16

Out of Scope

From: Michael Belsham
Sent: Wednesday, 6 April 2016 2:31 p.m.
To: Edwin Claridge
Subject: FW: B1 and C6 - structural stability in fire [UNCLASSIFIED]

Ed,

Clause C6 does not exempt the structural engineer from responsibility for demonstrating that there is a low probability of the building becoming unstable during fire.

Clause B1.3.1 must be met (low probability of rupturing, becoming unstable, losing equilibrium, or collapse...) as well as B1.3.4 (Due allowance shall be made for: (a) the consequences of failure, ... (e) accuracy limitations inherent in the methods used to predict the stability of buildings). At a minimum, I would expect that the structural engineer would have to demonstrate how C6 quantitatively achieves these B1 clauses.

there are provisions in the B1/VM and/or loading standards to demonstrate structural stability during and after fire (2.5% lateral load, 5 kpa wind load),

Is the C/VM2 being applied, in its totality, for compliance with fire provisions of the code, or is it just proposed to use one of the C/VM2 approaches for the structural fire engineering issue?

We will be adding the following to the high rise guidance.

"The fire resiliency of the structure for tall buildings warrants additional consideration due to the time required for occupant evacuation and firefighter operations, as well as the potential impact that local or global collapse could have on neighbouring property. While the C/VM2 provides for assessment of fire ratings, it is also required to demonstrate that the structural stability is not compromised by fire under Clause B1 the Building Code. It is therefore required that verification of structural stability during and after fire, as required in B1, be provided, in addition to compliance with C/VM2."

Kind Regards

Michael Belsham
FIRE ENGINEER

Building System Performance Branch | Building Resources & Markets
Ministry of Business, Innovation & Employment
Level 5, 15 Stout Street, PO Box 1473, Wellington 6143

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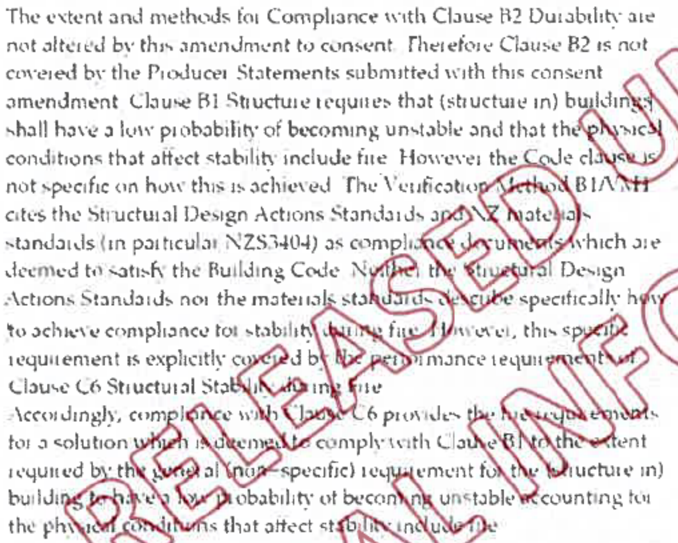
From: Ed Claridge [mailto:ed.claridge@aucklandcouncil.govt.nz]
Sent: Tuesday, 5 April 2016 2:19 p.m.
To: Michael Belsham; Brian Meacham
Subject: B1 and C6 - structural stability in fire

Hi Michael, Brian,

We have received the following response regarding our request for a PS1 and PS2 covering NZBC Clause B1 for a design which was amended following a 'specific structural design' which has removed the passive fire protection to the steel work originally specified by the original fire designer. The response is basically saying they don't need a producer statement covering B1 as B1 is met by meeting C6. At the moment I am uncomfortable with this response but my main concern is that this is the s 9(2)(b)(ii) and s 9(2)(a) design team that may be arguing the same for the s 9(2)(b)(ii) tall building so I possibly need to understand the situation more clearly going forward given that we are expecting to see the structural FEB for that design very soon.

Would you mind taking a look at the following response and confirming this for more or providing any comment on its applicability to low rise (which is this building) and also potentially for the tall buildings we will be seeing.

Any advice would be appreciated:



The extent and methods for Compliance with Clause B2 Durability are not altered by this amendment to consent. Therefore Clause B2 is not covered by the Producer Statements submitted with this consent amendment. Clause B1 Structure requires that (structure in) buildings shall have a low probability of becoming unstable and that the physical conditions that affect stability include fire. However the Code clause is not specific on how this is achieved. The Verification Method B1/VM1 cites the Structural Design Actions Standards and NZ materials standards (in particular NZS3404) as compliance documents which are deemed to satisfy the Building Code. Neither the Structural Design Actions Standards nor the materials standards describe specifically how to achieve compliance for stability during fire. However, this specific requirement is explicitly covered by the performance requirement of Clause C6 Structural Stability during Fire.
Accordingly, compliance with Clause C6 provides the fire requirements for a solution which is deemed to comply with Clause B1 to the extent required by the general (non-specific) requirement for the (structure in) building to have a low probability of becoming unstable accounting for the physical conditions that affect stability include fire

Provisions

FUNCTIONAL REQUIREMENT

C6.1 Structural systems in *buildings* must be constructed to maintain structural stability during *fire* so that there is:

(a) a low probability of injury or illness to occupants.

(b) a low probability of injury or illness to *fire* service personnel during rescue and firefighting operations, and

(c) a low probability of direct or consequential damage to adjacent *household units* or *other property*.

PERFORMANCE

C6.2 Structural systems in *buildings* that are necessary for structural stability in *fire* must be designed and constructed so that they remain stable during *fire* and after *fire* when required to protect *other property* taking into account:

(a) the *fire* severity,

(b) any automatic fire sprinkler systems within the *buildings*.

(c) any other active *fire safety systems* that affect the *fire* severity and its impact on structural stability, and

(d) the likelihood and consequence of failure of any *fire safety systems* that affect the *fire* severity and its impact on structural stability.

C6.3 Structural systems in *buildings* that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after *fire*.

C6.4 Collapse of building elements that have lesser *fire* resistance must not cause the consequential collapse of elements that are required to have a higher *fire* resistance.

Hence, for this consent amendment, which focusses specifically on structural stability during fire, Clause C6 is the appropriate specific Code Clause to cite for general compliance with Clause B1. The Producer Statements submitted with this consent amendment appropriately reference the more specific Code Clause C6 (rather than providing a qualified extent of compliance with Clause B1)
Compliance with the fire severity requirements from C/VM2 for compliance with Clause C6 and compliance with Section 11 in NZS3404 for achieving adequate fire resistance to maintain stability during fire is deemed to meet the stability requirements to the extent required by Clause B1

Regards

Ed Claridge | Principal Fire Engineer
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Out of Scope

17

Out of Scope

From: Ed Claridge [mailto:ed.claridge@aucklandcouncil.govt.nz]
Sent: Tuesday, 5 April 2016 2:19 p.m.
To: Michael Belsham; Brian Meacham
Subject: B1 and C6 - structural stability in fire

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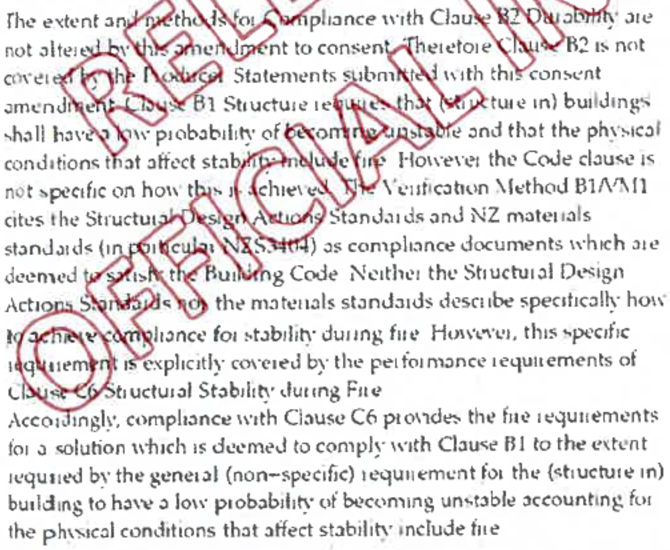

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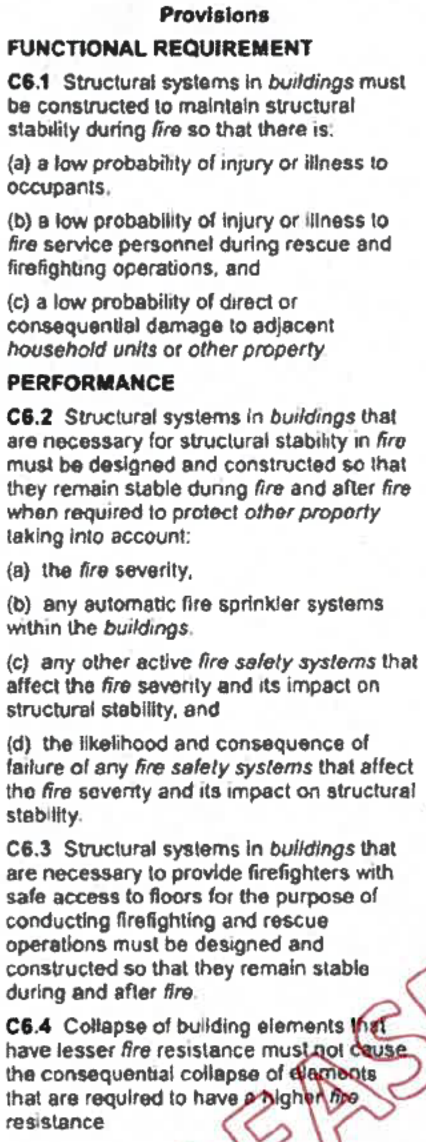

Provisions

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PERFORMANCE

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Compliance with the fire severity requirements from C/VM2 for compliance with Clause C6 and compliance with Section 11 in NZS3404 for achieving adequate fire resistance to maintain stability during fire is deemed to meet the stability requirements to the extent required by Clause B1.

