GLULAM BEAM REINFORCED SHORT-TERM FLEXURAL BEHAVIOR OF PRESTRESSED WITH CURVED TENDONS

Sridhar.N[1]& P.Shifana[2] & Dr.P.Paramaguru [3]

[1] PG Scholar, Department of Structural Engineering (FT), Ponnaiyah Ramajayam Institute of Science and Technology, Tamilnadu, India

(e-mail: ptnsridhar@gmail.com)

[2] Assistant Professor, Department of Civil Engineering, Ponnaiyah Ramajayam Institute of Science and Technology, ECR-Chennai, Tamilnadu, India

ABSTRACT

The short-term flexural behavior of prestressed glulam beams reinforced with curved tendons was investigated via four-point bending of 12 glulam beams. These beams were equally divided into four groups of three identical specimens: one group of unreinforced beams, one group of prestressed beams reinforced with straight tendons, and two groups of prestressed beams reinforced with parabolic tendons. For the last two groups, the initial prestress force was applied in two levels. The results revealed that, in contrast to the failure mode of the unreinforced beams, the failure mode of the prestressed beams changed from brittle failure to ductile failure. The flexural capacity and the flexural stiffness of the prestressed glulam beams reinforced with straight tendons increased by 56.9% and 14.9%, respectively, compared with that of the unreinforced beams; for prestressed beams reinforced with parabolic tendons, the capacity and the stiffness increased by 54.4%–75.5% and 14.2%–15.5%, respectively. Based on the experimental results, a theoretical model for predicting the flexural stiffness and capacity of prestressed glulam beams was proposed.

Keywords: Glulam beams; Prestressed; Parabolic tendons; Short-term flexural behavior; Experimental study

INTRODUCTION

Pretensioning procedure exists extensively used for beams and slabs in tangible arrangement remaining to their potential to resourcefully reimburse for the condensed tensile strength of concrete through precompression. The upgrading in strength achieve by pretensioning enables the use of thinner sections and provides an resourceful solution for controlling substance splitting and avoiding excessive deflections. For materials that have a tensile strength similar to or superior than their compressive strength, such as timber or steel, pretensioning offers significantly summary advantages. Moreover, timber has problems with its long-term performance; its inherent creep deflection can diminish the pretensioning effects over time, lessening its capability. Therefore, the pretensioning practice is hardly increasingly used for timber.

The reinforcement systems that have been used can be divided in two basic typologies: passive and active reinforcements. Passive reinforcement is made of metallic elements or fiber-reinforced polymers (FRPs) that are glued to the timber with structural adhesives. Active reinforcement can be complete with unbonded tendons or with bonded tendons that are glued to the timber with adhesive. Active reinforcement has been used to both reinforce frame connections and improve the behavior of beams

Reinforcement of structural wood products has been studied for many decades. In the previously stages of the examiner, the center was principally on using metallic reinforcement, including steel bars, pre-stressed stranded cables and bonded steel and aluminum plates. Recently, research on glued laminated timber (Glulam) beams reinforced with fiber-reinforced polymers (FRP) has been increased significantly, due to its light weight, high stiffness and the strength of the FRP materials. The type of reinforcement mentioned above covers almost the whole bottom surface of the beam. However, applications of strengthening the beam using CFRP, GFRP and other materials have not been widely used due to various limitations. Problems that the existing strengthening techniques are facing compatibility, de-bonding, stress relaxation and complex procedures.

Glued laminated timber (glulam), an engineered timber product, has been used in Europe since the end of the nineteenth century. Glulam beams still are widely used due to their excellent strength to- weight ratio, as well as their shape and size flexibility. However, these beams are susceptible to bending failures, stemming mainly from knots, cross grains, or other defects in the tensile zone of the timber. The strength of glulam, especially the compressive strength, therefore can be only partly utilized. Moreover, many other problems, such as large deformation, are encountered with use of these beams. Since the twentieth century, scholars have used metallic materials and fiber-reinforced polymer (FRP) to enhance glulam beams. Tensile zone reinforcement of the beams, in which the mechanical properties of a timber beam are improved by prestressing the tensile zone of the beam with unbonded high-strength strands, is presented.

