Effects of Dowels on the Mechanical Properties of Wooden Composite Beams in Ancient Timber Structures

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In order to provide more accurate suggestions for the restoration of ancient timber buildings, five types of specimens were designed for static loading tests. The tree species used for the specimens was larch. The wooden composite beams were composed of purlins, tie plates, and fangs. The study analyzed the effects of the number and position of dowels on the mechanical behaviors of wooden composite beams in ancient timber buildings. The bending moment, slippage, strain of the wooden composite beams under the deflection of the beam allowed according to code, and the ultimate bearing capacity of the wooden column composite beams under failure conditions were examined. The test results showed that the dowels could improve the bending capacity of the wooden composite beams. The even distribution of the dowels was beneficial in reducing the sliding effect of the wooden composite beams. Under the amount of deflection allowed by the code, the mid-span section strain along the height of the wooden composite beam approximately conformed to the plane section assumption. The wooden composite beam still had bending capacity after each member failed. The results of this study illustrated that dowels improved the overall mechanical properties of the wooden composite beams.

Keywords: Ancient timber structures; Wooden composite beam; Larch; Dowels; Mechanical properties; Slippage

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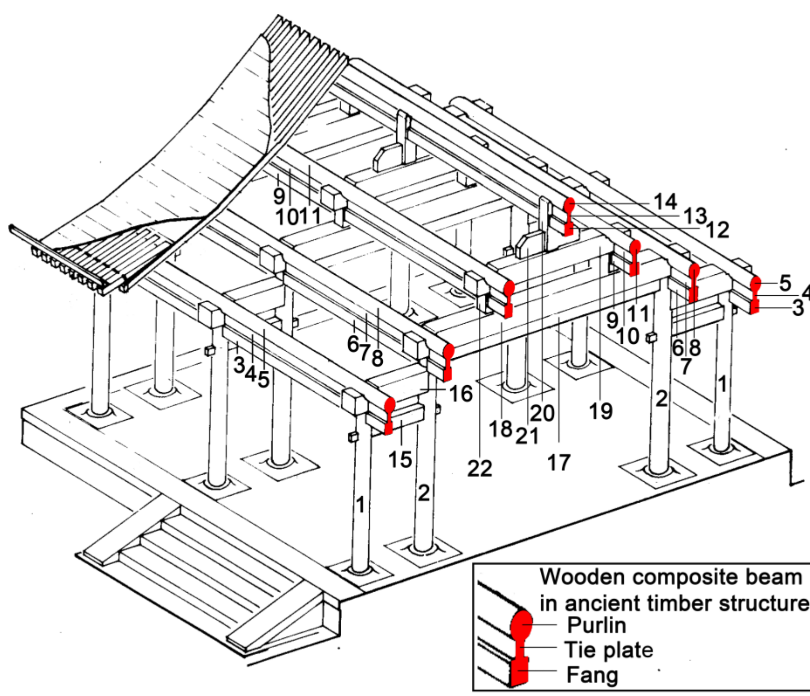
INTRODUCTION

Wood is widely used in ancient buildings and modern buildings due to its convenient processing and unique mechanical effects. In ancient Chinese buildings, the structures are primarily built with wood (Li *et al.* 2015; Han *et al.* 2020). The timber structures of ancient Chinese buildings are worth studying because of their values, *i.e.*, their artistic value, historical value, scientific value, social value, and cultural value (ICOMOS China 2015).

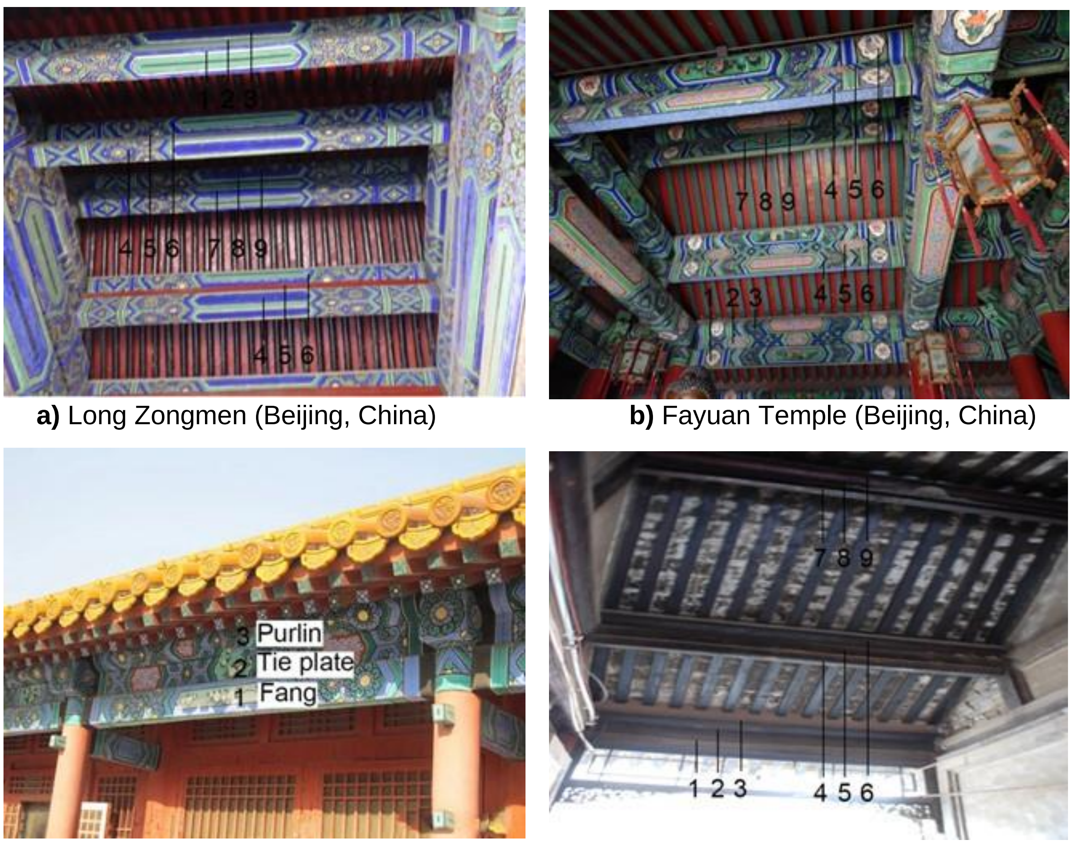
There are many recent studies on composite beams. The mechanical properties of double-layered composite beams in ancient Tibetan timber structures of China were studied *via* mechanical analysis and a nonlinear analysis model for double-layered composite beams was proposed (Cao *et al.* 2015). The deformation and bending capacity of two-layer composite beams with serrated teeth was studied *via* a static mechanical test (Rug *et al.* 2012). A four-point bending static test was used to study the flexural performance of wooden composite beams in ancient buildings; this study examined wooden composite beams with damaged components using reinforcement materials (Cavalli and Togni 2013). The strength and deformation characteristics of six light wooden composite beams with different cross-sectional profiles were studied *via* experimental methods (Bahadori-Jahromi *et al.* 2006). A three-point load test was used to study the structural performance of a multi-layer composite beam with welded-through wood dowels, and the results showed that reducing the screw spacing can noticeably improve the bending rigidity of the composite beam (O'Loinsigh *et al.* 2012). Four full-scale timber-to-timber composite-section beams were tested *via* four-point flexural bending, and the results showed that reducing the distance between the screws increased the composite-section beam flexural bending strength (Salem 2014). The effect of the wood dowels on the bending behavior of the multi-layer spruce beams was determined *via* experiment and simulation (Girardon *et al.* 2014). The rigid bodies-spring mode of an elasto-plastic analytical method was used to predict the bending properties of multi-layered timber beams (Tsujino *et al.* 2005). The lateral-torsional stability of vertically layered composite beams with inter-layer slippage was studied *via* a variational approach (Challamel and Girhammar 2012). The properties of small composite beams were tested to determine their modulus of elasticity, bending strength, and shear modulus (Castro and Paganini 2003). The stitching beam model in ancient timber structures was studied *via* mechanical analysis to determine its flexural performance, and the calculation formulas to determine the shear force of the bolt pin and the ultimate bending moment of the stitching beam were derived (Chun *et al.* 2013).



