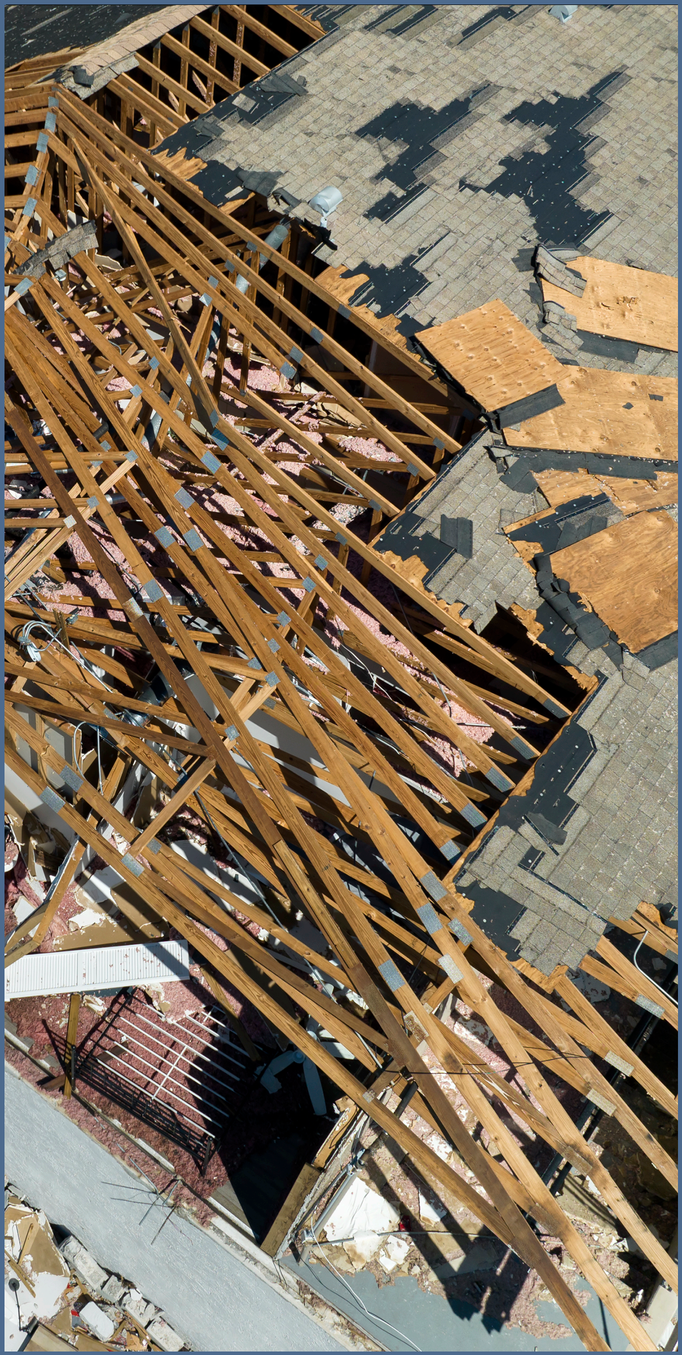

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PERSPECTIVES

Exploring Wood Framed Roof Collapses: Identifying Responsible Parties & Causes of Wood Truss Failure

Our perspectives feature the viewpoints of our subject matter experts on current topics and emerging trends.

AN OVERVIEW OF THE CAUSES OF ROOF FAILURE

Collapses of wood-framed roofs are frequently reported in North America, ranging from simple agricultural roofs to complex roofs in industrial buildings. Controllable factors such as chemical attacks, moisture attacks, lack of maintenance, inadequate materials, design, or construction are often found to be contributing or primary causes. Furthermore, negligence in handling controllable factors severely impacts the scale and scope of damages.

From the perspective of J.S. Held forensic engineers in Canada, this paper will examine common causes and contributors to roof collapses and identify which parties are typically liable. This discussion will be of value to lawyers, adjusters, and underwriters.

UNDERSTANDING WOOD-FRAMED ROOF COLLAPSES AMIDST INCREASING EXTREME WEATHER EVENTS

As extreme weather events are becoming the new global norm, many wood-framed roof collapses are occurring during significant weather-related events such as windstorms and heavy snowfalls. While these collapses appear simple to analyze from a causation perspective, a complete determination of causation is often challenging as design, construction, and manufacturing deficiencies frequently contribute to the scope of the collapse and scale of the resulting damages.

