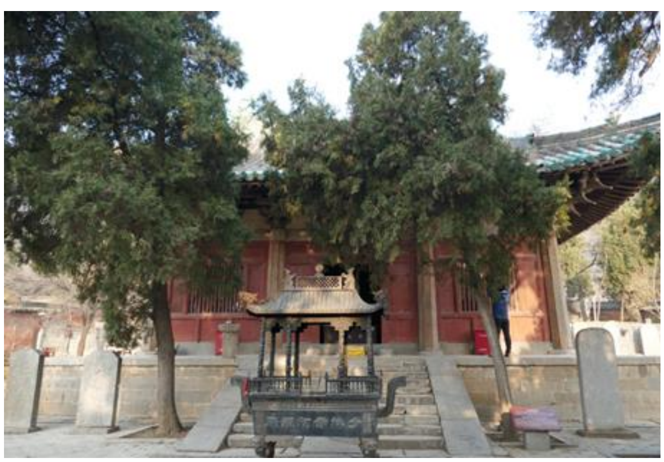


Fig. 1. Photo of the main hall of Chuzu Temple

In the 1980s, the National Cultural Heritage Administration of China appropriated funds to perform a survey and overhaul the main hall (Liu and Sun 2008). It has been approximately 40 years since the main hall was renovated. In the whole structure, the heavy roof loads eventually transmitted down to ground *via* the multiple-tier bracket complexes (shown in Fig. 2.), the intermediate horizontal and vertical components, and finally to the structural resisting beam-column components. Most structural members in the main hall of Chuzu Temple have been damaged to various degrees. Both the stone and wood have a certain degree of material degradation. To study the existing types of damage and their causes, the status of the dougong under the external eaves was investigated.

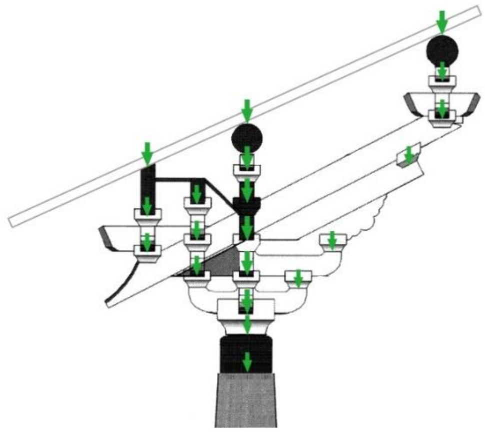


Fig. 2. Diagram of roof load transfer

Materials

There are 12 columns around the main hall of Chuzu Temple and four columns inside the hall. Each column has a dougong on the top (Zhang 2006; Yu 2016). The columns are made of stone. The dougong under the external eaves of the main hall were classified into three types: zhutou dougong (柱头斗拱, above the columns) (Fig. 3a)), bujian dougong (补间斗拱, between the columns) (Fig. 3c), and zhuanjiao dougong (转角斗拱, also called corner dougong under the corner of the eaves) (Fig. 3e).

To record information for each member clearly and conveniently, the dougong under the external eaves were numbered as presented in the column number index map of the main hall (Fig. 4a), and the dougong were numbered in the form of position-type. For example, A4-B4 East-south Bu means that it is a bujian dougong located between columns A4 and B4 on the southeast side. The names of the dougong members are shown in Fig. 4b.

Investigating the damage of the dougong under the external eaves of the main hall of Chuzu Temple was necessary. To provide an important basis for dougong reinforcement and restoration, the wood species were identified, and the wood material properties were tested. The ancestral temple has special historical value and protection regulations; therefore, the original wood that was replaced and preserved during the restoration of the main hall was selected for identification and testing. Because of the lack of an adequate systematic conservation and restoration process, the amount of remaining antiquated wood that was replaced during previous restorations of Chuzu Temple was limited. Chenghuang Temple on the west side of Wenmiao Street in Dengfeng City is in the same area as Chuzu Temple. It has a consistent architectural structure and wood material selection. Therefore, the antiquated wood of the structural members of Chenghuang Temple that was replaced during the repair process in December 2017 was selected for reference.