At present, in the field of timber structures, studies of prestressed glulam beams focused mainly on straight prestressed tendons. Previous studies established that the shape of the parabolic prestressed tendons usually is consistent with the common bending diagram of the flexural members. In prestressed continuous beams and frame beams, parabolic prestressed tendons are more applicable than straight tendons, owing to their adaptability to multiple alternating positive and negative bending moments along the member lengths. Therefore, the application of parabolic prestressed tendons is an important research topic for popularizing prestressed reinforced glulam beams, and is important from both scientific and engineering points of view.

RELATED WORKS

In [1] Huifeng Yang, Weidong Lu, Weiqing Liu, Shijun Zhu, Qifan Geng et al presents an investigational analysis curriculum and theoretical examination which examines the reinforcing in flexure of glued laminated timber beams using fiber reinforced polymer and steel materials. Sequences of four-point bending tests were conducted till malfunction on both unreinforced and reinforced Douglas fir glulam beams in a simply-supported scheme. The focus of this research was to appraise the effects of reinforcing materials, reinforcement ratio and agreement on the flexural behavior. Investigation result illustrate that the flexural capability, flexural worldwide rigidity and timber tensile strain at breakdown were each enhanced significantly for reinforced timber beams when compared to the unreinforced control beams, in which the average improvement reached 56.3%, 27.5% and 49.4%, correspondingly. On the bases of the experimental consequences, a theoretical model was planned to calculate the flexural capacity and flexural stiffness of the reinforced timber beams. Most of the differences between theoretical and experimental results for both flexural capacity and flexural stiffness were within 10.0%, which showed an elevated accuracy of the proposed model. Consequently parametric investigations, which embrace the axial stiffness relation of reinforcement to timber, the comparative location of tensile reinforcement, and the strength ratio of reinforced timber between flexural tension and compression, was undertaken to investigate the effects of the influential factors for both flexural capacity and flexural stiffness.

In [2] Wouter van Beerschoten, Gabriele Granello, Alessandro Palermo, and David Carradine et al presents Post-tensioning can be used to commence a precamber in timber beams, comparable to concrete applications, resulting in decreased deflections and, hence, optimizing material usage. However, the amount of tendon post-tensioning or eccentricity can be significantly superior than in concrete application since of the higher tensile strength of timber. Therefore, the secondary services can increase the ultimate capacity of the post-tensioned member. To inspect these potential benefits, experimental testing to breakdown was carried out on four full-scale coated veneer lumber beam specimens, three of which were post-tensioned with unbonded tendons. A three-dimensional finite-element-model approach was proposed to reproduce the behavior of the specimens. An investigative representation was also urbanized to calculate the static rejoinder of the beams for a preliminary intend by hand. Both modeling approaches, i.e., arithmetical and analytical, provided good results compared with the untried data. Results indicated that post-tensioning can augment the load-carrying capacity of timber beams at the ultimate limit state up to 56%, especially if draped tendon profiles are used and the top flange of the beam is appropriately dimensioned to resist mutual compression stresses from post-tensioning and bending moments

In [3] Gary M. Raftery, Peter D. Rodd et al presents The profitable expansion of composite reinforced timber beams contrived using low-grade covered wood would be significantly improved if the same adhesive was allowable to be used together at the wood–wood bond interfaces as well as the FRP plate–wood bond boundary. This dissertation illustrate a programme of tests undertake to evaluate the structural performance of low-grade glued laminated timber reinforced with glass fibre reinforced plate bonded using the predictable wood laminating adhesive, phenol resorcinol formaldehyde. The employ of a realistic reinforcement percentage of 1.86% of the cross-sectional area resulted in a sensible stiffness enhancement of 18% and substantial improvements in the decisive instant capacity of 31%. Strain profiles established that utilization of the compressive performance of the timber was improved in the reinforced beams. Most importantly, at no period during testing of any of the reinforced beams was the eminence of the FRP–wood bond compromised. The consequences from a nonlinear finite element model showed outstanding agreement with the experimentally determined ductile load–deflection behavior of the reinforced beams. Furthermore, satisfactory comparisons are obtained between the predicted and measured failure loads and strain profile behavior. Slip at the FRP–wood boundary, bond using a wood laminating epoxy resin, was measured insignificant

