# FF-2 and FSI Continuing Education – 5 Hours
# Lightweight Construction Part I

**Article by: Battalion Chief Sean Decrane CFD**
**Editing and graphics by Captain James Thomas, CFD**

The term Lightweight Construction has a variety of definitions depending on who is defining the term. The International Building Code does not define the term as 'Lightweight Construction' but rather as 'Light-Frame Construction' and it is defined as "A type of construction whose vertical and horizontal structural elements are primarily formed by a system of repetitive wood or light gage steel framing members".[1] A better term we should be using would be 'Engineered Products'. "Advocates in the Fire Service believe any product consisting of a combination of smaller components into a structural member and a design using engineering methodologies should be considered engineered. Engineered products are developed to use materials efficiently.", according to the American Forest & Paper Association[2], "Therefore, many engineered wood products are lighter in weight than the conventional product they are designed to replace".

According to the AF&PA, "Engineered wood products are structural components or assemblies that are offered as alternatives to solid sawn lumber, I-joists, and wood trusses are examples". If we noticed how many times the term engineered was used it is an indication of where the construction industry has directed the practices of building construction over the past few decades. In simpler times before computers and architects, engineers designed buildings calculating the required structural load and incorporated safety factors into those designs to ensure structural integrity in routine daily life and also in the event of emergencies. The Empire State Building was designed to withstand a direct hit by the largest aircraft at the time. With today's advanced design software packages and computer module testing, these same architects and engineers can now calculate the required structural integrity to the absolute perceived threshold. This requires less material therefore it reduces the cost of construction. As the late Francis Brannigan has indicated, "The Empire State Building weighs 23 pounds per cubic foot.

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[1] International Building Code
[2] American Forest & paper Association, *Engineered Wood Products Primer Awareness Guide*

Modern high-rise buildings weigh as little as 8 pounds per cubic foot".[3] This is an incredible savings of two-thirds in construction materials required, translating into millions of dollars in savings.

As we will realize throughout this Continuous Education segment and future segments, the underlying factor in today's construction industry is cost. The construction industry does not earn income being concerned with the safety of fire fighters, or the public for that matter; they conform to exactly what the Building and Fire Codes allow them to construct. It is because of this governance that the industry hires numerous code Consultants to lobby the Building and Fire Officials with the results of their "Computer Module Testing" that indicates the safety factor of their proposed construction practices. The Fire Service is starting to pay the price for our inactivity in the code process. In recent years we are beginning to experience first hand the consequences of fire involvement in lightweight, engineered, buildings.

In this Continuous Education article, we will address types of lightweight construction and indicators of the presence of certain types of construction. Over the year we will cover Tactical Considerations, effects of fire on types of construction, results of proposed testing by Underwriters Laboratories and the Chicago Fire Department, who received a $900,000 grant from Homeland Security to study the effects of fire on lightweight construction and additional issues. We will also cover additional forms of construction and the ramifications to the fire service, in addition to the importance of Risk versus Reward decision-making and also the importance of good inspections and pre-planning in ensuring the safe return of our members at the end of each shift.

## Truss Construction

A truss is defined as a framed structure consisting of a triangle, or group of triangles, arranged in a single plane in such a manner that loads applied at the points of intersections of the members will cause only direct stresses (tension or compression) in the members. Loads applied between these points cause flexural (bending) stresses. The rigidity of the truss rests in the geometric principle that only one triangle can be formed

[3] Francis Brannigan, *Building Construction for the Fire Service, Third Edition 2000*

from any three lines. Thus, the triangle is inherently stable.[4] Simply put, with the triangle design, when a load (weight) is placed on a truss the truss distributes the weight evenly through its tension and compression properties and reduces the stress at a single point. Trusses in buildings are easily identified by the triangulated framework construction. Triangles, not to harp on it, are what distinguish a truss from other structural products.

There are many types of trusses and many have been in use for hundreds of years. Identifying each and every type of truss is not in the scope of this article so we will concern ourselves with a few types and particulars concerning these trusses.

