BRANZ

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DESIGNING FOR THERMAL AND MOISTURE MOVEMENT

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- This Bulletin looks at the cyclical or reversible movement that occurs in building materials as the environmental conditions they are subjected to change.
- It provides useful information so this thermal and moisture movement can be predicted and allowed for in the building design.
- This Bulletin replaces Bulletin 418 *Providing for thermal and moisture movement.*

1.0 INTRODUCTION

1.0.1 A building is a complex structure of active parts, so materials, fixing and jointing techniques, waterproofing methods and tolerances must all take account of the movement that will occur.

1.0.2 Materials that deform extensively as temperature or moisture levels change may have limited external application or will need to be protected from harmful effects. Each element or material must be assessed for:
- its potential for deformation
- its interaction with adjacent or attached materials
- potential chemical interactions.

1.0.3 A contractor cannot be expected to construct a building that will remain free of failure if the designer has not successfully designed for movement. However, the builder must be aware of the design intentions so that movement design details are not compromised during construction.

1.0.4 This Bulletin looks in detail at the cyclical or reversible movement that occurs in building materials as the environmental conditions they are subjected to change. The information provided will allow this movement to be predicted and allowed for in the building design.

1.0.5 The Bulletin does not cover movement of materials that is not cyclical, for example, irreversible movement such as curing shrinkage of cement-based materials.

2.0 REVERSIBLE MOVEMENT

2.0.1 Materials do not remain static – hence the term 'reversible movement'. They respond as the conditions they are exposed to continually change.

2.0.2 Reversible movement occurs when a material's size changes in response to changes in:
- the temperature of the surrounding environment
- the amount of direct exposure to sun
- relative humidity (moisture content) of the air
- surrounding moisture conditions, for example, when rain wets materials.

2.0.3 The amount of movement that occurs will depend on:
- the material itself
- the colour of the material
- how much the temperature and moisture conditions change
- the way the material is installed, constructed or protected.

2.1 THERMAL MOVEMENT

2.1.1 Materials expand when heated and contract when cooled – some more significantly than others. Table 1 lists the movement that results from temperature change for a number of common building materials.

2.1.2 The amount each material changes in size varies widely and is influenced by:
- colour – darker colours make materials hotter, so a darker-coloured material will expand more than the same material finished in a lighter colour
- direct exposure to the sun – a material shaded for some or all of the time may not get as hot
- the amount of insulation behind the material – the more insulation, the hotter it will get
- the temperature when the material was installed
- the way the material is fixed in place – whether it is rigidly fixed or whether movement can occur
- the dimensions of the element – it is a requirement for a number of building materials that the installed size (length or area) be limited by the installation of movement control joints.

2.1.3 Each material has a coefficient of linear expansion – this is the figure that defines how much movement will occur in a particular material. It is usually expressed as a number x 10^{-6}, but Table 1 shows this figure translated into an actual increase or decrease in size (in mm) for every metre of material length and for every degree centigrade change in temperature (mm of movement/m length/°C temperature change).

2.1.4 Two examples of thermal movement:
- A spandrel panel installed on a cold winter's day will initially expand more and contract less from its installed size than one installed in summer because conditions were colder when it was installed. If installation temperatures are not allowed for when joints between panels are sized, sealant failure will occur because the movement capability of the sealant is exceeded.
- Metal cladding installed on the north side of a building will be subject to more expansion and contraction than the same cladding on the south side because it will get hotter. Similarly, a material with a dark finish will move more than the same material with a light-coloured finish.

2.1.5 Movement resulting from temperature change is more critical where:
- larger units with fewer joints are used
- materials that have different thermal expansion rates are bonded or fitted together
- thin materials that react quickly to temperature change are used
- adjacent similar elements vary in size, for example, large and small cladding panels used together.

2.2 MOISTURE MOVEMENT

2.2.1 Moisture movement only occurs in materials that are hygroscopic (porous or open-celled). This means that they are able to absorb and release moisture from their cell structure when they are wetted and as the relative humidity of the surrounding air changes – see Table 1 for movement characteristics.

2.2.2 As the relative humidity increases, materials swell, and as it decreases, they shrink. Moisture movement can also result from wetting from exposure to rain, leaks or construction moisture.

2.2.3 Specific points to note:
- Timber will only shrink and swell when the cell walls absorb and release moisture.
- Wood-based products such as particleboard and medium-density fibreboard behave like timber but do not completely return to their original size (particularly thickness) after initial wetting (by liquid water) and subsequent drying out – there is always some permanent swelling.

