



## STUDENT MANUAL MODULE 1c STRUCTURAL ENGINEERING SYSTEMS

### Module Purpose and Configuration

This module is intended to provide the Structural Collapse technician with information on the engineering aspects of structural collapse

The module is divided into five parts as follows:

- Part 1 Materials, Structural Systems & Building Characteristics
- Part 2 Causes of Collapse
- Part 3 Collapse Patterns
- Part 4 Hazard Identification, Introduction to Assessment and Mitigation
- Part 5 US&R Strategy & Structure Size-up

### Part 1 - Materials, Structural Systems & Building Characteristics


In this introductory section the Terminal Objectives are as follows:

The student shall understand the essential materials and components of structures, with emphasis on how they behave when subjected to extreme loading.

Key Learning Points are listed in the adjacent slide. We will quickly review the basics of how various building materials resist forces, the importance of Ductile vs. Brittle behavior, the concepts of Vertical and Lateral Load Resisting Systems, and Structural Redundancy.

Following this we will discuss the characteristics of The most common types of building found within the United States

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#### Terminal Objectives

- The Student shall understand the essential materials and components of structures, and how they behave when subjected to normal and extreme loading
- The Student will understand how Building are classified by Engineers and what are their Common Characteristics

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#### Key Learning Points

*The Student will become familiar with the following Basic Engineering Concepts*

- Brittle vs. Ductile Materials
- Vertical & Lateral Loading Systems
- Framed and Un-Framed Structures
- Redundancy
- Building Characteristics

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### Force Types

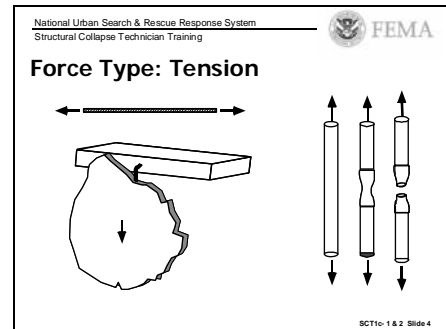
Individual **loads**, usually referred to as **forces**, can be divided into four types: **tension**, **compression**, **bending**, and **shear**.

- When a **force** is applied to an individual member, it produces **stress**, which is defined as the force divided by the cross-sectional area on which it acts.
- **Example:** A 1000 lb **force** (also called 1 kip or 1k) acting in tension on a 2 in x 2 in steel bar produces a tension stress of 250 lbs per square inch. (psi)
- For simplicity, we will discuss the effects of forces, and assume that the student understands the relationship between **force** and **stress**.

### Tension Forces

**Tension forces** stretch members of steel or wood. Concrete and masonry have no reliable tension strength.

- When a moderate tension force is applied, a steel bar will lengthen. When the force is removed, the bar will return to its original length. This change is called **elastic** behavior and can be repeated many times in competent steel or wood members.
- If a much larger force is applied to the steel bar, however, it will start to lengthen more rapidly. When this rapid lengthening occurs, the cross-section of the bar will start to get smaller (neck down), and when the force is removed, the bar will not return to its original length since it has experienced permanent yielding (**ductile** behavior).
- The **ductile** behavior of steel in tension provides the special property of forgiveness (warning of failure) and response that makes it especially desirable in resisting dynamic loading.
  - ♦ **Ductile** behavior is the ability of a material to stretch and/or bend without suddenly breaking; after the load is removed, it can remain stretched or bent and then be re-loaded.  
**Example:** One can bend a hook on a rebar, and even unbend it without breaking it.
  - ♦ **Brittle** behavior means that the material will break without warning (**catastrophic failure**).



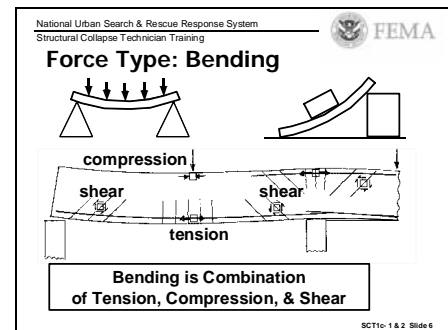
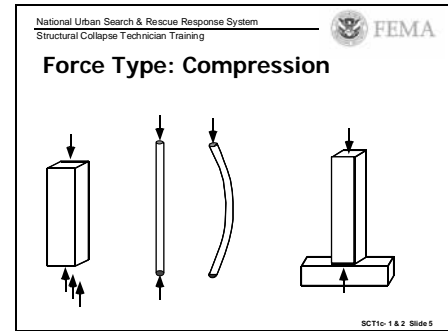


### Compression Forces

- Compression forces push on members and can lead to the crushing of materials when members are short and relatively fat (small length to width ratios,  $L/D$ ).
- At bearing surfaces between wood or concrete beams and columns, crushing can also occur. Crushing failures tend to give warning, such as local splitting of concrete and the noisy, slow, compression of wood fibers.
- When long, slender members are loaded in compression, they can fail suddenly by **buckling** (bowing).  
This type of sudden failure should be avoided.

### Bending Forces

- **Bending forces** occur mostly when vertical loads subject to gravity are applied to floor slabs and beams. Bending forces also occur in sloped roof rafters and in the sloped slabs found in rubble piles.
- Bending causes the bottoms of simple beams to become stretched in **tension** and the tops of beams to be pushed together in **compression**.
- Continuous beams and cantilever beams experience tension forces at the top in addition to compression at the bottom near their supports. In the mid-span of continuous beams, the forces are in the same locations as for simple beams and slabs.
- Vertical cracks develop near the mid-span of concrete members since the tension force causes the concrete to crack in order for the reinforcing steel (rebar) to resist the tension force.
  - ♦ Observing this cracking in damaged structures can aid in monitoring and determining the potential for collapse.
  - ♦ Stable hairline cracks are normal, but widening cracks indicate impending failure.
- Structural steel and reinforced concrete, moment-resistant frames experience tension and compression stresses on opposite faces (similar to continuous beams). These stresses can reverse themselves during earthquakes and high winds.
- Shear forces are also produced in beams and slabs and will be discussed next.





## Shear Forces

**Shear forces** occur in all beams and are greatest in areas adjacent to supports.

- Shear stress can be described as the tendency to tear the beam's surfaces apart.

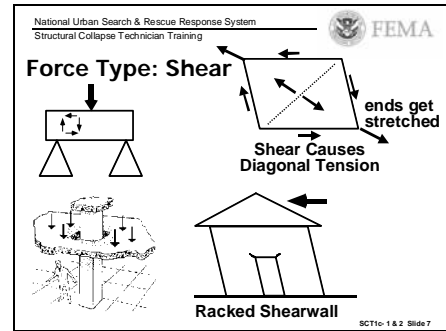
**Example:** Consider a beam made from a group of individual books as they sit on a bookcase, with a long threaded rod extending all the way through them, tightened with nuts at each end. If this beam is placed so that it spans the gap between two tables, and one attempts to push one of the books down to the floor, a **shear force** will be exerted on the surface of the books immediately adjacent to the one being pushed.

- In concrete beams, these shear stresses develop diagonal tension cracks because concrete is very weak in tension.
  - ♦ As shown in the slide, when an element is loaded in shear, it will tend to change from a square to a parallelogram. As this change happens, the element stretches in one direction, thereby causing tension across the diagonal.
  - ♦ This diagonal cracking can also be monitored in damaged beams, girders, columns, and walls.
- Wood beams are strong in tension and compression but are particularly weak in shear along the horizontal plane of the softer springwood.

**Punching shear** occurs where a flat, two-way, concrete slab is connected to a column and the tendency of the slab is to drop as a unit around the column.

- The column appears to punch through the slab.
  - ♦ The cracking that indicates the over-stress leading to this type of collapse is most visible on the top surface of the slab, which is often covered by debris during US&R activities.
  - ♦ The debris may be causing the overload, and also make it difficult to assess, since the cracking may not be visible.

**Bolt shear** is the tendency of a steel, pin-like connector (such as a bolt, nail, or screw) to break across its cross section.





**Example:** A roll of coins is sheared off as each coin slips past another.

- This type of failure can be sudden.

Nail failures in wood structures, which involve some degree of pullout, can occur with enough deformation to give warning.

### **Building Wall Shear and Overturn Forces**

- Lateral forces (forces applied horizontally to a structure) derived from winds or earthquakes cause shear and bending forces in walls.
- The shear forces tend to tear the wall surface, just as if one had a piece of paper attached to a frame and changed the frame's shape from a rectangle to a parallelogram.
  - ♦ This changing of shape is called **racking**.
  - ♦ When shear walls are pushed out of plumb in their plane, they are said to have been **racked**.
- At the ends of shear walls, there is a tendency for these walls to be lifted at the end where the lateral force is applied and a tendency for the wall to be pushed down at the end away from the force.  
This action is called **overturning**.


### **Material Properties**

#### **Wood**

- Wood is tough, light, fibrous, fire supporting, cut from living trees, and graded by humans.
- It has defects like knots, splits, and non-straight grain that concentrate stress.
- The growth pattern of fast-growing springwood versus that of slower-growing summerwood leads to structural problems. These problems include:
  - ♦ Weakness in cross-grain tension and compression;
  - ♦ Weakness in shear strength parallel to grain;
  - ♦ Shrinkage and splitting.
- Live wood may be as much as one half water, while older, seasoned wood (as found in a structure) may contain as little as 10 percent water.  
Wood's volume can change as much as 10 percent over this range.

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**Material Properties Brittle vs Ductile**

- Wood
- Steel
- Reinforced Concrete
  - C.I.P. or P.C.
  - Rebar or Prestressed Cable
- Reinforced Masonry
- Unreinforced Masonry

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- Shrinkage (usually in width or depth, not length) causes special problems in bolted connections.  
Splits may be formed that allow the bolt to slip out of the joint along the split.
- Connections are best made by bearing one member on its supporting member; however, metal connection devices can be successfully used.  
Nailed connections perform well as long as splitting is avoided, and bolting may be successful if adequate spacing and edge distances are provided.
- Properly proportioned wood structures can exhibit **ductility**.
  - ◆ When wood posts are kept short and bear on the cross-grain surfaces of beams or sole plates, slow crushing of the cross-grain can warn of failure.
  - ◆ Box cribbing will exhibit this same failure mode since all the load is transferred in cross grain bearing.
- The plywood sheathing of wood structures makes them very tough and earthquake resistant as long as the sheathing is nailed properly.

### **Steel**

- Steel is tough, light, strong, ductile, and formable into any shape but needs to be fireproofed.  
It starts to lose strength above 700° F.
- It has the almost magical property of **ductility**; that is, it can be stressed beyond its elastic limit and severely bent but still have enough strength to resist failure.  
This property makes it the ideal structural material, in that it gives warning of collapse (has forgiveness).
- Steel is strong with respect to tension, compression, and shear.
- Steel beams must be laterally braced so as not to buckle about their weak axis, especially if the ductile performance required for earthquake resistance is expected.

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**Material Properties Brittle vs Ductile**

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- Steel-framed structures must be properly proportioned in order to avoid the overloading of columns.  
As will be discussed later, diagonal bracing members can overload columns during earthquakes if these columns are not proportioned such that their strength exceeds the total force that can be delivered to them by the diagonals.
- Steel can be very efficiently connected by bolting or welding (older structures used rivets instead of bolts).
- Welded joints must be properly designed and constructed, or they can lead to a brittle failure.

### Concrete

- Concrete is essentially cast rock that is strong with respect to compression but weak in terms of tension and shear.
- Steel bars are cast into concrete to provide for the longitudinal tension force, and enclosing type steel ties and stirrups are added for confinement and shear resistance.  
Sufficient steel can be added to provide adequate toughness for seismic resistance, enabling reinforced concrete to exhibit **ductile** properties similar to those of structural steel.
- Concrete can also be reinforced by adding high strength cable or bars that are pre-tensioned prior to their being loaded by the structures weight (pre-stressed concrete).
- Structures of this type may be pre-cast in a factory using **pre-tensioned** reinforcing that is stretched in a form and then bonded to the concrete when it is cast.
- Another method is to place cables that are enclosed in plastic sleeves in the forms at a job site, pour the concrete, and then stretch and anchor the cables after the concrete has cured and achieved sufficient strength. (**post-tensioned**).
  - ♦ In this case, the cables are not bonded to the concrete but only anchored at the edges of the structure.
  - ♦ These **unbonded** cables can cause difficulties when dealing with a damaged **post-tensioned** structure.

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#### Material Properties Brittle vs Ductile

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- Reinforced Masonry
- Unreinforced Masonry

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- Concrete shrinks, cracks, and creeps under normal circumstances, and this **normal** behavior needs to be differentiated from the cracking and spalling that indicates failure.
- Concrete is easily connected together if cast in place but must be very competently connected together if it is pre-cast.
- Since pre-cast concrete members (especially pre-stressed, pre-cast members) can be very strong, the joints that connect them must be very tough (**ductile**) in order to resist the high dynamic forces generated by an earthquake.
- Properly reinforced concrete can provide seismically resistant construction if the reinforcing is proportioned such that the confining tie, hoop, and stirrups are sufficient to resist the shear that can be generated by the overall structural configuration and longitudinal reinforcement.
- Wall-like structures of cast-in-place and pre-cast concrete have outperformed frame type construction in most earthquakes.


### **Unreinforced Concrete**

- Unreinforced concrete walls can be found in structures built before about 1910.
- These structures perform very poorly in earthquakes, as they tend to break into large pieces defined by shrinkage cracks or original pour joints (**very brittle material**).

### **Reinforced Masonry**

- Reinforced masonry is made from clay brick or hollow concrete blocks formed into walls using mortar joints and concrete grout filling of interior cavities in seismically resistant construction.
- Since masonry properties are similar to concrete, reinforcing steel bars are normally added to provide tension and shear resistance.
  - ◆ In reinforced brick masonry, two, single-brick thick outer layers (wythes) are laid up and then rebar and grout are placed between the layers.
    - The wythes are connected with large wire to prevent blowout when the grout is poured.
    - Small, heavy wire, ladder-type reinforcing is used at the joints in some cases.

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#### **Material Properties Brittle vs Ductile**

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- ◆ In Concrete Hollow Unit Masonry (CMU), each block comes with preformed cavities.
  - As the units are laid up, horizontal reinforcing (small rebar or large wire) is placed in the joints.
  - After the wall reaches a predetermined height, vertical rebar is placed in specified cells and then grout is poured to bond the reinforcing steel to the concrete units.
- Masonry wall construction is highly dependent on workmanship if it is to provide adequate mortar and grout strength.

These products are often mixed on the job in small quantities.
- Adequately reinforced masonry walls can be used in seismically resistant construction and can exhibit very good **ductility** if carefully designed and constructed.

## Unreinforced Masonry (URM)

- Unreinforced masonry structures are not currently built in seismic risk areas, but many structures with URM walls still exist throughout the world.
- This is a **very brittle material**.
- Walls were constructed with a thickness of three or more bricks laid long ways, side by side, five or six layers high (courses), and then a layer was placed with the bricks at 90° (header course), and so on.
- URM buildings date back to the late 1800's in California and back to the 1700's in other parts of the U.S. The strength of the bricks is generally higher outside of California.
- The strength and seismic performance of unreinforced masonry is highly dependent on the mortar strength.
  - ◆ The shear strength of mortar can vary from 15 psi to over 150 psi and is determined both by the proportion of lime to Portland cement and the workmanship.
  - ◆ Lime produces a nice, buttery mortar, but too much of it produces a low strength.
  - ◆ Lime can also be leached out of the mortar by water over time.

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### Material Properties Brittle vs Ductile

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- Decorative veneers are a special seismic problem.
  - ◆ Veneers were often laid up with building paper between them and the URM wall, and were anchored with wire or galvanized ties.
  - ◆ The ties normally corrode away within 20 years or so, leaving a heavy brick face just waiting to peel off when subjected to a lateral load.
  - ◆ Masonry veneers are also found on the outside surfaces of wood walls.
- There veneers are subject to the same anchorage problems, as well as being dynamically incompatible with the flexibility of the wood walls.
- URM walls are made from native stone in many places in the world and have performed very poorly in earthquakes.

### **Vertical Load Systems**

Structural members in these systems can be divided into two types, those that form horizontal (or sloped roof) planes and those that provide the vertical support for these planes.

#### **Horizontal Members**

- Horizontal members support floor and roof planes and are normally loaded in bending, such as:
  - ◆ Wood: rafters, joists, purlins, beams, and girders;
  - ◆ Steel: corrugated sheets (filled with concrete), joists, purlins, beams, and girders.
- Reinforced concrete floor systems may be of many types. All have some relationship to the economy of providing adequate structural depth with available forming materials.
- Pre-cast concrete floors may contain planks, cored slabs, single or double tees, beams, and girders. Most modern systems in California combine a cast-in-place overlay slab to provide adequate interconnection of individual members and overall planar stability.
- These individual members need to be interconnected to their supported planes in order to provide the lateral stability to resist the extreme fiber compression forces associated with bending, which occur on the top or bottom of the members.

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**Vertical Load Systems**

- Concept of gravity load path
- Loads must be transferred from Source to Ground
- Top down approach
  - Plumbing system analogy
- Framed & Un-Framed
- Connections are particularly vulnerable

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**Concrete Floor Systems**

Most of the reinforcing steel is concentrated in and over Beams and over Columns

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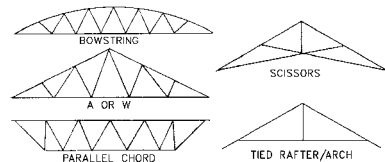
### Trusses

- Trusses are special vertical, load-resistant members that use greater depth for structural efficiency but require lateral bracing of compression members.
  - ◆ Trusses are usually made from wood or steel, although concrete is used in some areas of the world.
  - ◆ Individual members are stressed in either tension or compression, although stress may reverse itself in some members because of changes in live load (for example, people, vehicles, and rain/snow).
  - ◆ Compression members are usually governed by buckling, and tension members are usually governed by their connections.
  - ◆ Trusses have not performed well in many situations of overload, fire, and when wood tension have performed poorly. We will discuss this later in this section under Redundancy

### Vertical Support Members

- Vertical support members are normally configured as bearing walls or columns.
- In wood and light framed steel systems, the bearing walls are made using closely spaced columns (studs at 16 in to 24 in o.c.) that must be interconnected by a skin in order to provide the lateral stability that will allow the individual members to be loaded with respect to compression without buckling.
- Concrete and masonry bearing walls are proportioned so as to carry heavy vertical loads depending on their height-to-thickness ratios.
- Individual columns (posts) normally carry large compression forces and may be made of wood, steel, or reinforced concrete. In all cases, the load capacity is based on the member's slenderness ratio ( $l/r$ ,  $l/d$ ) as well as the adequacy of the connection between column and horizontal system.
- All vertical load systems need some system to provide for lateral stability (that is, the proper alignment of the vertical load path). These lateral load systems need to be capable of resisting lateral forces that constitute at least two percent of the structure's weight (much more in seismic zones).

