Multi-unit residential buildings in timber, the New Zealand experience

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ABSTRACT: This paper discusses the emergence of timber as a prime construction material used in low-rise multi-storey multi unit residential development. Historically residential timber buildings were limited to two and a half floors under the light timber codes, and further limited to concrete 'fire proof' inter-tenancy walls. Fireproofing is no longer restricted to concrete, and design methods have recognized the potential to build beyond 2-3 floors. Currently timber buildings are being constructed to five floors. Generally these buildings are constructed from small section gauged timber, with the occasional building utilizing post and beam construction. Both design approaches are discussed by reference to existing buildings, as are the approaches taken by the New Zealand codes/industry. The major problem facing timber utilization in multi-residential building is sound transmission, particularly over the low frequency range. While the current code requirements for sound attenuation are met, building users report undesirable levels of 'neighbour noise'. The acceptable level of sound transmission is under review, and the expected recommendations will see the requirements increased. This change will place greater demands on timber buildings, demands that exceed present construction practice. Current New Zealand research on sound transmission is presented and reviewed.

Conference theme: Building technology
Key words: timber, multi-storey, residential, acoustics

INTRODUCTION

The 1992 Building Act (Building Act 1992) replaced a host of codes and local authority decrees. The intention of this change was to move from a prescriptive set of codes to a national code that was performance based, overcoming the problems of local interpretation and restrictions on new building types and materials. Existing codes could still be used, but they had to meet the new standards.

Prior to 1992 two codes controlled the height of timber buildings. NZS 3604 “Timber Framed Buildings” (NZS 3604) and NZS 1900 Chapter 5 “Fire Resisting Construction and Means of Egress”. (NZS 1900) Of these the fire code was the most restrictive, limiting timber buildings to two stories, in the Outer B fire Zone, with the provision for a mezzanine floor that did not exceed one third of the floor area below. (NZS1900) It was by exploiting the mezzanine provision that timber buildings to a height of three stories were achieved over 1/3rd of the buildings floor plate. The zoning requirement also limited the development of commercial timber buildings, restricting them in the main to motel buildings. (Figure 1)

Figure 1: Three storey motel building in timber, constructed prior to 1992

The 38th International Conference of Architectural Science Association ANZAScA
"Contexts of architecture", Launceston, Tasmania, 10–12 November 2004
1.1. NZS 3604 first introduced in 1981 and subsequently reviewed and upgraded in 1990 to engage with the ‘limit state’ approach. It was revised again 1994 and again in 1999. NZS3604 is recognised as a means of compliance with the 1992 Building Act. However, the fire code was replaced. This was perhaps the most significant change for the industry, opening the way for multi-storey timber buildings to be considered in all fire zones.

1.2. Design loading

Buildings in NZ are required to be designed to resist gravity, seismic and wind loads as specified in the New Zealand Loading Standard. (NZS 4203) the requirements vary throughout the country, depending on location—Wellington is in a region of the highest design seismic loading, and one of the highest wind loading conditions. Loading conditions are also influenced by the importance attached to the building, the fundamental lateral periods of the building, site subsoil conditions and the ductility provided by the completed structure.

1.3. The four buildings reported below were designed or constructed in the post 1992 environment. Two are essentially low rise, application/extension of NZS 3604, while the latter two describe (in limited detail) the high rise timber buildings requiring specific engineering design.

2. EDEN OAKS APARTMENT BUILDING. 1994

![Figure 2: Eden Oaks, East elevation, - car park in concrete structure to lower level, note long external sound paths from one unit to the other.](image)

The five storey apartment building (Figure 2) of twenty units is located in an inner suburb of Auckland City, and could be considered as the forerunner of buildings that introduced construction concepts that exceeded the restraints of NZS 3604. The four floors in timber were constructed on the suspended concrete floor of the parking level, a three sided concrete box. Column lines of the car park line up with the dividing walls of the first two levels of apartments. At these levels the apartments are single storey and have a plan width of 8.238 m. The two top levels have a plan width of 4.119 m. (centre to centre) Consequently the upper two levels have the party walls coming down into the middle of the single storey units below. These loads are taken onto timber beams set into the ceiling space. This is different as the common structural approach is to carry a load path vertically through to the foundations. While the exterior sound path due to the set backs and flanking walls is helpful the sound path between units due to the over lapping of occupancies may compromise the soundproofing.