2.3 FACTORS INFLUENCING REVERSIBLE MOVEMENT

2.3.1 There are a number of influences on the way moisture or temperature changes can affect a particular material.

2.3.2 Materials that are free to move (other than timber) usually only change in size and do not deform with moisture and temperature changes. However, very few instances of movement are this simple, and changes in size often cause a change in shape. As an organic product, timber is different, because a uniform change in conditions may cause deformation in the material as a result of internal variations in its properties, for example, bowing and cupping. The amount of movement varies in relation to the grain of the material.

2.3.3 Where a material is rigidly fixed in place, i.e. where it is unable to move freely, it will always deform, generating stresses in the material and the fixings. A typical example is a rivet-fixed length of thin metal buckling on a very hot day.

2.3.4 Deformation from movement can also occur in these situations:
- Temperature or moisture influences are not uniform, for example, when the front and back of a material are subject to different moisture or temperature conditions.
- Temperature or moisture gradients are created across a material thickness when different temperature and/or moisture conditions affect each face. Each face may move differently, causing the material to deform and, when fixed, develop internal stresses – the amount of potential distortion depends on the type of material, the temperature difference, the coefficient of movement and the thickness.
- Two materials that respond differently to moisture and temperature changes are bonded together – this causes the element to bend or buckle, creating stress in both materials and in the fixings.
- Fixings used to attach a material or component cannot accommodate the movement.

2.3.5 An essential strategy when using finishing timbers is to ensure time is allowed for on-site conditioning so they are installed at or close to the in-service moisture content.

3.0 DESIGN STRATEGIES

3.0.1 Where movement is not allowed for in the building design, the end result can be:
- leaks
- cracks in joints, panels and finishes
- obvious distortion and buckling of materials
- tearing of sealants
- premature failure, such as loss of adhesion of sealants, adhesives and finishes
- damage such as loss of shape, which detracts from appearance
- loss of structural and material integrity
- fixing failure.

3.0.2 Movement need not cause failure, but insufficient knowledge of movement and lack of allowance for it is a known cause of building defects and failures.

3.0.3 The two design strategies are to:
- design to accommodate the movement, so the movement can occur freely, or
- design to contain the movement by rigidly fixing materials.

3.1 ACCOMMODATING MOVEMENT

3.1.1 The first step to accommodating building movement is to calculate or predict the amount of movement that is likely to occur. This can be done using information provided in this Bulletin on the movement characteristics of materials and expected upper and lower local temperatures and relative humidity conditions (see 3.3 and 3.4). Also make sure that:
- effects such as colour of materials and location are evaluated for the specific site conditions and the component location at the design stage and allowed for
- the likely temperature of the element at the time of installation is estimated and tolerances set accordingly.

3.1.2 A movement calculation may not be necessary for all building materials but must be done where failure to allow for movement could result in loss of performance. Typical examples of where a movement calculation may be required are:
- long runs of metal, particularly aluminium, and translucent roofing to ensure that the fixing method allows for the movement that will occur
- guttering, particularly where the ends of the gutter abut a wall surface
- cladding panels, particularly when lightweight and fitted into a heavyweight structure
- where materials with different movement characteristics are used next to each other.

3.1.3 Other factors to consider when detailing to allow for movement are ensuring that:
- loadbearing, structural and fixing systems are not compromised by detailing that allows movement
- the integrity of waterproofing, coating systems, sound insulation and fire protection systems are not compromised
- details allow for factors such as dirt build-up that, if ignored, might inhibit movement
- movement will be able to occur throughout the life of the building.