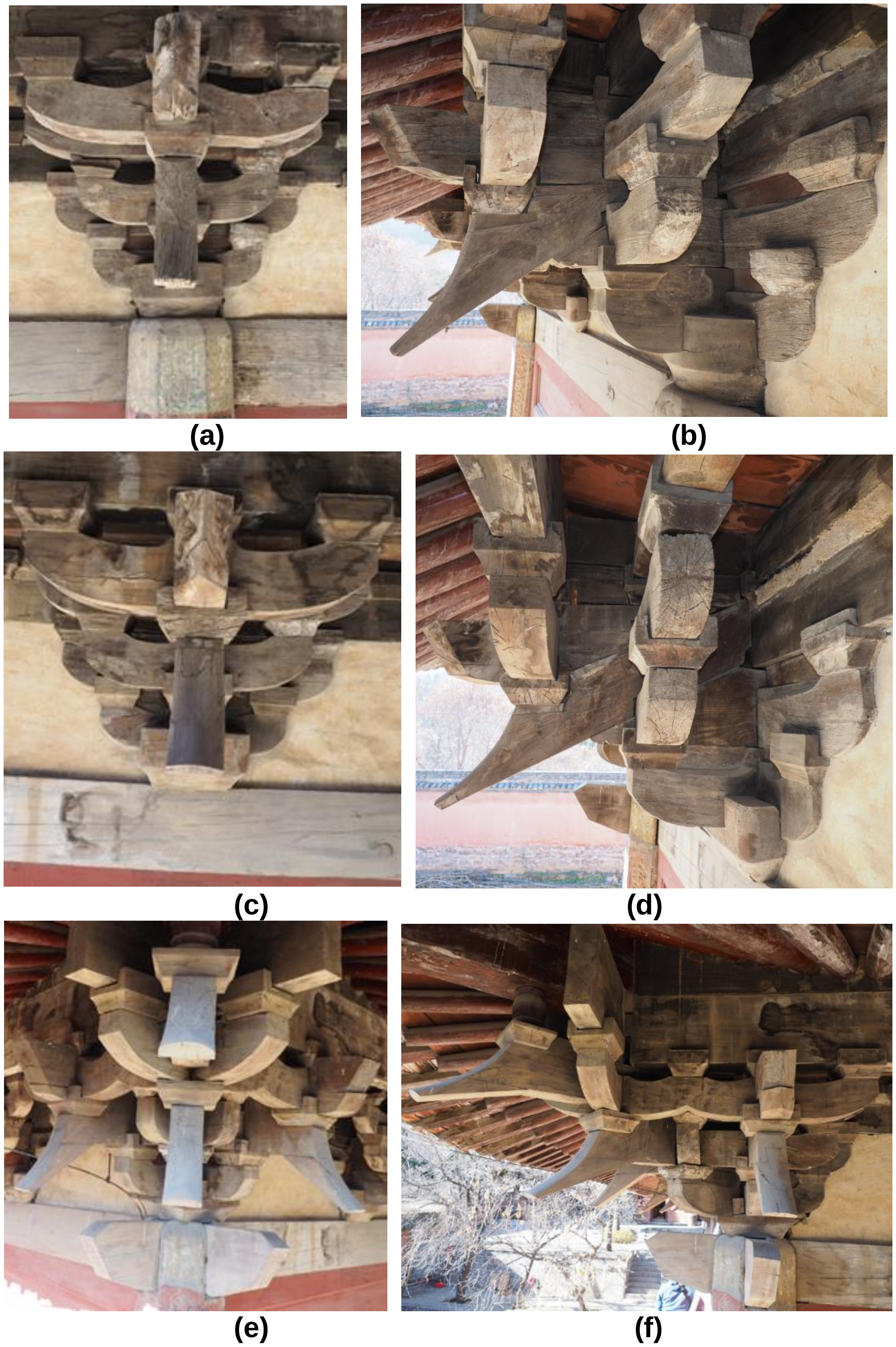
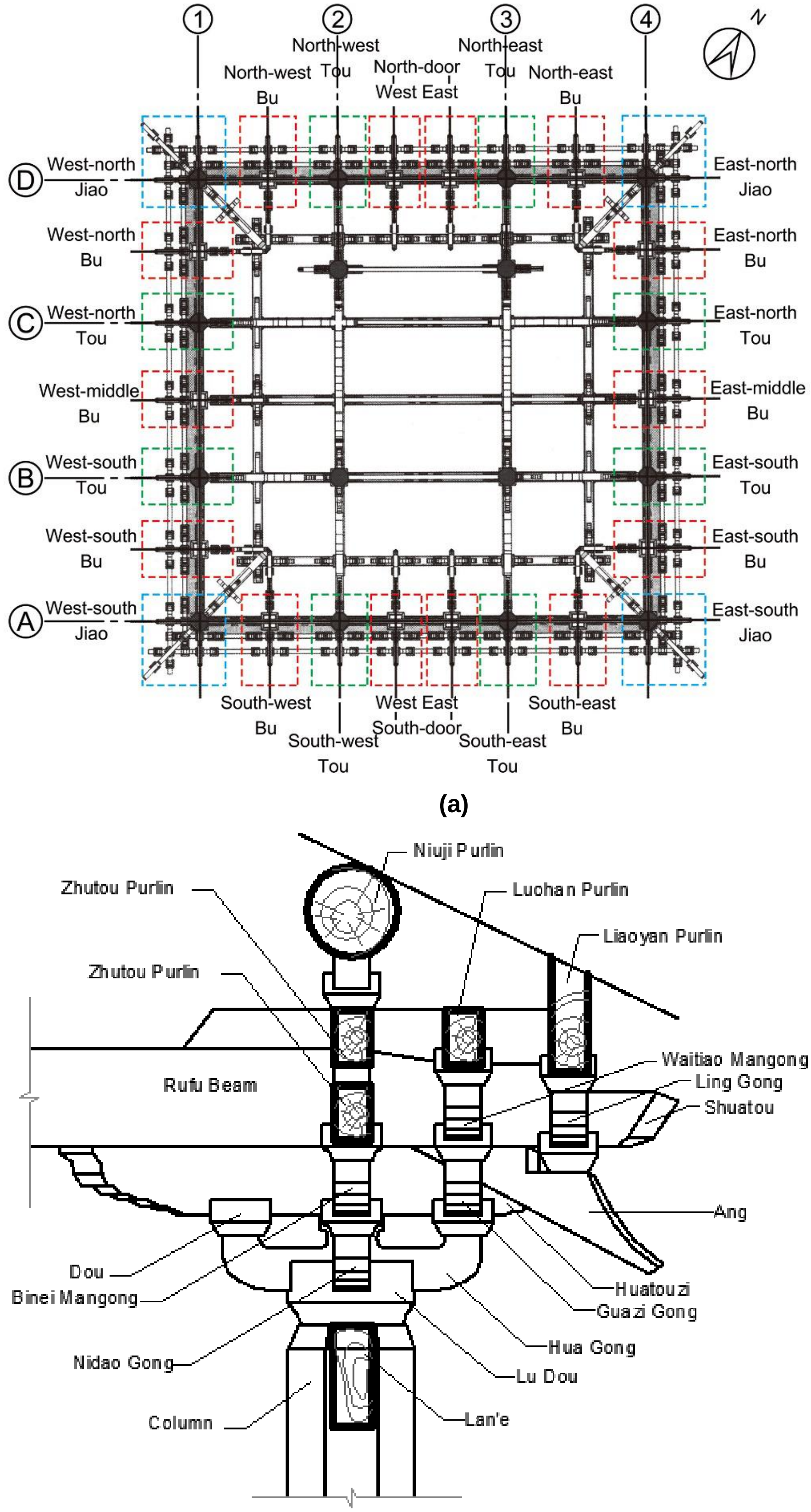