Regards

Ed Claridge | Principal Fire Engineer
s 9(2)(a)
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Out of Scope

18

-----Original Message-----
From: Ed Claridge [mailto:ed.claridge@aucklandcouncil.govt.nz]
Sent: Tuesday, 5 April 2016 11:43 a.m.

To: Michael Belsham
Subject: RE: Fire Engineering Brief Guidance, Fire Engineering Brief FAQ [UNCLASSIFIED]

Yes let's do that.

Attached is todays version - but it is much cleaner

Regards

Ed Claridge | Principal Fire Engineer
Ph (09) 353 9372 | |s 9(2)(a) | s 9(2)(a) Auckland Council, 35 Graham Street, Auckland
Visit our website: www.aucklandcouncil.govt.nz

-----Original Message-----
From: Michael Belsham [mailto:Michael.Belsham@mbie.govt.nz]
Sent: Monday, 4 April 2016 5:14 p.m.
To: Ed Claridge
Subject: Re: Fire Engineering Brief Guidance, Fire Engineering Brief FAQ [UNCLASSIFIED]

Thanks Ed

I'm in your offices Monday so could make sometime to compare notes in the late afternoon?

Regards,

Michael Belsham
Fire Engineer

> On 4/04/2016, at 16:03, Ed Claridge <ed.claridge@aucklandcouncil.govt.nz> wrote:
>
> Hi Michael,
>
> Some comments/observations on the two FEB documents attached. I also hope to be in a position to send you over my latest (and hopefully close to final) version of the Council FEB policy tomorrow.
>
> Possibly best we have a chat about some aspects of all these documents so I will follow up with a phone call when I get the policy document to you.
>
> Regards
>
> Ed Claridge | Principal Fire Engineer
> Ph (09) 353 9372 |s 9(2)(a)
> Auckland Council, 35 Graham Street, Auckland Visit our website:
> www.aucklandcouncil.govt.nz
>
> -----Original Message-----
> From: Michael Belsham [mailto:Michael.Belsham@mbie.govt.nz]
> Sent: Thursday, 31 March 2016 12:11 p.m.
> To: Ed Claridge
> Cc: Chris Rutledge
> Subject: Fire Engineering Brief Guidance, Fire Engineering Brief FAQ
> [UNCLASSIFIED]
>
> Ed,
>
> Attached is revised guidance for FAQ for your comments. It's now split

> to shorten it between FAQ and guidance note
>
> Main areas I want to clarify is that BCA needs to be involved and approve and also role of peer review.
>
> Michael
> www.govt.nz - your guide to finding and using New Zealand government
> services
>

> [Have your say on the draft Civil Defence, Emergency Management Group
> Plan.]<http://www.shapeauckland.co.nz/consultations/auckland-civil-def
> ence-and-emergency-management-draft-group-plan/?utm_source=Email%20foo
> ter&utm_medium=Email&utm_campaign=CivilDefence>
>

> <Fire Engineering Brief FAQ EC comments 20160404.docx> <Fire
> Engineering Brief Guidance EC comments 20160404.docx>
www.govt.nz - your guide to finding and using New Zealand government services

Out of Scope

19

From: Ed Claridge <ed.claridge@aucklandcouncil.govt.nz>
Sent: Wednesday, 30 March 2016 5:08 p.m.
To: Michael Belsham
Subject: What is intent of Block Exit Design Scenario
Attachments: What is intent of Block Exit Design Scenario.docx

Hi Michael,

Some comments in the attached

Regards

Ed Claridge | Principal Fire Engineer
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Auckland Council, 35 Graham Street, Auckland
Visit our website: www.aucklandcouncil.govt.nz

2.7 What is intent of Block Exit (BE) Design Scenario?

The construct of this design scenario has three requirements:

1. Any escape route (that is not a vertical safe path) that serves more than 50 people requires a second exit. This includes horizontal exitways.

2. This scenario limits vertical safe path to a maximum capacity of 150 people in a non-sprinklered building or 250 people where the building is sprinkler protected. If there ~~are~~ is more than one stair or exit available providing an alternative means of egress than this restriction does not apply. For buildings where one stair ~~is~~ provides a single means of escape from some floors but not others then stair shall be designed such that the maximum capacity is not exceeded assuming occupants are distributed evenly amongst all of the exits when considering a total building evacuation.

3. The travel distance shall be limited along the escape route to reach the stair which includes horizontal exitways. There is no requirement within C/VM2 to limit travel distance in vertical safe paths.

There is no tenability analysis required for this design scenario as this is a risk based assessment.

Comment:

I wonder if we need to specifically place a restriction on having a single means of escape portion of the egress at the top of a building. There are a number of buildings in Auckland where designers have designed the top 25m of the building as a single means fo escape and considered this acceptable because the lower portion of the building has 'multiple stairs'? the above does not capture a height limitation?

There used to be extra text surrounding the historical context to this issue and given that it is difficult to demonstrate using fire engineering what is an acceptable number of people to be placed in a dead end situation and where only a single means of escape from a multi storey building is provided.

If there can be extra text added perhaps the following could be considered to provide some context;

- Fundamental principles of fire safety rely on the ability for building occupants to turn their back and walk away from the danger of a fire. Dead end situations with long travel distances and Buildings with only a single means fo escape necessitate limitations to mitigate the risk associated with only a providing a single means of escape. The above limitations recognise this risk based on historical evidence and international practice in this area.
- Buildings with a single measn of escape present challenges for Fire Service intervention as they limit the access to the internal portions of the building by limiting choice and compromising egress routes once the Fire Service make access to the building. For tall buildings additional challenges are realised as the ability for external access by the Fire Service becomes severely restricted. This places additional emphasis on the need to utilise a single means of escape for both egress and fire fighting operations.

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Out of Scope

20

From: Michael Belsham
Sent: Wednesday, 23 March 2016 5:13 p.m.
To: 'Ed Claridge'
Cc: Chris Rutledge
Subject: RE: Guidance - Fire Safety Measures for High Rise Buildings [UNCLASSIFIED]
Attachments: 160123 Fire Breaching of Floors in Apartments Final Report for MBIE.pdf

Ed,

Thanks for sending this through this gives us valuable insight into the process.

Again I believe the issue here is peer review. s 9(2)(a) is a steel advocate and will be promoting lowering fire rating to steel such that the building is viable. I attach paper he gave us to trying to show light timber frame is unsafe and light steel frame should be used instead.

Having s 9(2)(a) peer review is a good call.

The critical comment in the determination was

In the second expert's opinion, due to a lack of a robust process and methodology the proposed alternative solution does not reasonably show compliance with the Building Code.

The peer review sounds confused if can't decide on FLED!

Kind Regards,

Michael Belsham
FIRE ENGINEER

Building System Performance Branch | Building Resources & Markets
Ministry of Business, Innovation & Employment
Level 5, 15 Stout Street, PO Box 1473, Wellington 6143

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New Zealand Government

From: Ed Claridge [mailto:ed.claridge@aucklandcouncil.govt.nz]
Sent: Wednesday, 23 March 2016 1:25 p.m.
To: Michael Belsham; Brian Meacham

Cc: Chris Rutledge
Subject: RE: Guidance - Fire Safety Measures for High Rise Buildings [UNCLASSIFIED]

Michael, Brian,

FYI – I have just reviewed two 'alternative' structural fire designs, which fortunately are for low rise buildings but I have found issues with the design. Coincidently the designs (by s 9(2)(b)(ii) reviewed by s 9(2)(a)) are the current proposed design team for the s 9(2)(b)(ii) and the issues with these designs made me go back and revisit this determination:

http://www.building.govt.nz/assets/Uploads/resolving-problems/determinations/2009/2009-100.pdf

This determination also involved the same designer and reviewer and it is interesting to read through the determination some years later and find that we are not only in the same position but it would appear to me that nothing has changed – except that we are now in C/VM2 territory.

The determination has many interesting statements throughout including:

"The determination has exposed an anomaly in C/AS1 when it is applied to buildings of this particular nature"

"… it is an extremely serious matter to propose that an 18 storey building may be supported on exposed steel structure that only has a 15 minute fire rating … this is not the intent of the compliance documents. [NZFS is] unaware of any building code internationally that would allow such a low fire rating in a basement beneath a sprinklered tall building."

"All basement beams are unprotected based solely it appears, on the qualitative statement that these elements '... will maintain stability without applied fire protection...' This is in contrast to the upper levels where calculations based on the HERA Report R4-131[3] are referenced.

"Where fire protection to the basement columns is shown, the manner in which the protection is applied is not specified. Instead alternative methods are offered some of which are described as 'partial protection' which appear not be supported by detailed analysis."

"For the reasons stated in 7.2.11 It is not clear that C 4.3.3 has been satisfied. The unprotected columns, beams and the consequence of any 'local instability' require proper engineering calculations to be carried out."

On a positive note s 9(2)(a) appears to be available to provide the Council with independent expert advice in this area. Please keep this confidential at the moment but I would suggest if we can agree the engagement with s 9(2)(a) that he would be a useful additional person to pull into the mix when discussing a way forward with these issues.

