Structural Considerations for Frame Supported Gypsum Area Separation Firewalls

BC Advisory Group on Advanced Wood Design Solutions

Edited by: Conroy Lum

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1. This guide is not a code and is not meant to replace any applicable codes.

2. This document is intended to be used by practitioners having experience with and knowledge of wood frame construction, fire protection engineering, and any other relevant and related disciplines.

3. Examples given in this guide are provided primarily to assist illustrating the concepts behind the solutions presented. The examples shown are not necessarily the appropriate or the only solution.

4. The content has been developed with the guidance of the British Columbia Advisory Group on Advanced Wood Design Solutions (AGW). Although every reasonable effort has been made to make this work accurate and authoritative, FPInnovations and members of the AGW do not warrant and assume no liability for the accuracy or completeness of the information or its suitability for any particular purpose or application.

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ACKNOWLEDGEMENT

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SUMMARY

The National Building Code of Canada (NBCC) permits firewalls having a fire-resistance rating of not more than 2h to be constructed with non-combustible materials other than masonry or concrete. One type of system is proprietary firewalls offered by the gypsum industry.

Whenever a proprietary firewall is used, practitioners need to demonstrate that the firewalls meet all the objective and functional requirements in the building codes. The lack of documented and clarity on the acceptable minimum levels of performance for these gypsum firewalls in wood frame construction has led to inconsistent acceptance of these systems by the Authority Having Jurisdiction (AHJ).

This guideline provides background information on gypsum firewalls and design considerations when gypsum firewall are used with wood frame construction meeting the requirements of the NBCC. Particular attention is given to discussing the structural issues so that due attention is paid to the structural detailing of these firewalls to ensure that they are sufficiently robust and will perform as expected. Results from exploratory tests on aluminum break-away clips and impact tests on gypsum wall liner are provided in the Appendix to provide practitioners with insight into the modes of failure.

Table of contents

List of figures

1 GUIDE LAYOUT AND OVERVIEW

This document consists of three parts:

- **Part A** – describes the application, conditions, and motivation for developing these guidelines.
- **Part B** – provides background information on the application and outlines how this application should be assessed, and considerations for developing the design details. It contains recommended primary and secondary design considerations.
- **Part C** – are issues and other recommended design considerations indirectly related to the design application.

Part A should be carefully reviewed to determine if this guide is applicable. Additional information is provided in the Appendices that may be useful for developing the alternative solution.

PART A

2 MOTIVATION FOR AND PURPOSE OF THE GUIDE

Since 2005, the National Building Code of Canada (NBCC) has permitted firewalls having a fire-resistance rating of not more than 2h to be constructed with non-combustible materials other than masonry or concrete. This has opened the door for alternative, proprietary firewalls such as those offered by the gypsum industry.

Several gypsum manufacturers have developed 2-hour fire-rated assemblies to provide fire separations intended to function as firewalls. Although all the systems are proprietary, they consist of more or less the same components: fire-rated gypsum shaftliner panels, and steel channels (C-runners and H-studs).

Where a proprietary firewall is used, practitioners need to demonstrate that the firewalls meet all the objective and functional requirements in the building codes. How and whether this has been achieved is generally not clearly specified. The lack of documented and acceptable minimum levels of performance for these alternative walls has led to inconsistent acceptance of the gypsum firewall in wood frame construction by the Authority Having Jurisdiction (AHJ). The purpose of these guidelines is to provide background information on gypsum firewalls and guidance on their design for use with wood frame construction meeting the requirements of the NBCC. Particular attention is given to discussing the structural issues so that due attention is paid to the structural detailing of these firewalls to ensure that they are sufficiently robust and will perform as expected.

3 SCOPE

This document applies only to Underwriters Laboratories of Canada (ULC) Listed gypsum area separation firewalls used in wood frame construction. Gypsum area separation firewalls are proprietary so only information generally applicable to this class of assemblies is provided. The guidance provided is intended to be used by experienced practitioners with knowledge of both wood frame construction, and fire protection engineering design. Users are strongly advised to consult with the gypsum shaftliner and component (see Figure 1 and Figure 2) supplier(s), and be familiar with any special requirements.

PART B

4 GYPSUM AREA SEPARATION FIREWALL

The 2-hour fire-resistance rated gypsum area separation firewalls (gypsum firewalls is used thereafter) are proprietary firewalls developed by gypsum wallboard manufacturers. ULC Listed firewalls are tested to demonstrate conformance with CAN/ULC-S101, Standard Methods of Fire Endurance Tests of Building Construction and Materials (ULC, 2007). A list of the 2-hour fire-resistance rated gypsum firewalls is also provided in the Gypsum Association GA-600, Fire Resistance Design Manual (Gypsum Association, 2009).

Although gypsum firewalls from each gypsum manufacturer are proprietary, current systems all consist of the same basic components: steel H-studs, steel C-runners, two layers of 1" thick fire-rated gypsum shaftliner panels, and aluminum clip angles. Figure 1 shows the components of the gypsum firewall assembly. More detailed guidance on the handling and the installation of gypsum firewalls is provided in the Gypsum Association publication GA-620, Gypsum Area Separation Firewalls (Gypsum Association, 2011).

The 1” gypsum panels, each having a 1-hour fire-resistance rating, consist of paperless surfaces and a moisture resistive, non-combustible core. Both steel H-studs and C-runners are made of 25-gauge thick steel, meeting the structural performance requirements in ASTM A653, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process (ASTM, 2009).

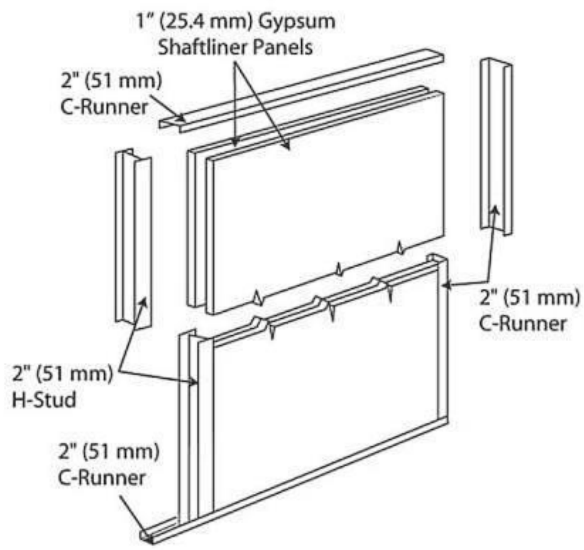


Figure 1 Primary components of gypsum firewall (aluminum clips not shown) (Gypsum Association, 2011)

The gypsum firewall is attached to the wood framing with aluminum clip angles (also referred to as breakaway clips) and typically drywall screws. The clip angles are also fastened to the steel H-studs of the gypsum firewalls, typically with pan head screws. Figure 2 is the standard clips referenced in Gypsum Association GA-620. The aluminum clips, having a melting point of 660°C, will soften when they are exposed to the heat of a fire on the fire side, allowing a damaged structure to break away from the firewall. Because the gypsum panels prevent the heat on the fire side from reaching the opposite side, the clips on the non-fire side will continue to hold the firewall in place.

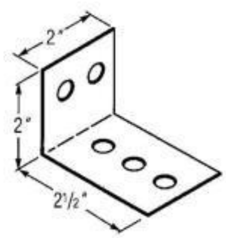
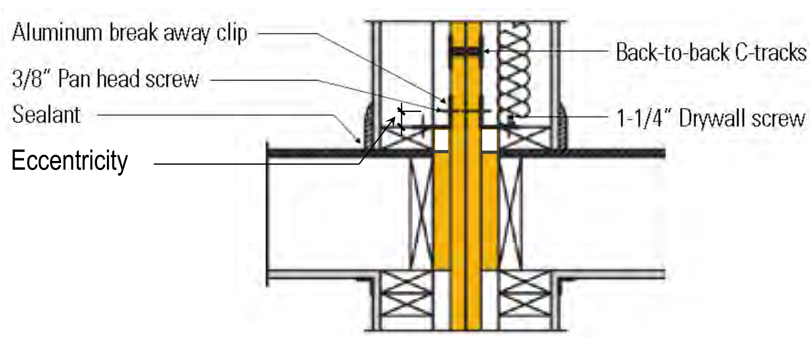
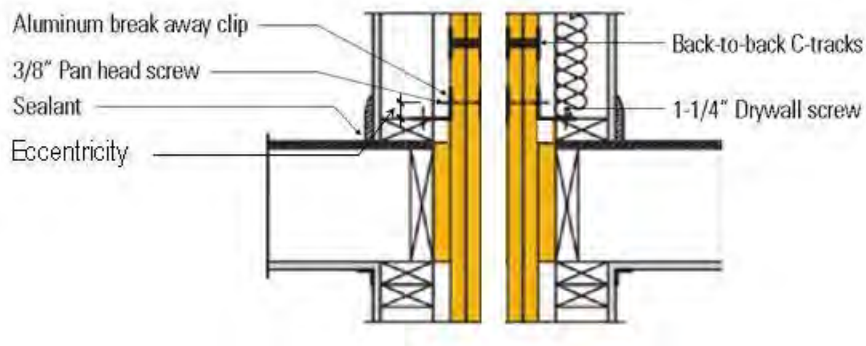


Figure 2 Aluminum clip angles to attach firewall to wood framing

For gypsum firewalls, either a single or double firewall solution can be used. The single firewall solution consists of a 2h fire resistance rated (FRR) gypsum firewall attached to the wood framing with aluminum clip angles installed on both sides of the firewall. The double solution consists of two gypsum firewalls each having a minimum of 1h FRR tied to its respective building frame with aluminum clip angles. The single and double firewall solutions are illustrated in Figure 3. The selection of the firewall solutions depends on the fire design, structural design, and construction considerations.



(a) Single gypsum firewall



(b) Double gypsum firewall

Figure 3 Single (a) and double (b) gypsum firewalls (Georgia-Pacific Gypsum, 2014)

5 APPLICABLE NBCC STRUCTURAL REQUIREMENTS FOR FIREWALLS

The NBCC (NRC, 2010a) contains the following structural requirements to ensure the appropriate design details are provided:

- Prevention of firewall collapse under fire condition (Clause 3.1.10.1)
- Protection to resist physical damage arising out of normal use that would compromise the fire-resistance rating of the firewall (Clause A-3.1.10.2.(4))
- Structural integrity of firewall under lateral load and fire condition (Clause 4.1.5.17)

Clause 3.1.10.1 requires that:

1) *Except as permitted by sentence (2), connections and supports for structural framing members that are connected to or supported on a firewall and have a fire-resistance rating less than that required for the firewall, are designed so that the failure of framing systems during a fire will not affect the integrity of the firewall.*

2) *Sentence (1) does not apply to a firewall consisting of two separate wall assemblies each tied to its respective building frame but not to each other, provided each wall assembly provides at least one half of the fire-resistance rating and designed such that the collapse of one wall assembly will not cause collapse of the other.*

3) *A firewall is permitted to be supported on the structural frame of a building of non-combustible construction provided that the supporting frame has a fire-resistance rating not less than that required for the firewall. (This requirement is not applicable to a building of wood construction.)*

4) *Piping, ducts and totally enclosed non-combustible raceways shall be installed so that their collapse will not cause collapse of the firewall.*

The code provisions pertaining to firewalls made with non-combustible materials other than masonry or concrete are provided in Appendix II. Article A-3.1.10.2.(4) of Division B, Appendix A states that a firewall need not be constructed of masonry or concrete provided it can retain both the fire-resistance rating and damage protection attributes. Though not specifically mentioned in Clause 3.1.10.2, inherent in the use of a firewall is the intent that this specialized wall construction provides the required fire-resistance rating while also being designed to resist physical damage – arising out of normal use – that would compromise the rating of the assembly. The fire-resistance rating and damage protection attributes of a firewall may be provided by a single fire- and damage-resistant material such as concrete or masonry, by a fire- and damage-resistant membrane on a structural frame, or by separate components – one that provides the fire-resistance rating and another one that protects the firewall against damage (e.g. stud wall). To achieve this, the firewall must meet the structural requirements of NBCC Clause 4.1.5.17.

