PROGRESSIVE COLLAPSE ANALYSIS OF CROSS LAMINATED TIMBER STRUCTURES

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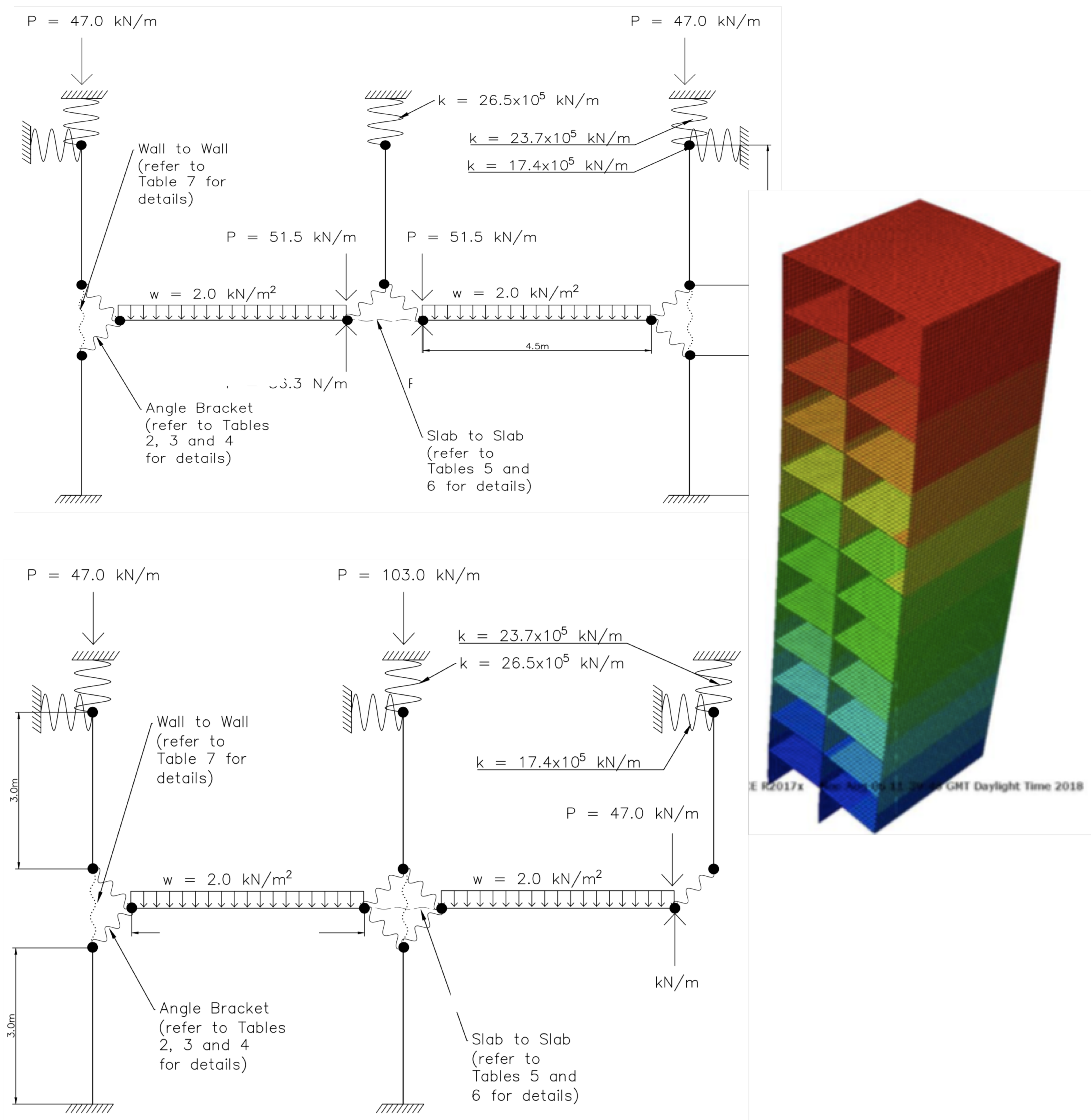
INTRODUCTION

