Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 02

April 2016, P.P.743-749

The Finite Element Analysis on Short-time Flexural Behavior of Glue-lumber String Beam

NAN GUO AND HAIXIN JIANG
Northeast Forestry University, School of Civil Engineering, Hei Longjiang, Harbin, Heilongjiang, China
Email:snowguonan@163.com

Abstract: ABAQUS finite element analysis was used in this paper to simulate the prestressed glulam string beams. The influence of the number of prestressed steel bar and the prestressing value to short-time flexural behavior of prestressed glue-lumber string beams has been studied. Under the same bearing capacity, the economy of prestressed beams and ordinary beams has been contrastively analyzed. The reason of the difference between the simulation results from finite element and the experimental results was illustrated. The results showed that: when the prestressing value remains unchanged, compared with prestressed beams with 2 prestressed steel bars, the ultimate bearing capacity of prestressed beams with 4 root prestressed steel bars increased 19.6 ~ 20.6%, and the ultimate bearing capacity of prestressed beams with 6 root prestressed steel bars increased 33.8 ~ 34.7%. When prestressed beams have the same number of prestressed steel bar, compared with prestressed beams with 0 kN prestressing value, the ultimate bearing capacity of prestressed beams with 3.077 kN prestressing value increased 2.6 ~ 38.3%, the ultimate bearing capacity of prestressed beams with 6.154 kN prestressing value increased 5.3 ~ 41.4%, and the ultimate bearing capacity of prestressed beams with 9.232 kN prestressing value increased 7.9 ~ 44.5%. Compared with ordinary glue-lumber beams, prestressed glue-lumber string beam with the same prestressing value can save wood about 64.63% ~70.58%, and reduce the cost of 6.31% ~ 63.66%. From comparison between analyzing test and the finite element analysis showed that material defect and loss of prestress of glue-lumber would make the stiffness and inverted arch different.

Keywords: *prestressed glue-lumber string beam; finite element analysis; constitutive relation; flexural behavior*

1. Introduction

For prestressed glue-lumber beam, the compressive strength can be fully used, and the span of the girder of glue-lumber beam can be increased, therefore the cost of glue-lumber beamscan be saved, which can promote the development of the wooden structure [1~2]. At present, the research of prestressed glue-lumber string beam, mainly reflected the motheds of using prestressed steel bars and fiber materials to apply prestress[3~9]. Prestressed glue-lumber string beam is a kind of beam, who's prestress was applied by screwing the web member in the middle of beams [10]. Currently, the research of prestressed glue-lumber string beam just related to preliminary theoretical analysis and experimental research for selection of glue-lumber wooden material, while, finite element simulation analysis of prestressed glue-lumber string beam has not been accomplished and the further research on how to properly build analytical models is needed.

In the analyzation of the prestressed glue-lumber beams by abaqus, the constitutive relation model of material needs certain simplicity. Currently, the simplified models include anisotropic elastic constitutive model and isotropic elastoplastic constitutive model, the two models have been more commonly used. Different constitutive models of glue-lumber were used to research its behavior by domestic research teams. Isotropic elastoplastic constitutive model is used to the research of the curved beam glue-lumber horizontal grain stress and cracking performance and the study of the temperature and humidity stress of the glue-lumber beams by Enchunzhu and others from Harbin industrial university [11~12]. In the literature [13], glue-lumber was seen as the transverse isotropic material to study its elastic stage performance. In the literature [14], the anisotropic elastic constitutive model was used to finite element simulation of glue-lumber, too, besides people use the glue-lumber load - displacement curves obtained in various constitutive models and the glue-lumber load-displacement curve obtained in tests for comparison, and they come to conclusions. The results showed that: compared with other two kinds of constitutive model, the anisotropic elastic-plastic constitutive can more truly simulate the state of the glue-lumber string beam, so the anisotropic elastic-plastic constitutive was used to simulate in this paper.
ABAQUS finite element analysis was used in this paper to simulate the short-time flexural behavior of prestressed glue-lumber string beam. The influence of the number of prestressed steel bar and the prestressing value to short-time flexural behavior of prestressed glue-lumber string beam has been studied. The economy of prestressed beams and ordinary beams has been contrastively analyzed. Compared analysis result to result from tests and this paper

analyzes the reasons of difference between analysis result and result from tests.

