Mechanical behaviors and its main influence parameters of flexible assembly joint of timber column and reinforcement concrete beam

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Abstract. Flexible assembly joint is the key problem to coordinate the deformation of hybrid structure. This study aims to investigate the mechanical behaviors and its main influence parameters of flexible assembly joint of timber column and reinforced concrete beam. Finite element models were established and analyzed. The mechanical behaviors of the flexible assembly joint were discussed including the horizontal bearing capacity, horizontal stiffness and load-displacement hysteretic loops. The influence of the vertical load and rubber performance property on the mechanical behaviors of flexible assembly joint was analyzed. The results indicate that the relationship curve of horizontal load and displacement is the bilinear form before its failure. The vertical load and rubber performance property have great influence on its mechanical behaviors including the horizontal bearing capacity, horizontal stiffness and load-displacement hysteretic loops, which are regarded as important indexes to do the performance design.

1. Introduction
In recent years, there had been a mixed residential building structure composed of concrete structure and timber structure in Tibetan areas. There were security risks in the hybrid structure caused by obvious defects in the connection between timber columns and concrete members, as shown in Fig.1. Experts and scholars at home and abroad have studied the hybrid structure. According the research on its key technology and the upper and lower composite structure of light wood and concrete, it showed that connecting bolt and anchor was the key to the connection of structural joints [1-2]. For the hybrid structure composed by the timber structure and reinforcement concrete structure, Shear and uplift resistance of joints were still key problems to be solved. Related research showed that the bolt connection of timber-concrete joint had good effect [3-6]. However, because there was the difference of local stiffness and overall stiffness of light wood-concrete hybrid structure, Substructure parameters had great Influence on seismic response of superstructure. So the proposed separate design can be used as a solution [7-9].

In order to control the shear and pullout of joints and coordinate the stiffness of the upper and lower hybrid structure system, a kind of flexible assembly joint was provided. The paper established the solid models of flexible assembly joint using the finite element software MARC, and did the finite element analysis for the mechanical behaviors of the flexible assembly joint, discussed the relationship between the horizontal force and displacement, analyzed the horizontal bearing capacity, pre-yield stiffness, post-
yield stiffness and hysteresis loops, and the effects of vertical load and rubber performance properties on mechanical properties were further analyzed.

![Figure 1. Connection joint](image1.png)

![Figure 2. Finite element model](image2.png)

2. Finite element model

2.1. Establishment of finite element model

According to the basic characteristics of the designed flexible assembly joints of timber columns and reinforced concrete members, Finite Element Model of Flexible Assembly Joints was established using the finite element software MARC. The model units adopted entity units. Solid elements for timber columns and concrete member chose the solid7 and rubber is super elastic and incompressible material and chose the solid84. Reinforcement chose bar elements truss 9. Main material parameters were selected according to 《Code for design of timber structures》 and 《Code for design of concrete》. The type of Pine column chose TC13B, its total length was 1600mm, the part inserted into the reinforcement concrete beam was 100mm, and the Diameter of Pine was 225mm, its compressive strength and tensile strength was approximately 10 MPa, Elastic modulus is 9GPa, Poisson’s ratio μ is 0.37. The length, width and height of concrete beams were 1400, 400 and 400, respectively. Concrete grade chose C30, compressive strength $f_c=14.3$MPa, tensile strength $f_t=1.43$MPa, ultimate compressive strain $\varepsilon_p=0.0033$, and elastic modulus $E=30$GPa. The ideal elastic-plastic model was adopted for the reinforcement, with the yield strength $f_y = 360$ N/mm$^2$, elastic modulus $E=200$GPa, and Poisson’s ratio $\mu = 0.2$. Flexible materials chose the Rubber using Mooney-Rivlin constitutive model. Different models with different rubber performance property were listed in the table 1, which were represented by S0.01, S0.5, S1, S2, S4, S100, respectively. The assembly node model was composed of a variety of materials, and the corresponding contact between the assembly components and components was set. The timber column was directly contacted with the concrete beam. When the tensile stress was greater than 1 Pa, the two components were separated. Rubber component bonded to the bottom of timber column. Rubber component was directly contacted with reinforcement concrete beams and was normally pulled apart.

| Table 1. Rubber performance parameters |
|----------------------------------------|
| model types | S0.01 | S0.5 | S1 | S2 | S4 | S100 |
| Rubber performance parameters/MPa | C$_{10}$=0.0657 | C$_{10}$=3.285 | C$_{10}$=6.57 | C$_{10}$=13.14 | C$_{10}$=26.28 | C$_{10}$=657 |
| $C_0$=0.0033 | $C_0$=0.164 | $C_0$=0.328 | $C_0$=0.657 | $C_0$=1.314 | $C_0$=32.8 |
2.2. Loading scheme and constraints

