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Short Course
Response of Materials and Structures to Fires
May 20 - 22, 2009
Carleton University, Ottawa, Ontario

Fire Resistance of Light Frame Steel Construction

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Background

- Light steel frame construction is widely used in one- to four-storey buildings, most often for residential occupancies
- The following slides show some examples of the lightweight steel framed constructions used in practice.

Lightweight Steel Construction

Lightweight Steel Construction

Background

- Walls and floors in multi-family dwellings are used for fire containment and safety of occupants and firefighters
- To act as a fire barrier, walls and floors must satisfy the fire resistance requirements in the NBC
- Walls and floors enclosing dwelling units must satisfy other requirements, including:
  - structural support
  - earthquake and wind resistance
  - noise transmission reduction

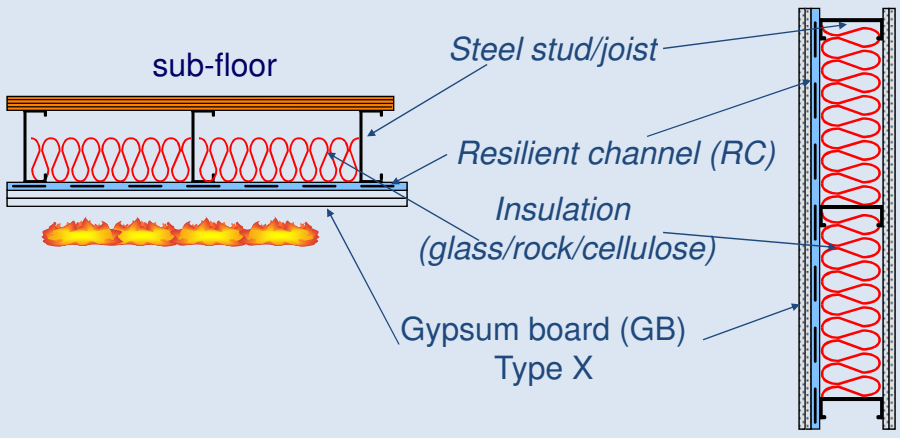
Description

- Light steel frame construction includes light steel framing, such as cold-rolled light steel joists or thin steel wall studs
- These are manufactured by cold rolling from thin steel strip, 0.5 to 1.5 mm thick

Description

- Walls and floors are constructed with:
  - –steel studs or joists
  - –gypsum board fixed to the studs or joists using nails or screws
  - –sometimes thin steel resilient channels to improve acoustic performance
  - –insulation placed in the cavities to improve fire resistance and sound attenuation

Steel Wall or Floor Assemblies



Test Facilities – Furnaces

Test Standard: CAN/ULC-S101

Load on Assemblies

- Assemblies may be:
  - load-bearing walls and floors
  - non-load-bearing walls
- Load is calculated according to the standard CAN/ULC-S101 (ASTM E119 in the US)

Failure Criteria

- CAN/ULC-S101 specifies the following failure criteria for fire resistance testing:
  - –integrity failure - flame penetration
  - –thermal failure - average temperature rise of 140°C or maximum of 180°C on unexposed face
  - –structural failure - loss of load-bearing capacity of load-bearing assemblies
- The fire resistance (time-to-failure) of an assembly is defined as the occurrence of the first criterion

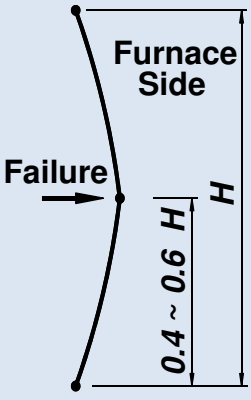
Fire Behaviour

- Light frame steel construction can have excellent fire behaviour, provided that it is well constructed
- Fire resistance is assigned to assemblies
- Due to small sizes of steel members used, performance of the lining material (e.g., gypsum board) exposed directly to fire is very important
- Not protected assemblies fail in a few minutes
- Gypsum board linings also contribute to the acoustic and thermal performance of the barrier