2.1. The walls between the units are fully lined and essentially fully braced and where necessary additional ply bracing is included. This shear wall structure with a low period and high frequency is centred on elastic design using timber frame construction as per NZS 3604 both for gravity loading, seismic and wind loading. The NZS 3604 approach exploited in this building were confirmed against the requirements of NZS 4203 and NZS 3603.(NZS 3603) (Nicholls 1995). These are loading codes applied to specific designs, rather than more general, universal non-specific NZS 3604

2.2. Construction

The building is structurally tied (longitudinally and transversely) at the concrete deck level and the roof, so resisting wind load as a block. However, for sound attenuation reasons double stud walls from its neighbour separate each apartment. The boundary wall (W elevation) is tied through at each level with an acceptance of some reduction in acoustic standards between the corridor and the apartment. The ‘standard’ double stud 100x50 mm @ 600 cnts were used for all party walls or load bearing walls over all floors. Walls are upgraded to their shear wall function as necessary by the addition of plywood, nail fixed to the cavity to ensure no interference with the gypsum board linings, which act as part of the acoustic system. Tie down strapping (nailed galv. steel- a NZS 3604 detail) were placed at each end of these shear walls.

Floors utilized 250 x 50 mm pinus radiata at 600 cnts fixed with metal joist hangers. The inner space filled with 75 mm fibreglass insulation. Ceilings comprise one layer of 12.5 Firexle overlaid with further layer of Firexle 16mm thick, and supported on metal battens fixed via hangers to the u/s of the joists.

2.3. Only platform framing, rather than the balloon framing is used with the 19mm particleboard flooring being nailed off as a structural diaphragm. The outer sheet cladding was detailed to allow for cross grain settlement. As there are only three timber floors the amount of cross grain settlement would not be significant.

2.4. To meet the acoustic requirements multiple layers of gypsum plaster board were applied as detailed in the Winstone handbook. (Gib noise control systems 2000)

This approach met the air borne STC ratings required by the Code, while at the same time meeting the fire resistance requirements. The performance of the structure to absorb impact sound is not clear from the documentation. The author suspects that it would be difficult to achieve a satisfactory level with the floor system provided.

3. GULF VIEW TOWERS; AUCKLAND NZ

Gulf view Towers is a ten-storey residential apartment and car parking building. Five storeys of this building are constructed in timber, and five in reinforced concrete. Four and a half of these reinforced concrete storeys were originally a spiral deck type carpark building constructed
in the early 1960's, but not completed. Analysis of the existing building, from what records could be obtained, coupled with site investigations showed that a further concrete floor as a parking deck could be constructed on the existing or a five storey timber building. (Figure 3)

![Figure 3: Gulf View Towers, North Elevation.](image)

### 3.1. Structural Concepts

Due to the desire for extensive openings to the north and the height of the building, insufficient strength for an all timber approach using ply as the main system for shear resistance was not possible. The solution adopted was to combine the compression qualities of timber, with the tension qualities of steel. Timber if adequately restrained performs well in compression with relatively simple connection design, providing the butt joints of members are in direct bearing. Tension forces are difficult to cope with, particularly as the joint design is often complex, which may see the member failing in a sudden non-ductile manner. Steel on the other hand performs well in tension, jointing can be readily achieved, and can be schemed to fail in a ductile manner. (Figure 4)

![Figure 4: Schematic sketch of structural system from the South. Details of the internal and external ply shear wall.](image)