2. Basic information of glue-lumber string beam

2.1. General Ssituation of mmodel beam

The size of glue-lumber string beam was used in ABAQUS finite element simulation analysis is 100 mm×100 mm×3150 mm. The 7 mm-diameter prestressed steel bar made of 1570 level prestressed steel wire with low relaxation of prestress was put to use. The size of glue-lumber string beam model is shown in figure 1.

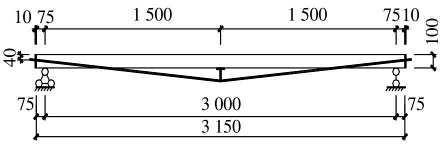


FIG.1: The size of glue-lumber string beam model

2.2. Grouping of modelbeam

To be easily and intuitively compared, prestressed glue-lumber string beam used in finite element simulation analysis has been divided into two categories, A and B, in accordance with the number of prestressed steel bar and the prestressing value. The prestressing value is controlled to a quantitative in the data of A. The number of prestressedsteel bar is variable, including 0 kN, 3.077 kN, 6.154 kN and 9.232 kN, four different prestressing value. Each kind of different prestressing value includes three groupsprestressed glue-lumber string beams, including 2, 4 and 6 of the prestressedsteel bar. Details are shown in table 1.

***Tab.1:** The data of A*

Beam number	Size/mm	Prestressing value/kN	Prestressing bars' number
$L_{0,1}$			2
$L_{0,2}$	100×100×3150	0	4
$L_{0,3}$			6
$L_{1,1}$			2
$L_{1,2}$	100×100×3150	3.077	4
$L_{1,3}$			6
$L_{2,1}$			2
$L_{2,2}$	100×100×3150	6.154	4
$L_{2,3}$			6
$L_{3,1}$			2
$L_{3,2}$	100×100×3150	9.232	4
$L_{3,3}$			6

The number of prestressed steel bar is controlled to a quantitative in the data of B. The prestressing value is variables, including 2, 4 and 6, four kind of different number of prestressed steel bar. Each kind of the number of prestressed steel bar include four group prestressed glue-lumber string beam, including 0 kN, 3.077 kN, 6.154 kN and 9.232 kN prestressing value. Details are shown in table 2.

***Tab.2:** The data of B*

Beam number	Size/mm	Prestressing value/kN	Prestressing bars' number
$L_{0,1}$		0	
$L_{1,1}$	100×100×3150	3.077	2
$L_{2,1}$		6.154	
$L_{3,1}$		9.332	
$L_{0,2}$		0	
$L_{1,2}$	100×100×3150	3.077	4
$L_{2,2}$		6.154	
$L_{3,2}$		9.332	
$L_{0,3}$		0	
$L_{1,3}$	100×100×3150	3.077	6
$L_{2,3}$		6.154	
$L_{3,3}$		9.332	

Control group had three kinds of ordinary glue-lumber beams. The section size of beam is 100 mm × 100 mm, 100 mm × 125 mm and 100 mm × 150 mm. The details of the control group are shown in table 3.

***Tab.3:** The data of control group*

Beam number	Size/mm	Prestressing value/kN	Prestressing bars' number
L_{100}	100×100×3150		
L_{125}	100×125×3150	0	0
L_{150}	100×150×3150		

3. The Main points of the finite element modeling

3.1. Constitutive relation

Wood is a kind of anisotropic material with three axis perpendicularing and intersecting each other. Three basic axis are used for the mechanical analysis are fiber direction (L), direction of radius (R) and chord tangent direction (T), as shown in figure 2. The wood often exist the phenomenon of knot, fiber tilted and distortion, so, currently, in the machining process of glue-lumber, radius direction of wood has not been strictly distinguished between chords and cutting direction. So it's difficult to regard glue-lumber as pure three-axis orthogonal anisotropic materials in the analysis, generally, the fiber direction of glue-lumber is called longitudinal, and the direction of radius and chord tangent direction are collectively referred to as transverse.