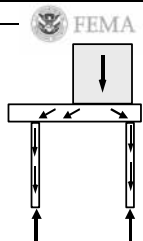
#### Typical Truss Configurations



- Tension in bottom chords
- Compression in top chords
- Small tension or compression in diagonals
- Very dangerous fire collapse hazard

#### Vertical Load Systems

- Concept of gravity load path
- Loads must be transferred from Source to Ground
- Top down approach
  - Plumbing system analogy
- Framed & Un-Framed
- Connections are particularly vulnerable



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- Vertical Load Systems are usually configured as either **Framed or Unframed systems**, but may be a combination of both
  - ♦ **Framed** systems have a uniform grid of columns and beams. Steel and Concrete Frame buildings are common examples.
  - ♦ **Unframed** systems usually employ bearing walls for vertical supports. Most residential structures from 1 to 12 stories have unframed systems.
  - ♦ Since **Unframed** systems normally have shorter spans and more redundancy (discussed later) they tend to perform better under extreme loading. Collapsed area may be limited to only one room, or between one pair of walls.
  - ♦ In **Framed** systems, since spans tend to be longer, the collapse of one column may involve an area twice the column spacing in each direction

### Lateral Load Resistant Systems

Most structures can be grouped into two basic types of lateral load systems: shear wall/box systems and frame systems. Buildings may contain sections of each type. Some buildings have been designed with a dual system containing both types of lateral bracing in order to provide a more redundant system, which is highly desirable.

### Shear Wall/Box Buildings

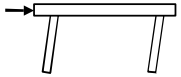
- Shear wall/box buildings are buildings with exterior walls that provide bearing strength as well as seismic resistance. They may or may not have interior, structural walls. Floors and flat or sloped roof planes called diaphragms form the horizontal surfaces to complete the boxes, with the walls forming the sides.
- The typical action of a box structure subjected to lateral loads is illustrated in the adjacent slide. Floor and roof planes act like giant beams as stresses in tension and compression are generated at the edges and shear stresses are distributed throughout the plane.

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### Lateral Load Resisting Systems

- Concept of load paths
  - Pushover analogy
- Connections are particularly vulnerable
- Systems
  - Box Buildings
  - Moment Frames (MUST BE DUCTILE)
  - Diagonally Braced Frames



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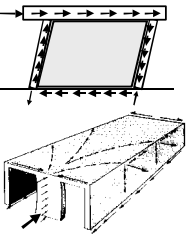
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### Lateral Load Path Concept - Box Building

**Basic Components**

- Roof/Floor – Laterally supports Walls
- Walls – Keeps System from Racking
  - Best to have walls on all Four Sides
  - Walls may have Openings



Load

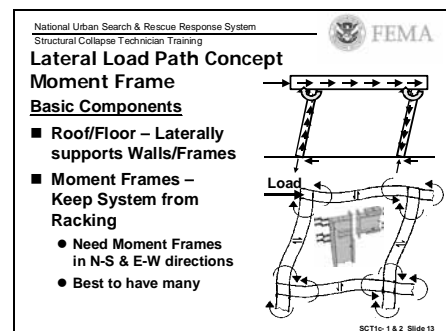
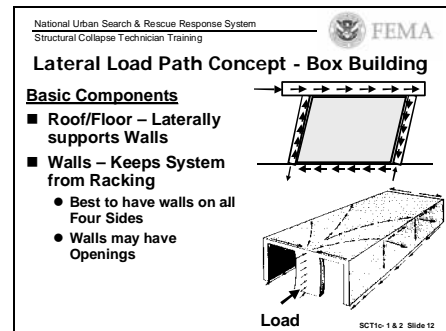
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- The floor and roof planes (diaphragms) span horizontally between exterior (and sometimes interior) walls, which provides each horizontal plane with lateral support. The shear walls are in turn loaded by the floor diaphragm and must be capable of resisting both the shear stresses and bending stresses caused by overturning.
- Floor and roof diaphragms are made of plywood, diagonal wood sheathing, corrugated metal deck (with and without concrete topping), and concrete.
- Shear walls are made of plywood and solid wood sheathing over studs, concrete, and concrete block.
- In the very lightweight wood systems, the skin (sheathing) carries all of the lateral shear force but is a minor vertical support member. In concrete and concrete block systems, the vertical and lateral loads are carried by bearing walls and the relatively heavy reinforced concrete slab.

### **Moment-Resistant Frame Buildings**

- The walls for this type are normally constructed for enclosure purposes only and may be of glass, light framing with a non-structural covering (such as plaster veneer, brick or stone, or finish wood), or a combination of pre-cast concrete and glass. Large, evenly spaced columns of steel or reinforced concrete carry the vertical load.
- The floor and roof diaphragms are constructed as in the box system. However, the forces developed in the diaphragms are usually smaller since they do not have to span as far.
- Lateral load resistance is provided by the interconnection of large, tough floor beams or girders and the columns. The “frame” made by the beams and columns is kept from changing into a parallelogram by making the connections as strong as the members. Structural steel and well-confined, heavily reinforced concrete are used today for these moment-resistant frames.
- Structural toughness—the ability to repeatedly sustain reversible stresses in the inelastic range without significant degradation—is essential for a moment-resistant frame. Most concrete frames built before 1965 in California (and other seismic zones with similar building codes) were not constructed with much structural toughness.



The Simpson Strong-Frame, bolted moment frame joint is shown inside the graphic of the 4-joint moment frame.

This is just one variation, showing a lower cost, bolted method, for making a moment frame for smaller, wood-frame structures.

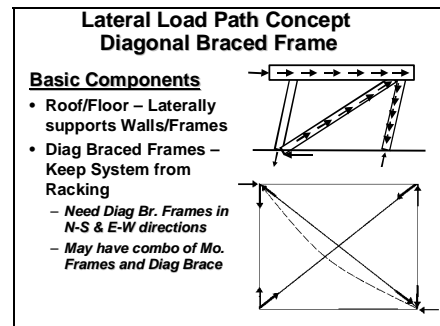
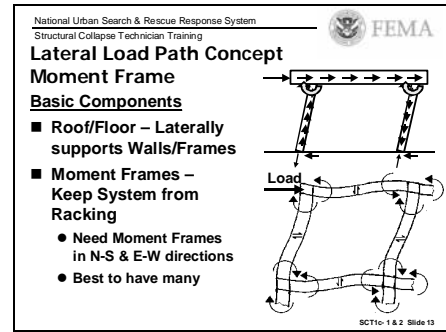


### **Moment-Resistant Frame Buildings (continued)**

- Structural steel frames have out performed concrete frames in the past. There are examples of lightly connected steel frames that survived the San Francisco 1906 earthquake. However, they were susceptible to fire damage.
- Tall buildings with moment-resistant frames may generate significant tension and compression forces in the exterior and/or corner columns. High tension can be very detrimental to older concrete frames since severe cracking can result in catastrophic failures when the loading is reversed and the member is also required to resist bending. High compression forces in steel frames can cause buckling of either tube or wide-flange columns.
- Modern building codes require that the columns be stronger than the sum of the connecting beams at any story so that when inelastic action occurs, it will form plastic hinges in the beams, not the columns. Since modern steel moment-resistant frames are connected by welding, good workmanship is critical. Visual inspection and ultrasonic testing are normally required to assure quality.
- Moment-resistant frames can be used in combination with concrete shear walls to provide a dual system.
- Older, pre-1960, steel moment-resistant frames may be covered with cast-in-place concrete fireproofing (important identification information).

### **Frame Buildings—Diagonally Braced**

- These systems are constructed similarly to moment-resistant frame structures.
  - ◆ Their lateral load resistance is provided by adding diagonal members between columns to prevent lateral racking.
  - ◆ Alternately reversing tension and compression forces are generated in the diagonal members, which are usually made of structural steel, although reinforced concrete has been used, especially in Central and South America.



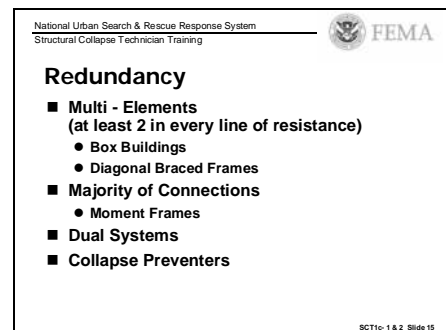
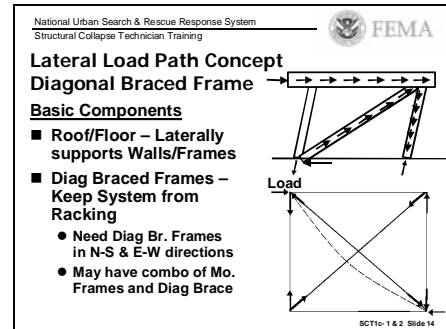


### Frame Buildings—Diagonally Braced (continued)

- Diagonal members should be able to resist both tension and compression since the whipping action of slender rod cross-bracing can allow too much distortion. An exception is that light, steel frame, industrial buildings have performed reasonably well with slender rod cross-bracing, since corrugated metal finishes are quite flexible.
- The columns in diagonally braced frames need to be proportioned so that they are stronger than the tension capacity of the braces that are connected to them. This proportion assures that failure will not occur in the columns, yet it has only been required in recent building codes.
- Diagonal members are normally made from double angles or tube sections, and connections must be carefully detailed and built in order to prevent local buckling and/or other joint failure.
- Diagonally braced frames have been used in combination with moment-resistant frames to provide a highly desirable, dual system. They are configured as eccentric braces within a moment-resistant frame bay to provide a bracing system that combines the toughness of a moment-resistant frame with the rigidity of a braced frame.

### Redundancy

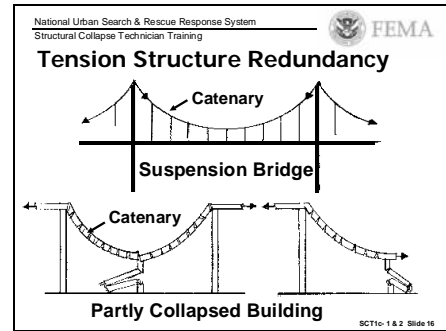
- Especially in seismic zones, it is important for the lateral load system to possess some degree of redundancy.
- Redundancy in a structure means that there is more than one path of resistance for lateral forces.
- Redundancy can be achieved by having:
  - ♦ More than one shear wall panel or more than one diagonal brace in every line of resistance;
  - ♦ A moment-resistant frame with many columns and beams, all with ductile connections;
  - ♦ A dual system, like shear walls in addition to a moment-resistant frame.





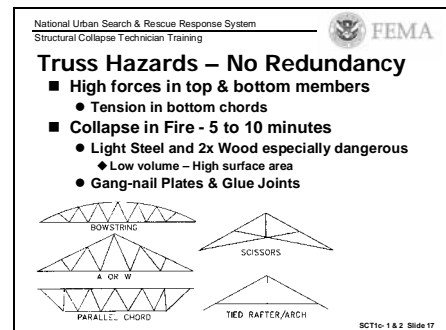
## **Suspension/Tension Structures**

- Suspension/tension structures are not commonly used in building structures. These very efficient structures require significant height (cable drape) to span great spaces.
- Earthquake-damaged, reinforced concrete slabs often form tension-like structures after the failure of a vertical support (as shown in the slide). Failures of a vertical support will cause unplanned tension forces in the remainder of the structure, which may cause lean-over of the remaining walls.
- This action can prevent complete collapse, but it leaves a condition that is difficult to assess. The slabs may be hanging on reinforcing steel with unknown and/or unreliable embedment.



## **Truss Hazards – No Redundancy**

- Wood trusses have failed many times due to seasoning defects. Wood checks (splits) that occur near the ends of tension members have led to many pull-through bolted connection failures. Overloads due to rain or snow can lead to sudden collapse resulting from a compression member buckling or tension connection failure. The use of closely spaced trusses with gang-nail connection plates and specially fabricated wood with steel pin connected bars has improved the reliability of wood trusses.
- Steel trusses have been fairly reliable, but they are also susceptible to sudden compression member failures due to temporary overload and loss of stability resulting from inadequate bracing.
- Trusses present special problems when shoring a hazardous structure. The support provided by the shoring must be applied so as not to cause a stability problem or overload of a small or inadequately braced individual truss member. It is usually a bad idea to shore a truss at the bottom
- Light wood and steel trusses are very susceptible to sudden collapse due to fire.
  - ♦ Wood trusses with 2x members, connected by gang nails or glue, provide an abundance of fuel in ceiling space, and collapse quickly.







### Building Types & Characteristics


ATC-20, Procedures for Post Earthquake Safety Evaluation of Structures and ATC-21, Rapid Visual Screening of Buildings for Potential Seismic Hazards, were funded by FEMA and written by the Applied Technology Council (ATC) in 1988. The ATC was created by the Structural Engineers Association of California to develop and manage research and other projects that add to the body of knowledge regarding structures.

- ATC20 & 21 defined 12 specific building types based on how they respond to earthquakes.
  - ◆ They are defined by the type of material used in construction as well as the type of lateral load resistant system employed.
  - ◆ As an example for concrete construction, we have a C1 Type that has a moment-resistant frame, a C2 Type that is a box building with shear walls for lateral resistance, and a C3 Type to cover the many buildings that have a moment-resistant frame with masonry infill walls for fireproof exterior enclosure.
- One exception is that Wood Buildings are subdivided by size into W1 for smaller, residential structures, and W2 for structures over 5000 sq feet.
  - ◆ The W2 classification covers 2 and greater story apartments as well as commercial, institutional and industrial structures
- There are also the other more descriptive definitions, such as: TU, PC2, URM, and Mobile Homes & Manufactured Units
- The FEMA US&R Response System has adopted the ATC-20 nomenclature for use in identifying damaged structures.

It is used in this training manual and for the Structures Specialist Forms.
- Other systems, such as the Building Code and Francis Brannigan's *Building Construction for the Fire Service*, are based on resistance and response to fire.

They are not as specific enough to differentiate to be useful in describing structural response to earthquake and the other destructive forces encountered in US&R.

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**Building Characteristics**  
**Building Types - ATC-20**

- W1 Dwellings & small wood buildings
- W2 Wood bldg over 5000sf & 3+ story
- S1 Steel moment resisting frames
- S2 Braced steel frames
- S3 Light metal buildings
- S4 Steel frames w/C I P conc walls

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**Building types - ATC-20**

- C1 Concrete moment resisting frames
- C2 Concrete shear wall buildings
- C3/S5 Conc/steel frame w/urm infill walls
- TU/PC1 Tilt-up concrete wall building
- PC2 Precast concrete frame buildings
- RM Reinforced masonry buildings
- URM Unreinforced masonry building
- Mobile Homes & Manufactured Units

SCT1c-1 & 2 Slide 19



- Another book, written for the Fire Service that is highly recommended is “Collapse of Burning Buildings”, by Chief Vincent Dunn, Fire Department of the City of New York. It describes many actual incidents, and gives insight from lessons learned.

### **Problem Buildings**

The slide lists some of the building types that have been susceptible to earthquake and/or wind damage in the past. The list includes most structural types.

- S2, C1, C3/S5, TU, PC2, and URM are expected to be most susceptible to earthquake damage throughout the U.S.
- W1 & W2 residential structures have also experienced a large number of failures on the U.S. West Coast, since they are, by far, the most prevalent building type. There is the potential for the entrapment of victims in the W2 wood structures. Poorly connected W1 & W2 wood structures are also very vulnerable to wind damage.

- Type S3 is listed since it is very susceptible to damage by wind.
- Mobile Homes & Manufactured Units are susceptible to damage in earthquakes and winds
- Many S1 structures experienced cracks in their welded connections during the Northridge (Los Angeles) earthquake, which is of great concern to the design profession.

None of these buildings were damaged to an extent that would cause collapse, but they may become a problem in future earthquakes.