Regards

Ed Claridge | Principal Fire Engineer
Ph (09) 353 9372 | s 9(2)(a)
Auckland Council, 35 Graham Street, Auckland
Visit our website: www.aucklandcouncil.govt.nz

From: Michael Belsham [mailto:Michael.Belsham@mbie.govt.nz]
Sent: Friday, 4 March 2016 9:25 a.m.
To: Ed Claridge
Cc: Chris Rutledge
Subject: Guidance - Fire Safety Measures for High Rise Buildings [UNCLASSIFIED]

Ed,

We had a managers meeting to discuss this guidance. It was decided not to release the guidance at this time until we had further discussions with overseas experts on a way forward.

However if you receive a submission for a tall building that you are uncomfortable with please contact us and we can look to publish the guidance to assist with encouraging designers to adopt better standards.

How is progress with updating the policy and FEB Guidance? As discussed a joint publication would be advantageous.

Kind Regards,

Michael Belsham
FIRE ENGINEER

Building System Performance Branch | Building Resources & Markets
Ministry of Business, Innovation & Employment

michael.belsham@mbie.govt.nz | Telephone: +64 (4)+ 896 5613 | s 9(2)(a)
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THE UNIVERSITY
OF AUCKLAND
FACULTY OF ENGINEERING
Department of Civil and
Environmental Engineering

Potential for Fire Breaching of Floors in Light Framed Apartments

Written by: s 9(2)(a)
University of Auckland

January 2016
Status: Document for MBIE, dated: 23 Jan 2016

Abstract.

With the need for increased medium density housing in New Zealand's main cities, especially Auckland, there are currently two research projects underway developing solutions for light framed apartment buildings up to 7 storeys high. One study on light timber framed construction is being undertaken by BRANZ; one study on light steel framed construction is being undertaken by NASH/HERA with input from the University of Auckland.
With multi-storey apartments, each floor comprises a firecell, with the apartments on each floor being separate firecells on that floor.
Floors are rated for fire from the underside.
This report is a numerical study which investigates the potential for severe fires breaching the apartment floors from either the underside or from burning down through the bearing layer of the floor and shows that breaching is possible in multi-storey apartment buildings of the type proposed.

Section 1: Background and Scope

1.1 Background

The Auckland Council Capacity Growth Study 2013 (Council 2014) is encouraging greater urban density through the multi-storey residential buildings. This has led to two studies currently underway to develop cost effective design solutions for light framed apartment buildings up to 7 storeys high. One is focussing on Light Steel Framed (LSF) construction and is led by NASH. The other is focussing on Light Timber Framed (LTF) construction and is led by BRANZ.

Both are using the exemplar 6 storey mixed use residential building shown in Figure 1 as the basis for developing design solutions.

This building has a retail ground floor, followed by 6 levels of apartments, with typically 4 apartments per floor. Two are two bedroom apartments, each of 74m^2 floor area, two are one bedroom apartments, each of 50m^2 floor area.

These buildings must meet the performance requirements of the New Zealand Building Code (MBIE_NZBC 2013), with the two areas of performance relevant to this report being:
Clauses C1 to C6: Protection from Fire
Clause G6: Airborne and Impact Sound

These provisions are typically implemented via the Approved Documents, through either a prescriptive route or a design based route. For the fire safety provisions relating to apartment buildings, the prescriptive route is through Acceptable Solution C/AS2 (MBIE_C/AS2 2012) and the design based route is through Verification Method C/VM2 (MBIE_C/VM2 2012/2013).

C/AS2 specifies a FRR = 60 mins for unsprinklered buildings and FRR = 30 mins for sprinklered buildings. C/VM2 requires the buildings to resist burnout when the escape height from the uppermost floor > 10m, which will be the case for these buildings. The most common method of determining burnout is through the time equivalent approach and Figure 2 shows the calculations for this based on use of an insulated steel member exposed to the Eurocode Parametric Fire (EN1991-1-2 2002) determined using the HERA Program FaST (HERA 2006). This gives teq = 60 mins for the design FLED of 400 MJ/m^2 floor area for Occupancy Class SM as specified in C/VM2; that can be reduced to teq ≈ 30 mins when the building is sprinkered, as the design FLED is multiplied by a factor of 0.5. However, the current provisions in C/VM2 relating to fire load reduction with sprinklers are under discussion and for a building of 6 storeys the reduction factor might increase to 0.75, meaning a teq ≈ 45 mins. This would require an R60 fire rated system.

Winstone Wallboards Ltd present a comprehensive series of fire rated solutions for floors and walls; an example for LTF floors to deliver R60 performance is shown in Figure 3. An alternative to the two layers of 13mm thick GIB Fyreline is to use 1 layer of 16mm thick GIB Fyreline. The same detail in terms of ceiling linings applies to a LSF floor.

For airborne and impact sound insulation, the Building Code current Clause G6 and the associated Approved Documents are out of date and are known not to deliver an appropriate level of performance. Solutions that are more closely aligned to proposed changes to these documents have been developed for Gib Board lining systems by Winstone Wallboards Ltd and are given in GIB Noise Control Systems (WWB 2006). A suitable LTF floor solution is shown in Figure 4

Both systems are shown for light timber floors which have joists at 600mm centres. The same solutions in terms of flooring and ceiling linings apply to light steel framed floors which have joists at 600mm centres. In practice the acoustic performance of the LSF systems will be up to 1dB higher than for the timber floors, given the greater elastic flexibility of the steel joist flanges.

These floor systems comprise:

1. Flooring of 20mm thick particle board, typically, or 17mm thick structural plywood. For Acoustic Impact Insulation purposes, this is required to be covered by either cushion backed vinyl or carpet on a rubber waffle underlay.
2. Floor joists at 600mm centres, sized as required for structural performance
3. Sound control infill material for acoustic insulation, typically glasswool insulation 75mm thick
4. Two layers of 13mm thick GIB Fyreline fixed as specified into the joists via a ceiling batten system or special direct fix clip.

The acoustic requirements dictate the details in 3 and 4 above, meaning that a floor which meets the expected acoustic insulation levels will develop R60 in fire.

In heavy steel/composite construction, the floor system typically comprises a relatively thin concrete floor on steel deck, supported on a system of primary and secondary steel beams. For apartment buildings, the thickness of concrete cannot meet acoustic insulation requirements directly, meaning that an envelope solution is required, as specified in HERA Report R4-121 (Burrows and Clifton 2004) and shown in Figure 5 right hand diagram. This requires the combination of 3 and 4 above in conjunction with the composite floor system, with the overlays as specified in item 1 on top of the concrete.

Given that a robust lining system is required for the composite floor to satisfy the acoustic requirements of the Building Code, it becomes a mandatory part of the building system. In 2004 the question was raised as to whether this could be used as an insulation layer for protecting the steel beams above from temperature rise in fire, on the basis that there is negligible combustible material in the ceiling void and that the concrete slab provides a barrier to air flow through the ceiling void from a fire below to the floor above, even where there are limited openings in the ceiling linings for services.

This question was answered in a ME Fire Engineering project in 2005/2006, which undertook experimental testing of natural fires in a purpose built enclosure to determining the effectiveness of GIB board linings as radiation barriers. Figure 6 shows the enclosure with test no 3 in progress. Three tests were undertaken:

- Test no 1 with 13mm thick standard GIB Board linings and FLED ≈ 400 MJ/m^2 floor area, in order to determine the failure criteria and unexposed surface failure temperatures for standard gypsum board.
- Test no 2 with 13mm thick Fyreline GIB Board linings and FLED ≈ 800 MJ/m^2 floor area, in order to determine the failure criteria and unexposed surface failure temperatures for fire resisting gypsum board.
- Test no 3, with 13mm thick Fyreline GIB Board linings and FLED = 405 MJ/m^2 floor area, in order to test the concept that if the lining remains in place throughout the fire, the steel members above the lining will remain at a temperature well below the failure temperature.

Details of this project are given in (Brown 2007), with summary details and design unexposed surface failure temperatures given in (Clifton and Brown 2006). The procedure has been incorporated into the computer program FaST, with details of the validation work undertaken for this given in HERA Report R4-127 (HERA 2006).

Brown's research covered floors and walls; his experimental testing showed that floors protected with fire resisting linings are more vulnerable to burn through than walls, given the effect of gravity acting out of plane on the degrading ceiling linings. For GIB Fyreline, the design unexposed surface failure temperatures recommended from this testing for determining the failure of the linings are 250 Deg C for ceiling linings and 400 Deg C for wall linings (Clifton and Brown 2006; HERA 2006). These are lower than the actual failure temperatures as noted in section 3.1. This shows that in terms of breaching from fire, the ceilings are the priority elements to check. The program FaST that has been developed from this work is used in this report to answer some of the questions raised in section 1.2

Research into the radiation barrier method showed that while the method provides a workable design solution, performance of the linings is strongly dependent on the fire severity, which is a function of the FLED. Given that FLEDs can vary significantly from space to space within an apartment, when the radiation barrier method is applied to heavy steel construction, it is used in conjunction with composite floor systems detailed in accordance with the requirements of the Slab Panel Method (Clifton 2006; Clifton and Abu 2014) in order to accommodate local inelastic deformations that would occur in the event of partial barrier failure in regions of FLED significantly above the design value of 400 MJ/m^2 floor area.

The final issue to cover in the background is the expected fire loads in apartment buildings. For FED to C/VM2 (MBIE_C/VM2 2012/2013), the design FLED = 400 MJ/m^2 floor area for all spaces where occupants sleep from Table 2.2. This reportedly represents the 80% loading for these spaces.