In order to analyze the mechanic behavior and its impact parameters of the flexible assembly joint, Pushover analysis and cyclic loading were adopted in this study. When pushover analysis was performed, Vertical load was applied on top of column to simulate upper structure load in each state, then lateral load was exerted on top of column. During the cyclic loading analysis, Vertical load was applied firstly and remained constant for each state, then the different kind of cyclic loading were exerted. Six degrees of freedom constraints were set at joint coupling at the bottom of reinforced concrete beam and it was equivalent to the fixed end constraint. Moreover, the influence of vertical load and rubber performance parameters were analyzed. The finite element model kept the other parameters constant, then changed the influence parameters. In addition, the analysis results of the assemble joint under the different influence parameters were compared to discuss the influence of parameters on mechanical properties of flexible assembly joints.

3. Finite element analysis

3.1. Relationship between horizontal load-displacement

Figure 3 shows the relationship curve between horizontal load F and horizontal displacement D of assembly joint model. The Figure 3(a) reflects the influence of vertical load for the same model state. Figure 3(b) reflects the influence of rubber performance parameters at the pressure of 2MPa. As shown in the two figures, the horizontal displacement of the top of timber column increases with the increasing of the horizontal load of the top of timber column. The initial curves are linear, and then the curves have obvious inflection point. Before failure, the curve is basically bilinear type. But the influence of the vertical load is significantly different from that of rubber performance parameters. It can be seen from the Figure 3 (a), the larger the vertical load is, and the larger the inflection point of yield load is, the faster the bearing capacity decreases after yield and the earlier the joint fails. It shows that the vertical load has obvious effect on the relationship curve between horizontal load and horizontal displacement. When the vertical load is approximately 3MPa, the horizontal bearing capacity is larger. And it has certain horizontal stiffness after yield. When the drift of the flexible joint model is 1/50, the horizontal bearing capacity doesn’t decrease and ensure that the flexible joint model has sufficient restoring force. As shown in Figure 3(b), the initial curves are almost identical and the initial inflection point of curve is close under different rubber performance parameters. The post-yield horizontal stiffness was obviously affected by the rubber performance parameters. Meantime, the smaller the rubber performance parameters are, the earlier the joints fail. In summary, it shows that the vertical load and rubber performance parameters have obvious influence on the relationship curve between horizontal load and horizontal displacement of assembly joint model. The failure state and mechanical properties of joints can be adjusted by optimizing parameters including the vertical load and rubber performance parameters.
### 3.2. Horizontal stiffness

There are certain correlations between axial compression ratio and pre-yield horizontal stiffness, as shown in the Figure 4 (a). The change of horizontal stiffness is basically the same. And it is in the range of 0.788-0.738, and the maximum error is 6.3 %. It shows that the effect of vertical load on the pre-yield stiffness is relatively small. And horizontal stiffness of assembly joint is stable before yielding. It can be seen from the Figure 4 (b); the post-yield horizontal stiffness decreases with increasing of vertical load of the flexible assembly joint. It indicates the vertical load has great influence on the post-yield horizontal stiffness. The trend of curve shows that when the axial force ratio is less than 0.3, the decrease of post-yield horizontal stiffness is obvious. But when the axial compression ratio is greater than 0.3, the relative change of post-yield horizontal stiffness is relatively stable. The post-yield horizontal stiffness is controlled by adjusting the axial compression ratio of timber column to change the damping ratio.

![Figure 4. Relationship of horizontal stiffness and vertical load of S1](image)

- (a) Pre-yield horizontal stiffness
- (b) Post-yield horizontal stiffness

Figure 4. Relationship of horizontal stiffness and vertical load of S1

![Figure 5. Relationship of Rubber performance parameter and horizontal stiffness under the pressure of 3MPa](image)

- (a) Pre-yield horizontal stiffness
- (b) Post-yield horizontal stiffness

Figure 5. Relationship of Rubber performance parameter and horizontal stiffness under the pressure of 3MPa

Figure 5 (a) shows the relationship between rubber performance parameters and pre-yield horizontal stiffness, the change of horizontal stiffness is basically the same and it consistent with that under the axial compression ratio, which is in the range of 0.759-0.793, and its maximum error is 4.448 %. It shows that the effect of rubber performance parameter on the pre-yield stiffness is relatively small. And horizontal stiffness of assembly joint is stable before yielding. In addition, it can be observed from the figure 5 (b), the post-yield horizontal stiffness increases with increasing of the rubber performance parameter of the flexible assemble joint. It is obvious that the rubber performance parameter has great influence on the post-yield horizontal stiffness. Therefore, the post-yield horizontal stiffness is controlled by adjusting the rubber performance parameter to change the damping ratio.
Meantime, the trend of curve shows that when the axial force ratio is less then 0.3, the decrease of post-yield horizontal stiffness is obvious. But When the axial compression ratio is greater than 0.3, the relative change of post-yield horizontal stiffness is relatively stable. Hence, the post-yield horizontal stiffness is controlled by adjusting the axial compression ratio of timber column to change the damping ratio.