Pitched wood-framed roofs are some of North America's most common roof structures for residential and agricultural structures whereas commercial structures frequently use flat wood-framed roofs. In both cases, prefabricated wood roof trusses are often utilized. Roof trusses are strong in resisting vertical loads; however, they are rather poorly suited to resisting lateral loads. Therefore, roof trusses must rely on a lateral load distribution and bracing system so lateral loads are transferred through the structure to the foundations.

Once applied loads approach the ultimate capacity of the trusses and/or bracing system, the roof structure will begin to deform. This deformation may lead to failure/collapse with very little additional load, or the deformation could reduce the ultimate capacity of the trusses by causing slip and deformation of the truss plates.

For low to moderate severity snow or wind events, the design and installation of the bracing system will frequently dictate the scale and scope of the roof failure/collapse. Well-designed and braced structures are significantly more resistant to progressive collapse, with localized collapse zones due to snow overloading, for example, as opposed to complete roof and/or structure collapses in poorly braced structures.

COMMON CAUSES OF TRUSS FAILURE

While many truss failures occur after significant weather-related events, causation investigations frequently identify preventable contributing factors. In some cases, the weather events are simply too severe for a roof structure to withstand, such as a direct hit from a tornado or major hurricane. In other cases, it is common for human error in design and/or construction to impact the scale and scope of resulting damage. In the following sections, we will explore some of these contributing factors and their impact on the occurrence and magnitude of loss.

PREVENTABLE FACTORS OF ROOF TRUSS FAILURE

1. **Communication Gaps and the Risk of Collapse: Inadequate Design and Installation of Temporary or Permanent Bracing**

Since the design, manufacture, and installation of metal-plated roof trusses often involve multiple parties, including a truss design engineer, truss manufacturer, contractor, the engineer of record (EOR), and the authority having jurisdiction (AHJ), one of the most common and easily preventable causes of loss is a lack of communication between parties.

For instance, lack of communication may lead to the omission of temporary roof bracing during construction. Collapse debris of inadequately braced roofs during construction typically show trusses neatly folded over on the ground as shown in **Figure 1**.

Figure 1 *- Roof collapse aftermath with neatly stacked trusses typically indicates inadequate or missing temporary roof/building bracing during erection.*

The omission of temporary bracing during truss installation is a common and dangerous practice in the construction industry. The economic and life safety risks resulting from insufficient temporary bracing are typically far greater than what an erection contractor may perceive, such as complete collapse of the structure, damage to adjacent structures and equipment, and loss of life. Inadequate bracing during construction is often a primary cause of collapse in the construction industry. It is paramount that the walls and roof are adequately braced during construction or the whole structure can collapse without warning.

Issued for construction (IFC) truss shop drawings typically delegate the permanent bracing design for the global stability of the roof structure to the EOR; however, the EOR may overlook the structure bracing design requirements. The contractor may overlook the footnotes in the truss design drawings and simply install the premanufactured trusses according to the design layout without knowing the temporary and/or permanent lateral bracing requirements, or by assuming that the roof structure was already adequately designed and reviewed by the truss design engineer and EOR. Such a series of miscommunications and assumptions could lead to the collapse of the roof trusses during or after installation.

Examples of temporary top chord bracing, permanent truss bracing, and temporary gable truss bracing are shown in **Figures 2, 3, and 4**, respectively.

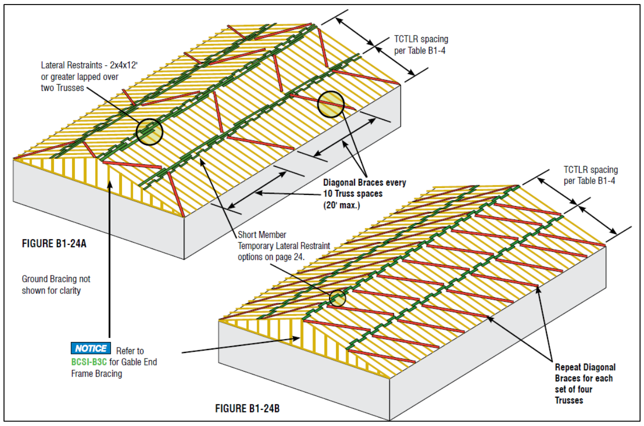

Figure 2 *- Typical temporary top chord bracing for erection (Source: BCSI Canada[1])*