Behaviour of Steel Frame Assemblies

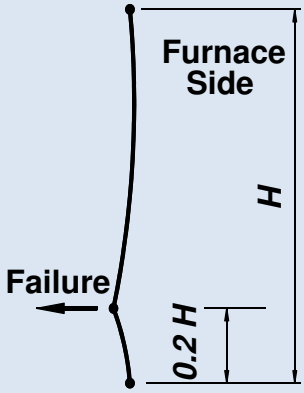
- Steel frame walls and floors show:
  - large deflections
  - local and global buckling in the steel.
- Steel frame walls and floors usually bend towards the furnace due to thermal expansion in the steel
- The critical factors are the thickness and integrity of the lining material exposed to the fire
- The strength of steel framing depends on the temp. of the studs or joists
- Fixings of lining are very important

Behaviour of Steel Stud Walls



Non-insulated walls

Behaviour of Steel Stud Walls



Insulated walls

Behaviour of Steel Joist Floors

Fire Resistance Design Methods

- The design process for fire resistance requires
  Provided fire resistance > Design fire severity
- Most often, design of fire resistance of light frame structures is in the time domain
- Fire severity is usually assessed in terms of standard fire exposure (required code fire-resistance rating or the equivalent fire severity for burnout of the compartment

Typical Fire-Resistance Ratings

Minimum gypsum board thickness (mm) to give fire-resistance ratings for cavity walls and floors

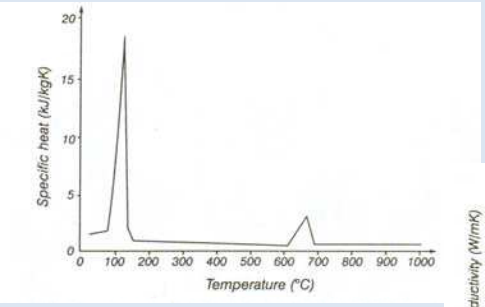
Fire-resistance ratings (minutes)		New Zealand				North America			
		Wood		Steel		Wood		Steel	
		Non-load bearing	Load bearing	Non-load bearing	Load bearing	Non-load bearing	Load bearing	Non-load bearing	Load bearing
Walls	30	9.5	9.5	12.5	16.0				
	45					(12.7)	(12.7)		
	60	12.5	12.5	12.5	19.0	15.9	15.9	15.9	
	90	16.0	16.0	16.0	28.5	[25.4]	[25.4]	[25.4]	
	120	19.0	32.0	19.0		31.8	31.8	25.4	31.8
	180	32.0						38.1	
	240							50.8	
Floors	30		12.5						
	60		16.0				12.7		25.4
	90		32.0				31.8		
	120		38.0		38.0				

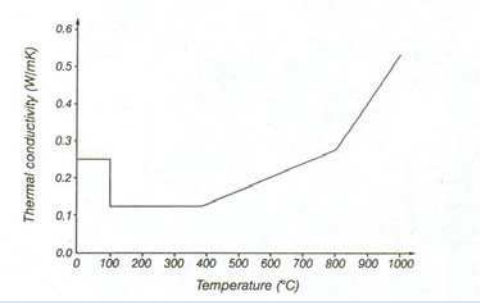
- NA listings are from Gypsum Association (94) except (12.7) from UL (96) and [25.4] from NBC (1995). NZ listings are for 'Gib® Fyreline' board, from Winstone Wallboards (97)

Properties of Gypsum Board

- Gypsum board is the most common lining material used to protect light frame structures
- There are three broad types of gypsum board:
  - Regular board (generic & not required to be fire-rated)
  - Type X board (defined to give a 60 minute load-bearing fire-resistance rating when one layer of 15.9-mm board is fixed to each side of a wall assembly or a 45 minute rating for 12.7-mm board)
  - Special purpose board (manufactured in non-standard thickness & formulated to meet special market needs)

Thermal Properties of Gypsum Board

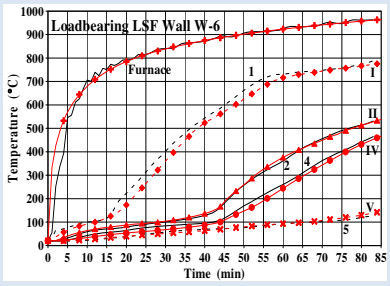




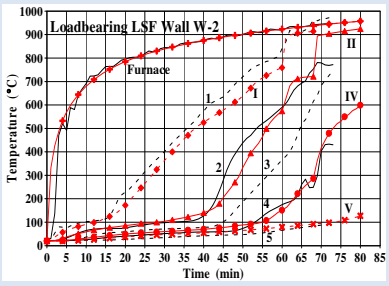
Calculation Methods of Light Steel Frame Assemblies