Why use a truss? The truss is lighter in weight than sawn lumber or other solid types of construction products, therefore it cost less to incorporate into the building. They also provide long clear interior spans giving maximum flexibility in the use of space and trusses are usually prefabricated and delivered ready for installation. There are important aspects to these to consider in the integrity of the truss: How long has it been stored outside? What is the grade of lumber used in construction of the product and will it deteriorate in the exposure to weather thereby reducing the safety factor in the incidence of fire induced stress? Has the truss been altered when installed? Trusses are designed to be installed without alterations or reduction in sizes. Any alterations made to a truss can have serious consequences at a later time.

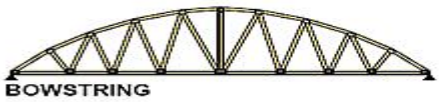
Trusses can be constructed using wood, wood and steel combined, or steel. It is important to remember we are discussing lightweight truss construction. As mentioned, there are quite a number of trusses including Timber Truss, Arched Trusses, Inverted King and Queen Trusses and actually concrete trusses. The difference in what is considered a lightweight truss is the size of the framing members. A general rule to remember is that trusses with structural framing members, web members can be smaller, less than 4 inches x 6 inches should be considered lightweight. A couple of types to familiarize yourself with include:

- **Bowstring Truss** – The bowstring truss gets its name from the curved shape of the top chord. They are sometimes confused with arched roofs but the difference is that arches will thrust outward while a truss directs its thrust downward. This type of truss will mostly be found in roof construction and can conceal a large

[4] Francis Brannigan, *Building construction for the Fire Service*

span of open area if the ceiling is covered. Bowstring trusses are the deadliest style of roof construction per incident. There is no excuse for these fire fighter deaths since the bowstring is such an easily identified type of truss. Even if the tell tale hump shape is hidden by a parapet wall the roof team should immediately be able to identify the presence of the bowstring and notify the Incident Commander. Due to the danger of a large-scale collapse, the Incident Commander shall immediately consider a defensive attack if the structural members have been compromised by fire. Usual spacing in the trusses is 20 feet, so a collapse can involve 40 feet or more of roofing. Bowstring trusses can be found in Bowling Alleys, Shopping Centers, Supermarkets and Auto Dealerships, to name a few.

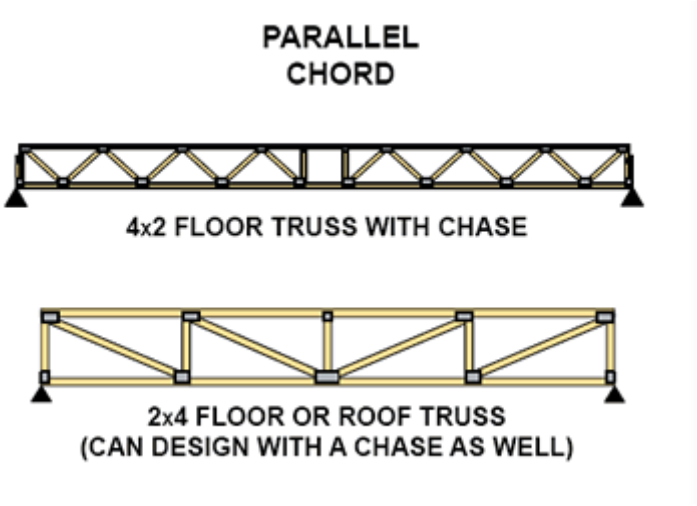
**Figure 1.1 – Bowstring Truss**




- **Parallel-Chord Truss** – In this type of construction the bottom and top chords are parallel (see figure 1.2). These types of trusses are usually used in floor construction, although they are also used in roof construction. One indication of this type of construction will be a long flat roof. However, in long expanses of roof construction, parallel chords may have a slight upward pitch to the center to facilitate water runoff. The use of this type of truss construction can create interstitial space, covered open areas, for a large area. If fire is suspected in this interstitial space, the Incident Commander needs to have the fire crews open the space to investigate. The only sure way to positively identify Light-Weight Parallel-Chord Truss construction is Pre-Plan. Through Safety Inspections, Building Inspections or even EMS Responses, fire fighters should take a moment to familiarize themselves with the type of construction in their running districts.

