BONDING PERFORMANCE OF BOLTED TIMBER-CONCRETE COMPOSITE BEAM

NUR FARHANA BINTI HARUN

A project report submitted as a partial fulfillment of the
requirements for the award of the degree of
Master of Civil Engineering

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2014

...Dedicated to my beloved parents, HARUN BIN ABD. RAHMAN & NIK ZAKIAH BINTI NIK HASSAN. Not to forget, my siblings, ANIS ATHIRAH, AHMAD FAIZ & MUHAMMAD IKMAL HAKIM for their endless love, support and encouragement...

ACKNOWLEDGEMENT

Praise to Allah S.W.T., this project report entitle “Bonding Performance of Bolted Timber-Concrete Composite Beam” is finally completed within the allocated time.

Herewith,

I would like to express my sincere gratitude to my supervisor, Dr. Yusof Bin Ahmad for providing me an opportunity to do my project work. Lots of thank as he always there to provide me guidance and encouragement in carrying out this project.

This project bears the imprint of many people. I wish to express a sense of gratitude towards all the lecturers and technicians at the Department of Structures & Material, Faculty of Civil Engineering, Universiti Teknologi Malaysia for their kind cooperation to the completion of my project work.

Last but not least, deep appreciation and love expressed to my beloved parent, siblings and all my friends for their manual support, help and for everything

ABSTRACT

This study covers bonding behavior of bolted timber-concrete composite beam. Timber-concrete composite (TCC) system is a construction technique that gives benefit in upgrading both strength and stiffness of existing timber structures. This system can be attractive for both refurbishment and new build projects. The process involved by attaching connectors to the surface of the timber plank and placement of concrete on top of it. In addition, the use of formwork can be minimized as the timber plank can be part of the formwork. Six samples of timber-concrete composite beam with different configuration of bolt connector are presented and all samples were tested under four point bending test including one additional sample as controlled sample. It is shown herein, different ultimate resistance of TCC beam is obtained for different configuration of bolt connector. Based on the results, inclined bolt leads to high slip stiffness. TCC system shown good effect on the performances in terms of ductility since almost all samples could sustain the applied load for slightly long time than solid timber beam alone. However, it is observed that interface slip was occurred at all specimens.

ABSTRAK

Kajian ini merangkumi prestasi lekatan di antara rasuk komposit kayu-konkrit . Sistem komposit kayu - konkrit adalah teknik pembinaan yang memberi manfaat dalam menaik taraf kedua-dua kekuatan dan ketahanan struktur kayu yang sedia ada. Sistem ini lebih banyak diguna dalam membaik pulih dan membina projek-projek baru. Proses yang terlibat adalah dengan memasang penyambung ricih ke permukaan papan kayu dan menempatkan konkrit di atasnya . Di samping itu, penggunaan acuan boleh dikurangkan kerana papan kayu boleh menjadi sebahagian daripada acuan. Enam sampel rasuk komposit kayu - konkrit dengan konfigurasi penyambung ricih yang berbeza dibentangkan dan semua sampel telah diuji dengan uji kaji pembebanan empat titik termasuk satu sampel tambahan sebagai sampel kawalan. Berdasarkan keputusan yang telah diperoleh, perbezaan dalam konfigurasi penyambung ricih menghasilkan daya ketahanan yang berbeza bagi setiap sampel rasuk komposit kayu - konkrit. Selain itu, konfigurasi penyambung ricih yang bersudut menghasilkan daya tahan gelinciran yang tinggi. Sistem TCC menunjukkan kesan yang baik pada prestasi dari segi kemuluran kerana hampir semua sampel boleh menampung beban yang dikenakan lebih lama berbanding rasuk kayu pepejal sahaja. Walau bagaimanapun, gelinciran antara permukaaan kayu dan konkrit telah berlaku pada setiap sampel.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF APPENDIX

LIST OF SYMBOL

SYMBOL		NOTATION
w_1	-	Initial mass of timber samples
w_2	-	Final mass of timber samples
h_c	-	Height of concrete layer
h_t	-	Height of timber layer
b_c	-	breadth of concrete layer
b_t	-	breadth of timber layer
E_c	-	Modulus elasticity of concrete
E_t	-	Modulus elasticity of timber
n	-	Ratio of modulus of elasticity
A_c	-	Area of concrete layer
A_t	-	Area of timber layer
Z_c	-	Distance from neutral axis to the centre of gravity of the concrete layer
Z_t	-	Distance from neutral axis to the centre of gravity of the timber layer
Υ_{ct}	-	The connection efficiency factor in plane between concrete and timber
$I_{y,eff}$	-	Effective moment of inertia

M	-	Bending moment
R_c	-	Resistance of concrete
R_t	-	Resistance of timber
Q_k	-	Characteristic resistance
N	-	Number of stud
Q_p	-	Capacity of shear connector
R_q	-	Resistance of shear connection