*Note: 1. Eave column; 2. Intermediate column; 3. Eave fang; 4. Eave Tie plate; 5. Eave purlin; 6. Lower intermediate fang; 7. Lower intermediate Tie plate; 8. Lower intermediate purlin; 9. Upper intermediate fang; 10. Upper intermediate Tie plate; 11. Upper intermediate purlin; 12. Ridge fang; 13. Ridge Tie plate; 14. Ridge purlin; 15. Penetrating fang; 16. Baotou beam; 17. fang; 18. 5 - purlin beam; 19. 3 - purlin beam; 20. Ridge short column; 21. Bracket; 22. Intermediate short column (Science Press 1997)

Fig. 1. Position of wooden composite beam in ancient timber structures

The bending behavior of big top - small bottom composite beams (Chun *et al*. 2014a) and small top - big bottom composite beams (Chun *et al.* 2014b) in ancient timber structures have been studied using various test methods. Composite T-beams and 6 composite I-beams were studied *via* a 2-point loading bending test method to experimentally examine the bending performance of the composite timber beam (Xiong *et al*. 2012). A refined nonlinear finite element method model was established to study the mechanical role of dowels in terms of their role in wooden connections in ancient Tibetan architecture (Li *et al*. 2010). The internal forces of composite beams and combination beams in ancient Chinese wooden buildings were studied *via* mechanical analysis (Zhou and Yan 2012). The bending performances of the decayed superposition beams at Yinghua Palace in the Forbidden City were studied *via* simulation to protect them more effectively (Zhou 2012).



a) Long Zongmen (Beijing, China) **b)** Fayuan Temple (Beijing, China)

c) Palace in the Forbidden City (Beijing, China) **d)** Domestic architecture (Beijing, China)

*Note: 1. Eave fang; 2. Eave Tie plate; 3. Eave purlin; 4. Intermediate fang; 5. Intermediate Tie plate; 6. Intermediate purlin; 7. Ridge fang; 8. Ridge Tie plate; 9. Ridge purlin

Fig. 2. Wooden composite beams in ancient timber structures

The current research mainly includes the following aspects: The wooden composite beams of modern buildings were studied *via* experimental methods, the double-layer wooden composite beams of ancient buildings were studied *via* experimental methods, and the three-story wooden composite beams of ancient buildings were studied *via* simulation methods. However, there is a gap in the mechanical research of three-layer composite wooden beams in ancient timber buildings with dowels. This study combined the research methods of the previous literature and the existing standard test methods to study the composite wooden beams. Wooden composite beams are widely used in ancient timber structures (as shown in Figs. 1 and 2), and they are primarily composed of purlins, tie plates, and fangs in post-and-lintel timber structures (Bai and Wang 2000; Ma 2003; Ssu-Ch'eng 2006; Jun 2007). Wooden composite beams are an important part of strengthening the structural integrity of ancient buildings, and they are also usually the most abundant place of color painting (as shown in Fig. 2).

In this study, five types of samples with dowels were subjected to static loads. The mechanical properties of the wooden composite beams with dowels were investigated. The effect of the number and position of dowels on wooden composite beams was studied. The work provides a reference value for the restoration of ancient timber buildings.

EXPERIMENTAL

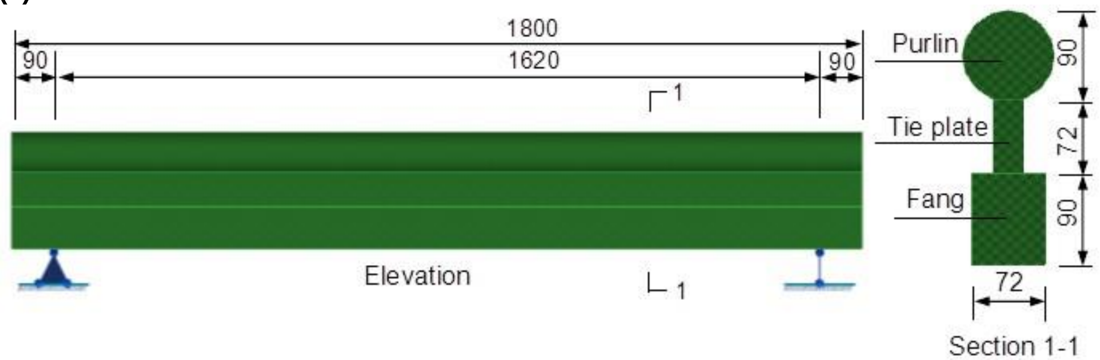
Sample Materials and Design

Larch was used as the wood for all samples in this experiment, as it is representative of the tree species commonly used in ancient timber structures. According to the preliminary works by Ma (2003), Ssu-Ch'eng (2006), and BMCC (2007), five types of wooden composite beam samples with different cross-sectional information were designed and manufactured in this experiment. The details of the five types of samples are shown in Table 1. The different cross-sections of the wooden compose beams samples are shown in Fig. 3. The span of the samples were determined based on GB/T standard 50329 (2012). The calculated span (l_0) of the sample was 1620 mm. The overhanging length of the sample was taken as a cross-sectional height of 180 mm, and the manufacturing length (l) of the sample was 1800 mm. The size, number, and location of the dowels are based on the repair experience of ancient wooden structures as well as ancient architectural documentation (Bai and Wang 2000). The size of the dowel was 10 mm x 20 mm x 30 mm. Type 1 to Type 4 are primarily composed of purlins, tie plates, and fangs, and the difference is the arrangement of dowels. Type 5 is a single sample of purlin, tie plate and fang, which is taken as a control group when analyzing some performances are analyzed.

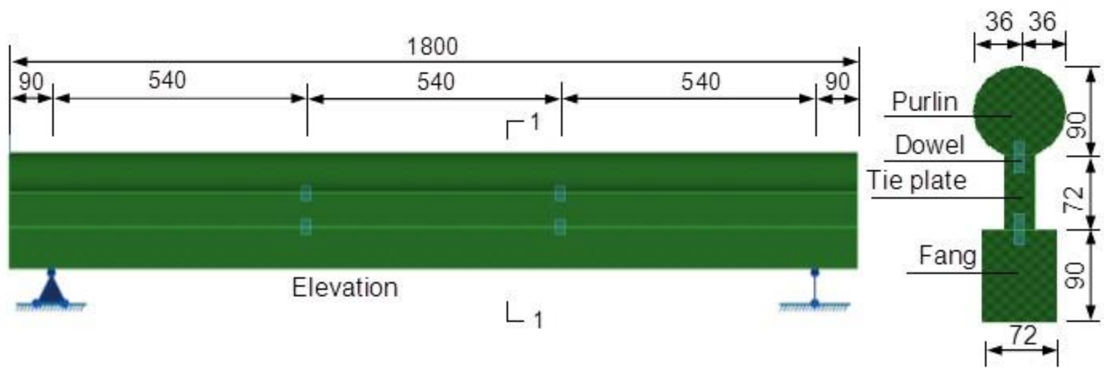
Table 1. Basic Information of the Samples

Sample Type	Sample Number	Sample Information	Material
Type 1	1-1, 1-2, 1-3	Type 1 (as shown in Fig. 3a) without dowels	Larch
Type 2	2-1, 2-2, 2-3	Type 2 (as shown in Fig. 3b) with two dowels arranged at ⅓ l_0	
Type 3	3-1, 3-2, 3-3	Type 3 (as shown in Fig. 3c) with three dowels arranged at ¼ l_0	
Type 4	4-1, 4-2, 4-3	Type 4 (as shown in Fig. 3d) with two dowels arranged near the support of the wooden composite beam	
Type 5	5-1-1, 5-1-2, 5-1-3 5-2-1, 5-2-2, 5-2-3 5-3-1, 5-3-2, 5-3-3	Details of Type 5 shown in Fig. 3e	
*Note: l_0 is the calculated span of the sample, which is 1620 mm.			