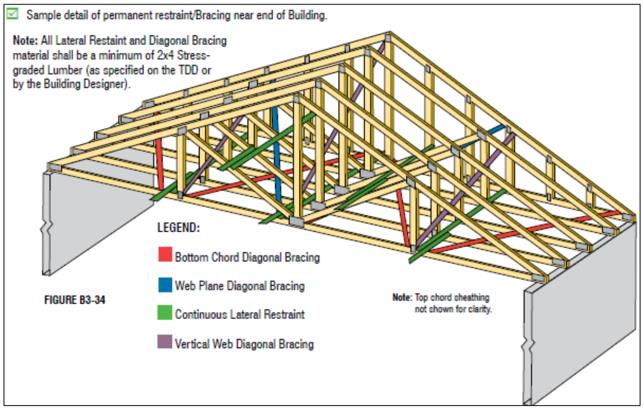

Figure 3 *- Typical permanent truss system bracing (Source: BCSI Canada).*

[1] Prepared by the Structural Building Components Association (SBCA)

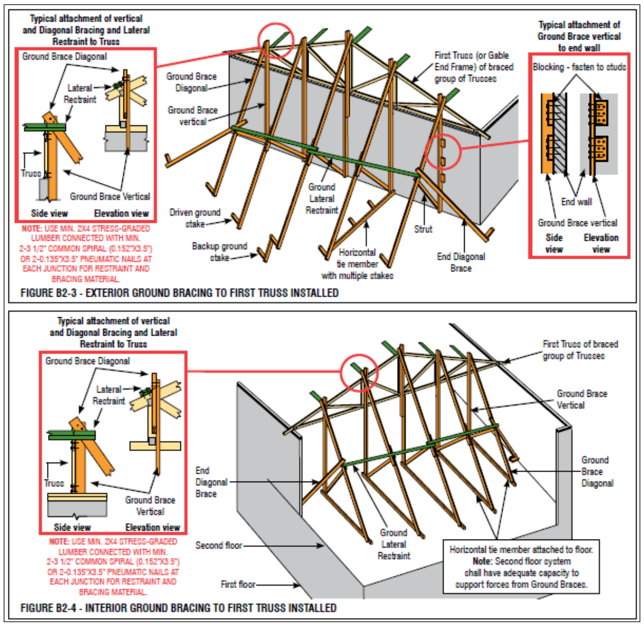

Figure 4 - *Example of gable truss bracing during truss installation (Source: BCSI Canada).*

2. Design or Installation Errors

Common design errors involve failure to consider snow drift loads or dead loads from heavy rooftop units (RTUs) permanently installed on the roof. Either of these scenarios can lead to a roof collapse.

Frequently, RTUs are moved from their design location by mechanical contractors in response to site conditions without informing the truss engineer or EOR. In these cases, large dead[2] loads are placed at the areas on the roof that are not reinforced for the RTU loads, and localized deflections, due to creep[3] under the RTUs, may eventually lead to collapse.

3. Mishandling of Large Trusses

On many occasions, the mishandling of the trusses during the installation process by inexperienced contractors could have a negative impact on the integrity of the trusses. For instance, some inexperienced contractors may choose to use any equipment that is conveniently available on-site, such as a telehandler or forklift, to lift trusses without using spreader bars as shown in **Figure 5**. Lifting large trusses without spreader bars could damage the trusses causing slip or deformation of the plates, sometimes in a manner not easily visible, which can significantly reduce their design capacity. In many cases, the trusses may not show signs of distress until they are fully loaded. The damage in the trusses could incubate for years before resulting in a collapse due to a heavy snowstorm which exceeds the threshold of the reduced actual capacity of the roof.