Clause 4.1.5.17 addresses the structural integrity of firewalls under fire conditions. It requires that firewalls shall be designed to resist the maximum effect due to the appropriate lateral design loads or a factored load of 0.5 kPa under fire condition. The Commentary C (Structural Integrity of Firewalls) of the User's Guide – NBC 2010, Structural Commentaries (Part 4 of Division B) (NRC, 2010) provides further explanation on Clause 4.1.5.17. The factored lateral load of 0.5 kPa is used to ensure that during a fire, the firewall will not collapse due to the explosion of unburned gases, glancing blows from falling debris, the force and thermal shock of a firehose stream and wind pressure. Although information is provided for protection under normal conditions, the intent is that measures need to be taken to prevent damage to the firewall that would compromise its fire-resistance rating from structural loads or movements that would not render the structure unusable. Examples of such actions include wind and moderate seismic events, and other building movements due to wood member shrinkage or foundation settlement.

6 DESIGN BRIEF

6.1 General Guidance

General guidance on the structural design of firewall is provided in the APEGBC Technical and Practice Bulletin on 5- and 6-Storey Wood Frame Residential Building Projects (APEGBC, 2013). The key structural considerations in the design of firewalls under normal use and fire conditions are as follows:

1) Design for gravity load and differential vertical movement
2) Design for lateral load and differential lateral movement
3) Protection of firewalls against physical damage
4) Prevention of firewall collapse under fire condition

6.2 Design for Gravity Load and Differential Vertical Movement

6.2.1 Gravity Load

The gypsum firewall can be assumed as a continuous wall, but with hinge points along the horizontal steel C-runners. The gypsum shaftliner panels should be qualified by the manufacturer to have sufficient compression strength to carry its self-weight. Because the panels will be bearing end-to-end, the height of the firewall will be limited by the shaftline bearing capacity. However, because of the hinge points along the horizontal C-runners, the aluminum clip angles, which ties gypsum firewall to wood frames, will need to be provided to ensure the stability of the firewall under gravity load, particularly when the structure on the fire exposed side breaks away from the firewall.

According to Gypsum Association GA-620, openings are not permitted in gypsum area separation firewalls. For typical apartment buildings where there needs to be doorway openings for passage between the fire separated sections of the building, attention needs to be paid to transfer the gravity load of the fire doors to foundation. As the gypsum firewalls are non-load bearing walls and have limited gravity load capacities, it is unlikely that the gypsum firewalls are able to support the fire doors. In this case, a clear load path to transfer the gravity load of the fire doors to foundation needs to be developed. An example of design details to transfer gravity load of the fire doors is shown in Figure 4 and Figure 5.

Figure 4 Plywood to transfer gravity load of the fire doors (courtesy of GHL Consultants Ltd.)

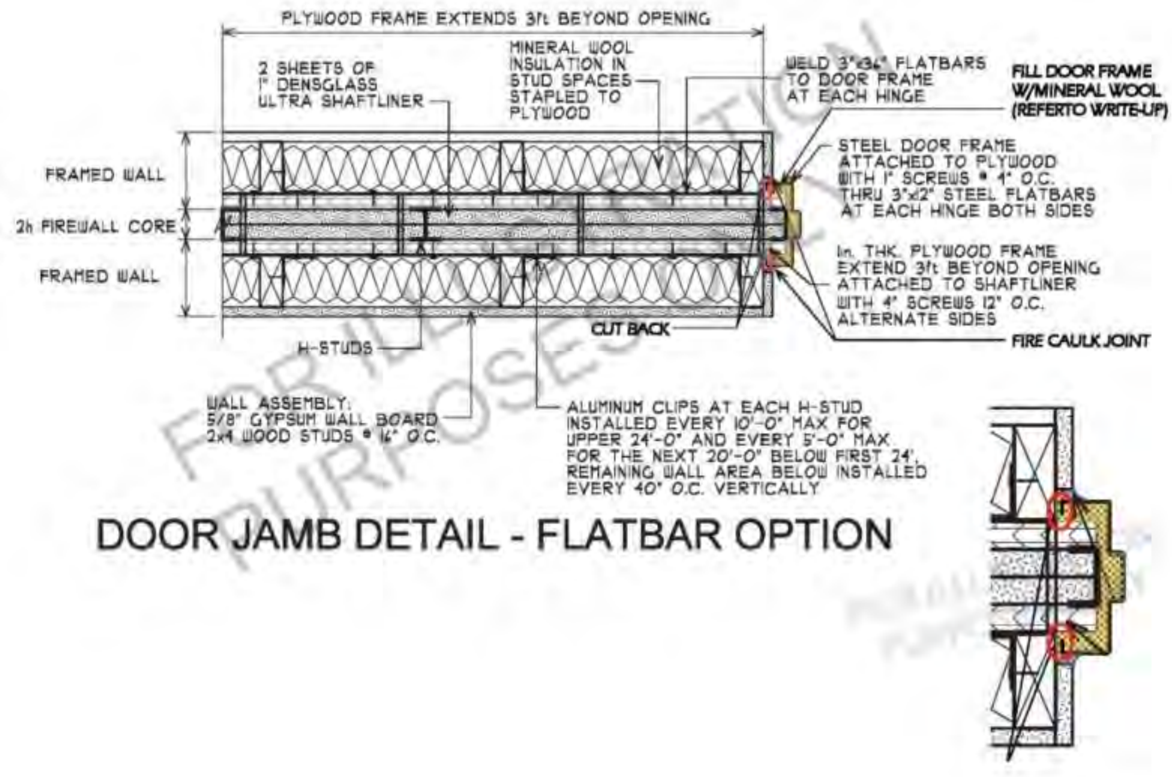


Figure 5 Example of design details to transfer gravity load of the fire doors (courtesy of GHL Consultants Ltd.)

6.2.2 Vertical Movement

Wood shrinks or swells with the change of moisture content, resulting in vertical movement in wood frame buildings. The vertical differential movement between the firewall and the wood framing needs to be considered. Vertically slotted aluminum clip angles can be used to accommodate a limited amount of differential movement between the gypsum firewall and the wood frames. To reduce the amount of vertical differential movement, it is recommended that engineered wood products or dimension lumber with MC $\leq$ 12% be used for floor joists. Prefabrication will also reduce the amounts and effects of vertical movement.

6.3 Design for Lateral Load and Differential Lateral Movement

6.3.1 Lateral Load

The seismic force on firewalls should be considered for buildings located in seismic areas. The two layers of 1hr FRR gypsum shaftline panels sit in, but are not fastened to, the C-runners or H-studs. Consequently, the in-plane shear stiffness of the gypsum firewall is relatively low compared to a monolithic firewall and movement between the components of the firewall is expected to provide some energy dissipation. Therefore, the gypsum firewall should be capable of resisting the in-plane inertial shear and overturning forces generated by the self-weight of the firewall under a seismic event. The out-of-plane inertial forces from the firewall needs to be resisted by the adjacent wood frame building through the aluminum clip angles. Design engineers need to ensure that the aluminum clip angles are able to transfer the out-of-plane lateral force to the wood frame building while considering all eccentricities in the connections. The total vertical differential movement (e.g. due to shrinkage) can be significant in a multi-story wood building and requires that any initial or final eccentricities in the aluminum clip angle connections as shown in Figure 3 be considered in the design. The aluminum clips are capable of yielding in bending and can accommodate considerable deformation (see Appendix IV) while still remaining attached. However, the amount of displacement and load capacity available will depend on what shrinkage or settlement has occurred and the final eccentricities of the screw fasteners.

6.3.2 Lateral Differential Movement

Lateral differential movements between the firewall and the wood frame buildings on either side of the firewall under wind or seismic load need to be considered. To prevent rupture of the aluminum clip angles, the aluminum clip angles should be able to accommodate the anticipated movements either parallel or perpendicular to the surface of firewall relative to the wood framing.

The wood frame buildings on either side of the firewall are free to move independently unless the two buildings are tied by rigid connections. This can be a challenge for designing single firewalls as the rigid connections need to pass through the gypsum firewall, and appropriate fire stopping and clearance will need to be provided around the connections. Where the two adjacent buildings are not tied by rigid connections, a space should be kept between the buildings to prevent pounding, and the aluminum clip angles should be attached or slotted to accommodate the anticipated minimum and maximum lateral displacement between the buildings. The space, however, will need fire stopping to prevent fire from spreading to adjacent floors. Where the lateral displacement cannot be accommodate by the aluminum clip angles, then two separate firewalls may be used so that each firewall can move along with its respective wood frame building to which the firewall is tied.

6.4 Protection of Firewalls against Physical Damage

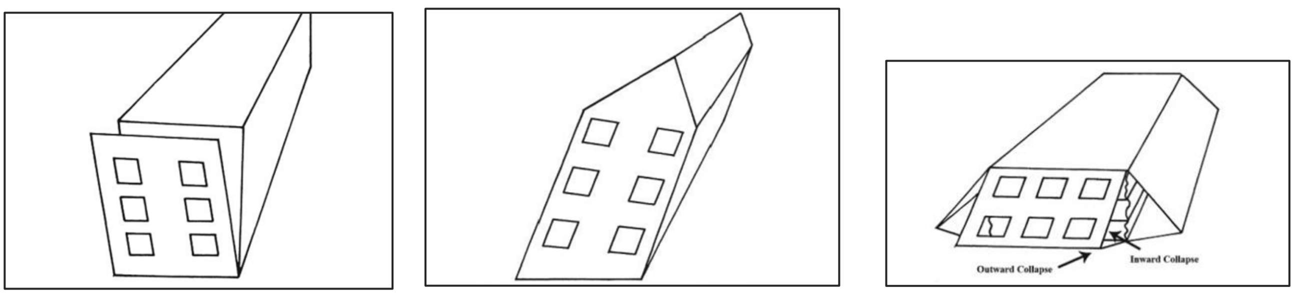
Article A-3.1.10.2.(4) of Division B, Appendix A states that though not specifically mentioned in Clause 3.1.10.2, inherent in the use of a firewall is the intent that this specialized wall construction provides the required fire-resistance rating while also being designed to resist physical damage – arising out of normal use – that would compromise the rating of the assembly.

The resistance to physical damage is intended to apply to all conditions, both under normal use of the building and fire conditions. Clause 4.1.5.17 requires that the firewall should be able to resist a minimum of 0.5 kPa lateral load under a fire condition to prevent firewall from damage/collapse due to the explosion of unburned gases, glancing blows from falling debris, the force and thermal shock of a firehose stream and wind pressure. However, the code is silent on the minimum concentrated load that firewalls need to resist to prevent the firewall from damage/collapse under fire conditions.

6.5 Prevention of Firewall Collapse under Fire Conditions

The stability of the firewall under fire conditions relies on the aluminum clip angles performing as intended, with the clips on the fire side of the building breaking away as the structure becomes unstable or collapses while the clips on the other side (unexposed to fire) keep the wall in place. This occurs if the fire is adjacent to the firewall and the clips on the fire side weaken due to exposure to high temperatures. However, if the fire is some distance away from the firewall and structural collapse begins without any fire effect on the clips, the clips on the fire side and the non-fire side would have similar strength. In this case, there is a question on whether or not the clips on the fire side will still break away and the clips on non-fire side can still hold the firewall in place.

According to Vincent Dunn (2010), there are three ways that a wood-frame building may collapse during a fire: one wall may fall straight outward at a 90-degree angle (Figure 6a), the entire building may lean over and collapse on its side (Figure 6b), or one or all four wood enclosing walls may crack apart and fall in an inward/outward collapse (Figure 6c).



a) Wall collapsing at a 90-degree angle

b) Wood-frame building falling in a lean-over collapse

c) Wood-frame building collapsing in an inward \ outward configuration

Figure 6 Collapse of wood-frame building (Vincent Dunn, 2010)

These are all modes of failure that are observed after there has been extensive fire damage to the several load bearing assemblies and the structure is on the verge of collapse.