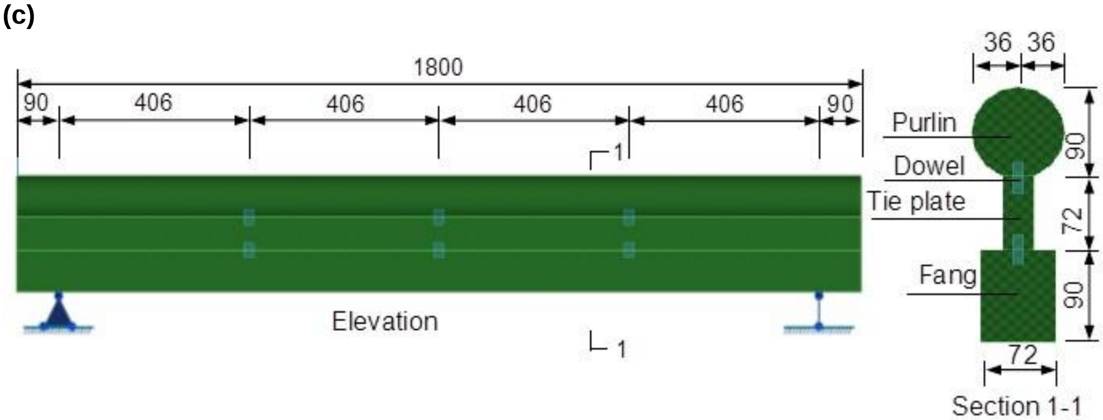
(a)


1800
90
1620
90
1
Purlin
Tie plate
Fang
90
72
90
72
Elevation
1
Section 1-1

(b)


1800
90
540
540
540
90
1
36
36
Purlin
Dowel
Tie plate
Fang
90
72
90
72
Elevation
1

(c)


1800
90
406
406
406
406
90
1
36
36
Purlin
Dowel
Tie plate
Fang
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72
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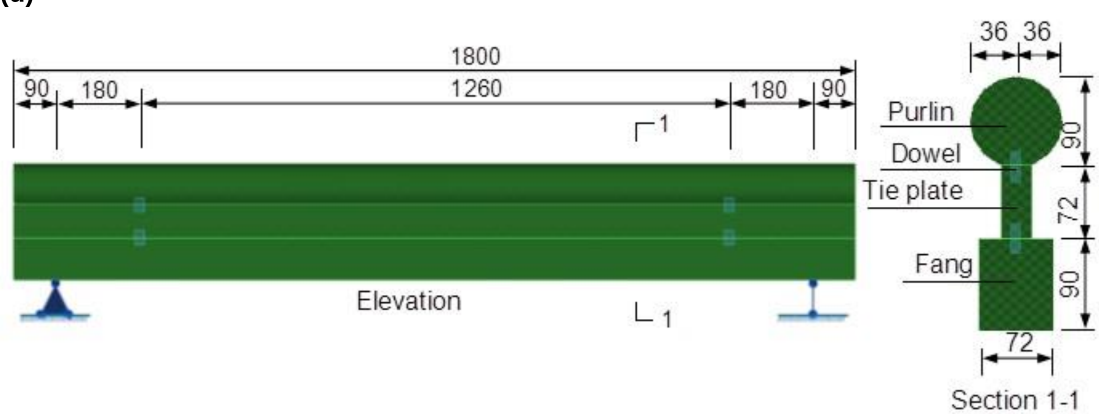
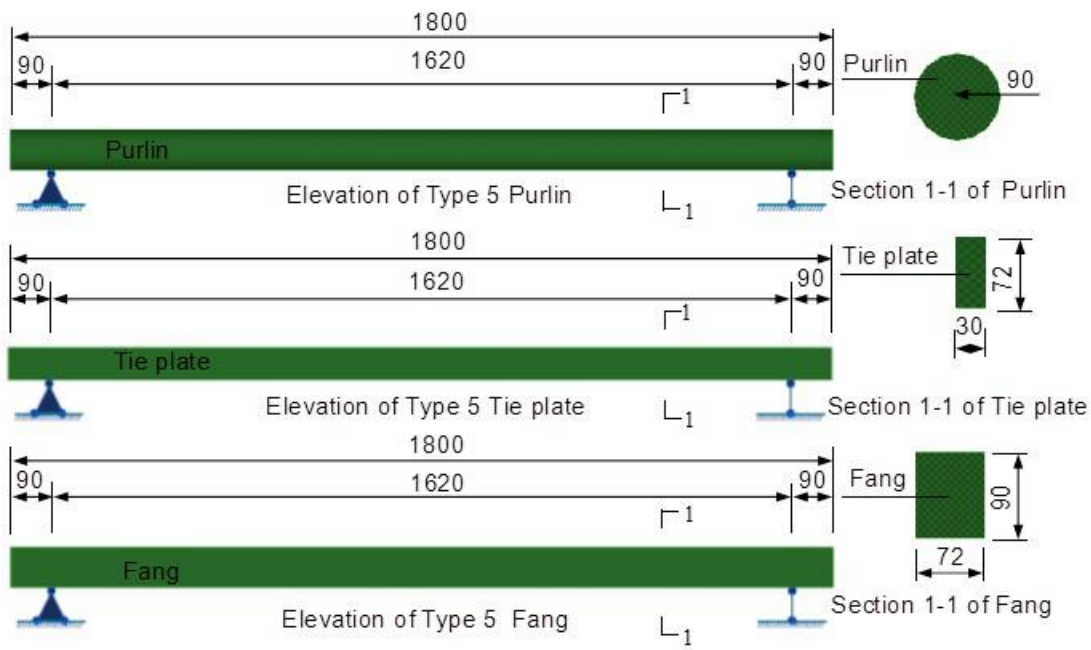
72
Elevation
1
Section 1-1

(d)


1800
90
180
1260
180
90
1
36
36
Purlin
Dowel
Tie plate
Fang
90
72
90
72
Elevation
1
Section 1-1



(e)
Fig. 3. Details of the (a) Type 1, (b) Type 2, (c) Type 3, (d) Type 4, and (e) Type 5 samples

Methods

The experiment was conducted at the Engineering Structure Experiment Center of the Beijing University of Technology (Beijing, China).