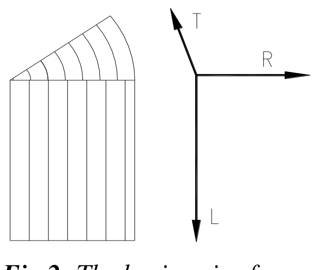


Fig.2: The basic axis of wood

When defining material elastic properties of glue-lumber, the type selection was chosen as orthogonal anisotropy. Stiffness matrix was input according to the software prompts. The stiffness matrix of the anisotropic material as follows:

$$\begin{bmatrix} D_{1111} & D_{1122} & D_{1133} & 0 & 0 & 0 \\ & D_{2222} & D_{2233} & 0 & 0 & 0 \\ & & D_{3333} & 0 & 0 & 0 \\ & & & D_{1212} & 0 & 0 \\ & & & & D_{1313} & 0 \\ & & & & & D_{2323} \end{bmatrix}$$

Among them, $D_{1111}=E_1(1\text{-}v_{23}v_{32})$r,
$D_{2222}=E_2(1\text{-}v_{13}v_{31})$r,
$D_{3333}=E_3(1\text{-}v_{12}v_{21})$r,
$D_{1122}=E_1(v_{21}+v_{31}v_{23})$r= $E_2(v_{12}+v_{32}v_{13})$r,
$D_{1133}=E_1\ (v_{31}+v_{21}v_{32})$r= $E_3(v_{13}+v_{12}v_{23})$r,
$D_{2233}=E_2(v_{32}+v_{12}v_{31})$r= $E_3(v_{23}+v_{21}v_{13})$r,
$D_{1212}=G_{12}$,
$D_{1313}=G_{13}$,
$D_{2323}=G_{23.}$

3.2. Establishing components

Glue-lumber beams, steel wire, steel plate, the end plate, steering blocks, bolt and anchor device have been newly built, among them, in addition to the basic characteristics of the prestressed steel bar that has been defined as a "line", the other parts have been all defined as three-dimensional. In order to avoid the meshing too abnormal to cause the calculation error, in the simulation, the bottom of block has been defined as plane surface instead of curved surface. Besides, bolt rod section has been built to circular cross section area that is equal to the square.

Both ends of the prestressed glue-lumber string beam have been hinged. Two three cent point position have been applied concentration. Simplified loading diagram is shown in figure 3.

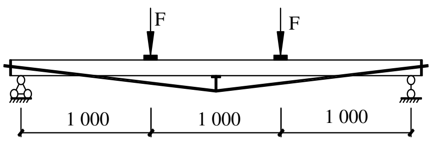


***FIG.3:** Simplified loading diagram*

3.3. Defining material properties

Finite element simulation of prestressed glue-lumber string beam need three kinds of material models. For glue-lumber beams, according to the prism compression test results of the specimens, D_{1111} = 6742 N/mm^2, D_{2222} = D_{3333} = 385 N/mm^2, D_{1313} = D_{1212} = 439 N/mm^2, D_{1133} = D_{1122} = 348 N/mm^2, D_{2233} = 149 N/mm^2, D_{2323} = 117 N/mm^2. Yield stress was 27 N/mm^2. For prestressed steel wire, the elastic modulus was 2.0 × 10^5 N/mm^2. The yield stress of the 7 mm-diameter prestressed steel bars made of 1570 level prestressed steel wire with low relaxation of prestress was 1100 N/mm^2. When defining the wire cross section, the category was beam and the cross section was circular. For the convenience of modelling, 2, 4 and 6 roots for prestressed steel wire have been modelled according to 2 roots. Section radius has been input 3.5 mm, 4.95 mm and 6.06 mm in turn. For steel plate, anchor, side plate and other components, without considering the elastic deformation in the simulation process, the elastic modulus was 2.0×10^7 N/mm^2.Diagram of the glue-lumber beams material direction is shown in figure 4.

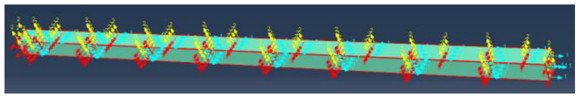
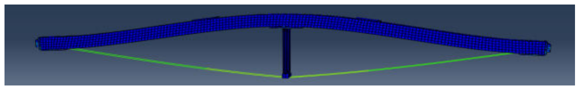


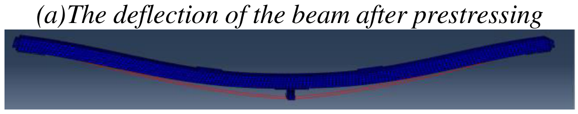
***Fig.4:** Diagram of the glue-lumber beams material direction*

4. The results of finite element analysis

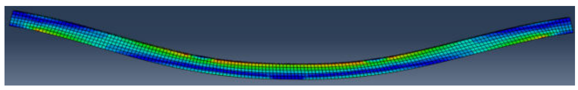
The stress nephograms after the completion of the ABAQUS analysis of prestressed glue-lumber string beam is shown in figure 5. Due to the stress of prestressed steel wire is much higher than that of glue-lumber beams, the stress nephogram glulam cannot be intuitively reflected beams and prestressed steel wire's stress distribution. Thus there are stress nephograms of glue-lumber beams and prestressed steel wire.