Fig. 3. Photos of the dougong under the external eaves: front view of zhutou dougong (a), side view of zhutou dougong (b), front view of bujian dougong (c), side view of bujian dougong (d), front view of zhuanjiao dougong (e), and side view of zhuanjiao dougong (f)



(a)

(b)

Fig. 4. Column number index map of the main hall (a): green box refers to zhutou dougong, red box refers to bujian dougong, blue box refers to zhuanjiao dougong; and dougong members (b)

Methods

Status and damage of dougong

The existing types of damage and their causes were investigated based on the site survey records and collected photos. The instances of damage were evaluated by referring to GB 50165-92 (1993). The dougong were divided into five categories according to their location in the building (east dougong, south dougong, west dougong, north dougong, and corner dougong) for use in the statistical analysis. Additionally, non-destructive testing was carried out using the non-metallic ultrasonic defect detector (MINGCHUANG MC-6310).

Wood species identification and analysis of physical properties of dougong material

The identification of the wood species was carried out according to GB/T 29894-2013 (2013). To be prepared for investigation under a light microscope, the wood samples were first soaked in distilled water. Then thin hand sections were taken by means of razor blades along the three planes, which were transverse, radial, and tangential sections. The thin flakes were mounted on microscope slides with the slide mounting medium and observed under the microscope (Olympus BX-51), then photographed by a digital camera (Olympus DP70).

The density of each species was tested according to GB/T 1933-2009 (2009). The size of a specimen was 20 mm×20 mm×20 mm. Also, 50 mm×50 mm×50 mm specimens were also tested for the column sample because the average growth ring width was more than 4 mm. First, the lengths in of each specimen in the transverse, radial, and tangential directions and the initial weight were measured. Secondly, the specimens were placed in the oven (Senxin DGG-9070B) at a temperature of 60 °C for 4 h. Then the temperature was adjusted to 103(±2) °C. Eight hours later, the specimens were taken out. After being weighed, the specimens were put back into the oven. Then the specimens were weighed every two hours. The drying was finished when the difference between the last two weighing values didn't exceed 5% of the specimen weight. Finally, the lengths in of each dried specimen in the transverse, radial and tangential directions were measured again. The density was calculated according to the equation as follows,

$$\rho_w = \frac{m_w}{V_w} \tag{1}$$

where ρ_w is air-dry density (g/cm^3), m_w is weight (g), and V_w is volume (cm^3). These values are corresponding to the moisture content W.