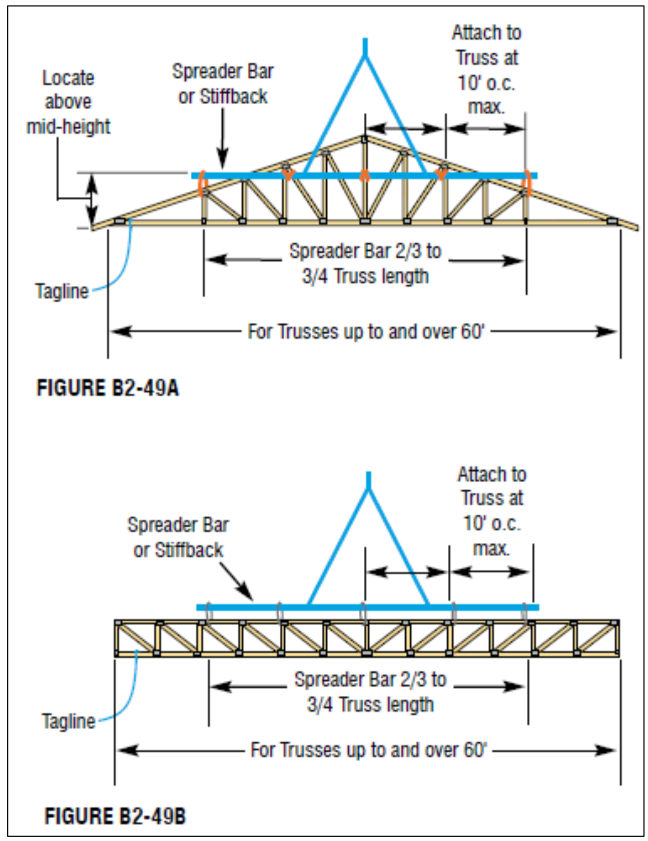

Figure 5 - *Example of how spreader bars are used for truss hoisting (Source: BCSI Canada).*

4. Errors in Truss Manufacturing

In other cases, errors during the truss manufacturing process can play a major role in roof collapses. For instance, changing the truss bottom chords to Machine Stress-Rated (MSR) 1650Fb lumber while the truss drawings required MSR 2100Fb would generally cause the roof to be critically

[2] Dead loads are permanent loads, such as mechanical HVAC equipment installed on a roof.
[3] Creep is a structural phenomenon whereby progressively larger deflections and/or deformations occur over a long period of time, typically underneath large dead loads.

deficient in capacity and place it at severe risk of collapse under design service loads.

Economic realities are such that wood trusses are typically designed close to the capacity limits of the lumber grades and truss plates sizes chosen. As such, it is crucial that the manufacturers respect the minimum lumber grades and plate sizes/grades indicated in the truss drawings and request a review from the truss design engineer if the replacement of any truss members with a different grade of lumber is required due to unforeseen situations.

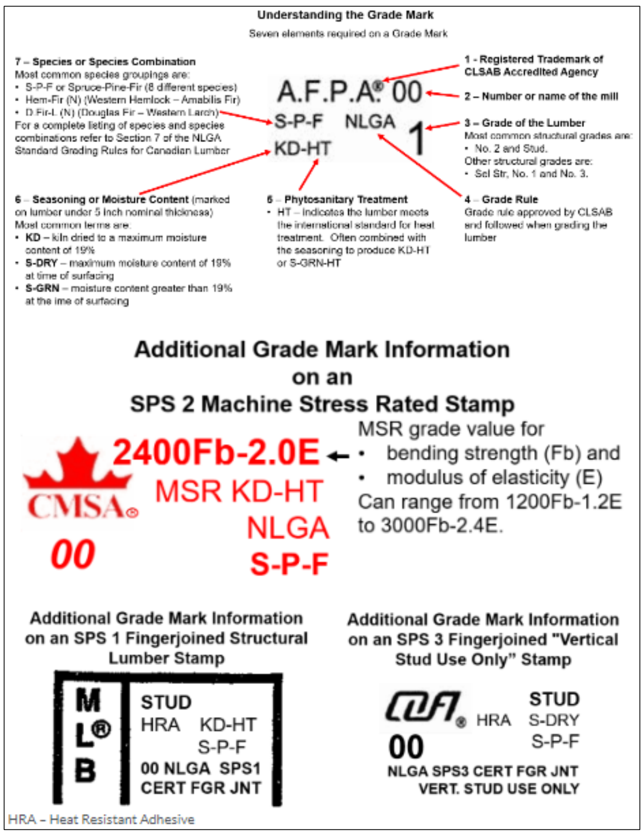

***Figure 6**- Typical Lumber Stamps identify the lumber grade (Source: [Canadian Lumber Standards Accreditation Board Quality Management in Canada's Lumber Industry]).*

5. Improper Roof Maintenance

Roof maintenance is often overlooked by the general public simply because it is not easily accessible and/or the trusses are hidden in the attic. For instance, although the valley on the roof is often designed to account for snow drift, it is still recommended to use a snow rake to remove large accumulations of snow. Caution should be taken when using a snow rake on the roof so that no damage is caused to the roof surface material as this inadvertent damage could also lead to premature deterioration of the trusses should the damage be severe enough to allow moisture intrusion.

