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Innovative Use of Wood and Steel in Construction

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ABSTRACT

Modern timber construction largely consists of residential structures. This is mainly due to the use of large wall panels being necessary for seismic resistance. Timber moment connections have previously been avoided due to difficulty of construction and significant costs. However, as global focus shifts towards sustainability and environmental concerns timber construction is an obvious choice for the future. The objective of this research is to investigate the feasibility of post-tensioned timber multi-storey buildings. This is carried out through the comparison of a case study building designed in concrete, steel and timber. Focus was to know about the lateral seismic loading, type of flooring, lateral forces, shear stress at the base of beam and size comparison between the timber and concrete structures.

1. Introduction

Timber is one of the most ancient building materials in the world. Multi storey timber buildings date back for thousands of years. Although timber construction has had a long history throughout the world, in later years it has been falling behind 'modern' construction material such as concrete and steel. Modern timber construction largely consists of residential structures. This is mainly due to the use of large wall panels being necessary for seismic resistance. Timber moment connections have previously been avoided due to difficulty of construction and significant costs. However, as global focus shifts towards sustainability and environmental concerns timber construction is an obvious choice for the future. Considerable work has also been performed regarding the design of multi-storey ply shear walls (Stewart 1987, Deam 1997) and hysteretic loops and analytical models have been developed. However, it is required that large walls be used for this method to ensure adequate lateral resistance. This study mainly focuses on how will a timber post-tensioned building be designed, how will these connections perform under lateral loading, how will a timber post-tensioned structure compare to the current steel and concrete structural design practice.

2. Methodology

2.1 Actual building

The case study building used for the project is a six storey structure that is to be built at the Patel Nagar, New Delhi as a shopping complex. The building has two distinct lateral resisting systems in order to resist loading in both the north-south and east-west direction. In the long (east-west) direction a moment resisting frame will be used. In the short (north-south) direction structural walls will be used.

Fig.1.1 Rendered view of the building

2.2 Steel Structure

The steel structure had the most significant change in its structural system of the three buildings. The frames and walls are removed and replaced with Eccentrically Braced Frames (EBF's) in both directions.

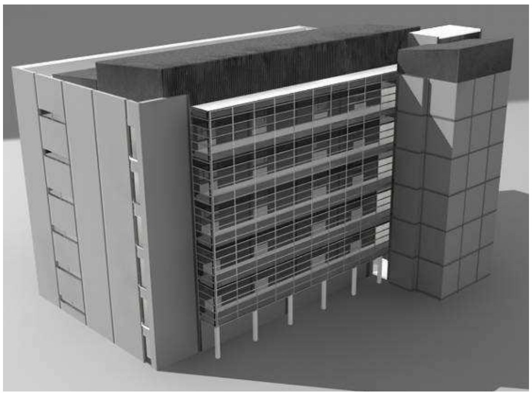


Fig.1.2 Rendered steel structure view

2.3 Timber Structure

The basic form of the Timber building will remain similar to that of the concrete structure with the use of frames and walls. This system is essentially damage free after a major event and will return to zero residual displacement; these are major advantages for any structural system.

Fig. 1. 3 Rendered view of timber structure

2.4 Loading Calculations

2.4.1 Timber Building Gravity Loadings

A 3kPa live load will be applied. The dead loading from the flooring units is assumed to be 3kPa and a superimposed dead load of 1.0kPa is also added Using the above floor loads the factored gravity loadings for the flooring can be calculated:

floor b f = 1.2*G* +1.5*Q*

= 1.2(3 +1) +1.5(3)

= 8.7*kPa*

2.4.2 Building Lateral Loadings

The Direct Displacement Based Design (DDBD) (Priestley et al. 2007) method has been proposed for the calculation of lateral forces arising from earthquake ground motion. The fundamentals of this design procedure are shown in Figure

