DESIGN ESSENTIALS FOR CONTROLLING MOVEMENT INDUCED STRESSES IN BUILDING MATERIALS

1. INTRODUCTION

The New Zealand building industry fields many thousands of claims and disputes relating to defective building work every year. Cracking of building materials is generally in the top 10 list. This document outlines the primary causes of cracking in buildings and provides some preventative solutions related to interior linings.

Why is cracking so important? What are the causes and who's to blame? Increased expectations from building owners! Cost of professional indemnity insurance! Cost of call-back and repairs! A willing legal profession and a plethora of media consumer watchdogs perhaps!

Most buildings develop cracks in their fabric. This most often happens soon after completion when materials are drying out. Most cracking of interior linings is not structurally significant but may be aesthetically offensive. On the other hand cracks in the external fabric may result in water penetrating to the interior. Buildings are subject to a wide range of forces or actions. Some are easily identified such as wind and earthquakes but others may be more subtle such as the effects of temperature and humidity.

Cracking is symptomatic of the stresses which can be imposed by these forces and for internal linings are essentially due to one cause – movement stress. Much can be done to minimise or even avoid cracking by recognising that in-service movement of building materials and components is inevitable and must be allowed for in design.[i]

2. REVERSIBLE MOVEMENT

Materials do not remain dimensionally stable in that they respond as the conditions continually change. Reversible or cyclic changes in the dimensions of a material can be due to:

- Temperature of the surrounding environment (air or adjacent materials)
- Relative humidity of the surrounding air
- Exposure to moisture (rain)

3. EXTENT OF MOVEMENT

The extent to which a material moves is dependent on factors such as:

- The properties of the material itself
- The degree to which temperature and/or RH changes
- The method of fixing or extent to which the material is constrained by adjacent materials

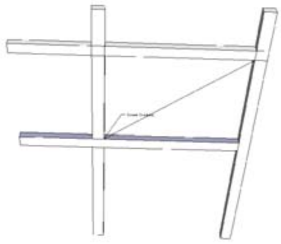
Table 1 Co-efficients of Expansion/Contraction of ***UNFIXED*** Materials

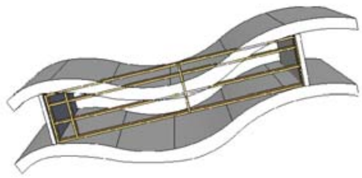
		Co-Efficient of Thermal	Co-Efficient of Hygrometric	mm/m/Change
PLASTERBOARD		0.0162	0.0072	
TIMBER		0.0034	0.012612	
STEEL		0.0121	0	

With most building materials, the normal cyclic (reversible) movements arising from seasonal or diurnal moisture and temperature changes will give a movement of approx. 0.25-0.5 mm per

metre length[ii].
Non porous materials such as metals and glass are only affected by temperature; Porous materials such as brick, concrete, timber and plasterboard are affected by moisture as well. Wood/timber framing is often a root cause for distress in plasterboard linings (see Section 6). As per **Table 1** above, the coefficients of thermal or hygrometric expansion of plasterboard are notable different to that of timber but have closer compatibility to light gauge steel. [iii]