As the snow continues to accumulate in the roof valley over time, and after a few freeze-thaw cycles increasing the density of the snow, the roof may eventually collapse from overloading.

***Figure 7**- Example of snow accumulation in a roof valley.*

6. Inadequate Roof Waterproofing and Attic Ventilation

Installation errors in the building/roofing envelope is another common root cause of roof collapses. Deficiencies in the water management of the roofing, such as inadequate installation of the underlayment, having exposed nails on the shingles, or inadequate installation of roof flashings, etc., could promote water ingress into the attic and result in decomposition of the sheathing and trusses. As the decay continues to develop, it could negatively impact the integrity of the trusses by reducing their net capacity.

While the decomposition of a few truss members alone may not necessarily result in a roof collapse, it is a much larger problem when accompanied by poor attic ventilation. Decay of trusses and/or bracing could be exacerbated by the generally humid environment resulting from poor ventilation. This could lead to widespread decomposition of the roof trusses, resulting in a global reduction of truss capacity, thereby increasing the likelihood of a collapse.

***Figure 8**- Decayed structural components in the attic due to poor roof waterproofing.*

7. Poor Attic Insulation

Inadequate attic insulation can often be identified by the presence of ice damming along the eaves of the roof. An ice dam is formed when there is a breach of the warm air from the living space into the attic, mostly due to inadequate placement of insulation and/or vapour barrier at the bottom of the attic. The warm air that escapes into the attic would heat up the roof sheathing, melting the bottom layers of the snow above the roof. As the melted water travels near the edge, it then re-freezes near the roof edge due to the absence of heat along the roof overhang, forming an ice dam. The combined weight of ice and snow along the roof overhang that overstresses the truss heels, along with the decay of the trusses due to water damage from ongoing ice damming, could result in a localized collapse of the roof overhang.

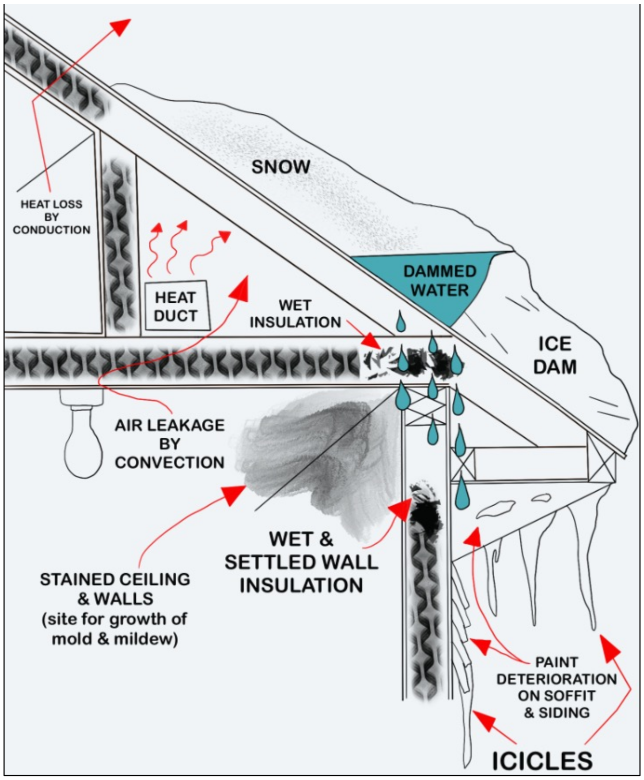

***Figure 9**- Schematic of ice damming (Source: https://extension.umn.edu/protecting-home-rain-and-ice/dealing-and-preventing-ice-dams).*

8. Corroded Truss Plates

Corrosion of truss plates and/or nails is another of the prominent causal factors in roof collapse, and it is particularly common in agricultural and industrial buildings. While corroded truss plates could also occur in residential structures due to excessive moisture for prolonged periods in the attic, it is often not as widespread as those found in farms, agricultural, and industrial structures simply because the environments in these structures are often more corrosive and/or humid.

