MULTI-STOREY TIMBER CONSTRUCTION – A FEASIBILITY STUDY

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SUMMARY

Multi-storey Timber construction took a quantum leap forward in New Zealand post 1992. This is when the New Zealand Building Code was introduced with the removal of the restriction on the number of storeys which could be built in timber. Since then, buildings have been built up to 5 storeys in height, within New Zealand, but construction of buildings beyond this size has not been forthcoming.

This paper attempts to explore some of the possible reasons behind why multi-storey timber construction appears to have reached its limit, and suggests some methods as to provide the impetus for another quantum leap in multi-storey timber construction.

INTRODUCTION

Multi-storey timber buildings exist in New Zealand up to 5 storeys in height. They are a relatively recent arrival to the construction scene and are proving to perform well.

Two recent examples are Gulf View Towers Apartment Building completed in 1995, and The Strand Apartment & Office complex completed in early 1999.

Feasibility studies on a 14 storey building have been carried out and the results of these are included in the body of this paper, along with some discussion on how the future of multi-storey timber construction may be progressed.

Figure 1: Multistorey Construction

Then & Now

In New Zealand, prior to 1992, timber construction was limited to 3 storeys.

A Performance based Building Code was introduced in 1992 removing this restriction to the number of storeys for which a timber building could be built, provided it met certain performance criteria. This has resulted in a significant increase in both the number and size of multi-storey timber buildings in New Zealand since 1992.

Examples of Buildings which have been constructed since 1992 which fall into this category are shown below.

Figure 2: Gulf View Towers

5 storey timber apartment building utilising a timber moment resisting frame, plywood sheathed shearwalls and plywood floor diaphragms. The lateral load resisting systems utilised steel tension tie rods within the components.

Figure 3: The Strand Offices and Apartments

4 storey utilising steel frames and plywood clad shearwalls with plywood floor diaphragms. As above, the shearwalls utilised steel tension chord members.

This leap in size from 3 storeys to 4 and 5 storeys has been a direct result of the legislation introduced in the form of the New Zealand Building Code, but what is limiting the size of construction to this 4 to 5 storey height ? The New Zealand Building Code places no restriction on size or height, therefore this restriction can only be as a result of the perceived limitation of the timber material and the risk of exceeding what is considered feasible.

Risk & Education

There is always a risk associated with doing something which has not been done before.
In order to minimise this risk, research into the project is essential.
Timber is one of our oldest building materials. Our existing knowledge of the material is extensive and research into its behaviour and applications, continue. The actual risk associated with the material must be reasonable low.

The Timber Engineering expertise exists, to enable the design of multi-storey structures which exceed those which are being built at present. The actual risk associated with the technical expertise of our designers must also be considered reasonably low.

The perceived risk must therefore be associated with the use of the material in ways which are new, and the potential cost of such unknown factors which may be encountered during the construction, which must ultimately be borne by the Building Contractor and or the Developer.

Why should a Building Contractor or a Developer take such a risk, when there are plenty of tried and true methods of construction available to them? The risk should be borne by those who have the most to gain.

As more and more timber resources become available for distribution world-wide, the supply of timber and timber products must become increasingly competitive. Investigating and discovering new uses for timber must increase the demand for a product for which its supply is also increasing.

A Possible Way Forward

The perceived risk associated with a prototype multi-storey timber project, which utilises timber wherever appropriate in conjunction with other materials, could be borne by a large multi-national timber supplier.

This could be achieved by forming a partnership for a specific project between the timber supplier and a developer.

A 'conventional' design of the developer's choice would be carried out in sufficient detail to enable pricing of the project to be carried out.

A timber alternative design would be completed for the project, with the aim of costing no more, and ideally less than the 'conventional' design.

The timber supplier would meet any cost overruns for the primary structure, where timber is the alternative. Any cost savings would be shared between the Developer and the timber supplier.

In this scenario, the perceived risk would be borne by the Timber supplier, whom in return would over time reap the benefits of a higher demand for timber products.

It may take more than one project to provide sufficient momentum for any significant increase in demand for timber products. However, should significant cost savings be achieved in these prototype projects, then a rapid increase in the demand of timber products for use in construction could be expected.

The Attributes of Timber

The compression strength of timber ranges from about 20 MPa through to 40 MPa. These figures are in the range of concrete compressive strengths. Timber is brittle in tension, much like concrete. With these attributes, why is it that we do not construct buildings of the size we do in concrete? Many of the principals of reinforced concrete design could be applicable to reinforced timber design. In general terms, this equates to using the timber components to resist compressive forces, and using steel, or other materials, to resist tensile forces. Of course, timber has a significant tensile strength, which can be utilised, as long as the principals of capacity design are applied, to ensure that a brittle failure mechanism will not occur.