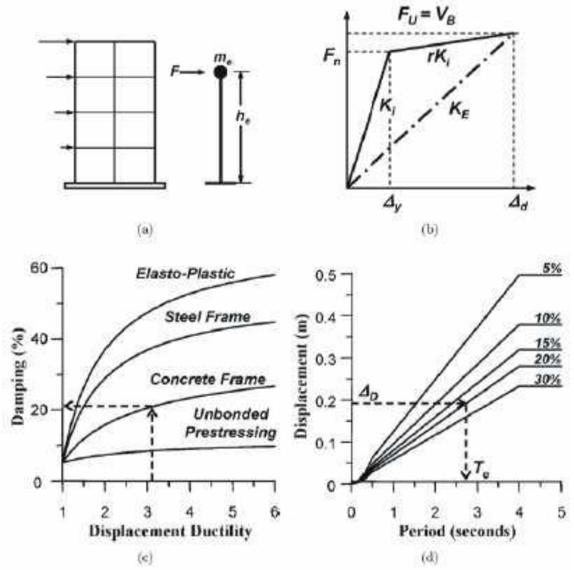


Figure 1.4 : Fundamentals of Direct Displacement Based Design Procedure (Priestley et al. 2007)

2.4.3 DDBD for Post-Tensioned Timber Frames

The use of this design procedure is deemed to be direct due to the estimation of the yield rotation meaning that iterations in the load calculations are not necessary as an adequate structural ductility is estimated. This estimation is simply based on geometric and material properties and provides good estimates for design purposes.

2.4.4 Lateral Load Calculations for Case Study Timber Building

The DDBD procedure is used for the lateral load calculations for the six storey case study building. For this the seismic mass at each floor must be calculated:

$$F = G + Q_a$$

$$= G + \Psi_c Q$$

$$= G + \Psi_c \Psi_a Q_b$$

Where:

$$\Psi_a = 0.3 + \frac{3}{\sqrt{A}}$$

Ψ_c = Combination factor for imposed 'live' loads

Ψ_a = Area reduction factor

Using these values the imposed loads show in Table 1.1 were calculated.

Table 1.1: Floor loadings for case study building

Level	Area (m^2)	Ψ_a	Ψ_c	G	Q_b	W_i (kN)
Roof	663	0.42	0	3.5	3	2321
5	726	0.41	0.4	3.5	3	2899
4	726	0.41	0.4	3.5	3	2899
3	726	0.41	0.4	3.5	3	2899
2	744	0.41	0.4	3.5	3	2970
1	766	0.41	0.4	3.5	3	3056

2.4.5 Calculation of Internal Design Actions

Once the total base shear is found it is distributed up the building following the assumed first mode displacement and weighted by the floor mass The base moments are then applied in accordance with the following equation:

$$M_{Ci} = 0.6 V_{Ci} H_{1i}$$

Where:

M_{Ci} = Moment at base of column i

V_{Ci} = Base shear taken by column i

H_{1i} = 1st storey height of column i

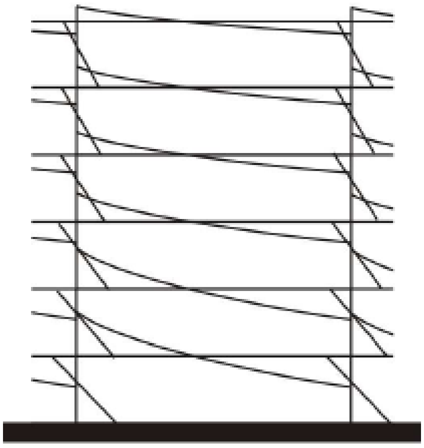


Figure 1.5: BMD for timber building

Table 1.2: Column face design moments for timber frame.

Floor	Height (m)	Moment (kNm)
Roof	22.86	56.0
5	19.05	96.8
4	15.24	131
3	11.43	158
2	7.62	177
1	3.81	188

The overturning moment at the base of each column is 275kNm.

2.4.6 Moment Calculation in Wall Direction

The total overturning moment for the building is divided equally amongst the three structure walls with 8242 kNm overturning moment at the base of each wall.

