ULTIMATE STRENGTH OF GLUED-LAMINATED TIMBER BEAM

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To my beloved wife, children and parents.

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ABSTRACT

Bending strength of timber beam has been the subject of interest ever since timber was used for structural purpose. Many studies have dealt with the strength prediction of timber beams in which compression and tension properties of timber were being correlated to their behaviour in bending. Issues relating to the bending strength models, stress-strain distribution, movement of neutral axis, modulus of elasticity, the proportional limit stress, the extreme fibre-tension stress, and the size effects of timber beams, put forward by many researchers, were focused on softwood timber of western countries. None thus far, has been verified for the hardwood species of local origin. This study present the verification of the ultimate bending strength models on local Dark Red Meranti (DRM) timber. The applicability of strength models proposed by Zakic, Bazan, and Buchanan on solid and glued-laminated (glulam) DRM beams are examined. Some of the findings prompted by previous researchers are observed in this study. The proposed modifications to the Bazan's and Buchanan's model have significantly improved the strength prediction of DRM beams.

ABSTRAK

Kekuatan lentur rasuk kayu telah menjadi subjek yang menarik semenjak kayu digunakan sebagai bahan kejuruteraan struktur. Banyak kajian telah dilakukan ke atas ramalan kekuatan rasuk kayu yang mana sifat mampatan dan tegangan kayu dikaitkan dengan kekuatan lentur. Isu-isu yang berkaitan dengan model kekuatan lentur, agihan tegasan-terikan, pergerakan paksi neutral, modulus anjal, tegasan had berkadaran, tegasan gentian terluar, dan kesan saiz rasuk kayu, yang diperkatakan oleh ramai penyelidik, adalah tertumpu kepada kayu lembut dari negara-negara barat. Setakat ini, ianya belum disahkan ke atas spesis kayu keras tempatan. Kajian ini membentangkan pengesahan model-model kekuatan lentur muktamad ke atas kayu Meranti Merah Tua (DRM) tempatan. Keboleh-gunaan model-model yang dicadangkan oleh Zakic, Bazan dan Buchanan ke atas rasuk kayu pejal dan kayu lapis berglu (glulam) DRM diuji. Sebahagian dari penemuan-penemuan yang diperkatatakan oleh penyelidik-penyelidik sebelum ini juga telah diperhatikan dalam kajian ini. Cadangan beberapa perubahan ke atas model-model Bazan dan Buchanan telah dapat memperbaiki ramalan kekuatan rasuk DRM.

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NOTATION

A	=	a constant.
a	=	distance between two loads placed $a/2$ each side of mid-span of the beam
b	=	width of cross-section.
C	=	force in the compression stress block.
c	=	Coefficient to account for the reduced stress at the extreme compression fibre ($c<1$).
d	=	depth of beam cross-section.
E	=	modulus of elasticity.
F_{cu}	=	ultimate compressive strength of the beam material as obtained from axial compression test
F_{tu}	=	ultimate tensile strength of the beam material as obtained from axial tension test
F_t	=	maximum tensile stress in the beam at failure ($F_t < F_{tu}$)
f_t	=	tensile stress in the extreme fibre in the elastic range ($f_t < F_{tu}$)
k	=	shape parameter as used in Buchanan study.
L	=	span of the beam.
M	=	bending moment.
M_u	=	ultimate bending moment capacity of the beam.
M_u'	=	corrected ultimate moment capacity of the beam.
N	=	ratio of axial tension to compression strength of the beam at ultimate load, $\frac{F_{tu}}{F_{cu}} > 1$
n	=	ratio of extreme fibre-tension stress to axial compression strength, $\frac{f_t}{F_{cu}} > 1$
[PL]	=	proportional limit load as measured in the load-deflection curve.
[UL]	=	ultimate limit load as measured in the load-deflection curve.
S_s	=	depth effect factor.
S_L	=	load configuration effect factor.
S	=	combined size effect and load configuration effect factor.
T	=	force in tension stress block.
α	=	position factor of the maximum compressive stress measured from the top of the beam.
β	=	position factor of the maximum compressive stress measured from the neutral axis.
γ	=	neutral axis factor measured from the bottom of the beam.
ξ	=	neutral axis factor measured from the top of the beam.
ε_c	=	strain at the extreme compression fibre.
ε_t	=	strain at the extreme tension fibre.
ε_y	=	yield strain in compression.

CHAPTER I

INTRODUCTION

1.1 GENERAL

The emergence of glued-laminated (glulam) material in timber structure has given a significant impact in the timber construction industry. This is a high strength to weight ratio materials. It can be virtually sized at any curved or straight shapes, spanned at a much higher length, designed at various strength requirements while maintaining the natural aesthetic appearance, and reducing the timber waste This engineered material can now pose a greater challenge to concrete, steel and other composite materials in the major structural applications of the construction industry.

The British Standards [17] define glulam as a member made of four or more separate laminations of timber The members are arranged parallel to the longitudinal axis with their grains approximately parallel and glued together to form a member that functions as a single structural unit. The American Standards [1,4] however do not set any minimum laminations such that glulam can be as minimum as two laminations.