Parallel-Chord construction can be covered with gypsum or other ceiling coverings. Remember, many of these structures look like sawn lumber construction but are actually lightweight products and can fail in five to ten minutes when subjected to the effects of fire. Bar Joists Parallel-Chord Truss can usually be found in Single-Family Homes, Row Houses, Apartment Houses and smaller Office Buildings.

**Figure 1.2 – Parallel Chord Trusses**




- **Pitch-Chord or Triangular Truss** – This type of truss is very common in construction practices to provide a peaked roof (see figure 1.3). The lightweight triangular trusses must be closely spaced. This area will also create possible storage spaces in the attics, a dormer window may be an indication of triangular truss construction. If extension is suspected open up to investigate. Builders are using this type of construction with increasing frequency due to the cheaper construction costs. It is estimated that 80% of residential construction is using Lightweight-Construction in the floors and roofs.

**Figure 1.3 – Pitch-Chord or Triangular Truss**

- **Steel-Bar Joists** – Steel-Bar Joist Truss construction has become very prevalent in the commercial construction area (see figure 1.4). Walk into any Shopping Mall, Department Store, Mercantile Store or any type of commercial construction with large open areas and there is a very good chance you will see unprotected Lightweight-Gauge Steel Bar Joist construction. Commercial structures with unprotected lightweight steel truss construction should be approached with extreme caution. The connection points on the steel truss can begin to elongate and fail at 800°. Considering that ceiling temperatures can reach 1000° in less than five minutes the Incident Commander needs to consider a defensive action immediately if there is no life hazard involved in the incident. This type of construction will be present in most types of commercial construction and can easily be identified when it is unprotected through visual inspection. Another indication will be large open floor area with no, or few, columns present. Extreme caution shall be used in fighting fires in unprotected Steel-Bar Joist construction. Another consideration for safety is that when bar Joists begin to fail they can expand causing an outward wall collapse. When a decision has been made to take a defensive approach to fighting a fire the collapse zone must be recognized and an outward collapse suspected.

**Figure 1.4 – Steel-Bar Joist Truss**

## Problems with Truss Construction

While Truss Construction has been used for a number of centuries, lightweight truss construction has become much more prevalent in recent years. This increased use of truss construction has been driven by the economic savings of using less materials and the need for fewer man hours on site due to pre-construction of the trusses. Of course this increased use did not come with the endorsement of the fire service. In fact, the fire service has not been intricately involved in the code process that allows the use of lightweight products in the construction industry. The construction industry invests millions of dollars to design, and sell, building systems that are cheaper to use. There has even been a movement, in the code arena, to actually recognize that there are acceptable losses to building occupants in the event of a fire. Imagine, they are discussing acceptable losses to the building occupants, what about firefighters who are now entering that structure after fire has compromised the structural stability for a period of time. This is the reason the fire service needs to be active in the code requirement process and also the reason why we need to educate our members on the aspects of building construction. The fire service also needs to recognize the limitations of structural integrity when it is compromised by fire and adjust tactical decisions to meet the real life expectations of the various types of lightweight construction.

