Chapter 6

Connection Node Design and Performance Optimization of Girder Truss

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Additional information is available at the end of the chapter

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Abstract

Girder truss is a kind of high-performance truss, which is combined with some single trusses by connectors. It is the common structural form of the key-bearing node in the modern wood structure floor and roof structure system. With the development of the sponge city and green building in China, girder truss is widely used in wood structure buildings and re-roofing project for its lightweight, high strength, good seismic performance, simple construction, design flexibility, and other excellent characteristics. Since the stress environment of girder truss is more complicated than single wood truss, the wood girder truss needs higher bearing capacity. This chapter emphatically provides a theoretical basis for practical engineering and mainly introduces a new type of girder truss connected with different diameters of wood dowels. The deformation of each node in the static loading process is measured in situ and continuously by using the self-designed loading device and the advanced measuring system. Research contents include the increasing effect of girder truss than single truss and influence of different connection modes on the mechanical properties of girder trusses. We can restore the mechanical properties and failure mechanism from the two aspects of phenomena and mechanism by comparing the test results.

Keywords: girder truss, static load test, carrying capacity, anti-deformation capability, connection node design

1. Introduction

For many years, the construction industry has been called the ‘big energy-consuming households’ in China with the industry and transportation. Building energy consumption accounts for one-third of the total energy consumption of the whole society, which is 2–3 times higher than other countries under the same climatic conditions (see Ref. [1]). This is mainly due to the traditional Chinese construction materials, such as steel, cement, clay bricks, etc. These materials not only waste a lot of natural resources but also cause pollution to the ecological environment. Therefore, the use of green building materials has become the key to energy conservation and emission reduction in the construction industry. On March 5, 2016, Premier Li Keqiang clearly stated in the "Government Work Report" of the Fourth Session of the 12th National People's Congress that the focus of the work in the field of housing construction is to further promote new urbanization and vigorously develop green buildings and building materials (see Ref. [2]). A very important direction for the development of green buildings is wood structure architecture (see Ref. [3]). A large number of studies have also shown that wood structure is better able to save energy and reduce emissions than other structural forms (see Ref. [4–6]). As one of the major trends in modern architecture, building energy efficiency can be beneficial to the growth of national economy as well as help protect the ecologic environment (see Ref. [6, 7]). Besides, timber structure building has a strong prefabrication because most of its components are processed in the factory. The study on the components is very crucial because the components are closely related to the safety and energy efficiency of timber structure.

As the important parts of timber structure building, floor system and roof are usually divided into two kinds of systems, the traditional grille-rafter system and light wood truss structure system, and the latter is more widely used. With the development of light wood structure in China, the application prospect of light wood truss in modern wood structure in China will be more and more broad. The girder truss is composed of several pieces of single light wood truss by connectors and commonly used in key parts of the roof or floor system in modern wood structure buildings and re-roofing projects. For the floor and roof system of modern timber structure, the key joints have suffered both the upper uniform load and the concentrated load from other trusses that connected with them. So the force circumstance is so complicated that the ordinary single wood truss can hardly bear (see Ref. [8–10]). A common solution in practical engineering is to increase the cross-sectional area of the member by combining a plurality of ordinary light wood trusses as a structural member to obtain a greater load carrying capacity (as shown in **Figure 1**). The form of the girder truss can be easily obtained and conforms to the developing trend of industrialization and modularization of buildings. Besides, some long-span and cantilevered structure is emerged with the development of modern timber structure building, which needs the wood truss with a higher carrying capacity. Emerging as the times require, the girder truss appears with a higher carrying capacity, greater span, and wider range of use, compared to the single wood truss. At present, the study on the single truss is very mature (see Ref. [11–13]), but few studies have been done on the girder truss. In most practical engineering projects, many builders work mostly depending on their experiences without any reliable standard, which will bring some potential safety issues. Girder truss is usually connected with nail and bolt, which is easy corrosion, and the mechanical property will reduce under the fire resistance circumstance. Therefore, this chapter has designed a new type of connection method that is used for girder truss (as shown in **Figure 2**). Wood dowel connector is not easy to be rusted and its mechanical property will not be reduced rapidly under fire resistance circumstance. Besides, wood-made connectors

Figure 1. Application of girder truss in building structure.

can increase the ductility of the connected components. Thus, the performance of girder truss is improved. The connection node of the wood structure is also related to the bearing capacity and normal use of the whole building in the future. Therefore, it is very meaningful to study the connection nodes of wood structure (see Ref. [14]).

2. New connection node design of girder truss

The connection modes of girder truss are currently relatively simple. The domestic connection method is recommended in the technical specification for light wood trusses (JGJ/T 265-2012), but the following problems remain when it is connected with nails.

1. Processing is complicated. The girder truss needs to turn over the truss constantly during processing. Nailing in different parts is not conducive to industrialized line processing.
2. Poor fire resistance. When subjected to fire, the steel will soften and its mechanical properties will rapidly decrease. The failure of the girder truss node affects its overall bearing performance, resulting in transient failure of the structure.

3. **Easy to rust.** Steel or iron nails are prone to rusting when exposed to air, which are more pronounced under conditions of high humidity and high salt, thus reducing the durability of the entire timber structure.
4. **Poor energy dissipation.** Nails are the fastening type joints, which constrain the relative rotation between the truss and the truss, and cannot consume the energy generated by the lateral force, which leads to the lateral resistance of the whole building becoming weak.

In response to the problems with connection modes of girder truss, this chapter proposes a new type of connection modes of girder truss, which replaces traditional iron connectors with wooden connectors. The specific scheme is as follows: all the single trusses that make up the girder truss are preassembled and temporarily fixed, then predrilled at specific positions of all the trusses and finally inserted into a wood or bamboo round dowel, which is a wood dowel connector (see Ref. [15]) (as shown in **Figure 2**).

The use of wood or bamboo connectors is mainly due to the fact that wood or bamboo joints are less susceptible to corrosion than iron joints (see Ref. [16, 17]). There is also no problem of a sharp drop in mechanical properties under fire-resistant conditions. In addition, the wood or bamboo joints can greatly improve the ductility of the connected members (see Ref. [18]), thereby improving the performance of girder truss when resisting lateral forces.

The selection of the position of the wood dowel connection is determined by the force characteristics of the parallel chord truss. Parallel chord truss can be considered as a simply supported beam when subjected to an upper uniform load. The force is mainly borne by the

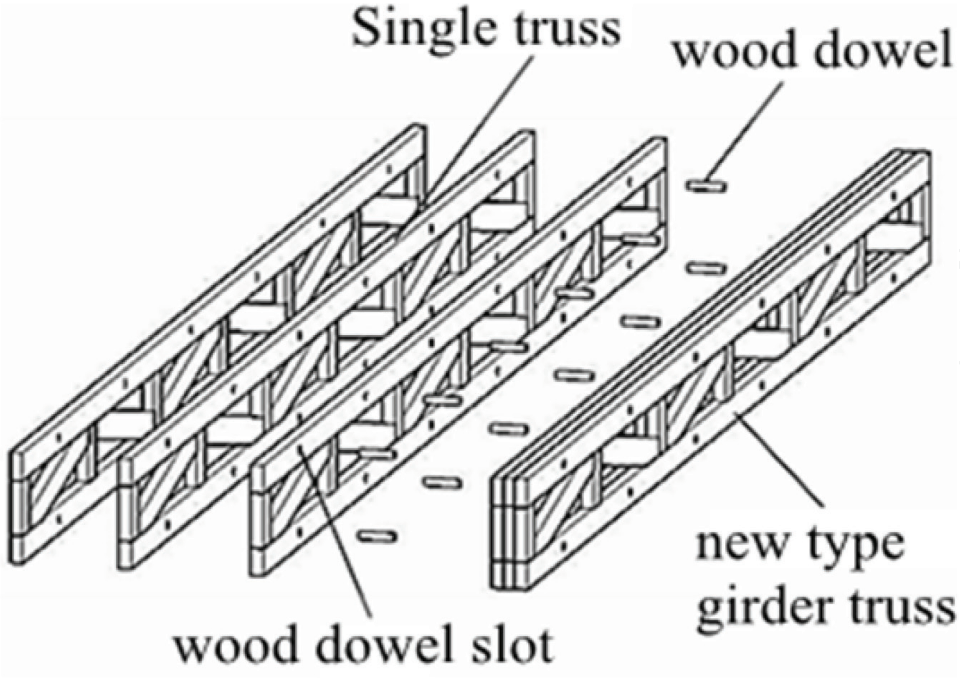


Figure 2. A new type of girder truss.