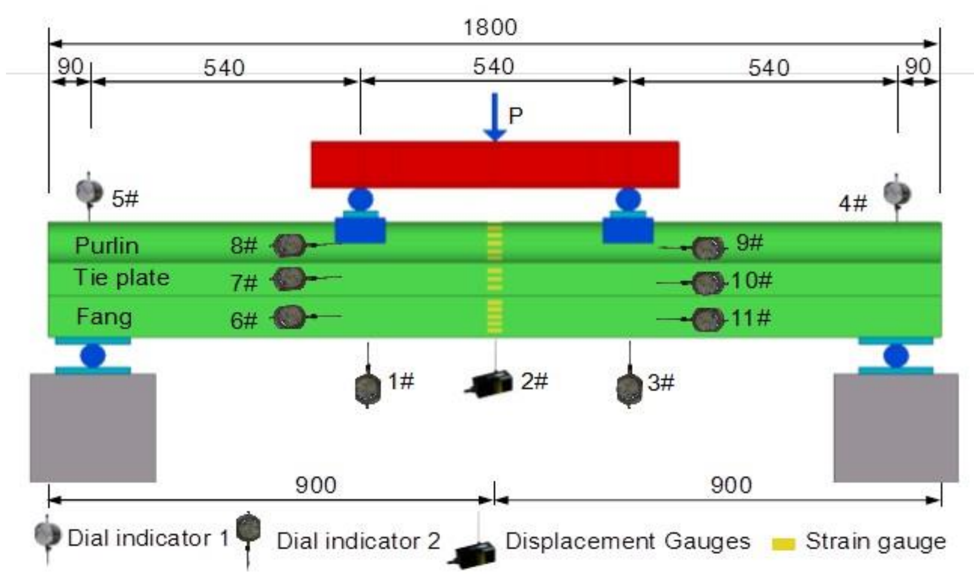


Fig. 4. Loading device and the locations of the transducers

According to GB/T standard 50329 (2012) and ASTM standard D198 (2002), the four-point loading method was adopted for the samples. The loading device model and locations of the transducers are shown in Fig. 4. The loading site is shown in Fig. 5. The control load was distributed and transmitted through the loading beam to ensure that the samples were evenly loaded.

Figures 4 and 5 show that displacement transducers (1# to 3#) were mounted to measure the vertical deformation of the samples. The vertical deformations of the support of the samples were obtained by the 4# and 5# displacement transducers. The relative slippages between the purlin, tie plate, and fang were measured with the displacement transducers at 6# to 11#, and 9# to 11 # displacement transducers were arranged on the other side of the wooden composite beams. The strain gauges arranged along the cross-section height direction of the cross-section in the middle of the beam were used to record the strain along the sectional height of the purlin, tie plate, and fang in the pure bending state of the samples. Strain gauges were arranged at the middle of the top surface of the purlin to record the strain at the middle position of the top surface of the purlin. Strain gauges were also arranged at the middle of the bottom surface of the fang to record the strain at the middle position of the bottom surface of the fang. Before the test started, the samples were repeatedly preloaded 3 times, with a control force of 2 kN, so that the samples were tightly combined to ensure that the samples were evenly stressed. The steel cushion blocks were placed at the concentrated stress points between the loading beam and the purlin of the wooden composite beam. The purpose was to ensure that the load is loaded in a stable state to prevent the wooden composite beam from being laterally crushed.

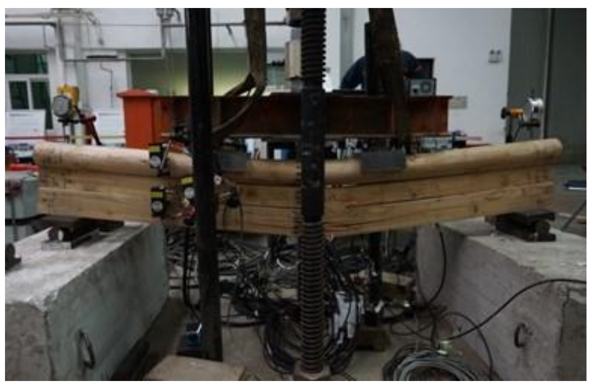


Fig. 5. Test loading site

RESULTS AND DISCUSSION

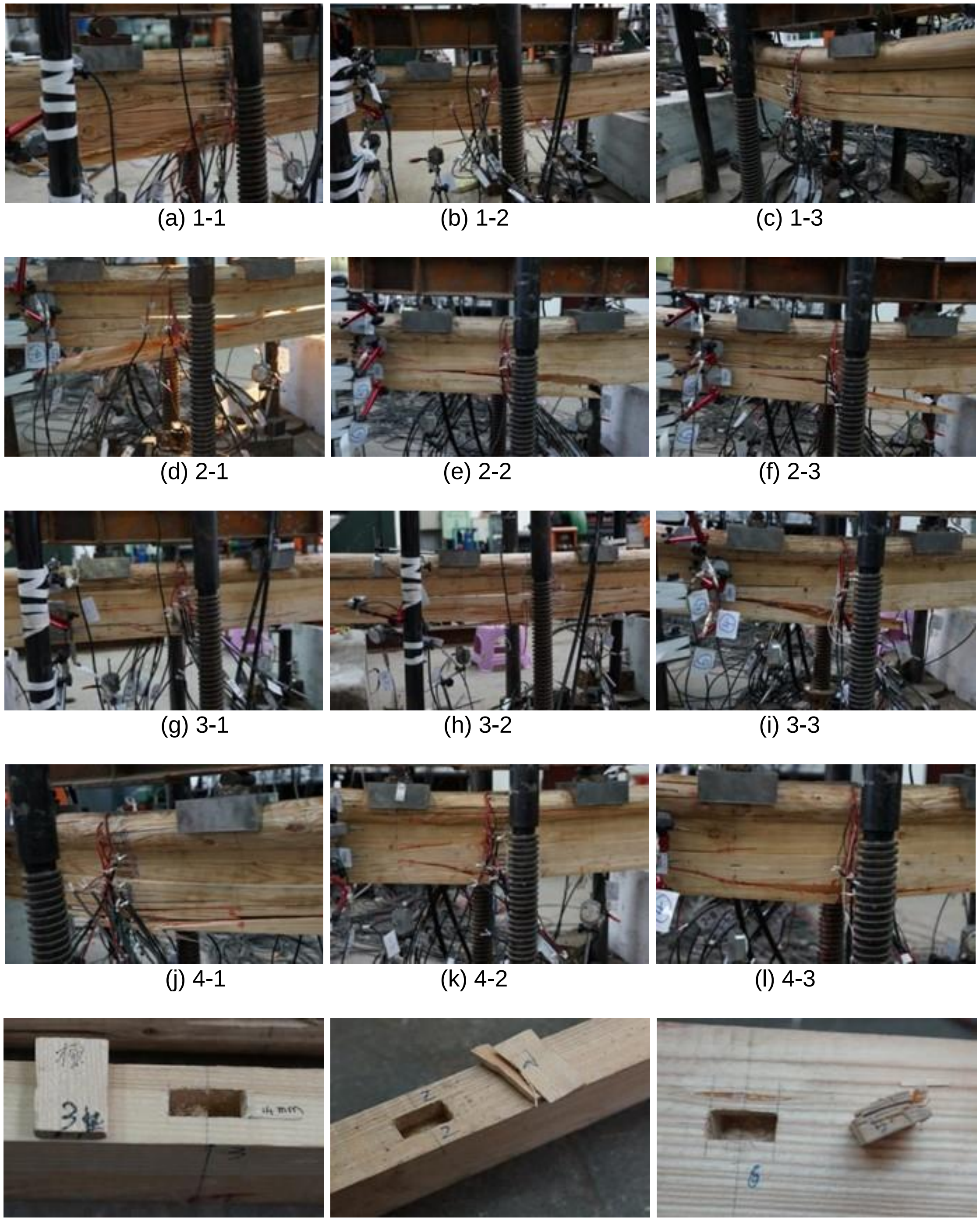
Test Phenomena

The primary experimental phenomena of the wooden composite beams were as follows:

(1) At the initial stage of loading, the samples had not yet been damaged due to the small control load. As the deflection of the samples became obvious, the contact part between the samples gradually produced an audible sound, and the interaction between the samples gradually increased.