- Earthquakes consistently cause damage to buildings with irregular shape and inconsistent stiffness.
  - ♦ Remembering that quakes produce motions (not Forces) , and the shaking is able “find” these inconsistencies, thereby causing severe overloading.
- For the most part quakes and windstorms effect different types of structures.
  - ♦ Mass and rigidity develop high forces during quakes, but provide resistance to high winds

**The characteristics of the various types of buildings are discussed on the following pages.**

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**Building types - ATC-20**

- C1 Concrete moment resisting frames
- C2 Concrete shear wall buildings
- C3/S5 Conc/steel frame w/urm infill walls
- TU/PC1 Tilt-up concrete wall building
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- RM Reinforced masonry buildings
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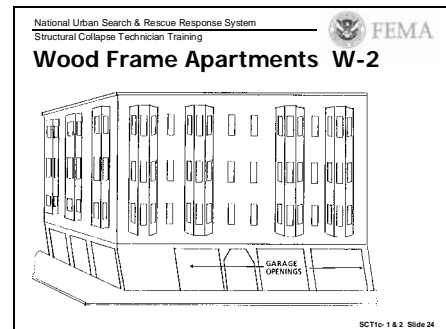
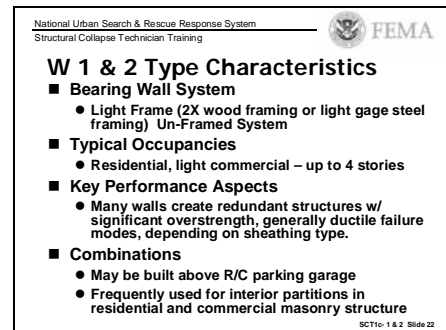
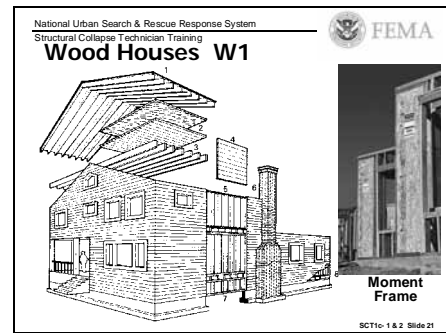
SCT1c-1 & 2 Slide 19



### Wood Frame Buildings – W1 & W2

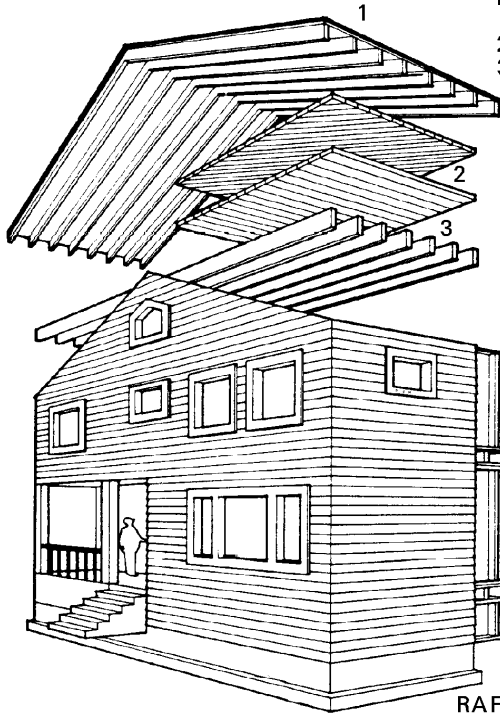
These structures can vary from 1 to 4 stories and contain from 1 to over 100 living units. W2 structures are larger than 5000 sq feet

- Lateral resistance of wood structures is dependent on the type and amount of wall sheathing.
- The adjacent slide shows a method of providing lateral resistance for very short walls. This is a factory built strong-wall that is cantilevered off the foundation using well embedded bolts
- Wood structures are unique in that the vertical load resisting systems (joist, beams, studs and posts) are covered with a “skin” to form the lateral load resisting system. This is different than other bearing wall systems. See adjacent slide for characteristics.
- Common problems in strong earthquakes are:
  - ◆ Walls are weakened by openings & becoming racked (rectangles become parallelograms).
  - ◆ This weakening can cause a significant offset of one floor from another, and in severe cases, collapse has occurred.
- Relatively modern, W2, 2- and 3-story wood apartment buildings may have walls that are braced using only plaster/gypsum board, let-in bracing, or inadequately designed plywood.
  - ◆ These structures may experience brittle, first-story failures, especially when upper story walls do not align with lower-story walls.
  - ◆ These structures are especially vulnerable to earthquake damage when lightweight concrete fill has been added to provide better sound control (greater mass means that greater earthquake force is generated).
- W1 houses with crawl spaces can shift or slide off their foundations.
- Masonry chimneys can crack and fall-off or into the structure.
- Masonry veneers can fall off walls and shower adjacent areas with potentially lethal objects. (Especially deadly for W2 Types)
- Structures can separate at offsets in floor/roof levels (such as porches and split level houses).
- A great danger of fire exists for these structures due to the presence of so much fuel.





## WOOD RESIDENCES - W1



### Roof/Floor Systems:

1. wood rafters and spaced or solid sheathing
2. wood ceiling joist with finish
3. wood floor joist and solid 1x sheathing or plywood sheathing in newer houses

### Wall Systems:

4. Wood finish on studs or Stucco on solid wood sheathing: plywood, 1x straight or diagonal boards.
5. Wood studs either platform framed as shown or balloon framed

### Other Features:

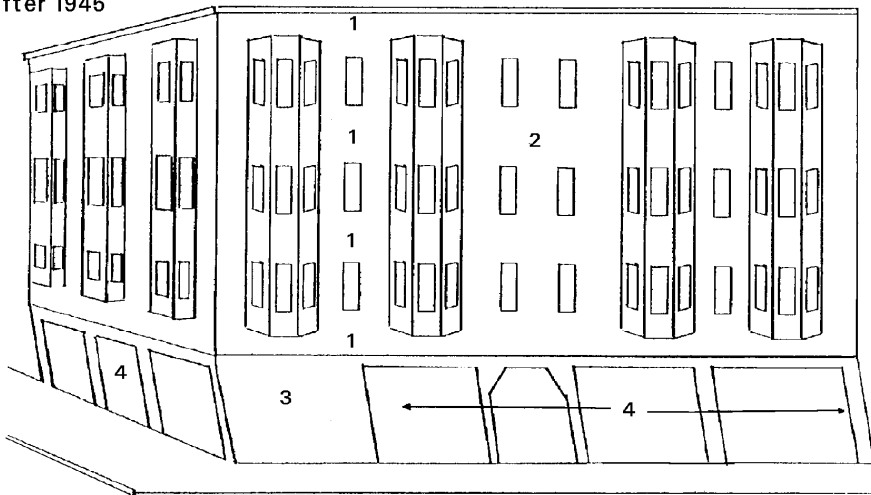
6. Masonry chimney
7. Cripple wall below 1st floor (often w/vent holes)
8. Floor joist may bear directly on footing.

### BOX TYPE STRUCTURE

RAFTERS, JOIST, & STUDS are VERTICAL LOAD SYS.  
 SHEATHING is LATERAL LOAD SYSTEM

## WOOD FRAME APARTMENT BUILDINGS - W2

1. 2x wood joist at roof/floors with 1x wood sheathing or plywood (post 1945)
2. Wood studs, platform framed with wood sheathing:  
 1x horizontal - pre 1935  
 1x diagonal - pre 1945  
 Plywood, Gypsum, or wire after 1945
3. Walls may have masonry veneer especially in first story
4. First story garage openings create a weak/soft story. This can be overcome by using properly designed shearwalls or by changing the garage to a concrete structure with strong shearwalls.





### Mobile Homes and Manufactured Units

These are relatively small structures that may have been made stationary on a “Park”.

In the case of portable classrooms there are two or more 8 foot wide units that have been attached together to form 16ft x 40 (or more) ft units.

All types have relatively light walls, and are box structures that have been moved over the highway on a steel base frame (usually a tubular frame)

Characteristics are shown in adjacent slide

The portable classroom units have more substantial framing than mobile home units, since they have at least one open side that is framed with a steel moment frame

The performance of these units when subjected to wind, quake, or blast pressures is related to how well they are attached to their bases and their bases connected to the ground/foundation.

Older mobile homes used 25 gage straps and staple connectors to connect walls to the frame, but newer units have 16 gage straps and screws.

Some portable classroom units have concrete foundations to which they are semi-permanently connected

In California, these structures are designed to resist earthquakes, and are carefully reviewed by State Building Officials.

These have much better connections at the base and may have concrete foundations.

In some cases, what start out to be temporary structure, remain for many years on relatively poor bases

Here is an example of how poorly connected modular units may become almost permanent structures .

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**Mobile Homes & Manufactured Units**

- **Mobile Homes in large neighborhoods**
  - Units remain mobile w/ wheels attached
  - Usually supported on jack stands
  - Compact interior spaces
  - Usually have utility connections
  - May contain propane tanks
- **Portable Classrooms**
  - Interconnected units, each with one open side
  - Usually supported on temporary foundation
  - Larger interior spaces, semi-permanent
  - Better structure usually with moment frame supporting open side

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**Mobile Homes/Mfr'd Units- Characteristics**

- **Structural Systems**
  - Very light, metal covered walls on steel base frame
  - Supported on jack stands or temporary foundations
- **Typical Occupancies**
  - Residential, classroom, office
- **Key Performance Aspects**
  - Performance of box structure is dependent on connection to base (25ga. Straps w/ staples = poor 16ga. w/ screws = better)
  - Base frame needs adequate connection to ground
  - Awnings, etc are very vulnerable
- **Combinations**
  - More than one unit may be interconnected to form larger space

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**Portable Classrooms – Seismic design**

- Low profile, near ground w/tiedown
- Steel moment frame each unit at 8ft o.c.
- Thicker walls/roof

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**Temporary Office – for 30 years?**

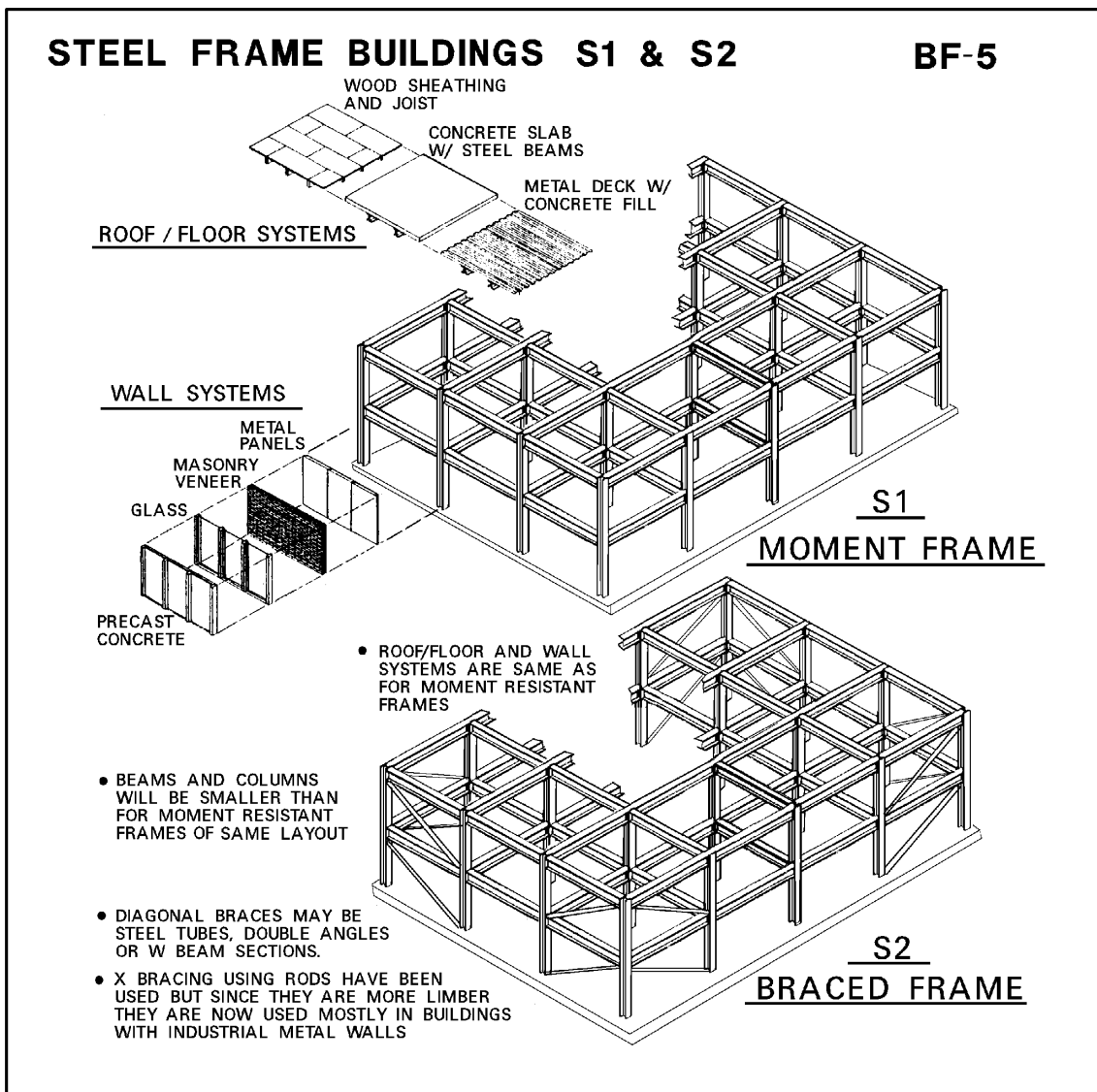
- 8ft wide units make 16ft x 40 ft space
- Jack stands may eventually rust-out

SCT1c-1 & 2 Slide 30



### Steel, Moment-Resistant Frame Buildings—S1

- Steel, moment-resistant frame buildings may be from 1- to over 100-story office buildings with glass or other non-structural exterior covering.
- Steel buildings in general have performed well, but in recent earthquakes **moment-resistant frames** have exhibited the following problems:
  - ♦ In both the Northridge and Kobe earthquakes, the violent shaking caused some welded connections to crack.
  - ♦ No buildings of this type collapsed during these earthquakes, but a few were racked out of plumb, and new, better performing joints have been designed to repair or replace questionable ones.





- Since these connections are what give moment-resistant frames their lateral resistance, it is possible that a future great earthquake (magnitude 7.5 to 8.5) could cause a catastrophic collapse, especially if the following occur:
  - ◆ Shaking lasts for more than 30 seconds.
  - ◆ A structure has little redundancy (only a few columns with welded joints), and the joints are the types that can crack and fail.
- The characteristics of Steel Moment Frame Structures are listed in the adjacent slide.

### **Diagonally Braced Steel Frame Buildings—S2**


These buildings may be from 1- to 20-story office buildings with glass or other non-structural exterior covering.

Characteristics are listed on adjacent slide.

Steel buildings have performed well, but those with diagonal bracing have had problems.

- Buildings that contain slender-rod cross-bracing may experience excessive distortion (story drift) that can lead to shedding or significant damage to brittle finish materials such as glass, masonry veneer, or pre-cast concrete panels. The whipping action has caused some slender cross-braces to break.
- When the braces/columns are not properly proportioned, especially in taller frames, the great tension strength of the braces can cause compression (buckling) failure of columns.
- The 1985 failure of the 20-story Pino Suarez tower in Mexico City is attributed to this effect.
- When tube-type members are used for diagonals, local crippling at cross-section corners has resulted. This crippling can occur when cold-rolled tubes are used since high stresses are originally induced during forming.
- Inadequate detailing or workmanship of connections has caused local failures, such as the buckling of connection plates and the rollover of beams. Although collapse has not resulted from these failures, significant non-structural damage has occurred.

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#### S1 Type Characteristics

- **Frame System**
  - Heavy Structural Steel (hot rolled sections)
- **Typical Occupancies**
  - Office & Commercial, Industrial, Highway bridges
  - 2 to 100 stories
- **Key Performance Aspects**
  - Normally well-engineered; Members very ductile. Overall performance dependent upon connections – welds may be brittle.
  - PC or URM, Ext wall panels usually perform badly
- **Combinations**
  - Precast or CIP concrete floors w/ or w/o metal deck
  - Masonry, precast or metal curtain walls +URM infill

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#### S2 Type Characteristics

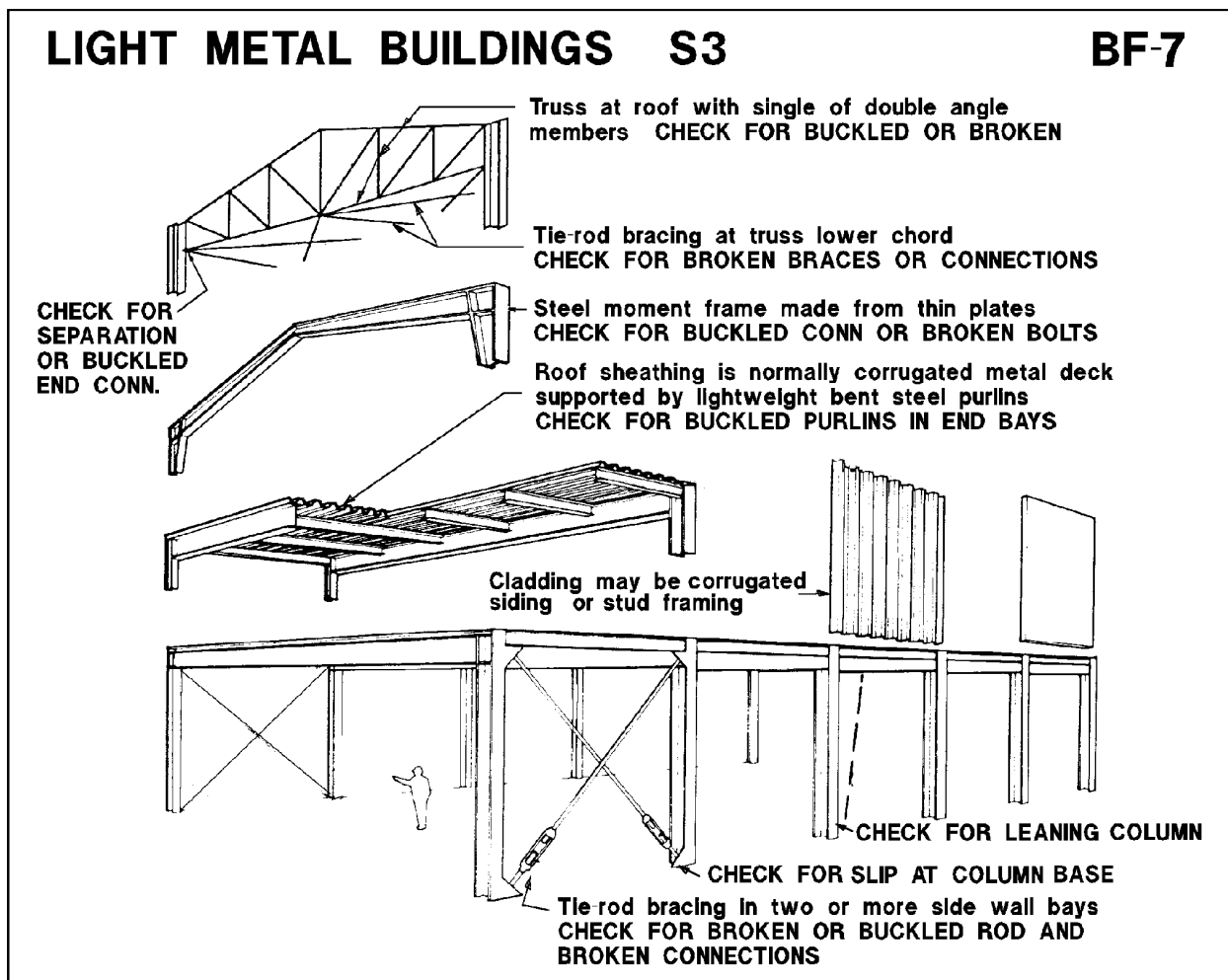
- **Frame System**
  - Heavy Structural Steel (hot rolled sections)
- **Typical Occupancies**
  - Office & Commercial, Industrial,
  - 2 to 30 stories
- **Key Performance Aspects**
  - Normally well-engineered; Members very ductile. Overall performance dependent upon connections and proper proportioning of column strength
- **Combinations**
  - Precast or CIP concrete floors w/ or w/o metal deck
  - Masonry, precast or metal curtain walls
  - Exterior precast walls may perform badly

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### **Light Metal Buildings—S3**

Light metal buildings are normally one-story, pre-engineered buildings sheathed with metal siding and roofing. These structures have been damaged during earthquakes due to poor connections and field errors such as the incomplete welding of joints. However, most of these structures respond well to earthquakes because of their lack of mass and abundance of flexibility. During strong windstorms, however, light metal structures have exhibited the following problems; building walls and roof lose sheathing and the purlins plus girts that were braced by the sheathing will buckle, often leading to the progressive buckling collapse of the entire structure.