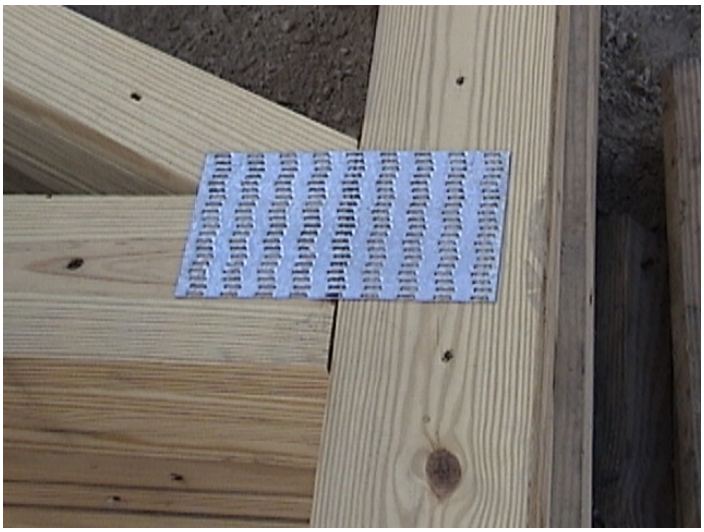
As we discussed, the top chord of a truss carries weight under compression basically acting like column. The distance between the panel points varies but where the contact points are, where the top of the triangles meet the top chord, is comparable to having a column at those points. This means that when one of the contact points fails, due to the effects of fire, or deterioration, the load carrying capabilities of the entire truss diminishes up to 75%. This can have fatal consequences because it can result in the failure of a large area of the floor or roof. In sawn lumber, since the compression loads, and tension loads (the bottom) are spread over a greater mass, its capabilities diminish at a slower rate.

It is the goal of the fire service to understand the principles of early failure and to recognize the scenarios when the likeness of these failures can occur.

One of the leading components where failures in trusses occur is the connection point. There are a number of ways to connect the truss connection points. Some of the ways are wood connections plates, wood dowels, metal bolts and the most common form of connection, the metal gusset plates. Believe it or not, the one form of connection that is growing in popularity is to glue finger points of the trusses together. The theory is the glue will maintain tension and connectivity for a longer period of time than the metal prongs of the gusset plates. Underwriter's Laboratories and the National Institute of Standards and Technology are doing separate studies on connection points at this time so we will address this issue at a later date. In this article we will address the problems of the metal gusset plates (see figure 1.5).

Metal gusset plates are simply a metal screen with teeth, or prongs, that are hammered over the connection points of the members of the truss. Their teeth, when properly attached, penetrate the wood components approximately ⅜ of an inch into the wood. That ⅜ of an inch must maintain structural integrity during a fire; your life depends on this ⅜ of an inch. Metal Bar Joists truss construction uses a simple weld at the connection points which can start to fail at 800º. When fire impinges on the connection points of the truss two things begin to happen. The wood at the connection point begins to deteriorate from the pyrolitic effects of the fire and the gusset plate begin to pull back from the connection point. In trusses connected with steel bolts, the bolt acts as a heat conductor and transfer of the heat from the steel bolt to the wood truss ends begins to take place causing a deterioration of the connection point from the inside out in addition to the exterior of the connection.

**Figure 1.5 – Metal Gusset plate**



The greatest cause of structural integrity compromise in Lightweight Construction is having less mass in the structural components. With less mass, the structural component loses its integrity at a more rapid rate than sawn lumber construction. Many of the components of the trusses are not much bigger than kindling and, with the increased air flow around the component, they will contribute to the fire load by burning at a more rapid rate. The truss floor building ordinarily gives no outward indication of its presence. The only solution is to pre-plan, record and retrieve, on the fireground, the construction information.[5] There are attempts in the Building Codes to address this information on a building marker.

Truss construction also introduces a new dimension into fire suppression of combustible buildings, a Truss Void.[6] Even without the strength comparison of truss versus ordinary construction, the truss introduces a new hazard with the large open areas within the truss area. With sawn lumber, each beam, rafter or joists, acts as a built-in Firestop. With the solid joists, the area of the void is limited. Carbon Monoxide can build up in these open

[5] Francis Brannigan, *Building Construction for the Fire Service.*
[6] Francis Brannigan *Building Construction for the Fire Service.*

areas, with heavy smoke conditions the flammability range may be too high for ignition but when air is introduced it can have explosive results. When properly vented from above, a fire fighter may encounter a rapid venting flame. If improperly vented from below fire fighter safety may be compromised. Remember, any fire in a concealed space, and involving possible lightweight construction must be opened immediately and investigated with a charged hoseline deployed.