(2) As the load increased, the squeezing sound between the samples gradually became denser, and the sound became louder. As the deflection increased, the components of the test piece were successively damaged. Figure 6 shows the damage of the wooden composite beams.

(3) After the test, the destruction of the dowels were observed. Figure 6m presents that the dowel was particularly squeezed. Figure 6n and Figure 6o present that the dowels were broken.



(a) 1-1 (b) 1-2 (c) 1-3

(d) 2-1 (e) 2-2 (f) 2-3

(g) 3-1 (h) 3-2 (i) 3-3

(j) 4-1 (k) 4-2 (l) 4-3

(m) 4-1 (n) 4-2 (o) 4-3

Fig. 6. Damage of the wooden composite beams

Bending Moment-Deflection

After the bending test of the wooden composite beam, the value and the fitting value of the bending moment could be obtained, when the mid-span deflection of the sample reached the allowable deflection $l_0/250$, as specified in GB 50165-2020 (2020). The test results of the Type 4 wooden composite beam were taken as an example. The test results and the fitting value of the Type 4 bending moment are shown in Fig. 7. The fitting formulas and the R^2 are shown in Table 2. The final fitting value was the average of the fitting values of each type. The bending moment fitting values of all the wooden composite beams are shown in Fig. 8 and Table 3. The bending moment of the Type 5 beam was the sum of the average fitting values of three single specimens.

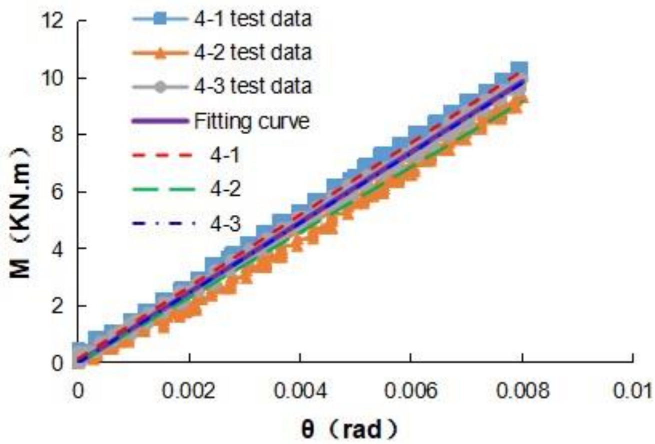


Fig. 7. Moment-deflection of the Type 1 samples

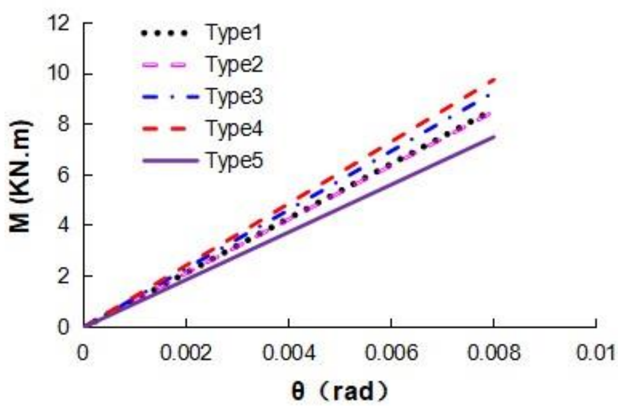


Fig. 8. Moment-deflection of samples Type 1 through Type 5

According to the analysis of the test data, the bending moment of the wooden composite beam was obtained, and the expression of the moment (M) was found by Eq. 1,

$$M = Pl_0/2 \tag{1}$$

where P is the force (kN) on the wood composite beam and l_0 is the calculated span of the wood composite beam (mm). The rotational angle (θ) of the wooden composite beam was calculated with Eq. 2,

$$\theta = \text{Arctan}\,(2\Delta / l_0) \approx 2\Delta / l_0 \tag{2}$$

where Δ is the vertical deflection of mid-span section of wooden composite beam (mm).

Figure 8 presents the data demonstrating that the relationship between the fitting bending moment and mid-span deflection of Type 1, Type 2, Type 3, Type 4, and Type 5 samples. It can be seen from Fig. 8 that the bending moment-mid-span deflection fitting value curve of the wooden composite beam is approximately linear. The slope of the fitting curve can be regarded as the equivalent bending stiffness (k) of the wooden composite beam, and the expression of the the equivalent bending stiffness (k) was found by Eq. 3:

$$k = M / \theta \quad (3)$$

Figure 8 illustrated that the equivalent bending stiffness (k) values of the wooden composite beams were as follows: k_4 was greater than k_3, which was greater than k_1, which was greater than k_2, which was greater than k_5. The test results showed that the performance of the wooden composite beam was better than the sum of the single samples. The equivalent bending stiffness (k_3 was greater than k_1, which was greater than k_2) showed that the number of dowels in the wooden composite beam affected the performance of the wooden composite beam. As the number of dowels in the wooden composite beam increased, the equivalent bending stiffness increased. The equivalent bending stiffness (k_4 was greater than k_1, which was greater than k_2). This means that the distance between the dowels and the support of the wooden composite beam affected the performance of the wooden composite beam. As the distance decreased, the equivalent stiffness of the beam increased.

Table 2. Fitting Values of the Moment-Deflection of sample Type 4

Type 1	Fitting Formulas	R^2	Average Value
4-1	$y = 1288.0x$	0.995	$y = 1219.9x$, 0.997
4-2	$y = 1145.8x$	0.998	
4-3	$y = 1226.0x$	0.998	

Table 3. Fitting Values of the Moment-Deflection of samples Type 1 Through

samples	Fitting Formulas	R^2
Type 1	$y = 1077.5x$	0.997
Type 2	$y = 1063.1x$	0.998
Type 3	$y = 1160.1x$	0.997
Type 4	$y = 1219.9x$	0.997
Type 5	$y = 937.9x$	0.963

The increasing bending moment trend of the Type 1, Type 2, Type 3, Type 4, and Type 5 wooden composite beams is shown in Fig. 9. Type 1, Type 2, Type 3, and Type 4 samples were compared against Type 5, and the bending moment of Type 1, Type 2, Type 3, and Type 4 beams increased by 13.68%, 13.14%, 24.14%, and 30.68%, respectively.

The increasing equivalent stiffness trend of the Type 1, Type 2, Type 3, Type 4, and Type 5 wooden composite beams is shown in Fig. 10, which was compared with the equivalent stiffness of the Type 5 beam. The equivalent stiffness of the Type 1, Type 2, Type 3, and Type 4 beams increased by 14.50%, 13.34%, 23.50%, and 30.07%, respectively.

As shown in Figs. 9 and 10, the moment increment and the stiffness increment of type 2 were lower than those of type 1. The reason is that the placement of dowels at the force position weakens the effect of the composite beam.