upper and lower chords of the truss. The upper chord is under pressure and the lower chord is subjected to tension, but the web only plays a supporting role. **Figure 3** shows the internal force diagram of the light wood truss supported by the upper uniform unit. It can be seen from the internal force diagram that if the parallel chord truss is regarded as a static combination structure, which means the chord is broken and both ends are hinged. Under the uniform load, the middle bending moment value of each chord is the largest and the shear force is at least zero. The use of wood dowel connectors requires predrilling the upper and lower chords of the truss, thus reducing the net cross-sectional dimensions of the chord. The shear force calculation formula of the structural member is:

$$\tau = \frac{Q}{A} \tag{1}$$

A represents the sheared net cross-section of the sheared member. The decrease in A means an increase in the shear stress in the member. Therefore, the position of the connector must be placed in where the chord shear force is the smallest, which is the middle of every two nodes of the chord.

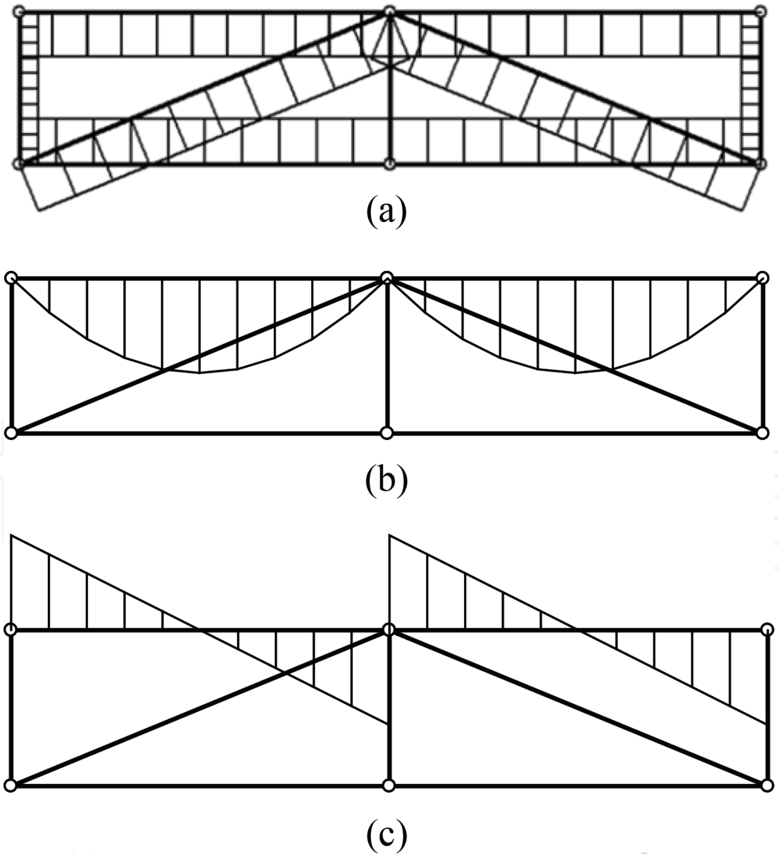


Figure 3. Internal force diagram of parallel chord truss. (a) Parallel chord truss axial force diagram; (b) parallel chord truss bending moment diagram; (c) parallel chord truss shear force diagram.

3. Experiment overview

3.1. Experimental design

The material used in the test is the Larch (*Larix gmelinii)* specification material imported from Russia. The material grade is grade II and the density is 0.657 g/cm^3. The moisture content is 17.4%, according to the general requirements for physical and mechanical tests of wood (GB/T 1928–2009).

According to the method of continuous loading of trusses in the standard for test methods of timber structures (GB20329-2012), the static load test of six types of small-span trusses was carried out, and the test piece number is expressed as S.

In order to explore the influence of different diameter wood dowels on the girder truss performance, the experiment in this chapter contains girder truss of three different diameter wood dowels. The wood dowels are 12, 16, and 20 mm in diameter. The performance evaluation of the three girder truss is still considered from the two aspects of ultimate bearing capacity and deformation resistance. Among them, the anti-deformation ability includes creep resistance and elastic recovery performance.

In addition, the experiment also set up a girder truss composed of three single trusses to explore the enhancement effect of girder truss with the increase of the number of single truss. The diameter of the wood dowels connecting the girder truss depended on the experimental results of the girder trusses with two single trusses. In order to distinguish other girder trusses with two single trusses, girder trusses with three single trusses are denoted by G3, while other girder trusses are denoted by G2.

Figure 4 shows the structural form and specific dimensions of the test piece used in this test. The girder trusses used in the experiment are all composed of this single truss.

The specific test piece composition is shown in **Table 1**.

3.2. Theoretical calculation

Calculation of standard load P_k

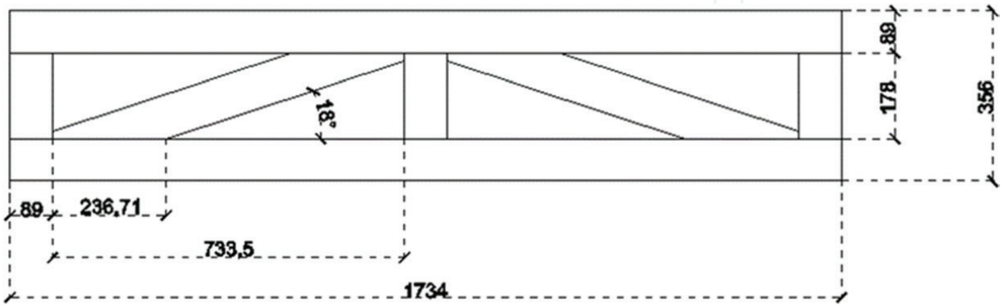


Figure 4. Module’s size of girder truss (unit: mm).

Truss number	Description	Quantity
SPT-S	Normal single truss	1
SPT-G2-N	Girder truss made by two SPT-S nails	1
SPT-G2-12	Girder truss made of two SPT-S connected by a 12-mm diameter beech wood dowel	2
SPT-G2-16	Girder truss made of two SPT-S connected by a 16-mm diameter beech wood dowel	2
SPT-G2-20	Girder truss made of two SPT-S connected by a 20-mm diameter beech wood dowel	2
SPT-G3	Girder truss made of three SPT-S connected by a 16-mm diameter beech wood dowel	1

Table 1. Sample number and description.

Assume that the truss spacing is 406 mm and the building life is 50 years.