- Doors and windows are blown in, leading to greatly increased outward pressures on the leeward wall and roof followed by the shedding of sheathing and, in most severe cases, progressive collapse.
- Tie-rod bracing can be broken or stretched by whipping action. Also, rod end connections can fail as a result of pullout or prying action.
- Lower chord bracing at end walls can buckle due to wind pressure against the wall.
- Since these structures have little redundancy, performance is usually governed by “weakest link” behavior (the failure of one element can lead to progressive/domino type collapse).
- The characteristics are listed on slide

### Concrete Frame Buildings—C1 & C3

C3 Types have infill walls and C1 do not. Older frames are from 1 to 13 stories high and may have URM infill walls. Older frames in California had thin concrete infill walls on property lines in some cases. The most hazardous configurations include soft (high and open) first stories, open front buildings (typical of retail one and two story), and corner buildings (torsion problems). Characteristics are shown in adjacent slide. See next page for graphic of C1 & C2.

The common earthquake problems are:

- Columns break at intersections with floor beam. Inadequate rebar and ties do not confine the concrete when subjected to high shear and tension stresses. Failures may be driven by a strong P-Delta effect.
- Short columns in exterior walls experience high shear and tension stresses focused into them by surrounding concrete mass.
- Bending and punching shear failure occurs at intersections of flat slabs (for example, waffle) and columns.
- URM infill can fall off or pop out of frames. In addition, URM infill can cause columns to shear off at the floor line or at the top of URM.
- Weak concrete and poor construction can make all the above conditions worse.

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### S3 Type Characteristics

- **Frame System**
  - Light-gage Steel (pre-fab metal buildings)
- **Typical Occupancies**
  - Office, Industrial & Commercial
  - Low-rise up to 3 stories
  - Most industrial/commercial are single story
- **Key Performance Aspects**
  - Highly engineered
  - Little redundancy or overstrength; very flexible
- **Combinations**
  - May have wood or light gage metal interior partitions and mezzanine
  - Masonry, precast, tilt-up or metal int./ext. walls

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### C1 Type Characteristics

- **Frame System**
  - Heavy Floor Structure - CIP Non-ductile Reinf Conc
  - CIP Ductile Reinf. Conc., CA & WA post 1980
- **Typical Occupancies**
  - Office & Commercial, Highway bridges
  - 2 to 30 stories
- **Key Performance Aspects**
  - Non-ductile = brittle failure modes when loaded beyond capacity; Cracking generally means significant loss of strength
  - Ductile = robust structural system can absorb considerable energy and sustain considerable cracking w/o loss of integrity
- **Combinations**
  - Various types of infill & partitions = C3 Type

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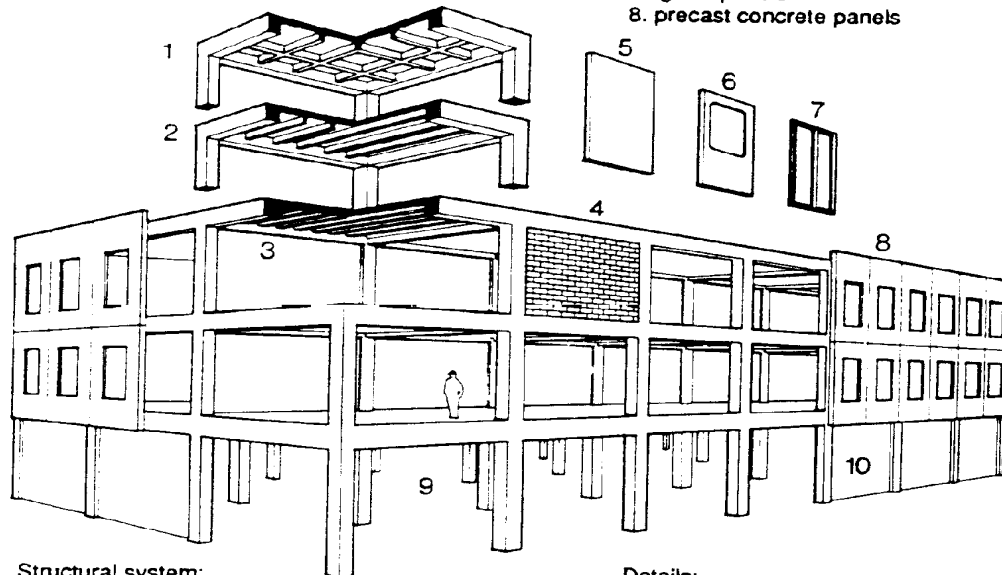
## CONCRETE MOMENT RESISTING FRAME C1 BF-8

Roof/floor diaphragms:

1. concrete waffle slab
2. concrete joist and slab
3. steel decking with concrete topping

Curtain wall/ non-structural infill:

4. masonry infill walls
5. stone panels
6. metal skin panels
7. glass panels
8. precast concrete panels



Structural system:

9. distributed concrete frame

Details:

10. typical tall first floor (soft story)

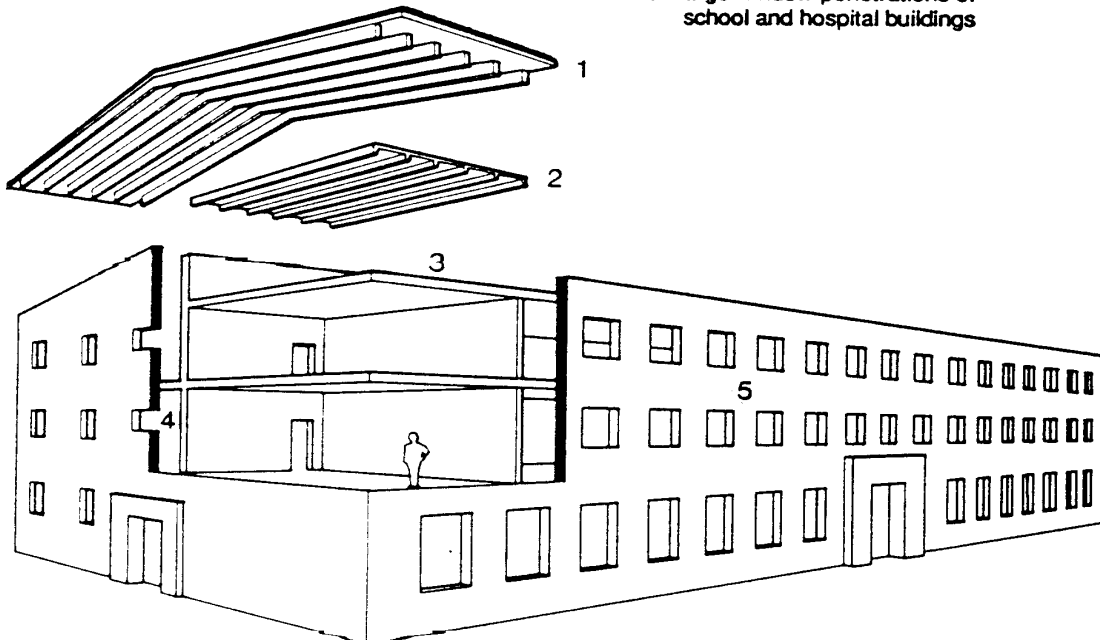
## CONCRETE SHEARWALL BLDG C2 BF-9

Roof/floor span systems:

1. heavy timber rafter roof
2. concrete joist and slab
3. concrete flat slab

Wall system:

4. interior and exterior concrete bearing walls
5. large window penetrations of school and hospital buildings





#### Concrete Shearwall Buildings - C2

These are from one to thirteen stories high with walls on all four sides and/or within the structure as corridor/stair or other divisions between spaces. Walls may have openings "punched in" as doors or windows, but in more modern buildings, the openings may be in groups that are placed between solid wall sections. See graphic on bottom of previous page.

These buildings **rarely collapse** in earthquakes but damage can occur, such as:

- X-cracking of wall sections between openings.
- Severe cracking of shallow wall/floor header sections that frame between solid wall sections.
- Severe cracking or collapse of columns that occur in "soft stories" of otherwise uniformly stiff shearwall buildings (soft first-story, etc.).


#### Precast Concrete Frame - PC2

Are usually one to ten stories tall, although precast wall panels may be used in taller buildings. Floors/roof may be tee, double tee, or hollow core concrete plank sections supported by precast girders and columns. Lateral resistance is often provided by reinforced masonry or concrete walls, but buildings that rely on moment frame resistance have performed very poorly (Armenia).

The common earthquake failures are:

- Joint failures at joints between roof/floor and walls, between roof panels, between wall panels and floor beam-column joints. This can lead to complete collapse as the building breaks into its original precast concrete parts.
- Wall panels separate from building and can fall. If panels are non-bearing only local failure may be the result. In cases the floors/roof supported by the walls can also collapse.
- Progressive collapse can be caused by a joint failure between column and beam or slab and wall panel. This then results in failure of the structure just above, due to lack of support, and also to the structure below, due to debris loading.


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 **C2 Type Characteristics**

- **Frame & Bearing Wall System**
  - Heavy Wall Structure - Reinforced Concrete Shearwalls
- **Typical Occupancies**
  - Residential, commercial, institutional and industrial
  - 1 to 20 stories
- **Key Performance Aspects**
  - Excellent quake, windstorm, blast & fire resistance
  - Special wall edge reinforcing provides ductility and improved ability to resist unanticipated loads
- **Combinations**
  - Structure may contain non-structural, non-ductile elements; Curtain walls & URM partitions

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 **PC2 Type Characteristics**

- **Frame System – (Residential Bearing Wall Sys)**
  - Precast Concrete columns, beams & slabs
  - May have CIP floor fill in CA & WA
  - Residential usually have PC bearing walls
- **Typical Occupancies ( 1 to 12 stories)**
  - Parking Garages, Office, Residential, & Commercial
- **Key Performance Aspects**
  - May have highly engineered prestressed systems – especially Parking Garages.
  - Brittle connections with little reserve strength
  - Bearing wall systems are highly redundant – better performance
- **Combinations (see TU for other walls)**
  - Precast panels used for floors and roofs of masonry and steel frame structures.

SCT1c-1 & 2 Slide 40



## PRECAST CONCRETE BUILDINGS PC2

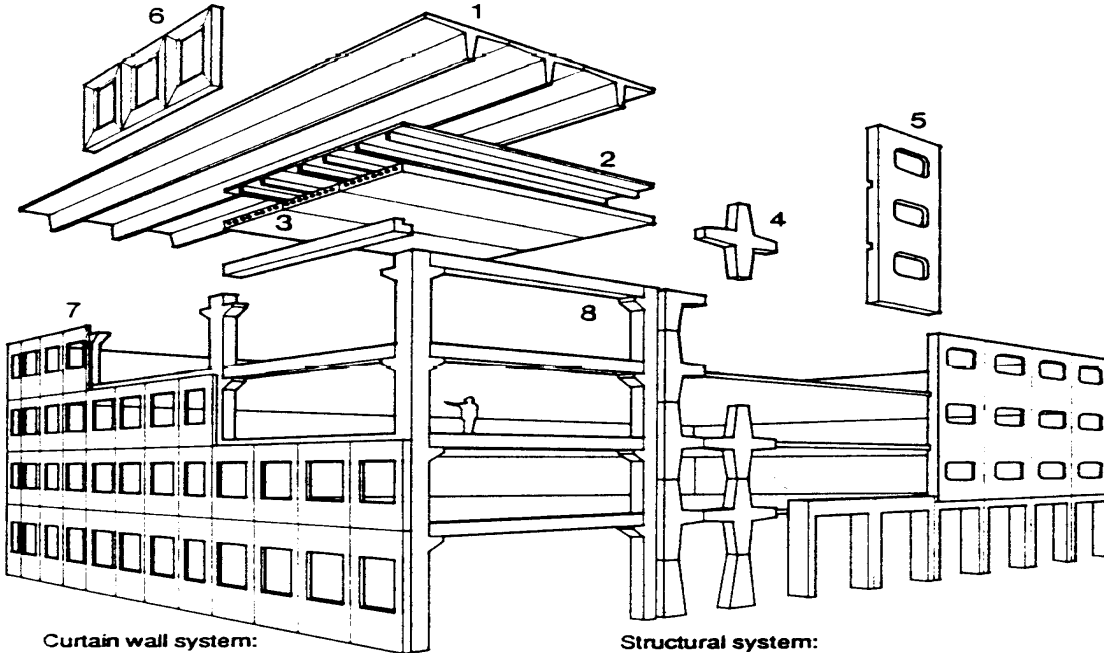
BF-10

### Roof/floor span systems:

1. structural concrete "T" sections
2. structural double "T" sections
3. hollow core concrete slab

### Wall systems:

4. load-bearing frame components (cross)
5. multi-story load-bearing panels



### Curtain wall system:

6. precast concrete panels
7. metal, glass, or stone panels

### Structural system:

8. precast column and beams

## TILT-UP CONCRETE WALL BUILDING

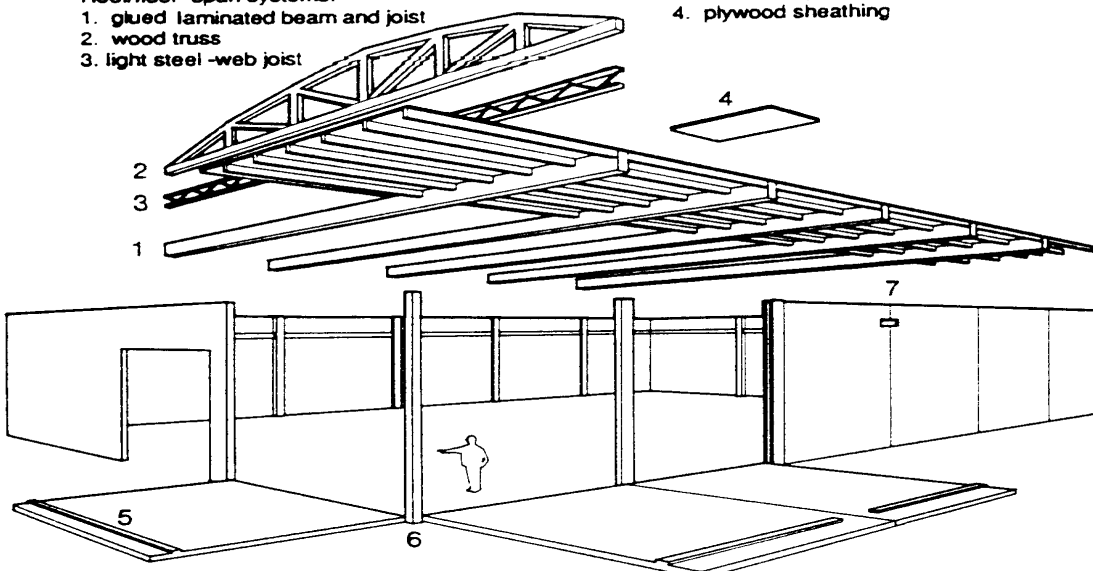
BF-12

### Roof/floor span systems:

1. glued laminated beam and joist
2. wood truss
3. light steel -web joist

### Roof/floor diaphragms:

4. plywood sheathing



### Details:

5. anchor bolted wooden ledger for roof/floor support

### Wall systems:

6. cast-in-place columns—square, "T" shape, and "H" shape
7. welded steel plate type panel connection

**ONE STORY TILT-UP BUILDING  
(MAY ALSO BE 2 OR 3 STORY)**



#### **Tilt-Up Concrete Wall Buildings - TU**


These are usually one-story buildings with wood roof, but may be up to three stories. May have wood floors, concrete floors, steel framing with concrete filled metal deck floors, or with up to 1½ " concrete fill on wood floor.

See adjacent slide for characteristics.

The common earthquake problems are:

- Walls separate from wood floors/roof causing at least local collapse of floor/roof, possible general collapse of walls and floor/roof.
- This problem occurred during the Northridge Earthquake to approximately 400 buildings, most of which had strap connections that were cast into walls and bolted to roof members.
- More substantial connections, that can resist both tension and compression, appear to be required, since it has been demonstrated that forces as high as 200% g can be generated at the mid-span of wood roof diaphragms.
- Suspended, precast concrete wall panels can fall off buildings. (Note: suspended concrete wall panels could be a problem on S1, S2, C1, C2, PC2, and RM buildings.)
- Walls may have short, weak columns between window openings that fail due to inadequate shear strength. Large buildings that are TEE, L, or other non- rectangular plan configuration can have failures at the intersecting corners.
- The major weight of these buildings is normally in the walls, and most failures are limited to exterior bays of the buildings, supported by the walls.