The lean-over collapse parallel or perpendicular to the firewall as a unit is unlikely to occur in a sprinkled modern multi-unit residential building that is highly compartmentalized. Provided the building is properly firestopped and designed with appropriate vertical and horizontal fire separations, the collapse mechanisms in a fire condition will initially be limited to a compartment. After a time other adjacent compartments will become involved. Figure 6 illustrates the possible cases of collapse scenarios in a sprinkled modern, multi-unit residential building.

In most cases, the shear wall (which consists of plywood on studs protected by gypsum wallboard) is tied together to provide a load path to the foundation to resist seismic loads and has a large degree of rigidity as a unit. The vertical dead load of the structure will also tend to keep the shearwalls attached to the rim joist.

Scenario 1: The joist will burn but leave the rim joist between the stud walls in place.

Scenario 2: The segment of the floor in the fire affected compartment fails and the shear wall may get twisted and pulled away from clips. However, because of continuity of the shear wall parallel and the firewall into adjacent unaffected compartments, the bulk of the wall remains in place due to the clips and the other walls and floors.

Scenario 3: If the shear wall burns through (unlikely to happen before the floor fails, but possible), joist may fall, but initially the floors above will stay due to continuity of the walls into the unaffected compartments.

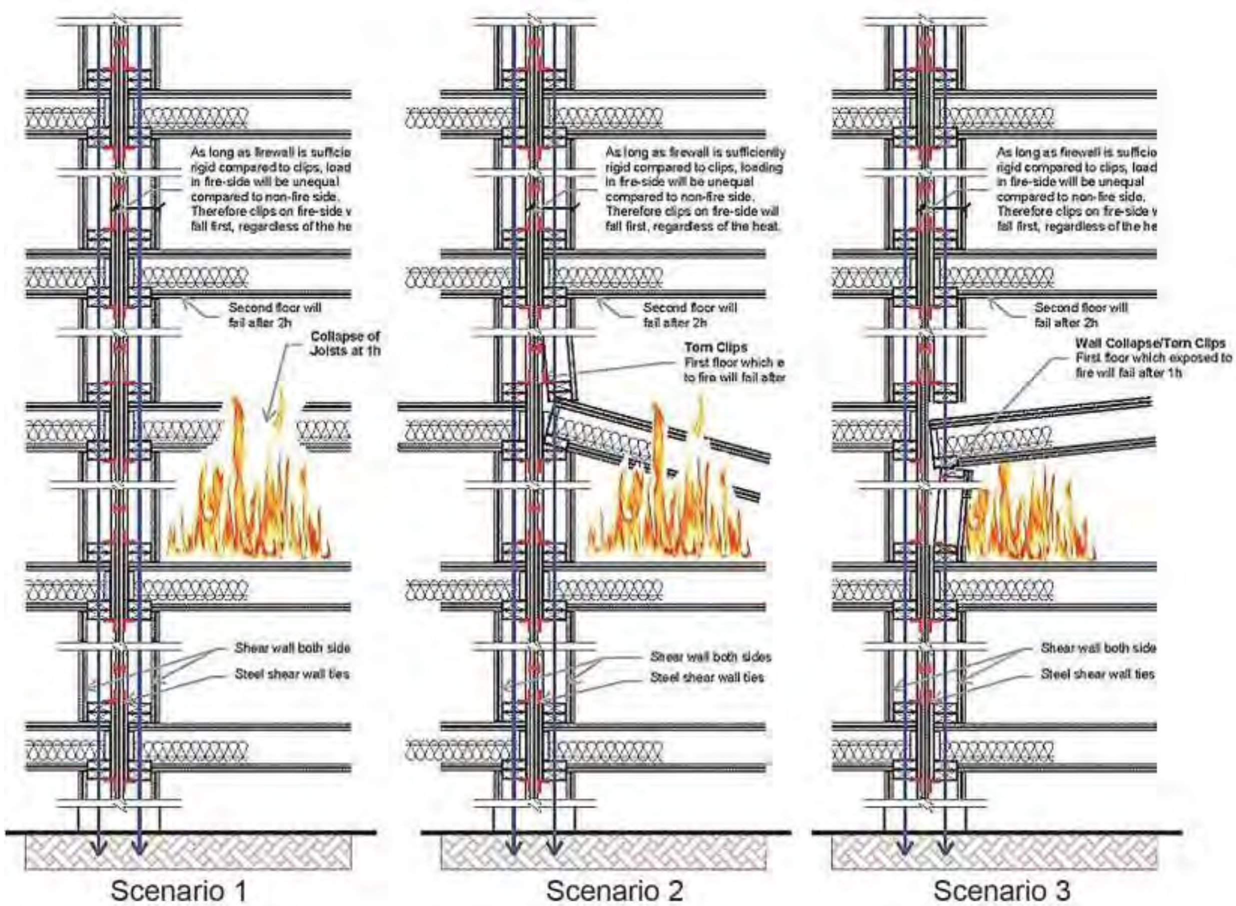


Figure 7 Possible collapse scenarios for multi-unit modern wood-frame building (courtesy of GHL Consultants Ltd.)

In all of the conceivable cases, the clips will be unevenly stressed on the fire side, with a small number of clips stressed and some clips failed. Provided the shear wall and firewall have some rigidity and continuity into the unaffected compartments, the load will be distributed over a large number of clips on the non-fire side; therefore the clips on the fire side will always fail first. This is the likely scenario in the early stages of a fire when the fire is confined to a few compartments.

Depending on the design and details of the building, other collapse scenarios are possible. These should be reviewed by the structural and fire design consultants on the project. To assist with this, a test program was conducted to study the failure of aluminum clip angles. The test report is provided in Appendix IV. The test results indicate that under the worst scenario where the building under fire leans over, the clips can break on either side of the firewall if the clips are not weakened by fire. However, in a modern, multi-unit residential building, the collapse mechanisms will initially be limited to a compartment. After a time other compartments will become involved, particularly if the fire continues to grow and there is no fire suppression. With the progress of fire, the building will mostly likely fall in an inward/outward collapse.

To further reduce the possibility of aluminum clips from rupturing on the non-fire side of the building, it is recommended that two separate firewalls be used. With this approach, only the firewall attached to the building under fire will collapse while the firewall attached to the other building remains intact. This approach, however, involves a more complex construction sequence and a different arrangement for fire doors to permit passage between the fire separated sections of the building.

7 EXECUTION AND IMPLEMENTATION

7.1 Vertically Segmented Firewalls

Some designers may find it challenging to estimate the movement with sufficient accuracy and/or detail a slotted clip that will accommodate all movements while ensuring the integrity of the wall is maintained. As an alternate to the single and double gypsum firewalls, it may be worthy to consider a double 2-hour firewall where the walls are broken at each floor and supported off the adjacent wood frame structures. Although the break in the wall needs to be addressed from a fire perspective (i.e. protected by fire stop that can accommodate some closure of the gap), such a wall will tend to reduce the cumulative lateral and vertical movements that occur in a multi-level building, and limit them to a per floor basis. Provided an adequate gap is provided between the buildings, such a wall may prove to be an effective solution in ensuring the integrity of the wall is maintained.

7.2 Service Penetrations of Firewalls

When there is relative movement between buildings, the potential damage caused by cables, conduits, ducts and pipes that pass through firewalls should be considered. The relative vertical (due to shrinkage of wood members) and in-plane horizontal (due to wind or moderate earthquake) movement between the wood frame buildings and the firewall during occupancy could cause damage to the firewall or the penetrating pipes. Adequate clearance and bracing of the services of the services should be provided.

Under fire condition, the pulling and sagging force from the penetrating pipes as sections of the building collapse can also cause damage to firewall and fire-stop system. For wood frame building, it can be assumed that the firewall is able to resist this force if it can resist the 0.5kPa lateral load under fire condition.

7.3 Protection of Firewalls – Impact Resistance

Neither the NBCC nor the BCBC provide specific guidelines with respect to quantifying an acceptable level of resistance to physical damage for firewalls during construction and occupancy. In Alberta, the Department of Municipal Affairs and Housing issued a StanData (06-BCI-005-R1) to provide guidance on how to interpret the requirements of Clause 3.1.10. It requires that gypsum firewalls be protected from damage due to any hazard present in the building during construction and occupancy, such as:

- fall, collapse, or expansion of stored items and building contents such as elevated vessels, racks, or shelving,
- explosion of contents in the area of the firewall such as pressure vessels or flammable materials,
- mechanical damage from vehicles, equipment or occupants,
- fracture, penetration, and fragmentation that can be caused by a fire, sprinkler activation, or fire-fighting efforts,
- collapse of adjacent roof and wall structures or adjoining buildings, or
- any other factors that may affect the ability of the structure to comply with the intent of the Alberta Building Code.

According to Triggs and Locke (1999), under most circumstances and occupancy classifications (i.e., Group A, B, C, D and F, Div. 3 occupancies requiring a 2-hour rated firewall), physical damage to the firewall construction from the above items is not considered to be of significant concern due to the relatively low hazard nature of these occupancies. However, in the cases where firewalls are incorporated in higher-hazard occupancies (i.e., Group E, and F, Div. 2 or 3 occupancies) where storage facilities such as warehouses or other industrial occupancies may cause potential damage to the firewall construction during normal operations, additional physical protection is warranted for such conditions. In fact, the necessary fire resistance, strength and structural stability required for these higher hazard occupancies, would in most cases be provided with the use of concrete or masonry materials based on current industry practice.

It should also be noted that gypsum firewalls will require support from the walls of the adjacent buildings. These walls will provide protection to the gypsum firewall during normal occupancy and it is expected that abuse and damage will be visible and promptly repaired. As with any firewall, maintenance personnel and renovators should be aware of inflicting any damage or penetrating the firewall or the supporting connection.

For other conditions, such as during a fire, exploratory tests by FPInnovations were conducted to investigate the impact resistance of gypsum firewalls. Although these tests were not carried out under fire conditions and test standards have not yet been established, the testing did identify the potential mode of failure under an impact load. The test report is provided in Appendix III.

8 FINAL REMARKS

Gypsum firewalls have many attributes that make them compatible with wood frame construction. Through standard testing, they have been demonstrated to provide the necessary fire resistance. However, the structural and fire consultants need to work closely on selecting the appropriate firewall configuration and supporting details to ensure that the firewall is able to function as expected in the event of a fire. Consideration should be given to building movement due to shrinkage, settlement, wind loading, and moderate earthquakes as may occur during normal occupancy. Aside from the occupancy, the compartment size may influence the potential mode of structural failures during a fire; these too will influence the choice of firewall configuration and supporting details. Details have been developed that are suitable for most wood frame residential construction.

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Appendix I Guideline Review Ranking System[1]

The following ranking system has been developed to monitor the status of the wood building design guidelines[2] maintained by the BC Advisory Group on Advanced Wood Design Solutions (AGW):

RANK	DEFINITION
#	This is a draft document this is being circulated for review and comments.
A	This guideline is new and represents the best available evidence at this time. It will be periodically reviewed to determine if it remains current.
B	This guideline was last reviewed on the date indicated and there have been new studies published since the guideline was developed. However, the AGW determined that these studies are not sufficient to warrant changing the guideline. The information contained in this guideline provides the user with the best evidence available at the time the guideline was published. Readers are encouraged to search the current literature as a supplement to using this guideline.
C	This guideline was last reviewed on the date indicated. As a result of that review, the AGW determined that new studies have been published that warrant an update of the chapter/section of this practice guideline. The AGW also determined that the remainder of the chapters/sections does not require updating and these recommendations remain current.
D	This guideline was last reviewed on the date indicated. As a result of that review, the AGW determined that new data are available that are sufficient to potentially change guideline recommend and a full revision is warranted.
E	This guideline was last reviewed on the date indicated. As a result of that review, the AGW decided it is outdated; however, it has been retained for historical and/or educational purposes. These guidelines should be used with caution for design purposes.

[1] This list was adapted from the Canadian Thoracic Society Policy and Evidence-Based Medicine, and the American College of Chest Physicians (ACCP) Guidelines Ranking System.