According to the 2012 edition of load code for the design of building structures (GB5009-2012):

Standard value of constant load: 0.885 × 0.406 = 0.359 kN/m

Truss weight: 0.106 × 0.406 = 0.043 kN/m

Snow load standard value: 0.5 × 0.406 = 0.203 kN/m

Standard value of live load: 2.0 × 0.406 = 0.812 kN/m

Load design value: (0.359 + 0.043) × 1.2 + (0.203 + 0.812) × 1.4 = 1.9 kN/m

Load on the node: 1.9 × 1.734 ≈ 3.3 kN.

3.3. Load program and device

According to the truss grading loading in the standard for test methods of timber structures (GB50329-2012), the truss static load test added a first-order load every 10 minutes during the failure phase, with a load of $0.2P_k$ per stage. This test used a mechanical testing machine to load. So the loading procedure could be carried out in a continuous loading mode, which is 0.2 P_k every 10 minutes. The loading per minute was 0.02 P_k. After the above theoretical calculation, P_k was 3.3 kN, and the loaded force per minute was 0.066 kN. However, in the

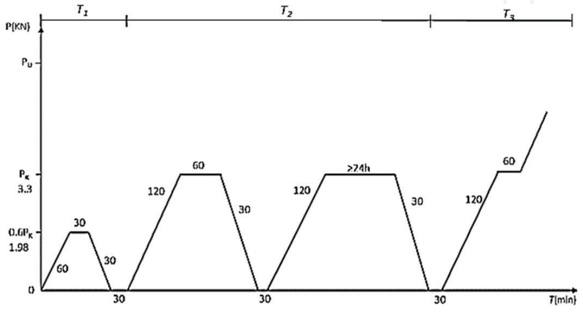


Figure 5. Loading system.

preliminary experiment, we found that the girder truss had more than twice the ultimate bearing capacity of the single truss. So during the loading process, the load of each stage was also doubled to 0.132 kN. If the girder truss is composed of three single trusses, the load per stage was also tripled to 0.198 kN. The specific loading system diagram is shown in **Figure 5**.

3.4. Evaluation index and measurement point arrangement

The purpose of this experiment is to explore the effect of different dowel diameters on the mechanical properties of the new dowel-connected girder truss. The performance evaluation

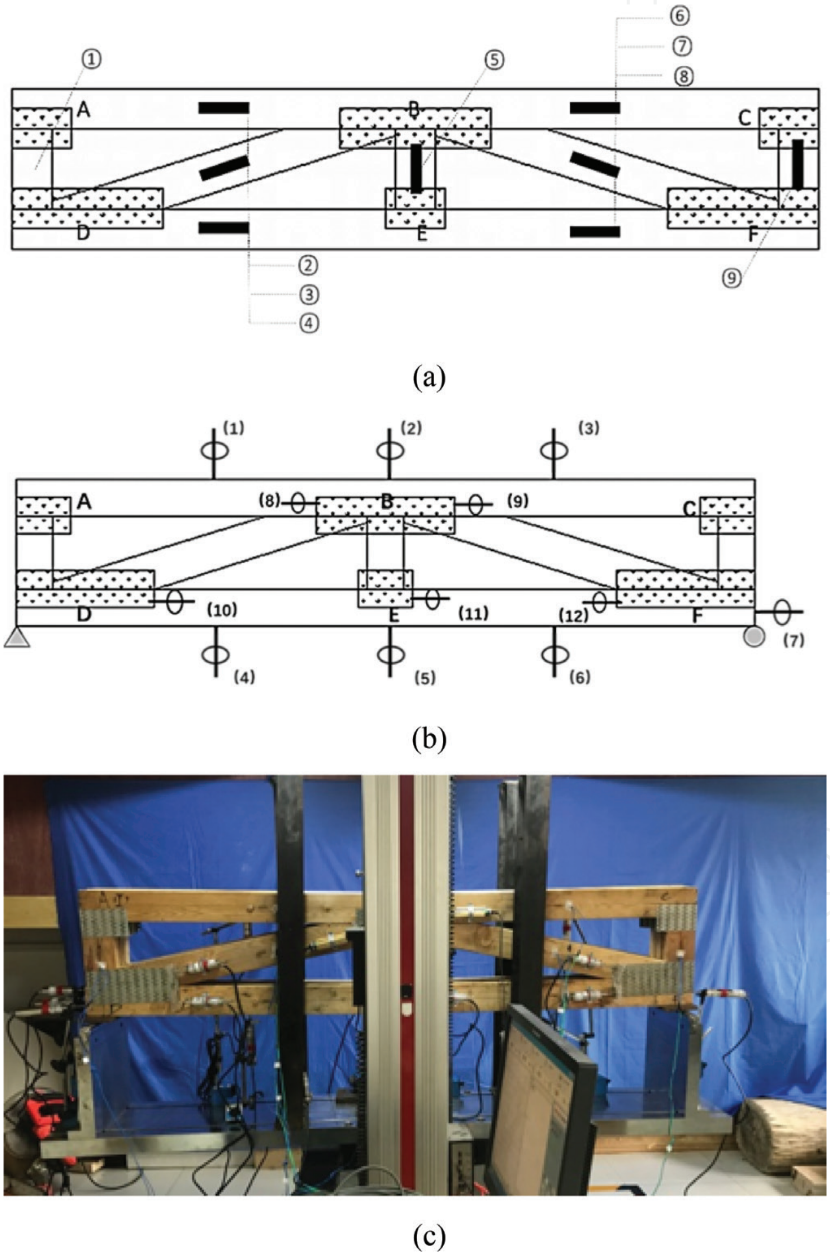


Figure 6. Layout of strain gauges and displacement gauges. (a) Layout of strain gauge; (b) displacement gauge; (c) universal mechanical testing machine.

of girder truss for different dowel diameters should also start from the aspects of ultimate bearing capacity, deformation resistance, failure form and mechanism. Therefore, similar to the static load test of large-span wood trusses, it is necessary to track the displacement changes of various nodes of different types of wood trusses continuously. In this experiment, a small-range displacement sensor was also arranged between the chord and tooth plate for measuring the relative slip of the tooth plate relative to the chord. In addition, strain gauges were arranged at the important chords to measure the strain at various stages of the chords. The specific measuring point layout is shown in **Figure 6**.

4. Phenomenon description

4.1. Overall destruction

This chapter performs a static load test on one single truss and nine girder trusses, including a girder truss composed of three single trusses. There is a big difference in the ultimate bearing capacity and deformation of various types of trusses. However, the overall form and process of destruction of the truss are roughly the same. The damage form of the connector taken out after the girder truss test is also quite different. This also fully illustrates the different connection between girder trusses, which will have a greater impact on its performance.

First, during the preloading of the T_1 stage, the truss did not produce significant changes. After 30 minutes of loading, all types of trusses produced very small residual deformations. Especially, the girder truss could achieve full elastic recovery. From the load-displacement curve of the T_1 stage in **Figure 7**, a certain creep value appeared in the single truss during the preloading phase. The creep variables of other girder trusses were negligible. The use of dowel connectors of different diameters had little effect on the performance of the girder truss.