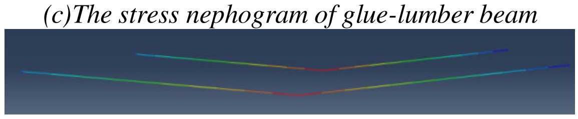
(a)The deflection of the beam after prestressing



(b)The whole deflection of the beam after loading Concentration



(c)The stress nephogram of glue-lumber beam

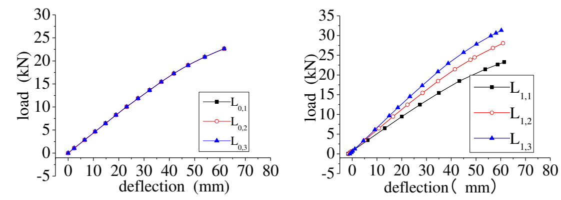


(d)The stress nephogram of prestressed steel wire

***Fig.5:** The results of finite element analysis for prestressed glue-lumber string beam*

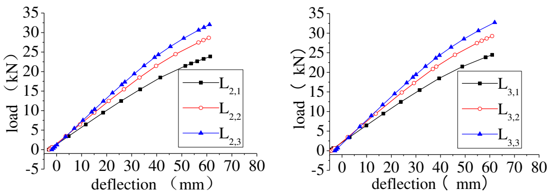
4.1. The influence of the number of prestressed steel wire

The displacement of a point, locating in the glue-lumber beams across, has been selected as x axis. Concentrated force of each of the three dividing point in each time has been selected as y axis. The load-deflection curve for each group beam has been drawn, as shown in figure 6.



(a)0kN prestressing value *(b)3.077kN prestressing value*

ISSN 0974-5904, Vol. 09, No. 02, April, 2016, pp. 743-749



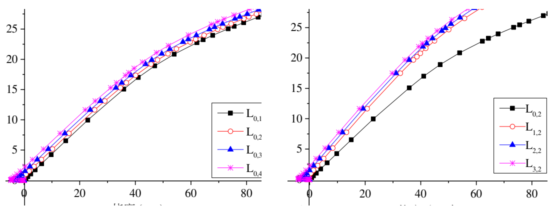
(c)6.154kN prestressing value *(d)9.232 kN prestressing value*

Fig.6: *Comparison of load-deflection curve for each group beam*

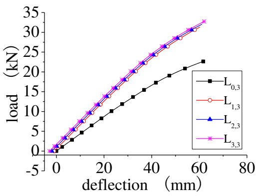
The finite element analysis results on above diagrams showed that, when prestressing value was 0, the load deflection curve is overlap with 2, 4 and 6 root prestressed steel bars. It proved that under the condition of the absence of prestress has not improved on stiffness of the beam. When to applying prestress on beam, with the increased of number of prestressed steel wire can make the bearing capacity of the beam increase. Compared with prestressed beams with 2 root prestressed steel bars, the ultimate bearing capacity of prestressed beams with 4 root prestressed steel bars increases 19.6 ~ 20.6%, and the ultimate bearing capacity of prestressed beams with 6 root prestressed steel bars increases 33.8 ~ 34.7%. The same load produced smaller deflection. In the case of prestressing, the more number of prestressed steel wire the lager prestressed beam string glulam bending stiffness.

4.2. The influence of the prestressing value

With the same prestressed steel wire number, each beam load-deflection curve is shown in figure 7.



(a)2root prestressed steel wire *(b)4 root prestressed steel wire*



(c)6 root prestressed steel wire

Fig.7: *Comparison of load-deflection curve for each group beam*

Above diagrams showed that, when the number of prestressed steel wire remains unchanged, with the increase of prestressing value make the ultimate bearing capacity lager. Compared with prestressed beams with 0 kN prestressing value, the ultimate bearing capacity of prestressed beams with 3.077 kN prestressing value increases 2.6~38.3%, the ultimate bearing capacity of prestressed beams with 6.154 kN prestressing value increases 5.3~41.4%, and the ultimate bearing capacity of prestressed beams with 9.232 kN prestressing value increases 7.9~44.5%. When, remaining same load, the increase of prestressing value could make the deflections of beam smaller. Under the same of the number of prestressed steel wire, with the increase of prestressing value, beams bearing capacity and stiffness are increased.