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**TU Type Characteristics**

- **Interior Frame & Exterior Bearing Wall System**
  - Modern low-rise, most single story but up to 4 stories.
  - Long span roof (50ft+) and floors (25ft+).
- **Typical Occupancies**
  - Office, commercial, light industrial and institutional
- **Key Performance Aspects**
  - Robust wall panels dependent upon diaphragms for out-of-plane support.
  - Wall/diaphragm connection vulnerable – Retrofit in CA
- **Combinations**
  - Light frame or steel joist diaphragms
  - Lt wt. concrete floor fill in multi story bldgs

SCT1c-1 & 2 Slide 47

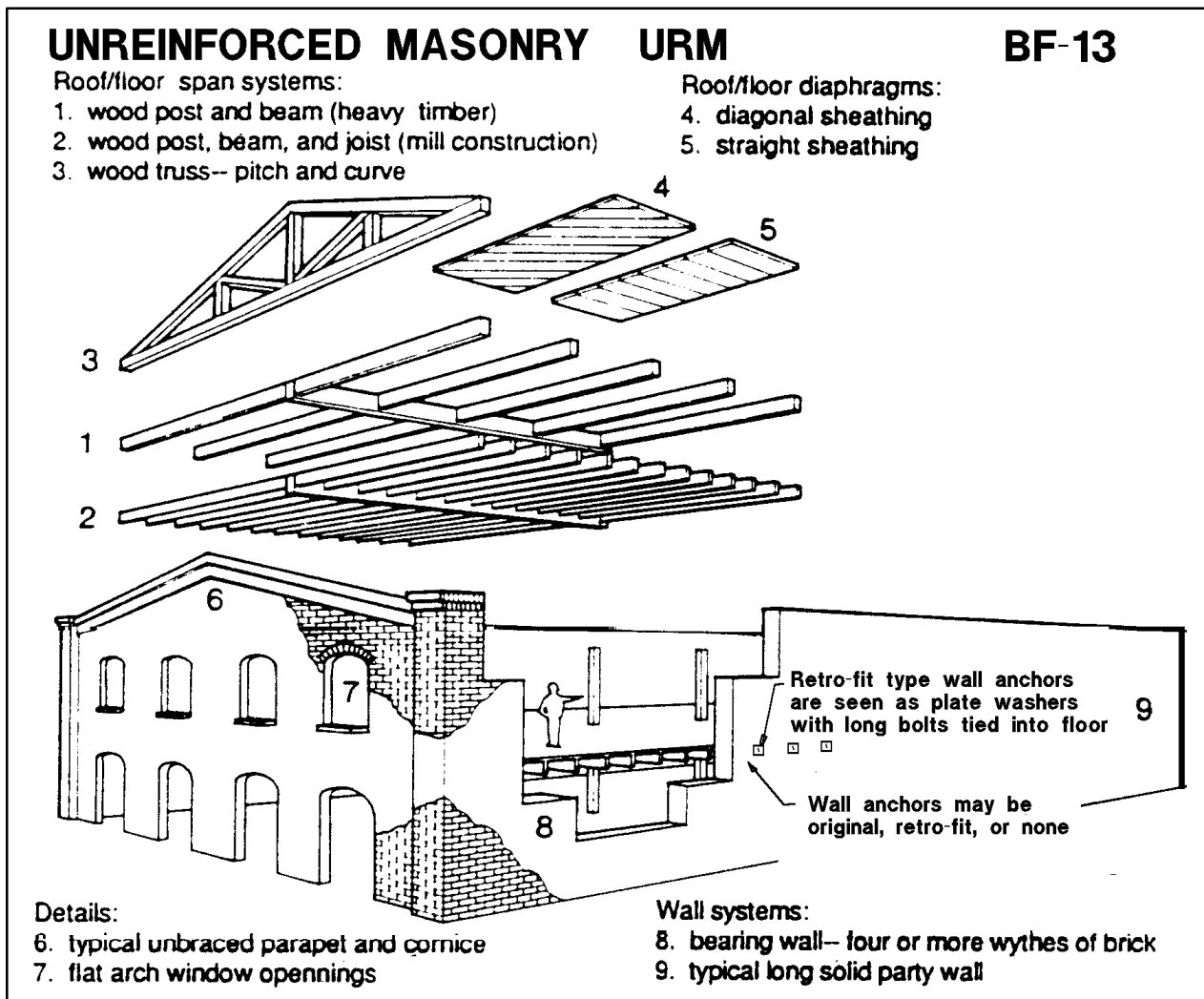


### **Unreinforced Masonry Buildings—URM**

Are usually from one to six-story buildings with URM bearing walls, wood floors, and wood interior, bearing and non-bearing partitions. There are estimated to be as many as 50,000 in California, however, most have been strengthened. This would include steel and concrete frames with URM infill.

In addition to bearing wall URM, there are structures with unreinforced or under-reinforced hollow concrete block walls, and native stone, adobe, etc., bearing wall structures.

Masonry veneer may be found on URM bearing wall structures, and wood or light metal frame structures.





### Unreinforced Masonry Buildings – URM

See adjacent slide for characteristics.


The following problems are common in earthquakes.

- Parapets and full walls fall off buildings due to inadequate anchors.
  - ◆ The parapets and upper story walls are most likely to fall first, due to experiencing higher inertial loads
- Multi-thickness walls split and collapse or break at openings.
- Mortar is often weak and made with too high a lime content.
- URM walls that are more heavily loaded by roof and floors tend to perform better than ones that are parallel to framing, since the load of the floor tends to compress the URM together.
- Roof/floors may collapse if there are no interior wall supports and if long duration earthquake occurs.
  - ◆ Interior wood bearing and non-bearing walls, will often support the roof and floors, especially in building with shorter spans
- Older steel frame buildings with unreinforced or lightly reinforced masonry infill, often shed this brittle covering as they flex to resist the quake.
- Broken bricks often line the streets where these buildings are located, and people can be trapped on the sidewalk or in automobiles.
- Cavities are usually formed by wood floors in familiar patterns of V, lean-to, and complicated pancake (which will be discussed later under Earthquake Collapse Patterns).

### **SUMMARY**

We have reviewed the basic concepts of structural materials, structural systems and common building characteristics in order to focus on how buildings behave when subjected to extreme loading.

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#### URM Type Characteristics

- **Bearing Wall System**
  - Heavy Wall Structure Unreinforced Masonry (includes unreinforced brick & CMU low-rise bldgs)
  - Older "red brick" with bond/header courses
  - Lack of strap anchors & ties (except Retrofit in CA)
- **Typical Occupancies (1 to 8 Stories)**
  - Residential, commercial, and industrial
- **Key Performance Aspects**
  - Brittle with little capacity to resist unanticipated loads. Numerous interior walls may prevent floor collapse
- **Combinations**
  - Heavy timber, light frame or steel joist diaphragms, with concrete floor fill in multi story bldgs.

SCT1c-1 & 2 Slide 53

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#### Types of URM Buildings

- **Brick bearing wall buildings -**
  - URM exterior walls w or w/o URM veneer
  - Wood floors & interior wood walls.
- **URM infill - in concrete or steel frames.**
  - Infill is brick, hollow clay tile, hollow CMU
- **CMU - Hollow conc block bearing wall .**
  - May have bond beams at floor & roof
  - Tie Beam/Tie Col is currently used in Florida
  - May also have vertical bars at edges of openings

SCT1c-1 & 2 Slide 50

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#### URM Type Characteristics

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SCT1c-1 & 2 Slide 53



## Part 2 - Causes of Collapse

The objectives for this section are listed in the adjacent slides. In this section, we will discuss the following:

- The types of forces that load structures,
- The method that is used to classify structures and the types of problems that buildings have experienced in the past,
- The collapse patterns that have occurred that will give us some insight into how structures will behave in the future.

### Earthquake Basics

Earthquakes are catastrophic events that occur mostly at the boundaries of portions of the Earth's crust called tectonic plates. When movement occurs in these regions, along faults, waves are generated at the Earth's surface that can produce very destructive effects. We will summarize the things that US&R response personnel **need** to know about these events.

### Earthquake Magnitude

*Earthquake magnitude* refers to a way of measuring the total energy released by a quake, which could also relate to the total damage done (all else being equal). If we compare the two quakes illustrated (Large Quake and Great Quake) on the slides, we can demonstrate what this means to US&R. With respect to a quake with a larger magnitude, the following can be said:

- The maximum intensity of shaking may be similar.
- The duration of the shaking (at the fault) is longer.
- The length of the fault break is longer (directly related to duration).
- The area of the Earth that will be effected by intense shaking is MUCH larger, and, therefore, the potential for greater US&R involvement is MUCH larger.

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### Terminal Objectives

- The Student shall understand the Extreme Environmental and Man caused Forces and how they Effect Structures.
  - Also how they may effect US&R Operations
- Those Forces are:
  - Earthquake – Motion, not a Force
  - Wind
  - Blast
  - Fire

SCT1c-1 & 2 Slide 57

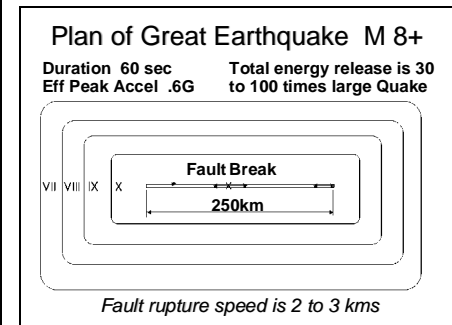
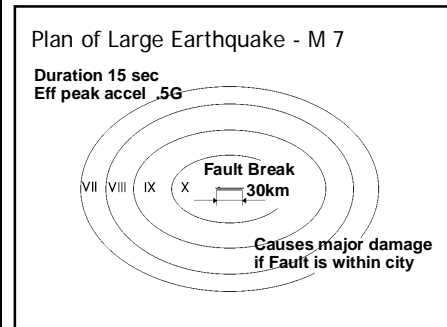
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### Earthquake Basics

- Extent of damage is determined by
  - Type of shaking that occurs at site
  - Coupled with the structures response
- Magnitude (energy release)
  - Mag. 8 releases about 30 times as much energy at Mag. 7
  - Determines POTENTIAL number of effected structures
- Aftershocks
  - Earthquakes are unique type of disaster
  - Just keeps on giving

SCT1c-1 & 2 Slide 58







### Aftershocks

These smaller quakes occur after ALL large earthquakes. They are usually most intense in size and number within the first week of the original quake.

- They can cause very significant re-shaking of damaged structures, which makes earthquake-induced disasters more hazardous to US&R than most others.
- A number of moderate quakes (6+ magnitude) have had aftershocks that were very similar in size to the original quake.
- Arrays of strong motion instruments can be set out after an earthquake, and data from aftershocks will allow the mapping of the fault surface. These instruments can also be coupled with a warning system to notify US&R TF before the effect is felt at a building site (discussed in Monitoring).
- Aftershocks diminish in intensity and number with time. They generally follow a pattern of there being at least one large (within one Richter magnitude) aftershock, at least ten lesser (within two Richter magnitude) aftershocks, one hundred within three, and so on (see the adjacent slide).
- The Loma Prieta earthquake had many aftershocks, but the largest was only magnitude 5.0 with the original quake being near magnitude 7.1.
- Wood, masonry, and concrete structures have collapsed during aftershocks, (even during one of the relatively moderate [5.0] Loma Prieta aftershocks).

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### Aftershocks

- Smaller quakes that occur on same fault as original quake.
  - Minor fault adjustments
- Occur after most quakes regardless of size of original shock
- On average largest is 1.2M less than original
  - Some have been almost as large as original. (in range of M 6)
- Will occur during US&R Ops since are most prevalent in first week.

SCT1c-1 A.2 Slide 59

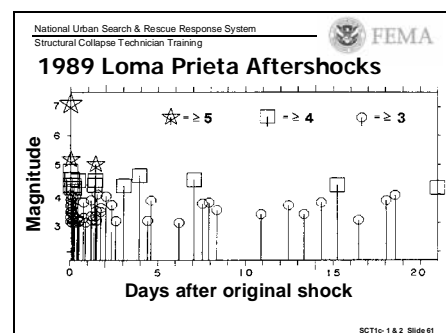
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### How Many Aftershocks ?

- USGS - Rule of Thumb
  - For every single decrease in magnitude, get 10 fold increase in number
- If original quake is M 7
  - 1 or so aftershock in range of M 6
  - 10 " " " " " 5
  - 100 " " " " " 4
  - 1000 " " " " " 3
- Have fewer as time passes
  - Day 2 = 1/2 as many as day 1
  - Day 3 = 1/3 as many as day 1
  - Day 4 = 1/4 as many as day 1, etc

SCT1c-1 A.2 Slide 60

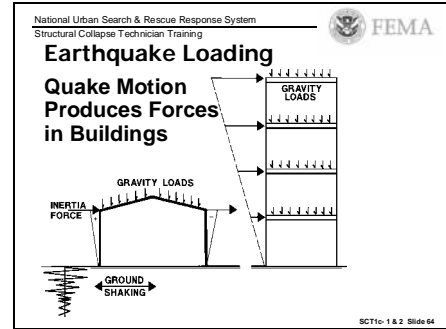




## **Basic Structural Loading**

### **Earthquakes**

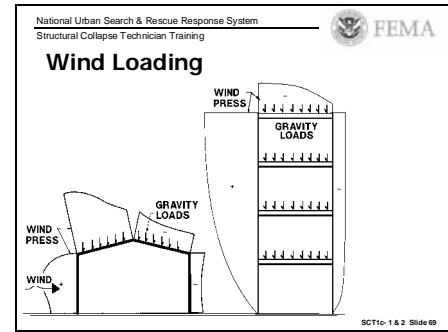
- Some of the most destructive effects caused by earthquake shaking are those that produce lateral loads in a structure. The input shaking causes the foundation of a building to oscillate along a more or less horizontal plane. The building mass has inertia and wants to remain where it is. Therefore, lateral forces are exerted on the mass in order to bring it along with the foundation. This dynamic action can be simplified (in an upside-down way) as a group of horizontal forces that are applied to the structure in proportion to its mass, and to the height of the mass above the ground.
- In multi-story buildings with floors of equal weight and relatively light walls, the loading is further simplified as a group of loads, each being applied at a floor line and each being greater than the one below, a triangular distribution. Seismically resistant structures are designed to resist these lateral forces through inelastic action and must, therefore, be detailed accordingly. These loads are often expressed in terms of a percentage of gravity weight and can vary from a few percent to nearly fifty percent of gravity weight.
- There are also vertical loads generated in a structure by earthquake shaking, but these forces rarely overload the vertical load resisting system. Earthquake induced vertical forces have caused damage to heavy concrete structures with high dead load compared to design live load. These vertical forces also increase the chance of collapse in concrete frame buildings due to either increased or decreased compression forces in the columns (increased compression that overloads columns or decreased compression that reduces column bending strength).





### Windstorms

- Forces are generated on the exterior of the building based on its height, local ground surface roughness (hills, trees, other buildings), and the square of the wind velocity. The weight of the building, unlike the earthquake condition, has little effect on wind forces but is helpful in resisting uplift.
- Unless the structure is penetrated, all the forces are applied to the exterior surfaces of the building, in contrast to earthquakes, in which both exterior and interior walls are loaded proportionally to their weight.
- Wind pressures act inward on the windward side of a building and outward on most other sides and most roof surfaces. Special concentrations of outward force resulting from aerodynamic lift occur at building corners and roof edges, especially overhangs.
  - ♦ Wind pressure becomes much greater with increased speed.
  - ♦ The Pressure is proportional to the Speed<sup>2</sup>. That is the pressure from a 100 mph wind is 4 times as great as a 50 mph wind.
  - ♦ Hurricane speeds vary from 74mph to 155mph.
  - ♦ Tornado speeds can exceed 250mph.
- The overall structure must be designed for the sum of all lateral and uplift pressures. Individual parts must be designed to resist the outward and inward pressure concentrations and must be connected to supporting members (beams, columns, walls, and foundation) to form a continuous resistance path. Forces are also generated on structures by airborne missiles that vary in size from roofing gravel to entire sections of roofs.



### **Destructive Windstorms**

- **Hurricanes**
  - Large circular systems created by low pressure over ocean near equator
  - May be 100 + mi. in diameter, winds up to 150mph
  - Damage due to wind + storm surge
  - Wind Force is Proportional to Speed<sup>2</sup>
    - Force from 100mph = 4 times that from 50mph
- **Tornadoes**
  - Violent vortices originating over land, usually created by colliding air masses.
  - May be 1 mi. in diameter, winds up to 300mph



## **Explosion**

- Explosions occur when a solid or concentrated gas is transformed into a large volume of hot gases in a fraction of a second.
- In the case of high explosives, detonation (conversion of energy) occurs at a very high rate (as high as 4 mi/sec) .
- Low explosives (such as gunpowder) undergo rapid burning at the rate of about 900 ft/sec.
- The resulting rapid release of energy consists of sound (bang), heat and light (fireball), and a shock wave that propagates radially outward from the source at subsonic speeds for most low explosives and at supersonic speeds for high explosives.
- It is the high magnitude, very short duration (milliseconds) shock wave, consisting of highly compressed particles of air that causes most of the damage to structures.
- When natural gas explosions occur within structures, gas pressures can build up within confined spaces, causing extensive damage.
- In all explosions, large, weak, and/or lightly attached wall, floor, and roof surfaces may be blown away.
  - ♦ The columns and beams in steel frame structures may survive a blast, but their stability may be compromised by the removal of their bracing elements (floors, shear walls).
  - ♦ In large explosions, concrete slabs, walls, and even columns may be blown away, leading to conditions that will produce progressive collapse as illustrated in the slide.
- In 1960, a progressive collapse started when a natural gas explosion caused the collapse of an exterior wall on the 18<sup>th</sup> floor of a 22-story building.
- The force of the falling weight of the floors above caused all the floors to collapse to the ground.