As the test progressed, there was no significant test phenomenon for each truss from the 24-hour holding load to the initial T_3 stage. However, when loading to 5 P_k, the test phenomenon began to occur in the span of the truss and there was no obvious phenomenon at other nodes. For example, a slight truss plate bulge occurred in the upper B node of the SPT-S and the lower chord appeared cracking near the knot (as shown in **Figure 8**). At other stages, other girder trusses were similar to the test phenomenon of single trusses, and the phenomena of destruction were also concentrated in these two places. In particular, the truss plate of the central B node of the upper chord bulged (as shown in **Figure 9**). This is mainly related to the force mechanism of parallel chord truss. When the parallel chord truss is subjected to the upper concentrated load, the upper chord is under compression and the lower chord is under tension. Combined with the analysis of structural mechanics, the diagonal web of the truss will generate a lateral force at the B node in order to resist the upper concentrated load. Therefore, the B node was subjected to the shear stress, and the stress environment was very complicated. Combined with the final failure form of the truss plate, the truss plate at the B node eventually appeared as a form of shear compression failure.

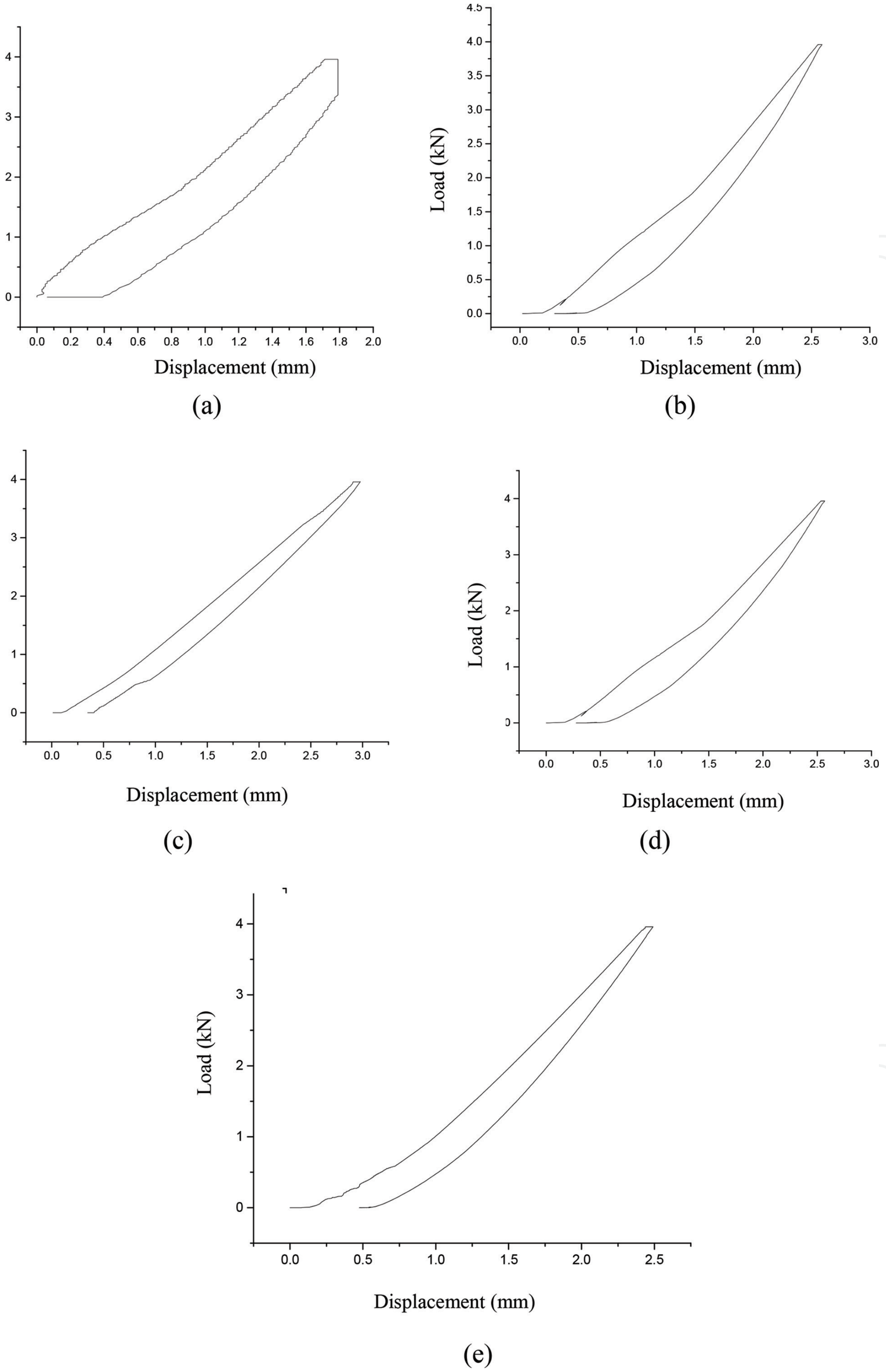


Figure 7. Load-displacement in T_1 stage. (a) SPT-S; (b) SPT-N; (C) SPT-G2-12 (d) SPT-G2-16; (e) SPT-G2-20.

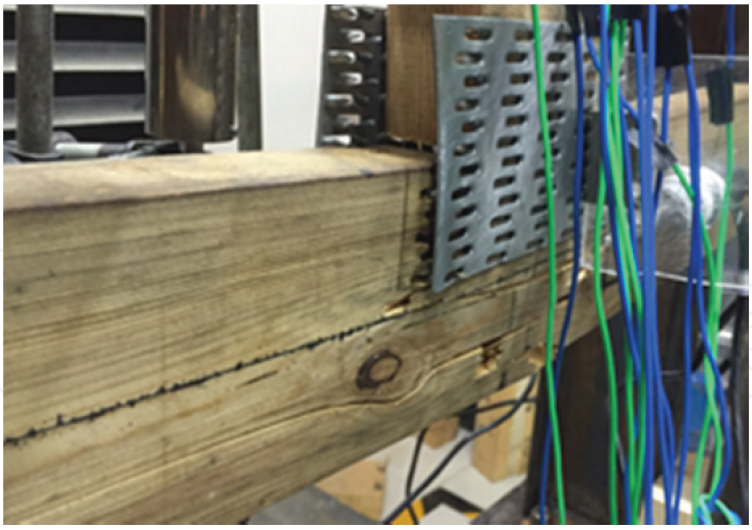


Figure 8. The lower chord cracks accompanied by tooth extraction test process of SPT-S1.