2.4.7 Force Calculations for Concrete and Steel Alternative Designs

The lateral loading calculations for the concrete and steel buildings were performed in accordance with a traditional force based approach which is considered to represent current practice techniques. The equivalent static method was used to distribute the forces up the height of the building and an elastic design package was used to calculate the internal forces.

2.4.8 Seismic Loadings

Recent developments in the field of seismic design have lead to the development of damage control design philosophies and innovative seismic resistant systems. In particular, jointed ductile connections for precast concrete structures (Priestley 1991, 1996; Priestley et al., 1999; Pampanin, 2005) have been implemented and validated. These solutions rely on a discrete dissipative mechanism placed in specific locations in the structure.

2.5 Material Properties

Table 1.3 Material properties

Elastic Moduli		(MPa)
Modulus of Elasticity	E	13200
Modulus of Rigidity	G	660
Characteristic Strengths		
Bending	f'_b	48
Tension Parallel to Grain	f'_t	33
Compression Parallel to Grain	f'_c	45
Shear in Beams	f'_s	5.3
Compression Perpendicular to Grain	f'_p	12
Shear at Joint Details	f'_{sj}	5.3
Density		620kg/m^3

2.6 Connection design

Table 1.4 Member comparison between timber and concrete buildings

	Timber		Concrete	
	Dimension (mm)	Area (m^2)	Dimension (mm)	Area (m^2)
Beam	600 x 378	0.23	800 x 400	0.32
Column	600 x 378	0.23	800 x 400	0.32
Wall	4000 x 252	1.01	4300 x 200	0.86

3. Testing Results

The first three tests were performed with the application of a 10mm steel plate between the face of the column and the end of the beam These tests were performed with three different levels of initial post tensioning; the results of these tests are shown in Figure 2.1.

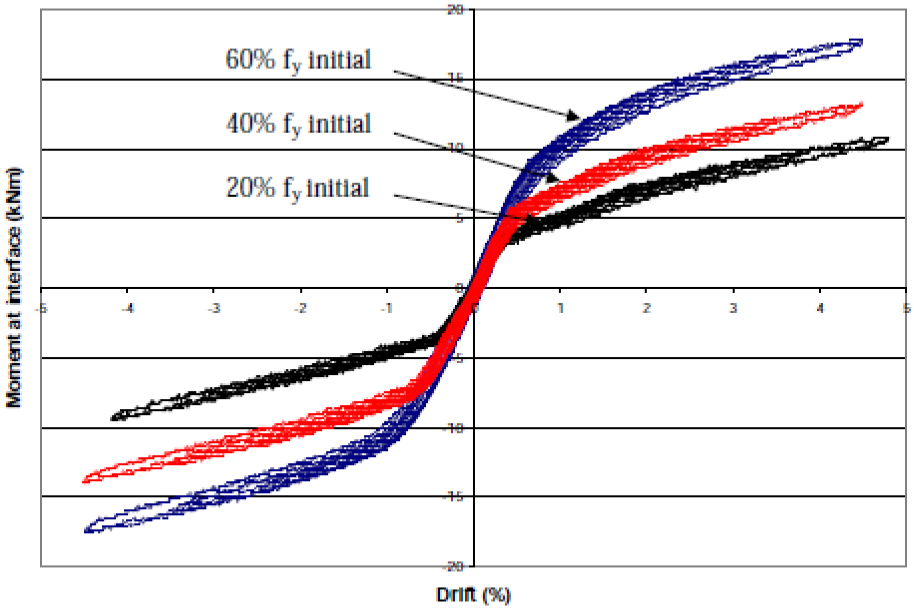
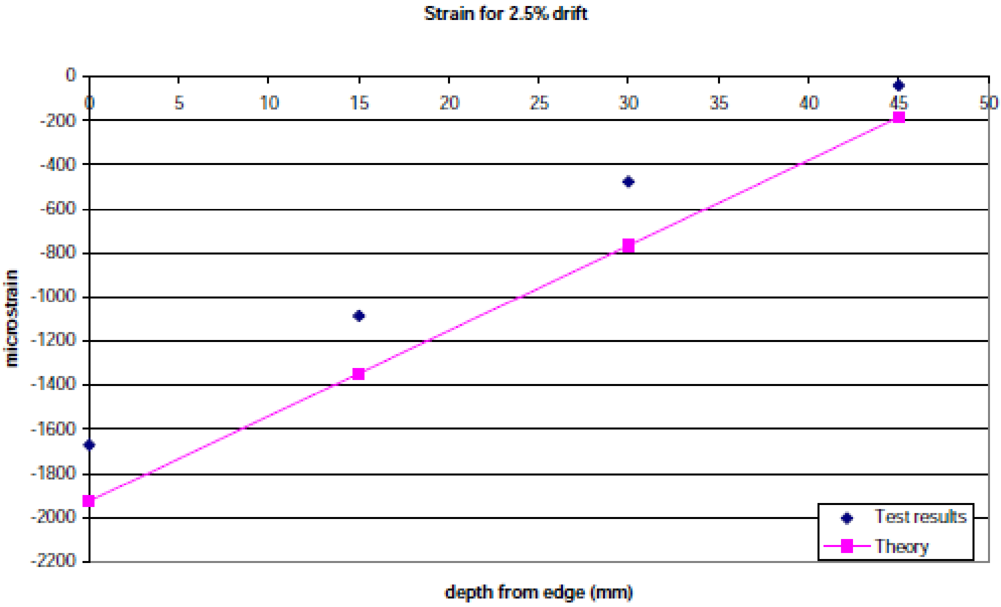