- Sultan and Alfawakhiri developed a FR model for steel assemblies based on test observations
- Thermal and structural responses are evaluated
- Thermal calculation provides temp. profiles and an assessment of the insulation criterion
- Structural calculation provides an assessment of the structural failure criterion
- Required thermal and mechanical properties of different components at elevated temperatures

Thermal Model for Walls Tests and Simulations



Non-insulated Wall

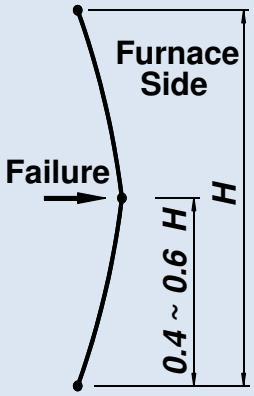


Insulated Wall

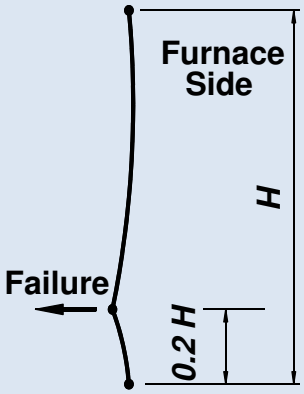
Temperature Locations
1. Between GB layers on Exp. Side
2. In the cavity on Exp. Side
3. In the cavity on Unexp. Side
4. On the unexposed side

Fire Resistance Tests - Walls

Structural Failure Modes

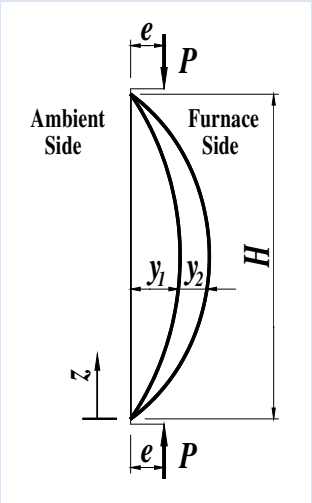


Non-insulated walls



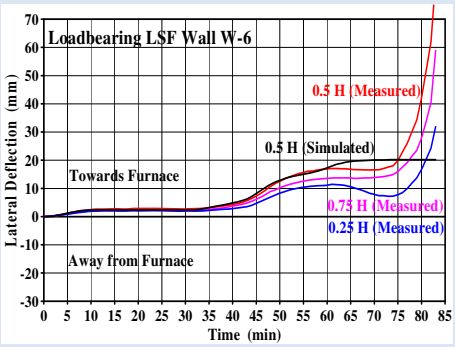
Insulated walls

Structural Model for Walls - Deflections

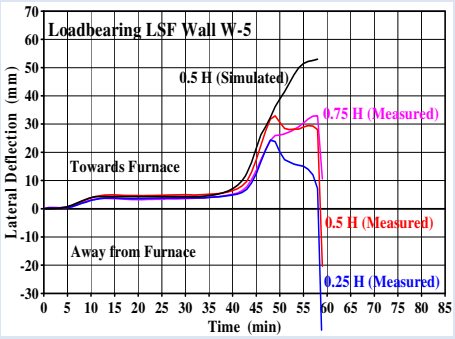


Modelled structural behaviour of wall assemblies

Structural Model for Walls - Simulations



Non-insulated wall



Insulated wall

Structural Model for Walls – FR predictions

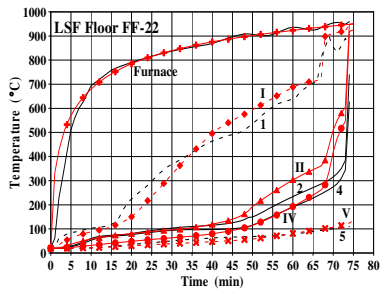
Assembly number	Insulation type (fibre)	Structural failure time in test (min.)	Initiation of failure in central studs in test (min.)	FR predictions based on measured temperatures (min.)	FR predictions based on simulated temperatures (min.)
W1	Glass	55	49	50	51
W2	Rock	73	50	52	52
W3	Cellulose	70	60	59	54
W4	-	76	N/A	77	73
W5	Rock	59	48	48	52
W6	-	83	N/A	84	85