4. HIGH RISE CONSTRUCTION



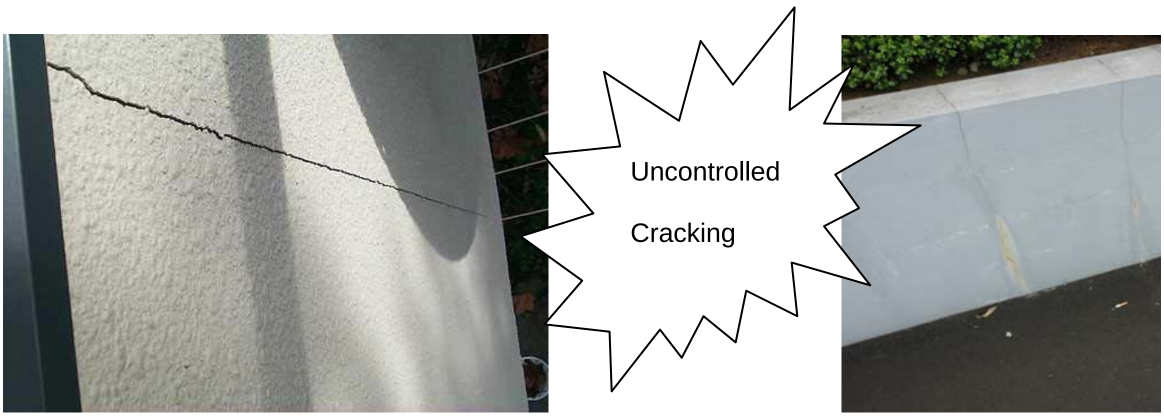


Multi storey high rise concrete or steel structures are subject to two specific forms of stress movement: racking and floor slab deflection. Racking is more likely in the upper floors of a building and/or where external columns are exposed to solar gain. Partitions walls and ceilings attached to these structural elements are thus subject to imposed stresses.
Designers can calculate the amount of anticipated racking movement or the anticipated floor defection based on initial dead load. Appropriate detailing of ceilings and walls/partitioning can then accommodate those movements. Designers should keep the following considerations in mind when considering perimeter relief or control joints in walls or ceilings:

- Problems are exacerbated when partitions or ceilings are tightly abutted or connected to the structure, rather than supported off them.
- For high rise building greater than 8 floors, a relief joint must be included at the perimeter of a partition to allow for anticipated vertical movement (incl Fire rated deflection heads).

5. RESULTS OF UNCONTROLLED MOVEMENT

The relief of stresses will occur at the weakest point. In the case of sheet materials, the cracking tends to occur at filled joints but may also occur in the body if shear or tensile forces are great enough.



6. RESIDENTIAL CONSTRUCTION

TIMBER

By accommodating wood movement right from the start with smart design and construction details, you can reduce time and expense when making good on your customer promise. Though it can't be eliminated, wood movement can be minimized, masked, and otherwise managed through attention to detail during design, installation, and finishing.

Wood and water

In the living tree, wood is saturated with water. Some of it fills the cavities of wood's hollow, straw-like cells; some of it swells the cells' walls. To increase its stiffness, strength, dimensional stability, and usefulness as a construction material, the water must be removed. During air- and kiln-drying of green timber, water evaporates first from cell cavities. But even when all the water in all the cavities is gone, the timber still hasn't shrunk. Only once water starts to leave the swollen cell walls will wood's dimensions diminish. For almost all kinds of wood, the moisture content (MC) marking the onset of shrinkage and the timber's greatest dimensions -the fibre saturation point- is about 30%. As moisture content falls below 30%, wood shrinks by about 1/30 of its total potential shrinkage for each one percentage point change in moisture content. The converse is true when dry wood picks up water and swells. Minimum dimensions are reached when wood is oven-dry, or at 0% MC. Typically, the in-service moisture content of wood in heated buildings can range from about 4% to 16% annually.[iv]

Because wood's straw-like cells are laid down in concentric circles (the growth rings), with their length parallel to the trunk of the tree, green timber shrinks by different percentages in length, width, and thickness during drying. With the exception of some kinds of abnormal wood, shortening along the grain, or longitudinal shrinkage, is so small (about 0.1% from green to oven-dry, expressed as a percentage of the green dimension) that it usually can be ignored. But shrinkage across the grain, whether around the growth rings (tangential shrinkage) or across them (radial shrinkage), is substantial, and has to be accounted for in the design of just about anything made from wood. Though shrinkage values vary widely among woods, tangential shrinkage averages about 8%; radial shrinkage, about 4%.

Unequal shrinkage and swelling in the longitudinal, tangential, and radial directions gives rise to the bowing, crooking, twisting, cupping, and other forms of warpage commonly seen in timber. It's also responsible for the wide checks and splits that open in large timbers used in post-and-beam construction. By cutting a saw kerf along the grain on a green timber's hidden face, you can encourage the widest check to open out-of-sight.

Shrinkage, not settlement

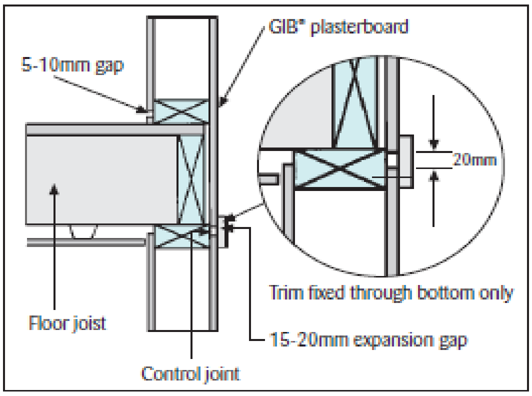
Contrary to popular belief, wood-frame buildings don't settle so much as they shrink. The year-round average equilibrium moisture content of studs, joists, and rafters in heated buildings is about 10%. But since framing timber is exposed to outdoor relative humidity, and possibly precipitation too, during shipment, storage, and construction, it's usually sold at a moisture content of 10% to 15%, so some shrinkage and warpage is inevitable.