As stated, pre-plan inspections are the surest way to determine the type of construction. When inspecting truss construction these are a few points to consider during the inspection of the trusses that have been found to impact the integrity of the truss:

- The presence of inadequate dimension lumber at joints where forces were high;
- Knots located in gusset plate contacts areas;
- Gusset plates not centered on members;
- Gusset plates not adequately embedded in the lumber;
- Defective lumber;
- The repair of split lumber with additional gusset plates;
- Use of juvenile lumber subject to shrinkage;
- Poor fit-up of joints;
- Inadequate connector sizes (The connector must be able to bear the designed load).

These have been but a few samples of issues that can be found to compromise truss construction. There is intense competition in the construction field and while most construction companies have conscientious employees there are those who will sacrifice integrity for profit. We need to be diligent in inspection, pre-plan, and size-up.

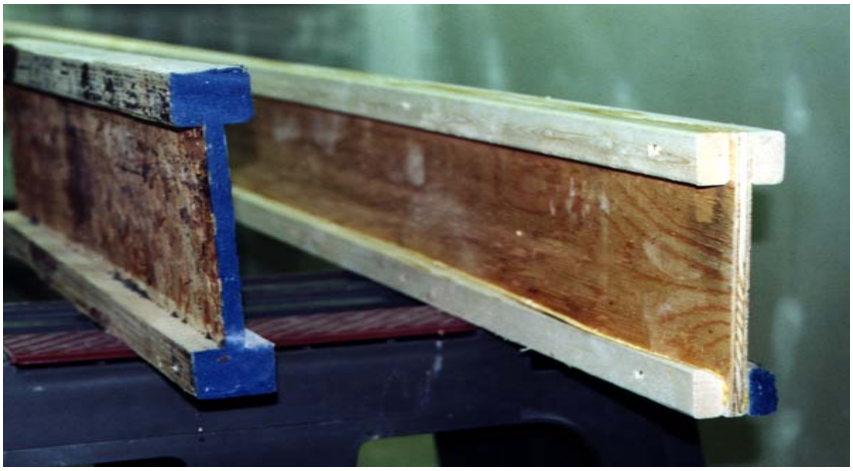
## Wooden I-Beam Floors

While there has been considerable attention within the fire service on truss construction, a form of construction has become increasingly more prevalent and it has serious concerns for those who enter these structures to perform firefighting tactics. This type of construction has a number of monikers including composite wood joists, wooden I-

Beams or Silent Floors. This type of construction has recently been linked to incidents of sudden collapse most notably a collapse in August of 2006 that killed Brother Arnie Wolf in Green Bay.

Wooden I-Beams (see figure 1.6) are constructed to look like an "I" with wooden flanges ranging from 1 5/16" to 1 ½" thick and from 1 ½" to 3 ½" wide. The flanges are the top and bottom chords. There is a web material usually made from OSB and is typically 3/8" to 7/16" thick. In residential construction spans are typically 9 ½" to 16" in depth, commercial construction can have a depth of 48 inches. Construction lengths can span up to 60 feet so builders enjoy the efficiency of using one piece in construction saving the costs of additional materials and labor costs of installation. The biggest disadvantage to firefighters is the use of less materials leading to less mass in structural components, which fail sooner in the event of a fire.

**Figure 1.6 – Wooden I-Beam/Joist**



Wooden I-Beams or Silent floors can be found in a variety of construction types including wood frame and mixed frame construction, residential and commercial occupancies, new construction and the rehabilitation of existing buildings in which the floors and roofs have been replaced. The Wooden I-beams can mostly be found in residential housing, townhouses and single or two family homes.

The American Forest & Paper Association recognizes the fact that due to the use of Wooden I-beams in construction that it is important for the Fire Service to understand the unique characteristics of wood I-joists and recognize their unique installation

requirements.[7] The AF&PA recommends the fire service conduct site visits to familiarize themselves with wooden I-joists construction and some of the construction site problems when installing the wooden I-joists. Remember, the wooden I-joist is a highly designed construction item that must be installed as designed. Any variation, alteration or compromise of the wooden I-joists can have disastrous effects for the responding fire fighters.

