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Investigation of a Proposed Long Span Timber Floor for Non-Residential Applications

By

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

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ABSTRACT

Design of floor systems for commercial and multi-residential buildings in many parts of the world is currently dominated by the use of structural materials other than timber, such as reinforced concrete systems. Recent research in Australia has shown that the major barriers to using timber in non-residential buildings are the fire performance and the lack of designer confidence in commercial and industrial timber-based constructions. In this regard, significant research initiatives have commenced in Australia and New Zealand with the aim of developing timber and timber hybrid systems for large span commercial and industrial applications. This PhD research provides a detailed procedure for designing and investigating the short term static behaviour of a proposed long span timber floor system for non-residential applications that meets serviceability and ultimate limit design criteria, with the use of timber as the only structural load bearing part of the system. The specimen's responses to long-term loading, in-plane loading, dynamic excitation, cyclic loading and loading history are outside the scope of this PhD research. Moreover, other aspects of performance such as assessment of acoustic performance, dynamic performance and the possible interconnection systems alongside floor modules are not covered in the scope of this research project.

In this study the behaviour of two types of LVL are investigated through a number of experimental and analytical tests. As a result of the tension and compression tests, a suitable constitutive law is developed which can accurately capture the stress-strain relationship and the failure behaviour of LVL, and it can also be incorporated into FE analysis of any LVL beam with similar structural features to the tested specimens. Further, the results of the full scale four point bending tests on LVL sections are used to identify the behaviour of LVL up to the failure point and to develop a finite element model to capture the behaviour and failure of LVL.

Moreover, after investigating the long span timber floors, one system is proposed to be fabricated for the extensive experimental and numerical investigation. The experimental investigation involved subjecting the full scale proposed floor modules (6m and 8m

clear span LVL modules) to both serviceability and ultimate limit state static loading to assess the strength and serviceability performance of the proposed system. A continuum-based finite element model is also developed to capture the behaviour and failure of the long span LVL modules and to adequately predict the serviceability and ultimate limit performance of the proposed floor system.

To evaluate the partially-composite strength and serviceable performance of LVL floor system, a series of push-out tests are conducted on the fabricated timber connections using normal screws as the shear connectors, and the stiffness of the connections are assessed at serviceability and ultimate limit state. A number of LVL beams (3.5m "T" shaped beams) were also fabricated using only normal screws as the load bearing shear connectors at the interfaces, and are tested under serviceability and ultimate limit state loads with different screw spacing. Furthermore, a closed-form prediction analysis is conducted to calculate the partially-composite ultimate load of the beams. A comparison between the experimental results and the closed-from predicted results is undertaken, and the results are used for predicting the partially-composite behaviour of long span 6m and 8m LVL modules.

The results of the full scale experimental tests together with the numerical investigation provide a robust model for predicting the performance of any timber beams with similar structural features to the proposed system while the dimensions and spans can be varied according to special requirements such as dynamic performance or fire resistance requirements.

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LIST OF PUBLICATIONS BASED ON THIS THESIS

Zabihi, Z., Samali, B., and Crews, K. (2010), "Modern trends in long span timber flooring systems", *Proceedings, 21st Australasian Conference on the Mechanics of Structures and Materials, ACMSM 21,* Melbourne, Australia, 7-10 December.

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Zabihi, Z., Samali, B., Shrestha, R., and Crews, K. (2012), "Ultimate Performance of Timber Connection with Normal Screws", *Proceedings, 22nd Australasian Conference on the Mechanics of Structures and Materials, ACMSM 22,* Sydney, Australia, 11-14 December.

LIST OF NOTATIONS

α	modification factor in Glos model
α_{tf}	distance between point of zero bending moment to centroid of top flange
α_{bf}	distance between point of zero bending moment to centroid of bottom flange
α_{tf}	distance between point of zero bending moment to centroid of web
γ_{tf}	partial factor for material properties of the top flange
γ_{bf}	partial factor for material properties of the bottom flange
γ_{web}	partial factor for material properties of the web
δ_{max}	maximum mid span deflection
δ_{Mid}	measurements of LVDTs under mid-span
δ_{Trd}	measurements of LVDTs under third-span
ε_t	tensile strain
ε_c	compressive strain
ε_0	strain coefficient
ϕ	Capacity factor for imposed load as per AS1720.1 (2010)
ϕN	axial design capacity of the timber cross-section
ϕM	bending design capacity of the timber cross-section
ϕN_p	bearing design capacity of the timber cross-section
$\phi\sigma_{tf,axial}$	top flange axial stress design capacity
$\phi\sigma_{bf,axial}$	bottom flange axial stress design capacity
$\phi\sigma_{tf,bending}$	top flange bending stress design capacity
$\phi\sigma_{bf,bending}$	bottom flange bending stress design capacity
ρ	density
$\sigma^*_{tf,axial}$	axial stress in top flange due to design action
$\sigma^*_{bf,axial}$	axial stress in bottom flange due to design action

$\sigma^*_{tf,bending}$	bending stress in top flange due to design action
$\sigma^*_{bf,bending}$	bending stress in bottom flange due to design action
$\sigma_{f,t,\max}$	tensile design stress of the extreme fiber of flange
$\sigma_{f,t}$	mean tensile design stress of the flange
υ	Poisson's ratio
v	relative slip of timer connections
Ψ	coefficient for long term load combination
ΔF/Δe	linear elastic slope of the load-displacement graph
Δ_{vib}	mid span deflection of the floor beams as a result of impact loading
Δ_b	mid span flexural deflection of the floor beams
1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
A_{tf}	top flange area
A_{bf}	bottom flange area
A_w	web area
b	width (breadth) of the timber cross section
b_{tf}	top flange width
b_{bf}	bottom flange width
b_w	web width
CoV	coefficient of variation
d	total depth of the timber cross section
d_{tf}	top flange depth
d_{tf}	bottom flange depth
d_w	web depth
E_{tf}	top flange modulus of elasticity
E_{bf}	bottom flange modulus of elasticity
E_w	web modulus of elasticity
E	modulus of elasticity
E_t	modulus of elasticity in tension
E_c	modulus of elasticity in compression