The moisture content of each species was tested according to GB/T 1931-2009 (2009). The size of specimen was 20 mm×20 mm×20 mm. First the initial weight of each specimen was measured and recorded. Second, the specimens were placed in the oven at a temperature of 103(±2) °C for 8 hours. Then the specimens were taken out. After being weighed, the specimens were put back into the oven. Then the specimens were weighed every two hours. The drying was finished when the difference between the last two weighing values didn't exceed 5% of the specimen weight. Finally, the weight of dried specimen was recorded. The moisture content was calculated according to the equation as follows,

$$W = \frac{m_1 - m_0}{m_0} \times 100 \tag{2}$$

where W is moisture content, m_1 is the initial weight (g), and m_0 is the dried weight (g).

The laboratory temperature was 13 °C and the relative humidity was 70% during the experiment.

RESULTS AND DISCUSSION

Types of Damage Observed on Wooden Members and their Causes

There were a large number of dougong members, with 734 visible under the external eaves, of which 472 were dou members and 262 were gong members. The types of damage were diverse and varied in their causes and degree of damage. Some members showed two or three kinds of damage at the same time. All types of damage observed on a member were recorded during the investigation process. However, to avoid confusion in the statistics, only the main damage types and their causes were analyzed.

The main types of damage (Fig. 5) included detachment, plucking (tenon pulled out), holes, cracking, crushing, separation, and missing parts. The summary statistics of the damage types are shown in Table 1. Percentages of the various damage types are shown in Fig. 6a.

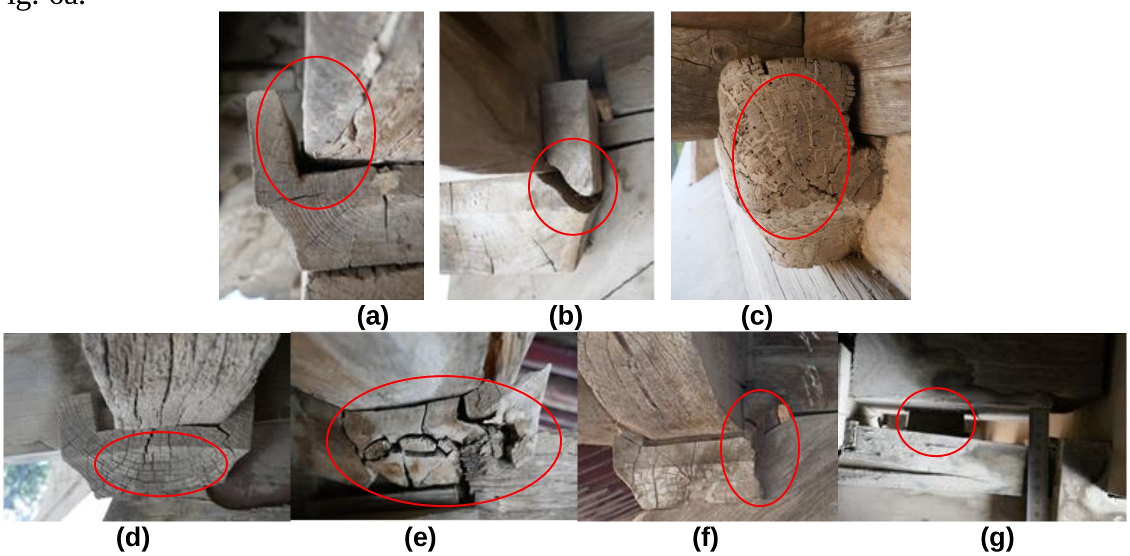


Fig. 5. Main types of damage: detachment (a), separation (b), holes (c), cracking (d), crushing (e), missing parts (f), and plucking (g)

Among all of the damaged members, the number of members with cracking damage was 241, which was the largest amount and accounted for a high proportion of the damage (32.8%). The number of cracked members of the east dougong was 56. Because the dominant wind direction in Dengfeng area is the northeasterly wind, the cracks resulting from degradation defect of wood material in the east was more significant. The Secondly, there were some members with detachment damage, which accounted for 8% of all of the damaged members. The number of members with hole defects accounted for 5.2%. The north side of the building was less exposed to sunlight and the roof is leaking, so the dark and humid environment was suitable for fungi and termites. Therefore, the hole damage in the north side was more significant than other three sides, and there were 20 members of the north dougong with holes caused by bioerosion. The plucked members accounted for 2%, and the proportion of the members with crushing damage was 1.8%. Additionally, there were 0.6% of the members with a separated part and 0.4% of the members with a missing part.

