Fire Engineering

FIREGROUND DYNAMICS IN STRUCTURAL COLLAPSE of FLOORS and ROOFS

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The dynamic fireground with fire impinging on and into a structure creates many times failures within floor and truss systems causing serious injuries and death to firefighters throughout history and even more so in modern day firefighting. Nowhere is it more important for commanders and our members to begin to comprehend fully the potentials in structural collapse for both floors and roofs and the reasons for their failures. By reviewing and understanding collapse potentials we should look into floor collapses and roof collapses individually to better comprehend their potential occurrences on the fireground.

Engineered Wood I-Joist Systems

The repeated injuries and deaths to firefighters as a result of compromised fire damaged floors are alarming to say the least. Firefighters are constantly at risk when working on the interior of residential structures with unknown burn times and unidentified locations of the main body of fire through unrecognized or improper size-ups upon arrival. Floors are known to fail within minutes when made up of engineered I-joist construction when exposed to fire. Many times firefighters are unable to recognize or feel heat emanating from floor areas due to their coverings and insulating factors when fire is burning underneath them. It must be realized by now in this day of engineered construction features within residential buildings that all firefighters understand that all wood-based construction materials are subject to failure when exposed to fire. More importantly is that all firefighters should assume even when responding to residential fires that between floors and wood truss that failure is likely especially when we add additional impact loads when performing over engineered I-joists. As firefighters attempting interior firefights we can never truly know how long a fire has been burning or how long a specific engineered system such as floors has been compromised and exposed to fire. NIOSH and its reports on firefighter fatalities relating to engineered I-joists construction failing under fie exposure is continually recommending that firefighters take extreme caution when operating on possibly weakened floors above fires burning below. Recognition and avoidance when possible is the preferred method of risk management to firefighters and their commanders when faced with a decision to operated above a fire on engineered floor systems. Any sign or element of communication that a firefighter reports weakened floors or has

partially fallen through a floor or stairway should alert all on the fireground that it's time to get out of the structure.

Engineered wood I-joist in today's modern construction of residential floors is the prominent floor system being used throughout the country. As we know the construction industry recognizes the benefits in employing them into modern home building. They provide for greater strength and quicker assembly as well as allowing for cutout designs to be made through them to allow for piping and conduit runs throughout the home. Their design also provides for lighter weight and they will not warp or twist like other wood framing materials. What we in the fire service do know through several studies conducted by various laboratories and our experiences is that they burn more rapidly than conventional wood made systems of old. Underwriters Laboratories (UL) have most definitely revealed to the fire service that failure of these wood I joists systems when exposed to fire can occur in as little as 6 minutes.

When it comes to surviving the fireground and operating offensively and interiorly within these structures we should have in the forefront of our minds from chief officers and all firefighters is that these floors will fail trapping us whether we work on them or below them. Light weight truss systems and engineered wood floors are high risk due to their quick degrading failure rates. Conducting thorough size-ups along with training and sound tactical decision making will lessen the dangers to our members. The following controlling and decision making parameters can help avoid injuries and deaths to firefighters at residential fires when deciding to commit firefighters to interior operations.

Identifying Factors In Degradation Risks Involving Wood Engineered I-Joist Construction

- **Conduct thorough size-up and communicate information to all on scene personnel before interior operations.**
- **Avoid interior firefighting when fire is suspected in below grade areas or unknown locations within a structure.**
- **The structural integrity of any floor with large bodies of fire should be suspect to collapse.**
- **Unless pre-planning reveals the presence or non-presence of engineered floors consider all structures built from the late 1980's onward to incorporate engineered floor joists.**
- **Provide solid operating guidelines to firefighters when confronted with large fires involving engineered I-joists construction.**

- **Ensure that all Rapid Intervention Crews are notified of below grade fires involving interior firefights to ensure proper equipment for possible rescues is present.**
- **Provide training in all aspects of recognition of compromised floors.**
- **Ensure the use of Thermal Imaging whenever possible to help recognize fires in below grade areas as well as to any areas within a structure that may reveal compromised floors**
- **Ensure emergency evacuation procedures when floors are compromised when interior firefighting is occurring.**
- **Be alert before committing firefighters post extinguishment when conducting overhaul procedures to ensure that floors are structurally stable to receive impact loads.**