3.3. *Hysteretic loop*

The hysteretic loops of flexible assemble joint model S1 under the different vertical load are shown in Figure 6. Where, their lateral displacement is different, the maximum drift ratio is 1/100 in figure 6(a), the maximum drift ratio is 1/50 in figure 6(b). It can be seen that all the hysteretic loops are basically spindle shaped, which show the flexible assemble joint has certain energy dissipation capacity. When the vertical load is very small, the hysteretic loops have obvious pinching phenomenon. With the increasing of vertical load, pinching area gradually decreases and opens from the middle to the outside to become fuller and enhance its energy dissipation capacity. From the two fingers 6 it can be observed, with the increasing of vertical load, the sharp angle of hysteretic loop will be lift and the equivalent stiffness of assembly joints increased at 1/100 drift; And vertical load has small effect on the sharp angle of hysteretic loop at 1/50 drift; therefore, equivalent stiffness of assembly joints is stable.

**Figure 6. Hysteretic loops of model S1 under the different vertical load**

**Figure 7. Hysteretic loops at the different rubber property under the pressure of 3MPa**

Finger 7 shows the hysteretic loops of flexible assemble joint under the different rubber performance parameters. The hysteretic loops in the fingers above are basically spindle shaped. It indicates that the flexible assemble joint has certain energy dissipation capacity. The hysteretic loop has obvious pinching phenomenon which isn’t affected by the rubber performance parameters. With the increasing of rubber
performance parameters, the sharp angle will be lift and the equivalent stiffness of assembly joints increases.

4. Conclusion
(1) The horizontal load and horizontal displacement of the flexible assembly joints of timber column and reinforced concrete beam are nonlinear. Vertical load has obvious influence on horizontal bearing capacity. With the increasing of vertical load, the horizontal bearing capacity increases, but it degenerates faster. In contrast, rubber performance parameters has little effect on horizontal bearing capacity.

(2) Vertical load and rubber performance parameters both has little effect on the pre-yield horizontal stiffness, but has great influence on the pre-yield horizontal stiffness. With the increasing of vertical load, the post-yield stiffness decreases. And with the increasing of rubber performance parameters, the post-yield stiffness increases. The post-yield stiffness can be adjusted by controlling the vertical load and rubber performance parameters to ensure that the flexible assemble joint have sufficient restoring force.

(3) The hysteresis loop of the assembly joint is basically fusiform, which shows that the flexible assemble joint have certain energy dissipation capacity. It is obviously affected by the vertical load. When the axial compression ratio is small, it has obvious pinching phenomenon. As the vertical load increases, the pinching range decreases, and the hysteresis loop is plumper, so its energy dissipation capacity is better.

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References
[1] Xiong, H.B FU, H and Ouyang, L (2018) Experimental and Parametric Analysis on the Shear Bearing Capacity of Single-bolted Wood-concrete Connection[J]. Structural Engineers. 3403 136-144.
[2] Xu, D.L Liu, W.Q Zhou, D and Xi, A.F (2011) Experimental study of bolted glued timber-to-timber joints[J]. Journal of Building Structures. 32(7) 93-100.
[3] Yan, H.D Hu, X.M and Lan, X.T (2013) Study on the push-out tests of the screw connectors in timber-concrete composite beams[J]. Special Structures. 30(4) 48-50, 97.
[4] Dias, A.M.P.G. (2012) Analysis of the nonlinear behavior of timber-concrete connections[J]. Journal of Structural Engineering. 138(9) 1128-1137.
[5] Ouyang, L (2017) Research on the mechanical performance in single-bolted wood-concrete connections[D]. Shanghai: Tongji University.
[6] Jiang, Y.C Hu, X.M Cao, X.J Hong, W and Zhang, B (2016) Experimental study on push-out tests of screw connector for glulam-concrete composite beams[J]. Journal of Nanjing Tech University (Natural Science Edition). 38 (5) 74-80.
[7] Xiong, H.B Ni, C Lu X.L and Jia, G.C. (2008) Shaking table tests on 3-storey wood-concrete hybrid structure[J]. Journal of Earthquake Engineering and Engineering Vibration. 28 (1) 91-98.
[8] He, M.J Li, S Guo, S. Y and Ni, C (2011) The seismic performance in diaphragm plane of multi-storey timber and concrete hybrid structure[J]. Procedia Engineering. 14 1606-1612.
[9] Nakagawa, M Isoda, H Kawai, N Koshihara, M and Araki, Y (2014) Shaking table tests of horizontal composite structure of reinforced concrete and timber frame[J]. Journal of Structural & Construction Engineering. 79(697) 401-410.