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THE FINITE ELEMENT MODELLING OF GLULAM TROPICAL TIMBER BEAM IN BENDING

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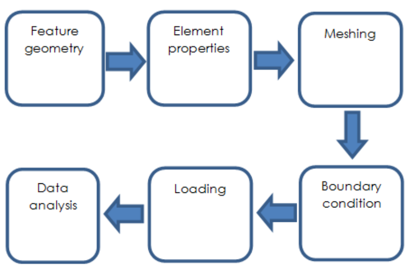
Graphical abstract



Abstract

A full scale bending testing of glued laminated (glulam) timber beam can be costly and time consuming. Therefore, computer modeling is an economical and an efficient tool to achieve the result within the acceptable accuracy. Among other modeling techniques, the finite element modeling (FEM) is widely used for its reliability to simulate and to verify the behaviour of structural elements exactly in the same way the elements perform in the experimental test. Further results of different structural element dimensions or materials can be predicted by modifying the input parameters that are of interest to the study. This study presents the verification of FEM with experimental bending test results on simply supported glulam timber beams made of Keruing and Resak species. The two dimensional (2D) FEM with LUSAS 14.3 software was used. The verification showed an acceptable agreement between the FEM and the experimental results.

Keywords: FEM, keruing, resak, tropical timber, glulam, lusas, beam, bending, four-point test

1.0 INTRODUCTION

Timber is an orthotropic material which has different material properties in the three perpendicular axes, i.e. axial, radial and tangential. In particular the mechanical properties in timber material such as strength and stiffness along the axial or fibre direction are typically 10 -15 times higher than in radial direction [10]. In common practice the determinations of timber material properties are based on the average of a large number of small clear timber specimens. The uses of clear timber are to eliminate any reduction in timber strength due to natural defects such as knots, checks and wanes [1]. In the structural applications the timber in structural size is used and therefore the material and mechanical properties of small clear timber specimen are unable to provide accurate values due to the huge difference in biological materials [2]. However the experimental tests of timber elements in the structural size are costly and time consuming. The use of computer finite element modelling (FEM) method is able to partially reduce the cost and time. Another advantage of FEM is that extensive investigation on the stress distribution in the timber can be carried out. The reliability of the FEM is crucial to determine its accuracy to simulate the behaviour of timber under any types of loading. This requires the experimental test verification.

For the beam elements parallel to x-axis, the loads are normally applied in vertical xy plane [2] and the beam is restrained to move laterally by flooring system it supports. Therefore, the effect of bending in xz and yz planes are very small relative to the bending in xy plane and can be ignored in the structural analysis [2], [9] provided the stress is considered uniform along the thickness of timber [9]. Thus many researchers modelled the timber beams in two-dimensional modelling using plane stress concept since the deformations on yz and xz planes are not their interests [9] as shown in Figure 1.

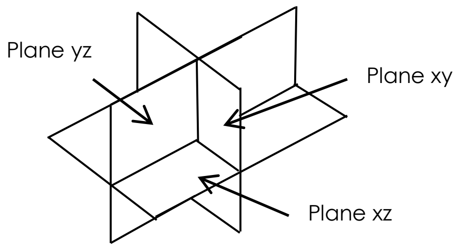


Figure 1 Orthotropic planes

Keruing (*Dipterocarpus spp*) is a tropical medium hardwood with the average density and modulus of elasticity of 830kg/m^3 and 9100N/mm^2, respectively. Resak (*Cotylelobium spp* and *Vatica spp*) is categorised as tropical heavy hardwood with the average density and modulus of elasticity of 980kg/m^3 and 11000N/mm^2, respectively [1]. In MS544 Part 2 2001, Timber keruing is in strength group (SG) 5, and Resak is in strength group (SG) 4 out of 7 strength groups. The larger number indicates the lower strength of timber [1].

2.0 FINITE ELEMENT MODELLING

This study verified the FEM with the experimental results of glulam timber beams in structural size. The experimental tests as detailed in Figure 3 [4] were based on BS EN 408 2010 4-point bending test procedures. The loading rate was set to achieve the maximum load within 300s [14].

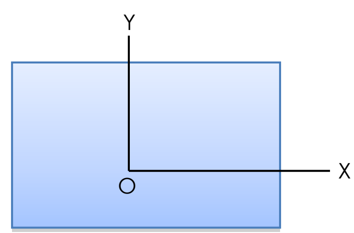


Figure 2 Plane stress element

Plane stress element as shown in Figure 2 has four mechanical properties in xy plane, i.e. moduli of elasticity, E_x and E_y in x and y axes, respectively, shear modulus in xy plane, G_{xy} and the Poisson's ratio, ν. These properties are very crucial to determine the reliability of the FEM. There have been many studies in the previous years to establish the relationship among material properties which resulted different values in different studies as shown in Table 1 [6], [10-12]. The variations of Poisson's ratio are within the acceptable margin [13].