The most comprehensive recent survey of occupant fire loads for apartment buildings that the author could find is by (Bwalya, Lougheed et al. 2008) and is based on Canadian apartments. Given that the author has been on sabbatical in Montreal from November 2015 to January 2016 while writing this report, staying in a Montreal apartment and visiting people in other apartments, he has first hand experience to compare the type of combustible material that this survey is based on with that in New Zealand apartments. Visually these contents look very similar and it is expected that the Canadian values will be relevant to New Zealand apartments.

The occupant apartment fire loads from (Bwalya, Lougheed et al. 2008) give FLED's substantially higher than the C/VM2 design value; see details in Table 1. This is especially the case in the bedrooms and kitchens.

Those values include the fire load from the overlay floor linings but do not include any fire load from the structural system, and typically fire engineering design of light framed buildings does not include a contribution from the flooring or the framing that is enclosed within the wall and floor linings. However, the combustible content of this material is potentially significant. For the 20mm thick particle board flooring most commonly used, the FLED = 160 MJ/m^2 floor area if this particle board is fully consumed.

For a timber flooring system, the structural timber constitutes an additional source of fuel. For a low rise building, the UK website http://www.timbertecs.co.uk/blog/2011/11/how-much-will-the-timber-frame-for-my-house-weigh gives a rule of thumb weight for the timber framing as 93 kg/m^2 floor area. This is a likely figure for New Zealand, given that LSF weights for lowrise buildings are around 30 to 40 kg/m^2 floor area and the weight of LSF is approx 1/3 that of LTF.

Using a typical FED calorific value for timber of 17 MJ/kg wood, this gives a potential FLED of 1581 MJ/m^2 compared with a design occupant FLED from (MBIE_C/VM2 2012/2013) of 400 MJ/m^2 . The floors constitute 1/3 of the weight of timber framing, so the potential FLED from the floors alone is 527 MJ/m^2 floor area.

This means that the potential fire load from the structural system materials can vary from 160 MJ/m^2 floor area for LSF construction to 687 MJ/m^2 floor area for LTF construction.

This background has assembled and summarised all the material needed to complete this study

1.2 Scope

The scope of this report is to provide indicative answers to the following questions:

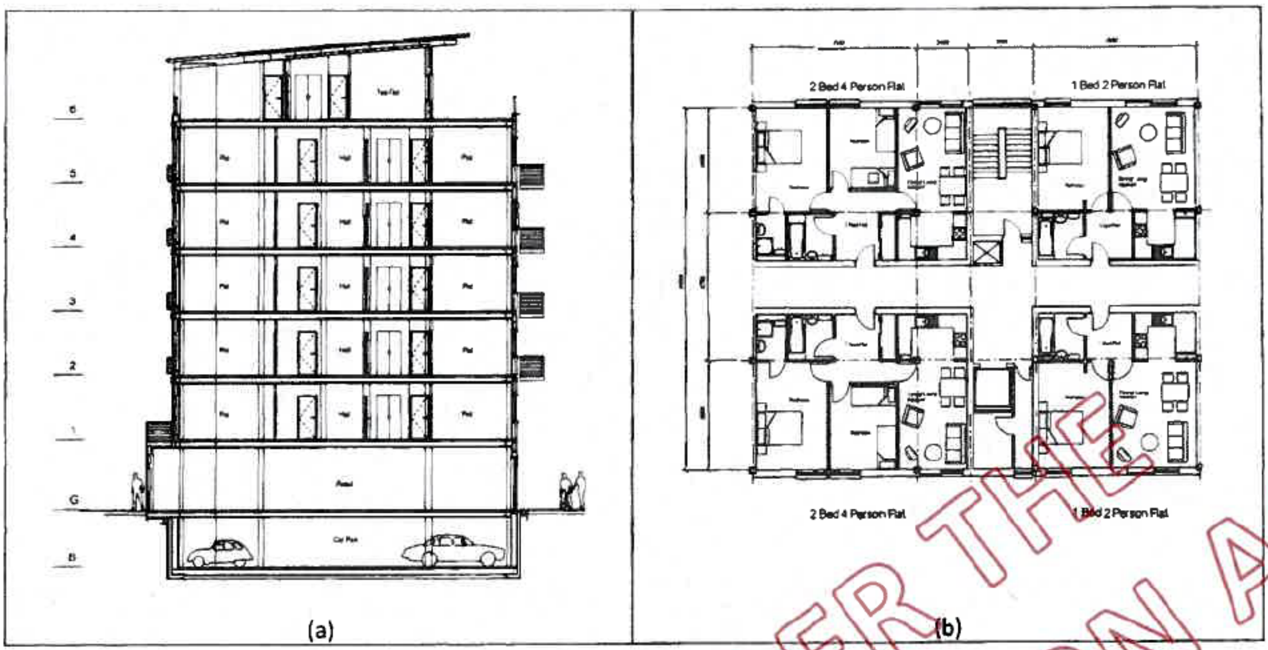
1. In multi-storey apartment buildings built using the floor system described in section 1.1 and subjected to fire from below, what is the possibility of fire breaching the ceiling linings, based on the expected FLED of spaces within an apartment?
2. If fire breaches the ceiling linings, what is the likely influence on the floor system protected by these linings
3. In light framed floor systems comprising particle board or ply on steel or timber joists, what is the likelihood of fire on the floor breaching the flooring and impacting on the joists and linings from above?
4. If fire breaches the flooring, what is the likely influence on the floor system supporting the fire floor?

1.3 Outline

This document comprises the following parts:

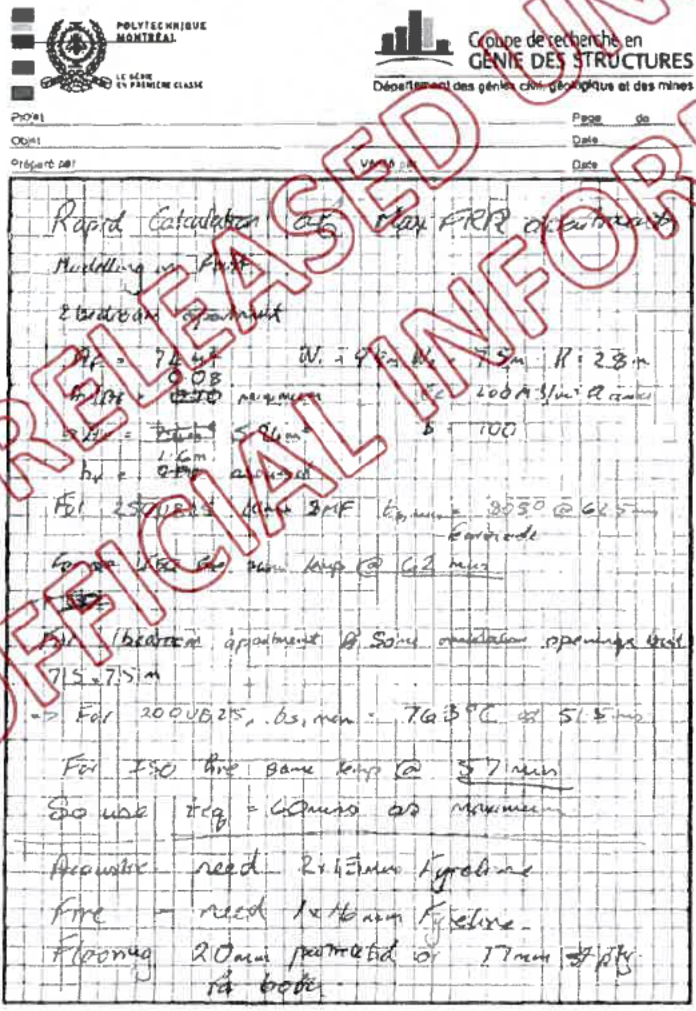
Section 1: Background and scope
Section 2: Methodology.
Section 3: Validation of the method for determining breaching of the ceiling linings
Section 4: Results
Section 5: Conclusions, recommendations and further research required
References

The figures and tables for each section are at the end of that section.



(a) (b)

Figure 1 Exemplar 6 storey mixed-use residential building (a) cross-section through building (b) repeatable floor plan area



POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

Groupe de recherche en GÉNIE DES STRUCTURES
Département des génies civil, géologique et des mines

Projet ______ Page ___ de ___
Objet ______ Date ______
Préparé par ______ Vérifié par ______ Date ______

Rapid Calculation of Max FRR of apartments
Modelling in [illegible]

2 bedroom apartment
Af = 74 m² W1 = 9.5m W2 = 7.5m H = 2.8m
Av/At = ~~0.20~~ 0.08 minimum qf 400 MJ/m² @ [illegible]
Av = ~~[illegible]~~ 5.86m² b = 100
hv = ~~2.1m~~ 1.6m assumed
For 250UB25 with 3MF t_max = 805° @ 62.5 mins
Eurocode
So use UBs with max temp @ 62 mins
~~[illegible]~~
For 1 bedroom apartment @ Same ventilation openings but 7.5 x 7.5 m
→ For 200UB25, θs,max = 763°C @ 51.5 mins
For 250 the same temp @ 57 mins
So use teq = 60mins as maximum
Acoustic need 2x13mm Fyreline
Fire — need 1x16mm Fyreline
Flooring 20mm particleboard or 17mm ply
to both

Figure 2 Calculation of teq for Two Bedroom Apartment

FIRE RATED FLOOR/CEILING SYSTEMS

SUSPENDED GRID

SPECIFICATION NUMBER	LOADBEARING CAPACITY	FIRE RESISTANCE RATING	LINING REQUIREMENTS	STC	IIC	SYSTEM WEIGHT APPROX
GBSC 60a	LB	60/60/60	Timber joists with suspension system & 2 layers 13mm GIB Fyreline®	53	43	60kg/m²

FLOOR FRAMING

Timber floor joists complying with NZS 3604 spaced at 600mm centres maximum.