CHAPTER 1

INTRODUCTION

1.1 Background

Timber is a renewable material that is widely available throughout the world. Throughout recorded history, the unique characteristic and relative abundance of timber have made it one of mankind's most valuable and useful natural resources. Malaysia is one of the main manufacturers of the world's good quality of timbers which are very highly demanded from all over the world as Malaysia enjoys one of the highest percentages of forested land among developing countries such as Brazil, Indonesia, Philippines and Thailand (FAO, 2005). More than 59% of its land area covered by forest with 45%, 59% and 69% in Peninsular Malaysia, Sabah and Sarawak respectively (Malaysian Timber Council, 2007). However it is unfortunate that the utilization of these resources as structural materials in Malaysia is slow-grown in contrast with other well-developed countries.

Timber has the benefits of lightweight, ease of construction, and high tensile strength in bending. Compared to steel and concrete, timber exhibits disadvantages of low stiffness, issues of decay and low absolute compressive strength. Reinforced concrete has the benefits of higher stiffness and compression strength than timber.

However, the low tensile capacity of plain concrete requires that steel reinforcement to be placed in the tension zone. (Gutkowski*et al.*2004).

The wide use of steel and concrete has becoming the current trend for the construction technique nowadays. As the current trends continue, the supply for both steel and concrete material has decreased and resulted in increasing prices for both materials. While no alternative has become a standard to replace steel and concrete as the structural material, timber material is becoming more common in new construction projects since timber is a renewable material and widely available .

Over the past several decades, timber-concrete composite structures (TCCSs) has generally been introduced and become more acceptable as many successful applications were generated in timber-concrete composite construction. The concept of timber-concrete composite behaviour was first used in bridge deck design in North America before been extended to Europe (Doehrer and Rautenstrauch, 2006). In Europe, the primary application for TCCSs is for flooring applications. The replacement of historical timber floors to TCCSs is to meet standards of acceptable vibration, small deflections and improved load carrying resistance while in United States, the technology of TCCSs has high potential in low-rise construction (Steinberg, 2003).

Timber-concrete composite (TCC) system is a construction technique that gives benefit in upgrading both strength and stiffness of existing timber structures. In addition, this type of construction technique is also used for new constructions such as multi-storey buildings and short-span bridges (David Yeoh, 2010) In timber-concrete composite structures (TCCSs), a concrete member is attached to a timber member either solid, glue laminated timber (Glulam) or laminated veneer lumber (LVL) by means of mechanical fasteners such as screws, nails, bolts, studs or any other special devices to transfer shear forces between timber and concrete.

Figure 1.1 Mechanical connector

This research works highlight the effectiveness of using bolt connectors as a method of joining concrete to timber and investigate the composite behaviour provided by bolt connector (Figure 1.1).

1.2 Problem Statement

The used of fasteners to connect timber-concrete structures are becoming more effective technique not only because they are easy to use and have good mechanical performance, but also because they are relatively cheap and available everywhere. However, most of related researches which used fasteners and materials that locally available were not completely described in most of the cases (Dias *et al.*, 2007). For that reason, comparisons between the test results remain difficult. Besides that, it is difficult to extrapolate these results to new situations.

Gelfi and Guiriani (1999) carried out a research work on a simple dowel which were reproduced everywhere. However, the number of tests was very low and the parameters studied were too few to allow a broad analysis.

When mechanical fasteners or adhesives interconnect the layers, flexure behaviour causes the layers to experience slip or horizontal motion at the interface. This behaviour is known as partial composite action (Figure 1.2). The single neutral axis of the composite cross section splits and as the slip between the layers increases, the two neutral axes move farther apart. Slip reduces the efficiency of the cross section below the levels of strength and stiffness present in a nonslip situation (Gutkowski *et al.*2004).

In addition, Yellow Meranti is a type of local timber species and it is widely distributed species in Malaysia. This type of timber species is classified as grade SG6 wood which in nature is less durable type of wood (MS 544, 2001). Previous related studies were mainly focused on softwood timber species rather than hardwood timber species like Yellow Meranti to be preferred as structural usage. However, as the extent of availability of Yellow Meranti in Malaysia, study has been conducted in Universiti Teknologi Malaysia (UTM) to determine the performance of implementing the Yellow Meranti in TCC system.