The figure 7 also showed that when the number of prestressed steel wire remains unchanged, the slope of glue-lumber beams without prestress is far lower than others with prestressed beam. The load deflection curve of all prestressed beams in almost the same slope. After applying the prestressed glue-lumber string beam, the magnitude of the prestress value had no obvious effect on stiffness of beam. But when the prestress value is bigger, beam causes larger arch, so compared with smaller values of the prestressed beam, the general deflection value is smaller.

4.3. Contrastive analysis of the economy for prestressed beams and ordinary beams

According to the ultimate load of prestressed glue-lumber beam, work out the section size of ordinary glue-lumber beams corresponding limit load, and the volume of a prestressed beam that can save wood at the same time. According to the market value of the compressed wood and prestressed steel wire, considering the cost of a tensioned anchorage device to evaluate efficiency of prestressed glue-lumber beam. Assume that the wide of all glue-lumber beam were 100 mm, the high of glue-lumber beam were variables. The market price at 13500 yuan/cubic meter, glulam wire and anchorage device is a total of 100 yuan. The analysis of the results is shown in table 4.

Tab.4, *The economy assessment of prestressed glue-lumber beam*

Group	Ultimate load /kN	The height of the conversion /mm	Save the wood /%	Save the cost/%
$L_{0,1}$	22.65	283	64.63	56.31
$L_{0,2}$	22.65	283	64.63	56.31
$L_{0,3}$	22.65	283	64.63	56.31
$L_{1,1}$	23.25	286	65.09	56.88
$L_{1,2}$	28.05	315	68.22	60.74
$L_{1,3}$	31.325	333	69.93	62.85
$L_{2,1}$	23.85	290	65.53	57.43
$L_{2,2}$	28.65	318	68.55	61.16
$L_{2,3}$	32.025	336	70.26	63.26
$L_{3,1}$	24.45	294	65.96	57.95
$L_{3,2}$	29.25	321	68.88	61.56
$L_{3,3}$	32.725	340	70.58	63.66

The table 4 show that: compared with ordinary glue-lumber beams, when bearing capacity remains unchanged, the prestressed glue-lumber beams can save 64.63% ~ 70.58% of timber and save 56.31% ~ 63.66% of cost.

5. The comparison of results for finite element analysis and tests

5.1. General situation of tests

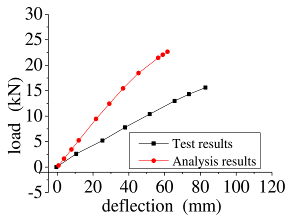
Flexural tests have been carried out on 36 prestressed glue-lumber string beams and 9 ordinary glue-lumber beams. The influence of prestressed steel bars' number and the prestressing value to prestressed glue-lumber string beams have been studied on the aspects of ultimate loads, failure modes, load-deflection curves and sectional strain curves. The results showed that: the more prestressed steel bars or the greater prestressing value, the greater the bending ultimate and the failure modes tend more too ductile failure. With the growth of the number of prestressed steel bar, the bending stiffness gets larger. While the increase of prestressing value could make the deflections smaller by increasing the inverted arch. Compared with ordinary glue-lumber beams, prestressed glue-lumber string beam can save the use of wood and significantly reduce costs. Before load test and after test the prestressed glue-lumber string beam as shown in figure 8 ~ 9.

***Fig.8** The picture of beam before load test*

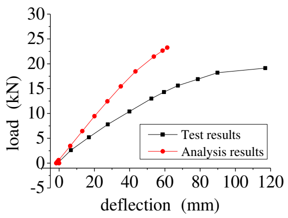
***Fig.9** The picture of beam after load test*

5.2. The comparison of load-deflection curves

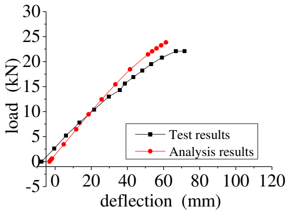
For conveniently comparing the results of tests and finite element analysis for each beam. Respectively, the load-deflection curves have been drawn in both cases for the same set of prestressed glue-lumber string beam. As shown in figure 10 ~ 13.