Table 1. Summary Statistics of the Main Types of Damage

Basic Information			Damage Types						
Location	Members	Amount	Detachment	Plucking	Holes	Cracking	Crushing	Separation	Missing parts
East Dougong	Dou	80	9	0	6	27	1	1	1
	Gong	45	2	5	9	29	1	0	0
	Aggregate	125	11	5	15	56	2	1	1
	Percentage	—	8.8%	4.0%	12.0%	44.8%	1.6%	0.8%	0.8%
South Dougong	Dou	96	11	1	1	27	1	1	1
	Gong	54	3	3	0	26	0	0	0
	Aggregate	150	14	4	1	53	1	1	1
	Percentage	—	9.3%	2.7%	0.7%	35.3%	0.7%	0.7%	0.7%
West Dougong	Dou	80	9	0	0	19	0	0	1
	Gong	45	3	1	0	22	0	0	0
	Aggregate	125	12	1	0	41	0	0	1
	Percentage	—	10.0%	1%	0.0%	33%	0.0%	0.0%	1%
North Dougong	Dou	96	9	0	8	29	5	2	0
	Gong	54	7	4	12	26	0	0	0
	Aggregate	150	16	4	20	55	5	2	0
	Percentage	—	10.7%	2.7%	13.3%	36.7%	3.3%	1.3%	0%
Corner Dougong	Dou	120	5	0	1	20	3	0	0
	Gong	64	1	1	1	16	2	0	0
	Aggregate	184	6	1	2	36	5	0	0
	Percentage	—	3.3%	0.5%	1.1%	19.6%	2.7%	0.0%	0.0%
In total	Dou	472	43	1	16	122	10	4	3
	Gong	262	16	14	22	119	3	0	0
	Aggregate	734	59	15	38	241	13	4	3
	Percentage	—	8.0%	2.0%	5.2%	32.8%	1.8%	0.6%	0.4%

Because of the diversity in the environment and complexity of the architectural structure, there were many factors that contributed to the damage of the dougong under the external eaves of the main hall of Chuzu Temple. When multiple factors interacted with each other, the same damage types could have been caused by one or more factors, either independently or synergistically, and one factor could have led to multiple types of damage. Only one factor was considered during the analysis of the damage to a specific dougong member. Simply, one type of damage corresponded with one type of damage cause.

The main causes were mechanical damage, bioerosion, and material degradation. The summary statistics of the damage causes is shown in Table 2. Mechanical damage caused cracking and crushing problems, and bioerosion caused damage such as wormholes and decay. Material degradation led to aging and cracking, which resulted in the wood cracking along the direction of the wood rays and caused large radial cracks. Some of these cracks were filled with mud which was filled in these members during restoration according to the information offered by local people. The percentages of the various causes are shown in Fig. 6b. Among the estimated members, the number affected by material degradation was 221, which was the largest proportion, accounting for 30.1%. The proportion of the members affected by bioerosion was 5%, and 1.9% of the members were damaged by mechanical damage. The cause of 13.8% of the damaged members needs to be further studied.

Table 2. Summary Statistics of the Main Causes of Damage

Basic Information			Damage Causes			
Location	Members	Amount	Mechanical Damage	Bioerosion	Material Degradation	Other Causes
East Dougong	Dou	80	1	6	25	13
	Gong	45	1	9	28	8
	Aggregate	125	2	15	53	21
	Percentage	—	1.6%	12.0%	42.4%	16.8%
South Dougong	Dou	96	1	0	25	17
	Gong	54	0	0	25	7
	Aggregate	150	1	0	50	24
	Percentage	—	0.7%	0.0%	33.3%	16.0%
West Dougong	Dou	80	0	0	19	10
	Gong	45	0	0	22	4
	Aggregate	125	0	0	41	14
	Percentage	—	0.0%	0.0%	33.0%	11.0%
North Dougong	Dou	96	6	8	21	18
	Gong	54	0	12	20	17
	Aggregate	150	6	20	41	35
	Percentage	—	4.0%	13.3%	27.3%	23.3%
Corner Dougong	Dou	120	3	1	20	5
	Gong	64	2	1	16	2
	Aggregate	184	5	2	36	7
	Percentage	—	2.7%	1.1%	19.6%	3.8%
In total	Dou	472	11	15	110	63
	Gong	262	3	22	111	38
	Aggregate	734	14	37	221	101
	Percentage	—	1.9%	5.0%	30.1%	13.8%

The east dougong members were mostly damaged by wormholes and cracking. The materials of said members were affected by material degradation. The members of the north dougong were damaged during rainy and snowy days because of water leakage from the roof during rainy and snowy days. As a result, problems involving decay and wormholes were notable, and cracking damage on the end surface of the members was common. The members of both the east and north dougong had relatively obvious cracks, which cracked along the direction of the wood rays, and both were affected by bioerosion. On the south and west sides, the members frequently had cracks that resulted from material degradation. Additionally, the detachment, plucking, and missing part damage types occurred in the dougong members on the south and west sides. As for the corner dougong, most of the members were installed during restoration according to the restoration records. Therefore, material degradation and cracking were not severe compared with other dougong. However, some members were crushed because of heavy load-bearing.

