Collapse of Burning Buildings

A Guide To Fireground Safety

2nd Edition

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Fire Engineering®

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GENERAL COLLAPSE INFORMATION

All firefighters fear the thought of sudden building collapse. Veteran firefighters will tell you, "I know how flames spread. I know the dangers of fire-flashover and backdraft, and I know ways to protect myself from these hazards. The only thing I cannot predict is sudden building collapse. The floors, walls, and roof can cave in all of a sudden, and there is nothing I can do about it." Being buried alive beneath tons of bricks, smoldering timbers, and plaster is the dread of all firefighters.

The sudden collapse of burning buildings can kill large numbers of firefighters at one time. The largest number of firefighters were killed in a single building collapse in Chicago, Illinois: 21 firefighters died in the collapse of a stockyard building in 1910. The wall of the building collapsed on top of the shed over a loading platform. During that same year, Philadelphia lost 14 firefighters in a single collapse when the floors and walls of a leather factory building suddenly caved in. First the floors collapsed and trapped three firefighters and then the walls collapsed on rescuers and killed 11 more firefighters. In Brockton, Massachusetts in 1941, 13 firefighters were killed when a steel truss roof in a movie theater collapsed. Firefighters pulling ceiling up in the balcony of the Strand Theater were crushed to death when the truss roof and wire lath ceiling collapsed. In 1966, 12 firefighters were lost when the floor of a drug store collapsed into a burning cellar.

In 1967, five mutual aid firefighters from Ridgefield, New Jersey, were killed when a timber truss roof of a bowling alley collapsed in Cliffside Park, New Jersey. The falling roof pushed out a masonry wall on top of firefighters outside the burning building. In Boston, Massachusetts, in 1972, nine firefighters were killed when the floors and walls of the Vendome Hotel collapsed. In 1988 in Hackensack, New Jersey, five firefighters operating a hose line died when a wood timber truss roof collapsed during a fire in an auto dealership. In Brackenridge, Pennsylvania, in 1991, four firefighters died when a floor in a wood refinishing building collapsed (fig 1-1). In Seattle, Washington, in 1995, four firefighters died when a fire in a warehouse caused a floor collapse, and in New York City, 343 firefighters died when the World Trade Center collapsed on September 11, 2001 after a terrorist attack and fire. Burning building collapse is one of the leading causes of fireground death. The National Fire Protection Association states that leading causes of firefighting deaths are:

- Stress
- Responding and returning to fires and emergencies
- Falls
- Falling objects

- Coming in contact with objects
- Firefighters caught and trapped
- Burning building collapse

Fig. 1–1. Column failure was the cause of this floor collapse that killed four Brackenridge, PA, firefighters.

Collapse of Burning Buildings

Structural collapse during firefighting can be expected to increase in the twenty-first century. Four factors that will increase burning building collapse are:

- Age of buildings
- Abandonment
- Lightweight construction materials
- Faulty renovations

Age of a building

A building, like a person, has an expected life span. A structure that is 75 or 100 years old, like a person, is near the end of its life expectancy. Beyond this age, a structure becomes badly deteriorated. Many structures in this nation are over a century old and are weakened by age. Wood shrinks and rots, mortar loses its adhesive qualities, and steel rusts. Unless there is a much greater effort toward building preservation, rehabilitation, and legal renovation, the older structures of this country will collapse at an increasing rate and kill more firefighters (fig. 1–2).

Fig. 1–2. The age of a building increases its collapse danger.

Abandoned derelict buildings

During the 1960s, 1970s, and 1980s, large numbers of the United States population moved to the sunbelt from the Northeast and Midwest urban areas. A large number of abandoned buildings were left behind in the wake of this migration. These dangerous unoccupied buildings increase the collapse danger to firefighters. However, in the 21st century some cities have experienced a rebirth; people moved to the urban areas and the number of vacant buildings has been reduced. But there are still many dangerous abandoned and neglected, unoccupied structures in cities. These are so-called *target hazards*. Buildings such as these must be targeted by fire departments for frequent inspections, board-up orders, and fire preplanning. They present a major collapse danger during a fire. A building, vacant for several years and exposed to rain, snow, summer heat, and freezing temperatures, will collapse more quickly during a fire than a building that is well maintained and occupied by residents or a business. In a vacant building, rain and snow penetrating broken windows quickly rots a wood floor, roof, or foundation. Wind and rain erode mortar between bricks. Water seepage into an unheated building's masonry walls will freeze, expand, and crack the bricks. This freeze–thaw cycle cracks masonry walls. In an unoccupied building, fire-retarding coverings are quickly stripped from structural supports by moisture in an unheated building. Homeless people and drug addicts take shelter in these structures and start deadly fires. In 1999, a fire started by a homeless person in a vacant storage warehouse killed six Worcester, Massachusetts, firefighters.

Lightweight materials and methods of construction

The widespread use of lightweight construction materials presents another serious danger to the firefighters of America. Today's buildings are constructed of building material such as lightweight wood trusses, sheet metal C-beams, wooden I-beams, open bar steel joists. Firefighting inside a burning building constructed of lightweight materials is much more dangerous than firefighting inside a burning building constructed of traditional materials and by traditional methods. For example, underwriters testing laboratories has documented lightweight wood trusses, fastened together by thin pieces of sheet metal, collapse more readily than do solid 2×8-inch continuous wood beams.

The National Fire Protection Association states: "Unprotected lightweight steel bar joists fail when exposed to 5 or 10 minutes of fire exposure." We know bar joist collapse more readily than solid steel I-beams. Today, high-rise buildings are increasingly using lightweight materials. The World Trade Center towers had 60-foot unsupported steel bar joist floors. This was a factor in the rapid collapse of the towers after the terrorist jet plane attack and fire. One tower totally collapsed in 8 seconds and the other in 10 seconds.

The National Institute of Standards and Technology (NIST) investigated the collapse of the towers and discovered that the floors were the first part of the building to collapse. Fire protection engineers know fire resistance and collapse resistance are directly related to the mass of a building. A wood bearing wall with studs 24 inches or 30 inches on center will fail more quickly than a wall with studs 16 inches on center. A ¼-inch thick floor or roof deck will fail before a deck ¾-inch thick one. Lightweight construction materials and methods are one of the answers given by the building industry as the solution to affordable housing, however, lightweight construction will kill and injure more firefighter in the future. Lightweight building construction includes small unseen changes also. For example: wood bracing between floor and roof beam are eliminated; wood stud wall and floor construction are spaced 36 inches on center instead of 16 inches; wood sheathing for roof and floor is ¼-inch thick instead of ¾- or 1-inch thick; roofs are supported by 2×4-inch wood beams instead of 2×8- or 2×10-inch beams. This trend will not stop, so the fire service must change its firefighting strategy and tactics when combating fires in lightweight structures.

Illegal renovations

Another cause of burning building collapse is illegal and improper building construction and renovation methods. Buildings newly constructed, and those renovated or enlarged must comply with existing building codes. Often they do not because an illegal or improper renovation is undertaken. The Vendome Hotel floor and wall collapse in Boston and the New York City 23rd Street Wonder Drug Store floor collapse had improper and illegal renovations as contributing causes. The cause of several recent burning building collapses in New Youk City that killed and injured firefighters were determined to be due to poor illegal or improper renovations. For example: fire walls that supported a floor were removed to increase rentable space; firefighters operating hose lines on this floor above a fire were killed when the unsupported floor collapsed (Captain Scott LaPedria and Lieutenant James Blackmore); the roof of a building constructed without building department notification or approval collapsed killing a firefighter advancing with a hose team (Firefighter Louis Valentino); illegal renovation was a factor in a store fire floor collapse that took the lives of Lieutenant Howard Carpluk and firefighter Mike Reilly (fig. 1–3).

Fig. 1–3. Floor collapse in this 99-cent store killed two FDNY firefighters.

Data on Building Collapse

Despite the potential danger to firefighters of sudden building collapse, local fire departments have compiled little information about the subject. Simple questions such as how a building falls down or what part of a burning structure collapses first are rarely answered after a structural failure. In all the studies and research on firefighting, little, if any, attention is paid to collapse causes: age of a building, abandonment, lightweight construction and illegal and/or shoddy building renovation methods. One reason for this is that any research into the subject of burning building collapse offers small benefit to anyone except firefighters. The general public will not receive any spillover benefit from information discovered about burning building collapse. Occupants have usually been safely evacuated from burning buildings before the collapse danger becomes great. Very few persons, other than firefighters, are killed by burning building collapse. Only firefighters are close to a burning building when it has been weakened by flames to the point of collapse danger. On the other hand, research and study into the other causes of firefighter death, such as physical stress, toxic smoke, and burns have been great, and information gained from this research has contributed to society and the general public.

Another reason there is little information about such an important subject is the fire service itself. After a burning building collapses and kills or seriously injures a member, the chiefs, company officers, and firefighters are usually unable to analyze objectively why the building collapsed or even how the structure collapsed. Emotions such as sorrow, guilt, and anger distort the investigation. Outside impartial investigators, who were not operating at the fire scene at the time of the collapse and who can objectively evaluate the collapse rubble, are needed to conduct an analysis of the incident. These investigators must be trained in the techniques and practices of post-fire investigation. Since 1990, objective investigations of burning building collapses are conducted by the National Institute for Occupational Safety and Health (NIOSH) and the National Institute of Standards and Technology (NIST), and can be found on the Internet.

A further reason why there has been so little accurate information obtained during an investigation of a collapse is the attitude of those conducting the investigation. Because of the legal considerations involved when someone is killed or injured at a fire, often the officials in charge of the investigation are concerned only with placing blame or avoiding legal problems. Valuable information about collapse danger and safety lessons which could be given to firefighters, company officers, and chiefs is often overlooked and lost during the investigation.

Another reason there is very little information about the danger of burning building collapse and firefighter survival during collapse is the absence of a standard definition of the term *collapse*. There is no fire service definition of the term collapse. Unless several tons of brick and mortar suddenly crash down into the street at a fire, any small part of a building that collapses may be called a *falling object*. The absence of an accurate, standard definition of the term "structural collapse" has led to an underestimation of the collapse problem.

The term *structural collapse* is defined in this book as "any portion of a structure that fails as a result of fire." If a burned section of plaster ceiling falls on top of a firefighter, it is a structural collapse—not a falling object. If a heated stone stair landing collapses beneath a firefighter, it is an injury caused by structural collapse—not a fall. If a small part of a lightweight truss floor collapses and a firefighter falls into a fire and dies, it is a death caused by collapse—not exposure to fire products.

The definition of a collapse in this book is when any part of a building falls and does not matter how small. If the falling piece is part of the structure, it is defined as a structure collapse. If one brick falls from a parapet and strikes a firefighter, the cause of injury should be structural collapse not falling object.

The definition of falling object is any object other than the structure that falls, is thrown, or knocked loose from burning buildings and strikes firefighters operating below. Firefighters are killed and injured by things falling near and around a burning building. These things are not part of the structure like a wall, floor, roof, or ceiling. Falling objects may be small and large objects but deadly to firefighters operating below. Some objects that have fallen from buildings during fires that killed and injured firefighters are: broken glass, tools, window air conditioners, smoldering mattresses, stuffed chairs, TV antennas, flower boxes, and even people jumping to escape fire. These deadly airborne missiles are a leading cause of firefighter death and injury.

The perimeter of a burning building is a dangerous area on the fireground because of building collapse and falling objects. There are more incidents of firefighters being injured by falling objects than by structure collapse each year. The front sidewalk, side alley, and rear yard are danger zones for falling objects. Firefighters have to work around the outside of a burning building near the front sides and rear walls where things fall. Because they must raise ladders, operate hose streams, vent windows, and conduct forcible entry around the perimeter of a burning building, they are frequently injured by falling objects, so they must be aware of dangers from above. As soon as the firefighting task is complete at the perimeter of the burning building, firefighters should either enter the building or withdraw from the danger zone.

Broken glass from windows being vented is the most common falling object at a structure fire. If glass falls from a window because the window frame was heated by fire and distorts allowing the glass to fall out of the frame or the glass cracks from the heat and falls, that is considered a burning building structural collapse. If the glass is broken by a firefighter venting, it can be considered a falling object. When firefighters are searching for trapped victims in a smoke-filled building that limits visibility, windows must be vented to clear smoke and increase visibility for the search. In older buildings that have many coats of paint preventing opening the windows, the glass must be broken. Several firefighters performing a primary search in a burning building can create a rainstorm of broken glass around the front, side, or rear of a building. Firefighters below can be cut by this falling glass. Glass in a residential building window is 1/16- or 1/8-inch thick and it is subdivided into small windowpanes. Commercial building window glass is larger, thicker, and heavier.