Glulam construction has a long existence in Europe since early 1826 particularly in Britain, France, Germany, Sweden, and Switzerland followed by the United States in 1934 and later by other western countries [30,31]. Since then, many research findings have been published relating to this industry In Malaysia however, this industry has not been commercially developed [38]. The only presence of glulam applications in the country are the footbridge and the mosque at Forest Research Institute Malaysia (FRIM) [40] while the remaining are more towards the non structural applications of laminated wood such as joinery works, laminated doors and window frames. At present very little research works on glulam materials are conducted locally.

1.2 BACKGROUND AND RATIONAL

Research on glulam using selected Malaysian timber species started at FRIM in the late 1980s during the Fifth Malaysia Plan (1980-1990) [39]. The research works however was very basic, considerably slow, and not aggressive. This was due to the lack of expertise and researchers within the research bodies and technical institutions to work on the research.

Glulam can offer a good application in the timber and construction industry of the nation. It maximizes the timber usage and provides more advantages compared with the solid timber. Despite of the advantages, the material has not been able to emerge in the building industry for many reasons. Initially, there is no production capability of glulam or no demand for it. Secondly, there is no confidence and technical know-how among the designers, engineers, and builders on the material which reflects the lack of research on the local timber species. The major stumbling block is that timber, in the first place, receives a poor public perception in the construction industry. Timber structures are normally considered as temporary or secondary structures, and that they are likely to burn. The development of timber houses or buildings in the construction industry are hampered by the high insurance premium imposed on them. The growth of these houses are therefore limited to the villages where no insurance is involved.

At present, there is no concerted efforts within the government and private bodies to expedite the research where reliable design standards can be established based on extensive and diversified local research works. There is also no initiative to establish an exemplary plant in promoting the design and usage of glulam to the local construction industry.

Numerous studies and publications [24,25,40,46,47,49] suggest that local Red Meranti timber species are the best materials for glulam. Apart from having a suitable property for being a glulam material, the species are quite abundant. In 1990, out of the total products of 12,819,375.19 m^3 sawn log in the Peninsular, 828,861.10 m^3 or 6.5 % is of Red Meranti which is the third largest production after Keruing and rubber wood [7], and widely distributed throughout Peninsular Malaysia [25].

However, further developments of glulam using Red Meranti are needed. The study on the properties and mechanical behaviour of glulam focuses on the strength, defects, gluability, jointing and other related properties. A good design standard can only be established if all the behaviour and properties are well understood.

1.3 RESEARCH PROBLEMS

Bending strength of timber beam has been a subject of interest ever since timber is being used for structural purpose. Numerous studies dealt with the strength prediction of timber beams where direct compression and tensile properties of timber are being correlated to that of behaviour in bending [21,37,50]. The problem associated to the strength and behaviour predictions are quite complex since it depends on three main factors namely the ratio of tension to compression strength of the material, the non linear ductile behaviour in the compression zone, and the size dependent in brittle fracture in tension zone [21].

However, almost all studies are related to the softwoods of western countries. Similar studies on local timber of hardwood types are very limited. In this country thus far, there is no systematic study to predict the ultimate strength of timber beams in particular of glulam type. Furthermore, the effect of lamination on beam behaviour and strength is in question, that is whether this effect provides a significant difference in performance between glulam and solid beams Thus, it is of current interest to attempt and verify the reliability of the existing research findings when they are applied to both solid and glulam beams of local origin.

1.4 RESEARCH OBJECTIVES

Among the objectives of this study is to predict the ultimate strength of glulam beams of Dark Red Meranti (DRM) timber. Basic mathematical model introduced by Bazan is used [10]. Predictions based on other strength models are also presented. The study will focus on the theoretical assumptions and observations made by Zakic, Bazan, and Buchanan as to whether the same would be true for the local timber A comparison between the strength performance of glulam to that of solid beams is also presented.

1.5 RESEARCH SCOPE

Twenty-three beams of various sizes are tested to failure in bending. Eight of them are solid beams while the rest are glulams. Eight glulam beams are considered as industrial sample since they are fabricated by Sindora Bhd. while the remaining are fabricated in the laboratory. Compression and tension samples are taken out from each beam for the determination of its uniaxial properties. These values are used in the application of formula in predicting the beam's bending strength. This research will look into the compatibility of the formula developed by Bazan [50,10,22]. The solid and glulam beams will be compared to find the differences in the predicted values The research focuses on the strength formulation and proposes an improvement to the existing models.

1.6 THESIS ORGANIZATION

Chapter II presents the developments of bending strength theory of timber beams. It discuses the theoretical aspects of the development and later, it focuses on a single model for the further verification of the theory with respect to DRM timber species.

Chapter III discusses the fabrication process of glulam beams. Two fabrication methods are experimented for comparison purposes. Other technical aspects of glulam production are mentioned for future consideration.

Chapter IV describes the experimental programmes involved in the study. Bending, axial compression and axial tension tests are conducted to investigate the strength and performance of the material.

In Chapter V, the test results are presented and analysed. The results are compared with the predicted values to validate the theory. The uniaxial strength properties of the material are established for DRM.

Chapter VI predicts the strength of the beams using Bazan's model. Predictions based on Zakic's and Buchanan's model are also presented for comparison purpose. Modifications to the existing models are then proposed to improve the accuracy of prediction.

Finally, Chapter VII provides some conclusions to the study and present several recommendations for future research.

1.7 LIMITATIONS

This study is limited to the prediction of clear solid and glulam beams of DRM. There is no attempt to verify the existing strength model with the strength-reducing defect beams. Glulam beams are fabricated without any jointing.

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