Installation concerns the fire service should be aware of:

- I-joists are glued together with adhesives continuously along their length, they are not held together with connections or gusset plates;
- Wooden I-joists must be installed vertically or their load strength will be compromised. The vertical alignment is usually accomplished with metal hanger connections or blocking materials;
- Inspectors should review plan drawings to determine the I-joists are spaced correctly;
- Ensure that hangers have a nail in every hole and are properly secured;
- IMPORTANT: Ensure that field modifications for the distribution of wiring and piping follow manufacturer's recommendations. The I-joists are designed for specific loads and uses and usually have specific instructions on the precise placement of penetrations. Some manufacturers actually place pre-marked cut outs for the wiring and piping. Any joist with penetrations too close to the flanges or having been altered in the field can lose its load carrying capabilities and may have a dramatic impact on time to failure in the event of a fire;
- I-joists are designed to be installed in dry conditions and can not be exposed to the elements of rain or snow for an extended period of time. Whether they have been installed or stored, if exposed to inclement weather, the I-joists can begin to deteriorate leading to structural failure;
- Flanges can not be cut, chipped or compromised in any way, it will diminish its load capacity;
- The improper use of small sections of the I-joist being used as a firestopping material in the voids. This is not permitted since the I-joist is not a firestopping

[7] American Forest & Paper Association, *Wood I-Joist Awareness Guide, 2006*

material. If this situation is found it shall be referred to the Fire Prevention Bureau or Fire Marshall for follow up.

There are a number of concerns on how this construction will perform when exposed to the effects of fire. Traditional dimensional lumber's biggest asset in the event of fire was the mass of the lumber. With the solid mass of dimensional lumber, when fire impinged on the lumber the exposed sections would begin to burn and char with the char actually protecting further damage to a point. As the damaged increased the lumber would begin to lose some of its mass, but it had the capacity to do so relatively safely since it had a built in safety factor, mass. The dimensional lumber could lose some mass and retain its load carrying capability for a longer period of time because it has more mass to sacrifice. When lightweight, or engineered wood products, such as wooden I-joists begin to lose mass it becomes a critical issue because the component has been designed to a specific load factor. It can not afford to lose any mass without serious risks of failure.

In the case of Brother Arnie Wolf, he and his partner entered a single family home to perform Search and Rescue operations. They felt the floor upon entering and continued to do so during their search. They encountered a sound feeling and sounding floor, as they felt along they had no idea that the fire in the basement below them was compromising the lightweight structural components of the floor beneath them. The floor felt solid since it was a concrete covered heated floor. Without warning a large section of the first floor collapsed sending Brother Wolf into the room of origin and his partner survived when she fell on the opposite side of the wall. A matter of inches saved her from a similar fate although she was seriously burned and had to perform a very difficult self-rescue.

The point of the story is that there was no warning of collapse. No sagging floor, no drooping and no additional outward signs of structural compromise. This is why fire fighters need to be cautious when entering structures suspected of lightweight construction. When in doubt, keep in mind that some estimates put the number of new houses using lightweight construction at 80%. Usually when someone assumes it makes an, well you get the idea but in these cases assuming a structure has lightweight construction and NO life safety concerns are involved, the assumption can save your life or those of your crew.

There have been a number of studies performed concerning the performance of wooden I-joists when exposed to fire. Remember, the I-joist is connected with glue. Various test results showed structural collapse, after the joist was exposed to fire, in a time frame of 4 ½ minutes to around 7 minutes. Times that directly correlate to alarm response times. In fact, on December 4, 2006 the International Association of Fire Chiefs issued a warning concerning the structural integrity of wooden I-joist construction and recommended:

> "Extreme caution should be exercised in any situation where entry is made above a basement fire. Conventional methods such as sounding ahead with a tool and checking for sponginess may not provide sufficient warning of a weakened floor. Using a thermal imaging camera is recommended to sweep the floor for hot areas before entering and to help avoid areas that appear to be hotter than the surrounding flooring. Be aware that thick carpets or tile floors may compound the risk by making it even more difficult to detect hot spots".