Beginning once the structure is weather-tight, most shrinkage takes place during the first heating season. A two-story home built with Radiata Pine timber at 18% MC, for example, will shrink about 18mm in height as it dries to 10% MC. Virtually all the shortening is due to across-the-grain shrinkage through the depth of the perimeter joists and the thickness of the wall plates. And that can lead to a multitude of headaches for builders.

For starters, joist and plate shrinkage can cause buckling of plywood panels outside or of plasterboard inside, especially in stairwells and spaces with cathedral ceilings. The problem arises when a panel crosses the perimeter joist between floors so that it's fastened to the studs above and below the joist. Vertical shrinkage of studs can be virtually nil, but vertical shrinkage of joists and plates can be substantial. As the joist and plates shrink, studs on the two floors are drawn together, compressing the panel fastened to them. Being stiffer, plywood cladding buckles, while plasterboard may buckle or crush.

Solution: Break panels between floors. For plasterboard this may mean using an expansion joint at the joist and a control joint at the ceiling, or applying the plasterboard to steel clips/channels. For plywood cladding, it means providing a flashed gap of about 6-8mm at the panel ends.

Two Storey Full Height Wall with Expansion Joint



The initial shrinkage of framing can also lead to roof leaks when chimney flashing is rigidly -and thus incorrectly- connected to both the masonry and the wood frame. We've read one case history in which casement windows on the top floor of a three-story apartment building clad in brick wouldn't open after the first heating season because the platform-framed floors shrank below the openings in the masonry veneer.

Framing members that bulge out of the plane of a wall, floor, or ceiling as they dry often contain abnormal wood that shrinks excessively along the grain (ten or more times as much as normal wood), causing timber to crook or kink. One kind, juvenile wood, forms around the center of trees for up to the first twenty years of growth, so just about all timber sawn near the pith of a tree contains it.

Another type, compression wood (See photo right), forms on the bottom of branches and on the underside of leaning softwood trees such as Radiata Pine and is a major contributor to extraordinary longitudinal shrinkage and expansion in timber decking and studs. [v]

Typical shrinkage values for radiata pine (green to 12% moisture content)

Direction	Shrinkage (%)	
	Normal wood	Compression wood
Tangential	4.0	Not determined
Radial	2.0	Not determined
Longitudinal	0.1	0.24

Diagnosing diagonal cracks

Diagonal cracks occasionally appear in plasterboard at the corners over windows and interior doors. In some cases, over fastening is to blame; in others, the use of grooved jambs is the cause.

But beware, there's one trap you can fall into when applying plasterboard to timber framing fired onto a structural steel beam or column. Beware of the differential movement between the steel, timber and plasterboard.

Cracking of board due to underlying differential movement

Stopping the popping

The familiar fastener pop was probably the most common plasterboard problem that cropped up when studs and joists shrink. When first fastened, plasterboard is driven tightly against framing.

But as the wood between the fastener tip, whose position is fixed, and the edge of the framing shrinks, it pulls away from the back of the panel, leaving a small gap between framing and panel. Later the panel face closes the gap, forcing the fastener head to lift. Pops are fewer and less pronounced with screws versus nails.

Solutions: First, for the same holding power, screws are shorter than nails, so there is less wood between the screw tip and framing face to shrink. And secondly, it takes higher pressure to force plasterboard along a threaded shank than it does to slide it along a smooth one. Thirdly the simple solution to prevent popping in ceilings is to specify light gauge steel battens rather than timber.