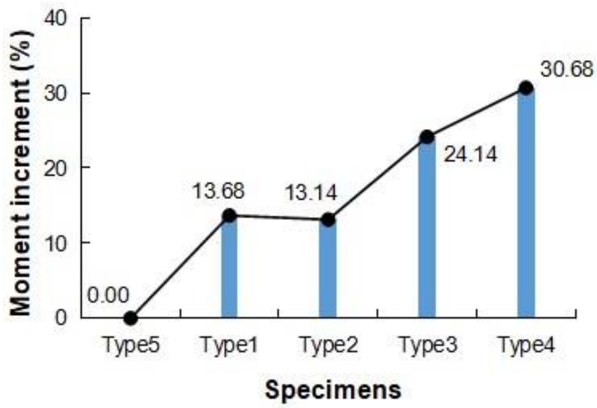


Fig. 9. Moment increment of samples Type 1 through Type 5

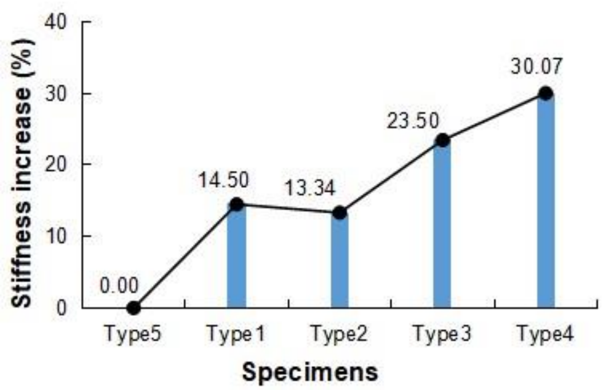


Fig. 10. Stiffness increment of samples Type 1 through Type 5

The test results illustrated that the dowels in the wood composite beams had a noticeable effect on the flexural performance of the wood column under a load. Through a comparative analysis of the test data of the Type 1 and Type 5 samples, the flexural performance of the combination of wooden beams had been noticeably improved. Through a comparative analysis of the test data of the Type 1, Type 2, and Type 3 samples, as the number of dowels in the wooden composite beam increased, the bending moment of the wooden composite beam increased, and the bending stiffness of the wooden composite beam increased. Through a comparative analysis of the test data of the Type 1, Type 2, and Type 4 samples, as the position of the dowels was closer to the support of the wooden composite beam, the bending moment of the wooden composite beam was greater, and the bending stiffness of the wooden composite beam was also greater.

Slippage - Deflection

In ancient timber structures, the wooden composite beam not only bears the vertical load, but it also bears a certain amount of horizontal action. In order to verify the horizontal effect of the wooden composite beam, the sliding of the wooden composite beam was measured in this test. The 6#, 7#, and 8# displacement gauges recorded the relative slippage between the purlin, tie plate, and fang of the wooden composite beam, this was called slippage 1. The 9#, 10#, 11# displacement gauges recorded the relative slippage between the purlin, tie plate, and fang of the wooden composite beam, this was called slippage 2. According to the analysis results of the test data, the relative slippage fitting curves were obtained (as shown in Fig. 11, Fig. 12, Fig. 13, Fig. 14, Table 4, and Table 5).

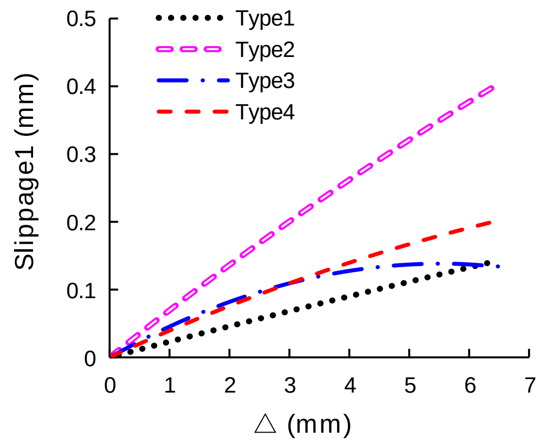


Fig. 11. Slippage 1 - deflection of the purlin and tie plate

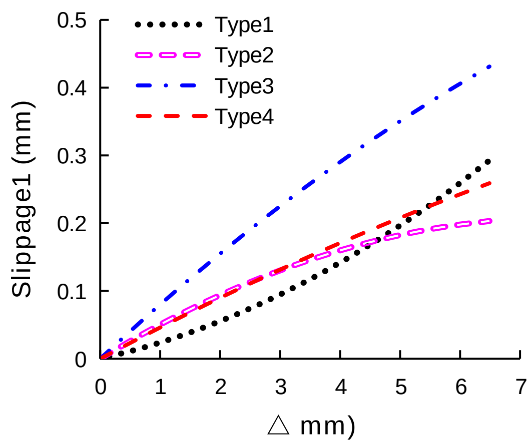


Fig. 12. Slippage 1 - deflection of the tie plate and fang

Table 4. Fitting Values of Slippage 1 - Deflection of samples Type 1 to Type 5

samples	Purlin - Tie plate		Tie plate - Fang	
	Fitting formulas	R^2	Fitting formulas	R^2
Type 1	$y = -0.0002x^2 + 0.0233x$	0.938	$y = 0.0039x^2 + 0.02x$	0.923
Type 2	$y = -0.0013x^2 + 0.0708x$	0.986	$y = -0.0035x^2 + 0.0539x$	0.965
Type 3	$y = -0.0045x^2 - 0.0499x$	0.944	$y = -0.0025x^2 - 0.0824x$	0.988
Type 4	$y = -0.0015x^2 + 0.041x$	0.936	$y = -0.0011x^2 + 0.0472x$	0.964

The fitting curves of relative slippage 1 between the purlin and the tie plate of Type 1 through Type 5 wooden composite beams are shown in Fig. 11. The fitting curves of relative slippage 1 between the tie plate and fang of the wooden composite beams are shown in Fig. 12. Judging from the trend of slippage 1 between the purlin and tie plate and trend of slippage 1 between the tie plate and fang, as the deflection increased, the limiting effect of the dowels of the wooden composite beam on the slippage 1 was gradually obvious, but the regularity was not clear. There were two reasons for this. The first reason was that the installation device was not particularly appropriate, and the second reason was that the dowel was set near the loading point to cause local weakening.

The fitting curves of relative slippage 2 between the purlin and the tie plate of the

Type 1 through Type 5 wooden composite beam are shown in Fig. 13. The fitting curves of the relative slippage 2 of the tie plate and fang of the wooden composite beam was shown in Fig. 14. Judging from the trend of slippage 2 between the purlin and tie plate and trend of slippage 2 between the tie plate and fang, at the same deflection, as the deflection increased, the limiting effect of the dowels of the wooden composite beam on the slippage 2 is gradually obvious with the increase of deflection, and the regularity is more obvious. The more even the dowels of the wooden composite beam are arranged, the more obvious was the limiting effect on slippage.