A case study

A firefighter was connecting a supply hose line to a standpipe inlet. Firefighters above were venting windows at a high-rise residence building at a particularly smoky fire. Glass shards were falling near the firefighter connecting the hose to the standpipe. The firefighter was wearing protective equipment. When bending over to connect the supply line to a Siamese inlet, a 3-inch sliver of glass went through the pump operator's turnout coat and severed part of his spinal column. The firefighter fell to the ground and could not get up. He was placed on a stretcher and rushed to the hospital where a three-hour operation was performed to remove the glass and prevent permanent paralysis.

Glass in a commercial building is much more dangerous because it is thicker and heavier, and can be ¼ or ½ inch thick and weigh 2½ or 5 pounds per square foot. This means an 8×4-foot display window of ½-inch thick glass when broken by a firefighter to vent smoke can create four, 40-pound razor-sharp glass shards. A firefighter could be decapitated by one of these falling objects. So, firefighters operating around the perimeter of a building where glass windows are being vented should beware.

Who is responsible when a firefighter inside a burning building performing search and rescue breaks a window in a smoke- and heat-filled room and the falling glass injures a firefighter operating on the ground around the perimeter of the burning building? Is it the firefighter who broke the window or the firefighter on the ground?

The firefighter inside, who broke the glass, is not responsible. The firefighter outside the burning building is responsible when injured from falling glass, because the firefighter inside is operating in a superheated, smoke-filled fire environment searching for life. However, if we change the question and the stage of the fire operation, then who is responsible for an injury that occurs after the fire has been controlled when during overhauling operations a smoldering object is thrown out of a window, or a glass is knocked out of a window frame and it strikes a firefighter below? Is it the firefighter inside or the firefighter outside? The answer, now, is the firefighter inside. Why? It's because the firefighter operating inside the building is not working in a life-threatening environment. The fire is out, the rescue operations have ended, and his actions must be more controlled. Firefighters inside a burned out structure performing overhaul and salvage should never throw any smoldering object out a window or trim glass shards by knocking them outside unless the area below has been cleared and a firefighter is standing guard outside at ground level. It is not sufficient to yell, "Watch out below" and then throw a smoldering chair or mattress out a window. Such a deadly, irresponsible act has killed and injured firefighters.

The safe procedure taken by firefighters when an object must be thrown out of a window during overhauling is:

1. Obtain permission from the officer in command of the fire.
2. Notify or assign a firefighter outside the building to clear the area of civilians and act as a safety guard.
3. After the area is clear, the firefighter acting as guard signals when to throw the smoldering objects out or breaks off the jagged glass shards.
4. When all objects have been discarded out the window, notify the firefighter below who's been assigned as a safety guard.

Several years ago at a fire, a company extinguished a small blaze in a stuffed chair. They removed a badly burned man who had started the fire by falling asleep in the chair with a cigarette. Firefighters dragged the smoldering chair to a window, pushed it out on to a fire escape and threw it over the rail into a back yard. Unfortunately, a firefighter assigned to the outside vent position was in the rear yard about to climb the fire escape. He was struck with the smoldering chair, knocked unconscious, suffered a disabling head injury, and was forced to leave the fire service.

1. Do not throw objects from a window during overhaul unless the area is clear, and you have been signaled to do so by another firefighter acting as a safety guard below.
2. When trimming broken glass from windows, knock the glass shard inside, not outside.
3. When assigned to operate around the perimeter of a burning building, be aware of the danger of falling objects and wear proper protective clothing. A well-fitted helmet, gloves, and an eyeshield in the down position can protect you.
4. When venting windows from inside, attempt to open the window before breaking glass. Double-paned windows in new and renovated buildings can be more quickly and fully opened manually then by breaking glass.

5. If a window is vented by breaking glass from the inside, first break a small section to warn firefighters inside and then take the entire window out.
6. A stuffed chair left inside a building often reignites. And, when dragging a stuffed chair outside, fresh air in the hallway can cause the chair to burst into flame, so have a portable extinguisher or hoseline in the hall near the chair ready to quench a flash fire.
7. Realize that commercial glass is more dangerous when broken then residential glass. The thickness and weight of falling glass pieces can cause serious lacerations and cut hoselines.
8. The perimeter of a burning building is a dangerous place. After completing your assignment there, go inside the building or withdraw outside the collapse danger zone.
9. When anything must be thrown out a window during salvage or overhaul, notify the incident commander and ask for a clearance below.

The final and most important reason for the absence of collapse information for firefighters after 200 years of firefighting experience in this country is the lack of fire department documentation and record of collapse. There is almost never a record or written report of a collapse unless several firefighters have been killed and the collapse is of national interest. Most firefighters who die in burning building collapses do so one at a time. These facts are rarely recorded in a written document which can be used as a source of training. The fire service records all types of information that is of little importance to a firefighter. For example, some fire reports include the community political district where the fire took place. The name and make of the electric product which overheats is sometimes required to be listed on the fire record also. However, to my knowledge there is no fire report that requires information about structural collapse to be recorded.

Recently the federal government and the National Fire Protection Association (NFPA) have provided useful information about burning building collapse. Starting in 1996, the National Institute of Occupational Safety (NIOSH) was mandated by Congress to investigate every firefighter death in this nation. Before this, many burning building collapses that killed firefighters were never investigated and causes were never determined. In 1999, the NFPA published a 10-year study of firefighters killed by building collapse. This study documented the exact parts of a building that collapse during fire. This landmark study found that 56 firefighters died in burning building collapses during the period from 1990 to 1999; 21 died by floor collapse, 19 by roof collapse, 14 by wall collapse, and two by ceiling collapse. This study instructs the fire service in which part of a building is more likely to collapse and kill firefighters. The floors collapsing kill most firefighters, the next most dangerous structural failure is roof collapse, then wall collapse, and finally ceiling collapse.

A study of burning building collapse was conducted by the National Institute of Standards and Technology (NIST) after the World Trade Center towers terrorist attacks. (See chapters 20 and 21.) This government agency conducted a comprehensive study of the disaster, and issued a report on the collapse of the World Trade Center Towers and issued a final report on the collapse of Building 7 in 2008.

Post-Fire Analysis

When a burning building collapse kills or seriously injures a firefighter, a post-fire investigation and analysis should be conducted by the fire department. A fact sheet recording building information should be completed, a fireground diagram should be drawn up showing the area of collapse, and a photographic color slide documentary of the area should be prepared. This information should be used for firefighter safety training sessions and to improve firefighting strategy and tactics.

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WOOD FLOOR COLLAPSE

A responding engine company turns into a street lined with vacant, brick-and-joist row houses. The last house on the block, a three-story, 20-by-60-foot structure, is fully involved in fire. Smoke pushes out around the sides of the tinned-up windows on the first floor. Through an opening on the second floor, flames can be seen spreading along the underside of the ceiling. On the third floor, smoke is being emitted from the windows.

The pumper stops near a hydrant several hundred feet up the street from the fire building. A firefighter dismounts from the side jump seat, runs to the back step, and grabs a fold of large-diameter hose connected to a hydrant fitting with a hydrant wrench attached. He pulls off several feet of hose, encircles the hydrant with it and shouts to the driver to go. As the engine moves up the street, the large hose tightens around the hydrant and the supply-line hose jumps out of the hose bed, length after length. When the pumper stops in front of the fire building, the cab door flies open and the officer gives the order to stretch. Two mask-equipped firefighters exit the side jump seats and start advancing a 1¾-inch preconnect toward the building. The motor pump operator, running to the rear of the engine, uncouples the supply line lying in the street and connects the male end to a gated inlet in the pump, which was prefitted with a reducer. He opens the inlet gate and gives the signal to the hydrant man to start the water. As the water flows, the pump operator awaits the order from his officer to start water into the attack hoseline.

The ladder company chauffeur swings the tiller rig into the street from the opposite direction. He brings the truck nose to nose with the pumper, giving the aerial maximum coverage of all side and front windows of the fire building. The officer and a two-man forcible entry and search team race to the entrance door, where the engine company is preparing for the fire attack. One firefighter strikes the one-piece, tinned-up entrance doorway in the center with a full swing of the back of an axe. Then, using the adz end of a Halligan tool as a hook, he pulls the top-left corner of the tin away from the doorway frame to which it is nailed. He pries the tin away on the left side, starting at the top and working downward. When the left side is free, he pulls out the tin and pushes it to the right side, exposing half of the door entrance.

With smoke enveloping him, the truckman steps into the doorway and swings the Halligan tool like a bat, banging the pried-open tin all the way back from the door. He backs out just before the flames explode out of the now opened doorway. The other forcible entry team firefighter, equipped with a 6-foot hook, runs to the rear of the fire building to vent for the advancing hose team. Starting at the window on the leeward side, he swings the 6-foot hook over his head into the center of a tinned-up window, piercing the tin at the center near the top half. He pushes the metal end of the hook through the small hole in the tin, and turns the hook sideways to catch the tin; he then begins a rapid in-and-out motion. Each outward pull brings the tin away from the window frame to which it is nailed, until the tin falls from the window and flames shoot out. The firefighter begins the same process on the next window.

Meanwhile, the chauffeur of the ladder company has raised the aerial to the roof of the three-story fire building, and the firefighter assigned to ventilate the roof is climbing the ladder. Arriving on the roof, he encounters a scuttle cover and a skylight. He is starting to break the panes of glass in the skylight when the entire metal frame and glass collapse into the interior stairway below. Smoke and flame rush up out of the roof opening. The soldered sections of the tin skylight frame had been melted by the fire.

"Good thing the engine company has not made it to the top floor yet," he thinks to himself. Moving over to the scuttle cover on the roof, he uses the Halligan tool to pry up one end of the tarred, flat square cover placed over an opening which provided access to the roof from the top floor. The cover breaks loose from the latch below. As the firefighter pulls off the cover using the tool's adz end, flames rush out of the opening. In the street, engine company members are crouched with a charged line, driving flames back into the front door. At that moment the chief arrives on the scene. Suddenly, thick black smoke billowing out of the second-floor windows explodes into fire. Flames shoot out front and side windows above the engine company on the first floor. A second later, the third-floor windows start to blow out flames and smoke.

The chief checks his clipboard with a computer alarm response sheet attached. "Where are the second-due companies?" he asks his aide. "They should have been here by now!" Before the aide can reply, the chief orders, "Go radio the dispatcher and check on the second-due engine and ladder. Also transmit a signal for a working fire."

Just then the Handy-Talkie crackles, "Ladder 2 roofman to Chief."

"Battalion 1, go ahead."

"Fire is burning front to rear on all floors. The roof has been vented. I think you should pull the engine company out. There's just too much fire in this old building."

"Battalion 1, 10-4. Get off the roof."

"Battalion 1 to Engine 8. Back the line out of the first floor."

"Engine 8 to Battalion 1. Chief, we have this fire almost out—we have only one more room to go."

"Battalion 1 to Engine 8. I don't care; back that line out." Engine 8 does not respond.

The battalion aide runs up to the chief. "Chief, the second engine broke down responding, and the ladder company is operating at another fire. The replacement units will be delayed."

Inside the burning building, the engine officer directs two firefighters to go out and tell the chief the fire is almost out and only one room of fire remains. Just then the chief transmits, "Battalion I to Engine 8. Did you get that last message? I said back that line out! The two floors above you are fully involved."

Engine 8 still does not answer. Flames are now reaching into the afternoon sky over the rooftop. The aerial ladder is being retracted from the roof. Two engine company firefighters and ladder company members exit from the smoky first-floor doorway. Just then there is a loud cracking noise and the third-floor timbers are visible as they collapse past the second-floor windows and crash violently on to the second floor. Then the second floor gives way and collapses down into the first floor with a loud, sickening rumble. When the smoke clears, the street-level entrance doorway is completely filled with wood joist ends, sections of lath, plaster, and brick.

"Dammit! I just lost a company!" shouts the chief as he throws the clipboard on the ground and runs toward the entrance where the still charged hoseline, on the ground, leads into the doorway packed tight with collapse rubble. The silence is suddenly broken. "Urgent! Urgent!" comes a voice on the radio. "Engine 8 to Battalion 1. Chief, did my two firefighters make it back out to you? The nozzleman and I were able to dive out the rear window before the collapse!"

"Battalion 1 to Engine 8. Yes, they made it out; they are okay," replies the chief with a sigh.