Alternatively, a proprietary I-joist system may be used subject to specific structural design and approval by the normal building consent process.

FLOORING

Minimum flooring shall be nominal 20mm thick particle board or minimum 17mm thick structural plywood fixed to the joists in accordance with the manufacturers' specifications.

Note: If tongue and groove sheet flooring is used, verification of performance must be obtained from the supplier of the flooring system.

SUSPENSION SYSTEM

Rondo® Key-Lock™ steel frame suspension system comprising 2.5mm wire hangers at 1200mm centres supporting top cross rails (part 128) spaced at 1200mm centres and furring channels (part 129) spaced at 600mm centres maximum.

USG Donn® ScrewFix™ steel frame suspension system comprising 2.5mm wire hangers at 1200mm centres supporting DJ38 strongback channels spaced at 1200mm centres and FC37 furring channels spaced at 600mm centres maximum.

Direct or clip fixed GIB® Rondo® Ceiling Batten system with full perimeter channel supports.

CEILING LINING

2 layers of 13mm GIB Fyreline® shall be fixed at right angles to the underside of the furring channels.

The joints of the second layer are to be offset from those of the first layer.

All sheet end butt joints must occur on the furring channels. Sheets shall be touch fitted.

FASTENING THE LINING

Fasteners

INNER LAYER: 25mm x 6g GIB® Grabber® Drywall Self Tapping Screws.

OUTER LAYER: 41mm x 6g screws as above.

Fastener Centres

200mm centres along intermediate furring channel, around the ceiling perimeter and where sheet end butt joints occur.

Place fasteners 12mm from bound sheet edges and 18mm from sheet ends.

WALL/CEILING JUNCTIONS

The internal angle between the ceiling and walls must be protected by GIB Cove® adhered with GIB Cove® Bond, or boxed corners (square stopped) filled and taped in accordance with the publication entitled "GIB® Site Guide".

JOINTING

INNER LAYER: Unstopped

OUTER LAYER: All fastener heads stopped and all sheet joints tape reinforced and stopped in accordance with the publication entitled "GIB® Site Guide".

In order for GIB® systems to perform as tested, all components must be installed exactly as prescribed. Substituting components produces an entirely different system and may seriously compromise performance. Follow system specifications.

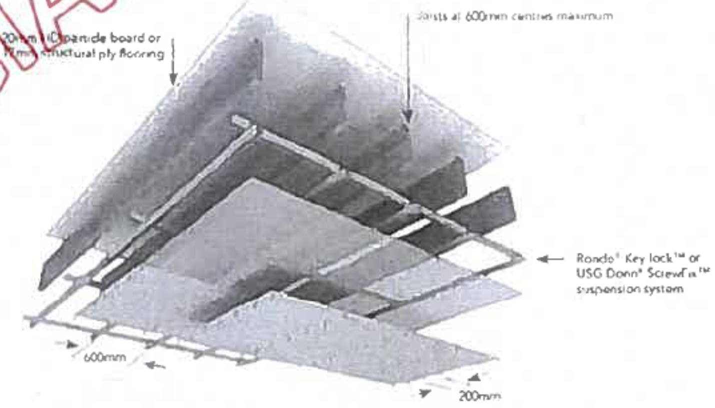


Figure 3 GIB Solution for R60 for Light Timber Framed Floor Construction

GIB® NOISE CONTROL SYSTEMS – INTERTENANCY

GIB

Floor/Ceiling – Timber Joists

MARCH 2006

SPEC No.	LOADBEARING CAPACITY	STC	RW	IIC	FIRE RESISTANCE RATING	LINING REQUIREMENTS
GBDFA 60c	LB	56	56	* 72	60/60/60	2 x 13mm GIB Noiseline®

FLOOR FRAMING

Floor joists shall comply with NZS 3604, be spaced at 600mm centres maximum and have a depth of 200mm minimum.

Alternative Floor Framing: Use either Hyspan® or Hybeam® HJ series joists designed for strength and serviceability, no less than 200mm deep and spaced at no more than 600mm. Consult the joist manufacturer regarding construction of the solid blocking contained in the floor/ceiling to wall junctions.

FLOORING

Minimum flooring shall be nominal 20mm particle board or minimum 17mm thick structural plywood fixed to the manufacturer's instructions. Nogs are required behind sheet joints. If tongue and groove flooring is used verification of performance must be obtained from the supplier of the flooring system.

GIB QUIET CLIP® AND BATTENS

The GIB Quiet Clip® shall be fastened to the joists at maximum 1200mm centres (and no less than 900mm centres) to support the GIB® Rondo® metal ceiling battens. The battens shall be spaced at 600mm centres maximum.

INSTALLING THE GIB QUIET CLIP®

Use 3 x 32mm x 8g GIB® Grabber® Wafer Head Screws. Insert the first screw into the middle rubber grommet, tighten enough to hold the GIB Quiet Clip® in place, adjust the clip to the correct height, insert the remaining two screws and tighten. Do not over tighten the screws to a point where the grommet is crushed. The screws should be tightened enough to allow the flexibility to remain in the connection between the grommet and the joists.

SOUND CONTROL INFILL

Ceiling overlaid with R1.8 (75mm) Pink® Batts® glasswool insulation.

CEILING LINING

2 layers of 13mm GIB Noiseline® fixed at right angles to the battens. Offset the joints of the outer layer by 600mm from those of the inner layer. All sheet end butt joints shall occur on the battens and are offset between the first and second layers. Sheets are touch fitted.

FASTENING THE LINING

Fasteners

INNER LAYER 25mm x 6g GIB® Grabber® Self Tapping Drywall Screws

OUTER LAYER 41mm x 6g screws as above

Fastener Centres

200mm centres along each batten and at 100mm along sheet end butt joints. Place fasteners no closer than 12mm to the sheet edges.

ACOUSTIC SEALANT

A bead of GIB Soundseal® acoustic sealant is required around the ceiling perimeter of the inner layer. The outer lining is then bedded onto the bead.

WALL/CEILING JUNCTIONS

The internal angle between the ceiling and the walls are finished with GIB Cove® adhered with GIB Cove® Bond or boxed corners (square stopped) filled and taped in accordance with the publication entitled "GIB Site Guide".

JOINTING

INNER LAYER Unstopped

OUTER LAYER All fastener heads stopped and all sheet joints tape reinforced and stopped in accordance with the publication entitled "GIB Site Guide".

IMPACT INSULATION CLASS (IIC)

A performance of IIC 46 is achieved by a bare floor.

A performance of IIC 50 is achieved with a cushion backed vinyl on particle board on structural plywood.

A performance of IIC 72 is achieved with a 48oz hard twist wool hessian backed carpet over a rubber waffle underlay.

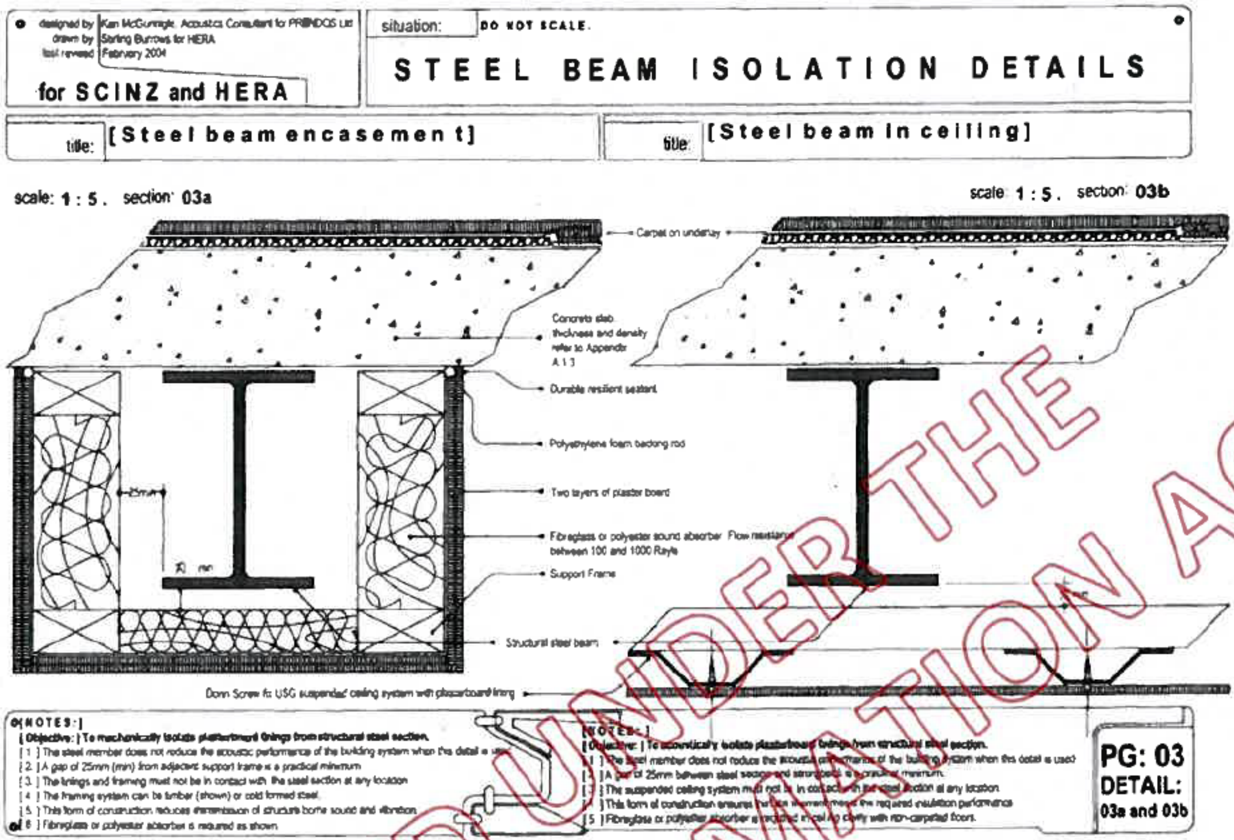
Note: *See page 61 for perimeter details*

Note: *Superior low frequency performance, see page 11*

In order for GIB® systems to perform as tested all components must be installed exactly as prescribed. Substituting components produces an entirely different system and may seriously compromise performance. Follow system specifications.