EI	flexural stiffness
$(EI)_{eff, LT}$	long term effective flexural stiffness
$(EI)_{eff}$	effective flexural stiffness
$(EI)_{Mid}$	flexural stiffness at mid-span
$(EI)_{Trd}$	Flexural stiffness at third-span
F, P	point load
F_{est}	peak load
F_{max}	Ultimate/failure load
F_{ave}	average reading of load cells 1 and 2
F_{bf}	shear load on a single screw in bottom flange
F_{tf}	shear load on a single screw in bottom flange
f'_b	characteristic strength in bending (bending design capacity)
f'_c	characteristic strength in compression (compression design capacity)
f'_s	characteristic strength in shear (shear design capacity)
$f'_{s,glue}$	shear strength (shear design capacity) of glue
f'_t	characteristic strength in tension (tensile design capacity)
$f'_{b,tf}$	top flange bending strength (design capacity)
$f'_{b,bf}$	bottom flange bending strength (design capacity)
$f'_{b,w}$	web bending strength (design capacity)
$f'_{t,tf}$	top flange tension strength (parallel to grain) (design capacity)
$f'_{t, bf}$	bottom flange tension strength (design capacity) parallel to grain
$f'_{t,w}$	web tension strength (design capacity) parallel to grain
$f'_{c,tf}$	top flange compression strength(design capacity) parallel to grain
$f'_{c,bf}$	bottom flange compression strength (design capacity) parallel to grain
$f'_{c,w}$	web compression strength (design capacity) parallel to grain
$f'_{s,tf}$	top flange shear strength(design capacity)
$f'_{s,bf}$	bottom flange shear strength (design capacity)
$f'_{s,w}$	web shear strength (design capacity)
f_1	fundamental frequency (first natural frequency of the structure)
f^*_s	shear stress due to loading (design action)
f'_p	bearing strength of the bottom flange
f_b	mean bending strength
f_c	mean compression strength

f_t	mean tension strength
$f_{c,y}$	yielding compression strength
f_t	mean tensile strength
f_v	mean shear strength
G	self-weight & permanent loading
g	acceleration due to gravity (9.81 m/s^2)
G_s	shear modulus; Modulus of rigidity
h_{tf}	distance between the neutral axis of the cross section and the centroid of htop flange
h_w	distance between the neutral axis of the cross section and the centroid of webs
h_{bf}	distance between the neutral axis of the cross section and the centroid of botom flanges flange
I	moment of inertia
I_{eff}	effective moment of area
j_2	creep factor (stiffness modification factor)
K	stiffness
K_{Mid}	stiffness at third-span of the beam
K_{Trd}	stiffness at mid-span of the beam
K_i	initial stiffness of the connection
$K_{s,0.4}$	serviceability stiffness
$K_{s,0.6}$	ultimate stiffness
$K_{s,08}$	near collapse
K_p	the strain-hardening stiffness in Richard-Abbott model
K_0	initial stiffness in Richard-Abbott model
k_1	duration of load (timber)
k_{12}	stability factor (timber)
k_4	moisture condition factor (timber)
k_6	temperature factor (timber)
k_7	length and position of bearing factor (timber)
k_9	strength sharing between parallel members factor (timber)
$K_{(11)}$	coefficient factor in Glos model

$K_{(22)}$	coefficient factor in Glos model
$K_{(33)}$	coefficient factor in Glos model
$K_{(44)}$	coefficient factor in Glos model
$(K_{(11)})_{mod}$	modified coefficient factor in Glos model
L	span of the floor modules or length of the timber beams
LL	live Load
LVDT	Linear Variable Differential Transformers
m	mass of the floor ; mass per unit area (kg/m^2)
M^*	maximum bending moment due to design action
MC	moisture content
M_0	oven dried mass
M_i	initial mass
N.A.	neutral axis
N	power in Glos model (chapter 4)
N^*	maximum axial force due to design action
N^*_p	bearing load due to design action
n	a parameter associated with the sharpness of the curve in Richard-Abbott
n_w	modular ratios for web of the LVL modules (Chapter 3)
n_{bf}	modular ratios for bottom flange of the LVL models (Chapter 3)
P_0	reference shear force in in Richard-Abbott model
Q_{tf}	first moment of area of top flange about the neutral axis
Q_{bf}	first moment of area of bottom flange about the neutral axis
Q_{max}	maximum first moment of area
Q	imposed loading
R^2	coefficient of determination
S	joist spacing
SDL	superimposed permanent load
S_s	screw spacing
S_{tf}	screw spacing in top flange interface
S_{bf}	screw spacing in bottom flange interface
V^*	maximum acting shear force (shear force due to design action)

$\bar{y}_c$, y_c	neutral axis of the LVL floor module
$\bar{y}_{tf}$	location of centroid of top flange from the base of the cross section
$\bar{y}_{w}$	location of centroid of web from the base of the cross section
y_{bf}, $\bar{y}_{bf}$	location of centroid of bottom flange from the base of the cross section
$y_{bf/2}$	the distance between the half of the depth of bottom flange and the centroid of the section