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### **Explosion Basics**

- **Explosion is chemical reaction involving:**
  - Rapid expansion of Gas
  - Liberation of Heat
  - Explosion is defined as bursting of an enclosure due to development of internal pressure
- **High Explosive (Primary & Secondary)**
  - Primary Explosives - detonate by simple ignition due to spark, flame, impact or friction
  - Secondary Explosives - are relatively insensitive to simple ignition and are detonated by shock from a Primary Explosive
  - Detonation results when a combustion zone (conversion of energy) proceeds at greater than the speed of sound (as high as 4mi/sec)

SCT1c-1 & 2 Slide 75

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### **Explosion Basics**

- **Low Explosive (or Propellants)**
  - Deflagration (rapid burning) results when a combustion zone proceeds from the ignition point at less than speed of sound
    - ♦ Black Powder, Rocket Fuel, Flammable Gas, Dust
  - If Low Explosives are confined they can Detonate
- **Detonations vs Deflagrations**
  - Detonation pressures usually much higher
  - Deflagration duration is normally longer
  - If collapse is not initiated, effects of Detonation can be more localized

SCT1c-1 & 2 Slide 76

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### **Explosion Effects**

- **Rapid release of Energy**
  - Sound (bang) and Heat and Light (Fireball)
  - Shockwave (very high, but short duration pressures)
- **Shockwaves (Pressure Wave)**
  - Propagates, radially outward in all directions from source and causes most of the damage to Structures
  - Diffracts, creates both amplifications & reductions
  - Short term nature (milliseconds) allows structures to survive much higher than "Static Design" pressures
- **Other Effects**
  - High speed winds (sucking effect after wave passes) propels debris
  - High intensity, short duration ground shaking

SCT1c-1 & 2 Slide 77

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### **Interior Explosion Loading**

SCT1c-1 & 2 Slide 78

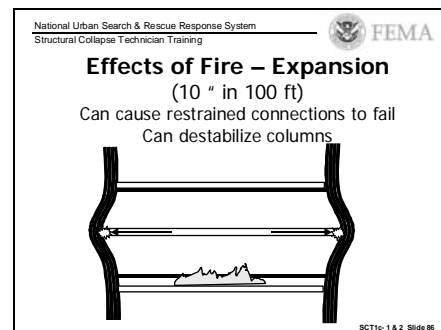
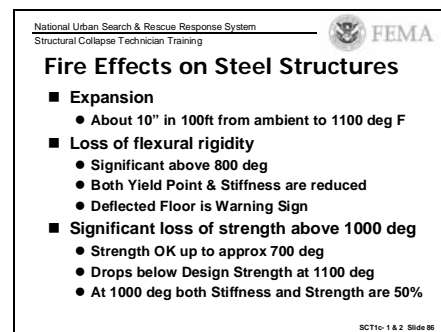
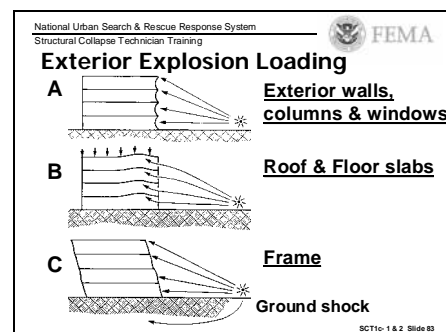
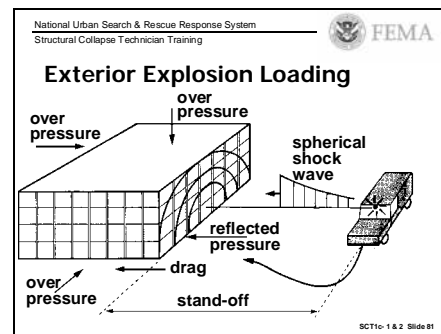


- In the case of an exterior explosion from a bomb, the shock wave is initially reflected and amplified by the building face and then penetrates through openings, subjecting floor and wall surfaces to great pressure.
  - ◆ Diffraction occurs as the shock propagates around corners, creating areas of amplification and reduction in pressure.
  - ◆ Finally, the entire building is engulfed by the shock wave, subjecting all building surfaces to the over-pressure.
- ◆ A secondary effect of an air-blast is a very high velocity wind that propels debris outward (as deadly missiles). In addition, a high intensity, short duration ground shaking (earthquake) may be induced.
- In very large explosions at close proximity to reinforced surfaces, the effect can be so severe that the concrete is locally disintegrated and separated away from the reinforcing steel.
  - ◆ Lighter wood, steel frame, and even pre-cast concrete buildings can be leveled by explosions as the wall and floor and/or roof planes are blown away, leading to an overall stability loss.

### Effects of Fire on Steel Structures

The excess heat caused by fire will have the following negative effects: expansion, loss of flexural rigidity, and loss of strength.

- **Expansion**
  - ◆ The coefficient of thermal expansion increases with temperature. At 70° F, it is .00065 for a 100° change in temperature, and this increases to .0008 inches per inch at 1000° F.
  - ◆ The total change in length for a change in temperature of 1000° is about 10 in.
  - ◆ In structures where lateral restraint is provided by walls or rigid columns, this excessive expansion can cause connections to fail and horizontal members to buckle.
  - ◆ Excessive expansion can also induce destabilizing forces in columns and exterior walls.



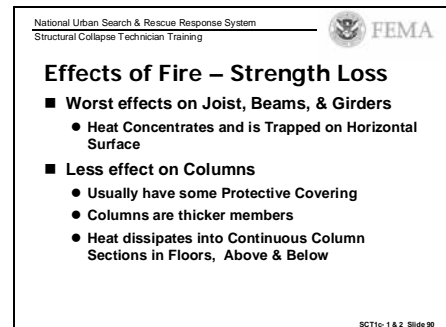
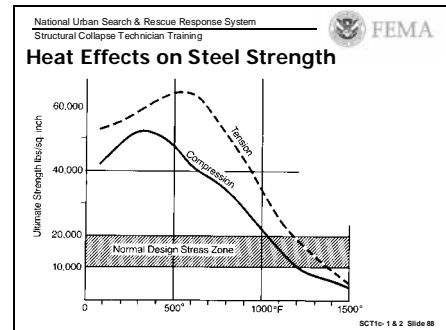
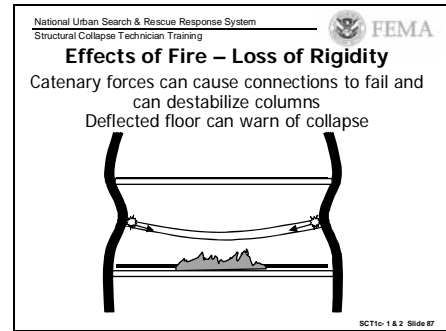


- **Loss of Structural Rigidity**

- ◆ Both the yield strength and modulus of elasticity of steel drop to about 75 percent of normal values when the temperature reaches 800° F. They drop at an increasing rate at greater temperatures.
- ◆ In fires, this drop results in the formation of “draped” or “bellied” beams and girders that generate significant tension stresses in their connections.
  - These stresses can lead to the failure of the joints and collapse of floor sections.
  - By being forewarned of this behavior, firefighters may avoid a deadly collapse.

- **Loss of Strength**

- ◆ Steel actually gains strength when the temperature is raised from ambient to about 700° F.
- ◆ For the normal structural steel used in buildings (A-36), both the strength and stiffness are reduced to about 50 percent at 1000° F.
- ◆ Steel drops below the “design” strength at about 1100° F, and failure of a loaded structure will occur more quickly above this level (see the slide).
  - Collapse due to strength loss is usually seen first in floor members, especially lightweight members such as bar joists and other trusses.
  - Heat is concentrated at the undersides of floors, and low mass, high surface area members will be heated most rapidly.
- ◆ Columns have a much better chance of surviving the effects of fire.
  - They usually have some sort of covering, even if it is not “fire rated.”
  - They are usually made from heavier, more compact sections.
  - They may be able to dissipate the heat if they extend to floors above the fire area.





- **Building Code Fire Resistive I.D.**
  - ◆ Building Codes divide buildings into five categories based on the combustibility of their materials and amount of fire resistance.
  - ◆ They are listed as Type 1 through Type 5, with Type 1 being the most fire resistive and Type 5 the least fire resistive.
  - ◆ These Types are defined in the adjacent slide.
  
- **Fire Effects on Type 1 Steel Structures**

Before the attack on the World Trade Center on 9/11/01, no Type 1, multi-story, fireproofed steel structure had ever collapsed due to fire.

  - ◆ A few of this type had burned for several hours, but none had collapsed.
  - ◆ The most notable fire of this type occurred at One Meridian Plaza in Philadelphia, when, based on the inadequacy of water supply, the decision was made to withdraw fire forces. The fire then burned through 10 floors, slowly transferring from floor to floor, until it was extinguished by an upper floor fire sprinkler system.
  - ◆ Spectacular high-rise fires in both Los Angeles and Las Vegas burned for hours but did not cause structural collapse. Well-organized evacuations were accomplished in both cases, with helicopters being used successfully in the early 1980's to remove occupants from the Las Vegas fire.
  
- **Fire Effects on Unprotected Steel Structures**

Several spectacular fire-caused collapses of unprotected, long-span, low-rise steel structures have occurred.

  - ◆ McCormick Place was a large exhibition hall in Chicago that burned in 1967 (loss of \$154 mi).
    - No fireproofing was required since the steel truss roof structure was more than 30 ft above the floor.
    - Exhibition booths that in some cases were two-stories high produced the fire load.
    - Once started, the fire was able to produce enough heat to collapse the roof structure.

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**Building Code Fire Resistive I.D.**

- **Type 1 - Non-combustible Construction**
  - 4-hour Exterior Walls
  - Structure has 2 & 3-hour Fire Protection
- **Type 2 - Non-combustible Construction**
  - May have 1-hour or Non-rated Protection
- **Type 3 - Non-combustible Exterior Walls**
  - 4-hour Exterior Walls
  - May have combustible Roof, Floor & Interior Walls, w/ or w/o Fire Protection
- **Type 4 - similar to Type 2**
  - Lower Fire Protection Requirements
- **Type 5 - Wood or Lt. Metal frame**
  - May require 1 hour Exterior and Dividing Walls

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**Fire Effects on Steel Structures**

- **Type 1 - Fire Protected Steel Bldgs**
  - Prior to 9/11 no Type 1, Steel Building had ever collapsed due to Fire
  - Some had burned for many hours
    - ◆ One Meridian Plaza, Philadelphia, 1991, 19 hours (11 hours uncontrolled)
    - ◆ Interstate Bank, L.A., 1988, 4 ½ hrs
    - ◆ MGM Grand Las Vegas, 1981, 11 hrs
      - Multi-Helicopter Rescue from Roof
      - Changed Fire Protection Requirement

SCT1c-1.6.2 Slide 92

**Fire Effects on Steel Structures**

- **Unprotected Steel Building problems**
  - Long span, low rise truss and bar joist structures had spectacular collapses
    - McCormick Place, Chicago - 1967, \$154mil
      - 30ft clear height Exhibition Hall
      - Fuel from 2 story high exhibits
    - Cobo Hall, Detroit, 1960
      - Bar joist roof & walls became spaghetti
  - Commonly used in Gyms & Arenas
    - High School to Professional




- ◆ Cobo Hall in Detroit was also an exhibition facility whose roof was constructed of unprotected, light steel trusses. The roof and some walls completely collapsed into spaghetti due to a contents fire in 1960.
- ◆ NFPA has published reports regarding these incidents, to inform firefighters of the dangers of sudden collapse in these light and long-span steel structures. Building codes have been changed to limit the use and permitted fire load for this type of structure.
- **Collapse of World Trade Center, Building 7**

The collapse of World Trade Center, Building 7 was probably the first Type 1, high-rise steel structure to collapse solely due to fire. It collapsed, starting at the bottom, after burning for about 7 hours, and it appeared that the interior collapsed first. There are several factors that could have contributed to the collapse.

  - ◆ The fire sprinkler system was ineffective because of an inadequate water supply and the situation made worse by a broken water main. (Most systems are designed to extinguish only localized fires.)
  - ◆ The building was constructed over an existing electrical substation that required the use of several transfer trusses. Main columns were terminated at the 5<sup>th</sup> floor.
  - ◆ Emergency generators and 275 gal fuel “day tanks” were placed on the 5<sup>th</sup>, 7<sup>th</sup> and 9<sup>th</sup> floors.
  - ◆ Pipes from a 6,000 gal tank on the 2<sup>nd</sup> floor and/or two, 11,000 gal buried tanks supplied most of the day tanks.
  - ◆ Fuel from broken pipes and/or the tanks could have contributed to the fire (though this theory is subject of study).

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**Fire Effects on Steel Structures**

- **Unprotected Steel Building problems**
  - Long span, low rise truss and bar joist structures had spectacular collapses
    - ◆ McCormick Place, Chicago – 1967, \$154mil
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  - Commonly used in Gyms & Arenas
    - ◆ High School to Professional

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**Collapse of WTC - 7**

- **Fire started at about 1000hrs**
- **FDNY abandoned fire suppression by 1200hrs**
  - Sprinkler system ineffective due to break in water main
  - Design of most Fire Sprinkler Sys assumes smaller fires – overwhelmed by large fires
- **Collapsed at about 1720hrs**
  - Collapse started near bottom of building
  - Initiated by interior collapse
  - Building imploded – stayed within its own footprint

SCT1c-1 & 2 Slide 94

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**Collapse of WTC - 7**

- **Collapse Observations**
  - East Penthouse disappeared first
  - West Penthouse disappeared next and then the entire building went down w/kink in roof
- **Potential Problems**
  - WTC 7 built over Electrical Substation
    - ◆ Used 3 Transfer Trusses at 5th to 7th FI Level
  - 6 locations of generators & 4- 275 gal fuel, “Day Tanks” - on 5th, 7th, 8th & 9th floors
    - ◆ Some Generators & Tanks were near Trans Trusses
    - ◆ Fuel from tanks or broken pipes MAY have contributed to the fire – DISPUTED BY RECENT REPORT

SCT1c-1 & 2 Slide 95





- **Collapse of World Trade Center Tower 1 and 2**

As noted in the adjacent slides, the WTC Towers 1 and 2 probably collapsed due to a combination of factors.

- ◆ After the jetliner struck the towers, the redundant outrigger truss system at the top of the structure redistributed the vertical loads that had been carried by the severed and badly damaged exterior columns to adjacent columns.
- ◆ The debris from the jetliner probably dislodged a significant amount of the sprayed-on fireproofing, especially from the floor trusses.
- ◆ The jet fuel fire ignited the contents of the building.
- ◆ The ensuing fire then caused the initial collapse of the un-fireproofed floors.
- ◆ Once the collapse was started, the load of the upper floors and the dynamics of the moving mass made it impossible to stop.
- ◆ The World Trade Center Building Performance Study, Report 403 is available from FEMA at 1-800-480-2520.


### **Effects of Fire on Other Structures**

- Type 3 and Type 5 buildings that have light wood trusses, especially those that “clear-span” between walls, have been a sudden-collapse problem.
  - ◆ The situation is especially dangerous when the light trusses are constructed in the hidden space above a ceiling. In this case an undetected fire can spread rapidly, fed by the abundant fuel, and cause a sudden collapse.
  - ◆ The National Fire Protection Association states that 34 firefighters have been killed in 19 incidents involving wood trusses from 1997 - 1999 (see [www.nfpa.org](http://www.nfpa.org) for reports).
- Type 3 buildings with concrete or masonry walls and wood roofs have also been the sites for deadly fires.
  - ◆ The wood roof/floors often collapse due to burn-through and can pull exterior masonry or concrete walls in or leave them standing in an unbraced condition (as in the case of the Worcester, Massachusetts fire in 1999).

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**WTC 1 & 2 Effect of Aircraft Impact**

- Impact fractured about 1/2 columns on impact face
- Partial collapse of floors
- Debris penetrated bldg core
  - Damaged some core columns – Severity ??
  - Damaged stair shafts and elevators
- Impact probably caused failure of some fireproofing
- INITIATED FIRE




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**Collapse of WTC – 1 & 2**

- Redundancy permitted structure to resist initial damage
  - Load re-distribution highly stressed many elements
  - Reduced lateral support for other highly stressed elements
- Fire effects
  - Further increase stresses due to expansion
  - Caused failure of some connections
  - Weakened highly stressed elements
- Once collapse initiated, debris weight on lower floors caused progressive collapse



SCT1c-1 & 2 Slide 98

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**Fire Effects on Other Structures**

- Type 3 Bldgs – Conc/Masonry walls, Wood Roof
  - Burnout of Wood roof/floors creates dangerous, unbraced heavy walls
  - Buildings with Light Wood Trusses have been a deadly, Sudden Collapse Problem – 2x members
    - ◆ 34 Firefighters killed in 19 incidents - 1977 thru 1999
  - Bldg's with Lt. Steel Trusses have collapsed suddenly
    - ◆ Furniture Warehouse in 2007 – 9 Firefighters killed
- Type 5 Bldgs – Wood Walls & Wood Roof
  - Many have Attics w/Light Wood Framing (1x & 2x)
  - Same Problem of Intense Attic Fires
    - ◆ Usually less Collapse Issue due to many walls
    - ◆ Still has Deadly Potential

SCT1c-1 & 2 Slide 99



- ◆ These structures tend to have longer span trusses, and a Lean-to collapse or fire caused expansion can push-out the exterior walls into a collapse.
- ◆ The collapse of a roof truss that supports sloped rafters in an end bay can also cause exterior walls to be pushed out (parapets over storefronts are especially vulnerable).
- Type 3 buildings with light steel roofs have also been the site of deadly fires
  - ◆ In 2007 the sudden collapse of a light steel roof at a furniture warehouse caused the deaths of 9 firefighters
- Concrete structures can be damaged due to spalling, and shear walls can be cracked due to floor expansion. This situation is less deadly, but it should be carefully considered.

### **Flood**

- Forces are generated on buildings due to hydrostatic lateral and lifting pressure, hydrodynamic forces, and debris impacts.
- Hydrostatic pressures can highly load foundation and basement walls and lift structures, when the water level is not equalized between exterior and interior spaces.  
Hydrostatic pressure can also lift wood floors and roofs off their bearings.
- River and ocean currents will load frontal and side walls that are submerged, and ocean waves and step-up flows can produce pressures as high as 1000 psf.
- Debris varying in size from floating wood pieces to floating structures can impact a building causing anything from broken windows to a total collapse.

### **Flood – Storm Surge & Tsunami**

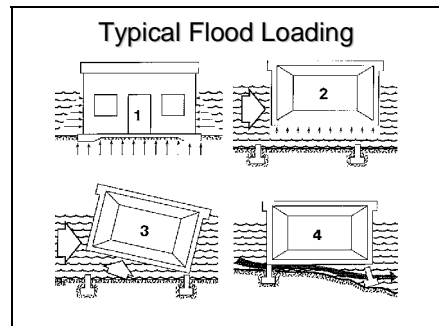
- Water in motion can do considerable damage to substantial structures as seen in the 2004 & 2005 Hurricanes, as well as the Indian Ocean Tsunami.
- Events that may lead to a US&R deployment include floods that may result from a swollen river or a failed dam, or tidal surge associated with a Hurricane or a Tsunami
  - ◆ For Hurricane-induced Storm Surge, evacuation of threatened areas generally minimizes or prevents victims.