To prevent the dougong under the external eaves of the main hall from being further damaged by dampness or biodeterioration, it is necessary to improve their moisture-proof conditions and keep them as dry as possible. Rain and snow should be cleared off the roof during and after rainy and snowy days. Preservative treatment should be done for the members susceptible to dampness and biodeterioration. The wood preservatives should meet the relevant requirements stated in GB 50165-92 (1993).

In addition to the seven main types of damage, there were some other defects (Fig. 7), such as incline, exfoliation, and knots. For instance, incline was observed in C4-D4 East-north Bu, C4 East-north Tou, and A2-A3 South-door East, and appeared in the vertical central axes of the members (Guazi gong (瓜子拱) and the dou above it, and Waitiao Mangong (外跳慢拱) and the dou above it) that were not in the same line. The ang (昂) member of the C4 East-north Tou inclined downwards. The surface materials of the west end surface of the ling gong (令拱) member of A2-A3 South-door East were exfoliated. There was a knot with cracks in the ang member of D3 North-east Tou.

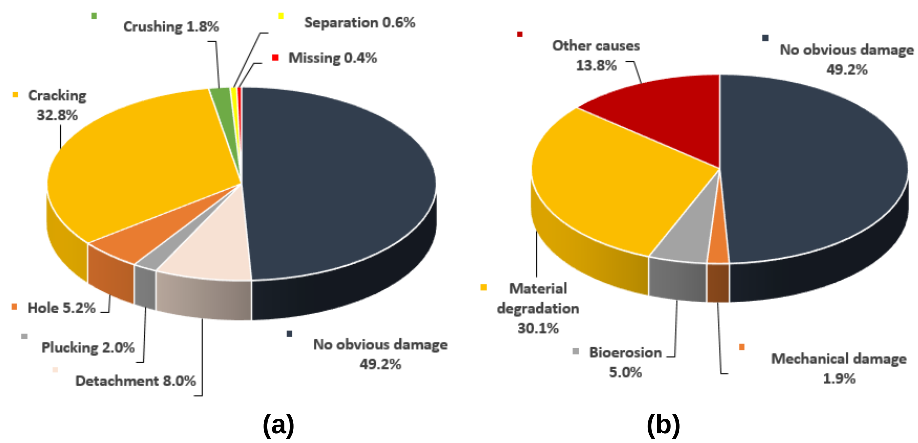


Fig. 6. Percentages of various types of damage (a) and causes (b)

Some members had been repaired and reinforced in the past. The shuatou (耍头) members of B4 East-south Tou, A2 South-west Tou, and D2 North-west Tou had been reinforced with fabric (Fig. 8a). Wedges (Fig. 8b) were present above the huatouzi (华头子) members of B4-C4 East-middle Bu, A3 South-east Tou, and D3 North-east Tou. Padding blocks (Fig. 8c) were found in some dou members. Figures 8 shows examples of repairs.

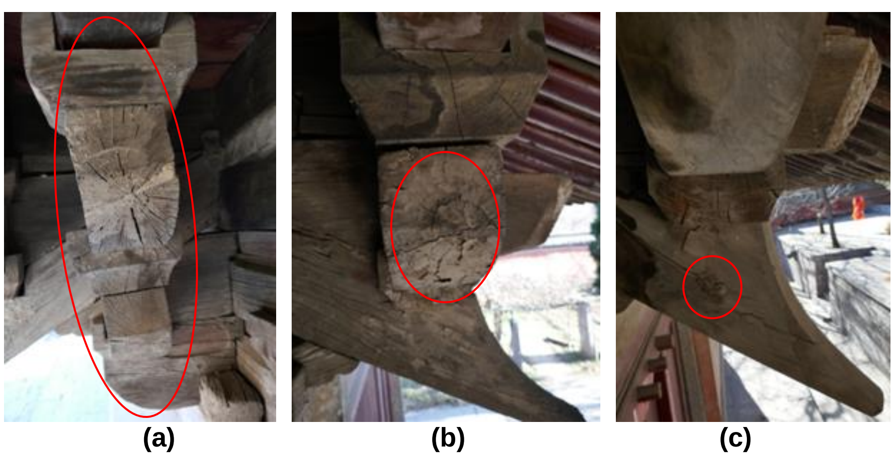


Fig. 7. Examples of other types of damage: incline (a), exfoliation (b), and knot (c)

(a) (b) (c)

Fig. 8. Examples of repairs: fabric reinforcement (a), wedges (b), and padding blocks (c)

The ultrasonic propagation velocity in the dougong members was around 1600m/s. But the inside defects should be further studied because the ultrasonic velocity was affected by many factors on site. Figure 9 shows output of tests with an oscillogram.