[2] Check fpinnovations.ca for the latest edition.

Appendix II Requirements pertaining to firewalls made with non-combustible materials other than masonry or concrete in NBCC

3.1.10.2 (4) *A Firewall permitted to have a fire-resistance rating not more than 2 h need not be constructed of masonry or concrete, provided*

1) *the assembly providing the fire-resistance rating is protected against damage that would compromise the integrity of the assembly, and*

2) *the design conforms to Article 4.1.5.17.*
(See Appendix A.)

A-3.1.10.2.(4) Firewall Construction

Inherent in the use of a firewall is the intent that this specialized wall construction provides the required fire-resistance rating while also being designed to resist physical damage – arising out of normal use – that would compromise the rating of the assembly. Traditionally, this has been accomplished by prescribing the use of non-combustible materials, which was in fact restricted to concrete or masonry. Sentences 3.1.10.2.(3) and (4) are intended to retain both of the characteristics of firewall, while permitting greater flexibility in the use of materials and designs. The fire-resistance rating and damage protection attributes of a firewall may be provided by a single fire- and damage-resistant material such as concrete or masonry, by a fire- and damage-resistant membrane on a structural frame, or by separate components – one that provides the fire-resistance rating and another one that protects the firewall against damage.

If the firewall is composed of separate components, the fire-resistance rating of the fire-resistive component needs to be determined for this assembly on its own. In addition, if the damage protection component is physically attached to the fire-resistive component (for example, as a sacrificial layer), then for the purposes of determining the overall performance of the assembly, it is also necessary to determine through testing whether failure of the damage protection component during a fire affects the performance of the fire-resistive component.

4.1.5.17. Firewalls

1) *Firewalls shall be designed to resist the maximum effect due to*

   a) *the appropriate lateral design loads prescribed elsewhere in this Section, or*

   b) *a factored lateral load of 0.5 kPa under fire conditions, as described in Sentence (2).*

2) *Under fire conditions, where the fire-resistance rating of the structure is less than that of the firewall,*

   a) *lateral support shall be assumed to be provided by the structure on one side only, or*

   b) *another structural support system capable of resisting the loads imposed by a fire on either side of the firewall shall be provided.*

Commentary C Structural Integrity of Firewalls

1) NBC Sentence 3.1.10.1.(1) requires that, where structural framing members are connected to or supported on a firewall and their fire-resistance rating is less than that required for the firewall, the connections and supports for such members must be designed so that the collapse of the framing members during a fire will not cause the collapse of the firewall. NBC Sentence 4.1.5.17.(1) requires that the firewall be designed to resist a factored lateral load of 0".5 kPa under fire conditions.

2) These requirements, along with others in NBC Subsection 3.1.10., form part of the general requirement that a fire not spread between compartments separated by a firewall within the required fire-resistance rating for that wall (4 h for high fire hazard occupancies and 2 h for other occupancies). To achieve this, the firewall must not be damaged to such an extent that it allows a fire to spread within these periods.

3) In order to meet the requirement for structural integrity of firewalls, the following loading conditions must be applied.

Lateral Loads on Firewalls

1) NBC Sentence 4.1.5.17.(1) requires that firewalls be designed for a factored lateral load of 0.5 kPa so that, during a fire, the firewall will not collapse due to the explosion of unburned gases, glancing blows from falling debris, the force and thermal shock of a firehose stream and wind pressure. If the structure exposed to the fire has less fire resistance than that required for the firewall, it is assumed to have failed and therefore to provide no lateral support to the firewall.

2) NBC Sentence 4.1.5.17.(1) also requires that the firewall be designed in accordance with the typical structural requirements applicable to interior walls with regard to wind and earthquake, as well as pounding damage.

3) The building structure, including the firewall, should also be designed to provide structural integrity in accordance with the recommendations of Commentary B.

Thermal Effects

1) The thermal expansion of a structure exposed to a fire must not damage the firewall as this would allow the premature spread of fire through the wall.

2) To assess the potential for such damage, the thermal expansion of the structure should be estimated based on a 500°C temperature increase in combination with the thermal coefficients given in Table E-1 of Commentary E. The expansion of the structure toward the firewall can be assumed to begin at a vertical plane in the fire compartment at 20 m from the firewall or half the width of the fire compartment, whichever is less.

3) In assessing thermal effects, attention should be given to the effect that distortion of the firewall due to temperature differential through the wall has on the stability of the firewall.

4) If thermal movements are sufficient to damage the firewall, either adequate clearances should be provided or the firewall and structure on both sides should be detailed to prevent wall damage.

Appendix III Exploratory Tests at FPInnovations on Gypsum Firewall Impact Resistance

By

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III.1 Objective

To investigate gypsum firewalls modes of failure under impact loading

III.2 Impact Tests

III.2.1 Test Materials

Materials used to construct the gypsum firewall were CGC Sheetrock® Glass-Mat Liner Panels (1" thick x 24" wide x 10' long), metal H-studs (2 inches wide) & C-channel (2-1/8 inches wide), and 9/16-inch Type S wafer head fine thread screws to tie the H-Studs to the C-channels. For comparison, GP Toughrock

III.2.2 Methods

All panels were tested horizontally by dropping a 'soft body impact bag' on to the center of each panel. The impact bag is made of leather with an 11-inch diameter padded bottom and was filled with smaller bags of lead shot to a final weight of 27.3 kg (60 pounds). However, with the additional hoisting hardware, the final weight was 29.5 kg (65 pounds). An overhead crane was used in conjunction with an electromagnet to lift up the bag to specific heights before being dropped on to each firewall.

After each impact, the bag was removed and the amount of panel deflection along with any damage/failure was recorded. Deflection was measured using a Stabila LD-320 Laser Measure (Figure 8) from the floor to the bottom surface of the center panel. Each drop was repeated 3 times, unless a failure occurred first.

Figure 8 Stabila Laser Measure

Each specimen is 48-inch wide x 10-ft long. Two specimen configurations were used: 1) 24-inch wide x 10-ft long gypsum wallboard in the center section and 12-inch wide x 10-ft long gypsum wallboard on each side; 2) 24-inch wide x 10-ft long gypsum wallboard side by side.

The long edges of the gypsum wallboards are fitted into the channel of the metal H-studs (Figure 9) which are at the same length. C-channels (Figure 10) were cut and fitted onto the short edges at the top and bottom of the specimens over the H-stud. At each corner (Figure 11) and intermediate overlap on both faces, one 9/16” Type S wafer head screw is used to attach the C-channel and H-stud.

Figure 9 H-studs shown with panels on one side

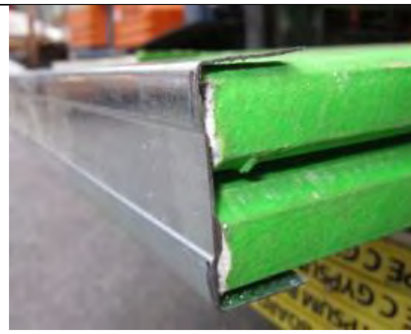

Figure 10 C-channel over panel ends

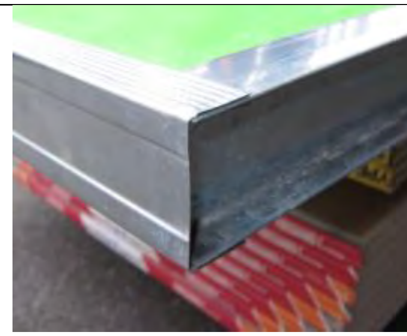

Figure 11 C-channel and H-stud

The panels were placed on to 26.5-inch high metal support stands at each end, which were firmly clamped to the floor. The stands are spaced approximately 109 inches apart. For each test, the panels were held in place by clamping a metal plate onto the top surface of the panel and to a section of each support.

During testing, it was discovered that the outer edges of H-stud should be clamped together to limit the amount of buckling/rotation of the H-studs. This was initially achieved with wooden blocks and tie down straps around the center of each panel and eventually a wooden frame was used to prevent the straps from interfering with the panels. The frame is approximately 24 inches wide which gave a drop zone area of 24 square inches on the center panel.

Upon further testing, it was decided to install a stud frame placed 1-inch below the test panel. The spacing of the wood studs lined up with the metal H-studs. This simulated a wall frame next to the firewall, which would limit the out-of-plane deflection of the panel.

Figure 12 shows the specimen configurations and test setup.

a) 1/2” plywood on each side

b) small wood blocks and straps tied at outer edges of H-studs

c) wooded frame and straps tied at outer edges of H-studs

d) stud frame

e) stud frame below firewall

f) 1/2" Type C gypsum wallboard and stud frame

g) Two 24" wide panels and stud frame

Figure 12 Configurations of impact tests

III.3 Test Results

A summary of the test results are provided in Table 1.

Table 1 Test results and observations

Specimen	Impact height* (m)	Impact #	Panel deflection (m)	Observation
2 layers of 1" thick fibre-glass GWB on center section, 4 layers of 1/2" plywood on each side (Figure 12a)	0.5	1	0.024	Center H-studs rotated and center portion of panel came loose. Plywood sides may be too stiff.
2 layers of 1" thick fibre-glass GWB on center section and each side, wood blocks and straps tied at outer edges of H-studs (Figure 12b)	0.5	1	0.00	No damage.
		2	0.00	No damage.
		3	0.00	No damage.
	1.0	1	0.015	'Wavy' deformation on all H-studs.
		2	0.043	Further deformation with center H-studs buckling/rotating slightly and panel coming loose. However, the straps held the panel in place, which prevented further deflection/damage.
		3	0.063	Further deformation with center H-studs buckling/rotating more and bottom center panel coming free. However, the straps held the panel in place, which prevented further deflection/damage.

Specimen	Impact height* (m)	Impact #	Panel deflection (m)	Observation
2 layers of 1" thick fibre-glass GWB on center section and each side, wood blocks and straps tied at outer edges of H-studs (Figure 12b)	1.5	1	0.053	Center H-studs buckled/rotated and center panel came loose.
		2	Panel broke	Panel broke in half.
2 layers of 1" thick fibre-glass GWB on center section and each side, wood frame and straps tied at outer edges of H-studs (Figure 12c)	1.5	1	0.066	Center H-studs buckled/rotated and center panel came loose.
		2	Panel broke	Panel broke in half.
4 layers of 1/2" thick Type C GWB on center section and each side, wood frame and straps tied at outer edges of H-studs (Figure 12f)	1.5	1	0.009	Very slight deformation on H-studs. No apparent damage to panel. Panel bounces off stud frame.
		2	0.012	Further 'wavy' deformation to the H-stud. No apparent damage to the panel. Panel bounces off stud frame.
		3	0.016	'Crack' and dent on top surface layer of gypsum. Bottom surface panel also torn. Panel bounces off stud frame. When taking apart wall panels, all 4 layers were damaged.
2 layers of 1" thick fibre-glass GWB on center section and each side, stud frame 1" below gypsum firewall, wood frame and straps tied at outer edges of H-studs (Figure 12e)	1.5	1	0.007	Slight 'wavy' deformation on all H-studs. Panel bounces off stud frame.
		2	0.025	Center H-studs buckled/rotated as well as the side wood frame. Bottom center panel resting on stud frame. Panel slightly torn on bottom.
		3	0.030	Center H-studs buckled/rotated further as well as the side wood frame. Bottom center panel resting on stud frame. Panel torn on bottom layer. When taking apart panels, the bottom layer of the top panel was also torn.
2 layers of 1" thick fibre-glass GWB side by side, stud frame 1" below gypsum firewall, wood frame and straps tied at outer edges of H-studs (Figure 12g)	1.5	1	0.009	Very small deformation of H-studs. Panel bounces off stud frame. No apparent damage to panels.
		2	0.020	Outer H-studs buckled/rotated and wood frame came off. No apparent damage to panels.
		3	0.022	Outer H-studs were buckled/rotated. 'Kink' in middle H-stud. Panel bounces off stud frame. No apparent damage to panels.