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**Fire Effects on Other Structures**

- **Type 3 Bldgs – Conc/Masonry walls, Wood Roof**
  - ◆ Burnout of Wood roof/floors creates dangerous, unbraced heavy walls
  - ◆ Buildings with Light Wood Trusses have been a deadly, Sudden Collapse Problem – 2x members
    - ◆ 34 Firefighters killed in 19 incidents - 1977 thru 1999
  - ◆ Bldg's with Lt. Steel Trusses have collapsed suddenly
    - ◆ Furniture Warehouse in 2007 – 9 Firefighters killed
- **Type 5 Bldgs – Wood Walls & Wood Roof**
  - ◆ Many have Attics w/Light Wood Framing (1x & 2x)
  - ◆ Same Problem of Intense Attic Fires
    - ◆ Usually less Collapse Issue due to many walls
    - ◆ Still has Deadly Potential

SCT1c-1.6.2 Slide 99



**Flood Types**

- **Riverine**
  - Slow Inundating Type
  - Fast moving, Flash Flood
- **Hurricane - Tidal Surge**
  - Fast Moving at Coast
  - Rains may lead to Riverine Flooding
- **Tsunami**
  - Create Catastrophic Waves – more than one
  - Can move inland for one mile or more
  - Create massive debris flows



#### **Soil- Landslide, Mudslide, Debris Avalanche**

- Avalanche is a closely related hazard involving frozen water rather than soil.
- Devastating Mudslides, sometimes called Debris Avalanches, have occurred in many locations throughout the World.
- They most often occur due to the saturation of surface soils, caused by torrential rain. This may cause a mass movement of soil that can devastate most everything in its path.
- On steep hillsides, where upper soils may be marginally stable, at “normal” moisture content, the saturation can de-stabilize the equilibrium by:
  - ◆ Increasing the weight of the soil mass,
  - ◆ Reduce the shear strength of the soil by separating the grains/particles, and,
  - ◆ By lubricating the interface between shallow soils and a more dense, impervious rock material below.
- Examples of landslide disasters are the Love Creek debris flows in Northern CA in 1982 and La Conchita in Jan2005.
  - ◆ In most circumstances, viable voids are unlikely, given the flowability and pressures of the material and the lack of oxygen within the material.
  - ◆ The greatest concerns for Struct Specs in these events would be dealing with potentially unstable soil masses and collapsed structures shifting under the pressures and movement of the debris. As water flows out of the mass, it may consolidate, causing continual later movement and settlement.
  - ◆ At higher water contents, the soil behaves as a very heavy (i.e. 145pcf concrete) fluid, therefore trenches into the soil/debris mass should be shored/braced for twice the forces normal assumed in heavy trench rescue.
  - ◆ The headscarp and upslope debris, and debris mass, all should be monitored for movement.

#### **Landslide, Mudslide – Debris Avalanche**

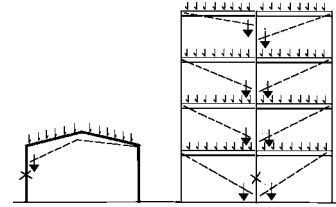
- Often occur due to saturation of surface soils
  - Torrential rains – 6 or more in/day
- Soils on steep hillsides may be marginally stable
  - High water content increases weight and reduces shear strength (inter-pour pressure)
  - Lubricates underlying soil/rock interface
- Produces four US&R issues
  - Continued flow from Headscarp
  - Consolidation/movement as debris mass gives-up water
  - Trench bracing to resist concrete like material
  - Flowability reduces chance of survivable voids
- Need Monitoring of Headscarp and Debris Mass



### **Construction Bracing, Urban Decay, and Overload**

- These sudden collapses usually occur due to gravity loading when a vertical support is either inadequate, overloaded by snow, overloaded because of a plugged roof drain, or reduced in capacity because of age, corrosion, or non-engineered alteration.
- Failures of this type occur all too frequently, but most often affect only one structure at a time. In some cases, building structures with very hazardous conditions have been left standing in this type of collapse (for example, multi-story URM walls left unsupported when wood floors pancaked).

#### **Construction Bracing, Overload**



### **Vehicle Impact Loading**

- Structures have been severely damaged and set on fire by vehicle impacts.
- A 1989 train derailment in California led to a well-organized, integrated response that was successful in saving a victim in what was originally perceived as an un-survivable condition.

#### **Vehicle Impact Loading**

- Planes, Trains, Boats, & Highway Vehicles have impacted Structures
- Collapse and often Fires have resulted
- 1989 Train Derailment in So Cal buried several homes.
  - CAL OES organized and directed a successful deployment of K9 Search to aid local Fire/Rescue forces
  - Demonstrated Value of Integrated US&R

### **Summary**

- We have discussed both Natural and Man-made effects that have been the Causes of Collapse in the past. Each produces unique effects on structures that must be understood.
- Some like Earthquake and possibly Blast can have secondary effects that need to be planned for during US&R incidents.

#### **Review Key Learning Points**

- There are many Environmental and Man caused Forces that Effect Structures.
- Each of these produce Unique Effects on the various Types of Buildings
- Some, like Earthquakes (and possible Blast) have Secondary Effects that must be planned for during US&R Response



### Part 3 - Collapse Patterns

The Objectives for this section are listed in adjacent slides. We will discuss the Collapse Patterns that have occurred which will give us insight on how structures behave when subjected to different types of extreme loading. **The student should then be able to use this knowledge in determining the most probable location of victims.**

Most building collapses occur due to loss of stability. In other words, the basic shape is significantly changed when subjected to a combination of forces. The new, changed shape is much less capable of carrying the forces; therefore, the structure will rapidly continue to change until it finds a new shape that is stable. A typical example of lost stability is that of the slender column that “gets out of the way of the load by buckling” as the load comes to rest on the ground.

**Basic Collapse Patterns** include the following:

- Inadequate shear strength,
- Inadequate beam/column joint strength,
- Tension/compression failure,
- Wall-to-roof interconnection failure,
- Local column failure,
- Single floor collapse.

#### **a. Inadequate Shear Strength**

Inadequate shear strength failures are normally caused by earthquake shaking, but high velocity winds can produce the same effect. It is most commonly seen in wood structures that have weak wall sheathing or walls of insufficient length. It may also be seen in buildings with unreinforced masonry and/or unreinforced concrete walls, as well as in diagonally braced steel frames. In rare instances it could occur when reinforced concrete walls are present.

Basic instability occurs when gravity load is offset a distance that is large enough to overcome the shear capacity of walls at a particular level, in first story. The horizontal resistance required to maintain stability in the racked condition is proportional to the percent of offset. For example, when a 10-foot-high story is offset 1 foot, then 10 percent of the total gravity load above that level is required to keep the parallelogram from becoming flatter. This is the **Offset Collapse Pattern**.

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**Terminal Objectives**

- The Student shall understand the how building structures can be separated into specific types that exhibit unique collapse patterns when subjected to extreme forces due to Earthquake, Wind, and Explosions
- The Student will be able to use this knowledge to assist in determining locations of Potential Victims

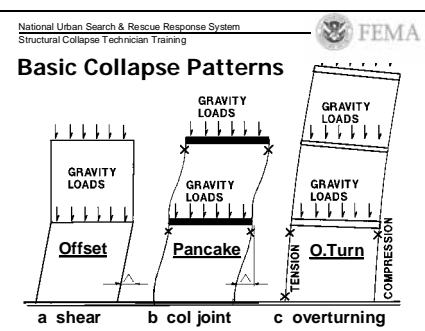
SCT1c-3 Slide 2

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**Key Learning Objectives**

- Quake, Wind and Blast produce Unique Effects on Different types of Structures
- Each of these produce Unique and Recognizable Collapse Patterns
- This Knowledge will allow us to Recognize the Survivable Voids and potential victim location

SCT1c-3 Slide 3





### **b. Inadequate Beam/Column Joint Strength**

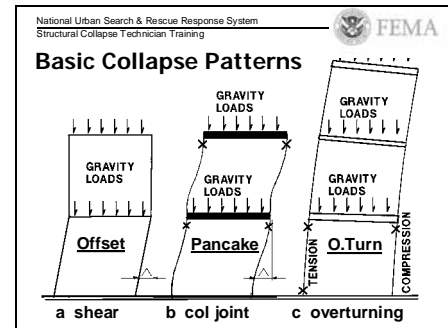
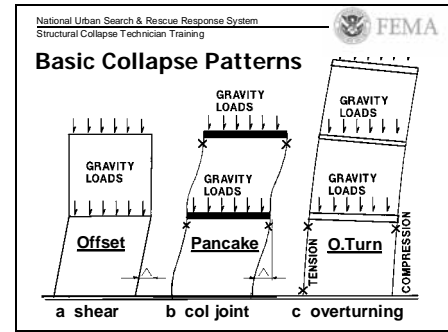
Inadequate beam or column joint strength failures are caused mostly by earthquake shaking of buildings that have joints with poorly confined concrete.

- The cycling of the structure when excited by the earthquake causes moment-resistant joints to unravel as concrete chunks are stripped away from the reinforcing steel cage.
- The gravity load can no longer be supported by these columns, and it drives the structure earthward until it stops on the ground or lower floors that have sufficient strength to stop the falling mass.
- This type of collapse may result in a pancaked group of slabs held apart by broken columns and building contents, or a condition in which columns are left standing, punched through the slabs. The slabs may or may not be horizontally offset from each other. This is a **Pancake Collapse Pattern**.

### **c. Tension/Compression Failure**

Tension or compression failure is caused mostly by earthquakes and usually occurs in taller structures with concrete shear walls and/or concrete or structural steel moment-resistant frames.

- The tension that is concentrated at the edges of a concrete frame or shear wall can produce a very rapid loss of stability.
- In walls, if the reinforcing steel is inadequately proportioned or is poorly embedded, it can fail in tension and result in the rapid collapse of the wall by overturning.
- A more common condition occurs when the tension causes the joints in a concrete moment-resistant frame to lose bending/shear strength. As previously discussed, a rapid degradation of the structure can result in partial or complete pancaking, as is the case with beam or column failure.
- The failure of the Pino Suarez Tower is an example of how poorly proportioned, steel structures can catastrophically overturn as a result of the compression failure of the columns. We will call this an **Overturn Collapse Pattern**.





### d. Wall-to-Roof Interconnection Failure

In a wall-to-roof interconnection failure, stability is lost since the vertical support of the roof/floor is lost in addition to the horizontal out-of-plane support of the wall.

This condition can be triggered by any of the destructive forces previously mentioned.

We will call this a **Wall Fall Collapse Pattern**.

### e. Local Column Failure

Local column failure can lead to a loss of stability and/or a progressive collapse in a part of a structure and may, again, be caused by any of the previously mentioned forces.

Pre-cast concrete and structures that have wood floors tend to be more susceptible to a progressive type failure because of a lack of continuity in these construction configurations.

### f. Single Floor Collapse

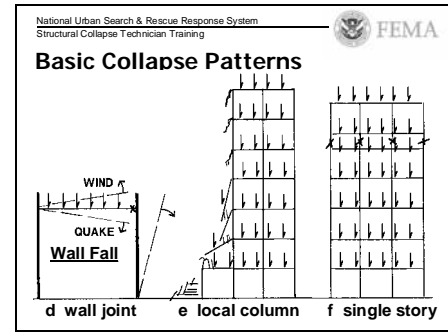
Single floor collapse has occurred in earthquakes due to pounding or vertical irregularities that focus the damaging effects on a single story.

Most common of this type of collapse is a **Soft First Story Collapse**, which we will discuss later.

### Summary, Basic Collapse Patterns

In summary, in most collapses (except cases in which wind causes lifting), the driving force is the gravity load acting on a structure that has become unstable because of horizontal offset or insufficient vertical capacity. In addition, subsequent lateral loads from wind or aftershocks can increase the offset, exaggerating the instability. The structure is often disorderly as it collapses. Some parts may remain supported by adjacent un-collapsed bays as tension structures.

**The issue in US&R is not the academic one of how the structure collapsed but what additional collapse is possible, how stable is the existing configuration, and where are the most probable location of survivors.**





### NFPA, 5 Collapse Patterns

There are five collapse patterns that have been defined by the NFPA 1670 Committee. This committee sets the standards for various types of training that involves first responders.

These five were taken from WW-II Civil Defense documents, and are useful in communicating basic patterns. In this manual we will present additional collapse patterns that better describe collapses that involve more modern construction.

Understanding the types of collapse patterns will provide valuable information in determining everything from the need for shoring, the types of shoring to be used, possible victim location, and victim access to the probability of victim survivability.

It should be noted that one may find more than one collapse type in addition to the primary type at a given incident.

### Earthquake Collapse Patterns

#### The Basic Principals

- Earthquake shaking causes damage to structure.
- Gravity causes collapse.
- Redundancy and ductile behavior can prevent or reduce the extent of a collapse.
- Brittle behavior enhances the possibility and increases the extent of a collapse.

### Earthquake Survivability

As discussed on Section I, the focus of US&R is to find and remove as many trapped victims as possible. As shown on adjacent slide, the survival rates decrease with time. The first 24 to 36 hours are often referred to as the **Golden Hours**. Even though survivors have been located and removed after as many as 14 days for earthquakes, these are rare occurrences. It is important that responders use their knowledge of collapse patterns to assist search in prioritizing the disaster site.

We will later discuss that survivability following blasts is very low, as few, have survived within the collapse zone

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**NFPA 1670, 5- Collapse Patterns**  
Based on WW-2 Arial Bomb Damage

Lean-To Vee A-Frame  
Pancake Cantilever

**We will look at All Collapse Types**

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**Earthquake Collapse Patterns**  
Basic Principles

- Earthquake shaking causes damage to structural load resisting system
- Gravity causes structural collapse
- Redundancy and Ductile behavior can prevent structural collapse
- Brittle behavior enhances possibility of structural collapse

SCT1c-3 Slide 7

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**Earthquake Survivability**  
Survival vs Time of Extrication

1 Hour	95 %
1 Day	81 %
2 Day	37 %
3 Day	34 %
4 Day	19 %
5 Day	7 %

Individuals have survived for as long as 14 days in confinement

SCT1c-3 Slide 8





#### Basic Building Types

Based on previous earthquakes, the ATC-20 building types can be further divided into five separate groups, each exhibiting a distinctive collapse pattern. These groups are:

- **Light Frame:** mostly wood frame;
- **Heavy Wall:** URM, tilt-up, and other low-rise buildings with concrete and masonry walls;
- **Heavy Floor:** concrete frame buildings and highway bridges;
- **Pre-cast Concrete Buildings:** fairly heavy floors and some heavy walls.
- **Steel Frame Buildings:** either moment frame or diagonally braced frame buildings. Most collapse problems have occurred in diagonally braced buildings.

#### Light Frame Collapse Patterns

- These structure are unique in that they may be described as **Skin and Bones** structures. The lateral load resisting Skin is separate from the vertical load resisting studs, posts, and columns. In an earthquake the sheathing is the element that attempts to resist the lateral movement, and the bones only receive additional stress if they are located at the edges of walls
- Collapse usually occurs when the sheathing on the lower walls have insufficient strength to resist the lateral forces and the walls rack (become parallelograms). This is called an **Offset Collapse Pattern**.
- If there is a sufficiently heavy load on these walls, they can completely collapse as the wall top moves sideways a distance equal to its height, as shown in the slides.
- This movement causes the structural collapse to be in the form of part or all of the building being projected away from its original foundation by the height of the story walls that fail.

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#### Earthquake Collapse Patterns

- **Light Frame - Wood Frame Buildings**  
1 to 4 stories, Residential & other
  - Offset Collapse Pattern
- **Heavy Wall - URM, TU, & other low rise w/Concrete or Masonry Walls**
  - Wall Fall Collapse Pattern
- **Heavy Floor - Concrete Frame Bldgs**
  - Pancake, Overturn & Soft First Story Collapse
- **Precast Concrete - fairly Heavy Floors & some w/Heavy Walls**
  - Random Fall Collapse Pattern
- **Diagonally Braced Steel Frame**
  - Overturn Collapse Pattern

SCT1c-3 Slide 9

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#### Light Frame Collapse Pattern

**"Offset Collapse"**

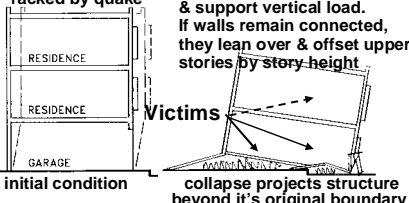
1st story walls are racked by quake

Sheathing fails, but wall studs/posts are undamaged & support vertical load. If walls remain connected, they lean over & offset upper stories by story height.

initial condition

collapse projects structure beyond it's original boundary

Victims



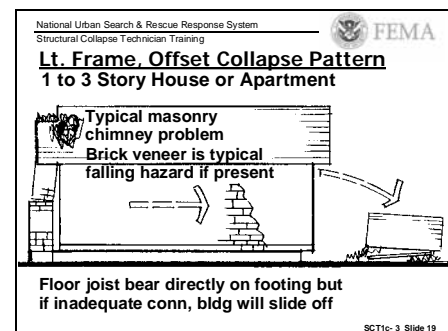
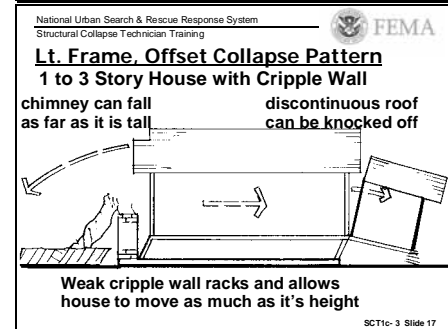
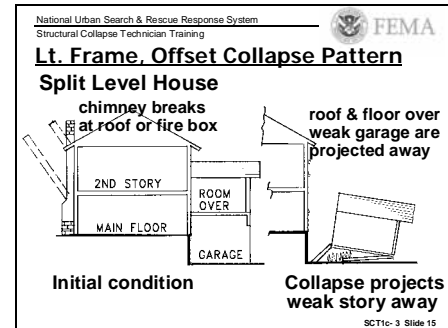


- This offset can occur in a split level house as well as a 3 or 4 story building.
- When the bottom story of a multi-story structure fails in this way, additional stories can collapse due to the impact of the first story hitting the ground.
- In an **Offset Collapse**, most victims will be found within the story or stories that have offset and collapsed. Due to the light nature of wood buildings, furniture, appliances, kitchen cabinets, etc may form voids. Safest access will be achieved by cutting through the wood floors from the story above. However, in multi-story, stacked construction, rescuers must recognize that there has been an offset between stories
- Victims may be found above the offset story, as they may have been injured due the sudden and violent movement of these upper stories as the structure below offsets.
- In some light frame, wood construction, there is a crawl space below the first story. Structures of this type may be as tall as 3 stories. In older buildings of the type the crawl space walls may not have structural sheathing, and are vulnerable to an Offset Collapse, in the weak story.
- Most modern buildings of this type have plywood sheathing in the crawl-space story, and many older building of this type have been strengthened
- In wood structures, when the lower floor rests directly on the foundation, but is not well connected to that foundations, the entire structure can slide over or off the foundation
- In all cases, a great danger of fire exists as a result of the combination of broken gas (or other fuel) lines and combustible debris.