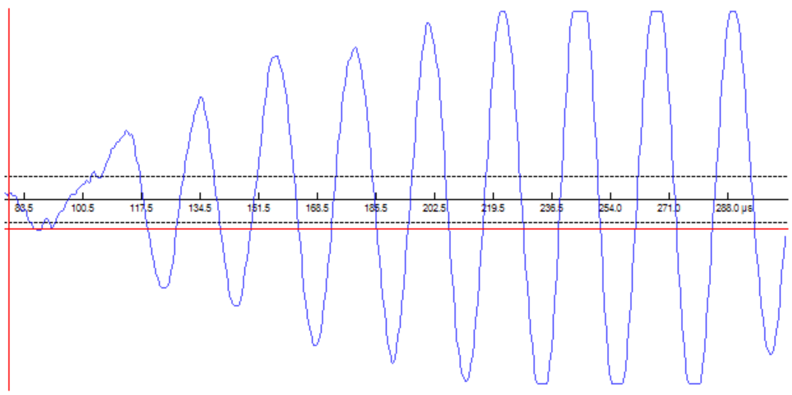


Fig. 9. Ultrasonic oscillogram

Tree Species Identification and Measurement of Physical Properties

The results showed that the wood species used in the ancient buildings in the Dengfeng area included *Larix* sp., *Ulmus* sp., *Quercus* sp., and *Populus* sp. Among the samples collected, the dougong members and feizi (飞子) member wood samples were identified as *Ulmus* sp. which was observed to have the following typical microscopic features: ring-porous wood, tyloses present, axial parenchyma vasicentric, pores in latewood arrange in tangential direction, wood ray of medium width. The column members were wood samples were identified as *Quercus* sp., which was observed to have the following typical microscopic features: ring-porous wood, wood ray wide, axial parenchyma tangential, pores in latewood dispersely arrange in radial direction. Also, the purlin member wood samples were identified as *Larix* sp., which was observed to have the following typical microscopic features: soft wood, growth ring abruptly changes from earlywood to latewood, latewood containing longitudinal resin canal. Other small member wood samples were identified as *Populus* sp., which was observed to have the following typical microscopic feature: diffuse-porous wood. The density of these small members wood samples was lower than that of the other three wood species. The test results are shown in Table 3.

Table 3. Wood Species Identification and Basic Physical Property Test Results

Member	Species	Density (g/cm³)	Moisture Content (%)
Purlin I	*Larix* sp.	0.616 (0.02)	16.9 (0.56)
Purlin II	*Larix* sp.	0.581 (0.01)	15.1 (0.83)
Dou	*Ulmus* sp.	0.733 (0.05)	10.0 (0.35)
Feizi	*Ulmus* sp.	0.661 (0.05)	9.6 (0.22)
Column	*Quercus* sp.	0.790 (0.03)	12.0 (0.65)
Small Member	*Populus* sp.	0.420 (0.02)	10.6 (0.37)

* Value in parentheses is the standard deviation; the Purlin I sample is from Chuzu Temple, and the other samples are from Chenghuang Temple.
The density is corresponding to a moisture content of 12%.

Based on the selection and application of each species, the property values of the corresponding wood species should be considered when creating the parameters for the material properties during the simulation analysis of the structural performance of Chuzu Temple. Additionally, selection of the corresponding wood species should be considered when planning reinforcement and restoration of the wooden structure. The same wood species as that of the existing members should be used first. If the wood is difficult to procure, wood with a strength grade closest to that of the original member should be selected instead.

CONCLUSIONS

1. This study investigated and analyzed the status and damage of the dougong under the external eaves of the main hall of Chuzu Temple in the Shaolin Temple complex. 50.8% of the dougong members under the external eaves of the main hall had different types of damage. The seven main types of damage were detachment, plucking (tenon pulled out), holes, cracking, crushing, separation, and missing parts. The main causes comfirmed were mechanical damage, bioerosion, and material degradation.
2. The wood species used in the ancient buildings in the Dengfeng area included *Larix* sp., *Ulmus* sp., *Quercus* sp., and *Populus* sp.

ACKNOWLEDGMENTS

This work was supported by the Research on the Status Investigation and Conservation of the Ancient Architectures in "The Center of Heaven and Earth" in the Dengfeng Area project.

REFERENCES CITED

Chen, Z., Zhu, E., and Pan, J. (2012). "A review on structural mechanics of Chinese ancient wood structures," *Advances in Mechanics* 42(5), 644-654. DOI: 10.6052/1000-0992-11-134

Cheng, J. Q. (1992). *Chinese Wood Journal*, China Forestry Press, Beijing, China.