One distinct advantage that timber has over other materials is its strength to weight ratio. This lightweight nature has other advantages such as attracting significantly lower seismic loads as opposed to heavier building materials.

For example; for a given structure, the sizes of timber members could be less in volume than say for a concrete structure of the same overall size.

However, the taller a building gets, the more likely it is that wind loads will govern.

Timber members of chunky section sizes have an inherent fire rating by means of the charring rate of the outer layers. This is a distinct advantage over steel structures which may require additional fire rating.

Timber as a resource has numerous advantages over other materials from a global impact standpoint. Timber is a renewable resource. It requires less energy to produce the many other building materials. Carbon is locked into the timber for the full duration of its life as a building material. The process of growing timber and utilising it as a building product is a natural process which has less potential impact on our atmosphere and climate, as opposed to other building materials.

Important Design Issues

Timber, as with other materials, has specific issues to be addressed when using it as a structural building material.

Timber, unlike most other building materials is isotropic possessing different structural properties in relation to the direction of the grain.

Endeavouring to use members to resist forces which are parallel to the grain is the most efficient way to utilise the material and also eliminates problems associated with perpendicular to the grain compression strains or separation/delamination/splitting under perpendicular to the grain tension forces. It is not always possible to avoid loading perpendicular to the grain, but being aware of this weakness, allows designers to compensate with strengthening techniques, if necessary.

Strain compatibility is an issue that must be addressed when using timber in conjunction with other materials, such as steel and concrete.

This strain compatibility must exist, not only under design action forces, but also simultaneously with temperature and moisture change induced forces.

One method to achieve this is to post tension the timber members, ensuring that the member always remains under compression after being subjected to a combination of tensile and compression forces arising from the applied external forces and the internal forces arising from temperature and moisture content change.

It may not always be possible to maintain a net compressive strain on the member once the external forces are applied. This is very much dependent on the individual structure, its geometry and the economies of having members sizes large enough to achieve this.

A resultant tensile strain is not an insurmountable problem. All that is required is to ensure that the tensile steel members (tie rods for example) are sized so that the tensile strain is not so large as to overstress the timber component or to pull apart the timber joints in the system.

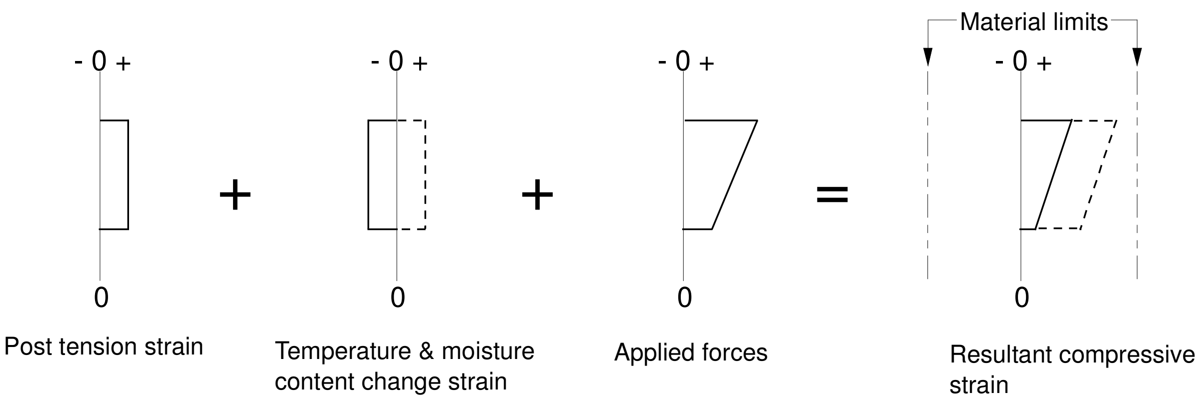


Figure 4: Strain Diagram

A Future for Timber in Multistorey Construction

There exists a wide range for the potential use of timber in multistorey construction beyond that for which it is primarily used today.

This range consists of the use of Secondary Timber components through to the use of timber for the primary structural elements.

To follow are brief examples of preliminary feasibility designs carried out for the purpose of exploring the potential to construct multistorey buildings containing a range of timber structural elements.