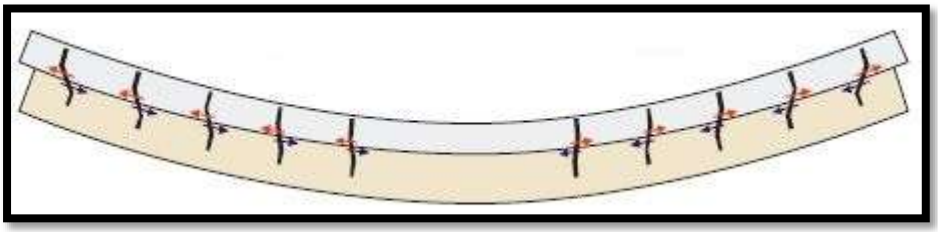

Figure 1.2 Partial composite actions

1.3 Objectives of the Study

The objectives of this research are:-

1) To investigate the performance of bolted timber-concrete composite beam.

2) To determine the optimum configuration of bolt connection in timber-concrete composite beams.

3) To evaluate the effect of bolts configuration on the failure modes of timber-concrete composite beams.

1.4 Scope of the Study

The scopes of the study are:-

1) Slender bolt with a length of 150 mm and a diameter of 6 mm will be used as timber-concrete connection.

2) There are six samples of timber-concrete beam with different configuration of bolt connection.

3) Yellow Meranti timber is selected to be used as timber member.

4) The dimension of all samples are 1000 mm x 150 mm x 200 mm

5) The depth of concrete member was fixed at 130 mm while the timber member depth was 70 mm.

1.5 Significance of Study

Renovating of conventional timber structure to TCCSs has become a great interest among researchers. The renovation process involve by attaching connectors to the surface of the timber plank and pouring concrete on top of it. In addition, the use of formwork can be minimized as the timber plank can be part of the formwork. The results concern the global behavior of timber-concrete composite beams. A significant improvement such as increase in the stiffness as well as an increase in its bearing capacity is expected to be achieved in this experimental work. Higher in stiffness will lead to the reduction of deflection (Gelfi and Giuriani, 1999).

New technology in structural field can be well developed by adapting TCCSs in construction since in Malaysia the application of TCCSs in the market for renovations is still not substantial. Apart from that, the optimum configuration of bolt connection in timber-concrete composite beam that is suitable for industrial purposes will be justified so that there will be a large potential market for this system in Malaysia.

1.6 Thesis Structure

The study conducted is presented in this thesis as follows:

1) Chapter 1 described briefly the general overview on the concept of timber-concrete composite beam throughout the conducted study.

2) Chapter 2 described a review from the previous research related to the objectives of the study.

3) Chapter 3 described the experimental work, sample preparation and also procedures for the combined bending and shear test.

4) Chapter 4 interprets the experimental results, analyze and discuss the experimental results that had been interpreted.

5) Chapter 5 concludes and makes recommendations for further investigation.

REFERENCES

Aicher S, Klock W, Dill-Langer G, Radovic B. (2003). Nails and nailplates as shear connectors for timber-concrete composite constructions. *Otto-Graf-Journal 14:189-209.*

Akhras, G. and Foo, H. C. (1994). A knowledge-based system for selecting proportions for normal concrete. *Expert system with applications*, 7(2): 323-335. 1994.

Bathon, L. and Clouston, P. (2004). Experimental and numerical results on semi-prestressed wood-concrete composite floor systems for long span applications. *Proceedings of the 8th World Conference on Timber Engineering,* Lahti, Finland, 1, 339 – 344.

Benitez, MF. (2000). Development and testing of timber/concrete shear connectors. *In; Proceedings of the World Conference on Timber Engineering, Vancouver, BC*, Canada, paper 8.3.2.

BSI (British Standards Institution). (2004). Eurocode 5: *Design of Timber Structures. Part 1.1: General Rules and Rules for Buildings.* BSI, London, BS EN 1995-1-1.

Ceccotti, A. (1995). *Timber-concrete composite structures*. In: Blass HJ et al. (editor) Timber Engineering, Step 2, 1st edition. Centrum Hout, The Netherlands. E13/1-E13/12.

Dias. A.M.P.G. (2005). *Mechanical behaviour of timber-concrete joints*. Phd Thesis, University of Coimbra, Portugal, ISBN 90-9019214-X.

Doehrer, A., and Rautenstrauch, k. (2006). The construction of road bridges as timber-concrete composites. *Proc., WCTE 2006—The 9thWorld Congress on Timber Engineering*, paper 2.24.1

FAO. 2005a. *Global Forest Resources Assessment 2005 – progress towards sustainable forest management*. FAO Forestry Paper No. 147. Rome.

Fragiacomo M, Gutkowski M, Balogh J, Fast RS (2007b). “Long-term behavior of wood-concrete composite floor/deck system with shear key connection detail.” *J StructEng ASCE* 133(9): 1307-1315.

Gelfi, P., Giuriani, E. (1999). Behavior of stud connectors in wood-concrete composite beams. *Proc., 6th Int. Conf. on Structural Studies, Repair, and Maintenance of Historical Buildings*, Dresden, Germany.