Figure 10- *Example of roof collapse for a cattle barn contributed by corroded connector plates.*

Figure 11- *Example of a corroded connector plate in a collapsed roof.*

In Canada, farm and agricultural buildings, such as livestock barns and riding arenas, are not required to be designed by engineers as commercial structures are. Farm buildings are currently governed by the 1995 National Farm Building Code, and it relaxes many requirements of the National Building Code (NBC) such as design loads and regulatory requirements in order to allow farmers to quickly construct and use structures on farms.

Many agricultural owners purchase ready-to-install standard truss packages for their applications without engaging an engineer to properly design the trusses or conducting adequate research on the required design specifications for their applications. While the normal or standard residential/commercial grade connector plates are fabricated from sheets that are hot dip galvanized to Coating Designation G90 in accordance with ASTM A924, these plates are not adequate for service in moist, corrosive, and dusty agricultural environments where they can develop severe corrosion in fewer than 10 years.

RESPONSIBILITIES OF PARTIES INVOLVED IN DESIGN AND CONSTRUCTION OF COMMERCIAL STRUCTURES

Commercial structures have the most clearly defined responsibilities in roof design and construction, and these typically outline the clearest path to establishing liability for a collapse from the professional and contractual responsibilities of the engineers and architects who owe a duty of care to the owners and the public.

1. Owner

In general, the responsibilities of the owner begin before a structure is constructed and extend beyond the completion of the construction to the full ownership period of the structure.

- Before the beginning of the construction, the owner is responsible for:
  1) Retaining a coordinating registered professional to coordinate all design work and field reviews of the registered design professionals in order to ensure that:
     a. the design will comply with the National Building Code requirements, and
     b. the construction of the project complies with the National Building Code and design drawings and specifications.
  2) Retaining the registered professionals of record to complete the design work and field review required for the project.
  3) Providing the Authority Having Jurisdiction (AHJ) with letters in the forms set out in Schedules A-1, A-2, B-1, and B-2 per the NBC.

- After the structure is in use, the owner is responsible for:
  1) The upkeep in regular maintenance of the building structure.
  2) Making sure not to amend the building in any way that may risk compromising the integrity of the structure without consulting a registered professional in the respective discipline.

2. Contractor

A responsible contractor should use the best construction practices to ensure the structure is built as per the design drawings and National Building Code (NBC). In general, the contractor is responsible for:

- The construction safety aspects of the construction.
- Complying with the requirements per the design drawings and the NBC in effect.
- Engaging required sub-trades for each respective aspect of the project as required.
- Ensuring coordination with and between sub trades and project professionals as required.
- Keeping a record of all field logs and construction progress updates.
- Coordinating with the AHJ and/or the engineer of record for the required inspections.

3. Authority Having Jurisdiction (AHJ)

AHJ may include the municipality, city, or provincial government where the structure is built, or the department of municipal affairs, township or county building code offices, department of health and safety, etc. They are responsible for:

- Reviewing building permit applications for compliance with local, provincial, and national code requirements.
- Receiving assurance in the form set out in Schedule C-1 from the coordinating registered professional that the construction complies with the requirements of the NBC.
- Completing the inspections during construction to ensure construction complies with the intent of drawings submitted for the permit application.
- Issuing an occupancy permit or giving permission to occupy.

4. Coordinating Registered Professional of Record

The coordinating registered professional is typically an architect but can also be an engineer. In a single-disciplinary project, it is not uncommon that the engineer of record is also the coordinating engineer. The coordinating registered professionals are responsible for:

- Ensuring the design requirements are coordinated between disciplines and that they comply with the requirements of the NBC.
- Ensuring that all project professionals, including the truss engineers, complete their field reviews.
- Carrying out and noting any corrective actions taken as a result of a field review.
- Coordinating with the AHJ upon their request.
- Signing off Schedules A-1 and A-2 as per the NBC.
- Ensuring all other project professionals coordinate design elements amongst themselves in addition to their expert scope of work.
- Providing a letter to the AHJ in the form set out in Schedule C-1 stating that the project for which the registered professionals were retained substantially complies with the NBC in effect.

5. Structural Engineer of Record (SEOR)

The SEOR holds a crucial role in the integrity of the entire building structure. They are responsible for:

- Specifying loads.
- Coordinating with the Truss Design Engineer and Roof Designer.
- Signing and sealing the drawings required in support of the building permit application.
- The design of the permanent bracing and bracing required during construction.
- Ensuring that drawings comply with the requirements of the NBC.
- Ensuring that field reviews are completed.
- Signing off the Schedules B-1, B-2, C-1, and C-2 per the NBC.
- Providing a letter to the coordinating registered professionals in the form set out in Schedule C-2 stating that components of the project for which the SEOR is responsible are constructed to substantially comply with the plans and supporting documents and the requirements of the NBC in effect.