7. WHAT'S DIFFERENT NOW?

Every building is unique and numerous factors may combine to produce the observed defect.
One factor is clear which is that the weather patterns around the country have changed. Whilst the issue of expansive or reactive clay soils is well established, this when combined with the changes in weather conditions, is resulting in increased incidence cracking both internally and externally. Skillion roof construction also introduces the element of small cavities which quickly react to significant swings in temperature. BRANZ research into air movement in a variety of skillion roof designs in 1994 found a surprisingly good rate of air movement but inherently the smaller volume of air in the cavity will heat up quicker and to higher temperatures than conventional pitched truss roof designs.[vi]

8. RESEARCH

One piece of research was of paramount importance in improving our understanding of the causes for 'joint peaking' and cracking of linings in residential buildings:

'Plasterboard peaking & cracking under timber roof trusses'
Prof Bob Milner - Monash University in Melbourne 1999. [vii]
This paper was concerned with an experimental investigation into the phenomenon of plasterboard peaking, the unsightly undulations and cracks which develop in ceilings as a result of moisture movement. It is shown that the peaking is caused by the differential expansion / contraction rates which occur under seasonal moisture change of plasterboard and timber to which it is attached. The differential movement is accommodated by a combination of sheet stressing and joint movement. Where the joints are formed by flexible joining tapes the accommodation is almost entirely within the joint with high joint movements. Where more rigid joints are formed, for example with back blocking, more sheet stressing and less joint movement arises. The construction of joints with tapes on the underside only leads to high joint movement and the unsightly rotations characteristics of peaking.

Conclusions
Peaking and inverse peaking are the result of differential shrink-swell rates of plasterboard and timber. It does not matter which of them expands most, it is the differential which causes peaking. In fact, the longitudinal expansion rates of both timber and plasterboard are both quite small.
The practice of forming joints by a tape on the underside only of joints tends to exacerbate inverse peaking action. It tends to restrain the joint eccentrically and thereby induce a joint moment and consequent rotation characteristic of peaking undulations.
Solution: Back blocking counteracts both inverse peaking rotations and reduces nett joint movement by progressively stretching the plasterboard sheet between joints.

Other Research
In the USA Michael Jundt, a registered structural engineer in Fresno, Calif., worked closely with a group in its effort to pinpoint the cause of the 'plasterboard' cracking. According to Jundt[viii],

the use of juvenile, rapidly grown timber in truss assemblies makes them much more responsive to extreme humidity fluctuations. Framing cut from the center of a tree is more reactive to humidity changes, as is framing cut from rapidly grown trees, as evidenced by wide growth rings.

It's not the heat, it's the humidity

Both research groups had certain expectations as to what the testing would bear out, but they were caught off-guard by the results. While it was expected that temperature fluctuations—which cause nearly all building materials to expand and contract—were a likely contributor, temperature changes alone did not account for an appreciable amount of movement. Both wood framing and plasterboard have similar thermal coefficients of expansion, meaning they expand and contract in response to changes in temperature at pretty much the same rate. However, the groups learned that when you add a significant change in humidity to environmental conditions, certain wood framing members are far more responsive by expanding or contracting to a much greater degree than gypsum plasterboard. As the moisture content of timber increase, the framing expands—in all dimensions—pulling apart any wallboard attached to it. When wood framing dries, it contracts, compressing sheets of wallboard together.

Fortunately, the expansion or contraction does not occur every time the humidity shifts. Both groups noted that humidity levels must change by at least 50 percent and must be maintained for a prolonged period of time. The Australian research team were able to introduce cracks in their test assembly by changing the humidity of the climate chamber from 20 to 90 percent, maintaining the higher level for 18 days. Similarly, the U.S. group's electronic monitoring of Las Vegas homes found that a change of 50 percent in relative humidity lasting for at least 30 days was needed to cause a significant change in the moisture content of framing members, resulting in dimensional movement.

Solution: Jundt reported that installing resilient (light gauge steel) channel provided the only effective means of remedying problems in the ceilings of troubled homes, and that—as a preventative measure—it's a relatively cheap and practical way of keeping problems at bay.

9. DESIGN STRATEGIES

Fundamentally this comes down to the following:

- Specify adjacent materials with similar movement characteristics
- Strengthen those Weak Points
- Isolate those Stresses

In residential construction we are somewhat fortunate that the NZ Building Code Clause E2/AS1 11.2a (ii) calls for timber framing to be at a maximum of 18% at the time of lining (for KD framing as per NZS 3602). This reduces the issues apparent when the use of 'green' timber was widespread up until the mid 1990's.

Standards - AS/NZS2589[ix]

This Joint NZ & Australian Standard is not called up in the NZBC but is widely referenced in MasterSpec. It contains information for designers including requirements for control joints (and maximum centres for such).