Gutkowski, R. M., Brown, K., Shigidi, A. and Natterer, J. (2004). Investigation of notched composite wood-concrete connections. *J. StructEng*, ASCE, Reston, Virginia 2004; 130(10): 1553-61.

Gutkowski RM., Balogh J., Natterer J., Brown K., Koike E., Etournaud P. (2000). Laboratory test of composite wood-concrete beam and floor specimens. *In: Proc. of world conference on timber engineering*, Whistler, BC, Canada. University of British Columbia, Vancouver.

Gutkowski RM., Thompson W., Brown K., Etournad P., Shigidi A., Natterer J. (1999). Laboratory testing of composite wood-concrete beam and deck specimen. *In: Proc., RILEM symposium on timber engineering*, Stockholm, Sweden, September 13-14, pp 263-272.

Illston, J.M. and Domone, P.L.J., (2001). *Construction Materials – Their Nature and Behavior* (3rd ed.). New York, Spon Press.

Koh H.B., Mohamad Diah A.B., Lee Y.L., Yeoh D. (2008). Experimental study on shear behaviours of timber-lightweight concrete composite shear connectors. *In:Proceedings of the 3rd Brunei International Conference on Engineering and Technology*, Bandar Seri Begawan (Brunei).

Kuhlmann, U. and Michelfelder, B. (2001). Grooves as shear connectors in timber-concrete composite structures. *In: Proceedings of RILEM conference on joints in timber structures*, Stuggart, Germany; 2001.

Lukaszewska E., Fragiacomo M., and Johnson H. (2010). Laboratory tests and numerical analysis of prefabricated timber-concrete composite floors. *J. Struct. Eng.*, 136(1), 46-55.

Lukaszewska E., Fragiacomo M., and Johnson H. (2010). Laboratory tests and numerical analysis of prefabricated timber-concrete composite floors. *J. Struct. Eng.*, 136(1), 46-55.

Malaysian Standard (2001). MS 544: *Code of Practice for the Structural Use of Timber*. SIRIM.

Malaysian Timber Council (2006). *Yellow Meranti (Brochure)*. Kuala Lumpur: Malaysian Timber Council.

Malaysian Timber Council (2007). *Malaysia: Sustainable Forest Management*. Malaysian Timber Council, Malaysia, March 2007.

Macia, N. T. and Soriano, J. (2004). Benefits of timber-concrete composite action in rural bridges. *Journal of Materials and Structure*s. Vol. 37, March 2004, pp 122-128.

Meierhofer, U. (1993). A timber/concrete composite system. *Structural Engineering International*. 3(2): 104-107.

Mettern, C. (2003). Structural timber-concrete composites –advantages of a little known innovation. *The Structural Engineer*, 18 February 2003, 17-19.

Nadhir, A. T. (2001). *Effect of Moisture Content on the Tensile Strength of Yellow Meranti Timber*. Master Degree, UTM, Skudai.

Natterer, J., Hamm, J., and Favre, P. (1996). Composite wood-concrete floors for multistory buildings. *Proc., Int. Wood Engineering Conf.*, Omnipress, Madison, Wis., Vol. 3, 3431-3435.

Natterer, J. (1997). Sustainable economy of forestry and value added utilization of forests. Restoration of forests – Environmental challenges in Central and Eastern Europe, R.M Gutkowski and T. Winnicki, eds., *NATO ASI Ser. 2*, Kluwer Academic, Dordrecht, The Netherlands, 30, 97-118.

Nežerka, V. (2010). *Timber-concrete composite structures*. Bachelor Thesis. Czech Technical University.

Persaud, R. and Symons, D. (2006). Connectors for timber-lightweight concrete composite structures. *Journal of Structural Engineering*. 129(11): 1538 - 1545.

Steinberg, E., Selle, R., and Faust, T. (2003). Connectors for timber-lightweight concrete composite structures. *J. Struct. Eng*., 129(11), 1538-1545.

Symons, D., Persaud, R., and Stanislaus, H. (2009). Slip modulus of inclined screws in timber-concrete floors. *Proc. of the Institution of Civil Engineer.* August, 2010.245-255.

Van der Linden, M. L. R. (1999). *Timber-concrete composite floor system*. Ph.D. thesis, Delft Univ. of Technology, Delft, The Netherlands.

Walker, J.C.F. (1993). *Primary Wood Processing: Principles and Practice*. Chapman & Hall, London, 1993, pp 197-246.

Wood handbook. (1999). *Wood as an Engineering Material*. Forest Products Society, Madison,Wis.

Yeoh D (2004). *Behaviour and design of timber-concrete composite floor system. Thesis Doctor of Philosophy*. University of Canterbury.

Yusof A. (2010). *Bending Behavior Of Timber Beams Strengthened Using Carbon Fiber Reinforced Bars And Plates*. Thesis Doctor of Philosophy. Universiti Teknologi Malaysia.