### 3.2. Loading

The gravity load supporting system consisted of a combination of long span proprietary floor joists and ordinary sawn timber floor joists, supported between load bearing timber framed walls, load bearing plywood sheathed shear walls and the occasional steel beam. Machine stress graded, kiln dried timber was used. Balloon framing techniques were used where load bearing studs are butt jointed and floor joists are fixed to the sides of the wall studs. This reduced cumulative perpendicular to the grain compression and shrinkage, which over a tall building could be significant if the construction method was based on the 'platform' framing method. The lateral loads in the longitudinal direction were resisted by a series of 'ply box' type construction shear walls, along the rear face of the building and a moment resisting frame consisting of 'ply box' construction columns with glue-laminated beams. The lateral loads in the transverse direction were resisted by a combination of 'ply box' type shear walls and 'internal ply wood' type shear walls. (fig 4)

Steel tie rods resist tensile forces in both the shearwalls and the moment resisting frame columns. These tie rods were anchored at each floor level using steel plates. Access points were left in the ply box type shear walls to ensure that a final tightening of the tie rod systems could be carried out prior to internal linings being placed. It is interesting to reflect on the Californian use of steel tension rods between concrete basement level and roof.

In California the purpose of such rods was to prevent the vertical movement of the building when subjected to vertical acceleration from earthquake forces. Both the 'internal plywood' and the 'ply box' type of shear wall operate in the same way. Shear forces are transferred to the reinforced concrete structure via the plywood panels. These panels are restrained from buckling by the timber framing, which also provides for the transfer of the shear flow from one panel to the next, and to support the gravity loads from the suspended floors, while the cantilever bending moment induced in the wall is resisted by the cluster of tension (steel) and compression (timber) members at the ends of the walls.

### 3.4. Construction method dictated basis of design

The construction method preferred by the contractor saw the construction on site of rigid plywood shear walls of approximately 10 m wide by 6 m high. To achieve erection without damage the panels were glued up using the West (epoxy) system. As this system produces non ductile behaviour the design approach was consequently

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(Nicholls 1996)
effects of a Maximum Credible Earthquake (MCE) situation verified that ultimately a ductile mode of failure would exist. This would be achieved by the yielding of the tension tie rods in both the moment resisting frames and the shear walls prior to any brittle type failure of the timber members.

The moment resisting frame formed with timber compression chord, steel tie rod moment resisting couple is utilised in the ply box columns. The chords are manufactured from glue laminated timber, and these pass continuously through the beam column joint with splices at mid span.- possible at mid span as the moments are small. Fabricated steel sections, anchor plates and coupling nuts connect the steel tie rods. Ply is then nailed over the entire surface, enclosing the steel anchor plates, and forming the ply faced columns. (Figure 5)

4. MARTIN SQUARE WELLINGTON NZ (MILBURN & BANKS 2004)

Accommodation Building for 130 students. Six floors of timber building on a concrete car park structure. Building footprint 21 x 31 metres (Figure 6)

4.1 Timber Super-structure Concept

The 6-level timber super-structure consisted of an approximately rectangular floor plate, braced by predominately plywood-lined walls in each direction. These walls are typically on the line between adjacent apartments and two of the boundary walls where they can run 6 levels through the super-structure without penetrations. In addition, there are some walls between studios, at approximately 4m centres, and the corridor, which are used as bracing walls. In the North-South direction, there are nine plywood-lined walls bracing the structure, in addition to one steel k-brace. In the East-West direction there are 10 plywood-lined walls bracing the structure in addition to two steel k-braces. These k-braces were used in order to maintain an even distribution of bracing elements across the floor plate, and to provide a high degree of torsional restraint to the structure. This required incorporating bracing into the perimeter face of the building which is pierced regularly by window openings. Plywood-lined walls would not be effective in such situations, where as the steel k-braces are. The k-brace lateral stiffness was set to approximately match that of a typical plywood lined wall. This entailed spacing the diagonal braces further apart than usual, to reduce the brace stiffness. This also allowed the braces to accommodate typical window openings.

The floors for each level consist of 19-mm plywood fixed to proprietary timber I section joists, built up of mechanically graded timber chords glued to a plywood web, and provide superior engineering properties. They are handled and fixed in the same way as sawn timber joists.