Case 1: 14 Storey Building
Reinforced Concrete Shear Core
Timber Gravity Frame & Flooring System

This combination of timber and reinforced concrete results in a building utilising primary structural timber members and would exceed the number of storeys of any existing timber structure.

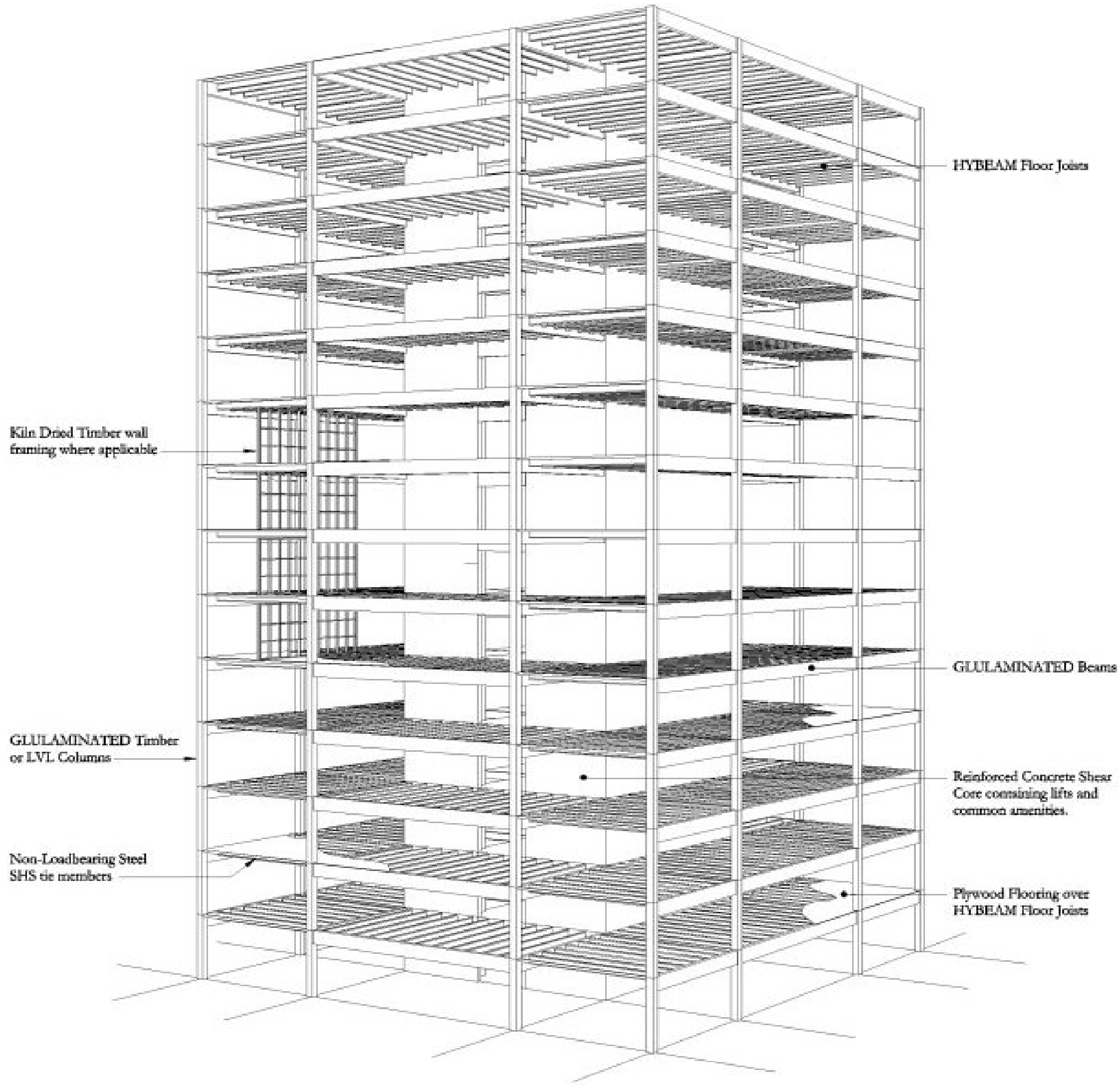
The reinforced concrete shearcore withstands all lateral and torsional loads. The timber columns and beams resist gravity loads, as do the timber composite floor joists. The plywood diaphragm flooring transfers lateral loads to the shearcore.

It is important to utilise the strength of the timber columns with the load parallel to the grain. This means that the butt joining of the columns, with the face fixing of beams is essential to avoid cumulative perpendicular to the grain compression and or temperature/moisture content change induced strains, becoming too great.