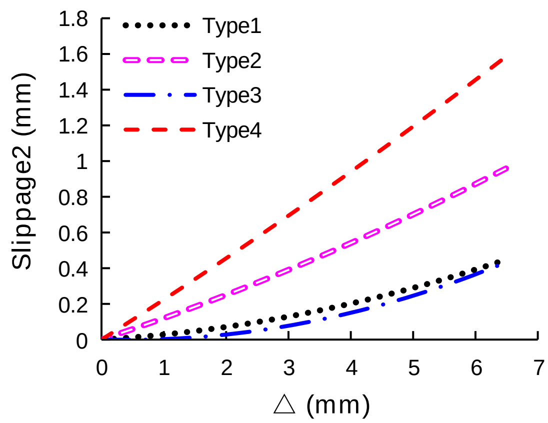


Fig. 13. Slippage 2 - deflection of the purlin and tie plate

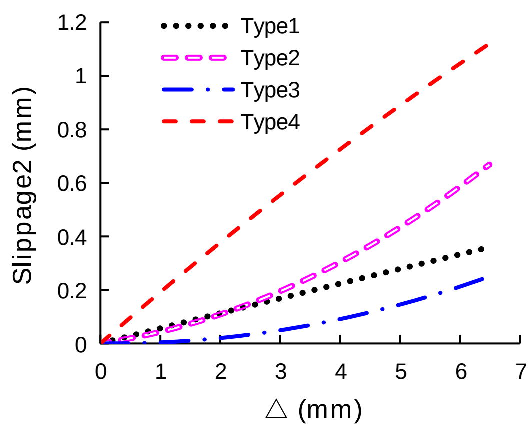


Fig. 14. Slippage 2 - deflection of the tie plate and fang

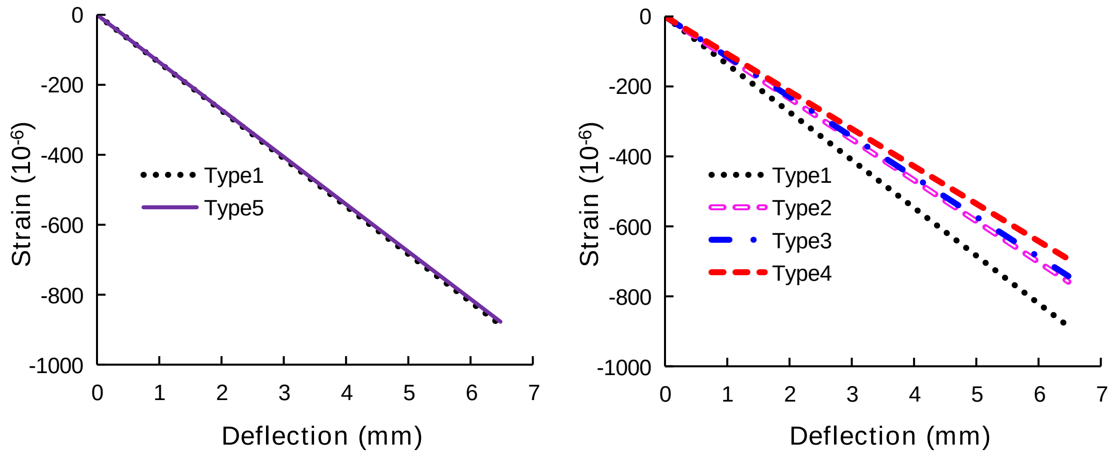
Table 5. Fitting Values of Slippage 2 - Deflection of samples Type 1 to Type 5

samples	Purlin - Tie plate		Tie plate - Fang	
	Fitting formulas	R^2	Fitting formulas	R^2
Type 1	$y = 0.0075x^2 + 0.0206x$	0.984	$y = -0.0002x^2 + 0.0569x$	0.971
Type 2	$y = 0.005x^2 + 0.1153x$	0.994	$y = 0.0108x^2 + 0.0326x$	0.984
Type 3	$y = 0.0117x^2 - 0.0091x$	0.981	$y = 0.0063x^2 - 0.0025x$	0.956
Type 4	$y = 0.0037x^2 + 0.2204x$	0.996	$y = -0.0035x^2 + 0.1955x$	0.998

The test results showed that, on the whole, the dowels of the wooden composite beams effectively reduced the slippage effect between the components of wooden composite beam and enhanced the composite effect of the wooden composite beam. However, due to the installation of dowels, which needed to be slotted in the wood composite beam, the limiting effect of the dowels of the wooden composite beam on the slippage was reduced because of the slotting.

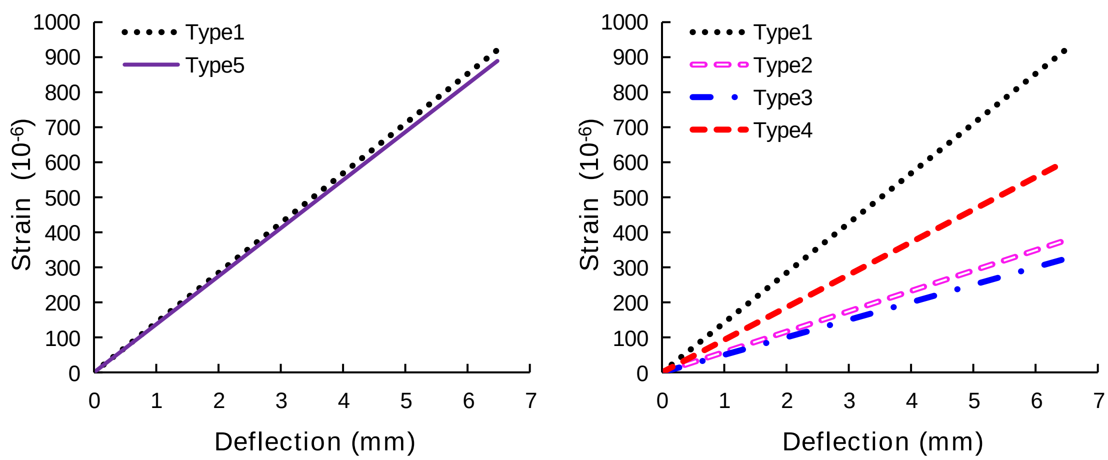
Strain in Mid-span

The fitting curves of the purlin top strain and the fang bottom strain along the height of the cross-section of the wooden composite beam are shown in Figs. 15 and 16.



(a) Type 1 and Type 5 (b) Type 1, Type 2, Type 3 and Type 4

Fig. 15. Strain-deflection at the top of the purlin in mid-span



(a) Type 1 and Type 5 (b) Type 1, Type 2, Type 3 and Type 4

Fig. 16. Strain-deflection at the bottom of the fang in mid-span

As shown in Figs. 15a and 16a, the strain at the top of the purlin and the strain at the bottom of fang of the Type 1 wooden composite beam were larger than the strain at the top and bottom of the Type 5 beam. Although the composite beam enhanced the composite effect of a single sample, the strain in the mid-span was increased due to the composited effect. As shown in Figs. 15b and 16b, the regularity of the strain at the top of the purlin and the strain at the bottom of fang of the Type 1, Type 2, and Type 3 wooden composite beam was obvious. However, the regularity of the strain at the bottom of the fang of Type 4 beams is inconsistent with that at the strain at the top of the purlin. The test results showed that the dowels enhanced the strain of the wooden composite beam. The greater the number of dowels, the greater the impact on the strain of the wooden composite beam. However, the influence of the position of the dowel on the strain of the wooden composite beam has no obvious regularity.

The strain gauges were evenly arranged along the height of the cross-section of the wooden composite beam (as shown in Figs. 4 and 5). The distribution of the strain along the height direction of the mid span section was analyzed.