Truss System Failures Under Fire Conditions

It is relatively common knowledge the construction industries and the fire service that well over half the structures whether residential or commercial involve construction using lightweight and heavy timber truss systems. These systems contain a significant fuel load many times providing disastrous results at structural fires to firefighters. Many truss systems are not readily seen by firefighters due to their various coverings as well as the lack of pre-planning by fire departments making firefighters unaware of their presence. Fires undetected in truss systems can spread quickly throughout a trusses components when undetected causing the inevitable in their collapse upon firefighters working above them or below them. The fire service at this point should be redirecting their thinking in committing firefighters risking their lives for essentially just property when there is no concern or involvement of life rescue. There are a few realizations that firefighters and their commanders need to resolve in their minds when it comes to structural fires and truss systems and that is first that fire can be unpredictable within any given structure. Conditions can also deteriorate rapidly damaging trusses causing their collapse without ever a hint of a warning. Another important factor regarding fire impingement of trusses is that their fire resistive ratings are established under controlled fire conditions not uncontrolled fire conditions that are present at structural fires.

Fire service personnel may not always be able to determine or establish early detection of fires involving truss construction and that is why whenever possible pre incident planning is so advantages to the safety of firefighters when confronting these types of fires. Knowing and identifying these types of buildings, their contents, their load bearing capabilities related to exterior and interior walls along with the presence of trusses will aid all on the fireground in

managing these incidents. Fire departments start by making changes involving fires presented with lightweight and heavy truss construction.

Recognition and Tactical Changes Involving Truss Construction At Structural Fires

- **Firefighters working on suspected truss roof construction provide safety and exit strategies off the roof.**
- **Firefighters should open up areas above and below the roof for concealed fire.**
- **Firefighters and Commanders are aware of alarm time out the door through fire involvement time on scene.**
- **All firefighters on scene ensure communications on changing conditions to commanders.**
- **All firefighters are aware of deteriorating conditions affecting the structure.**
- **Defensive posture should be tactically implemented once fire has impinged truss construction.**
- **Employ the use of thermal imaging technology whenever possible and appropriate.**

Heavy Timber Truss

In studying modern truss construction especially in roof systems the fire service is basically dealing with three types; heavy timber truss roof and floor systems, lightweight wooden truss roofs and floors and steel truss roofs and floor systems. Firefighters need to have acquired at least some basic understanding along with providing correct tactical approaches at structures incorporating these elements. Since we have previously discussed engineered I-joist construction and concerns; here we will briefly concentrate on predominately roof trusses and our concerns under fire conditions.

Heavy timber truss whether pre-existing in older construction or new engineered systems are designed to provide wider spans creating larger open areas. Usually they are assembled with large steel plates and bolts in order to transfer stresses and heavy loads onto the truss at the bolt connections. Firefighters are very familiar with earlier construction methods using the bowstring truss with its curved surface. Whatever the design features of heavy truss roofs they all carry grave dangers to firefighters when exposed to fire. Time is the only significant difference in their failure between heavy truss and lightweight truss roofs and even that is dependent on exposure times and fire conditions. As we have learned the basic concepts of truss construction are that the bottom chord of a truss is under tension while the top chord is

under compression. The failure of any one element of a truss especially its chords can lead to failure of the entire truss. When one truss fails even another truss can fail just from sheer load transfers of unbearable weight which has shifted and impacted another truss that may be several feet away from the original failed truss. Also the web members of the truss usually of smaller dimensional components connecting the chords are critical to the stability of the entire truss and can easily fail under fire conditions. When large trusses fail large areas of collapse are likely.

Heavy timber truss does may take longer to be affected by fire due to its mass then lightweight wooden truss but firefighters need to beware that when operating on these roofs the thin decking or roofing material may become unstable long before the heavy truss is affected. Also the spacing on truss construction especially heavy timber truss can be several feet wider than conventional roof systems. With this fact in mind a firefighter operating on decking that is compromised can place firefighters on unsupported areas causing them to fall through the decking between the trusses into the structure several feet below. Another concern with truss construction and its metal connections is the ability of metal bolts and metal plates transferring large amounts of heat into the wood which can lead to the degradation of these connects causing failure of the truss. When heavy timber truss begins to collapse any portion of the buildings support masonry walls will fall possibly trapping firefighters on the exterior as well. In addition any static loads placed on truss roofs such as HVAC systems over wide span truss can easily collapse into the structure when roof decking as well as the truss is affected or impinged by fire.