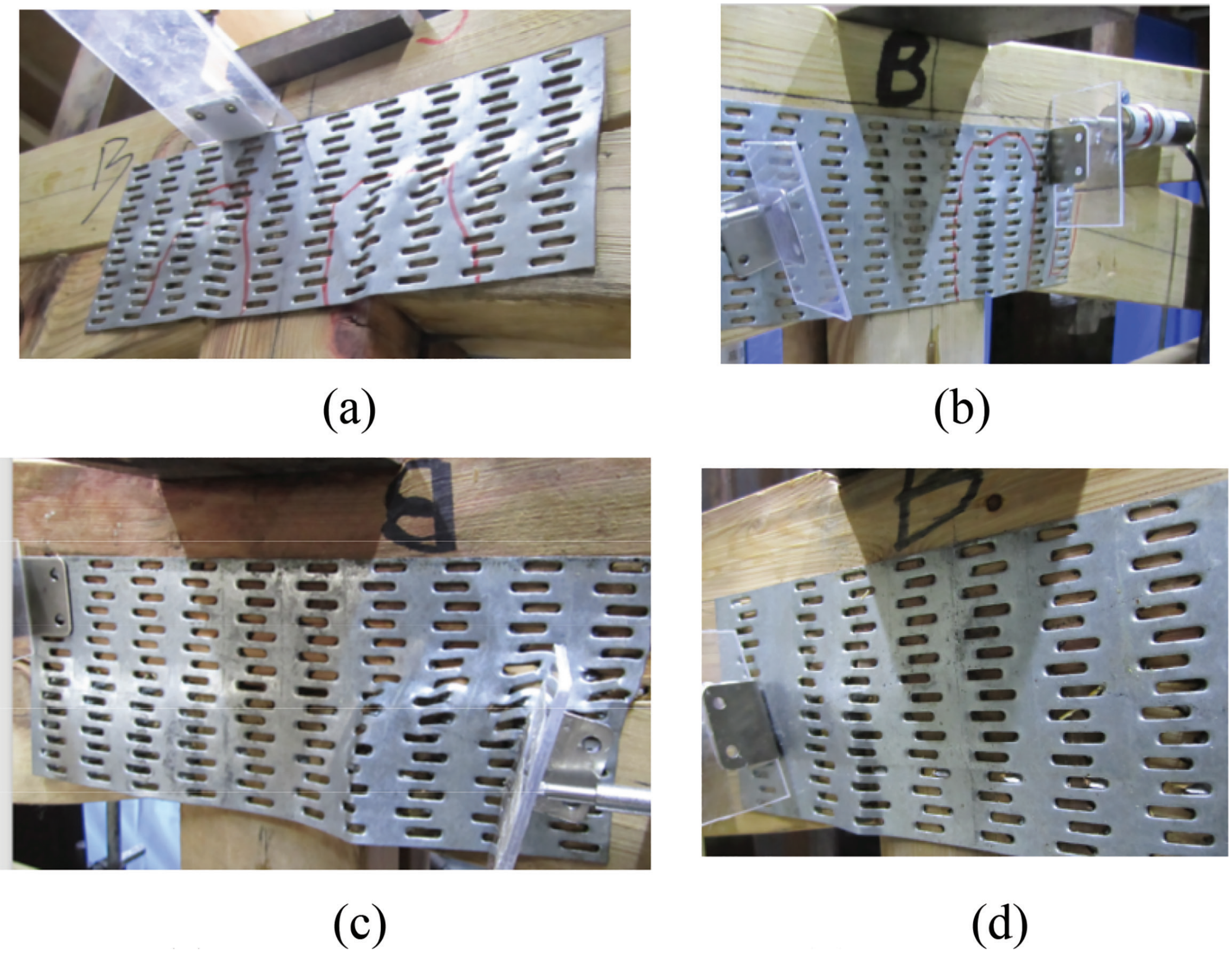


Figure 9. Shear compression failure of mate plate in B node. (a) SPT-G2-N; (b) SPT-G2-12-1; (c) SPT-G2-16-2; (d) SPT-G2-20-2.

In addition, many experiments have found that the overall damage of the truss is destroyed by the destruction of the lower chord. The knot of the lower chord also directly affects the force performance. **Figure 10** shows the actual photo of destruction in lower chords of trusses. When processing the truss, the experimenters must pay attention to the selection of the lower chord and try to avoid too many specifications with the knots. However, the upper chord and the web of the truss had obvious shear damage and the chord did not have obvious damage. Therefore, when the wood truss is processed, the grade of the processing material can be appropriately reduced.

The destruction of the lower chord of the girder truss SPT-G2-20 was due to different reasons. The SPT-G2-20 had a 19.5-mm diameter hole in its upper and lower chords. The opening of the lower chord was too large, destroying the fibers in the direction of the wood and also reducing the net cross-sectional area of the truss chord. Under the condition of constant force, reducing the net cross-sectional area of the rod will increase the stress on the chord. The tensile strength of large-sized wood is less than the compressive strength, so the lower chord is easily damaged. **Figure 11** shows the real photo of the girder truss SPT-G2-20 chord

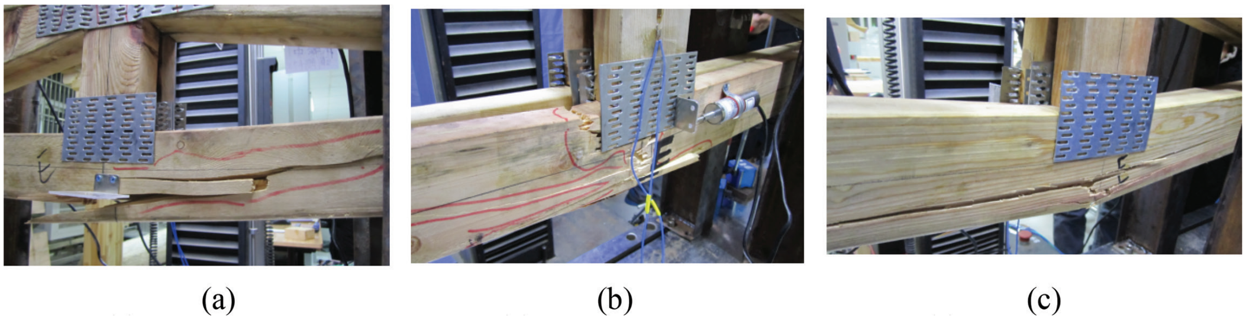


Figure 10. Destruction in lower chords of trusses. (a) SPT-G2-N; (b) SPT-G2-12-2; (c) SPT-G2-16-1.

Figure 11. Failure phenomenon of SPT-G2-20-1.

failure. The lower chord crack started from the wood dowel joint and run through the entire chord. This ultimately led to the overall destruction of the truss, yet there was little damage to dowel.

4.2. Connection node destruction

The previous section described the node failure mode of a girder truss connected by a 20-mm diameter dowel between the single trusses of girder truss. The final damage was caused by the destruction of the lower chord, but the dowels showed almost no deformation. The size of the dowels and the nail connectors was damaged to varying degrees. **Figure 12** shows the connector removed from the truss after the final destruction of each girder truss connector.

From **Figure 12**, the deformation caused by the nail connection was large. Similar to the long-span nail connection girder truss, a plastic hinge appeared in the middle of the nail. When the truss was loaded to the later stage, a more obvious dislocation occured between the single trusses that make up the girder truss. Different diameters of dowels produced different forms of deformation or damage. First, similar to the nail, a 12-mm diameter wood dowel also produced a plastic hinge. However, the amount of deformation was less than the nail connection. The diameter of the wood dowels affected its stiffness. The dowel deformation of a large diameter was small. The dowels with a diameter of 20 mm showed almost no deformation. Wood dowels were almost unaffected by truss damage. The deformation of the wood dowels with 16 mm was also not obvious. The cross-sectional loss of the chord was reduced while providing sufficient joint strength. The relationship between the diameter of hole and dowel of the truss member also had an effect on the connection performance. The black color at the end of the 20-mm diameter dowel in **Figure 13** is the result of carbonization when dowel was screwed into the slot. When the hole diameter of the chord was less than 0.5 mm of the diameter of the

Figure 12. Failure form of connectors.

wood dowel, the wood dowel screwed in the rod was carbonized by the high-speed rotation heat generation and the carbonized layer formed on the surface of the dowel, which protected the surface of the wood dowel. The surface strength was improved. Therefore, it is necessary to select the connectors well and fit the appropriate size of predrilling from the perspective the durability of girder truss.