In [4] Vincenzo De Luca, Cosimo Marano et al presents a succession of four-point bending tests that were accomplish to failure on unreinforced, reinforced and reinforced-prestressed glue plastic-coated timber beams with steel-bars in a simply supported scheme to decide their flexural behavior. The cross sectional ratio flanked by the steel and the wood was 0.82%. To append to the stage of reinforcement, a variety of reinforced beams were prestressed by be relevant a reasonable force to the lower bar. The experimental and numerical data provide the load–deflection, load–strain associations and strain profiles of the tested beams. The consequences of the reinforced beams showed that the unconscious strength, the load-carrying ability and the stiffness for together the easy and prestressed beams were superior compared to the unreinforced beams. For the merely reinforced beams, the stiffness bigger by 25.9%, the ultimate load increased by 48.1% and the ductility enlarged by 43.8%. For the reinforced and prestressed beams, the stiffness improved by 37.9%, the ultimate load amplified by 40.2%, and the ductility augmented by 79.1%.

In [5] Marinella Fossetti, Maurizio Papia, Giovanni Minafò, et al presents Glued plastic-coated timber is extensively used as a creation substance to prepare up lightweight and enormous distance structures. The essential standard of this fabric consists in bonding jointly a numeral of layers of dimensioned timber with structural adhesives, in order to supplement strength and stiffness of attach, and permit making up sustainable structures with immense visual impact. Topical relevance demonstrates the effectiveness of fiber-reinforced polymer composites in ornamental the structural presentation of glulam beams, with particular orientation on their flexural and shear strength. In fact FRP reinforcements might be used to strengthen existing structures or to reduce the dimensions of novel structures to be designed. Allowing for the significance of the latter application, the present employment shows the consequences of four-point bending tests on fifteen small level glulam specimens, reinforced with glass or carbon cords, unreliable the kind of adhesive. Eight further large-scale beams were tested in order to appraise the position of the scale effect. Finally, an analytical model was urbanized, able to predict the behavior of multilayer heterogeneous wood sections and which takes into description the outcome of the reinforcements

Glulam beams and their reinforcement

In Glulam, the members consist of lengths of timber of small cross-section, called laminations. These are bonded mutually beneath heaviness using structural adhesives. The grain of the laminations runs parallel to the longitudinal axis, distinguishing Glulam from forms of plywood, for example. Glulam beams can be horizontally or vertically laminated. It also illustrates the fact that curved members can be more easily produced by the horizontal method. Because of this, and also due to the fact that horizontal laminating disperses defects more efficiently, allowing higher design stresses, the horizontal method is far more common.

Glulam timber

Glulam timber is made of wood laminates glued together to form a specific piece of wood for a specific load. The attention to employ this technology is to diminish creation variability and make it less affected by natural growth characteristics like knots. In addition, the Glulam knowledge offers approximately unlimited possibilities of shape and design for construction, and is widely used for load bearing structures in houses, warehouses, pedestrian bridges, etc. Its application on highly loaded structures are still limited due to its lower bending strength and stiffness, high costs, durability and maintenance drawbacks compared to concrete and steel structures. However, wood as a natural material will become a more competitive building material in the future due to its environmentally friendly and aesthetic characteristics, also more advanced reinforcing techniques.