Lightweight Wooden Truss

It is no secret to the fire service by now that laboratory testing under laboratory set conditions can produce failure of unprotected lightweight wooden truss by fire within 6 to 13 minutes. Firefighters should not plan their actions and tactics on time studies for the fireground in structural firefighting especially at residential fires which is anything but predictable.

Like any truss type construction the design and purpose has similarities to heavy timber truss. The truss chords are a continuous run while the connecting web members transfer the loads to different areas on the truss. Even if one of the web members where compromised it may not cause failure to the truss. What are of concern are the connection points of the web members to the chords of the truss. Engineered truss incorporates several different products and methods in connecting the web members to themselves as well as their connection points to the chords. One of the most common methods used in lightweight truss is the use of gusset plates. When exposed to fire conditions the metal gusset plate can transfer heat and expand loosening its small teeth from the wood removing its ability to grip the wood that the gusset plate and its teeth were sunk into. The gusset plate may then very well just fall to the floor or

partially hang unattached to its important counterpart protecting the integrity of the truss potentially causing collapse of the truss and roof decking. Another recent manufacturing technique is finger glued joint applications of prefabricated lightweight wooden truss applied to the connection points of web members to web members and web members to the chords. At the manufactured assembly site the web members and the chords have been mitered into finger grooves with the application of glue heated to approximately 300 to 400 hundred degrees poured into the finger grooves and then cooled. The truss along with the glued joints is then allowed to cool creating a sufficiently strong complete prefabricated truss ready for shipment for home building. It doesn't take much for firefighters to realize that if the assembly of these lightweight wooden trusses is put together at 300 to 400 degrees then we can expect them to come apart under fire conditions at those temperatures as well.

There are so many factors and potentials that affect lightweight wooden truss under fire conditions and that to try to provide some type of predictable behaviors at structural fires is nearly impossible. The loosening of gusset plates, degrading of glue laminated joints, increased span widths, alterations to trusses after their erections and excessive loads placed above or below them make for firefighting disasters on the fireground make firefighting extremely dangerous regarding their collapse.

Steel Truss Systems

The final type of truss system firefighters should be concerned with is steel truss. Steel truss poses its own unique problems regarding their makeup and collapse potentials. Depending on their design will determine the potential for failure under fire conditions. The heavier the steel along with the size and surface area will affect how they will react to fire conditions. The thicker the steel members which also include webs and chords the more resistant they are to fire. Again this is based on time of exposure. The longer the exposure to fire and heat the more the probability in their collapse or failure. Larger sections of steel truss can take longer to reach a failure point because it can absorb more heat for a longer period of time. Lightweight steel truss with less mass will fail much faster due to open web designs incorporated into their design. When steel truss is exposed to fire it absorbs heat raising its internal temperature which then causes its failure. Findings and reports by several different laboratories have indicated that lightweight steel truss and joist can fail in as little as 4 to 6 minutes when exposed to fire conditions. NIST studies have revealed that steel truss and joist with open web design features when unprotected can reach up to 1200 degrees in as little as 6 to 8 minutes. With these type of laboratory exposures they estimate that the steel can lose its strength significantly.

As we know steel does not contribute fuel loads to fires but it does hold the ability in retaining high heat and transferring high heat to other areas of a structure and any materials within that area. With this being said it is important to note that this heat transferring ability affects all

elements of at steel trusses connections which includes its web members, chords and anything that may be running through it. Another factor influencing the possibility of collapse at structural fires is the steels ability to expand when heated. A 50 foot steel truss could expand as much as 3 to 4 inches according to laboratory studies. In structural firefighting this can relate to the steel truss connections to the building itself pushing and loosening its connection points into the walls causing collapse of bearing walls as well as parapets that also may be connected into steel truss at the roof line. These lateral thrusting type forces have caused major collapses and have killed and injured firefighters at many fires throughout history while still being a major threat on today's fireground.