Table 1 The relationship among timber mechanical properties

Mechanical properties	Values
$\frac{E_x}{E_y}$	12.5, 30
$\frac{G_{xy}}{E_x}$	$\frac{1}{26} \to \frac{1}{7}$
ν_{zy}	0.35
$\nu_{xy} = \nu_{xz}$	0.015
$\frac{\nu_{xy}}{E_x} = \frac{\nu_{yx}}{E_y}$	

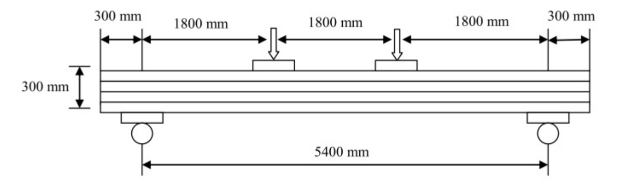


Figure 3 Details of experimental test setup [4]

In the FEM, the glulam timber beams were modelled to simulate the behaviour in the experimental. The material and mechanical properties of the glulam timber beams were in accordance to MS544 Part 2 2001. Because of the symmetrical arrangement in load application, only half of the timber span was modelled [11]. Each lamella in the glulam timber beam was modelled as separate entity to allow the use of individual material and mechanical properties [6], [11. The boundary conditions were applied to the end support and at the midspan. The end support and the midspan were restricted in y and x directions, respectively. The FEM of glulam timber beam is shown in Figure 4. The timber grain was assumed to be parallel to the beam longitudinal axis to allow the two-dimensional (2D) FEM. This was reported adequate to predict the bending strength of the timber beam [11].

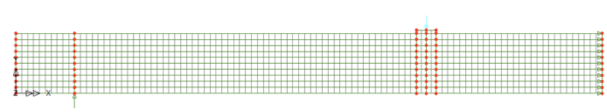


Figure 4 The FEM of glulam timber beam

In the 4-point bending test according to BS EN 408 2010, the glulam timber beam shall be restrained laterally to prevent buckling. Therefore the 2D plane stress element is preferred due to the lateral buckling effect is not significant. The meshing using 4-node quadrilateral, QPM4M elements with two-translational in-plane degree of freedom per node was used to model the plane stress element in the FEM. The element size of 30 and 21 with aspect ratio of 1 was used for glulam timber beam and load bearing pad, respectively. These element sizes have showed better accuracy in the analysis. Since the glulam timber beams exhibited elastic-plastic behaviour in the experimental tests [4], the non-linearity of timber material and analysis was used in the FEM. The orthotropic Hill yield elastic-plastic material is the generalised version of the Von-Mises plastic yield and was chosen over the Hoffman plastic yield for better convergence [3], [5-11]. The values of timber plastic strain hardening and the initial yield stress in compression were according to the simplified stress-strain behaviour as shown in Figure 5 [15].

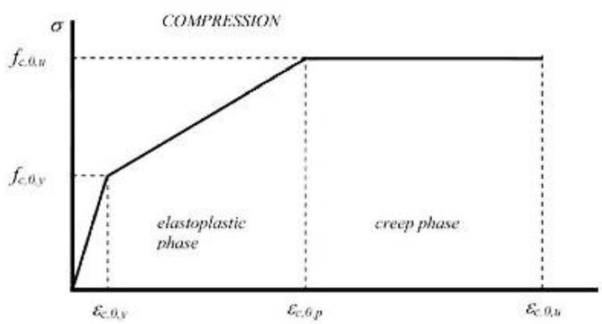


Figure 5 Simplified stress-strain behaviour of timber [15]

The non-linear analysis in LUSAS 14.3 was achieved using the automatic incremental load to failure within 300s [14] which yielded to 150mm in total vertical displacement. The initial load in elastic range of 15kN was used and has been reported adequate [5], [14] with incremental load factor of 0.5 and the maximum change in load of 0.2.

The terminating strategy was chosen to allow the analysis stopped when the vertical displacement at the mid span reached 150mm. This was achieved with the maximum load factor set to 2000. The convergence of solution at each load increment, the out of balance forces was set to 0.1% of the reactions and the iterative change in displacements was set to 1% of the displacements for the incremental load [16]. The details of values used in the FEM are shown in Table 2.