The increased use of various types of construction should give the fire service cause for concern and the impetuous to inspect buildings being constructed in their districts. Keep in mind that on a quick glance, a wooden I-joist may look like a dimensional piece of lumber, but a closer look will display the signature I shaped construction. Because of the ease of use and the realized savings of construction costs, the construction industry will continue to promote these Silent Floors. It is incumbent on the fire service to educate members to the dangers associated with this construction and mobilize resources to ensure the protection of this form of construction. As John Norman stated, "The owner of the nice, quiet floor should hear the screams of the fire fighter as he plunges into the flames below".[8]

For additional valuable information concerning the Silent Floors, I recommend an article available on the Fire Engineering web site, wwwfireengineering.com called Silent Floors, Silent Killers? By James Kirsch.

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[8] *Fire Officers Handbook of Tactics, Second Edition*, John Norman

## Tactical Considerations in Lightweight Construction

These construction practices and materials demand major changes in fire fighting tactics. Fire fighters can no longer just charge into building fires or vent the roof from the roof deck. We must know more about the building construction of the structures we are entering.

In the case of fires in structures involving Trusses or Wood I-Beam construction, Incident Commanders, should consider evacuation as soon as trusses are involved in fire, or in the case of steel trusses, when they are being substantially heated.

Due to the truss voids, a charged hose line should be in place when opening concealed spaces with lightweight construction. A large concealed space can conceal a fire of substantial proportion with little smoke showing and literally explode when exposed.

There are a number of actions fire fighters can take to protect themselves when confronted with buildings utilizing lightweight structural building components:

- Size up a building for indicators denoting the presence of lightweight construction, occupancy type, type of building, large unsupported spans, age of building and pre-plan inspection data;
- Study known weaknesses in lightweight construction and identify these deficiencies during inspections and document;
- Visit construction sites and observe construction types in your running districts;
- Understand and factor for possible void spaces;
- Recognize the possible use of storage space in Triangular Truss construction which can lead to a substantial fuel load when exposed to fire;
- Educate yourself on the signs of failure and collapse indicators in lightweight construction;
- Communicate any sign of possible collapse to the Incident Commander immediately;
- Be concerned when operating in an altered or renovated building. Full dimension lumber may have been replaced with lightweight components in the rehabilitation process;

- Use roof ladders or ventilate using aerial apparatus when operating above a roof with lightweight structural components;
- When performing Search and Rescue in a known Life Safety situation, stay close to the wall or possibly use a portable ladder to distribute the weight;
- When pulling ceilings attempt to do so from a doorway. This will utilize the protection of the doorway and keep an open means of egress;
- Utilize only the personnel needed inside of a structure in checking for extension or overhaul;
- Be aware of hidden fire in void spaces;
- Anticipate a rapid failure of structural components when lightweight construction is known to be present. Real world incidents have shown failure in less than five minutes in some cases. If no life safety is involved Risk vs. Reward should be utilized with the deferral to safety;
- Be cognizant of dead loads on the roof of lightweight construction. This concentration of a heavy load can accelerate failure when the structure is compromised by the effects of fire;
- Realize that lightweight construction allows for greater expanses and that one failure can lead to a failure over a large area;
- REMEMBER, failure in lightweight construction will not be precipitated by the traditional feeling a sagging or weakness. The majority of cases involve sudden failure over a large area with no warning.
- You are responsible for your safety and to recognize potential hazards. Be aware of your surroundings and perform a continued size up of the situation and construction type being encountered. One structure, whether it is residential or commercial, can have multiple types of construction. Be aware of your surroundings.

There are a number of attempts currently being pursued in the Building Codes to cover and protect ‘Lightweight Construction” and to place identification labels on the exterior of buildings to warn fire fighters of the presence of these forms of construction. There are also additional efforts to require sprinklers in residential

construction and additional occupancies. Until those attempts are successful, the Fire Service will need to stay vigilant in pre-plan and safety inspections to identify the types of construction in response areas and the dangers associated with them.