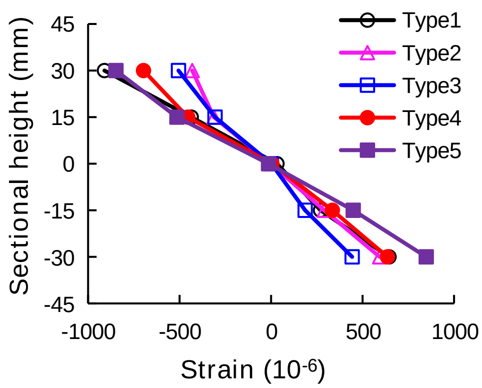


Fig. 17. Strain of the purlin along the section height in mid-span

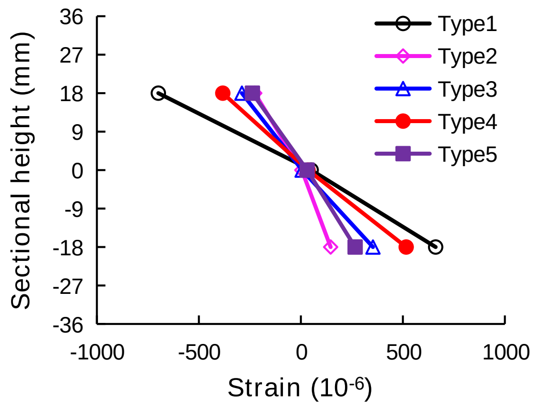


Fig. 18. Strain of the tie plate along the section height in mid-span

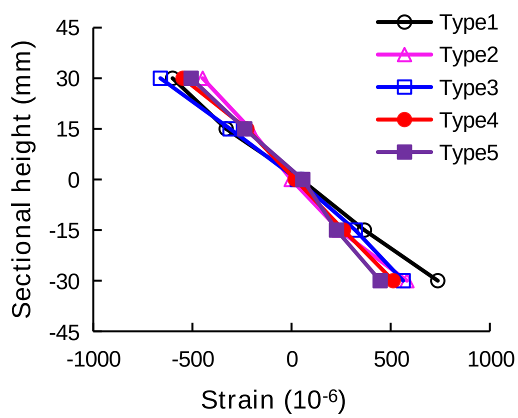


Fig. 19. Strain of the fang along the section height in mid-span

The middle of the height direction of the purlin, tie plate, and fang were taken as the zero axis. Figures 17, 18, and 19 showed that the strain distribution of the purlin, tie plate, and fang along the mid-span section was basically anti-symmetric. Therefore, under the amount of deflection allowed according to code, the samples were still in the elastic stage. When the deflection reached the amount of deflection allowed according to code, the strain distribution of the purlin, tie plate, and fang along the mid-span section in the composite state basically followed the assumption of plane section along the mid-span section. The test results showed that the number of dowels of the wood composite beam had an obvious impact on the strain of the wooden composite beams. There was no obvious regularity of the effect of the position of the dowels on the strain of the wood composite beam.

Bending Moment-Ultimate Deflection

In order to further study the flexural behavior of the wooden composite beams, the samples were tested to ultimate failure, and the curves of the ultimate bending moment and deflection were obtained (Fig. 20). During the initial loading stage of the wooden composite beam, the deflection was small, and the deformation of the samples was minor. When the loading deflection was small, the wooden composite beam was still in the elastic stage. The moment-deflection curve developed linearly, and the slope of the curve was small. As the loading deflection increased, the deformation of the wooden composite beam gradually increased, and the bending moment of the sample gradually increased. When one specimen of the wooden composite beam samples was damaged, the moment-deflection curve entered a non-linear development stage.

According to the analysis results of the test data and the results shown in Fig. 20, the damage of each component of the composite wooden beam, as the deflection increased, was obtained, as shown in Table 6. Figure 20 and Table 6 showed that the failure deflections of the components of the five types of wooden composite beams were higher than the deflection of the beam allowed according to code.

Judging from the trend of bending moment based on ultimate deflection, the influence of the dowel on the bending moment was not consistent before and after the failure of the wooden composite beam. The type 1 wooden composite beam without dowels was completely destroyed after the failure of each component of the wooden composite beam. The bending moment of the Type 2 beam with two dowels arranged at ⅓ l_0 was not higher than the bending moment of Type 1, but the bending moment of the Type 4 beam with two dowels was higher than the bending moment of Type 1. The bearing capacity of the Type 2 beam was lower than the bearing capacity of the Type 1 beam. The reason for this was that the location of the dowel was at a place where the load was concentrated, which weakened the bearing capacity of the wooden composite beam. The dowels in the Type 4 beam avoided the concentrated load, so the dowels improved the bending capacity of the wooden composite beam. The bending moment of the Type 3 wooden composite beam with three dowels arranged at ¼ l_0 was greater than the bending moments of the Type 1 and Type 2 beams. The bending moment of the Type 4 beam was greater than the bending moment of the Type 3 beam before the sample was broken, so the dowels were closer to the support of the wooden composite beam and was more conducive to improving the bearing capacity of the wooden composite beam. However, after the failure of the wooden composite beam, the bending moment of the Type 3 beam was greater than the bending moment of the Type 4 beam, so the increase in the number of dowels was conducive to the improvement of the bearing capacity of the wooden composite beam.

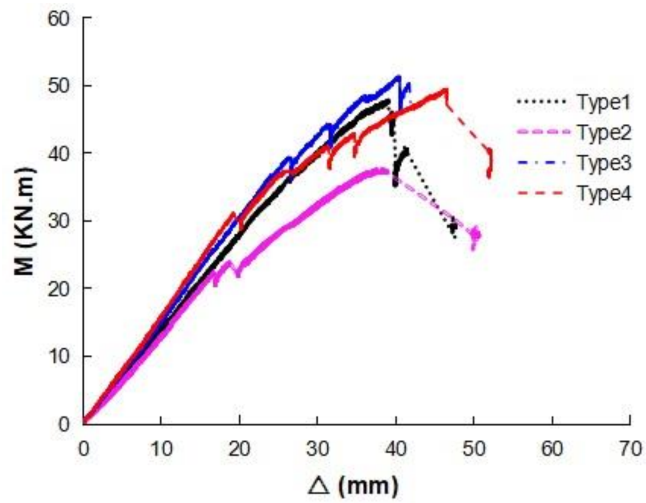


Fig. 20. Moment-deflection cure of the composite beams

Table 6. Failure Records of the Wooden Composite Beams

Type	Fang		Tie plate		Purlin		Wooden Composite Beam	
	△ (mm)	Moment (kN·m)	△ (mm)	Moment (kN·m)	△ (mm)	Moment (kN·m)	△ (mm)	Moment (kN·m)
Type 1	39	49	40	45	42	41	-	-
Type 2	17	22	19	24	39	38	-	-
Type 3	28	40	33	53	41	52	45	50
Type 4	21	31	47	50	33	40	65	48

This study provides a reference for some suggestions and related research for the restoration of wooden composite beam in ancient timber buildings.

CONCLUSIONS

1. The dowels in the wooden composite beam improved the composite effect of the wooden composite beam, and the wooden composite beam still had bending capacity after the component was damaged.
2. Under the amount of deflection allowed according to code, the relationships between the bending moments and the types of wooden composite beams were as follows: Type 4 was greater than Type 3, which was greater than Type 1, which was greater than Type 2, which was greater than Type 5. The Type 1, Type 2, Type 3, and Type 4 samples were compared again against Type 5, and the bending capacity of the samples increased by 13.68%, 13.14%, 24.14%, and 30.68%, respectively. The test proved that the dowels improved the bending capacity of the wooden composite beams.
3. A good distribution of the dowels was beneficial in reducing the slippage between the components of the wooden composite beam.
4. After the failure of all components of the wooden composite beam, the relationships between the bending moments and the types of wooden composite beams were as follows: Type 3 was greater than Type 4, which was greater than Type 1, which was greater than Type 2. The bending moment of the Type 3 wooden composite beam with

three dowels arranged at ¼ l_0 was the greatest and the bending moment of the Type 4 wooden composite beam with two dowels arranged near the support of the wooden composite beam was the second greatest, while the bending moment of the Type 1 wooden composite beam without dowels was greater than the Type 2 wooden composite beam with two dowels arranged at ⅓ l_0. Therefore, it is necessary to arrange more dowels in the wooden composite beams that bear larger bending moments, but the layout of the dowels needs to avoid the load position.

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