Fig 2.1 Moment at interface versus drift for beam to column testing with armoring Results from Beam to Column testing with steel armour

For Strain as the depth of the compression region directly affects the amount of tendon stress, this inaccuracy is also seen in the prediction of tendon force.



	With Armour			Without Armour		
PT initial	20%	40%	60%	20%	40%	60%
θ_y	0.4	0.5	0.7	0.3	0.4	0.6
M_y (kNm)	3.7	5.3	8.7	2.4	4.0	6.2
M_m (kNm)	10.6	13.3	17.3	8.7	11.1	14.5

Table 2.1 : Yield drift and moment, maximum moment for beam to column test

4. Interpretations

1. The usage of angled shear keys at the base of a wall or column is preferable to that of the half circular shear keys as it reduces stress concentrations and damage.
2. A minimum characteristic strength of 10kN is suggested for the beam to floor diaphragm coach screw connection due to this being the minimum value of the observed onset of non-linear behavior, however, larger values than this may occur followed by a sudden slip failure.
3. The placement of steel armour at the beam to column interface causes a significant increase in both ‘yield’ moment and maximum moment (at 4.5% drift) by reducing the neutral axis depth.
4. Altering the initial post tensioning value in the column has the effect of increasing ‘yield’ drift, ‘yield’ moment and maximum moment (at 4.5% drift).
5. The placement of corbels on the underside of the beam does not affect the moment response of the beam to column connection.

5. Conclusion

This assessment was performed with the use of case study buildings designed in timber, concrete and steel. The structural design of the timber building was presented with emphasis placed of the connection design. Subassembly testing was performed to investigate the performance of a selection of critical connections. The lateral seismic loading of the building is assessed using a modified version of the Direct Displacement Based Design Procedure. Simple modifications can be made to allow for both the anisotropic and flexible nature of timber.

Lateral resistance is provided using the ductile post-tensioned timber connection. This system combines the use of post-tensioned steel elements with the use of sacrificial yielding elements. Design of these connections follows the procedure for the design of a concrete ductile post-tensioned connection. The principle aim of the connection design was simplicity. Joist hangers are currently common in practice and can also be used for the composite flooring. Bearing is used for gravity load transfer due to its simplicity and ease of design. The floor diaphragm is connected to the seismic elements through the use of discrete connectors cast into the topping. The design of these connections largely follows current code previsions. The placement of steel armour at the beam to column interface causes a significant increase in the moment capacity of a beam to column connection by reducing the effect of the perpendicular to grain stiffness.

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