A study on the response of a 12 storey cross laminated timber (CLT) structure designed by TRADA [1] was conducted. This consisted of a series of nonlinear dynamic analyses on the sub-assemblage models shown in Figure 1. The connection idealizations follow those specified by Gavric et al. [2]

FIGURE 1 – LOCAL MODELS

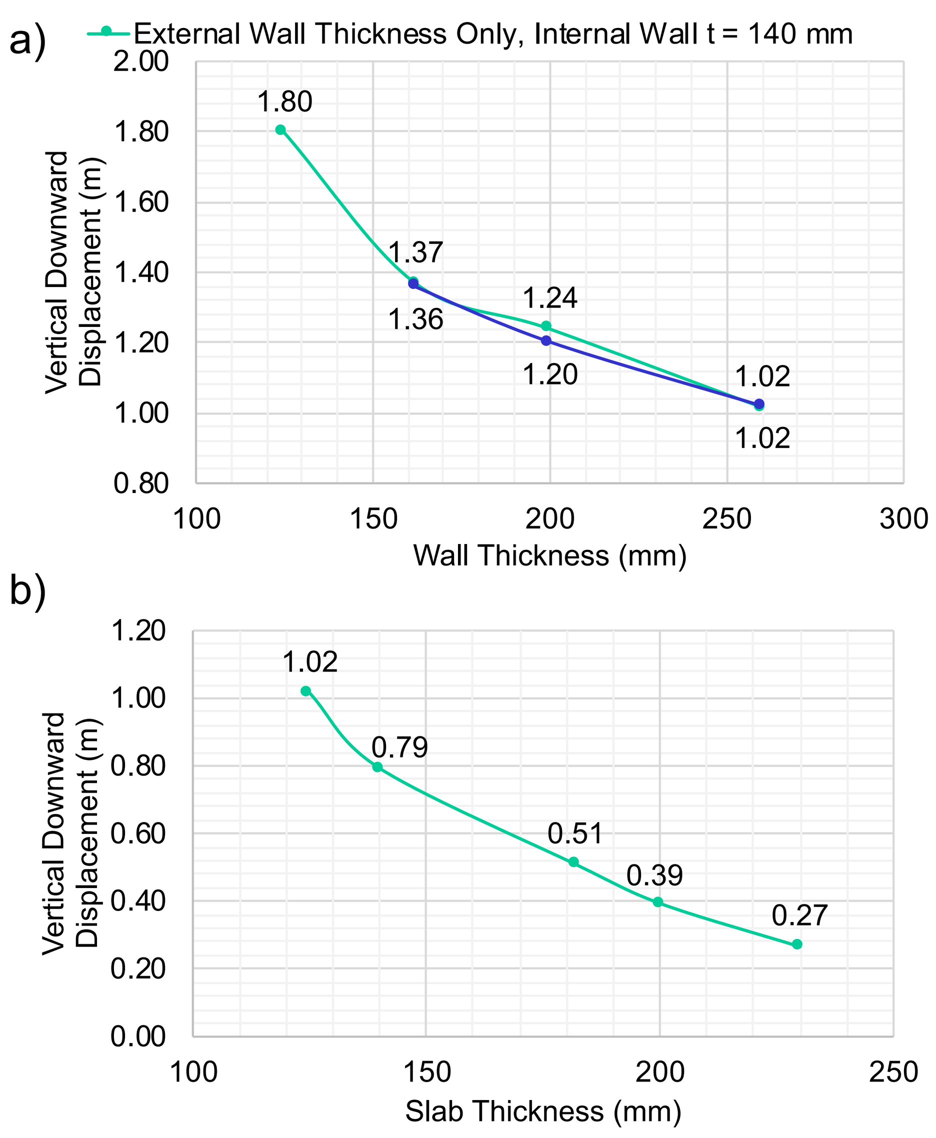


Two scenarios were studied, one where the main floor interior wall was assumed to fail (top left), and the other where a main floor edge wall was assumed to fail (top left). The floor loading seen in the figures was determined by means of static analyses. Global models (right) were also employed to verify the dynamic response of the building.