4.2. Concrete Sub Structure

The timber super-structure is connected to a suspended reinforced concrete slab and beam structure at level 1. This level is in turn supported by a series of reinforced concrete columns, and perimeter concrete basement walls. Because the lay out of columns in the bottom level is chosen to optimise car circulation and parking, the columns do not line up with the load bearing elements from the timber super-structure above. Accordingly the floor slab and beams are designed to resist the vertical loads arising from gravity and earthquake action. The slab also acts as a diaphragm and distributes the shear forces from the plywood-lined walls and k-braces into the perimeter concrete walls and some internal steel braces in the basement.

4.3. Timber framing.

All timber is MSG, grade F8, with 140 x 45 over the lower two levels and 90 x 45 over the upper 4 levels. Studs are designed to transfer the vertical loads from gravity down to the level 1 concrete deck and the plywood and nailing is designed to transfer the earthquake shear forces similarly. The Eden Oak apartment building used ex 100x50 over all levels, but on a double stud basis, rather than single studs as provided here.

4.4. Ply bracing

Ply bracing walls vary in length from 4 – 8 metres long, with the majority being 6.5 metres, providing an aspect ratio of about 2.4. Plywood thickness over the lower 2
levels is 19-mm, reducing to 15-mm over the central two levels and 12-mm over the top 2 levels. The plywood is nailed to timber studs using bright steel nails (not galvanized). Ductility of the wall is achieved by the bright steel nails bending (in response to lateral loading) when the load exceeds the design loading, hence achieving a displacement ductility factor of 4 as permitted in the New Zealand Timber Standard (NZS 3603:1993). Such ductility requires that other failure modes in the wall be contained, as the over-turning moment on the wall and the resulting tension and compression chord forces at the wall ends derived from the nail “over-strength” loads were too high. The resulting tension and compression chord forces exceed what timber members could comfortably resist. Consequently, steel posts were introduced to the ends of each wall, 125-mm square over the lower 2 levels and 89-mm square over the upper 4 levels, all concealed within the wall thickness. To achieve integration of the structural system, the timberply shear walls were bolted to the steel posts and in turn both steel post and bottom plate bolted to the concrete diaphragm at the car park level.

4.5. Floor wall junctions

At these junctions horizontal loads must be transferred to the walls, and subsequently to the floors below, along with the vertical loads. The practice of supporting the floors directly on top of the top plate is not appropriate for buildings of this height, or for that matter any exceeding three floors. The use of balloon framing provides an improvement to the platform construction method. (Multi-storey Timber Buildings Manual 2001) Two aspects are important here. In the day to day service condition the cumulative deformation of the timber across the grain due to loading or moisture change could see finishes damaged. In the event of earthquake attack the modulus of elasticity across the grain is far smaller than along the grain. Here the top and bottom plates are bolted to transfer wall shears, and the joists are suspended from a ribbon plate. The ply flooring is not continued through to the adjoining room. For sound reasons a saw cut in the floor separates the two areas. Where needed for the transfer of tension and shear forces, metal straps connect the two floors. In the Eden Oaks project there was no physical connection of this type, and the gap (larger than a saw cut) was filled with an acoustic seal. The detail (fig 7) shows the connection of walls and suspended floors at Martin Square.

Figure 7: Detail of wall/floor junction. (Ceiling is not shown.)

5. SOUND; IMPACT AND AIR BORNE IN LIGHT TIMBER FRAMED (LTF) BUILDINGS

All lightweight structures have issues with occupants hearing the neighbours. This problem is not limited to timber buildings as the drive to reduce weight and changes in construction methods have seen the same issues emerging in concrete and steel framed buildings. This lack of adequate acoustic isolation has emerged as a main source of occupant dissatisfaction in medium and high density housing. The problem is more acute in the timber buildings with their low mass and stiffness.