40 FOR FURTHER INFORMATION VISIT WWW.GIB.CO.NZ AND SEARCH SPECIFICATION CODE GBDFA60c

Figure 4 GIB Solution for Acoustic Insulation of Light Timber Framed Floor Construction



[NOTES:]

[Objective:] To mechanically isolate plasterboard linings from structural steel section.

[1] The steel member does not reduce the acoustic performance of the building system when this detail is used

[2] A gap of 25mm (min) from adjacent support frame is a practical minimum

[3] The linings and framing must not be in contact with the steel section at any location

[4] The framing system can be timber (shown) or cold formed steel.

[5] This form of construction reduces transmission of structure borne sound and vibration

[6] Fibreglass or polyester absorber is required as shown.

[NOTES:]

[Objective:] To acoustically isolate plasterboard linings from structural steel section.

[1] The steel member does not reduce the acoustic performance of the building system when this detail is used

[2] A gap of 25mm between steel section and strongback is a practical minimum.

[3] The suspended ceiling system must not be in contact with the steel section at any location.

[4] This form of construction ensures that the element meets the required insulation performance

[5] Fibreglass or polyester absorber is required in ceiling cavity with non-carpeted floors.

Figure 5 Acoustic Insulation Requirements for Composite Floors Supported on Steel Beams (left hand side, isolated beam; right hand side, floor system with ceiling lining

Application of the equivalent fire severity to the natural fire test shown in the figures below gives the following:

W_1 = 2.4 m
W_2 = 3.6 m
H = 2.4 m
h = 2.0 m
A_v = 1.2 x 2.0 = 2.4 m2
FLED = 405 MJ/m2
k_b = 0.09 (from Table 5, using the value for plasterboard ceiling and walls as this enclosure was lined with plasterboard which remained in place throughout the fire)
A_v/A_f = 0.28
OF = $Av\sqrt{heq}/At = 0.074$
k_m = 13.7x0.074 = 1.01 (if unprotected steel elements are to be used); otherwise = 1.0
w_f = 0.84
t_e = 405 x 0.09 x 0.84x 1.01 = 31 mins

405 MJ/m^2 16% plastic

Figure 6 Radiation Barrier Test Enclosure and Details/Picture of Test No 3 in Progress

Table 1 Fire Load Energy Densities for Various Rooms (from (Bwalya, Lougheed et al. 2008))

Room	Mean FLD (MJ/m^2)	Standard Deviation (MJ/m^2)	Minimum (MJ/m^2)	Maximum (MJ/m^2)	95th Percentile	Sample Size
Kitchen	807	123	420	1244	940	515
Secondary bedroom	594	146	107	1,000	846	129
Primary Bedroom	534	125	249	920	753	347
Living Room	412	127	106	897	610	397
Dining Room	393	132	119	901	576	292
Basement Living Room	288	96	103	633	450	130

Section 2: Methodology

The methodology used in this study involves the following:

1. Consider an enclosure space within one of the apartments comprising either a bedroom or a kitchen. These spaces are shown in Figure 1 (b). Use the mean room areas from the Canadian study; these are Af = 10m^2 for the kitchen and Af = 14m^2 for the bedrooms (average of primary and secondary bedrooms used) Take the rooms as square for determining the FaST imput dimensions W1 = W2, giving W1 = W2 = 3.2m for the kitchen and 3.7m for the bedroom. Consider the enclosure height of 2.6m which is typical for an apartment.
2. Consider the enclosure space ventilated by either 1 or 2 window sets. From (WANZ 2015) the standard window size is 2.41m wide x 1.21m high, giving a clear dimension of 2.4x1.2m. This gives the ventilation conditions as:
    a. For the one window condition, Av = 2.88m^2 and hv = 1.2m
    b. For the two window condition, Av = 5.76m^2 and hv = 1.2m
3. For the fire load, use the mean and the 95th percentile values from the Canadian study (Bwalya, Lougheed et al. 2008) without including the fire load from the floor linings. Then, where the floor linings are expected to be breached using the criterion from section 3.2, consider the case with the floor linings fire load added.
4. For the light timber floors, the fire load of the timber joists is exposed to combustion after the ceiling linings are breached. From (Yudong and Drysdale 1985?), the combustion temperature of timber in the presence of an ignition source is 350 Deg C, so determine and record the time from ceiling lining failure until the temperature decreases to 350 Deg C. Note that this is not including the fire load from these joists into the fire time temperature conditions so is unconservative, but appropriate for this indicative study.
5. Use the program FaST to determine the fire time temperature conditions and the performance of the ceiling linings. Run both the Eurocode and the modified Eurocode fire curves and use the more severe of the two for determining the fire conditions and lining failure.

The results are presented in Section 4. The validation of FaST for this study is presented in Section 3.1.

Section 3: Validation of Method for Determining Breaching of the Ceiling and the Floor Linings

3.1 Validation of method for determining breaching of ceiling linings from the underside

The radiation barrier method is used for this study. As described in (Brown 2007) there were three natural fire tests undertaken, in the enclosure shown in Figure 6. A description of the FLED and linings used for each test (taken from (Clifton and Brown 2006)) is as follows:

Test No 1: The test FLED = 405 MJ/m^2 floor area (note this is incorrectly written as 450 MJ/m^2 floor area in that reference). The linings were 13mm thick GIB Standard board. The purpose of the test was to determine the performance of GIB Standard ceiling and wall linings under FHC1 design fire conditions, the temperatures on the unexposed face at ceiling and wall failure and the conditions within the ceiling and wall cavities up to and after failure.

Test No 2: The test FLED = 830 MJ/m^2 floor area, being slightly above the office design fire load from C/VM2. The linings were 13mm thick GIB Fyreline board. The purpose of this test was to determine the performance of GIB Fyreline ceiling and wall linings under FHC2 design fire conditions, the temperatures on the unexposed face at ceiling and wall failure and the conditions within the ceiling and wall cavities up to and after failure. From the performance of the linings in this fire, a prediction was then made that the 13mm GIB Fyreline would remain intact throughout the fully developed period of an FHC1 fire in this enclosure and would keep the temperatures of the steel beams above the ceiling well beneath the limiting temperature, thus demonstrating its acceptability as a radiation barrier.

Test No 3: The test FLED = 405 MJ/m^2 floor area, being the same as for test no 1. The ceiling and wall linings were 13mm thick GIB Fyreline board.

Key points from the results are as follows:

In test no 1 the ceiling failed when the fire temperatures were over 900°C. The steel temperatures in the ceiling space reached 100°C just prior to ceiling failure then rose to 95% of the fire temperatures in the bottom flange and web. The wall lining did not fail. Temperatures prior to ceiling failure in both sides of the ceiling enclosure (ie side with openings and side without openings) were within 10°C of each other.

In test no 2 the ceiling failed just into the decay phase. The steel temperatures in the ceiling space were around 200°C prior to failure but rose locally to much higher temperatures immediately before the ceiling was seen to fail.. The wall lining partially failed. The ceiling openings made less than 10°C difference to the ceiling space temperatures up to ceiling lining failure.

In test no 3 the ceiling underwent localised failure in one corner well into the cool-down phase. The steel temps did not exceed 175°C and did not show an increase when the localised failure of the ceiling linings occurred. The average fire temperature reached 950°C. The ceiling openings made less than 20°C difference to the steel beam temperatures.

From these tests, experimentally determined failure temperatures on the unexposed side of the GIB board linings were:

GIB Standard	120 Deg C for the ceiling 230 Deg C for the walls
GIB Fyreline	275 Deg C for the ceiling 400 Deg C for the walls (assessed from the wall partial failure)

When the program FaST is applied to implement the radiation barrier method, the emphasis is on determining the temperature rise of structural steel members on the unexposed face. Validation studies using SAFIR were undertaken to determine the width of radiation barrier to use in the program for this purpose and these are presented in section 2.5.3 of (HERA 2006). However in this application the aim is simply to determine the appropriate radiation barrier width to use to determine whether the linings fail and, if they do, the time of failure and the temperature of the fire at that time.

The width of radiation barrier used in FaST to determine the linings performance which gives the closest agreement to the failure times and fire temperatures observed in the three tests is 0.5m. Using that width and the failure temperatures on the unexposed side of the GIB board linings given above generates the following lining performance:

For test no 1, FaST predicts ceiling lining failure at between 900 Deg C and 1000 Deg C, just before the beginning of the decay phase and wall lining failure well into the cooling down phase. The Modified Eurocode Curve gives the best approximation to the recorded fire time temperature conditions.

For test no 2, FaST predicts ceiling lining failure just into the beginning of the decay phase and wall lining failure well into the cooling down phase. The Modified Eurocode Curve gives the best approximation to the recorded fire time temperature conditions.