MAIN FLOOR INTERIOR WALL REMOVAL

Parametric studies were conducted on the wall and slab thicknesses for both models, used to simulate the effects of increasing the respective structural element stiffness (Figure 2). Support load removal time intervals between 1.0s and 0.01s were employed.

FIGURE 2 – INTERIOR WALL REMOVAL PARAMETRIC STUDIES



The top figure shows the results of the parametric study with relation to increasing the wall thickness. Increasing the exterior wall thickness was found to reduce the vertical displacement by 57% for a respective increase in the thickness of 108%. Increasing the interior wall thickness did not contribute substantially to reducing the vertical deflection. It was found that increasing the perimeter wall thickness was necessary to engage the slab in catenary action. Without the increased wall stiffness, lateral deflections in the perimeter wall would be as much as 1m in magnitude.

The bottom figure shows the study conducted with relation to increasing the slab thickness. This was conducted with an increased perimeter wall thickness of 260mm. It was found that with an increase of 84% of the slab thickness, the vertical deflection can be reduced by 73%.

MAIN FLOOR EXTERIOR WALL REMOVAL

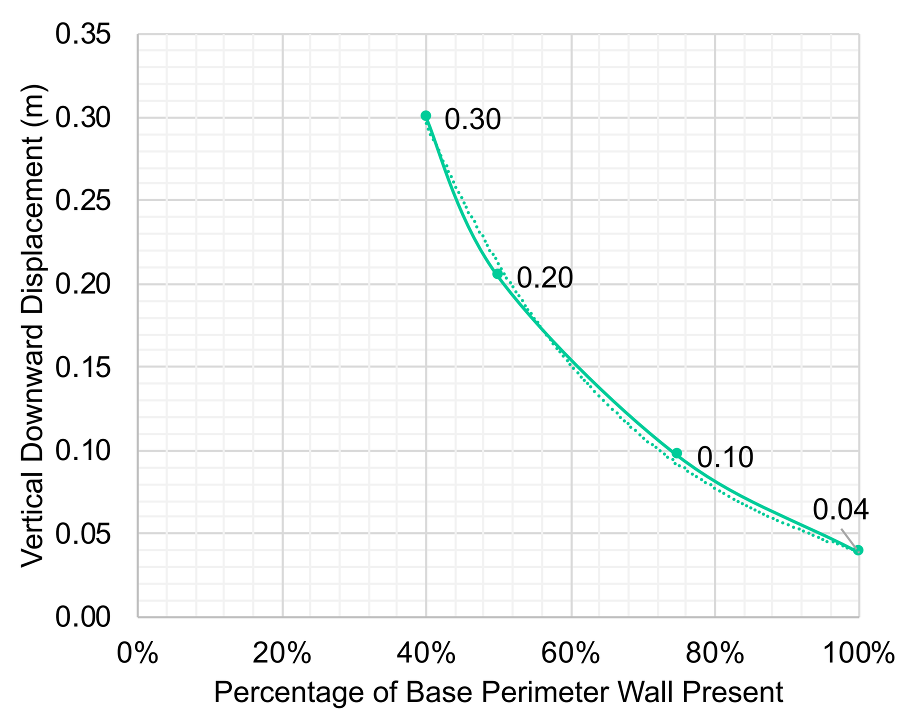
Parametric studies were conducted on the wall and slab thicknesses. It was found that the wall thicknesses did not contribute to reducing the vertical displacement. When the support load removal time interval was 1.0s, increasing the slab thickness from 125mm to 320mm was found to reduce the vertical displacement to 320mm from 3.37m.

This was not sufficient when the support load removal time interval was increased to 0.01s, or when considering non-rigid connections. Therefore, perimeter walls were added (with thicknesses of 125mm) to the original design to study the effectiveness of deep beam action in CLT structures.