5. Ultimate bearing capacity

Figure 13 is a comparison of the ultimate bearing capacity of a category five trusses. Among them, the new wood dowel-joined girder truss takes the average of two tests. It can be seen from the figure that the ultimate bearing capacities of all kinds of wood trusses are much higher than its theoretical calculation value, so reducing the span of the truss will effectively improve its carrying capacity. In addition, the ultimate bearing capacities of various girder trusses are much larger than that of single truss, but the ultimate bearing capacities of the various girder trusses have little different from each other. The 12-mm and 16-mm wood dowel-joined girder trusses have a relatively high ultimate bearing capacity. The nail connection girder truss affected the synergy of girder truss due to the mutual dislocation between its single trusses, thus reducing its bearing performance. The girder truss with a wood dowel diameter of 20 mm had a large opening area at the lower chord of the truss, which reduced the net cross-sectional area of the tension member, thereby reducing the load-bearing performance of the truss.

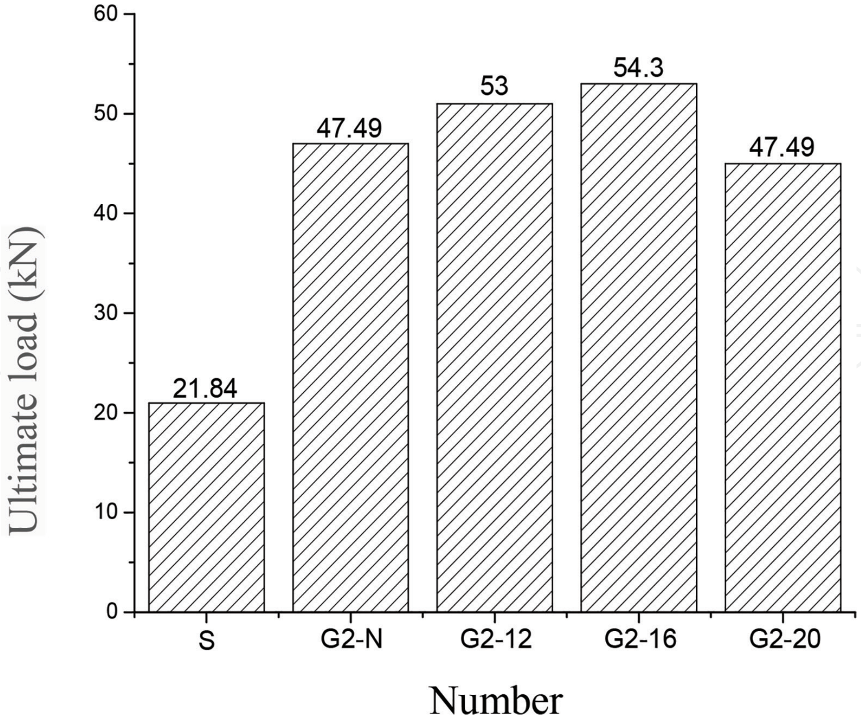
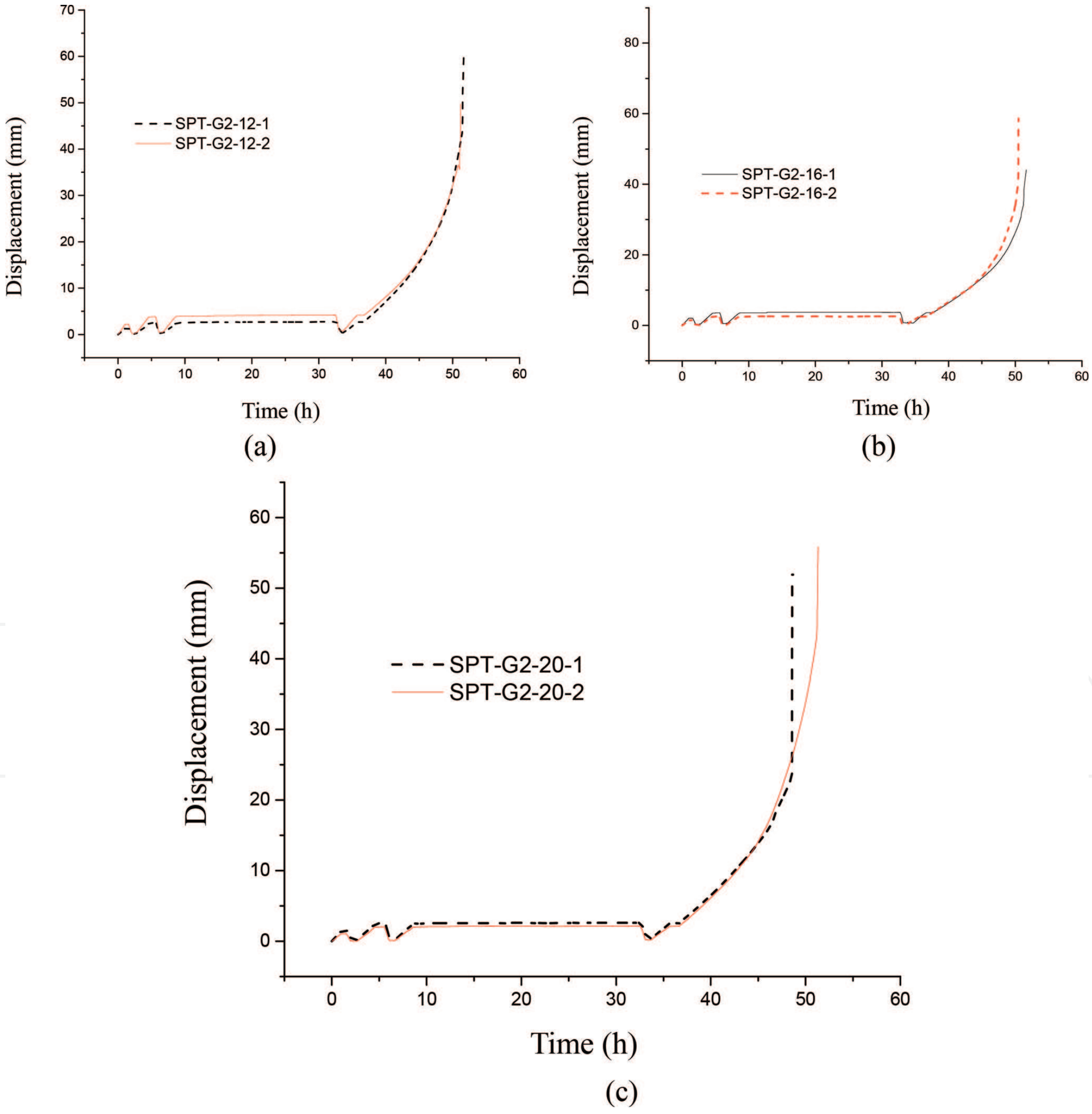


Figure 13. Ultimate bearing capacity of trusses.

6. Analysis of node deflection test results

Figure 14 is a deflection diagram of the lower chords of three girder trusses using two different diameter wood dowel connections. It can be seen from the figure that the three types of trusses show good consistency in the first two stages of loading. The truss enters the nonlinear stage when it enters the failure stage, and the results of the two tests will vary due to the variability of the wood. **Figure 17** shows the variation of the overall deformation of the truss during the loading process. The image shows that it is difficult to distinguish the influence of different connection methods on the creep resistance, elastic recovery performance and deformation resistance of the truss on small-span truss specimens. Only in the stage of truss failure, the deflection curve can be distinguished and different failure modes and mechanisms of various trusses can be analyzed.



(a)

(b)

(c)

Figure 14. Time-deflection of new girder trusses from start to finish. (a) SPT-G2-12; (b) SPT-G2-16; (c) SPT-G2-20.