Failure criteria for insulated Walls: check section at 0.2 H

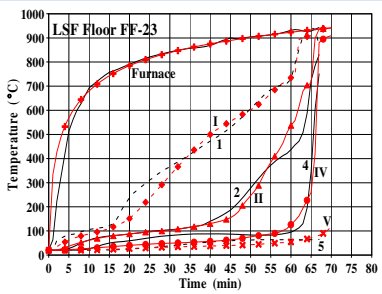
Failure criteria for non-Insulated Walls : check section at 0.4 H

Reasonable agreement with structural failure times from tests

Thermal Model for Floors - Simulations



Non-insulated Floor

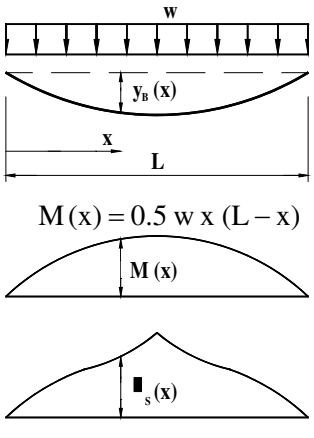


Insulated Floor

Temperature Locations

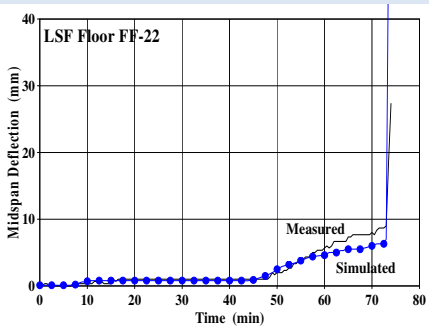
1. Between GB layers on Exp. Side
2. In the cavity on Exp. Side
3. In the cavity on Unexp. Side
4. On the unexposed side

Structural Model for Floors - Deflections

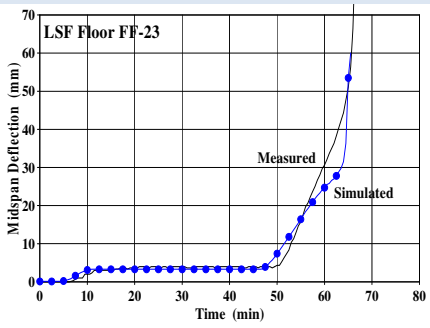


Modelled structural behaviour of floor assemblies

Structural Model for Floors - Simulations



Non-Insulated Floor



Insulated Floor

Structural Model for Floors – FR Predictions

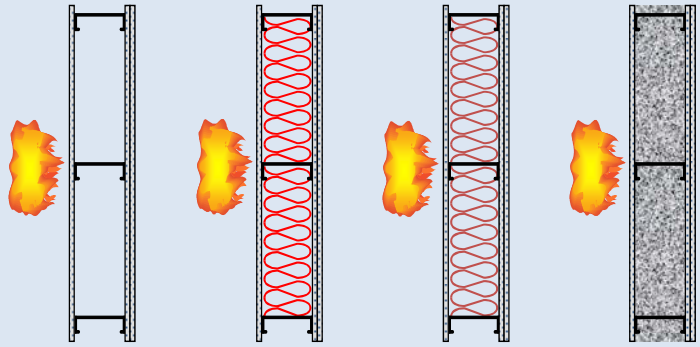
Assembly number	Structural failure time in test (min.)	JOIST predictions based on measured temperatures (min.)	JOIST predictions based on simulated temperatures (min.)
FF-22	73	73	71
FF-23	67	65	63
FF-24	68	66	63
FF-25	46	45	43
FF-27	61	56	55

- Failure Criterion $M(0.5L) = wL^2/8 > M_R$
- M_R is the moment resistance of the joist based on the inelastic capacity of the heated section