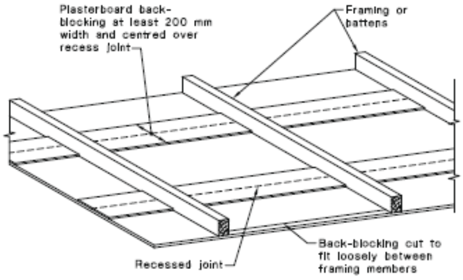
'Strengthen those Weak Points'

By this we mean the paper taped joints. In large ceilings AS/NZS 2589 stipulates that *all sheet end butt joints are backblocked* (essentially reinforcing the joint).

Sheet end Butt joint backblocking

Level 4

Backblocking is required for the *edge or recess joints* in ceilings specified to Level 4 for any area with 3 or more recessed joints (i.e. 4.8m wide)
NOTE: Backblocked *recess joints* are *not* required when a suspended ceiling or steel clip/batten system is used as these enable stress isolation.



Recess/Taper joint backblocking

Level 5

All recessed joints shall be backblocked regardless of ceiling support system.

'Isolate those Stresses'

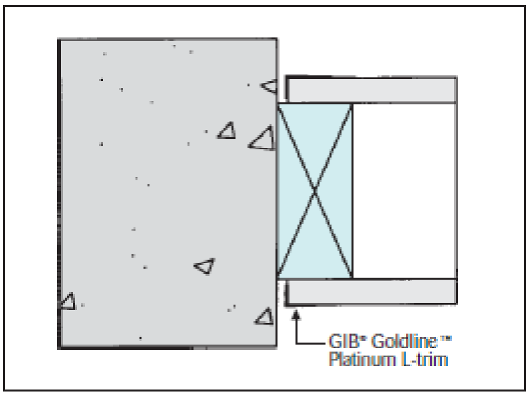
Raked Ceilings

- Metal Ceiling battens fixed at maximum 600mm centres with clips. This method gives a degree of separation between timber structure and the plasterboard diaphragm.
- 13mm Plasterboard for enhanced stiffness and improved quality of finish
- Perimeter relief

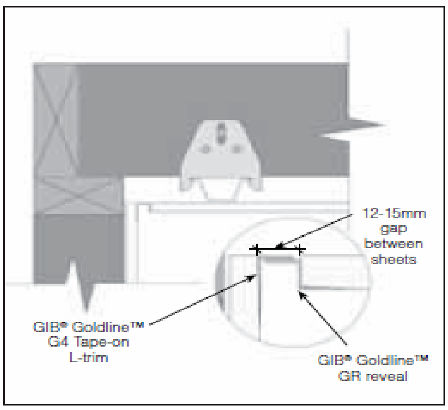
Control Joints

We commonly see the application of control joints in concrete, concrete masonry or fibre cement sheet but not in plasterboard linings. Why Not? The same theories apply for large runs or areas of *any building material,* including plasterboard or fibrous plaster sheeting. Control joints are also required where differing structural materials abut each other such as steel/concrete or timber/fibre cement or brick/fibre cement etc.

Masonry Junction Timber Frame



Perimeter relief using GIB® Goldline™ Tape-On Trims



Joint Position	Maximum Centres
Walls	9 metres
Ceilings	9 metres (without perimeter relief) 12 metres (with perimeter relief)

Walls & Ceilings
Control joints:

Insert Control Joints in ceilings at junctions of hallways and large open spaces

---

[i] Cracking and Building Movement, Dickinson & Thornton, 2006
[ii] BRANZ Bulletin 418 July 2001 'Providing for Thermal and Moisture Movement'
[iii] Cracking and Building Movement, Dickinson & Thornton, 2006
[iv] NZS 3602 Timber & Wood Based Products for use in Building
[v] Wood Processing Newsletter SCION July 2003 Simpson & Turner
[vi] 'A Field Study of moisture performance of roofs etc.' Technical Report 127. 1994 Cunningham et al
[vii] 'Plasterboard Peaking and Cracking under Timber Roof Trusses' 1999 - Prof H Robert Milner, BE, MEngSc, PhD, FIEAust, AIWSc and CY Adam, BE, MEngSC Monash Engineering Timber Centre, Monash University, Australia
[viii] 'Walls & Ceilings' Magazine 'Drywall Cracking on a Global Scale' By Greg Campbell March 9, 2001
[ix] AS/NZS2589 2007 – Gypsum Linings - Application & Finishing