Materials and Methods

Twelve glulam beams (four groups) were designed in this experiment: one group of three unreinforced control glulam beams (C), one group of three prestressed glulam beams reinforced with straight strands (PS65), and two groups of six prestressed glulam beams reinforced with parabolic strands (PP65 and PP130). The initial prestress forces of 65 and 130 kN, applied through the tendon, were 27.3% and 54.6%, respectively, of the nominal yield stress. The maximum compressive stresses produced by the initial prestress forces in the midspan of the beam were 7.82 and 15.64 MPa (21.4% and 42.8% of the compressive strength), respectively.

Flexural reinforcement

One of the methods to increase the load carrying capacity or bending capacity of Glulam beams is to reinforce them locally or globally. Reinforced Glulam beams cost fewer since the employ of reinforcement will diminish necessitate of a top evaluation laminate on the extreme tension face (i.e. a lower grade material can be used); moreover the volume of wood is reduced. Also, reinforced Glulam beams have subordinate product inconsistency, they are not unnatural by natural growth characteristics, and the manufacture of reinforcement is consistent and controlled.

Materials

The lamina employed in the experiment was fabricated, without finger joints, from Douglas fir. This lamina was machine graded as ME12, and the grade of the glulam was TCT30 after layup, in accordance with the technical code of glued laminated timber structures. The material property testing was conducted in the laboratory of the manufacturer. Table 2 lists the average and standard deviation of the physical and mechanical properties determined through the material property testing of the glulam. The density and moisture content were obtained from the test results of six specimens (20 × 20 × 20 mm); the tensile strength was taken from 15 bending specimens (50 × 125 × 2,400 mm); and the compressive strength and modulus of elasticity were obtained from compression tests performed on 15 short columns (75 × 75 × 400 mm).

Design of Anchorage

Because the length of the experimental beams was only 4 m, the use of a conventional wedge anchorage would have resulted in an excessively large anchorage loss value. Thus, a new type of single hole anchorage (composed of a wedge anchorage, an outer nut, and a cover plate) was designed. The procedure of prestressing involved two steps. The tendons were pretightened in the first step. Without installation of the support feet, the jack pretightened the tendon directly against the wedge, thereby reducing the gap between the wedge and the anchor plate. Consequently the prestress anchorage loss was reduced. The tendons were prestressed in the second step. When the support feet were installed, these tendons were stretched by the jack against the support feet. When the prestressing force reached the prestressing control force, the outer nut was tightened to complete the anchoring. The anchorage consisted of two main features: 1. After tensioning of the strand was finished, the outer nut was tightened to ensure that this nut and the specimen could bear the force directly. This reduced the retraction deformation value of the anchor, thereby reducing the anchorage loss. 2. After tensioning was completed, the cover plate on the single hole anchor effectively prevented the loosening of the wedge (caused by various factors), thereby ensuring the effective clamping of the wedge to the strand.

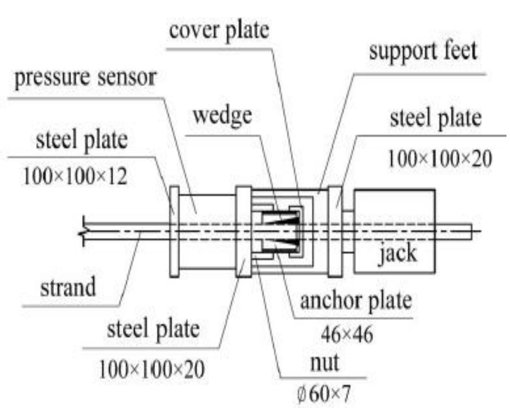

Fig. 2. Structural form of the anchorage

Manufacturing Process of Slotting

Curved slots were fabricated via the following manufacturing process: (1) prefabricating the eight laminates; (2) gluing from the second to the seventh layers for the first time; (3) splitting the glued timber laminates in the middle along the direction of the beam height; (4) slotting the left and right grooves, respectively; (5) gluing the slotted laminates again, together with the top and bottom laminates, and then curing; and (6) processing and molding. To facilitate comparison of the experimental results, the unreinforced glulam beams were prepared using the same manufacturing process