As shown in **Figure 15**, the load-deflection curves of the single truss, the girder truss of the nail connection, and the girder truss of the wood dowel connection are selected in the failure stage. It can be seen from the figure that different types of trusses exhibit different failure modes and mechanisms. Single truss showed obvious characteristics of brittle failure. There was no obvious sign in the vicinity of the failure. A crack occurred near the knot of the lower chord (as shown in **Figure 8**). Then, the crack continued to increase. Eventually, the overall failure of the truss was caused by the sudden fracture of the lower chord.

The ductility of the two girder trusses is significantly better than that of single truss. In the middle and later stages of truss failure, the load-displacement curve often shows a twist at one end. The reason for the twists and turns is that one single truss in the girder trusses was destroyed first. Since the other truss still had the carrying capacity, it would quickly bear the upper load. However, it would also be destroyed quickly because only one single truss was stressed. Due to the different connections between the selected single trusses of girder trusses, the above situation would be different. Although the shear span ratio was reduced, the girder truss of the nail connection still exhibited in-plane instability at the later stage of loading. Larger span trusses were not very obvious. There was mutual dislocation between the upper trusses. The girder truss would be obvious that one single truss were destroyed first and then another truss would be destroyed quickly. Therefore, the nail connection girder truss did not produce the expected effect of “one plus one is greater than two.” The girder truss connected by wood dowel could still maintain good synergy between the loaded trusses. Therefore, SPT-G2-16 also had its first wave where SPT-G2-N had its twists and turns. However, it can be seen that the drop in displacement was very limited, indicating that the truss had not been

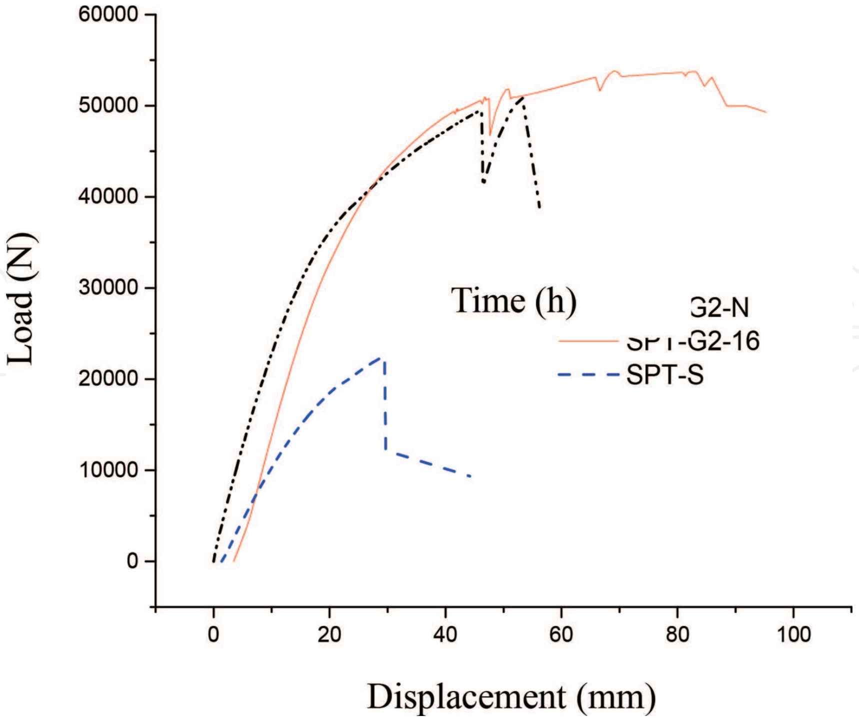


Figure 15. Load-deflection curve of trusses.

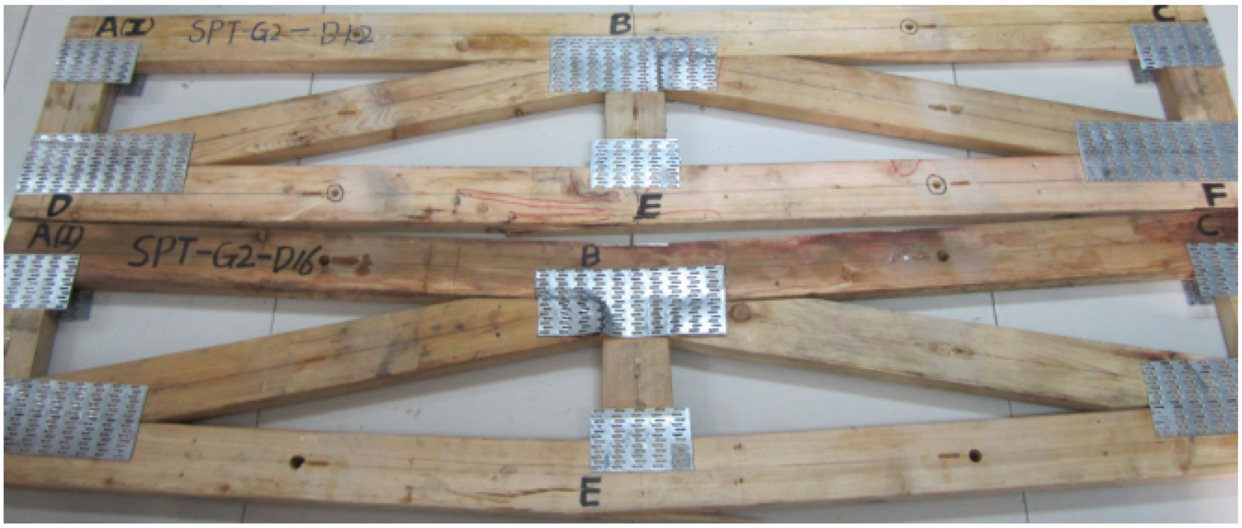


Figure 16. Failure phenomenon of SPT-G2-16.

completely destroyed. As the load continuing to increase, the curve appeared three or four small twists. Eventually, the cracks that was generated at the bottom of the two lower chords of the truss were excessive and completely penetrated (as shown in **Figure 16**), resulting in failure of the truss.

Figure 17 shows the load-deflection curves of three new girder trusses with different diameters of wood dowel as the connection between single trusses. It can be seen from the

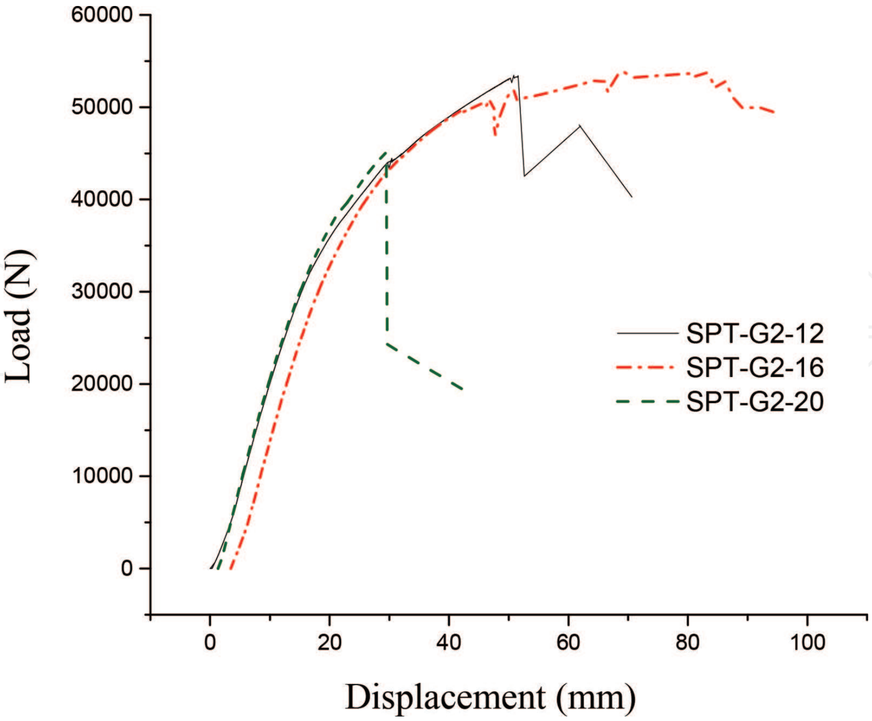


Figure 17. Load-deflection curve of new girder trusses.