Specimen	Impact height* (m)	Impact #	Panel deflection (m)	Observation
2 layers of 1” thick fibre-glass GWB on center section and each side, stud frame 1” below gypsum firewall, wood frame and straps tied at outer edges of H-studs (Figure 12e)	2.0	1	0.022	Center H-studs buckled/rotated and center panel came loose. Panel bounces off stud frame.
		2	0.032	Center H-studs buckled/rotated further as well as the side wood frame. Bottom center panel resting on stud frame.
		3	0.037	Center H-studs buckled/rotated further as well as the side wood frame. Bottom center panel resting on stud frame. Panel torn on bottom. When taking apart panels, the bottom layer of the top panel was also torn.

* 65-lb mass (bag, lead shot fill, and hardware released with the bag); impact height from top surface to specimen to the bottom of the impact bag.

Figure 13 to Figure 17 show the typical failure modes that occurred during testing.

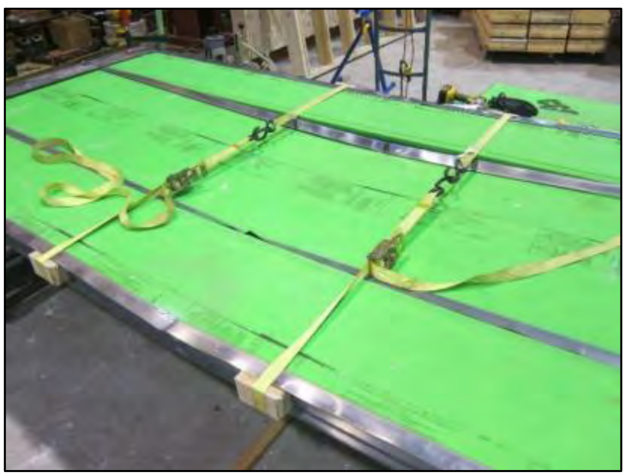

Figure 13 Center H-studs buckling/rotating

Figure 14 Panel failure

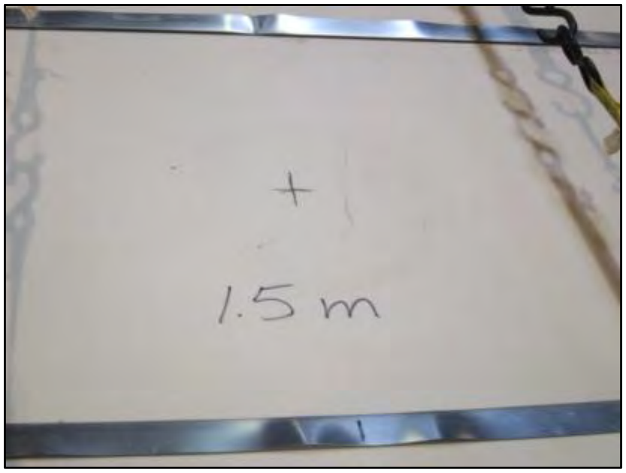

Figure 15 Top surface damage (Type C GWB) and 'wavy' H-studs

Figure 16 Center H-stud damage for 2 panels

Figure 17 Bottom panel face damage

Appendix IV Structural Evaluation at FPInnovations of Aluminum Angle Clips used in Gypsum Firewalls

By

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FPInnovations

IV.1 Introduction

The structural stability of the gypsum firewall under fire conditions relies, in most parts, on the aluminium angle clips performing as intended, with the clips on the side exposed to fire breaking away as the structure becomes unstable or collapses while the clips on the side unexposed to fire keep the gypsum firewall in place. This may occur if the fire is adjacent to the firewall and the clips on the fire side weaken due to exposure to high temperatures. However, if the fire is some distance away from the firewall and structural collapse begins without any significant fire effect on the clips, the clips on both sides of the firewall may have similar strength. Question is raised on whether or not the clips on the side exposed to fire will break away and the clips on side unexposed to fire can still hold the firewall in place. There is a need to carry out a test program to better understand this potential mode of failure.

IV.2 Objectives

The purposes of the test program are:

- To evaluate the capacities and failure modes of aluminum angle clips
- To determine the failure mechanisms of a segment of a gypsum firewall assembly (hereafter referred to as the “firewall assembly”) with clips attached to wood framing on both sides

IV.3 Materials used in the Tests

The gypsum boards, metal channels, aluminum angle clips and screws used in the tests were ordered from local building material suppliers. In this test program, 1/2" thick Type C gypsum panels were used in lieu of 1” thick gypsum panels.

Steel Framing:

- Standard steel C-channels, 2-1/8 inches wide (54 mm) and having nominal base metal thickness of 0.018-inch (0.457 mm). There are no product stamps to indicate which standards this products is in compliance with.
- Two types of steel H-studs were received from the local supplier:

  a) The first one is a standard steel H-stud which is 2 inches wide (51 mm) and has a nominal base metal thickness of 0.020-inch (0.508 mm). There are no product stamps to indicate which standards this products is in compliance with.

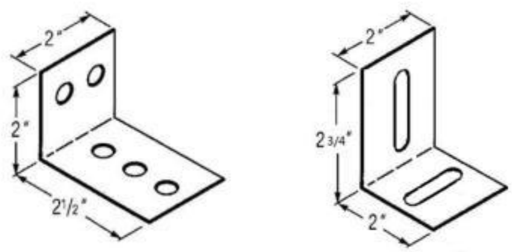
  b) The second one is proprietary H-studs which are in compliance with ICC ES Legacy Report 92-19 (ICC Evaluation Service, 2008). The H-stud is 2 inches wide (51 mm) and has a nominal base metal thickness of 0.027-inch (0.686 mm). According to the report, the H-studs are fabricated from cold-formed steel complying with ASTM C645 (ASTM, 2013a).

Gypsum Panels:

- 1/2" thick Type C gypsum panels, 4 feet (1220 mm) wide by 10 feet (2440 mm) long, complying with ASTM C1396 (ASTM, 2013b) and CSA A82.27 (CSA, 1991).

Aluminum Angle Clips:

- Two types of aluminum clips were used. The first one, 2 inches (51 mm) wide and 0.049-inches (1.24 mm) thick, is a standard clip as specified in Gypsum Association GA-620 "Gypsum Area Separation Firewalls" (Gypsum Association, 2011). The other one, 2 inches (51 mm) wide and 0.061" (1.55 mm) thick, is a modified clip in which slots are made to allow for relative moment. Schematic drawings of the two types of clips are shown in Figure 18. According to Gypsum Association GA-620, the aluminum clips have a melting point of 660°C.



a) Standard clip b) modified clip

Figure 18 Aluminum angle clips to attach firewall to wood framing

Screws:

- 9/16-inch (14.3 mm) Type S wafer head fine thread screws to tie the C-channels together, the H-Studs to the C-channels, and the aluminum clips to H-studs.
- 1-1/4 inch (31.8 mm) Type W bugle head coarse thread screws to secure the aluminum clips to supporting wood framing members.

Wood framing:

- Stud, top and bottom plates made of 2 × 6 SPF No.2 & better lumber
- Floor joist made of 1-3/4 inch thick by 12 inch deep Oriented Strand Lumber

IV.4 Test Matrix and specimen configuration

The test program consists of: a) clip joint test, and b) firewall assembly test.

Clip joint test:

The matrix of the clip joint test is given in

Table 2. Configurations of aluminum angle clip joint tests are shown in Figure 19. In the clip joints, the short leg of the standard aluminum clip was connected to H-stud with two 9/16" (14.3 mm) Type S wafer head screws, and the long leg of the clip was connected to framing member with two 1-1/4" (32 mm) Type W bugle head screws (outer 2 screw holes were used). A space of 3/4-inch (19 mm) was left between the H-stud and the framing member, in accordance with the Gypsum Association GA-620 “Gypsum Area Separation Firewalls”.

Table 2 Summary of clip joint tests

Joint Test	H-stud	Clip	Load Condition	No. of specimens
1	Standard	Standard	A	5
	ICC ES 92-19	Standard	A	3
2	Standard	Standard	B	5
	ICC ES 92-19	Standard	B	3
3	Standard	Standard	C	3
	ICC ES 92-19	Standard	C	3

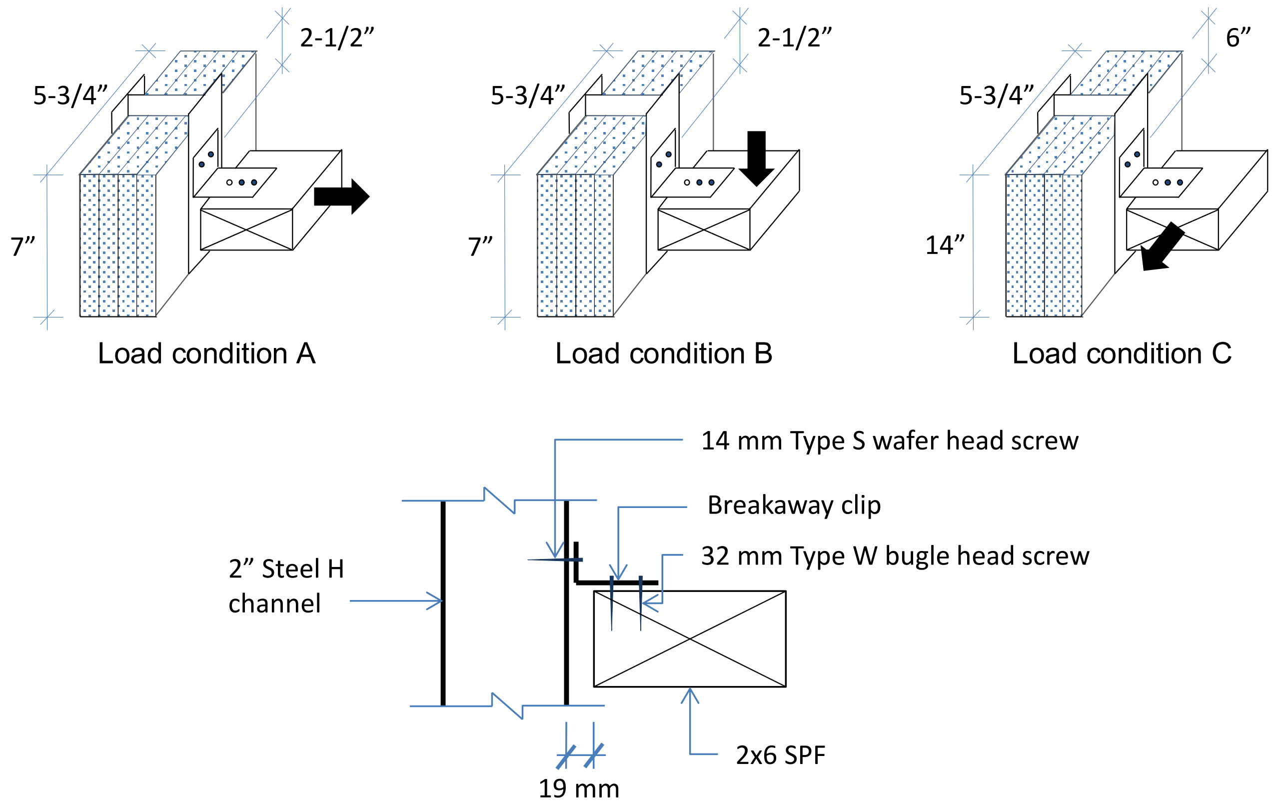


Figure 19 Configuration of clip joint tests

Firewall assembly test:

The matrix of the firewall assembly test is given in Table 3. Configurations of firewall assembly tests are shown in Figure 20. For the firewall assembly, each gypsum firewall is made with four layers of 1/2 inch Type C gypsum panels (cut 24” wide and to a specific height) stacked together. Both vertical edges of the gypsum are fitted into the channel of the metal H-studs which are cut to the same height as the firewall. C-channels are then fitted onto the top and bottom of the firewall over the H-stud. At each corner on both faces, one 9/16” Type S wafer head screw is used to attach the C-channel and H-stud. If a firewall is stacked on top of another firewall, a C-channel would first be screwed onto the top C-channel of the firewall below. The two back-to-back C-channels are connected with two 9/16” Type S wafer head screws near each end.