Construction Details and Design Parameters

- Insulation in cavities
- Resilient channels
- Gypsum board
- Stud arrangement
- Stud spacing
- Type of frame
- Shear panel (membrane)
- Fixing of sheets
- Penetrations, Fire Stopping, Junctions

Effect of insulation use and type (non-load-bearing steel walls)



12.7-mm
GB Type X

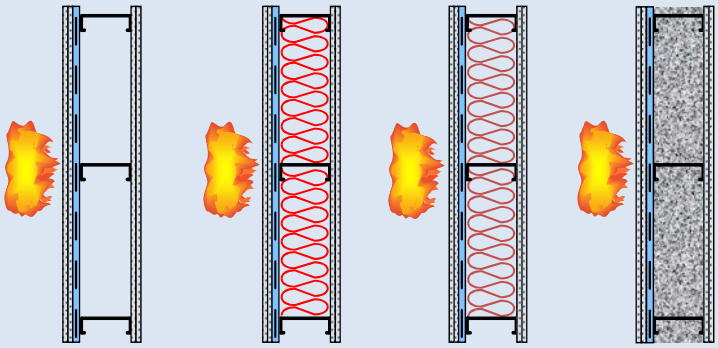
No insulation
65 min

Glass fibre
65 min

Rock fibre
100 min

Cellulose
(wet sprayed)
62 min

Effect of insulation use and type (load-bearing steel walls)



12.7-mm GB Type X

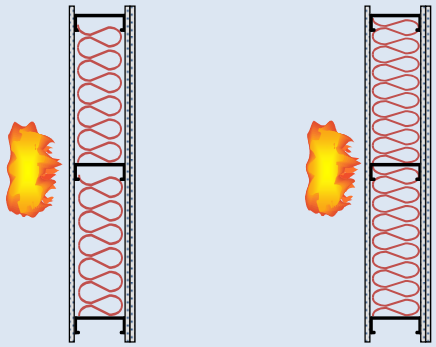
No insulation **77 min**

Glass fibre **56 min**

Rock fibre **59 min**

Cellulose (dry blown) **71 min**

Effect of insulation width (non-load-bearing steel walls)

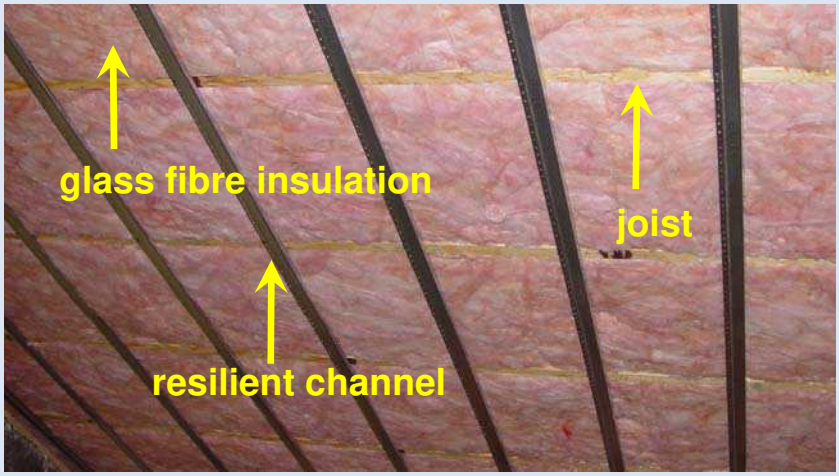


12.7-mm GB Type X

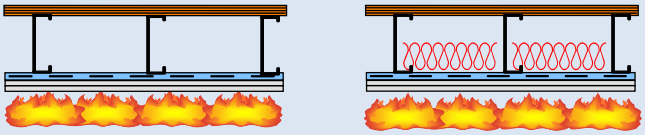
Loose-fit rock fibre (584 mm wide) **60 min**

Tight-fit rock fibre (615 mm wide) **100 min**

Insulation in floor cavity



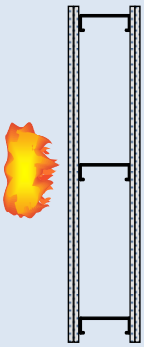
Effect of glass fibre insulation (2 layers of GB and RCs)