The temperature/moisture content change induced strains are relatively small and manageable for movements parallel to the grain. It is essential however to ensure that the timber remains as close as possible to its inservice temperature and moisture content through-out the construction, as is reasonably practicable. Beam column joints can be made using fabricated steel plate connectors and bolts.

The lightweight nature of the timber construction means a lower seismic mass and hence a lower level of seismic load will be imposed on the reinforced concrete shear core, than would be the case for a totally reinforced concrete structure. This lightweight construction also has benefits with respect to the size of the foundations required to support such a building.

Large sized timber members of approx 300 mm square for the column and 180 mm wide x 600 mm deep for the beams can be fabricated from glue laminated timber or laminated pieces of L.V.L. (laminated veneer lumber). The floor construction could consist of fabricated proprietary long-span floor joists and plywood flooring. The plywood flooring with nailed fixing would provide a ductile floor diaphragm.
Acoustic insulation is achieved by utilising suspended ceilings, double framed or staggered framed partition walls and or resilient channel supports for gypsum wall linings. These methods have a proven performance in the recent upsurge in lowrise multistorey timber construction we have seen in New Zealand since 1992.
This form of construction is most definitely feasible and certainly would warrant further investigation, perhaps in the form of a prototype project mentioned earlier in this paper.



14 STOREY BUILDING - OPTION 1

STRUCTURAL SYSTEM

This 14 storey building utilizes a reinforced concrete shear core to resist all lateral loads and torsional loads.
The gravity system is entirely timber with 300mm square GLULAMINATED timber or LVL columns and 180mm wide x 600mm deep GLULAMINATED timber beams

The flooring consists of HYBEAM floor joists and PLYWOOD flooring which provides diaphragm action to transfer loads to the shear core

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Figure 5

Case 2: 14 Storey Building
Steel Moment Resisting Frame
Composite Timber Long span Floor Joists & Plywood Flooring

While the primary structural frame of this building form is from structural steel, the flooring system which supports gravity loads and acts as a diaphragm to transfer lateral loads to the steel frames could be constructed entirely from timber.

The form of construction for these floors would be as for Case 1 with proprietary long span composite floor joists and a plywood floor with suspended ceilings.

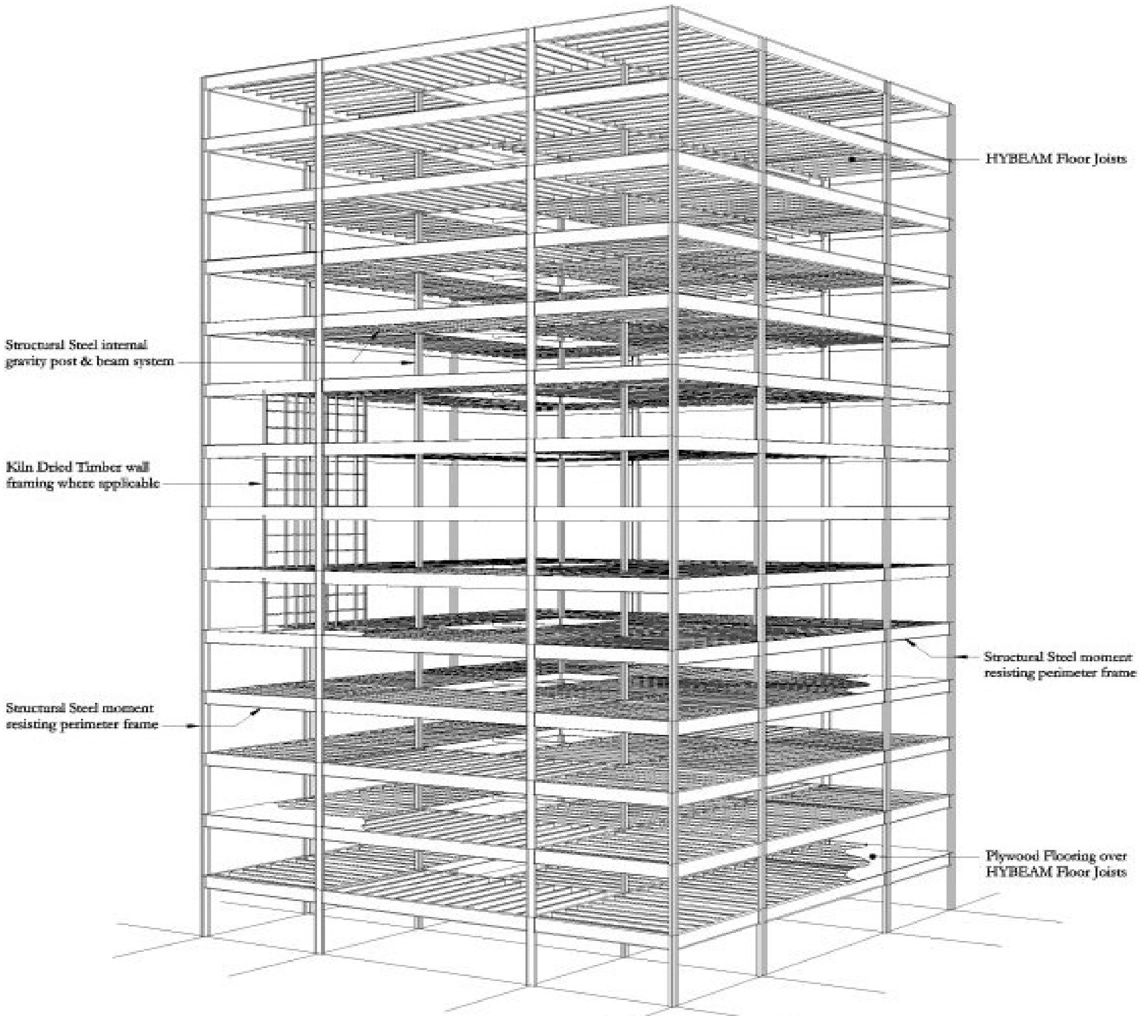
There are many steel framed concrete floor buildings constructed throughout the world.