For the wood frame assembly, the floor joist and wall plates are stiffened to ensure they will work as one unit during the tests. The studs and plates are connected in such a way that they would represent the real construction condition. To achieve this, the floor joist and wall plates are connected with two Simpson Strong-Drive screws (¼" in diameter and 3" in length) per joist. The studs are end-nailed or toe-nailed to plates with 3-¼" x 0.131 common nails.

On the back of the firewall, a steel column was used to represent wood framing on the non-fire side. To ensure clips are installed symmetrically on both sides of the firewall, 2x6 lumber is attached to the column to match the heights of the wall plates of the wood frame wall in front of the firewall. A space of 3/4 inches was left between the firewall and wood plates. The 9/16" Type S wafer head screws were used to attach the clips to the H-studs and 1-3/4" Type W bugle head screws were used to attach the clips to the wood plates. For firewalls where modified clips were used, the screws were first tightened all the way down into the plates and H-studs and then turned 1/4 back to ensure that clips can slide during the tests.

Table 3 Summary of firewall assembly tests

Wall No.	H-stud	Clip	Load Condition	No. of specimens
1	ICC ES 92-19	Standard	A	1
2	ICC ES 92-19	Standard	B	1
3	Standard	Standard	B	1
4	ICC ES 92-19	Modified	B	1
5	ICC ES 92-19	Modified	A	1
7	Standard	Standard	A	1

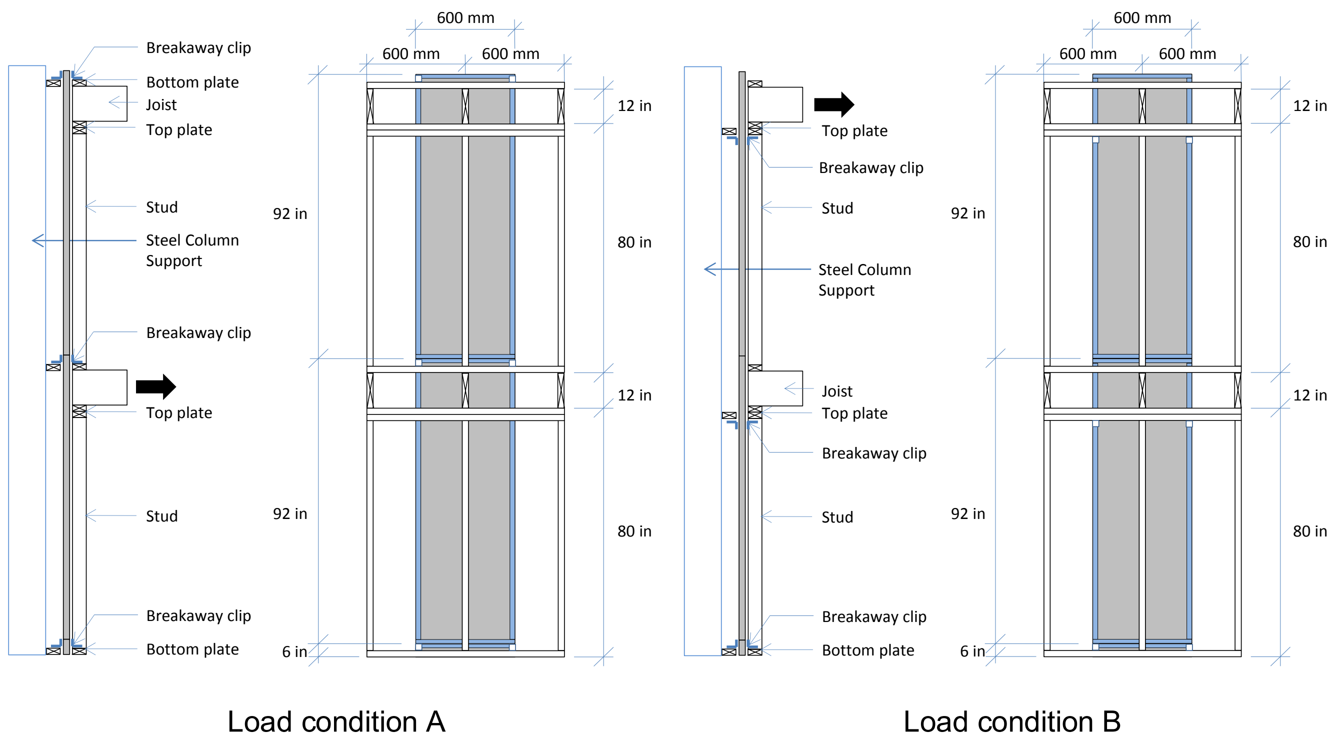


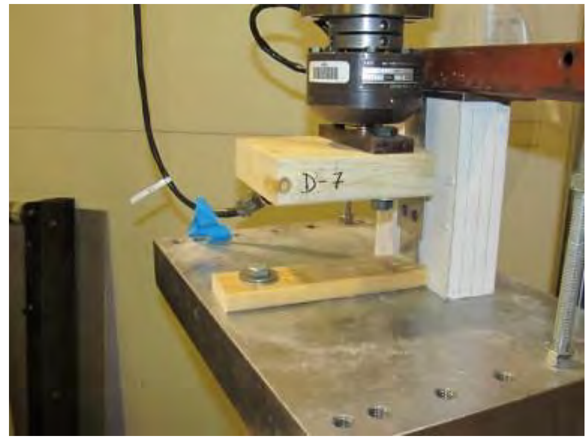
Figure 20 Configuration of firewall assembly tests

IV.5 Test Set-up and Loading Rate

Joint Connection Tests:

The setups of clip joint tests are shown in Figure 21. The load was applied through a steel plate attached to the specimen. The wood member was prevented from rotation by the steel plate which holds the member in place. The firewall section was held down onto the actuator table by clamping a long narrow metal tube onto the edge of the gypsum. The actuator table moves downward during testing. Loading rate was 0.25 in/min for load condition A and 1.0 in/min for load conditions B and C.

a) Load condition A



b) Load condition B

c) Load condition C

Figure 21 Clip joint test setups

Firewall Tests:

The fire wall test setups are shown in Figure 22. The actuator is connected to the framing members through 2 short pieces of 2x4 lumber bolted at each end. The load was applied at the center of the floor joist at the first or second storey. Loading rate for each wall test condition was 0.50 in/min.

There are 8 transducers used to measure movement of the gypsum firewall; 4 at mid-level and 4 at the top level with 2 on the front face (firewall surface facing actuator) and 2 on the back face (firewall surface facing steel column) at each level. The transducers were located next to each aluminum angle clip.

For the wall assemblies, the plate of wood frame on the foundation was tied to the wood plate at the same location on the back of the firewall through wood straps. For wall assembly 1, the plate of wood frame at the top of the wall assembly was also tied to the wood plate at the same location on the back of the firewall through wood straps. The connectin details are shown in Figure 23.

a) Load condition A

b) Load condition B

Figure 22 Firewall test setups

a) Connection at bottom of wall assembly

b) Connection at top of wall assembly

Figure 23 Firewall test setups

IV.6 Test Results

Clip Joint Test:

A summary of the test results is provided in Table 4. For clip joints under load condition A, the maximum load ranges from 400 – 740 pounds and the displacement at maximum load is from 1.2 – 1.7 inches. For clip joints under load condition B, they had the maximum load from 340 - 440 pounds and the displacement at maximum load from 0.8 – 1.9 inches. Under load condition C, the clip joints had the maximum load from 280 – 540 pounds and the displacement at maximum load from 1.2 – 3.2 inches.

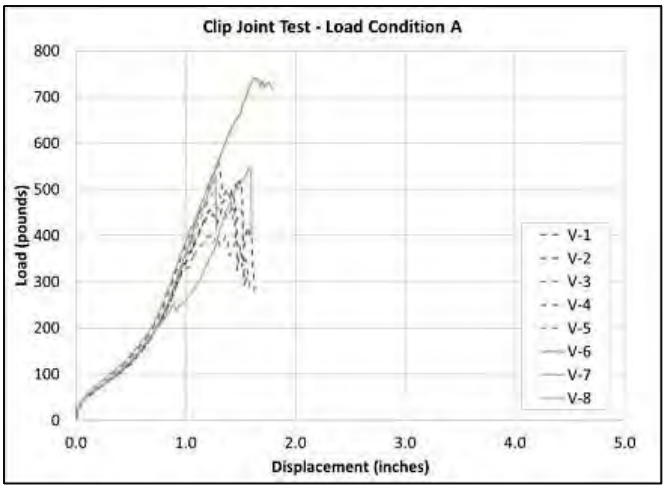
Table 4 Maximum load and the displacement at maximum load of clip joint tests

Load Condition	Specimen		Maximum Load	Displacement at Max Load
	H-stud	No.	(pounds)	(inches)
A	Standard	V-1	554	1.306
		V-2	460	1.468
		V-3	496	1.306
		V-4	519	1.514
		V-5	401	1.233
	ICC	V-6	740	1.668
		V-7	530	1.295
		V-8	548	1.612
B	Standard	D-7	453	1.440
		D-8	483	1.300
		D-9	503	0.812
	ICC	D-10	526	1.484
		D-11	492	1.297
		D-12	503	1.451
C	Standard	H-1	317	1.150
		H-2	344	2.903
		H-3	369	1.639
		H-4	470	3.024
		H-5	275	1.648
		H-5b [1]	341	2.588
	ICC	H-6	296	2.328
		H-6b [2]	342	3.190
		H-7	346	2.967
		H-8	538	2.966

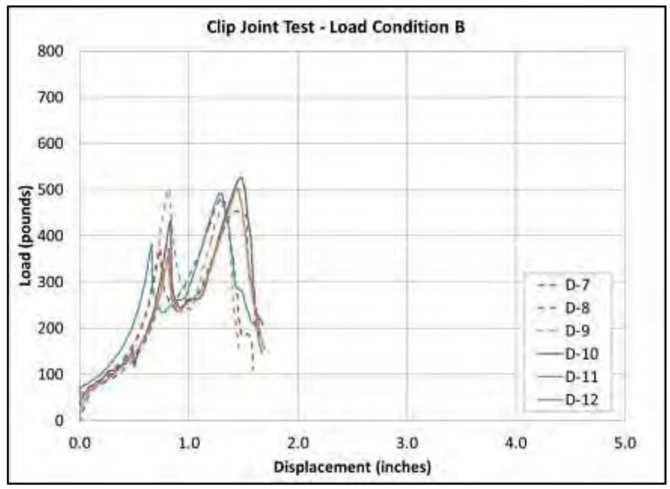
Note:

1. Specimen H-5b was retested after Specimen H-5 in which the head of screw on wood member (closer to H-stud) was broken.
2. Specimen H-6b was retested after Specimen H-6 in which the head of screw on wood member (closer to H-stud) was broken.