Floor Collapse

Floor failure is the leading cause of firefighter death by collapse. Firefighters use floors as platforms from which to launch interior searches and hoseline attacks. They depend on the floors inside a burning building to support them and their action. When floors do not support firefighters and collapse unexpectedly, there is often a loss of life or serious injury. When floors collapse, firefighters can be caught and rapped in the broken smoldering building and asphyxiated, crushed beneath the ton of rubble, or burned to death. Floor decks, floor beams and floor supports, such as, columns and girders, collapse during fires causing catastrophic, progressive, multilevel floor failures.

Case study of a floor collapse

A deadly floor collapse in the 1990s killed four firefighters in Brackenridge, Pennsylvania. The four firefighters were killed when a floor in a two-story 75×75 foot structure, built in the 1930s collapsed; First Lieutenant Rick Frantz, firefighters David Emanuelson, Michael Cielicki Burns, and Firefighter Frank Veri Jr. died when they were caught and trapped by a ball of fire after the floor failed.

The floors were 4-inch-thick concrete, supported by steel columns, steel girders and steel floor beams with masonry walls. This building originally was occupied as an auto dealership selling new cars. However the auto dealership went out of business and the occupancy changed. A furniture refinishing company moved into the cellar of this noncombustible structure built of steel and concrete. At the time of the fire, there was a large amount of furniture storage, a wood refinishing workshop, and a paint-spraying booth near the front of the cellar directly below the first floor entrance, and large amounts of flammable paints, lacquers, varnishes, and thinners in 55-gallon drums.

The fire started in the workshop. Upon arrival two attack hoselines were stretched to the burning cellar from the rear doors (exposure "C") to attack the fire. Heavy smoke and heat prevented the lines from advancing towards the front of the cellar where ıe fire was burning. A third hoseline was ordered stretched into the first floor, front entrance (exposure "A") to prevent vertical fire spread up an interior stairway located in the center of the building. This stair extended from the cellar to the first floor and smoke and heat were extending up the stair enclosure. As firefighters stretched the line through the first floor front entrance, a large section the first floor collapsed behind them. The floor collapse cut off their escape. As the floor collapsed, it crushed large drums of flammable liquid in the basement and caused a massive fire-ball explosion, killing the four firefighters on the first floor.

The structural hierarchy

A post-fire analysis revealed the series of events which caused the collapse. The first structure to fail was a massive steel column. The unprotected steel column twisted and sagged, causing a steel girder to warp and move backward, pulling floor beams out of the foundation and collapsing the first floor. This collapse was another example of the *structural hierarchy* effect during a collapse (fig. 6–1). The structural hierarchy effect means, the destructiveness of a collapse depends on the first structure to fail, and where this structure is positioned within the building supporting system. The structural hierarchy principle was first identified as a factor in floor collapse at the Boston Vendome collapse, of June 17, 1972. This floor collapse killed nine Boston firefighters. Firefighters must know that when the first structure to fail is high up on the structural hierarchy, the more widespread and deadly the collapse will be. For example, the "hierarchy" of a floor system has the bearing wall and column highest on the scale. Progressing downward in the structural hierarchy of a floor system, the girder come next, and a floor beam next, followed by the floor deck. So if a column fails, it affects the girders and floors and the deck. A column failure will have more consequences than if a girder fails. If a girder fails, it will create more destruction, than if a floor beam collapses but not as much as if a column fails. And if a floor beam fails during a fire, it can have more impact than if a floor deck fails but not as much as when a column or girder fails.

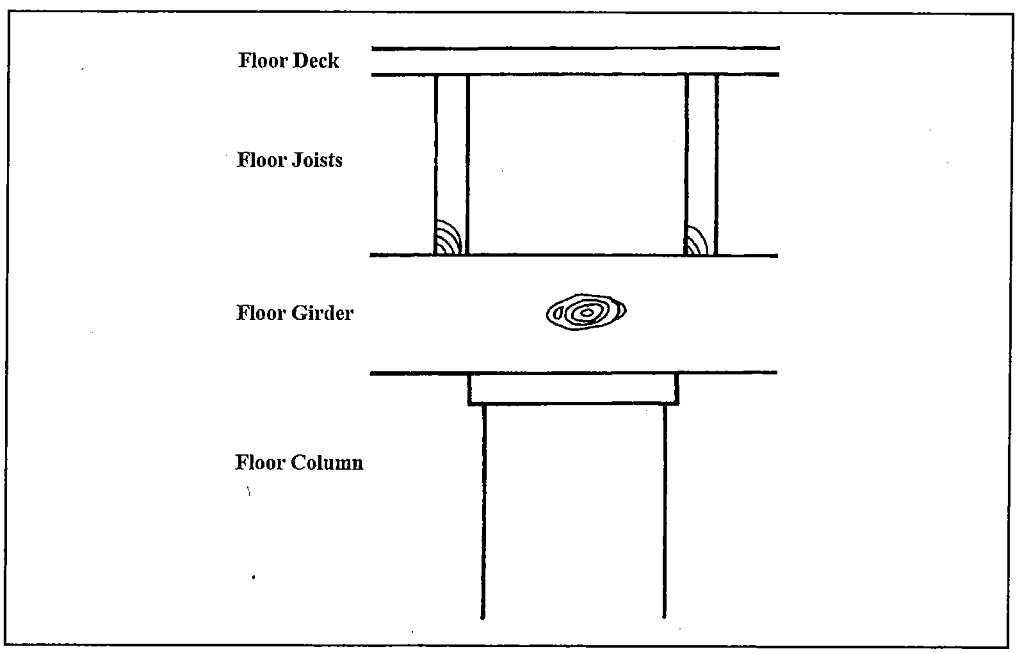


Fig. 6–1. The seriousness of a floor collapse depends upon the first structure to fail. A column failure is more serious than a girder collapse, a girder collapse more serious than a beam, and a beam more serious than a deck.

Floor Construction

A floor can be constructed of masonry, steel, or wood. Floors in many modern and renovated buildings are lightweight construction. Lightweight constructed floors can collapse during the early stages of a fire. A floor of wood truss, wood laminated I-beam, lightweight cold-formed steel C-floor beams, and open-web bar joists are considered lightweight truss floors. Fire resistance of a floor is directly related to its "mass"—bulk and spacing in the floor system. These lightweight floors have less mass and greater spacing between joists. Instead of traditional wood floor beams, which are 16 or 18 inches on center, lightweight floors can be 2 or 4 feet apart. The mass of the lightweight floors is reduced when the inside or middle section of the floor truss is replaced by thin bars or wood web pieces. The I and C floor beams are hollowed out or thinner than the top and bottom beam sections. This reduction of mass and increased spacing reduces fire resistance and allows floors to burn through and fail faster than conventional solid wood floor beams.

A floor of wood I-beam collapsed during a cellar fire in a private dwelling killing Deputy Chief Steven Smith of the Wea Township Community Fire Department in Lafayette, Indiana, on August 25, 2006. Chief Smith was this nation's first firefighter killed by a collapsing wood I-beam construction floor. The lightweight wood truss has killed 20 firefighters since 1984. We now have the first firefighter to die in the collapse of a wood laminated I-beam; and the fire service is holding its breath on the sheet metal C-shaped floor supports.

New buildings have lightweight floor construction. However, older and existing buildings still have solid wood floors. The conventional wood floor used in older brick-and-joist, and wood-frame construction, is a solid wood joist system 2×8-inch, 2×10-inch, or 2×12-inch floor beams spaced 12, 16, or 24 inches on center. The solid wood floor supports an under-floor of rough wood board or plywood, which in turn is covered by a finished floor of wood or tile. All types of floor systems, lightweight and conventional solid wood, can collapse when attacked by fire, but the lightweight constructed floors may collapse faster when exposed to flame and heat.

Types of Floor Collapse

The three ways all floors fail during fire are:

1. Floor deck may collapse, where only the wood deck may burn through and collapse, leaving the supporting joists intact. An example of a floor deck collapse occurred when FDNY Fire Lieutenant John Clancy died December 31 1995. The floor deck of an entrance landing on a two-story ordinary constructed private dwelling collapsed (fig. 6–2). This was a vacant building, and the fire was in the cellar when Lieutenant Clancy stepped inside a smoke-filled, first-floor, side doorway. The floor deck collapsed sending him into the burning cellar. Visibility was zero as the door opening was completely filled with smoke.

Fig. 6–2. Lieutenant John Clancy died when this floor deck collapsed.

2. Floor beam collapse, where several floor joists fail, causing a localized failure of a section of floor within room is a more deadly collapse (fig. 6–3). An example of a, recent, deadly floor beam collapse occurred when FDNY Lieutenant Howard Carpluk and firefighter Michael Reilly were killed at a Bronx fire on April 27, 2006, when the conventional solid wood floor beams of a one-story ordinary constructed strip store collapsed. The most deadly floor beam collapse occurred on October 17, 1966, when 12 FDNY firefighters were killed in the Wonder Drug store located on 23rd Street in Manhattan.

3. A multilevel floor collapse describes a progressive floor failure. Here a floor collapse triggers the subsequent collapse of floors below and of one or more enclosing walls (fig. 6–4). This is the most deadly type of collapse. The two most deadly multilevel floor collapses in the history of the fire service occurred June 17, 1972, when the Vendome Hotel collapsed and killed 9 Boston firefighters, and on September 11, 2001, when the terrorists attacked the World Trade Center. The two towers collapsed and killed 2,749 people, including 343 New York City firefighters.

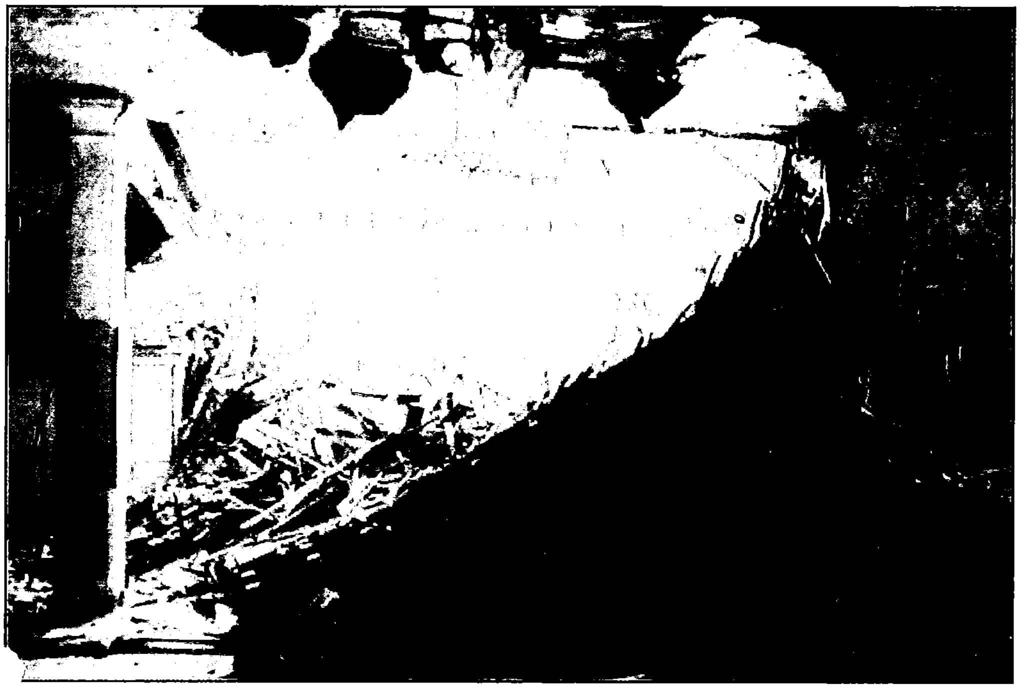


Fig. 6–3. An example of a floor beam collapse

A multilevel floor collapse most often happens in burning buildings that have columns and girders supporting floors. A building with a frontage of 25 feet or more usually has columns and girders. A building 25 feet or less can have floor beams supported by bearing walls on each side. Floor beams supported at each end by bearing walls are called "simple" beams—beams supported at both ends. A building, over 25 feet frontage, with a system of columns and girders may have floor beams supported at each end by bearing walls; however, at the center of the floor span, the beams are supported by a girder and columns. These are called "continuous" beams. And in these buildings, if the column or girders fail, there can be a progressive collapse of the floors and walls of the building. The chances a multilevel floor, or, so called, "progressive collapse," occurring are great when the first structure to fail is a column, girder, or bearing wall.

Figures 6–5 through 6–9 illustrate types of floor collapses.