TABLE 1. REVERSIBLE MOVEMENT DATA				
Material		Reversible thermal movement	Reversible moisture movement	
		mm/m/°C	mm/m length	% change
CEMENT-BASED				
Concrete		0.010–0.014	0.2–0.6[a]	0.02–0.06[a]
Lightweight concrete		0.008–0.012	0.3–0.6[a]	0.03–0.06[a]
Cement mortar		0.010–0.013	0.2–0.6[a]	0.02–0.06[a]
Concrete blocks		0.006–0.012	0.2–0.4[a]	0.02–0.04[a]
Cellulose fibre-cement sheet		0.008–0.012	1.4–2.7[a]	0.14–0.27[a]
Glass fibre-reinforced cement		0.007–0.012	1.5–2.7[a]	0.15–0.27[a]
CLAY-BASED				
Ceramic tile		0.005–0.008	[b]	[b]
Clay brick		0.005–0.008	0.1–0.5[a]	0.01–0.05[a]
Porcelain tile		0.005–0.007	[b]	[b]
STONE				
Granite		0.008–0.010	0.1–0.15[a]	0.01–0.015[a]
Limestone		0.003–0.004	0.1[a]	0.01[a]
Marble		0.004–0.006	[b]	[b]
Slate		0.009–0.011	[b]	[b]
WOOD AND WOOD-BASED – see also Tables 4 and 5				
Hardwood	with grain	0.004–0.006	8–95[c,d]	0.8–9.5[c,d]
	across grain	0.03–0.07	5–40[d,e]	0.5–4.0[d,e]
Radiata pine	with grain	0.004–0.006	39[c,d]	3.9[c,d]
	across grain	0.03–0.07	21[d,e]	2.1[d,e]
Douglas fir	with grain	0.004–0.006	49[c,d]	4.9[c,d]
	across grain	0.03–0.07	28[d,e]	2.8[d,e]
Macrocarpa	with grain	0.004–0.006	32[c,d]	3.2[c,d]
	across grain	0.03–0.07	18[d,e]	1.8[d,e]
Western red cedar	with grain	0.004–0.006	50[c,d]	5.0[c,d]
	across grain	0.03–0.07	24[d,e]	2.4[d,e]
Rimu	with grain	0.004–0.006	42[c,d]	4.2[c,d]
	across grain	0.03–0.07	30[d,e]	3.0[d,e]
Particleboard	width/length	0.03–0.04	3–5.5[f]	0.3–0.55[f]
	thickness	0.03–0.04	80–150[f]	8.0–15.0[f]
Hardboard	width	0.010	1–2[f]	0.1–0.2[f]
	length	0.010	2–3[f]	0.2–0.3[f]
	thickness	0.010	70–90[f]	7.0–9.0[f]
MDF	width/length	[b]	2.5–3.5[f]	0.25–0.35[f]
	thickness	[b]	110–130[f]	11–13[f]
Plywood	with grain	0.02	1.5–2.0[g]	0.15–0.2[g]
	across grain	0.02	2–3[g]	0.2–0.3[g]
Softboard	width/length	[b]	1–2[h]	0.1–0.2[h]
	thickness	b	80–100[h]	8.0–10.0[h]
GYPSUM				
Plasterboard		0.018–0.021	0.166	0.4
METALS				
Aluminium		0.024	No effect	No effect
Brass		0.018–0.021	No effect	No effect
Cast iron		0.010	No effect	No effect
Mild steel		0.012	No effect	No effect
Copper		0.017	No effect	No effect
Lead		0.030	No effect	No effect
Stainless steel – ferritic		0.010	No effect	No effect
Stainless steel – austenitic		0.018	No effect	No effect
Zinc	With rolling	0.03	No effect	No effect
	Across rolling	0.07	No effect	No effect

TABLE 1. REVERSIBLE MOVEMENT DATA (CONTINUED)			
Material	Reversible thermal movement	Reversible moisture movement	
	mm/m/°C	mm/m length	% change
RUBBER AND PLASTICS			
Asphalt	0.03–0.08	No effect	No effect
Acrylic	0.03–0.09	No effect	No effect
Epoxy	0.05–0.09	No effect	No effect
Glass fibre-reinforced plastic	0.02–0.035	No effect	No effect
Melamine formaldehyde	0.02–0.05 low density	No effect	No effect
Neoprene	0.19–0.21 high density	No effect	No effect
Polycarbonate	0.06–0.07	No effect	No effect
Polypropylene	0.08–0.11	No effect	No effect
Polyethylene	0.16–0.20	No effect	No effect
Polystyrene EPS (16 kg/m^2)	0.005–0.007	[b]	[b]
Polystyrene EPS (24 kg/m^2)	0.007	[b]	[b]
Polystyrene XPS longitudinal	0.008	[b]	[b]
Polystyrene XPS transverse	0.006	[b]	[b]
Foamed rigid polyurethane	0.002–0.007	[b]	[b]
PTFE	0.05–0.10	No effect	No effect
PVC (including uPVC, cPVC)	0.04–0.07	No effect	No effect
GLASS			
Ordinary	0.008–0.009	No effect	No effect
Tinted or solar control glass	0.008–0.009	No effect	No effect
Clear float	0.008–0.009	No effect	No effect
Low-E glass	0.008–0.009	No effect	No effect

a. Values based on the difference in size from extreme wet (but not submerged) to extreme dry for external exposures.
b. No data found.
c. Flat sawn (tangential) shrinkage.
d. Values based on the change from green to 12% moisture content.
e. Quarter sawn (radial) shrinkage.
f. Values based on 65% and 95% relative humidities.
g. Values based on 33% and 90% relative humidities.
h. Values based on 50% and 90% relative humidities.