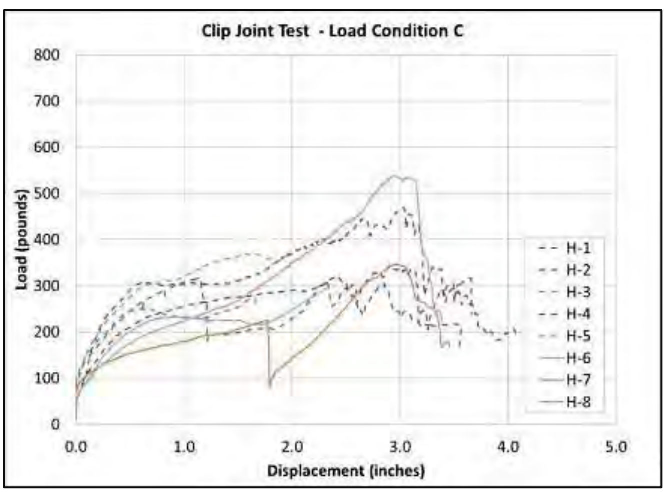
Figure 24 shows the load-displacement curves of the clip joint tests. As can be noticed from Figure 24b, there is a drop of load at approximately 0.8 inches under load condition B. This is probably due to the fracture of aluminum clip around the screw which is connected to wood member. Figure 27b shows the fracture of the aluminum clip. For joints under load conditions A and B, aluminum clip was straightened out first before the screws started to pick up the force. From the load-displacement curves, it seems to indicate that the aluminum clip was straightened out at approximately 0.7 inches under load condition A and at around 0.5 inches under load condition B. Figure 25 shows the straightened out clips during the tests. For joints under load condition C, the load-displacement curves indicate that the screws started to pick up the force right from the beginning of the tests. This is because that the clip angle cannot be easily twisted, as shown in Figure 26.



a) Load condition A

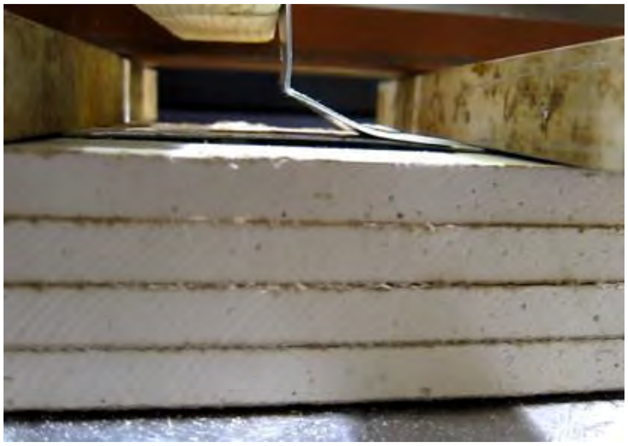


b) Load condition B



c) Load condition C

Figure 24 Load-displacement curves of clip joint tests



a) Load condition A

b) Load condition B

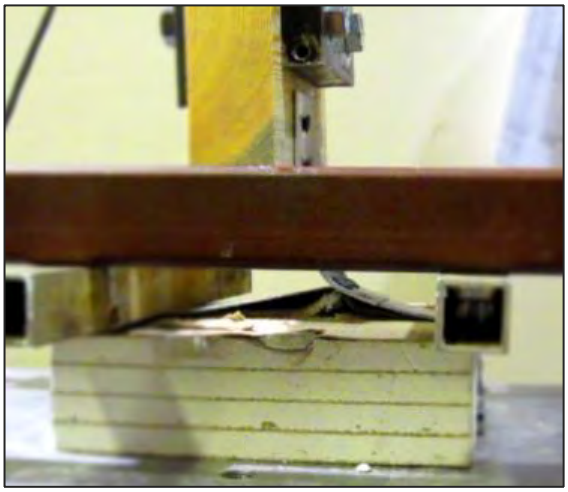
Figure 25 Aluminum clips straighten out

Figure 26 Twist of aluminum clips under load condition C

Figure 27 shows the typical failure modes of the clip joints. As noticed from Figure 27a, once the clip was straightened out, the screws started to pull the metal H-stud, causing the metal H-stud to deform under load condition A. Different failure modes were observed with standard and proprietary H-studs. For the standard H-stud, the joint failed after the screws were pulled out from the H-stud; while for the proprietary H-stud joint failed after the screw head was snapped off. For both standard and proprietary H-studs, there is no obvious deformation on screws connected to wood member. The test indicated that the joint capacity is governed by the withdrawal capacity of screws on metal H-stud.

Under load condition B, failures occurred at two different stages, which correspond to the peak load observed in Figure 24b. At the first peak load, either the wood screw connected to wood member was pulled out of the wood member or the aluminum clip was torn open at the screw, as shown in Figure 27b. At the second peak load, the wood screw, which is connected to wood member and away from the metal H-stud, was pulled out of the wood member. The failure modes were similar for joints with either standard or proprietary H-stud. There is no obvious deformation on screws connected to H-stud. The above failure modes indicate that the joint capacity is governed by the withdrawal capacity of screws on wood member or the fracture strength of aluminum clip.

Under load condition C, different failure modes were observed for joints with standard metal H-stud: a) the screw connected to wood member was pulled through the aluminum clip; b) metal H-stud was opened up and screws connected to H-stud were pulled out, as shown in Figure 27c; and c) the head of wood screw connected to wood member broke off. For the proprietary H-stud, the joint failed after the head of wood screw, which is connected to wood member, broke off. No proprietary metal H-studs were opened up during the test, as shown in Figure 27d.



a) Failure of clips under load condition A

b) Failure of clips under load condition B

c) Failure of clips under load condition C

d) Failure of clips under load condition C

Figure 27 Failure modes of clip joints

Wall Assembly Test:

Table 5 summarises the test results of wall assembly specimens. It is noticed that the displacements at the back of the firewall (deformation of clips attached to plate connected to steel column) are always larger than the displacements at the front of the firewall (deformation of clips attached to plate of wood frame). This is because the floor joists were tilted under the applied load. As the transducers are fixed to the wall plate, the rotation of the plate causes the transducer to move further closer to the firewall. Figure 28 shows the movement of the floor joists.

Table 5 Maximum load and the displacement at maximum load of wall assembly specimens

Wall specimen	Metal stud	Clip	Load position	Maximum Load (pounds)	Displacement at Max load (inches)	
					Front	Back
1	ICC ES 92-19	Standard	A	902	1.154	1.305
2 [a]	ICC ES 92-19	Standard	B	1165	-	-
3	Standard	Standard	B	673	0.762	1.235
4	ICC ES 92-19	Modified	B	365	1.544	2.160
5	ICC ES 92-19	Modified	A	537	2.265	2.412
7	Standard	Standard	A	823	1.194	1.327

Note:

a. No data was collected for transducers at top level.

Figure 28 Rotation of floor joist under horizontal load

Wall 1 – load condition A (loaded at the first floor of the wall assembly):

The load-displacement curves of Wall 1 are shown in Figure 29. The actuator displacement refers to the total displacement from the actuator. The average displacement at the back of the firewall (transducers 1 and 3) is the average deformation of clips attached to plate connected to steel column. The average displacement at the front of the firewall (transducers 2 and 4) is the average deformation of clips attached to plate of wood frame.

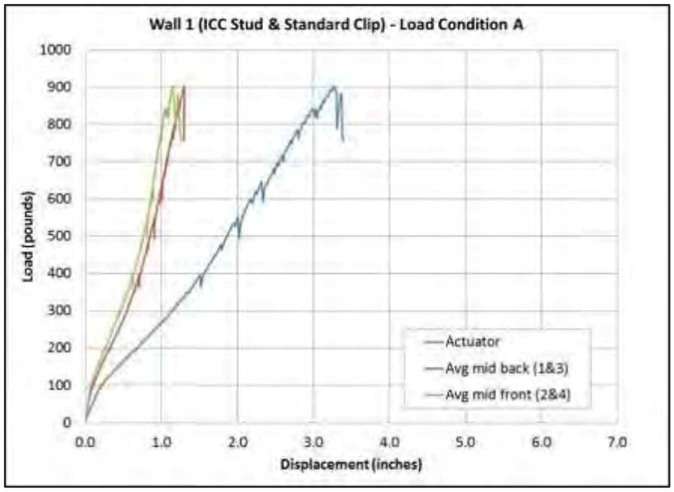


Figure 29 Load-displacement relationships of Wall 1

Figure 30 shows the failure mode observed in Wall 1. The screw on the clip was pulled out of the H-stud next to transducer #2 (front left at first floor). As shown in the photo, local deformation of H-stud was observed at location where clips are attached. This seems to indictes that concentrated force was applied on the H-stud through the screws symmetrically placed at both sides of the walls. It is not clear whether or not the localised deformation of H-stud has any negative impact on the fire performance of the gypsum firewall. Further study is needed.

Figure 30 Failure mode of Wall 1

Wall 2 – load condition B (loaded at the seond floor of the wall assembly):

The load-displacement curve of Wall 2 is shown in Figure 31. Unfortunately, except the displacements at the first floor, the displacements at the second floor where load was applied was not recorded. As noticed from Figure 31, the displacements at the first floor were very small. This indicates that almost all the applied load from the actuator is resisted by the clips at the second floor. The fact that the H-studs are discontinuous at each storey also contributes to the load distribution. As the the H-studs at intersection are connected by back-to-back C-channels, it is a pin joint and will act as a pivotal point for the H-studs. Under the horizontal load, the H-studs in the second storey rotated around this joint.

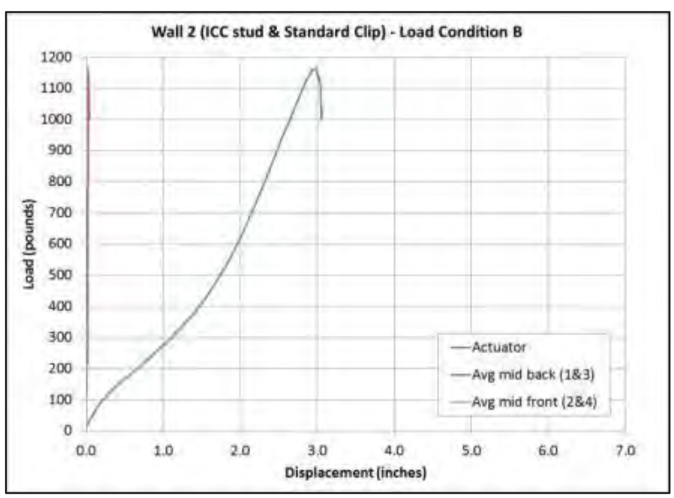


Figure 31 Load-displacement relationships of Wall 2

Figure 32 shows the failure mode observed in Wall 2. The screws on the clip was pulled out of the H-stud next to transducer #5 (back right at the second floor). This indicates that clips could break on either side of the firewall. This is not surprising as the clips on both sides of the firewall receive the same amount of force. As shown in the photo, local deformation of H-stud was observed at location where clips are attached.

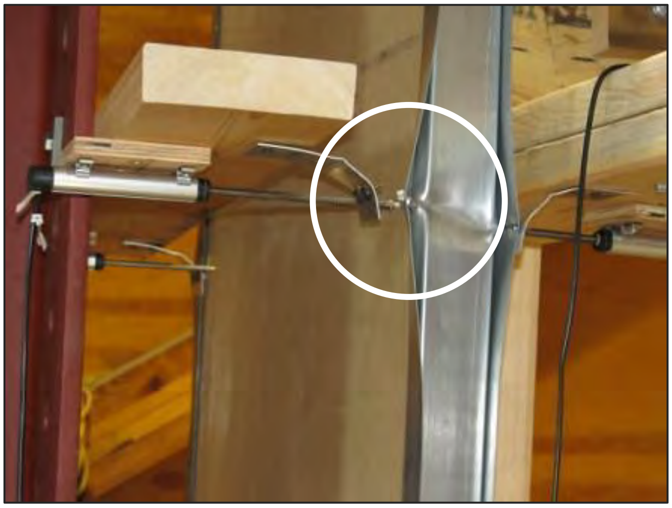


Figure 32 Failure mode of Wall 2

Wall 3 – load condition B (loaded at the seond floor of the wall assembly):

Except standard H-stud which was used in this test, the load condition and materails used for Wall 3 are the same as those used in Wall 2. The load-displacement curve of Wall 3 is shown in Figure 33. As noticed from Figure 33, the clips at the second floor had experienced large deformation with little happening on clips at the first floor. As mentioned earlier, this implies that the almost all the load from the actuator is resisted by the clips at the second floor.