5.1. The New Zealand Building Act, being performance based set out, via the regulations the minimum levels to be achieved. The section that is of concern is G 6. Currently it calls for a Sound Transmission Class (STC) of 55 db, and an Impact Isolation Class (IIC) of 55. Achieving the current STC levels is possible, particularly through walls but the situation with floors is far more complex, and more exposed to inconsistent trade practice. Recommended solutions have been published by Winstone Wall Boards, (Gib Inter-tenancy Noise Control Systems 1998) for both wall and floor assemblies and these have been adopted as meeting the standards set in the Building Act. However those standards are considered by occupants as being too low. The situation with IIC is far more difficult to resolve and an area that research is being undertaken, as the demand for solutions with sufficiently improved performance is urgent if we are to avert rejection of LTF construction in favour of masonry or steel frame. The initial goal is to determine what techniques/assembly are required to render impact noise insignificant to building occupants.

The single figure STC and IIC ratings bundle a range of frequencies. Sound attenuation in buildings in the upper frequencies ranges are well represented by this approach, the lower frequencies are not and this is the major problem area. This is particularly the situation with floors, be they covered with carpet, other resilient covering or non at all. At present we do not know what will be the acceptable low frequency waveforms in building structure, or the construction configurations that will achieve acceptable levels of neighbour noise. Research is being carried out around building responses to frequencies lower than those typically addressed in regulatory documents. This is coupled with subjective investigations to establish an acceptable level of impact noise involving users subjected to typical impact sounds on a range of floor constructions, while occupying a representative environment. New structures are being investigated both with full-scale testing rigs and companion theoretical modelling. This work will also explore the sound and structural implications of the introduction of viscoelastic materials into the construction as part of the approach to develop passive energy dissipation solutions. The Swedish SodraSemi floor system and the SodraSinus framing systems are being tested for comparison methods with New Zealand construction methods and costs.

5.2. Site measurements of the Motel shown in figure 1 returned an STC rating of 50 db between walls and 35 db through the floor to the unit below, and an IIC rating of 56. The construction method was the same as for the Eden Oaks building. Several motels, in addition to the motel shown in fig 1, were tested, all had been constructed to
the Winstone Wall Board specification and none met the measured laboratory performance. While the local authorities accept that field results will be lower than laboratory conditions, (by about 5db) the approach with the testing planned will be to replicate the field conditions as closely as possible. This would include investigations of the degree of stiffness imparted to the floor by the end fixing, -the wall to floor junction.

5.3. Separation of units.
The majority of multi unit, owner occupied, timber buildings presently being constructed in New Zealand are low rise, three storeys with garaging at ground level and the balance of the unit over the two floors above. This strategy avoids the problem of floor transmissions. Separation of the units with double walls achieves the currently acceptable STC rating required by the Building Act. However, where multi-units with different owners are stacked above one another the transmission through floors, in particular, becomes a major issue. Physical separation of the ceiling from the floor above is an aspect being considered. The time share building in Tauranga an example of this approach, is informative on several levels. This building has been constructed from first floor up in a factory in Auckland, and then transported to the site. A distance of over 200 Km. Factory production, much like the car industry has provided an environment where construction tolerances are held to a minimum, and the modules are completed to final coat finish. The pricing advantage comes from the reduction in holding costs. Being essentially boxes, the ceiling has no connection with the floor/unit above. Further, each unit is supported clear of the one below by rubber isolation pads. Coupled with double inter-tenancy walls, the isolation of one unit from the other is maximised and sound transmission minimised.

CONCLUSIONS

The evolution of timber buildings in New Zealand from the limited range of single owner domestic to three storey motel buildings and then on to multi storey apartment buildings housing permanent residents has been brought about by the application of well defined and proven engineering principles. Two of the more adventurous designs clearly show the opportunities that timber can exploit. The Gulf view tower apartment building was uncommon, being built on an existing concrete parking building. The Martin Square building is on the other hand potentially a more general solution to the issues of high rise timber buildings. The upper height limit has not been reached. This building, and the majority of the taller buildings provide for temporary accommodation, and consequently issues of sound transmission while being important can be tolerated over the short term. The bulk of multi unit housing is limited to a row housing scenario comprising of buildings of not more than three floors that only have side wall connection. This has avoided the issue of through floor sound transmission. The resolution of sound transmission particularly through floors is the most pressing if comfortable multi-storey buildings in timber for permanent occupation are to be successful. The research programme outlined above will be attempting to provide solutions.

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