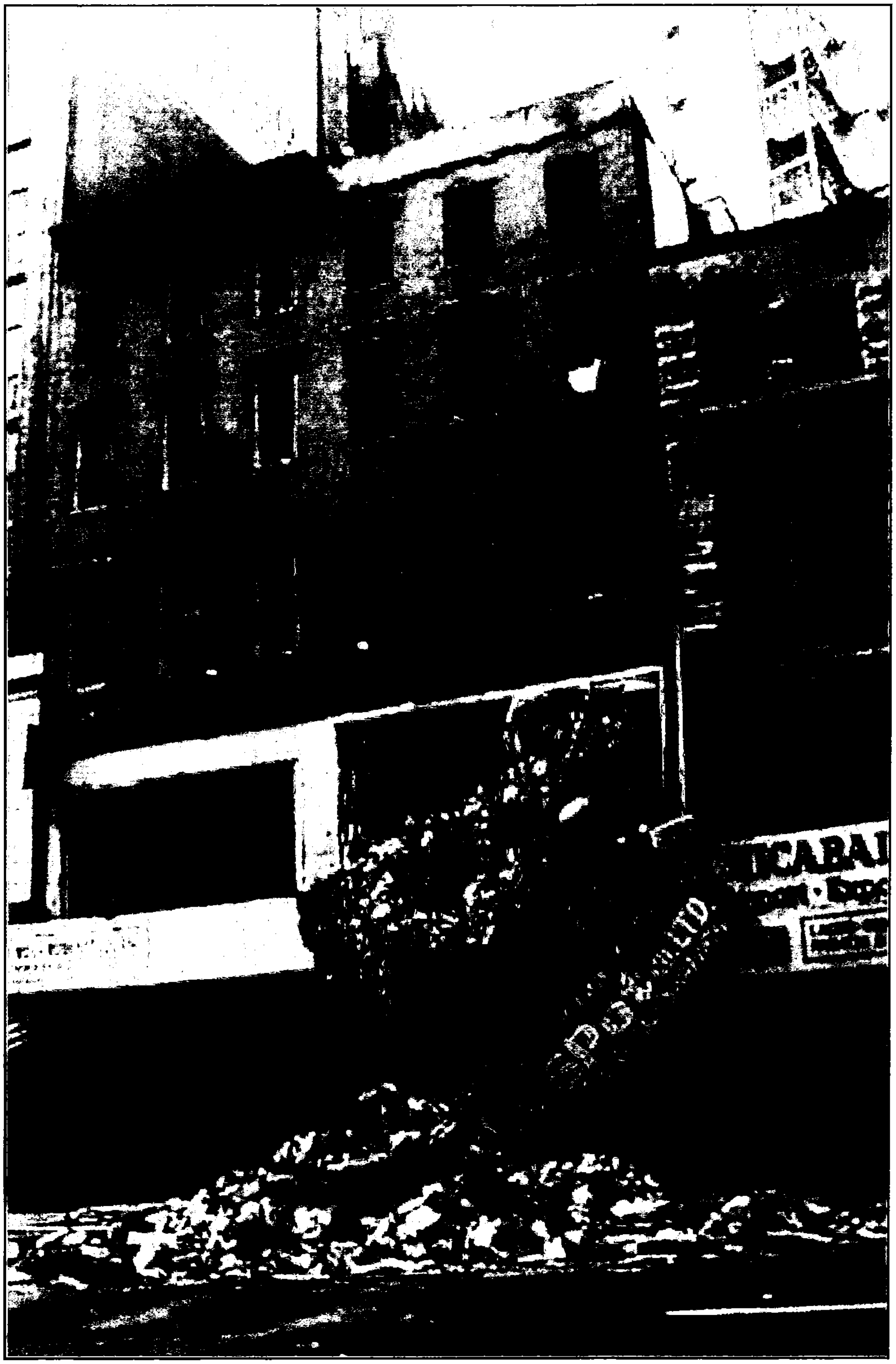


Fig. 6–4. An example of a multilevel floor collapse

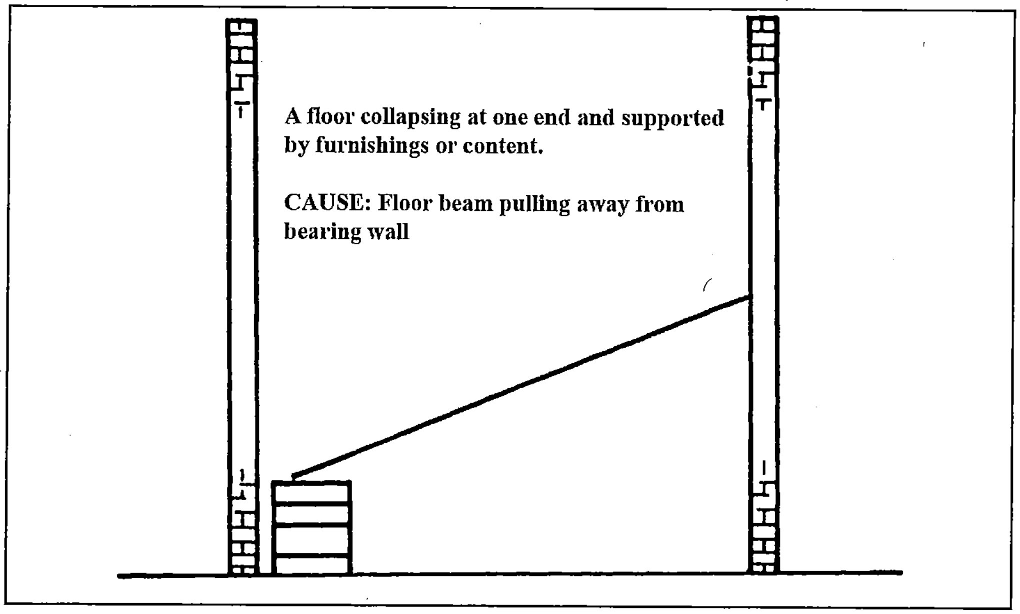


Fig. 6–5. A supported lean-to floor collapse can be caused by a floor pulling away from a bearing wall.

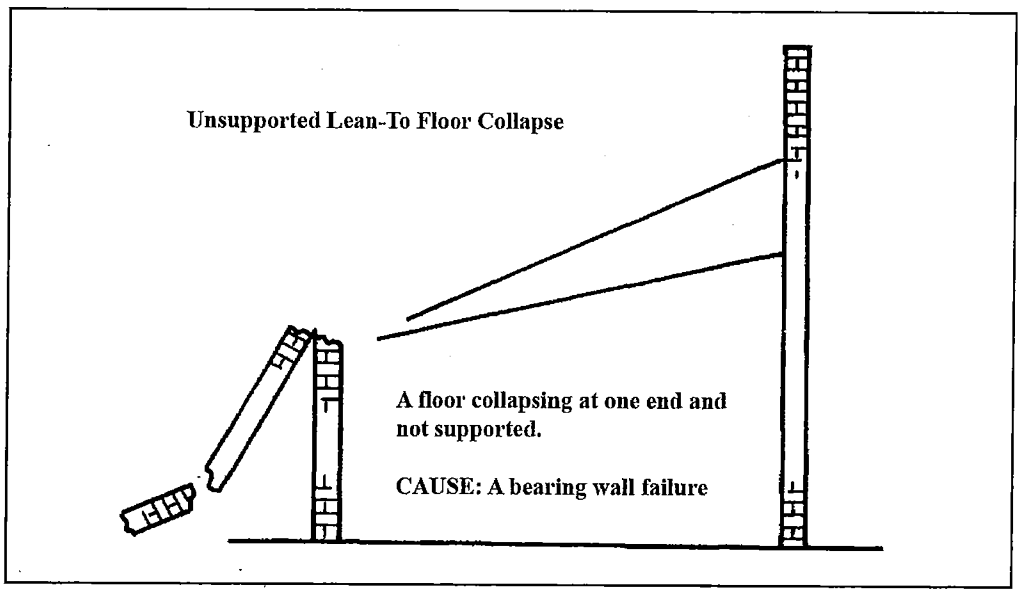


Fig. 6–6. An unsupported lean-to floor collapse can be caused by a bearing wall failure.

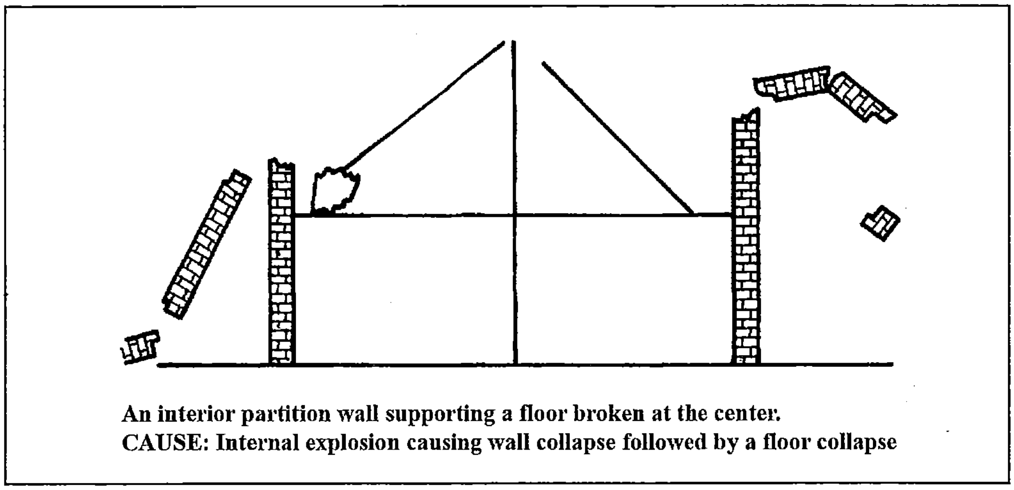


Fig. 6–7. A tent floor collapse can be caused by an explosion, resulting in bearing wall failure followed by floor collapse.

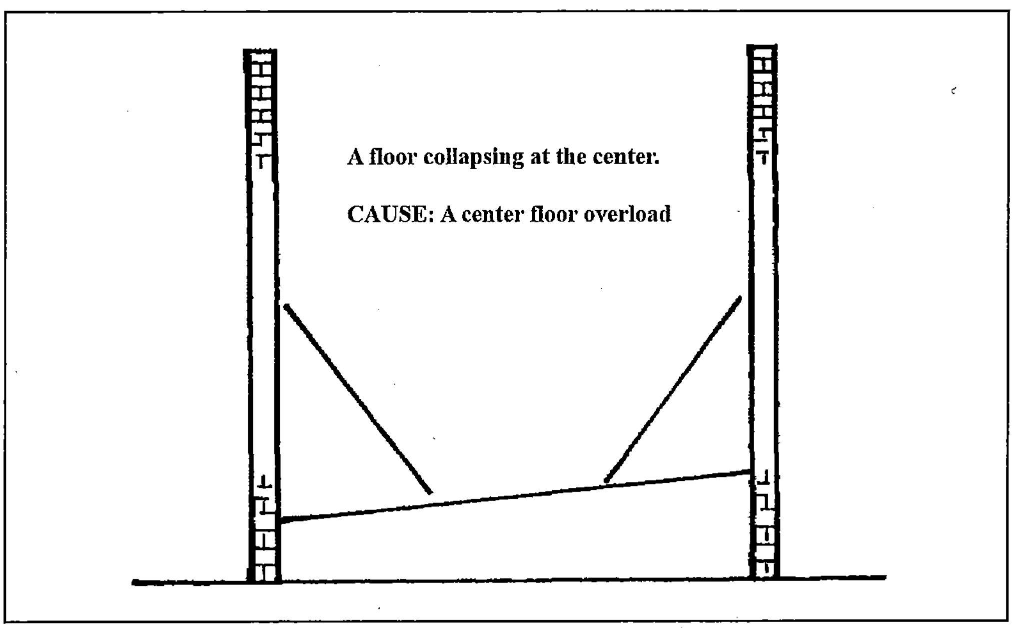
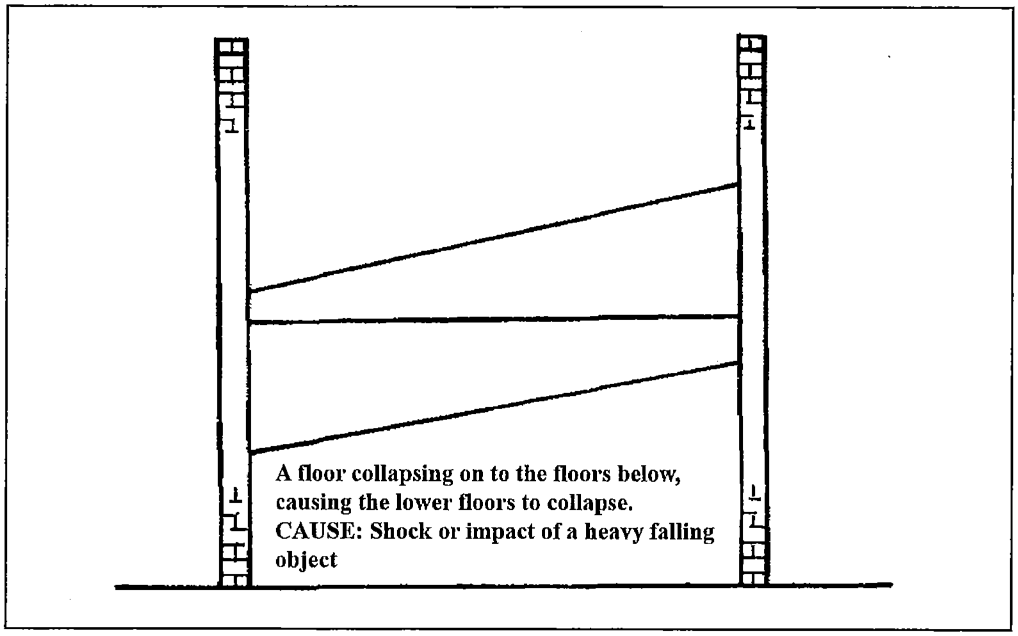


Fig. 6–8. A V-shape floor collapse can be caused by a center floor overload.