TABLE 2. GUIDE TO SURFACE TEMPERATURE VARIATION FOR INSULATED ROOFS[1]		
Colour and material	Roof surface temperature	
	Daytime for a 20°C air temperature[2,3]	Night-time for a 0°C air temperature[4]
Black steel	70°C	-10°C
Red steel	63°C	-5°C to -10°C
Unpainted steel	60°C	
Aluminium painted steel	50°C	
Cream steel	48°C	
White steel	44°C	
Concrete	30°C to 35°C	-5°C

1. Installing insulation material immediately behind the roofing material will raise the surface temperature of the material.
2. Roof surface temperatures will increase as the air temperature increases.
3. Air temperatures in many parts of New Zealand will be significantly more than 20°C in summer (for example, in Alexandra, Ashburton and Blenheim).
4. Air temperatures in many parts of New Zealand will be less than 0°C in winter.

TABLE 3. ESTIMATED EXTREME TEMPERATURES ON BUILDINGS		
Building element	Extreme temperature °C	
	Maximum	Minimum
Light-coloured precast concrete or exposed concrete eaves or floor slab edges	50°C	-5°C
Dark-coloured precast concrete or exposed concrete eaves or floor slab edges	65°C	-5°C
Light-coloured masonry wall	50°C	-10°C
Dark-coloured masonry wall	65°C	-10°C
Light-coloured ceramic tiles with insulation behind	60°C	-10°C
Dark-coloured ceramic tiles with insulation behind	80°C	-10°C
Light-coloured metal with insulation behind	60°C	-10°C
Dark-coloured metal with insulation behind	80–90°C	-10°C
Light-coloured glass with insulation behind	60°C	-10°C
Dark-coloured glass with insulation behind	80°C	-10°C
Black metal panel exposed behind single-glazed clear glass with insulation panel behind	120°C	0°C
Black metal panel exposed behind double-glazed clear glass with insulation panel behind	80°C	-10°C
Aluminium curtain wall mullion (white or natural colour)	50°C	-5°C

TABLE 4. ACTUAL TIMBER SHRINKAGE FROM GREEN						
Dried to moisture content of	Shrinkage in mm for					
	150 mm flat-sawn board (tangential)			150 mm quarter-sawn board (radial)		
	20%	15%	10%	20%	15%	10%
Cedar	2.5	5.0	7.4	1.3	2.6	4.0
Douglas fir	3.4	5.9	8.3	2.0	3.4	4.8
Radiata pine	2.9	4.4	5.8	1.6	2.4	3.2
Rimu	3.5	5.2	7.0	2.5	3.7	5.0

TABLE 5. FIBRE SATURATION POINTS FOR NZ TIMBERS	
Species	FSP %
Douglas fir	27
Eucalyptus	30
Kahikatea	28
Kauri	26
Macrocarpa	25
Matai	24
Radiata pine	29
Red beech	24
Redwood	25
Rimu	27
Silver beech	30
Tawa	30

3.1.4 Failures will occur if:
- the allowance for movement is inadequate, which leads to excessive stress levels, cracking, tearing or breaking in materials and finishes
- gaskets, sealants and fixings are unable to accommodate the amount or rate of movement
- poor maintenance practices or detailing allow corrosion and dirt to restrict movement.

3.1.5 Typical strategies used to accommodate movement are:
- over-drilling fixing holes
- using slotted fixing holes
- using sliding clips
- using sealant joints, provided the joints are correctly designed and a maintenance programme is in place to ensure the sealant remains effective. (Criteria for sealant joints include correct width to depth ratio to give an hour-glass shape, adhesion to the sides of the joint only and, ideally, protection from UV rays.)

3.2 CONTAINING MOVEMENT

3.2.1 To contain movement, building elements are rigidly assembled so responses to temperature and moisture are accommodated by deformation of and/or development of stress in the element. Rigidly fixing a material reduces the amount of movement that can occur, for example, using rivets to fix to metal items.