DEEP BEAM ACTION – SENSITIVITY AND EFFECTIVENESS

The contribution of deep beam actions from the perimeter wall were studied. This was done by including perimeter walls with a thickness of 125mm (Figure 3).

FIGURE 3 – DEEP BEAM ACTION SENSITIVITY STUDY



A sensitivity study on the percentage of the main floor perimeter walls present (with the removal taking place from the bottom upward) was completed with rotationally and translationally rigid connections. The support load removal time interval was 0.01s.

As it can be seen in Figure 3, the response of the structure is highly sensitive to a reduction in the presence of the perimeter wall due to deep beam action.

Slab and wall thicknesses did not need to be modified to reduce the deflection of the structure, given the smaller magnitude of the vertical displacements observed.

TABLE 1 – EDGE DISPLACEMENT VERSUS PERIMETER WALL SCENARIO

Perimeter Wall Scenario	Maximum vertical displacement (m)
Upper Perimeter Wall	-0.17
Lower Perimeter Wall	-0.10
Upper and Lower Perimeter Wall	-0.05

In order to study the possibility of allowances for openings in the perimeter walls, a comparison of the influence of the presence of the upper storey and the lower storey perimeter walls in isolation were reviewed, as well as the influence of both. In these scenarios 100% of the perimeter walls were present and a stiffness multiplication factor of 14 was applied to the original connections (as per convergence necessity when 100% of the main floor perimeter wall alone was present).

Given that convergence was reached when the upper storey perimeter walls were considered in isolation, it is possible to allow for openings in the main floor perimeter walls provided that sufficient upper storey capacity is provided.

TABLE 2 – NET CONNECTION FORCE AND BENDING MOMENTS IN CONNECTIONS

Original Connection Configuration		
Connection	Max. Net Force (N)	Force at Failure (N)
Interior Angle Bracket	17135.3	11070.0
Edge Angle Bracket	16495.2	0.0
Perimeter A. Bracket	20499.2	0.0
Continuous Slab Configuration		
Interior Angle Bracket	13839.7	3720.1
Edge Angle Bracket	16535.4	0.0
Perimeter A. Bracket	19527	0.0
Rigid Connection Configuration		
Slab-to-slab	5123.7	N/A
Interior Angle Bracket	15488.8	N/A
Edge Angle Bracket	33031.1	N/A
Perimeter A. Bracket	486014.0	N/A

Original Connection Configuration		
Connection	Max. Moment (Nm)	Moment at Fail. (Nm)
Interior Angle Bracket	50327.1	50327.1
Edge Angle Bracket	4533.8	0.0
Perimeter A. Bracket	75.1	0.0
Continuous Slab Configuration		
Interior Angle Bracket	26076.5	26076.5
Edge Angle Bracket	1517.8	0.0
Perimeter A. Bracket	325.94	0.0
Rigid Connection Configuration		
Slab-to-slab	2847.7	N/A
Interior Angle Bracket	2914.5	N/A
Edge Angle Bracket	5302.3	N/A
Perimeter A. Bracket	236.2	N/A

In order to determine where the connection stiffness was at a maximum, the maximum net forces and bending moments were observed when 100% of the main floor perimeter wall was present.

As it can be seen in Table 2, the maximum forces were observed in the edge angle bracket and the maximum bending moments were observed in the interior angle bracket.

Therefore, development and further research into detailed rotational stiffness and connection strength of CLT angle brackets should be conducted.

It may be noted that the distribution of forces and moments along the slab edge above the removed wall were distributed like that observed in a simply supported beam. The distribution of forces and moments along the perimeter wall edge was similar to that of a cantilever beam,

ACKNOWLEDGEMENTS

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REFERENCES

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[2]Gavric, I., Fragiacomo, M. & Ceccotti, A. (2015) Cyclic behaviour of typical metal connectors for cross-laminated (CLT) structures. Materials and Structures. 48 (6), 1841-1857. doi: 10.1617/s11527-014-0278-7.