6. Truss Design Engineer

The truss design engineer is responsible for ensuring the roof is designed correctly by the truss designer. The main difference between a truss design engineer and the SEOR is that the scope of the truss design engineer is limited to the structural integrity of the individual trusses, whereas the SEOR is responsible for specifying loads and the structural integrity of the entire structure including the roof structure bracing. A truss design engineer typically works directly for a truss supplier/manufacturer or manufacturer of metal truss plates, and he/she is responsible for:

- Verifying the work of the roof designer, sealing individual truss designs, and specifying minimum web and chord bracing required.[4]
- Confirming the loads on the trusses, which should account for HVAC, drift, and sliding loads from higher adjoining roofs.
- Inspecting trusses after installation, producing inspection/compliance reports for the trusses, and completing building code schedules for the SEOR.

7. Roof Designer

The responsibility of a roof designer differs, yet overlaps to certain extents, with that of the truss design engineer. A roof designer is typically a technician who works directly for a builder or truss supplier/manufacturer and may be under the direct supervision of the truss design engineer for a specified project. The roof designer is responsible for:

- Setting the roof truss profiles and dimensions to match the intent of the building drawings.
- Using truss design tools and software for the truss design.
- Ensuring adequate roof loads per the NBC in effect or those specified on engineered drawings to design roof trusses are used, sizing the truss plates, as well as selecting the correct lumber sizes and grades for the project.

ASSIGNING RESPONSIBILITY FOR A ROOF COLLAPSE

With so many parties involved, liabilities for collapse are frequently shared. Furthermore, the responsibility of each party differs between occupancy types with residential and agricultural roofs requiring much less code-mandated professional oversight.

In the case of agricultural or residential roof design, the truss design engineer typically has more liability exposure than on commercial projects:

Commercial Roof Collapse Liabilities

As noted above, commercial structures require the involvement of architects, engineers, and coordinating professionals of record.

- Construction deficiencies are common causes of collapse which can occur many years after construction. In such cases, the causation investigations frequently focus on the roles of the design and construction professionals specifically in relation to their design and field review obligations.
- Commercial collapse cases are frequently litigated with multiple experts opining on the standard of care of the professionals involved in the design and construction.
- Liabilities are typically spread to more than one party and are rarely agreed upon by forensic experts representing the various parties involved.
- Litigations are rarely straightforward and there are typically multiple points of contention stemming from the varied causation findings that require testimony from most experts involved.

Agricultural and Farm Roof Collapse Liabilities

- Liabilities usually fall on the contractor and/or the owner.
- The contractor is responsible for ensuring the temporary building bracing and roof bracing are compliant with industry standards[5].

[5] Truss Industry Standards include the BCSI Canada guide prepared by the Structural Building Component Association, typically included with every truss package purchase, that provides a wealth of information for safely erecting , installing, and bracing trusses.

- Structural engineers are rarely involved in design and construction.
- Roof designers can be liable for mistakes in interpreting design drawings.
- Truss design engineers are typically involved on behalf of the truss manufacturer/supplier and can be held liable for not noticing loading and/or design errors by the truss designer or errors of the design software.
- These structures present significant life-safety risks to workers during construction and ongoing risks to the owners after construction.

Residential Roof Collapse Liabilities

- Liabilities usually fall on the contractor.
- Structural engineers are only involved if portions of the house design fall under the commercial (Part 4) code and they are only responsible for those portions of the house – such as flat roofs.
- Roof designers can be liable for mistakes in interpreting the design drawings.
- Truss design engineers are typically involved on behalf of the truss manufacturer/supplier and can be held liable for not noticing loading and/or design errors by the truss designer or errors of the design software.

CONCLUSION

Bracing and other matters are complex design issues that are frequently misunderstood and neglected during design and/or construction of wood framed roofs. There are multiple parties involved which can make apportioning liability for a collapse challenging. Furthermore, preventable errors in design and construction can frequently exacerbate the magnitude of loss and resulting damages, but experts can help accurately assess collapse causation and identify liable parties by conducting a forensic investigation of the collapsed structural members.

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