Glue Injection Process

For the bonded internal prestressed glulam beams, effective coordination of prestressed tendons and the beams depended on the compactness of the glue in the slots used for the bonding of these members. Therefore, the glue injection process was critical. After tensioning the strands, a high-pressure grouting machine was used to inject glue into the injection hole (located at the side surface in the mid-span of the beam) at an injection rate of 0.5 L=min. The maximum output pressure of the grouting machine was 25 MPa, and the injection process lasted 30–40 min for each specimen

Procedure

Because the initial setting time of the glue was only 60–90 min, excessive stirring at a single time was avoided to prevent the glue from solidifying in the machine and affecting the subsequent injection process. Poor fluidity of the glue prevented prolonged injection. The injection process was stopped for ~30 s after every 10 s of glue injection; the glue was injected again after being spread in the reserved slot. The pressure gauge reading was observed to prevent the injection pressure in the tube from becoming too great and bursting the tube. In the experiment, the pressure gauge reading was limited to 20 MPa (80% of the maximum output pressure of the grouting machine). If the glue flowed outside the anchorage pads in each end of the glulam beams, and continued injection became difficult and the pressure gauge reading increased significantly, the entire glue injection process was stopped. After glue injection, the grouting machine was cleaned with industrial alcohol, and engine oil was used to maintain the machine in a timely manner.

Layout

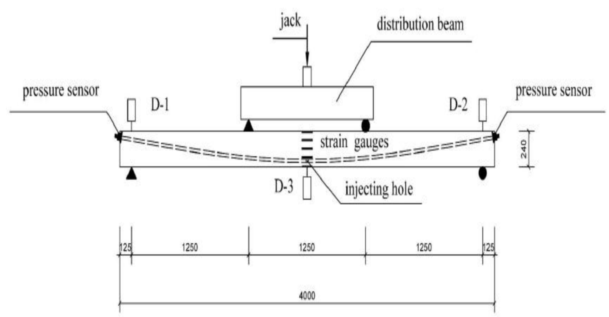

Fig Layout process

Fig Loading device

The load on a glulam beam was applied to the two trisector points by the distribution beam. A cushion block was placed in the concentrated force point to prevent the specimen from being damaged by local pressure. The loading device is shown in Fig. The experimental measurements included the strain, displacement, load, and internal force of the prestressing tendon. The strain was measured using gauges arranged along the height direction of the beam at midspan. These gauges were spaced 60 mm apart and were affixed parallel to the wood grain symmetrically on both sides of the beam. The displacement was measured using displacement gauges placed at both ends of a beam and the midspan, with the testing load measured automatically by the integrated load cell. Furthermore, the internal force of the prestressing tendon was measured using the pressure sensor

CONCLUSION

The curved slot manufacturing method and gluing process were effective. This was evidenced by a lack of damage along the slots during testing of the produced glulam beams. The glue injection process was quite effective and strong strand-laminate bonds were realized. The prestress loss of prestressed beams reinforced with parabolic strands was 59% larger than that of prestressed beams reinforced with straight strands. The equations describing the prestress friction loss of concrete beams can be used in the calculation of timber beams with different parameter values. The stiffness of the beams improved significantly because of the reinforcement, but improved only slightly with increasing prestressing force. In contrast to that of the unreinforced glulam beams, the failure mode of the prestressed glulam beams changed from brittle failure to ductile failure. Severe folding occurred in the compressive zone prior to failure. Under the same conditions, the ultimate bearing capacity of the PP65 beam was slightly lower than that of the PS65 beam. The prestressing tendon line type had only a small effect on the ultimate bearing capacity of the glulam beams. The flexural stiffness of prestressed glulam beams can be accurately calculated using the composite section method. Similarly, the flexural capacity can be accurately predicted via the method described

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