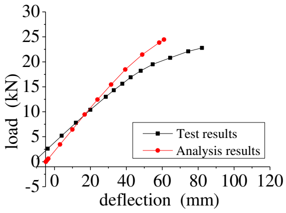
(a)The load-deflection curve of $L_{0,1}$



(b)The load-deflection curve of $L_{1,1}$

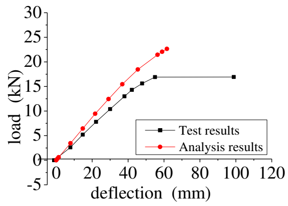


(c)The load-deflection curve of $L_{2,1}$

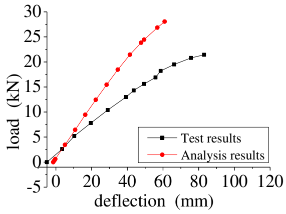


(d)The load-deflection curve of $L_{3,1}$

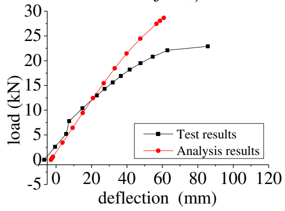
***Fig.10:** The load-deflection curve of beam with 2root prestressed steel wire*



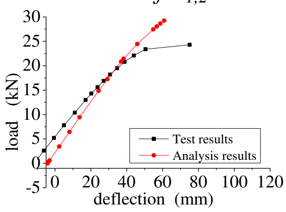
(a)The load-deflection curve of $L_{0,2}$



(b)The load-deflection curve of $L_{1,2}$

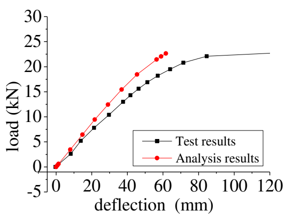


(c)The load-deflection curve of $L_{2,2}$

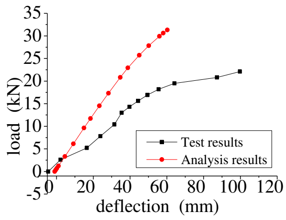


(d)The load-deflection curve of $L_{3,2}$

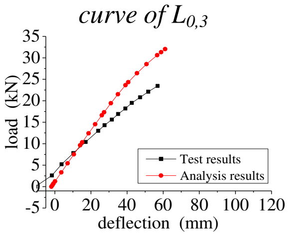
***Fig.11:** The load-deflection curve of beam with 4 root prestressed steel wire*



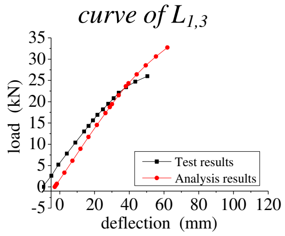
(a)The load-deflection curve of $L_{0,3}$



(b)The load-deflection curve of $L_{1,3}$

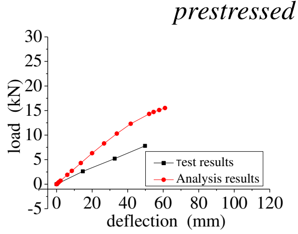


(c)The load-deflection curve of $L_{2,3}$

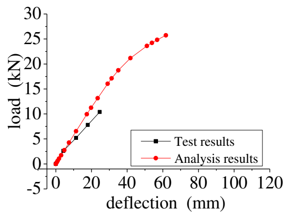


(d)The load-deflection curve of $L_{3,3}$

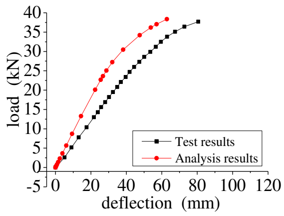
***Fig.12:**The load-deflection curve of beam with 6 root prestressed steel wire*



(a)The load-deflection curve of L_{100}



(b)The load-deflection curve of L_{125}



(c)The load-deflection curve of L_{150}

Fig.13: *The load-deflection curve of ordinary beams*

Above figures showed that: the slope of the load-deflection curve for tests significantly less than the curve obtained by finite element analysis. The stiffness of prestressed glue-lumber string beam by finite element analysis is larger than the test. The reason was caused mainly by two aspects: first, the quality of the test beam was influenced by knag, crack and the strength of rubber. However, the process of finite element simulation did not exist these problems, second, in the process of installing prestressed glue-lumber beam, the tightness of prestressed steel wire,prestress and beam steering block, anchorage and the gap can cause a certain loss of prestress.The effect of prestress has been weakening. And in the finite element analysis, components were the ideal of seamless close contact between each other. The length of the prestressed steel wire has been accurately calculated. So there were no such problems.