For test no 3, FaST predicts no ceiling lining failure when a failure temperature of 275 Deg C is used; if a failure temperature of 250 Deg C is used (which is the design lining failure temperature recommended by (HERA 2006) then ceiling lining failure is predicted late in the decay phase, as shown in Figure 7. Wall linings don't fail. The Modified Eurocode Curve gives the best approximation to the recorded fire time temperature conditions. Figure 7 shows the experimental and predicted fire and steel temperatures from test no 3, with the predicted temperatures based on a lining unexposed side failure temperature of 250 Deg C. A very similar experimental fire curve was generated by Test No 1.

The radiation barrier tests were all on single layer linings, in order to avoid the complication of heat transfer through multiple layers and determining the failure conditions for multiple layers. However, the ceiling linings used in apartments will comprise two layers, as described in Section 1.1 Background and shown in Figure 3.

When applying this method of determining the point of failure in the fire to linings with two layers, a layer thickness has to be input into FaST. The following must be considered in determining the input thickness to use for multiple layers:

1. The join between the two layers will have thermal impedance, slowing down the temperature rise on the layer not directly exposed to the fire (called the upper layer from now on).
2. When the lower layer fails, the fire exposure to the upper layer will be more severe than at the start of the fully developed fire, thus the temperature rise through the upper layer once the lower layer has failed will be quicker than the temperature rise through the lower layer.
3. When the lower layer fails, it may mechanically damage the upper layer, reducing its fire resistance.

Two Standard Fire tests are available which are used to answer the question of what thickness to use taking into account these three factors; the first on two layers of 12.5mm fire resistant gypsum plasterboard (BRANZ 1997) and the second on three layers of 12.5mm thick fire resistant gypsum plasterboard (Hicks and Lawson 2015).

For the two layers BRANZ test, using the experimentally determined unexposed side failure temperature of 275 Deg C for fire resistant gypsum plasterboard, the radiation barrier width of 0.5m and the lining width = sum of the two linings, FaST predicts failure of the linings at 62 minutes, compared with the recorded failure time of 63 minutes.

For the three layers UK test, using the experimentally determined unexposed side failure temperature of 275 Deg C for fire resistant gypsum plasterboard, the radiation barrier width of 0.5m and the lining width = sum of the three linings, FaST predicts failure of the linings at 90 minutes, compared with the recorded failure time of 92 minutes.

So for multiple layers, the sum of these layers without modification should be used.

3.2 Validation of method for determining breaching of floor lining from the top down

This requires answering the question as to how long the bearing surface of a LSF or LTF floor system will sustain the impact of fully developed fire from above.

Unlike the case for the ceiling linings reported above, there is no robust test data to answer this question.

The bearing surface is typically 20mm thick particle board. If the charring rate of this material is assumed to be the same as that for solid timber (which is a questionable assumption) then the time to burn through under fully developed fire conditions is at most 20/0.65 = 30 mins and at least 15 minutes. (The most is the NZ method, which uses a charring rate of 0.65mm/min with no subtraction of a minimum thickness. The least is the Australian method, which subtracts 10mm from the actual thickness and then applies the charring rate to the remaining thickness).

The author's understanding is that in one set of natural fire tests undertaken at BRANZ on LTF floor systems with just the particle board floor lining, the fire breached the floor system from the top down at around 20 to 25 minutes after full development. However he doesn't have the report on this test and is recalling that from memory. The tests described in Jonathan Nyman's thesis (Nyman 2002) used two layers of gypsum fireboard on top of the particle board, as shown in Figure 8. This floor resisted burn-through for fire tests with FLED = 1200 MJ/m^2 floor area.

In practice, however, the use of a non combustible lining on top of the floor bearing surface is not mandatory, nor typical. The floor covering over the floor lining will be that required for acoustic impact insulation performance, either carpet on rubber waffle underlay or vinyl. These coverings will add little time to the resistance of the floor linings to burn through from above.

Also unlike the ceiling linings, the floor linings are supporting the permanent and imposed loadings on the floor system. As the floor lining degrades, it will be vulnerable to localised failure from concentrated loads applied eg from bed legs or from some kitchen appliances.

Considering all these factors, for the purposes of this study breaching of the floor linings is considered likely after exposure to 20 minutes of fire temperatures above 600 Deg C. This is the criterion used in the results section of this report.

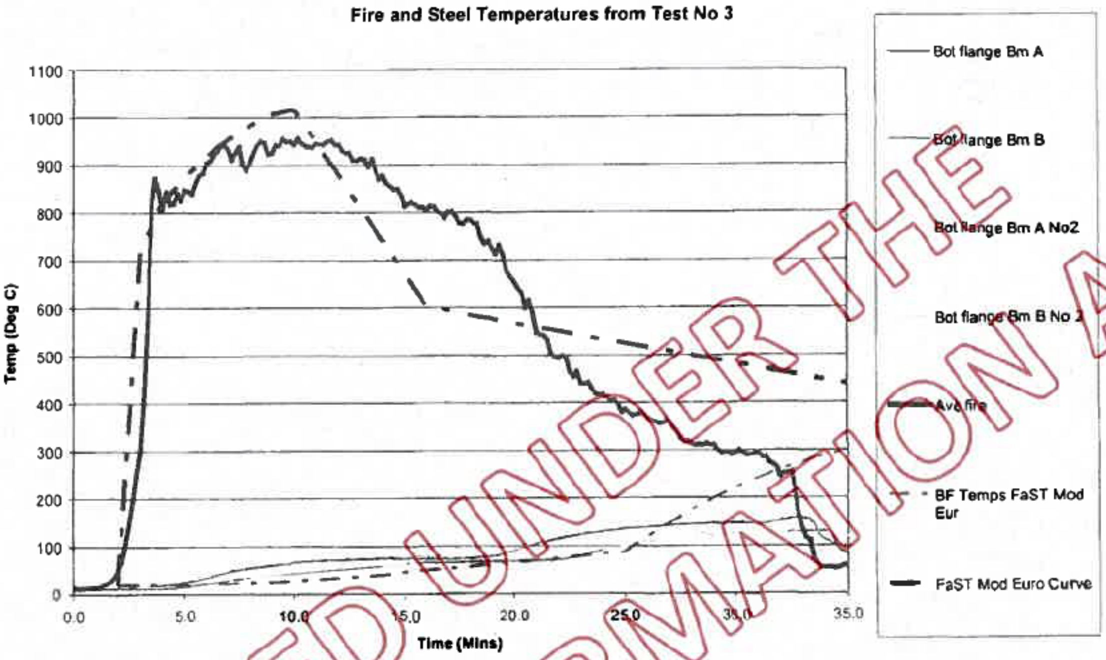


Figure 7 Fire and Steel Temperatures from Test No 3, With Lining Unexposed Side Failure Temperature of 250 Deg C used in the FaST prediction

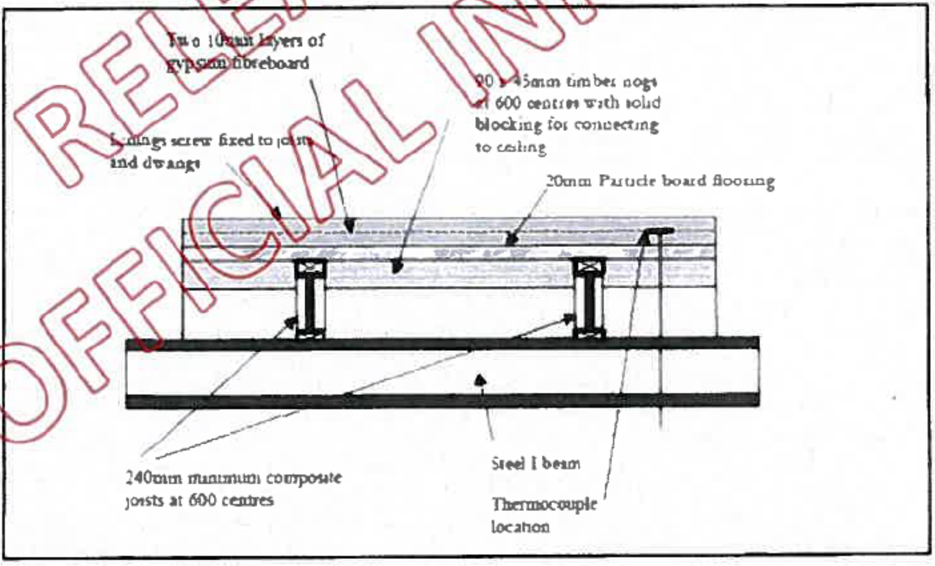


Figure 8 Compartment Floor Cross Section in Natural Fire Tests (from (Nyman 2002))

Section 4: Results

The results are presented in two tables. Table 2 gives the results for the enclosure fire scenarios with one window opening, while Table 3 gives the results for the enclosure fire scenarios with two window openings.

Note that the structural fire severity and influence on the linings is much greater for the lower ventilation case. The Canadian study identifies the kitchen and bedrooms as being the locations of potentially greatest structural fire severity, with fires in the living room and dining room being considerably less severe. This is due to their lower fire load (see Table 1) and greater ventilation. The bathroom is an area of minimal fire load, typically and the loads observed were not considered sufficient to warrant inclusion in the study ((Bwalya, Lougheed et al. 2008).

The key points from these results are that:

1. The structural fire severity in an apartment is very variable, ranging from lower than that predicted using C/VM2 or the FRR from C/AS2 to much higher.
2. For ceiling systems designed to deliver R60 performance and to meet acoustic insulation good practice, breaching of the floor systems from underneath through the ceiling linings is likely in regions within the apartment of higher fire load and lower ventilation, such as the bedrooms and kitchens.
3. If the floor bearing surface is 20mm thick particle board without a non-combustible layer on top, breaching of the floor system from the top down through the floor linings is likely in a wider range of circumstances.
4. For LTF, the additional fire load from the floor system (527 MJ/m^2 floor area as determined from section 1.1) will make complete combustion of the floor system leading to combustion of the complete building likely when the ceiling linings are breached. (This is indicated from Table 2, where for all but the cases 1D1, 2D1 and 1B1, the ceiling space will be subjected to temperatures higher than 350 Deg C for a period of at least 10 minutes. This indicates that neglecting the contribution of the combustible material within the structure is potentially unsafe.