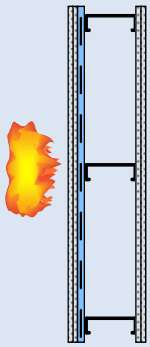


no insulation 74 min

glass fibre 68 min

Resilient channel use (load-bearing steel walls)



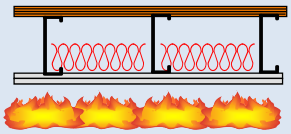


12.7-mm
GB Type X

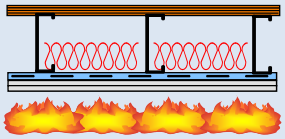
Without RC
83 min

RC on exposed side
77 min

Effect of resilient channel use (2 layers of GB)

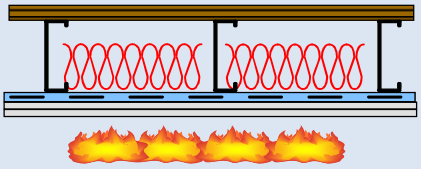


without RC 67 min

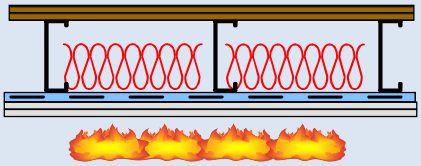


with RC 74 min

Effect of resilient channel spacing (2 layers of GB and RCs)

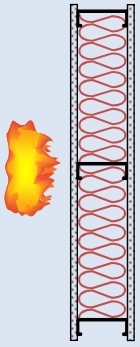


RCs at 406 mm (16”) o.c.
68 min

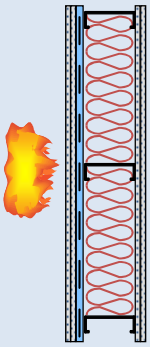


RCs at 610 mm (24”) o.c.
61 min

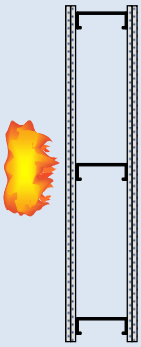
Number of gypsum board layers (load-bearing steel walls)



(1&1) 15.9 mm
31 min



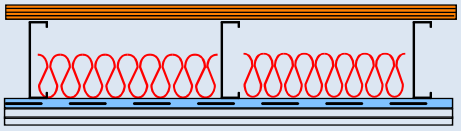
(2&2) 12.7 mm
59 min



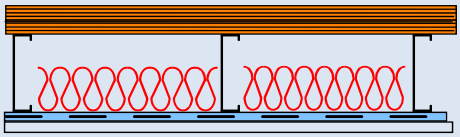
(2&2) 12.7 mm
83 min

GB Type X

Use of 2 gypsum board layers versus use of 2 sub-floor layers

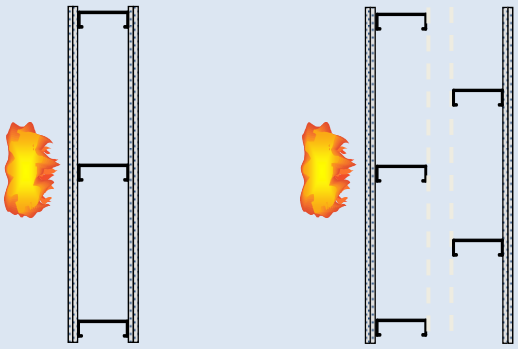


fire resistance
74 min



fire resistance
39 min

Steel stud arrangements (load-bearing steel walls)

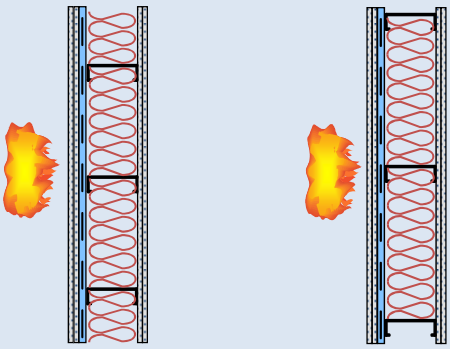


12.7-mm
GB Type X

Single row
83 min

2 rows – staggered
(double plate)
100 min

Effect of stud spacing (load-bearing steel walls)