Table 2 The timber characteristics used in FEM

Timber Characteristic	Keruing	Resak
Element type	Plane stress	
Element shape	Quadrilateral	
Interpolation order	Linear	
Material	Orthotropic and non-linear	
Thickness	150mm	
Angle of orthotropic	0° (timber grain is parallel to the axial direction)	
Modulus of elasticity (average)	E_x = 9100N/mm^2 E_y = 303N/mm^2	E_x=11000N/mm^2 E_y= 367N/mm^2
Poisson's ratio (axial direction)	0.02	
Shear modulus	569N/mm^2	688N/mm^2
Density	830kg/m^3	980kg/m^3

3.0 RESULTS AND DISCUSSION

Figure 6 shows the comparison between the results from the experimental test and finite element analysis for glulam timber of resak species. The results showed good agreement although the finite element analysis showed smooth curve with slightly lower ultimate load at longer displacement relative to the experimental results. This has been expected because the FEM of glulam timber beam was ideal which neglected the defects in real timber and the analysis assumed the plane section remains plane. The plastic range in finite element analysis was wider and did not show sudden failure. The main reason is that in computer modelling, the incremental load can be controlled easily to the smallest load factor thus exhibited more ductile behaviour. The ultimate load in experimental result was 117.4kN, slightly higher than in finite element analysis of 109kN with difference in percentage of 7.2%. This finding proved that FEM with separate lamella entity and ignoring the glue line was able to predict the ultimate load of glulam timber beam well [6], [11].

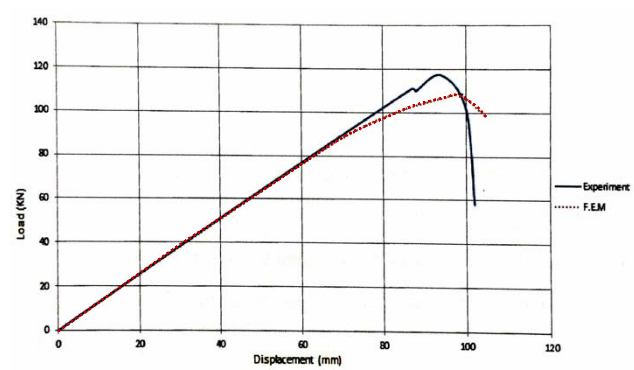


Figure 6 Load - displacement curve for Resak species

Figure 7 shows the comparison between the results from the experimental test and finite element analysis for glulam timber of keruing species. The results did not show a good agreement although the ultimate load in finite element analysis was 107.2kN relative to the experimental test was 116.3kN differed in percentage of 7.8%. The finite element analysis showed slightly lower ultimate load with smooth curve until failure. In the experimental test, the curve showed sudden decreased but increased gradually until failure. This is because the finite element analysis was carried out in ideal case without defects and lateral buckling. Block diagram in Figure 8 show the system process of glulam timber of keruing species.

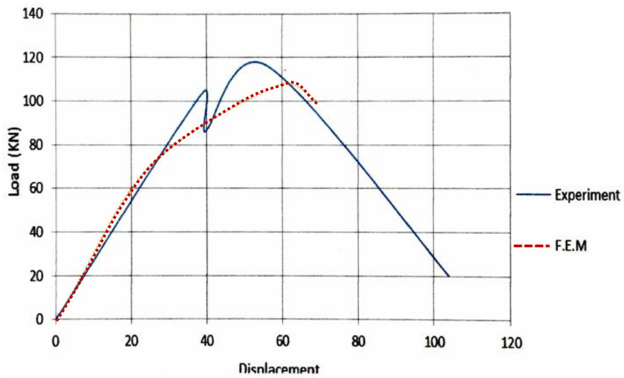


Figure 7 Load - displacement curve for Keruing

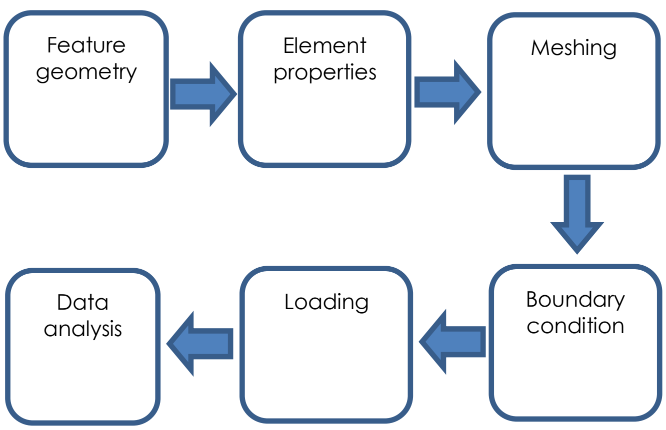


Figure 8 Block diagram of the processes of the system

4.0 CONCLUSION

The FEM using LUSAS 14.3 was used to verify the finite element analysis with the experimental results. The following results were obtained:

- The finite element analysis showed good agreement with smooth curves and wider plastic range. This is because the FEM was based on clear timber with excellent control of incremental load.
- The ultimate loads in finite element analysis were slightly lower. This suggested the glulam timber beam plane section in finite element analysis remains plane.
- Comparing the ultimate load in finite element analysis and experimental test showed slight difference in percentage of less than 8%. This proves that the FEM is able to predict the glulam timber beam well.

Acknowledgement

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