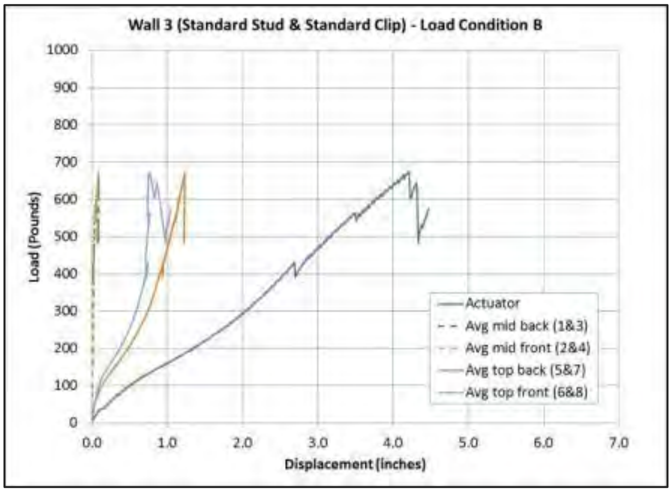


Figure 33 Load-displacement relationships of Wall 3

Figure 34 shows the failure mode observed in Wall 3. The screws on the clip was pulled out of the H-stud next to transducer #6 (front left at the second floor). For standard H-stud, local deformation of H-stud was also observed at location where clips are attached.

Figure 34 Failure mode of Wall 3

Wall 4 – load condition B (loaded at the seond floor of the wall assembly):

Except modified clips which was used in this test, the load condition and materails used for Wall 4 are the same as those used in Wall 2. The screws were installed at the middle of the vertical slot (attached to H-stud) and horizontal slot (attached to wood member). Because of the slots in the clips, the wood frame become unstable in the plane of the framing. To solve this issue, OSB panels were attached to the framing with two screws on each stud (at the top and bottom of the panels). Figure 35 shows the positions of the screws in the clip slot and placement of the panels.

Figure 35 Construction details of Wall 4

The load-displacement curve of Wall 4 is shown in Figure 36. Compared to Wall 3, the modified clips underwent almost twice the deformation of standard clips. This is due to the slot which allows screws to slide under the load, as shown in Figure 37. With modified clips, the displacement (deformation of clips) at first floor is still very small, almost negligible.

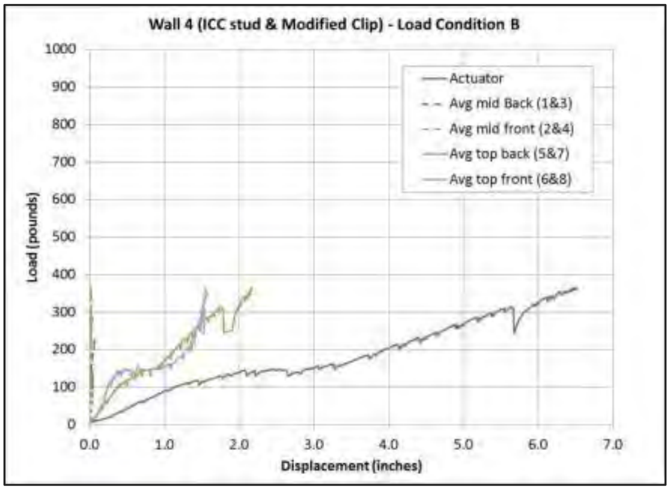


Figure 36 Load-displacement relationships of Wall 4

Figure 37 Movement of clips in Wall 4

Figure 38 shows the failure mode observed in Wall 4. The horizontal slot of the clip popped off of wood screw next to transducer #2 (front left at the second floor). The screw head was broken when it was removed from the plate. Compared to standard clips, this failure mode seems to be more desirable as the metal H-stud had much smaller local deformation around screws.

Figure 38 Failure mode of Wall 4

<u>Wall 5 – load condition A (loaded at the first floor of the wall assembly):</u>

Except modified clips which was used in this test, the load condition and materails used for Wall 5 are the same as those used in Wall 1. The load-displacement curves of Wall 5 are shown in Figure 39. Compared to Wall 1, the modified clips in the front and back of the firewall underwent almost twice the deformation of standard clips. This is similar to the results observed in Wall 4. The maximum load is approximately half of Wall 1. This is because only one screw was is used to connect the clip to H-stud and wood member, while two screws were used in standard clips.

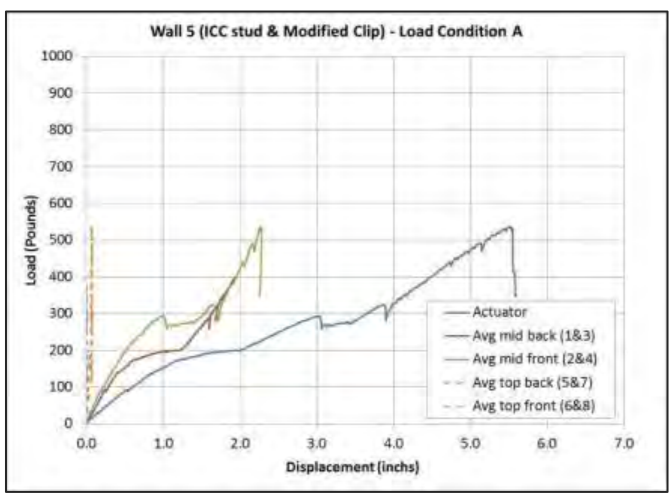


Figure 39 Load-displacement relationships of Wall 5

Figure 40 shows the failure mode observed in Wall 5. The horizontal slot of the clip popped off from wood screw next to transducer #1 (back right at the first floor). Similar to Wall 4, metal H-stud had little local deformation around screws.

Figure 40 Failure mode of Wall 5

Wall 7 – load condition A (loaded at the first floor of the wall assembly):

Except standard H-stud which was used in this test, the materials used for Wall 7 are the same as those used in Wall 1. Based on the tests of Wall 1 and 5, it was observed that the floor joist was tilted up during the test. This does not represent what would happen in a real fire condition in which floor joist will likely to fall due to the collapse of adjacent structural members. As a result, the load was applied at the top of the floor joist, instead of at the center of the floor joist. Figure 41 shows the position of the actuator and the deformation of the wall framing under load. As noticed from Figure 41b, the floor joist in the first floor did not rotate in this test.

a) Position of actuator   b) deformation of wall framing under load

Figure 41 Test setup of Wall 7

The load-displacement curves of Wall 7 are shown in Figure 42. They are similar to the test results of Wall 1 in Figure 29.

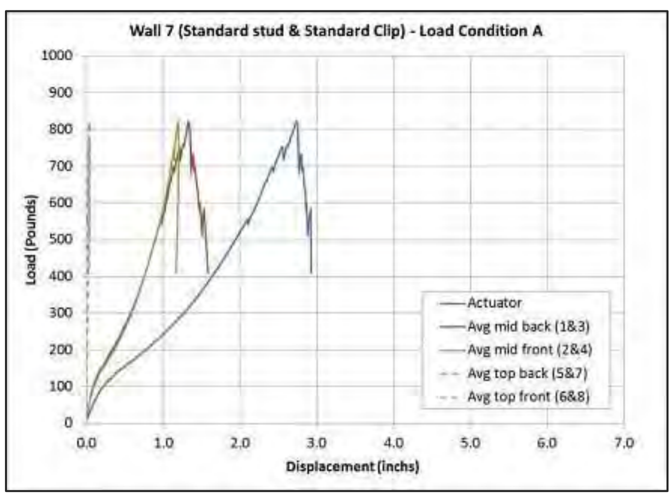


Figure 42 Load-displacement relationships of Wall 7

Figure 43 shows the failure mode observed in Wall 7. The screws on the clip was pulled out of the H-stud next to transducer #1 (back right at the first floor). H-stud was deformed at location where clips are attached.

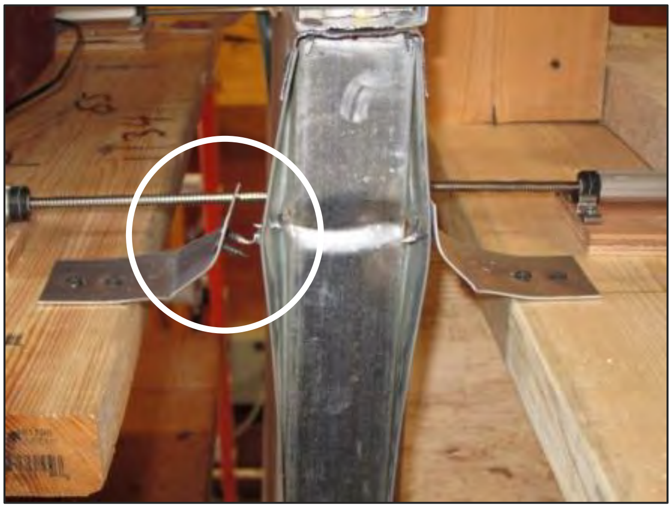


Figure 43 Failure mode of Wall 7

IV.7 Conclusion

A test program was developed to study the structural performance of aluminium angle clips used in gypsum firewalls. The test program consists of clip joint test and a short segment of a firewall assembly test. Two types of aluminum clips were used in the tests: a) standard clip as recommended in GA-620 "Gypsum Area Separation Firewalls", and b) modified clip in which slots are made to allow for relative moment. The findings from the test results are summarized as follows:

1. Under different load directions, the joint with standard clip can resist 300 – 700 pounds load and can deform up to 1.0 - 3.0 inches before the joint is broken.
2. Under load condition A (joint was loaded perpendicular to the firewall surface), the joint failed after the screws were pulled out from the H-stud. No obvious deformation was observed on screws connected to wood member. The joint capacity is governed by the withdrawal capacity of screws on metal H-stud.
3. Under load condition B (joint was loaded parallel to the firewall surface and H-stud), two peak loads were observed. At the first peak load, either the wood screw closer to H-stud was pulled out of the wood member or the aluminum clip around the hole for screw was torn open. At the second peak load, the wood screw away from the metal H-stud was pulled out of the wood member. No obvious deformation was observed on screws connected to H-stud. The joint capacity is governed by the lesser of withdrawal capacity of screws on wood member and the fracture strength of aluminum clip.
4. Under load condition C (joint was loaded parallel to the firewall surface but perpendicular to H-stud), different failure modes were observed for joints with standard metal H-stud: a) the joint

failed after the screw connected to wood member was pulled through the aluminum clip or the head of wood screw connected to wood member was broke off. Besides the above failure mode, it was also observed that in some joint specimens with standard H-stud, the metal H-stud was opened up and screws connected to H-stud were pulled out.

5. For the wall assembly with standard clips symmetrically attached on both sides of firewall, the clips can resist 650 – 1100 pounds load and the clips on each side of the firewall can deform approximately 1.0 inches. The clips failed after they were pulled out form the H-studs. The clips on each side of the firewall had similar deformation. Localized deformation of H-stud was observed at location where clips are attached. Where wood framing is loaded with horizontal force (representing the collapse of adjacent structural member) from one side of the firewall, results showed that the clips can break on either side of the firewall.

6. For the wall assembly with modified clips symmetrically attached on both sides of firewall, the clips can resist 350 – 500 pounds load. The clips on each side of the firewall can deform approximately 2.0 inches. The clips failed after they popped off of wood screw connected to the wood plate. The clips on each side of the firewall had similar deformation. Localized deformation of H-stud was not obvious at location where clips are attached. Where wood framing is loaded with horizontal force from one side of the firewall, the clips can break on either side of the firewall.

7. The adjacent clips above or below the clips at the load level had minimum deformation. This indicates that almost all the load is resisted by the clips at the load level. Very little load is resisted by the adjacent clips above or below the clips at the load level.

IV.8 Future Work

In the wall assembly tests, a horizontal load is applied to the floor joist of the wood frame. This is unrealistic as the collapsing floor or roof system under fire condition would likely to pull away from the firewall at an angle. In this case, the clips on the fire side would resist a combined horizontal and vertical loading while the clips on the non-fire side would resist only the horizontal load due to the rotation of firewall. This may cause clips on the fire side to fail first. To verify this, it is recommended that additional firewall assembly tests be conducted with load applied to the framing at an angle to represent a more realistic scenario under fire condition.

There may also be differences in performance if a more realistic width of firewall (not a narrow segment) were tested that takes into account the continuity of the firewall in the horizontal direction. This, however, will need to take into account the compartment size which will make the evaluation more complex.

Lastly, experiments on the structural capacity of the aluminum clips exposed to heat should be conducted in order to assess the intended breakaway behavior when exposed to fire conditions.

IV.9 Acknowledgement

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IV.10 References

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