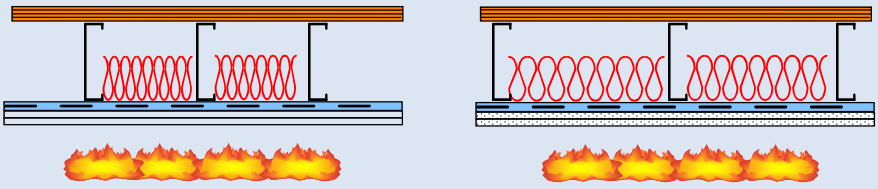


12.7-mm
GB Type X

406-mm spacing
59 min

610-mm spacing
74 min

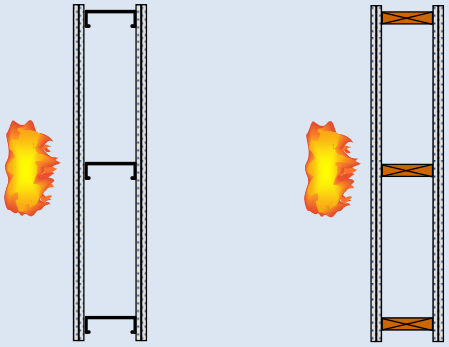
Effect of joist spacing (2 layers of GB and RCs)



joists at 406 mm (16”) o.c.
68 min

joists at 610 mm (24”) o.c.
69 min

Effect of stud type (non-load-bearing walls)

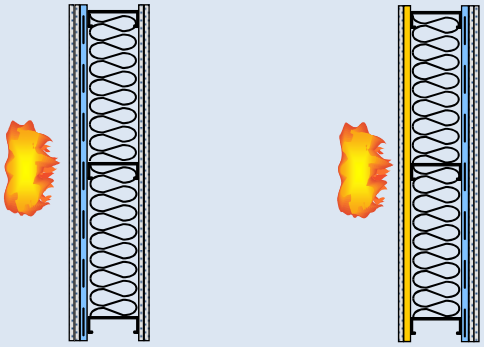


12.7-mm GB

Steel studs
63 min

Wood studs
65 min

Shear panel (load-bearing steel walls)

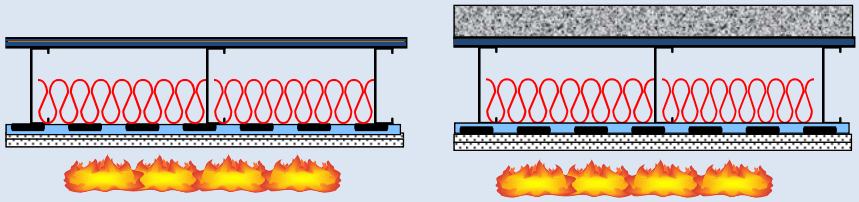


12.7-mm GB Type X

2&2 and no panel
56 min

1&2 and a panel
33 min

Effect of adding concrete topping (2 layers of GB and RCs)

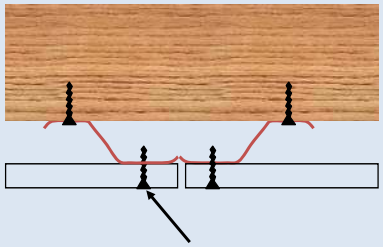


fire resistance 69 min

fire resistance 60 min

Fixing of sheets

- Tests show an increase in fire resistance if the screws are located at 38 mm from the edge of GB
- Distance between screws and edge of gypsum board increased with the use of resilient channels



38 mm from edge

Penetrations, Fire Stopping and Junctions

- A major concern about the reduction in fire resistance of assemblies is effects of penetrations for services/fixtures
- This problem is reduced if the cavity is completely filled with mineral wool insulation
- For junctions between floors and a fire-rated wall, blocking (insulation or OSB) in the floor cavity, may be used to prevent fire spread through separating wall

Important fire resistance parameters for detailing

- Use rock or cellulose fibre insulation for one layer of GB assemblies
- For two layers GB use either glass or rock or cellulose fibre
- More layers of GB provide significant increase in FR
- Install screws at 38 mm from edges of face gypsum board layers
- Use resilient channels at 406 mm (16”) o.c.

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Questions?