'ig. 6–9. A pancake floor collapse can be caused by the impact of a heavy falling object, which makes several floors collapse.

Managing the Risk of Floor Collapse

There are strategies and tactics that can protect firefighters from the three types of floor collapse listed above. These are:

1. **Floor deck collapse: Sound the floor.** When searching in smoke, use a tool to probe the floor in front as you move forward or when advancing and directing a hoseline, keep one leg outstretched to feel for floor openings or weakening. Sounding the floor can protect a firefighter from floor deck collapse.
2. **Floor beam collapse: Use the reach of the hose stream.** When encountering a weakened section of floor, use the reach of the hose stream to avoid the danger area. Using the reach of a hose stream can protect firefighters from a floor beam collapse.
3. **Multi-Level floor collapse: Withdraw firefighters.** When there is a danger of multilevel (progressive or disproportionate) floor collapse, withdraw firefighters from inside the burning building and set up defensive master streams around the building outside a collapse zone. When floors collapse they can sometimes cause a secondary enclosing wall collapse. So firefighters must be withdrawn outside the collapse zone or positioned to flank the fire, away from all four walls. When there is a multilevel floor collapse, firefighters outside the building can be killed by the secondary wall collapse. The National Institute of Standards and Technology (NIST)

in its final report on the World Trade Center tragedy estimates 160 FDNY firefighters where killed outside the towers. The falling floors and walls killed firefighters in the streets around the towers.

Fire Service Understanding of Fire-Resistive Ratings

Floors may have fire-resistive ratings of one, two, three, or four hours. However firefighters must realize that a fire-resistance rating has nothing to do with collapse. Fire-resistive rating only indicates how long a small test sample in a laboratory has resisted fire spread. The fire service has always understood the fire-resistive hourly rating of a floor does not have much significance on firefighting strategy. How long firefighters are allowed to remain inside a burning building is not determined by the fire-resistance rating of the floors. A fire chief would never keep firefighters inside a burning building for one or two hours because the floor had that rating. A floor with a two-hour fire-resistive rating may spread fire and collapse much sooner than two hours. The floor can collapse upon arrival of the firefighters. Fire-resistance ratings have little significance to firefighters because we do not know how long the fire has burned before our arrival. The fire could have burned for four hours before discovery.

Floor Testing

The fire-resistance tests are conducted on small portions of the floor. A floor can receive a one-hour rating when a small reproduced section approximately, 18×14 feet, is placed over a top surface of a testing oven, loaded to its intended design load, and subject to a controlled standard test fire from below. If it withstands the test fire for one hour without the top surface of the floor exceeding an average rise in temperature of 250 degrees Fahrenheit to 325 degrees Fahrenheit at any one point, it receives a 1-hour rating. If the floor collapses after the test ends it still gets a 1-hour fire resistance rating. There is no test for collapse resistance.

Another reason that fire-resistance ratings have little significance with the fire service is that large sections of a building's floor may not react the same as a small test sample. A 60-foot floor beam will not resist fire as long as a smaller 20-foot test sample. Also, renovations to a floor may negate the fire-resistive rating; and the workmanship of test sample and the actual floor construction at the building site often varies. Changes of the construction design and real-life construction can vary. Also, requirements for installation are not always followed and the real fire may reach higher temperatures than the test fire.

Builder's Understanding of Fire-Resistive Ratings

The significance of the hourly fire-resistance rating of a floor means little to builders. According to the NIST, "to a building architect and engineer, a fire-resistive rating expressed in hours does not mean that the structure will sustain its performance for that length of time in a real fire. The architect or engineer knows the actual fire performance may be greater or less that what is achieved in the test fire. The building professional will only say that a floor rated at two-hour fire resistance will block fire longer that than a floor rating of one hour." It will not block fire twice as long, just longer. And this is true only if the floor has been installed properly and is the same size as the test sample.

Time Limits for Fire Attack and Fire-Resistive Ratings

One way an incident commander can use a fire-resistive rating is to use the hourly designation as a "time limit" for interior operations. Over the past 25 years there has been an increase in the time firefighters spend inside burning buildings during firefighting operations. For example at the 1990 One Meridian fire in Philadelphia, the firefighters were battling the blaze inside the burning high-rise for 11 hours before the chief ordered all firefighters to evacuate the building due to structural damage and a danger of collapse. The floors had a 2-hour fire rating. Was it a good decision in the 1970s to conduct firefighting by New York City firefighters inside the 1 New York Plaza fire for four hours when the floors were rated for two hours? In the 1980s was it safe to have Los Angeles firefighters inside the First Interstate building fire for six hours when the floors had a 2-hour fire rating? I do not think so. The NIST nvestigation final report states the World Trade Center towers survived the impact of the terrorist planes. The ensuing fire caused the 110-story buildings to progressively collapse. Tower 2 collapsed after 58 minutes of burning. Tower 1 collapsed after an hour and 42 minutes of burning. The floors of all World Trade Center buildings had fire-resistive ratings of 2 hours.

The fire service must rethink strategy that has firefighters inside unoccupied, burning buildings five or ten hours that have fire-resistive ratings of only 1 or 2 hours. Should we depend on the support of floors with fire-resistive ratings that, even the construction industry states, may not resist fire for the approved hourly rating? Unless the incident commander determines otherwise, during an uncontrolled fire in a high-rise building, there should be a "time limit" for interior operations. The time limit for interior operations might be the floor fire-resistive ratings. For example, if the floor has a fire-resistive rating of two hours and the fire is burning, uncontrolled, for this time, withdrawal of firefighters and defensive firefighting might be considered. This could be a guideline. Fire-resistive floor rating could also be a guideline for occupant evacuation. For example, all occupants should be able to leave a burning building within the hourly fire resistance rating of the floors. If the floors have a 2-hour rating, everyone should be able to be evacuated from the building within 2 hours. There should be sufficient exits capacity to allow all occupants to leave a high-rise office building within the maximum fire-resistance rating of the floors.

The Philadelphia fire chief's decision at the Meridian fire was a historic action. When the chief ordered the firefighters to withdraw due to the structural dangers, he ordered outside master streams from surrounding buildings, and continued to upply the partial sprinkler system. This landmark fire strategy decision (the first time a fire chief ordered firefighter out of a high-rise burning building) established a new benchmark for the fire service—the evacuation of all firefighters from a burning high-rise building due to structural danger. This benchmark must be included in the command and control decision making for future fire chiefs. This benchmark decision was per the priorities of firefighting, which are life safety as first priority (this includes firefighters), incident stabilization is the second priority, and property protection is the third priority. After the firefighters withdrew from the burning high-rise, nine sprinkler heads stopped the uncontrolled fire that spread from the twenty-second floor to the thirtieth floor. After years of litigation, the 38-story, burned-out structure was declared structurally unsound and demolished.

A progressive multilevel floor collapse of a burning, fire-resistive, high-rise structural steel building was something many fire chiefs (myself included) could not believe could happen until we saw the World Trade Center towers crumble down in 10 seconds. After 9/11, the fire service must acknowledge new lightweight building construction calls for new firefighting strategy. Instead of the standard "controlled burn" interior attack strategy we use for high-rise fires, the fire service must also consider full evacuation of high-rise buildings, and withdrawing firefighters from unoccupied burning high-rise buildings. When fires rage out of control for hours, despite the firefighters' efforts, structural engineers should be called to evaluate the buildings stability. If firefighters are withdrawn, continue to supply a sprinkler system, and use master streams from adjoining high-rise buildings.

Floor Collapse Causes

There are three reoccurring factors that contribute to floor collapse in a burning building. Vacant buildings, renovated buildings, and buildings overloaded with heavy machinery or dense content, such as baled paper or textiles are risks associated with burning building floor collapse.

When a building becomes vacant or unoccupied, the maintenance stops and the building deteriorates. The floors can be quickly weakened when exposed to the freeze-thaw cycle of weather changes. Experience shows vacant buildings are "fire breeders" and collapse hazards. Fire breeders are buildings where arsonists can start a fire and remain hidden from view. Floors of vacant buildings that are rotted by the elements and experience several fires are collapse dangers.

Renovated buildings sometimes have floor construction that is not as stable as the older floor. When a building is renovated, the floor supports can be changed to lightweight or substandard construction. Floors may be further weakened by removing supporting walls or columns. A partition that was indirectly supporting a floor may be removed. And now the span of the floor beams may be greater and the danger of collapse exists.

The third factor contributing to floor collapse is overloading. Loading floors with merchandise that can absorb water, or heavy machinery, makes a floor vulnerable to failure during a fire.

Floors Collapse and Time

Firefighters must know when the floors are most likely to collapse during a fire. There is a time during a fire's growth when floor collapse danger increases. There are three stages of a fire:

1. The growth stage
2. The fully developed stage (active flaming) after flashover
3. The decay stage after most of the fuel is consumed and/or extinguished

The most dangerous time for floor collapse is during the end of the fire, in the decay stage, after it has been extinguished. The history of multilevel floor collapse, the most deadly type of floor collapse, tells us the salvage and overhauling time of a fire is when collapse danger is highest. A building may collapse at any time during a fire, however, experience shows that this final stage of a fire, when salvage and overhauling is conducted by firefighters, is most dangerous. At this time, the building structure has been destroyed by fire, the impact of powerful hose streams have weakened the structural supports, and the buildings content and structure may have absorbed tons of water from the hose streams. When firefighters perform salvage and overhauling, they add weight and vibrations to the weakened building. They must move heavy objects, pull down ceilings, and cut open walls and floors. After a major fire when master streams have been used, the building should be inspected before salvage and overhauling begins. During the inspection, if the building appears in danger of collapse, overhauling should not be undertaken. Instead the incident commander should use outside master streams to cool down the smoldering fire. This is called "hydraulic overhauling" or "defensive overhauling." In this strategy, firefighters are not sent back in to overhaul. They are sent back to quarters. A "watch line" of one or two firefighters and a supervisor remain on the scene to pour tons of water on the smoldering hot spots from a safe distance.

Lessons Learned

Floor collapse is the nightmare of all chief officers. At most floor failures there are no warning signs, no time to act and withdraw firefighters to safety, and no satisfactory explanation of the incident. A sudden floor collapse without warning sign makes the concept of firefighting strategy seem useless. It is this fear that causes fire chiefs to withdraw firefighters from interior firefighting operations.

Three defensive strategies to safeguard firefighters during floor collapse danger are:

1. For deck collapse, use a tool to probe ahead or keep one leg outstretched and support the weight of your body with the back leg.
2. For a floor beam collapse, use the reach of a hose stream to stay away from the weakened floor or order defensive outside attack.
3. For a multilevel floor collapse danger, firefighters must be withdrawn from the building and away from the walls of the building too. Multilevel floor collapse can cause progressive collapse of the walls.

A collapse zone must be considered for wall collapse after the floors fail.

Note: For more information on floor collapse, search the Web for: *Firefighter Fatality Investigation F2004-05.*

11

LIGHTWEIGHT WOOD TRUSS COLLAPSE

An engine company responds to a fire in a row of two-story town houses under construction. Arriving at the scene, the company sees smoke coming out around the second-floor eaves of several of the new wood-frame row houses. A construction worker runs up to the arriving pumper and excitedly tells the officer, "There is smoke coming from the ceiling of the top floor of that building!"