3.2.2 When a material is rigidly fixed and the stresses created exceed the strength of the material, it will fail.

3.2.3 When designing to contain movement:
- the expected extremes of temperature and moisture must be accurately determined so that the expected movement and the effect of that movement can also be determined
- the acceptable amount of deformation must be defined
- elements or materials being fixed through or to must be able accommodate the stress generated – if the stress generated by expansion or contraction is higher than the strength of the fixing or the item(s) being fixed, those materials will tear or deform.

3.2.4 Designing to contain movement requires specialised (expert) knowledge of the materials being used to determine:
- the point at which deformation ceases to be elastic (reversible)
- the stress relaxation characteristics of the material
- the permissible stress and the level of acceptable deformation for that material
- the properties of a material under expansion and contraction, for example, generally plastics have good impact resistance when warm but become brittle on cooling.

3.3 THERMAL MOVEMENT – WORKED EXAMPLES

PVC spouting installation

Calculate expansion and contraction over a 24-hour period so that sufficient allowance can be made to accommodate the movement. If the spouting is prevented from expanding or contracting it will deform and possibly crack.

• Installed length of spouting	10.0 m
• Daily range of surface temperature	say 40°C
• PVC thermal movement (Table 1)	0.07 mm/m/°C
• Installation temperature	12°C

Calculation of maximum movement over a year:
= length (m) x temperature range x thermal movement = 10 x 40 x 0.07 = 28 mm

If the surface temperature varied from -10°C to +30°C, for an installation temperature of 12°C the daily movement would be:

- expansion = 10 m x 18°C temperature range x 0.07 mm/m/°C = 12.6 mm
- contraction = 10 m x 22°C temperature range x 0.07 mm/m/°C = 15.4 mm

Aluminium long-run roofing

Calculate movement over a 24-hour period to determine allowance for movement to prevent buckling initially and possible tearing at fixing points.

• Normal length of roofing	15.0 m
• Daily range of surface temperature	60°C
• Thermal movement (Table 1)	0.024 mm/m/°C

Calculation of maximum movement:
= length (m) x temperature range x thermal movement = 15 x 60 x 0.024 = 21.6 mm

Accommodating large annual changes in temperature

For example, a 65 m dark-coloured steel roof in Blenheim may, over a year, range from -10°C surface temperature on a cold winter's night to an estimated +90°C when air temperatures exceed 30°C on a hot summer's day. Roofing materials such as membrane roofing systems will be subject to stress as a result of thermal movement in the supporting plywood substrate.

Calculation of the potential maximum contraction and expansion over an annual weather cycle:
= thermal expansion coefficient (in mm/m/°C) x temperature range (in °C) x length of the roof = 0.012 mm/m/°C x 100°C x 65 m = 78 mm

For an aluminium roof, which has higher thermal movement, the calculation would be:
= 0.024 mm/m/°C x 100°C x 65 m = 156 mm

3.4 MOISTURE MOVEMENT – WORKED EXAMPLES

Unfixed sheet of particleboard flooring

Calculate expansion due to a change in moisture content resulting from a long period of damp weather (95% RH). The consequence of moisture movement in particleboard is a swelling of the sheet .

• Sheet size	2.4 m x 1.2 m x 20 mm	
• Moisture movement (Table 1)	length and width	5.5 mm/m length
	thickness	150.0 mm/m thickness

Calculation of expansion due to moisture:
= length (m) x moisture movement factor (mm/m) = 2.4 x 5.5 = 13.2 mm
= width (m) x moisture movement factor (mm/m) = 1.2 x 5.5 = 6.6 mm
= thickness (m) x moisture movement factor (mm/m) = 0.02 x 150 = 3.0 mm

If the sheet had been fully nailed to the substrate, movement with respect to length and width would be approximately half the above figures. The thickness increase would still be as above.

Moisture movement in timber

$$\text{dimensional change} = \frac{\text{average shrinkage green to 12\% x material size x \% change in moisture content}}{\text{(FSP - 12) x 100}}$$

Calculation for radiata pine:

• Tangential shrinkage (Table 1)	3.9%
• FSP (Table 5)	29%
• Material size (width)	100 mm
• Change in moisture content	10%

Width shrinkage:

$$= \frac{3.9 \times 100 \times 10}{(29 - 12) \times 100} = \frac{3900}{1700} = 2.3 \text{ mm}$$

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