figure that the load-deflection curves of the three girder trusses show different shapes. The girder truss with a wood dowel diameter of 20 mm had a similar failure mode of single truss, which was brittle failure (as shown in **Figure 10**). The lower chord was broken under the combined action of tension and shear. The 12-mm diameter dowel connected girder truss was similar to the nail-connected girder truss. Although the load-displacement curve had undergone a twist, the truss did not show good synergy. Finally, a plastic hinge appeared similar to the wood dowel and the nail. Therefore, the dowel connected girder truss showed a better mechanical performance with a 16-mm diameter wood dowel.

7. Further experiments of girder truss composed of three single trusses

In the last section, the girder trusses connected by three different diameter wood dowels were tested for static load, and the girder truss with 16-mm diameter wood dowels was the best. All previous experiments were performed on girder truss composed of two single trusses, but girder truss composed of three or more single trusses were not tested. For the girder trusses to be widely used in larger span structures and more complicated bearing environments, they cannot be composed of only two single trusses. It must consider more forms of single truss combinations. Combined with the test results of the previous section, this section performs a static load test on a girder truss composed of three single trusses connected by 16-mm diameter wood dowels. The enhancement effect of girder truss was explored by comparison with girder truss composed of two single trusses connected by the same diameter wood dowels.

In terms of bearing capacity, the girder truss composed of two single trusses was 53 kN and the girder truss composed of three single trusses had a bearing capacity of 77 kN, increasing 45%. Thus, the more quantities of the single trusses that make up the girder truss are, the more obvious enhancement effects have from the perspective of the failure mode, the two girder trusses were similar and the chord was destroyed under the tensile

Figure 18. The failure of SPT-G3-16.

shear environment, resulting in the destruction of the truss. As shown in **Figure 18**, the middle truss first appeared as cracks at the lower chord. The increase in force resulted in an overall failure of the intermediate truss, with only two trusses being stressed, but girder truss had lost synergy at this time. Then, the wood dowels of the lower chord were also destroyed (as shown in **Figure 19**). The lower chord of the single truss on the outside of girder truss was completely cracked in the direction of the grain. The truss failed as a whole. As shown in **Figure 20**, the load-displacement curves of the two girder trusses in the final failure stage, it can also be found that the two girder trusses have very similar failure modes and both exhibit good ductility.

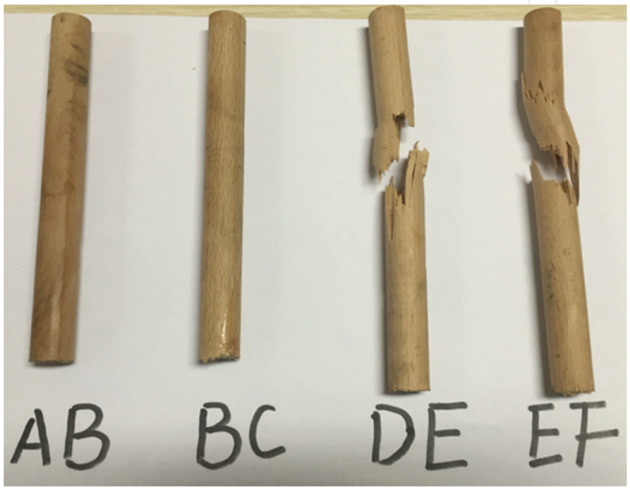


Figure 19. Failure of connectors in SPT-G3-16.

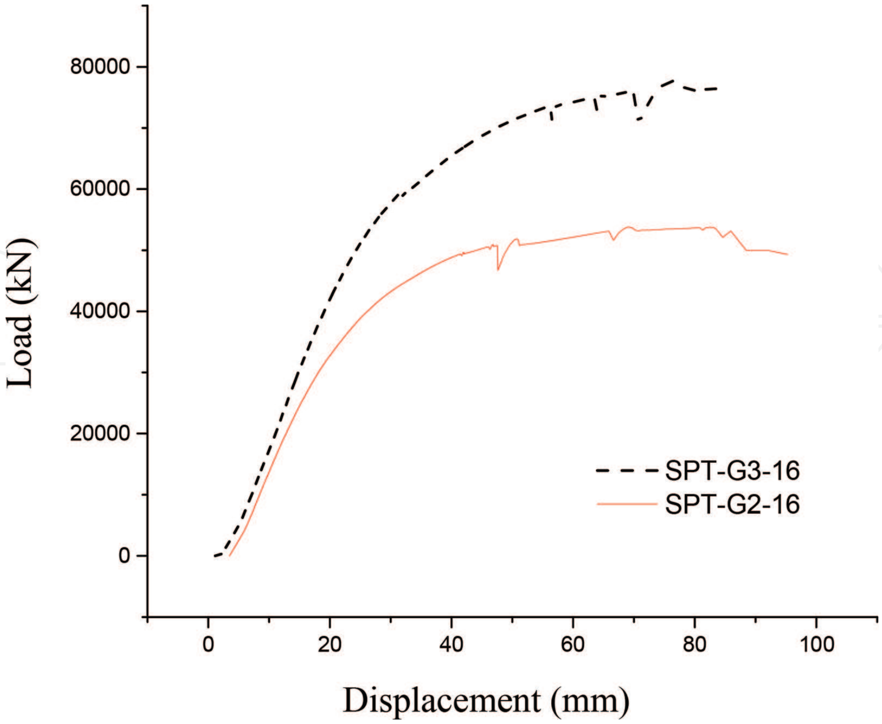


Figure 20. Load-displacement curve in failure stage.

8. Conclusion

In this chapter, the static load test of wood trusses was carried out to investigate the influence of different joints on the mechanical properties of girder truss between single trusses of girder truss, especially the influence of different dowel diameters on girder truss. The results showed that:

1. The girder truss with wood dowel connection should be connected to the girder truss as a whole, but the diameter of the wood dowel should be chosen reasonably.
2. From the perspective of the load capacity, failure mechanism, and mode of the truss, the girder truss has the best performance when the wood dowel diameter is 16 mm.
3. Under serviceability limit states, the use of dowel connectors of different diameters has little effect on the resistance to deformation of girder truss.
4. On the upper chord connected to the truss plate, the truss plate is prone to shear damage due to the combined action of pressure and shear. In the actual project, it should try to do partial reinforcement.
5. As the number of single trusses that make up the girder truss increases, there will also be a significant improvement in its mechanical properties.
6. Wood knots, especially dead knots, have a strong weakening effect on the carrying capacity of the chords of wood trusses. The overall failure of the truss is often due to the presence of the knot, so the selection of the truss should be done. The chord of the truss should avoid the use of materials with knots. If necessary, It can be chosen that using steel instead of wood, developing steel-wood composite structure.

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