The lightweight nature of the floor construction has benefits in reducing the overall weight of the building which, once again has a positive spin off with regards to seismic design and foundation sizes.

There are also construction benefits with respect to the possibility of prefabricating lightweight sections of floor panels which could be lifted into place with less cranage than would be required for heavier materials. A building may only require a mobile crane rather than a tower crane, as a result.

Other possibilities exist whereby the floor system may be built on top of the previous floor and hoisted into place by a series of screw jacks placed at strategic locations. This system is similar to that already utilised in some countries with post tensioned concrete slabs, however the weight of construction is once again, far less than concrete.

To develop a market for a timber floor alternative in high rise construction would be both feasible and beneficial.



14 STOREY BUILDING - OPTION 2

STRUCTURAL SYSTEM

The floor is constructed from timber HYBEAM joists and plywood flooring, which provides the diaphragm action.

This 14 storey building utilizes a perimeter moment resisting frame of structural steel, with a structural steel internal gravity post & beam system.

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Figure 6

Case 3: Timber Moment Resisting Braced Frame with Timber Floor Construction

Note: At the time of writing this paper, Case 3 was no more than an idea and has had no formal feasibility design or costing work carried out.

This case utilises a complete timber alternative. The lateral load resisting system would be braced similar to that of Case 2 with a braced frame system. This perimeter frame would essentially consist of a series of pin jointed compression and tension members. All gravity loads would be supported by an internal gravity only post and beam system.

The perimeter moment resisting frame would consist of fabricated steel plate connectors at the node points with timber compression members between the nodes. These members would be fabricated from laminations of timber or L.V.L. to form chunky sizes in the order of 300 – 600 mm square. These timber members would be utilised for compression forces only, while the tensile forces would be resisted by steel tie rods and tensioners connected between the same fabricated steel plate node point connectors.

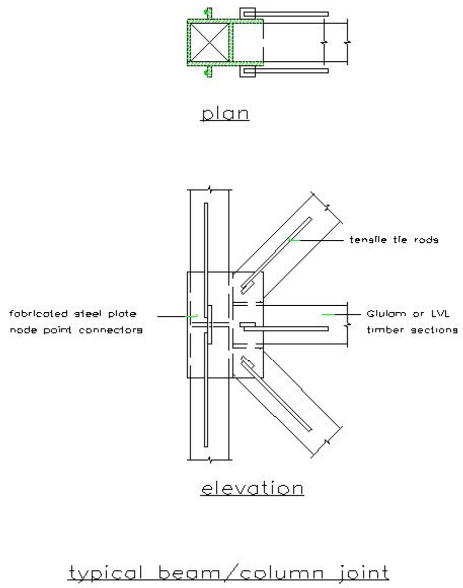

Figure 7: Typical beam/column joint

While a structural assessment of Case No. 3 has not been carried out, it is the belief of the writer that such a structure is most definitely feasible. The economies of such a structure would require further analysis.