The captain of the engine company turns to order the hoseline stretched but sees a firefighter already pulling the nozzle and preconnected 200 feet of 1½-inch hose off the apparatus. The captain runs back to the radio and gives a preliminary status ›ort. "Engine 8 to Communication Center. We have smoke showing in a row of town ›ouses under construction. The attached structures are two-story, 20 feet wide by 40 feet deep, wood-frame construction. Engine 8 is on the scene. Transmit an alarm for a working fire. Send two more engines and two ladder companies."

The officer jumps out of the cab of the engine and catches up with the firefighter who is stretching the hoseline. The officer helps the firefighter assemble excess hose in the second-floor hallway for an advance into the fire. He then opens the door to the apartment slightly; dark brown smoke and the smell of burning wood blow out of the opening. The officer quickly closes the door and looks around; construction work is almost finished in this building. The plaster board ceilings and walls are in place, but there are many open voids awaiting utility finishing touches to be made to the town house.

After sufficient excess hose for an advance is in place, the officer calls the pump operator on the Handy-Talkie, "Engine 8 to pump operator, start the water."

"Engine 8 pump operator to Engine 8 command, O.K., here it comes, Captain."

The officer looks at the firefighter with the nozzle, who is crouched down on one knee, and says, "Let me know when you are ready."

The firefighter, moving quickly, drops gloves and helmet on the floor, pulls the face mask straps over the top of his head, replaces helmet and gloves, picks up the nozzle, closes it fully, then cracks it open slightly to bleed the oncoming rush of air from the hose, looks up, and nods to the officer. The captain pushes the door open all the way; smoke billows out. The mask-equipped firefighter and officer disappear inside the smoke-filled doorway. Smoke is banked down to the floor. The heat is stratified just above their heads.

As they advance, the nozzle is ready but not yet opened because there is no red glow visible through their face mask lenses, just dense smoke and the heat above. Cautiously moving forward, they encounter no fire. They crawl through several rooms of smoke and still see no fire. A crackling sound of fire can be heard, but no flame can be seen. "We must be in the wrong apartment. Back out to the hallway." The muffled voice of the officer speaking through the mask is heard in the smoke.

The two begin to back the charged hoseline out of the apartment, when suddenly the ceiling in front of them collapses downward, showering the room with sparks and a flaming wood truss roof beam. The burning crisscross of the truss web members is clearly visible. One end of the flaming truss has fallen to the floor; the other remains held up above the ceiling. The firefighter quickly opens the nozzle and directs the stream on the flaming truss. Another burning truss crashes through the ceiling. This one collapses behind them, blocking the path back to the apartment door with a maze of burning and broken truss web members. Sparks are now raining down into the entire apartment through the broken ceiling.

With the nozzle open, the stream of water blasts away at the fire, but the heat and flame continue to flow from the ceiling. The captain and the firefighter must lie on the floor to escape the superheated gases. Another wood truss collapses through the ceiling on top of the firefighter. The room bursts into flame; he drops the nozzle and attempts to make a dash for the exit doorway through the trusses blocking his path. Punching, kicking, and ducking through one truss, he trips, gets up, and crashes through the next maze of web members blocking his escape. There is a blast of heat, and another collapsing truss, falling from the ceiling, knocks him to the ground. He slowly staggers up from the floor but falls, seriously burned, into another collapsed burning truss. Entangled with broken pieces of wood and overtaken by flames and heat, the firefighter stops moving. The captain, fighting his way to the rear of the flaming apartment, crashes through a glass window and falls from the second-floor window. He lands in a high pile of sand and rolls down into construction rubble. Staggering up on one knee, he radios, "Urgent! Urgent! Engine 8, we have a firefighter trapped inside the second-floor apartment!"

Lightweight Wood Truss Construction

There are two types of wood truss systems used in building construction: heavy timber truss systems and lightweight wood truss systems. Most building codes define heavy timber roof construction as that in which the wood dimension is at least 4 inches wide and 6 inches deep. Connections and fastenings used to connect web members and chords of heavy timber trusses are made of steel bolts and plates. The lightweight wood truss, on the other hand, incorporates wooden members which can be as small as 2 inches wide and 4 inches deep—and these wood pieces are connected by sheet metal surface fasteners called *gusset plates* or gang nails. This connector, which is critical to the integrity of the lightweight truss during a fire, is a piece of sheet metal with many V-shaped points punched through it. These V-shaped nailing points fasten only the surface of the 2×4-inch wood truss. Three wood truss members are sometimes held together by sheet metal points that penetrate the wood surface to a depth of only ¼ inch to ½ inch. This type of lightweight truss system is being used at an increasing rate in the construction of homes and apartment houses throughout this nation (fig. 11–1). By engineering calculations and practical firefighting experience, lightweight trussed rafters may be expected to collapse after about ten minutes in a fully developed fire. The fire services of this nation are alarmed and disturbed by this new lightweight structural element.

Fig. 11–1. There is nothing larger that 2×4-inch lumber in this lightweight truss roof and floor constructed building.

The sheet metal surface fastener

The main concern of the fire service is the sheet metal surface fastener used to connect the truss members together. The surface fastener, which only connects the outer ½ inch of wood truss members, is a deficient structural connection from a fire protection point of view. The design of the truss can be defended from an engineering viewpoint, but no architect, engineer, building construction contractor, or code official can defend the sheet metal surface fastener. This device is a dangerous structural connection (fig. 11–2).

Fig. 11–2. The fire service should seek to outlaw the sheet metal surface fastener.

In any structural element, the critical area subject to failure during fire is the point of connection. At a fire, the points of connection are the first to fail. The most serious defect in the surface fastener connecting lightweight wood trusses is the insufficient depth of penetration of the nailing points. As the name indicates, the metal surface fastener only fastens the outer ½-inch surface of the truss. The V-shaped nailing points enter the wood to a depth of only ½ inch. During a fire, when the outer layers of wood char, the surface fastener loosens more quickly than would a nail or steel bolt, which penetrates the entire thicknesses of truss members. In addition, even if the fire is not of sufficient intensity to char the wood, heat from the flames can warp the thin sheet metal surface fastener and cause it to curl up and pull away from the wood truss.

The lightweight wood trusses are prefabricated at a factory and shipped to the construction site, where they are stored until needed. If these trusses are improperly transported or stored at the site, or if they are dropped or handled roughly, the metal surface fastener can pull away from the wood surface or become loosened. In this instance, the truss has been weakened even before it is installed in the building. Still another problem with the metal surface fastener is corrosion. When installed in an enclosed, well-insulated roof space, where moisture becomes trapped, the sheet metal surface fasteners will probably rust and weaken. The treatment of wood trusses with certain fire-retarding chemicals or wood preservatives may also lead to corrosion of these fasteners.

Fire Spread

A flat roof or floor supported by a lightweight wood truss will allow fire to spread more quickly throughout the concealed space than one supported by a solid wood beam. Unlike the new lightweight wood truss, a solid wood beam has some minor fire containment value. For example, when a fire travels up into a concealed ceiling space, flames may travel in the space between the solid beams, but fire spread in a direction perpendicular to the solid beam will be blocked. There is no such temporary perpendicular fire blocking with an open-web lightweight truss. When fire enters the concealed space of a parallel chord lightweight truss, it spreads, simultaneously, quickly between the length of the truss and perpendicularly through the web members. If fire enters any attic or concealed roof space with a lightweight truss, it will spread rapidly and quickly involve the entire area (fig. 11–3).

Fig. 11–3. When fire enters the concealed spaces there is a 100% faster fire spread. Flames spread through web members.

The rate of fire spread inside a building's concealed space will be 100 percent faster than in concealed spaces of a building with conventional solid wood beam construction. Condominiums, town houses, and private homes throughout this nation are being built with lightweight wood truss construction held together with sheet metal surface fasteners. These roof and floor supports can be expected to fail more rapidly than solid beam constructions, which have nails penetrating several inches into the wood at connecting points.

Lessons Learned

It is not always possible during a fire operation to identify a building as having lightweight wood trusses. So, to safeguard the firefighters at a structure fire from collapse of any type of truss, everyone must be aware of the presence of the truss in the building. There is a trend in the fire service of requesting laws requiring the truss building to be marked. Hackensack, New Jersey, has truss buildings marked with a triangle. Cheasapeake, Virginia requires truss buildings to have a letter T and New York has two vertical lines to identify truss construction. However laws requiring truss marking, identifying truss construction in most cases only applies to commercial buildings. Laws requiring marking of building identifying truss construction, in most cases, exempt residence buildings. One notable difference are local marking ordinances being enacted in Bergen County, New Jersey. Unfortunately the problem of lightweight truss roof and floor collapse is in residence buildings.

So what is the fire service to do? The fire service can not depend on these laws to safeguard firefighters. Each fire department must identify truss buildings in their community, program them into the dispatch system, and notify fire responders of the truss danger before they arrive at the scene. Preplanned visits, close-up inspection of the truss design and the sheet metal surface fasteners, and, finally, the development of a defensive standard operating procedure based upon collapse potential are necessary safeguards for firefighting operations. For example, during inspections the truss constructed building address must be identified. This information is recorded and programmed into the dispatch system and when a fire call comes in for the address of the building, the first responders must be notified by radio while responding of the presence of truss construction.

Once on the scene of a fire in a truss constructed building, the incident commander must have a firefighting strategy for combating various types of fire inside. The recommended strategy for fighting a fire in a building with lightweight wood truss roof or floors is as follows:

- Content Fire: If fire is burning content such as a couch or mattress, standard operating procedures should be followed. Stretch an interior hoseline and extinguish the fire.
- Structure Fire: If fire involves the structure and is burning throughout the concealed roof or floor spaces, the people should be removed and exterior attack should be the strategy.

James Pressnall of the Irving, Texas, Fire Department is the first known firefighter to die after being trapped by the collapse of a lightweight wood truss, inside a burning two-story apartment house on February 27, 1984. This firefighter's death was the first of many more to come as lightweight wood truss construction spreads throughout the nation.

Since Firefighter James Pressnall died in 1984 there have been many other firefighter deaths due to collapse of lightweight truss construction:

- James Pressnall, Irving, Texas, 1984
- Todd Aldridge, Orange County, Florida, 1988
- Mark Benge, Orange County, Florida, 1988
- Alan Michelson, Gillette, Wyoming, 1990
- James Hill, Memphis, Tennessee, 1993
- Joseph Boswell, Memphis, Tennessee, 1993
- Strawn Nutter, Louisville, Kentucky,1994
- John Hudgins, Chesapeake, Virginia, 1996
- Frank Young, Chesapeake, Virginia, 1996
- Edward Ramos, Branford, Connecticut, 1996
- Brant Chesney, Forsythe County, Georgia, 1996
- Gary Sanders, Lake Worth, Texas, 1999
- Brian Collins, Lake Worth, Texas, 1999
- Phillip Dean, Lake Worth, Texas, 1999
- Lewis Mayo, Houston, Texas, 2000
- Kimberly Smith, Houston, Texas, 2000
- John Ginocchetti and Tim Lynch, Manlius, N.Y., 2002 (fig. 11-4)
- Cyril Fyfe and Kevin Olson, Yellow knife Canada, 2005
- Arnie Wolfe, Green Bay, Wisconsin, 2006

Fig. 11–4. Firefighters Tim Lynch and John Ginocchetti died when the floor collapsed in this private dwelling.

The trend toward use of truss construction is increasing. Collapse during fires in truss buildings that kill and injure firefighters will be increasing. This sad fact will not change, so the fire service must change. We must change the way we fight fires. The defensive firefighting strategy described above must be used for fires in truss constructed buildings. A veteran fire officer said, "Chief, we cannot use defensive firefighting when a fire involves a truss structure as you recommend."

My question for him was, "What would you say to me if you were the chief, and a firefighter in your department was killed by a collapsing truss?"

He did not have an answer. I did.

Note: For more information about truss construction, search the Web for: *Preventing Injuries and Death to Firefighters Due to Truss Construction NIOSH 2005-132.*

15

WOOD-FRAME BUILDING COLLAPSE

All hands are heavily engaged during a major fire at an old three-story corner building. Firefighters using several outside aerial and ground master streams have confined the fire to the wood braced-frame building, keeping it from spreading to a one-story structure attached to the rear. "You wait here," says the captain to a firefighter directing a hose stream through a window of the burning building. "I'm going inside the one-story building to see if we can get a better shot at this fire." The captain enters the doorway of the one-story structure and soon reappears, waving his arm for the firefighter to come to him. The firefighter shuts down the nozzle and [illegible]gs the charged hoseline through the doorway of the uninvolved structure. Inside, the captain reaches down and pulls some hose into the building. "Don't go through that archway into the fire building," he warns the firefighter. "We can hit the fire from here."