Procedures in Minimizing Risk in Structural Fires Involving Truss Construction

- **Instruction and training delivered to firefighters enabling them to identify types of roofs and floor systems and their hazards.**
- **Whenever possible conduct pre-incident size-ups locating buildings whether residential or commercial incorporating truss construction.**
- **Establish fireground operating procedures employing sound tactics and strategies at structural fires involving roof and floor truss construction.**
- **First-in officers and commanders should perform adequate size-ups assessing risk before committing to interior firefights.**
- **When truss compromise is suspected remove firefighters operating above or below trusses.**
- **Ensure that when known potentials indicate defensive operations establish proper and adequate collapse zones.**
- **Use extreme caution during overhaul operations when fire has degraded roof and floor trusses.**
- **Be aware of water adding to the weight loads put upon trusses along with fire impingement.**
- **Be aware of roof loads added by HVAC and other mechanical system units sitting on truss construction.**
- **Firefighters ensure that when firefighting is being conducted that early inspection by opening concealed areas and when fire is located in truss systems that it is reported immediately.**

- **Never estimate or utilize time studies to dictate a trusses predictable collapse potential.**

The interface and interaction of interior fire extinguishment, roof operations, firefighter search and rescue along with other operational actions all interact and affect a given structures performance especially those incorporating truss systems. Listed below are the classes of building construction along with common features relating to their full or partial collapse potentials when fire, fire extinguishment, overhaul, roof operations and water weight are being conducted within and on the structure.

Building Construction Classifications and Collapse Potentials

Type I-Fire Resistive: Two types consisting of reinforced concrete and structural steel buildings.

Collapse Elements and Hazards

- **Flame spread usually contained to one floor with limited to little flame spread to other floors.**
- **Large fires with high heat release heated concrete ceilings areas can collapse onto firefighters while steel frame buildings with concrete floors can separate and bulge upward or downward.**
- **Rapid expansion of moisture heated by fire expanding the concrete exposed to heavy fire from below.**
- **Heavy sections small or large can collapse onto firefighters.**
- **In steel corrugated buildings heat transfer is through corrugated steel to the concrete flooring above causing expansion and bulging.**

Type II-Non-Combustible: Three types consisting of metal-frame structures with metal exterior walls, metal frame enclosed in concrete block and concrete block or slab supporting metal roofs.

Collapse Elements and Hazards

- **Roof collapse from exposure to fire to unprotected steel joists with open web design.**
- **Unprotected steel elements affected due to large quantities of combustibles within the structure.**

- **Dangerous to firefighters operating on roofs held in place by steel open web designed joists impinged by fire.**
- **Steel bar open web designed joist is the predominate danger to firefighters in non-combustible constructed buildings**

Type III-Ordinary Construction: Consist of masonry walls with wood framing, floors and roofs. Usually within 2 to 8 stories in height.

Collapse Elements and Hazards

- **Floors and decking burn through before structural failure.**
- **Structures carrying high dead loads such as HVAC or large amounts of stock.**
- **Bearing walls carry the load of the structure while distributing loads to floors and roof systems bringing large portions down unexpectedly.**
- **Buildings are constantly going under renovations creating new voids through ceilings and walls allowing hidden fire to travel undetected.**
- **Cockloft areas can create rapid fire spread that is undetected.**
- **Aged structures with multiple renovations can allow rapid fire spread with collapse potentials inevitable.**
- **Structural features to include parapet walls extending above the roof lines subject to collapse.**
- **Aged structures have load bearing walls exterior and interior that have gone under many repairs can compromise stability under fire conditions.**
- **Realigned walls with installed rods and spreaders indicated by exterior stars or circles on exterior walls for decorative purposes covering attachment points of the spreader points to the exterior wall. Early failure in large fires causing major collapses of large portions of the building and its roof.**

Type IV Heavy Timber: Masonry walls incorporating large wooden beams and columns with wooden floors. Large masonry buildings with brick, stone or block construction. Large lintels and arches transfer loads over large openings. These buildings are usually made of thick exterior masonry walls.

Collapse Elements and Hazards

- **With large bodies of fire masonry walls collapse with extreme force due to the weight of large sections.**
- **Several hours of fire exposure cause major collapses of floors and walls.**
- **Predict large amounts of wall with extreme heights to collapse after large fires and long fire exposure demanding large collapse zones for firefighter and apparatus protection.**

Type V Wood Frame: Buildings incorporating the use of dimensional lumber or lightweight engineered systems utilizing 2 x 4 and up to 2 x 12 lumber elements in most of its framing and support.

Collapse Elements and Hazards

- **Combustible bearing walls of wood construction failing under fire conditions.**
- **Side walls are usually bearing walls which can collapse under fire conditions bringing in the roof as well as well as floors.**
- **Collapse of any and or all wood system construction can cause collapse of an entire section of a residential structure when exposed to sufficient fire over a short period of time.**

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