Chun, Q., Yu, M.-Z., and Pan, J.-W. (2013). "Research on damage characteristic and structural performance of the main hall of Baoguo Temple in Ningbo," *Sciences of Conservation and Archaeology* 25(2), 45-51. DOI: 10.16334/j.cnki.cn31-1652/k.2013.02.004

Dong, M.-Y., Lu, Y., Jiang, X.-M., Wang, W.-B., Zhou, Y.-C., Zhao, G.-J., Zhou, H.-B., and Yin, Y.-F. (2017). "AMS ^{14}C dating and wood identification in ancient timber structures in Shanxi Province, China," *J. Archaeol. Sci.* 13, 361-371. DOI: 10.1016/j.jasrep.2017.03.003

GB 50165-92 (1993). "Technical code for maintenance and strengthening of ancient timber buildings," Standardization Administration of China, Beijing, China.

GB/T 29894-2013 (2013). "General method of wood identification." Standardization Administration of China, Beijing, China.

GB/T 1931-2009 (2009). "Method for determination of the moisture content of wood," Standardization Administration of China, Beijing, China.

GB/T 1933-2009 (2009). "Method for determination of the density of wood," Standardization Administration of China, Beijing, China.

Guo, D. H. (2009). "Songshan historical architectural complex between the heaven and earth," *Chinese Cultural Heritage* 3, 10-18.

Kisternaya, M., and Kozlov, V. (2007). *Wood-science Approach to the Preservation of Historic Timber Structures*, Izd-ro KarRC RAS, Petrozavodsk, Russia.

Li, Z. R. (2017). *Material and Structural Behavior of Dougong Bracket Complex, A Case Study of Tianwang Hall, Luzhi, Ming Dynasty*, Master's Thesis, Nanjing Forestry University, Nanjing, China.

Liu, C., and Sun, C. (2008). "Interpretation of the measured data of Chuzu Temple of Shaolin Temple complex," *Journal of Architectural History of China*, pp. 27-64.

Ma, B. J. (2003). *Construction Technology of Chinese Ancient Wooden Architecture (Second Edition)*, Science Press, Beijing, China.

Mertz, M., Gupta, S., Hirako, Y., de Azevedo, P., and Sugiyama, J. (2014). "Wood selection of ancient temples in the Sikkim Himalayas," *IAWA J.* 35(4), 444-462. DOI: 10.1163/22941932-00000077

Qi, Y. T. (1979). "A preliminary analysis of Chuzu Temple of Shaolin Temple complex," in: *Science and Technology History Collection (Second Series)*, Shanghai Science and Technology Press, Shanghai, China, 61-70.

Que, Z., Li, Z., Zhang, B., Hou, T., and Pan, B. (2015). "Experimental analysis on shaking table tests of Dougong in Tianwang Hall, Luzhi, Ming dynasty," *Journal of Civil, Architectural & Environmental Engineering* 37(3), 26-34. DOI: 10.11835/j.issn.1674-4764.2015.03.004

Tong, L., and Liu, C. (2018). "Study on structural properties of timber frame load-bearing system of the Chu Zu-an Temple." *Structural Engineers* 34(01):9-15. DOI:10.15935/j.cnki.jggcs.2018.01.002

Wang, H. (2003). "An explanation of how the building technology in Jiangnan area affected the book *Yingzao Fashi* in the light of Chuzuan Temple," *Huazhong Architecture* 21(3), 104-107. DOI: 10.13942/j.cnki.hzjz.2003.03.035

Yin, Y. F., Luo, B., Zhang, Z. P., Liu, B., Cheng, Y. M., and Jiang, X. M. (2010). "Identification of timber species used in ancient buildings in southeastern Shanxi Province," *World of Antiquity* 4, 33-36.

Yu, M. (2016). "On the segmented column style Tingtang framework during Song and Jin dynasty," *Huazhong Architecture* 34(6), 143-146. DOI: 10.13942/j.cnki.hzjz.2016.06.030

Zhang, S. Q. (2006). "Analysis of the phenomenon of the main hall of Chuzu Temple in the south of north structure," *Architectural History* (00):84-89.

Zhang, S. Q. (2012). *The Main Hall of Baoguo Temple in Ningbo: Investigation Analysis and Basic Research*, Southeast University Press, Nanjing, China.

Zhou, Q., Yan, W., Guan, H., and Ji, J. (2014). "Research advances in Tou-kung's mechanical performances of Chinese ancient wood buildings," *Journal of Water Resources and Architectural Engineering* 4, 18-26. DOI: 10.3969/j.issn.1672-1144.2014.04.004

Article submitted: November 1, 2018; Peer review completed: February 24, 2019; Revised version received: March 22, 2019; Accepted: March 24, 2019; Published: April 3, 2019.
DOI: 10.15376/biores.14.2.4110-4123