The two men crouch down in front of a large doorway between the burning structure and the attached building. The firefighter opens the nozzle and sweeps the hose stream across the flaming ceiling, extinguishing fire near the doorway entrance and playing the stream deep into the interior of the burning floor area. The reach of the pressurized hose stream enables the firefighter and the captain to stay safely inside the one-story building. "Say, Captain, you were right; we have a perfect shot at this fire," says the firefighter.

The officer nods his head. As the hose stream turns the flames at the ceiling into white steam, the three-story building suddenly starts to collapse. The walls appear to explode outward. Flaming timbers crash through the ceiling where the hose stream had extinguished fire seconds before. A blast of superheated smoke blows through the doorway into the faces of the firefighters. "Drop that line and let's get out of here!" shouts the officer. Seconds after they move back, the roof of the one-story structure crashes down on the spot where they were standing.

The floor rocks violently from the impact. Struggling to keep their balance, the firefighters stagger toward the door, while plaster dust and smoke fill the room that is crumbling around them. As they reach the concrete sidewalk, outside the half-collapsed one-story building, the front wall begins to fall. Propelled outward at a 90-degree angle, the heavy wooden structure crashes down to the sidewalk, smashing [illegible] the head and shoulders of the running captain. As the officer falls, he shoves the [illegible]ighter ahead of him. The top of the collapsing wall hits the firefighter on the back and legs, slams him into the concrete sidewalk, and pins him from the waist down under the falling structure. As the dust settles, the stricken firefighter cries out, "Help! Help! Get the wall off me!"

Wood-Frame Building Collapse

There are three ways that a wood-frame building can collapse during a fire: one wall may fall straight outward at a 90-degree angle (fig. 15–1 and fig. 15–2), the entire building may lean over and collapse on its side (fig. 15–3), or one or all four wood enclosing walls may crack apart and fall in an inward/outward collapse (fig. 15–4). A three-story braced frame structure frequently falls in an inward/outward collapse. The top two stories collapse inward, back on top of the pancaked floors; the lower story collapses outward on to the sidewalk.

Warning signs

A 90-degree-angle wall collapse is often signaled by the corners of the falling wall splitting apart from the remaining walls. The lean-over collapse is often indicated by the burning structure slowly starting to tilt or lean to one side. An inward/outward collapse may not exhibit any structural warning at all—sometimes the only indication that a collapse is imminent is a serious fire burning for a long time on the lower floor. When such a collapse occurs, firefighters report that they see no signs but that they hear a sudden, loud cracking noise, feel a hurricane-like gust of wind on their backs, and then they are engulfed in a cloud of dust as they turn to run from the falling structure. Of the three types of collapses, the inward/outward collapse is the most dangerous because it is sudden, it gives no visible warning signs prior to failure, and, unlike most other building failures, it may involve the collapse of two, three, or four walls simultaneously.

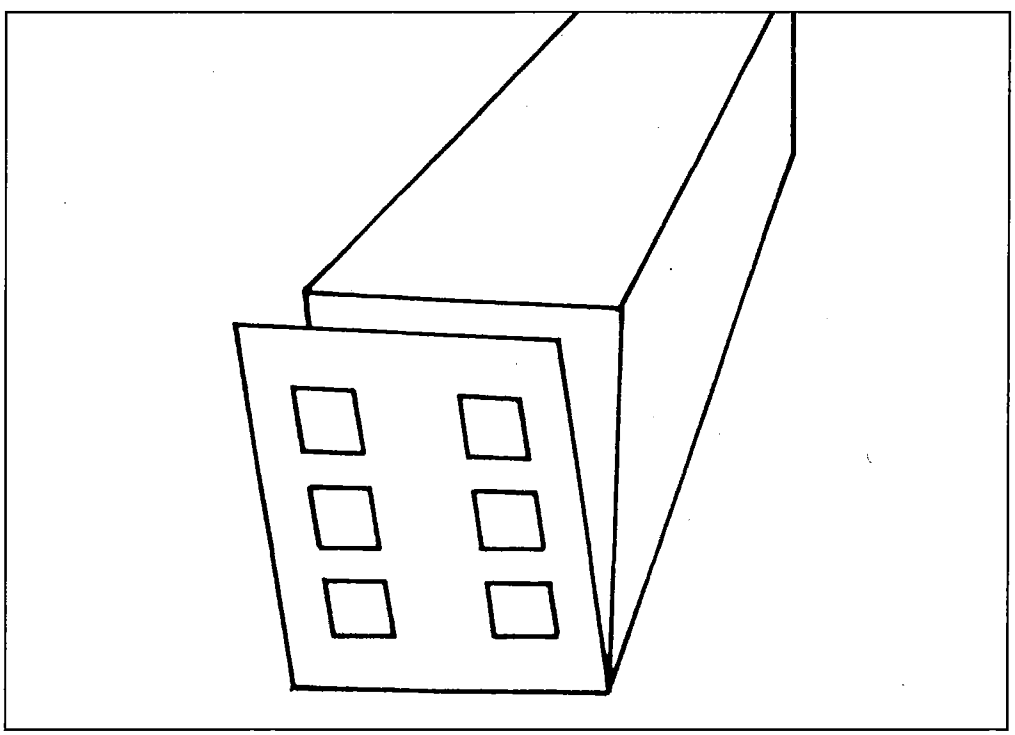


Fig. 15–1. The wall of a wood-frame building collapsing at a 90-degree angle

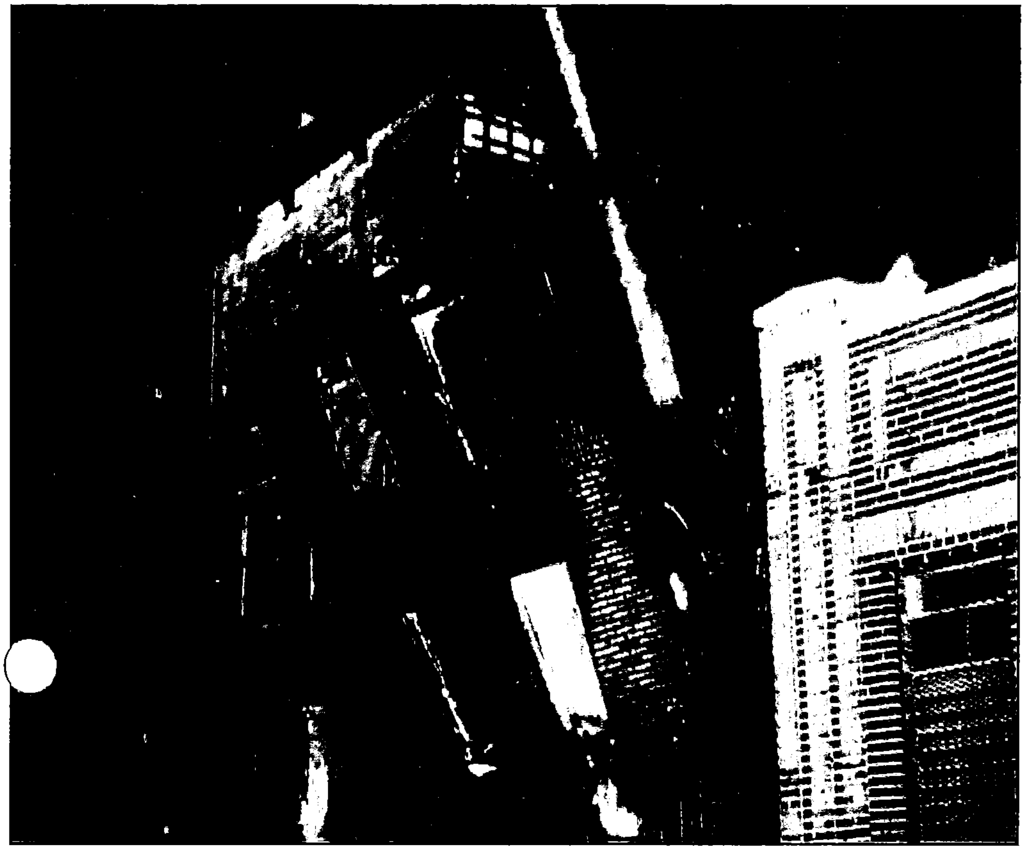


Fig. 15–2. A 90-degree wall collapse

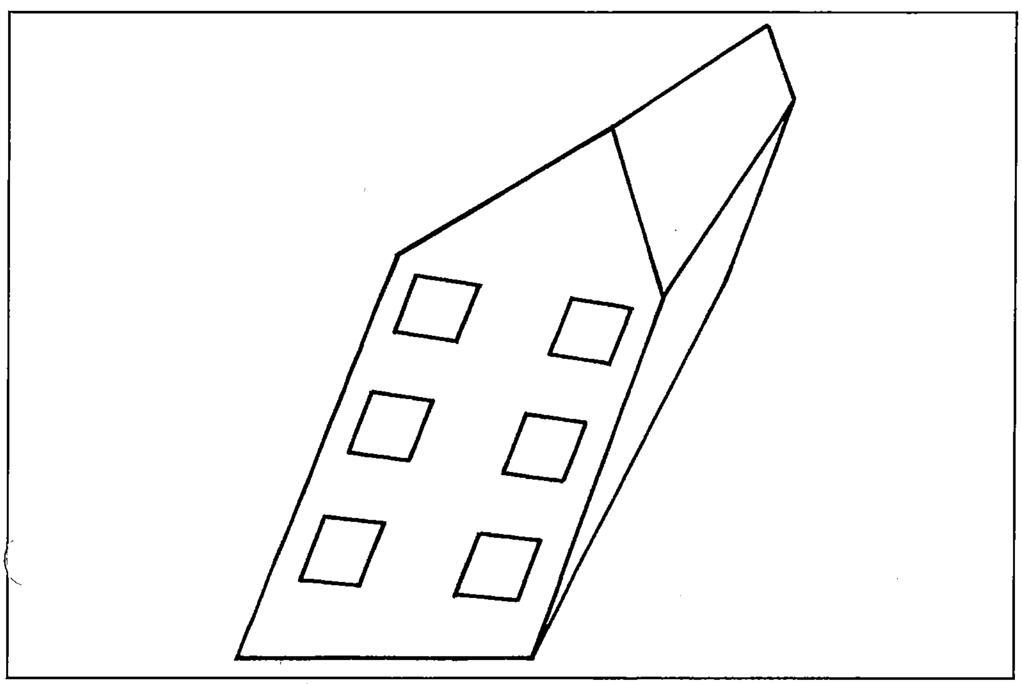


Fig. 15–3. A wood-frame building falling in a lean-over collapse

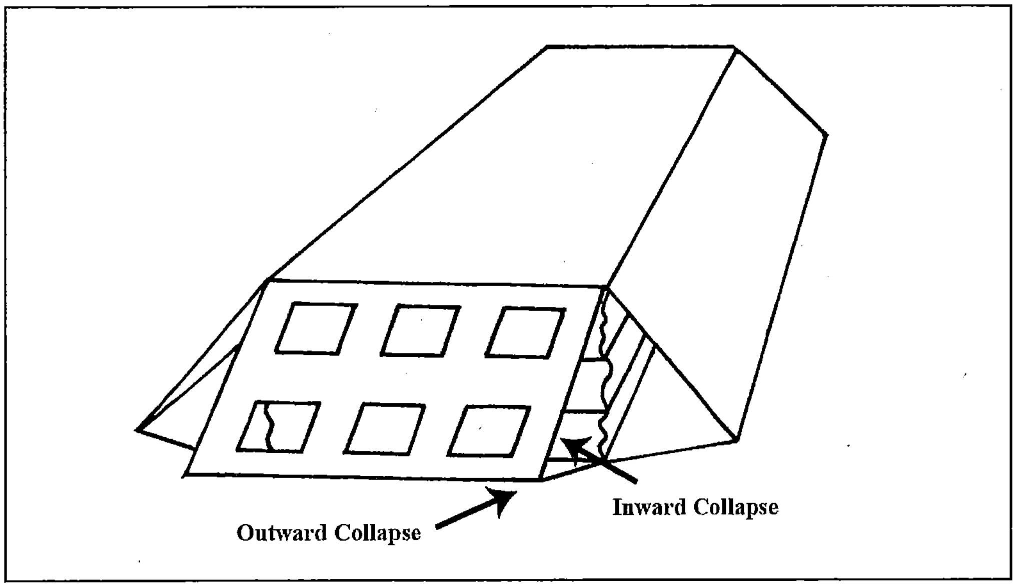


Fig. 15–4. A wood-frame building collapsed in an inward/outward configuration

During a fire in a structure with masonry walls, it is rare that more than one wall will collapse at one time (except in the case of an explosion). When a braced-frame wood building collapses, however, all four walls may collapse at one time. Only firefighters in the corner safe zones will survive a collapse. The corner safe areas are the four flanking zones around a burning wood frame building. When you look at a four-sided building from a bird's-eye view you imagine the four walls collapsing and covering the ground with bricks, you will find there are four areas at the corner of the collapse building that have fewer bricks.