Further supporting evidence for that comes from a fire in 2014 that destroyed a Nottingham University timber framed laboratory under construction and for which the occupant fire load was not present. Details are in: http://www.theguardian.com/uk-news/2014/sep/13/nottingham-university-fire-police-investigate-significant-blaze also article in HERA News https://www.hera.org.nz/Story?Action=View&Story_id=2109

Table 2 Fire Linings Breaching Study: Results for Enclosure with One Window Opening

Case no and type	FLED MJ/m^2 floor area	Governing fire curve	Duration of fire temp above 600 Deg C (mins)	Ceiling lining failure (Yes/No)	Fire temp when ceiling lining fails (Deg C)	Time of fire temp above 350 Deg C after lining failure (mins)
Note 1		Note 2	Note 3		Note 4	Note 3
1D1	400	E	30	No	-	-
2D1	560	E	50	Yes	520	5
1B1	564	E	50	Yes	520	5
2B1	800	E	65	Yes	950	35
3B1	724	E	60	Yes	830	20
4B1	960	E	80	Yes	1070	45
1K1	807	E	45	Yes	620	10
2K1	940	E	55	Yes	830	15
3K1	967	E	60	Yes	890	20
4K1	1100	E	65	Yes	1045	25

Notes to Table 2:

1. D = design FLED case, B = bedroom, K = kitchen. The right hand number is the number of window openings to the enclosure
2. E = Eurocode curve; ME = Modified Eurocode curve. See a description of both and references in section 2.2 of (HERA 2006)
3. This is determined by eye from the graphical output of FaST. Because of the relatively low accuracy of that method, the results are presented to the nearest 5 minutes
4. This is determined by eye from the graphical output of FaST. Because of the relatively low accuracy of that method, the results are presented to the nearest 10 Deg C

Table 3 Fire Linings Breaching Study: Results for Enclosure with Two Window Openings

Case no and type	FLED MJ/m^2 floor area	Governing fire curve	Duration of fire temp above 600 Deg C (mins)	Ceiling lining failure (Yes/No)	Fire temp when ceiling lining fails (Deg C)	Time of fire temp above 350 Deg C after lining failure (mins)
Note 1, 5		Note 2	Note 3		Note 4	Note 3
1D2	400	ME	10	No	-	-
(2D2)	560	ME	15	No	-	-
1B2	564	ME	15	No	-	-
(2B2)	800	E	30	No	-	-
3B2	724	ME	20	No	-	-
(4B2)	960	E	35	No	-	-
1K2	807	ME	15	No	-	-
(2K2)	940	ME	20	No	-	-
3K2	967	ME	20	No	-	-
(4K2)	1100	E	25	No	-	-

Notes to Table 3:

For notes 1 to 4, refer to the Notes to Table 2:

5. The case numbers in brackets are included for completeness but full combustion of the floor linings is unlikely due to the duration of the fire above 600 Deg C not equal to or exceeding 35 mins. This means the fire load in these cases is likely to be less than that stated but greater than that for the unbracketed case above

Section 5: Conclusions, Recommendations and Further Research Required

5.1 Conclusions

This study on the potential for fires in apartments breaching the floor systems shows that breaching is likely to occur in the regions of higher fire load and lower ventilation. That raises the question as to what happens in multistorey light framed construction when the linings are breached.

We don't have good knowledge of this for either LSF or LTF systems.

In the case of LTF buildings, limited fire case histories indicate complete destruction of the building without fire service intervention. See:

- 7 storey timber framed apartment building fire in Los Angeles. http://www.cbsnews.com/pictures/apartment-fire-in-l-a-shuts-down-freeway/
- http://www.timberframefires.co.uk/background.asp, which presents evidence from several UK fire case histories and the experience in the multi storey timber framed test building at Cardington.

The Cardington 6 storey timber framed apartment building is a good example which occurred under controlled conditions. In 1999 a natural fire test was undertaken in an apartment in a 6 storey timber framed building inside the Cardington Large Building Test Facility, UK. The fire load of principally wooden cribs contained the design FLED for an apartment building and the walls and floors were fire rated to the specified FRR which (from memory) was 60 minutes. Towards the end of the decay phase there was no visible breach of the linings and the Fire Service extinguished the embers and declared the building safe. Into the evening, several hours later, the fire re-ignited within a cavity on a floor below the test floor and the fire service spent the next five hours fighting the blaze which had spread through the upper floors to finally engulf all the building. The building did remain standing.

What happens if the fire breaches the linings in LSF buildings is unknown. There are no examples in the literature that could be found of this happening.

There is detailed evidence from a FED forensic study of a fire in a single storey LSF building (Pantham 2014), in which the fire in the room of origin (the kitchen) did destroy all the linings on the exposed side walls and ceiling. It did not spread into the roof cavity nor breach the walls on the unexposed sides of the room of origin and the roof of the building was still weathertight after the fire, expect for where the fire service had lifted the roofing to investigate the roof cavity in the unexposed part of the house. In this case, however, the structure over the fire was supporting only a lightweight roof and the fire service did intervene and extinguish the fire.

The evidence from this house and from a fire in a lounge of another single storey house shows that the light steel frame assembly has a much higher fire resistance than that of the individual members or of assemblages subject to one way load bearing Standard Fire Test conditions.

In North America, the benefits of non-combustibility of the structural framing system is recognised by insurers through lower premiums for builders and owners, however the author doesn't have access to the data from which those lower premiums have been derived: The web link is: http://www.steelframing.org/insurance.html

5.2 Recommendations

Fire case histories indicate that, in the event of fully developed fire in an apartment of a multi-storey apartment building will, in the absence of fire service intervention, breach the floor system between apartments and spread throughout the building. This is likely to lead to complete destruction of the building. The above study is consistent with these case histories.

However, the likelihood of this scenario occurring is very low, especially in a sprinkler protected building which these will be.

In the Building Code Clauses on fire, many of the clauses C2 to C6 specify performance requirements that are required to occur with a low probability of failure. It can be argued on the basis of sprinkler protected buildings, both under normal operating conditions and in the experience of the 2010/2011 Christchurch earthquake series in fire following severe earthquake, the performance requirements are met through the reliability of the detection and suppression systems in preventing fully developed fire occurrence. However, other Building Code Clauses, particularly in C5 and C6, require the building to remain stable during and after fire, which these buildings are unlikely to meet.

The behaviour of these buildings in fully developed fire needs to be realistically addressed and appropriate decisions made on how to deal with new, multi-storey light framed apartment buildings, before a significant number of these are built. In the author's opinion, the reliability of the current detection and suppression systems to suppress fully developed fires in these buildings make their operation acceptable on the basis that:

1. The linings that are required for acoustic insulation deliver R60 performance for the structural elements exposed to the fire.
2. Structural elements behind the linings are shielded from the effects of fire such that their contribution to the fire severity or to instability of the structure can be ignored.
3. Maybe a non combustible layer on top of the flooring linings should be required to prevent burn through from the top down.

If this is to be accepted, it will require changes to the NZBC to the satisfaction of all parties. Particularly in regard to the fire service, it may mean restricting this approach to buildings that can be reached externally for search, rescue and fire fighting operations.

5.3 Further research required.

Designs for multi-storey light framed apartment buildings are currently being developed for both LSF and LTF buildings to meet significant future demand. Research projects are currently underway by NASH and BRANZ respectively to develop these designs and detailing requirements.

These buildings are of a height that requires the building to remain stable during and after fire, according to several fire safety clauses of the NZBC (NZBC_Clauses_C1-C6 2012). However, there are significant uncertainties over the behaviour of these buildings in fire, with case history and first principles studies showing that in the event of fully developed fire in an apartment, complete destruction of the building is at best possible and more likely probable.

In order to get a better understanding of the behaviour of these buildings, the author is recommending a natural fire test on two, two storey buildings. This could be done relatively small scale using say the size of building featured in Nick Brown's ME thesis for the radiation barrier method (see Figure 1 and (Clifton and Brown 2006; Brown 2007)) but with the building having two storeys with the fire load on the bottom storey only (to save cost) or more realistically the fire load on both storeys and the fire started in the bottom storey.

The suggestion to MBIE would be to fund the testing of two nominally identical enclosures, one light steel framed with fire rated walls and floors (first floor under the lower level and the second floor between the two storeys) and the other light timber framed with the same R rating for the fire rated walls and ceiling. This would be an R60 system as described above. The bottom storey containing the fire would also have to be an elevated floor so the fire is on the top of this floor, ie on the particle board or ply bearing surface. This is to test the "burn down" resistance of the fire floor. The top floor should have glass in the openings while the bottom openings are open to ensure full fire development.

The estimated cost of each test at around 40k; these could be done at BRANZ, which is where the Nick Brown project was undertaken, (or potentially at the University of Auckland Ardmore site). This would yield valuable real fire data on the performance of light steel framed and light timber framed structures in fires of the structural fire severity associated with apartment buildings, the results of which would be very useful to quantifying the potential fire risk involved in building larger numbers of these.

While MBIE would have to be the principal funder of this, it is expected that there would be industry support in terms of supply of materials and building components to help with the cost. That is factored into the $40k estimate above.

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