Figure 13 showed that: for the same set of beam, when prestress is larger, the arch of the finite element analysis is greater than tests. Due to the statement of the loss of prestress, when it reaches the same magnitude of stress, bolt rod need to provide greater elongation for tests. That may cause bigger reverse.

6. Conclusions

(1) When the prestressing value remains unchanged, the more number of prestressed steel bars the beam had, the greater the ultimate bearing capacity the beam had, compared with prestressed beams with 2 prestressedsteel bars, the ultimate bearing capacity of prestressed beams with 4 prestressedsteel bars increases 19.6~20.6%, and the ultimate bearing capacity of prestressed beams with 6 prestressedsteel bars increases 33.8~34.7%.

(2) When the number of prestressed steel bars remains unchanged, the greater prestressing value the beam had, the greater the ultimate bearing capacity the beam had, compared with prestressed beams with 0 kNprestressing value, the ultimate bearing capacity of prestressed beams with 3.077 kNprestressing value increases 2.6~38.3%, the ultimate bearing capacity of prestressed beams with 6.154 kNprestressing value increases 5.3~41.4%, and the ultimate bearing capacity of prestressed beams with 9.232 kNprestressing value increases 7.9~44.5%.

(3) Compared with ordinary glue-lumber beams, prestressed glue-lumber string beam with the same ultimate bearing capacity can save wood about 64.63%~70.58%,and reduce costs 56.31%~63.66%.

(4) By comparing the test results with the analytical values finite element analysis and tests, we have known that material defect and the loss of prestress of glue-lumber would make the stiffness significantly different. And due to the loss of prestress, the arch of the finite element analysis is greater than that of tests.

7. Acknowledgments

In the process, this project was supported by “the Fundamental Research Funds for the Central Universities” (41415016) and “the project of state forestry administration science and technology research” (41314401) .

8. Reference:

[1] Lin C, Yang H F, Liu W Q, et al. “Prestressed glulam beams flexural performance test research”. *Journal of structural engineers*, 2014,01:160-164.

[2] Zuo H L, Yang Y W, Guo N, et al. “Prestressed beam string glulam flexural performance of finite element analysis”. *Journal of liaoning engineering technology university (natural science edition),* 2015 01:390-394.

[3] Zhang J M, Pan J L. “ANSYS analysis of beam string deformation performance”. *Architectural technology at low temperature*. 2008, then 0-71

[4] Zhang J M, Pan J L, Dong H B. “Experimental study on the deformation characteristics of string beam”. *Architectural technology at low temperature*. 2006. 2:49-51

[5] Anshari B, Guan Z W, Kitamori A. et al. “Structural behaviour of glued laminated timber beams pre-stressed by compressed wood”. *Construction and Building Materials*, 2012, 29(4):24-32

[6] Guan Z W, Rodd P D, Pope D J. “Study of glulam beams pre-stressed with pultruded GRP”. *Original Research Article. Computers & Structures*. 2005, 83(28-30):2476-2487

[7] Anshari B, Guan Z W, Kitamori A. et al. “Structural behaviour of glued laminated timber beams pre-stressed by compressed wood”. *Construction and Building Materials*,2011,29:24-32

[8] Vincenzo D L C, Marano C. “Prestressed glulam timbers reinforced with steel bars”. *Construction and Building Materials*,2012,30:206-217

[9] McConnell E. McPolin D. Taylor S.“Post-tensioning of glulam timber with steel tendons”. *Construction and Building Materials*,2014,73:426-433

[10] Guo N, Zuo H L, Zhao J N. “Prestressed agglutination bamboo, significance and the preliminary research and popularization of the wooden beams”. *Journal of building materials decoration*. 2012 (6): 54-56.

[11] Zhou H Z, Zhu E C, Zhou G C. "Curved beam glulam horizontal grain stress and cracking study". *Journal of building materials*, 2013 (5): 913-918.
[12] Chen X. "The study of the temperature and humidity stress of the glulam beams". *Heilongjiang province Harbin industrial university*, 2008.
[13] Wang Q. "Larch glulam beams mechanics performance test research". *Hunan: central south forestry university of science and technology*, 2013.
[14] Ma J. "The bearing capacity of prestressed product becomes useful research". *Beijing: Beijing Jiaotong University*, 2011