Braced-Frame Wood Construction

Of the three major types of wood-frame construction in the United States, braced-frame wood-constructed buildings present the greatest firefighting danger (fig. 15–5). In a two-year period, a chief and an officer were killed and an officer and nine firefighters seriously injured in four separate collapses of braced-frame wooden buildings in New York City. Three of these structures were located on corners and one was the end building in a row of three which stood next to an open lot. As the last building was unsupported at one end, it was, in effect, the same as a corner building. All four buildings were three stories high and in each, a serious, long-burning fire had destroyed the first floor of the structure.

Corner Wood-Frame Buildings

Wooden buildings constructed side by side receive support and stability from the adjoining structure. If the lower floor of a wood building burns and one of the wood bearing walls is destroyed by fire, the structure will begin to lean to one side. Adjoining

Fig. 15–5. Braced-frame construction

structures built up against a wood building can prevent such a fire-weakened structure from collapsing. When weakened by a fire on a lower floor, however, a wood-frame corner building will collapse on its unsupported side into the street or an empty lot, The bearing walls of a wood structure, unlike those in any of the masonry construction types, are combustible and can collapse when exposed to fire. The side bearing walls on the first floor of a three-story wood building are 2×4-inch wood studs spaced 16 inches on center, the same as the bearing walls on the second and third floors. Though the bearing wall studs of the first floor support more weight than the second- and third-floor wall studs, there is no compensation for the increased deal load (unlike some multistory, masonry bearing-wall buildings, in which the lower levels of the bearing walls are thicker than the upper levels). Therefore, if a fire weakened the bearing wall studs of all three floors at the same time, the ground floor wall studs would fail first because they support more weight than the second-or third-floor bearing wall studs.

Based upon the four New York City building collapses mentioned earlier and other wood-frame building failures, it is apparent that the height of the structure affects its stability. Three-story wood-frame buildings collapse more frequently than one- or two-story wood-frame buildings. To understand how a burning wood-frame residence can collapse and how to extinguish a fire burning within a wood-frame building, a firefighter must know how a wood-frame building is constructed. The four most widely used methods of wood-frame construction over the past 200 years are:

- Braced-frame
- Balloon frame
- Platform frame and
- Lightweight wood frame construction

(Plank-and-beam and log cabin construction are also used, but are much less common.)

Braced-Frame Construction Methods

In the 18th and 19th centuries, the first large wood-frame buildings constructed along the East Coast, which still stand today, were of braced-frame construction, sometimes called "post-and-girt" construction. This type of wood-frame structure has a braced framework of vertical timbers called "posts," which are positioned at each of the four corners of the building, and horizontal timbers called "girts," which are found at each floor level. These large timbers reinforce the entire 2×4-inch wood-frame structure and are connected together by mortise-and-tenon joints. (The large timbers and the mortise-and-tenon joints are indicators of braced-frame construction.) The ends of the horizontal timbers are cut down to fit mortise openings which are cut through the vertical timbers.

Balloon Frame Construction Methods

As the population moved westward in the 19th century, the need for housing increased, and cut and finished large timbers and skilled craftsmen became scarce. A lightweight, quickly assembled wood structure, which needed no large timbers, called "balloon frame construction" replaced the Eastern braced-frame method of constructing wood structures. To erect a balloon frame structure, four wood exterior walls are constructed flat on the ground. Two-by-four-inch wood studs, extending in one piece for the full height of the wall, form the enclosing walls; the four walls are then lifted upright from the ground and connected like a box at the corners. The advantage of this type of wood construction is speed and the absence of large timbers. The drawback is a vertical void between the wall studs, which extends from the foundation sill to the attic cap and allows hidden fire and smoke that penetrate the wall space to spread vertically for two or three floors. This unobstructed opening between each stud in the exterior wall, extending from the foundation sill to the attic cap, is an indicator of balloon construction. The vertical void of a balloon constructed building will be the exterior wall. However, if an addition is added to the building, the exterior wall can become an interior wall. The attic should be quickly examined for fire spread during the early stages of a fire in a building of balloon construction.

Platform Construction Methods

Platform construction superseded balloon construction and today, is the most widely used method of wood-frame construction. The platform construction method builds a structure one level at a time. One complete level of 2×4-inch wood enclosing walls are raised and nailed together; the floor beams and deck for the next level are placed on top of these walls. The next level of 2×4-inch wood enclosing walls are constructed on top of the first, and the floor beams and deck for the next level are placed on top of these exterior walls. From a fire protection standpoint, platform construction is superior to balloon or braced-frame construction, because there are no concealed wall voids that extend for more than one floor.

Lightweight Wood Construction Methods

Lightweight wood truss construction is replacing platform construction. From a fire protection point of view, it is inferior construction. Lightweight wood truss construction suffers floor and roof collapse, not wall or "global" (total) collapse of the entire structure. The danger is early floor and roof collapse of the truss floors and roofs. The entire building may eventually collapse, but it is during the early stage of a fire, when firefighters first arrive that a floor or roof fails—especially the floors. Because floors collapse so fast, there is a saying among firefighters, "Through the door and through the floor." Tests have shown the thin metal connections used to fasten truss floors and roof beams together fail during the early stages of a fire The connectors are ces of sheet metal that only fasten the wood surface of the trusses together. The metal fasteners only penetrate $^{3}/_{8}$ to ½ inch into the wood, so when the wood chars, the fasteners fall away. Heat of a fire can also cause the fastener to bend away from the wood truss and leave the structural element unconnected. In 2008, the Underwriters Testing Laboratory documented the lightweight wood truss and sheet metal fasteners and documented failure in less than 10 minutes of fire exposure. Because of the early roof and floor collapse and because of the large number of firefighters killed fighting fire in lightweight wood truss buildings (20 in 24 years.), it is recommended that when a fire involves truss structure such as a concealed space of the floor or roof, the strategy be to remove occupants and fight the fire defensively from the outside.

Causes of an Inward/Outward Collapse

Three factors contribute to the inward/outward collapse of a braced-frame wooden building:

- Fire destruction of bearing walls
- Failure at the mortise-and-tenon connection
- Exterior wall overload

Unlike the exterior walls of the four other basic construction types (fire-resistive, noncombustible, ordinary brick-and-joist, and heavy timber), the bearing wall of wood-frame construction *can* be destroyed by fire and can collapse when flames spread of a window and consume the outside or inside of this load-bearing wall. Burning wood-frame buildings exhibit a rapid fire spread. When the fire department arrives on the scene, both the wooden exterior walls and the structure's interior are often involved with flame. When wood buildings are built close together or when there is a common roof space running through a row of wood houses, fire spread will be extremely rapid and will probably involve more than one structure (fig. 15-6). In addition to placing hose streams in the interior of the burning structure, firefighters will need one or more hoselines to control exterior fire spread along the outside combustible walls and to protect exposures from radiated heat.

Fig. 15–6. The common roof space is a structural defect in row buildings.

A firefighter should know which of the four enclosing walls of a burning wood building are the load-bearing walls that support the floors and roof. Because these walls are interconnected, the interior floors will collapse if the bearing walls fail during a fire. Conversely, if the interior floors collapse, they may cause bearing wall failure. In older urban neighborhoods, wood-frame buildings were built close together, with the bearing walls usually being the side walls and the non-bearing walls were the front and rear enclosing walls. This practice has changed in suburban communities. Private homes, built on large plots of land, are designed to have the larger area of the building face the street front, so the front and rear walls are load-bearing and the two side walls non-load-bearing. Condominiums and row town houses have the same design. During a fire in a suburban row of town houses, if the floors inside collapse, the front or rear walls may collapse outward. In peaked-roof buildings, the bearing walls support roof rafters and are parallel to the ridgepole. In flat-roofed wood buildings, the bearing walls are usually the walls with the greatest dimension: the non-load-bearing walls have the shortest dimension.

Mortise-and-tenon joints

The structural framework of a braced-frame wooden building that collapses inward/outward consists of vertical timber corner posts and horizontal timber girders or girts at each floor level. The corner posts and girders are connected by mortise-and-tenon joints (fig. 15–7). When a braced-frame wood timber collapses, it fails at the weakest points—often the mortise-and-tenon connection. The mortise hole has removed the center section of the corner post timber and reduced its strength; the tenon end of the girder is only a fraction of the original girder's thickness and therefore has only a fraction of its strength. In addition to this design weakness, the connection can be destroyed by fire. Furthermore, unlike concrete and steel fastenings, the wood mortise-and-tenon connection is susceptible to collapse by rotting. A vacant wooden building open to the elements can be quickly weakened by rotting structural components like the mortise-and-tenon connections.

Fig. 15–7. A wood mortise and tenon connection

Exterior wall overload

The exterior wall of a wood-frame building can be weakened by the weight of a metal fire escape landing and ladder. This heavy metal structure attached to the outside wall of a wood building is anchored to 2×4-inch wall studs behind the wood sheathing. The weight of the metal fire escape can exert a slight outward pull on the wall studs to which it is attached for support. This pull causes the wall studs to curve or bow slightly outward. The load above, supported by the curved wall studs, is no longer transmitted through the studs as an *axial* load (centered or evenly distributed), but becomes an *eccentric* load (off-centered or uneven). During a fire, the wall supporting a metal fire escape must be considered a structural danger. The weight of the fire escape will accelerate the collapse of a fire-weakened wood wall.

There are two types of masonry surfaces applied to outside walls of old wood buildings: A brick-and-mortar veneer wall can be attached to the wooden structure by thin strips of sheet metal, one strip every two square feet; or a thick stucco coating, spread on wire mesh, can be nailed to the old wooden surface of the building. These wall surfaces increase the collapse danger during a serious fire in a wood-frame building by adding considerable weight to the structure. As much as eight pounds per square foot of stucco and wire mesh have been found on a collapsed wall. Brick veneer not only overloads a wall but also hides major structural defects of the wall. It can conceal an obvious collapse warning sign, such as the wood walls splitting apart, or hide the burning of the wood bearing wall behind it. These masonry wall coverings also contain the heat and flame inside the building, thus increasing the destruction of the structural framework.

Lessons Learned

- Burning wooden buildings of three or more stories suffer global collapse more frequently than burning one- or two-story wood buildings.
- Wooden buildings located on a corner plot or standing alone are more susceptible to global collapse when exposed to fire than wood buildings in the center of a row of similar buildings.
- When a serious fire burns out the entire first floor of a three-story wood building, there is a danger of global collapse.
- Of the three types of wood-frame building collapses, the inward/outward collapse is the most dangerous. It gives no warning and can result in the simultaneous collapse of four sides of the structure.
- Large buildings three stories in height collapsing on top of smaller one-story buildings cause the smaller buildings to collapse.
- Lightweight wood truss and wood I-beam construction has made wood frame buildings more deadly. Now there is deadly inside floor and roof collapse danger added to the global outside structure failure.

- Three contributing causes of wood-frame building collapse are fire destruction of bearing walls, the mortise-and-tenon joint of a braced-frame wooden building, and the overload of an exterior wooden wall.

- Renovated wood frame buildings can create an another collapse danger. Today old buildings are renovated under so-called "performance" building codes, not "specification" building code. A performance code does not require the same type and dimension of building element be replaced in the structure. There are no specifications allowed in a performance code. The New York City performance code allows conventional construction to be replaced with lightweight materials and it allows buildings to be renovated using different designs, layout and materials. Once the building is renovated under a performance code, it is not the same. A firefighter size-up based on old construction, no longer applies. In 1998, FDNY Captain Scott LaPiedra and Lieutenant James Blackmore were killed when a second floor of a three-story braced-frame building collapsed. This building was renovated under a performance code, which allowed removal of a partition wall that was a floor support to the second floor below the collapse area. This weakened the structure and created an unprotected opening between two buildings that allowed a large area of fire to develop. The renovation sealed off the first floor rear of the building from the front entrance where the fire occurred delaying extinguishment.

- When a triple-decker wood frame building collapses in an inward/outward type all four sides may collapse simultaneously. During an inward/outward wood building collapse, where all four sides fall simultaneously, only firefighters in the corner safe zones can survive. The corner safe areas are the four flanking zones around a burning wood frame building. When you look at a four-sided building from a bird's-eye view and you imagine the four walls collapsing and covering the ground with bricks, you will find there are four areas at the corner of the collapsed building that have fewer bricks.

Note: For more information on wood frame building collapse, search the Web for: *Firefighter fatality investigation NIOSH F2002-32.*