### **Mobile Homes & Manufactured Units**

Mobile homes are a problem in quake and just about any disaster type. Base connections are usually critical These are the common problems:

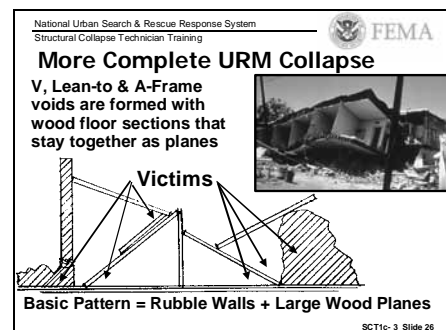
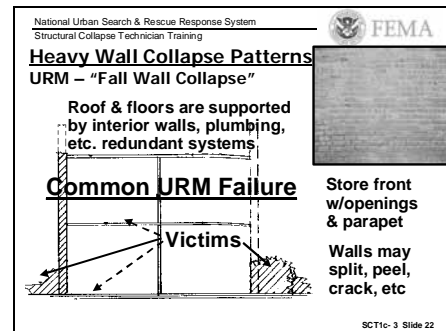
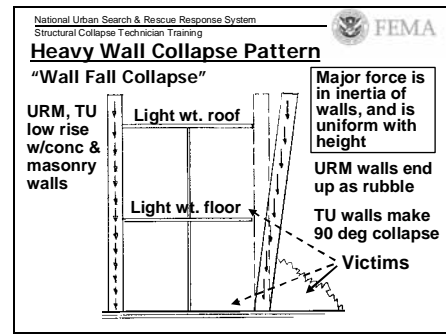
- Units will offset off their jack stands
- Jacks can punch through floors
- Utility connections may be broken.
- If propane gas is used for fuel, there may be a fire/explosion hazard





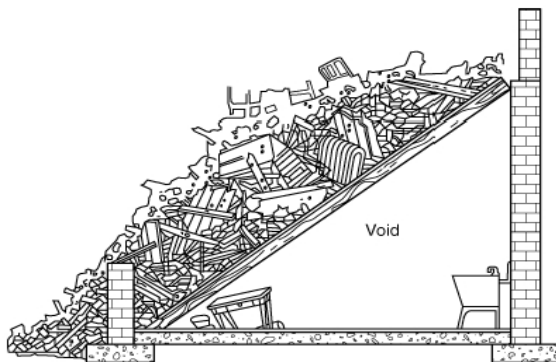
#### Heavy Wall Collapse Patterns URM

- Collapse is usually partial and is strongly related to the heavy, weak bearing walls falling away from the floors. This is the **Wall Fall Collapse Pattern**.
- In URM buildings, the walls normally fall away from their original position but most often do not project out as far as their height.
- The combination of the weak interconnection of the masonry pieces and gravity tends to cause the debris to stay within 10 to 15 feet of the building face.
- When property line walls fall on an adjacent, lower building, these structures will usually have some sort of roof/floor collapse.
- In many URM Wall Fall Collapses, large, room size, void spaces remain within the structure. Most occupants in that case are likely to have exited. Areas outside and adjacent to the walls where parts of the heavy walls have fallen often contain badly injured or dead victims.
- When sections of the wood roof and/or floors collapse, many easily accessible voids can be created by furniture, machinery, appliances, etc
- However, in collapses resulting from the failure of interior columns or fire, a very precarious situation involving multi-story heavy walls that are left standing without any laterally supporting floors/roof is possible. Under such conditions, it is probable that the walls could fall in such a way that they extend their full height along the ground, and trap and kill anyone outside the building
- The combination of broken gas lines and debris can lead to fire.
- As mentioned previously the experience with this type of building lead to the development of the 5 NFPA collapse patterns as shown on the following page. We will discuss probable victim location for these on the page following



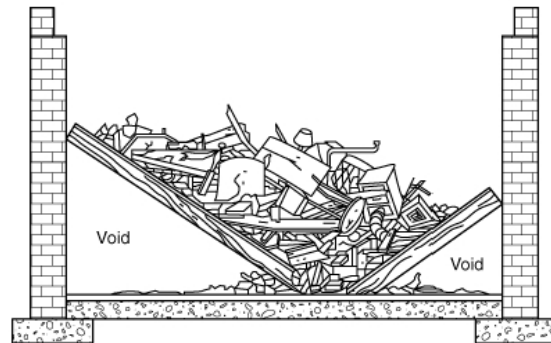


**FIVE COLLAPSE PATTERNS DEFINED BY NFPA 1670**  
(taken from WW2 Civil Defense Publications)



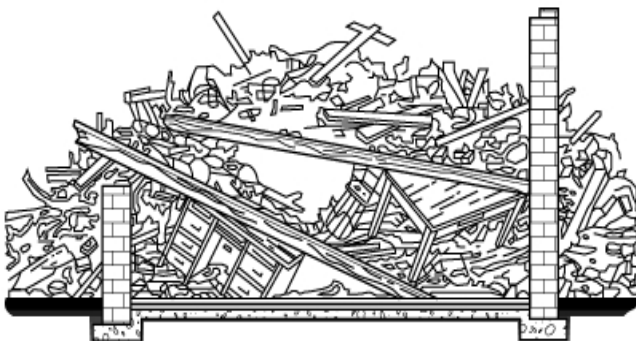
**LEAN-TO**

Formed when one wall collapses, leaving other end with questionable support  
(URM, TU, Heavy Floor & PC Concrete)



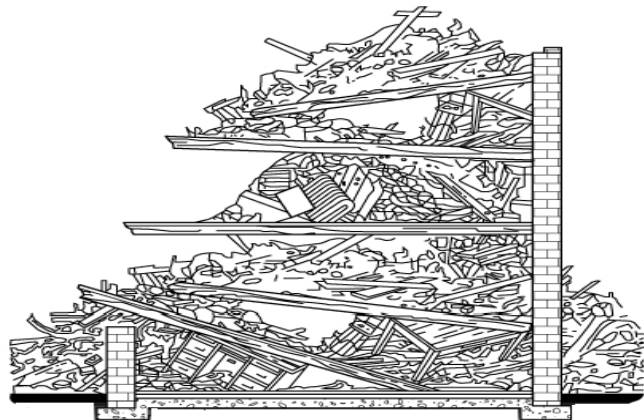
**VEE**

Occurs when interior support fails  
More common in decay/overloaded column  
(URM, Heavy Floor and PC Concrete)



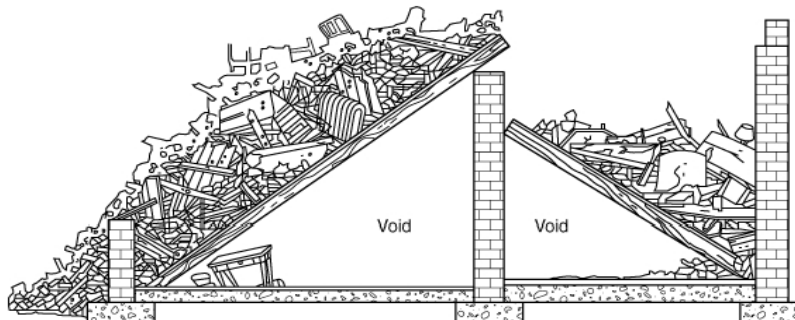
**PANCAKE**

Occurs when all vertical support fails  
(URM, Heavy Floor and PC Concrete)



**CANTILEVER**

Essentially a Pancake with extended floors  
(URM, Heavy Floor and PC Concrete)



**A-FRAME** – Occurs with Lead-To collapse in adjacent spaces or buildings



### Heavy Wall Collapse Patterns URM (continued)

- In the Lean-to, V and A-Frame collapse patterns, large voids may be created as shown in the diagrams on the previous page. However the trapped victims may be found on top of the sloped floor, near the bottom. The contents of this space above the floor have slid to this location, and may have captured victims as well. It should be easy to access this type of collapse, but care must be taken when moving heavy objects, and some shoring may be advisable.

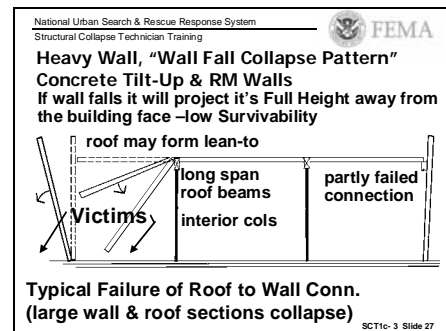
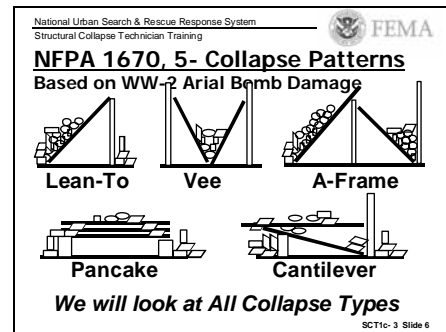
In this type of collapse, victims may also be trapped below the sloped floor at the shallow end. In this case access may be made by cutting through the floor. Unless it has been carefully evaluated by a Structures Specialist, the URM walls should not be breached

- For Pancake and Cantilever collapse patterns, survivable voids may be formed between floors by furniture, machinery, appliances, etc, if the weight on the floor is relatively light. Access may be made by cutting the wood floors, or by finding roof hatches, stairs, or elevator shafts

In Heavy Floor Concrete construction, the voids are usually smaller and are created by broken parts of the structure, like columns and walls. Access is still made by breaching the concrete slabs from above with saws and drills

### Heavy Wall Collapse Patterns – Tilt-up

- **Walls in tilt-up buildings** normally fall away from the roof or floor edge, but since they are very strong panels, the top of the wall will fall as far away from the building as its height. This **Wall Fall Collapse** is somewhat different from one that involves URM construction
- Since tilt-ups have longer roof/floor spans, the adjacent section of roof will usually collapse, although it may still be supported at it's far end, and form a Lean-to collapse.
- Tension forces will be imposed on the roof system; therefore, all beam-to-beam and beam-to-column connections may be damaged and/or pulled out.





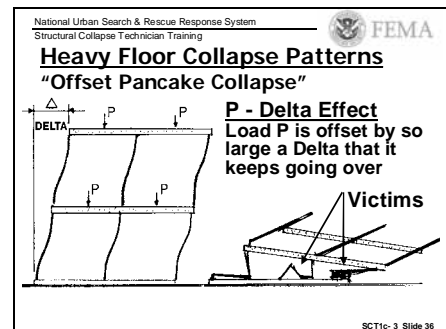
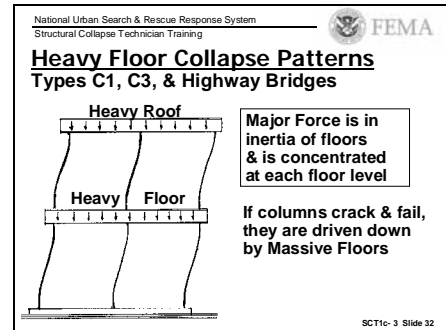
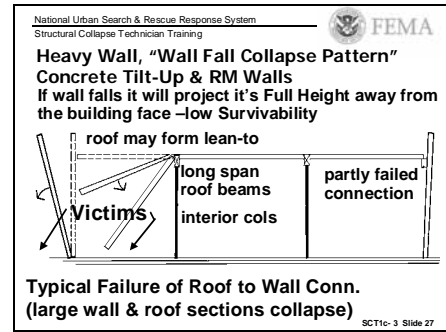
### Heavy Wall Collapse Patterns – Tilt-up (continued)

- Since tilt-up walls are relatively strong and collapse as a unit, it is unlikely that victims in the wall fall zone can survive
- Within the structure, since the roof is relatively long span and light, lean-to voids may be created. In this case, victims should be found under to sloped surface near to bottom.
- If there are interior partitions within the structure, many types of survivable voids can be formed, including Lean-to, A-frame, Vee, or one or more levels of a pancake condition

### Heavy Floor Collapse Patterns

- A heavy floor collapse can be partial to complete. It is usually caused when columns are weakened at the column-floor joints by earthquake motion, are then, unable to support the heavy floors.
- The collapse patterns are varied, as will be discussed. They include pancake, offset pancake, soft story (mostly first story), overturned, and torsion (corner buildings)
- These heavy floor structures usually fall on themselves, but they can project laterally as they fall, if the columns and/or walls are strong enough not to fracture. In other words, the columns can fail due to hinging at the top and bottom, and then the collapse becomes an **Offset Pancake**.
- The voids can be very difficult to access; they are usually still well interconnected with reinforcing steel, and fairly well in tact. Although time consuming, access can be made by breaching the concrete slabs from above with saws and drills
- If the floors are sloped, similar to a lean-to collapse, triangular voids can be formed. It is most likely that entrapped victims will be found above and below floors at the bottom of the slope, and access should be sought within the void

However, since the floors are heavy and may have been forced down by upper stories, fully pancaked floors may also be found in this type of collapse. Heavy pancake will be discussed next



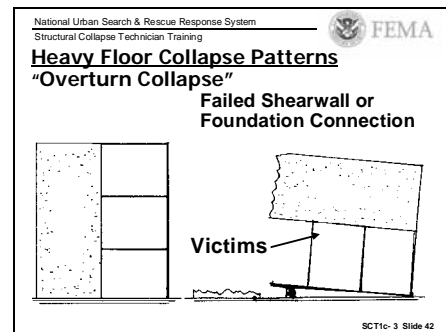
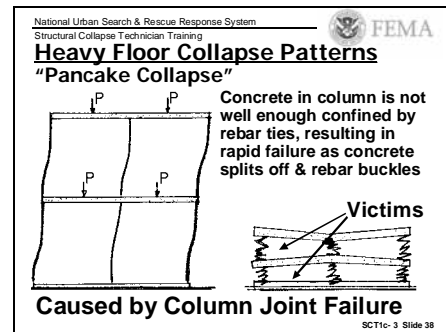


#### Heavy Floor Collapse Patterns (continued)

- Complete pancake collapse can occur when the column-floor joints fail and the structure is so heavy that gravity causes it to collapse onto itself.
- The height of the remaining voids between floors in **Pancake Collapsed** buildings will depend on what projections the slabs originally had (like beams and thickened slabs at columns) and broken concrete columns or partly crushed contents.
- As discussed in Offset Pancake, victim access is difficult, but can be done by saws and drills in the hands of trained rescue personnel. The mostly intact slabs can span obstructions and form life saving voids, but they are also much more difficult to breach than wood floors
- Earthquake motion can cause reversing tension and compression forces at the faces tall, moment-resistant frame structures. When these quake induced forces in the exterior columns abruptly change from tension to compression, a sudden and progressive failure can occur. If several stories are effected this can lead to a pancake collapse. However some taller heavy floor structures have been subjected to overturning collapses
- **Overturned Collapses** have occurred in these taller structures when columns or walls fail due to tension and shear failure at the base. The leading cause of this is inadequate anchorage to the foundation.
  - ◆ Under these conditions, the structure can project sideways by its full height.
  - ◆ Survivability has been high in this type of collapse, since the original structural configuration has been maintained above the lower story.

The victims in the upper stories may have been thrown about and injured, but they can be easily accessed using ladders, man lifts, etc.

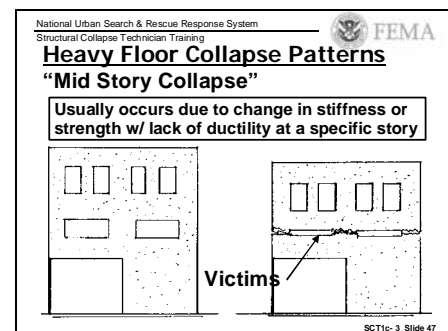
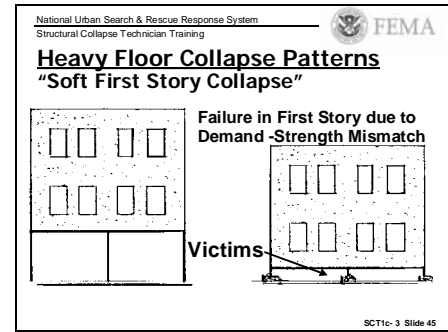
There were many collapses of this type following the Taiwan Earthquake in 1999, and most of the occupants survived





### Heavy Floor Collapse Patterns (continued)

- A **Soft First-Story Collapse** occurs in buildings that are configured such that they have significantly less stiffness (many fewer walls or no walls) in the first story than in the stories above.
  - ◆ This configuration often occurs in building where the first story occupancy is commercial (few if any walls are desired) and the upper stories are residential.
  - ◆ The quake damage becomes focused on the “Soft Story”, and what lateral resistance that is present becomes overwhelmed.
  - ◆ Soft first story configuration is not viable in and type of rigid construction (concrete, masonry, etc), and even wood structures with this defect perform poorly .
  - ◆ The collapse is often limited to the one “soft story”, as the building becomes about one story shorter.
  - ◆ Most all victims will be found within the first story, and the survival rate is very high above the second floor.
  - ◆ The first story should be accessed by cutting through the second floor, although properly tanned search dogs can be directed into the first story voids from ground level
- A **Mid-Story Collapse** can occur when a middle story is configured with much different stiffness than the stories above and below. **Can occur at any abrupt change in stiffness**
  - ◆ It can occur when a story has no walls and the ones above and below have significant walls.
  - ◆ It can occur when a story has stiff, short columns and the ones above and below have longer, more limber columns.
  - ◆ Survival should be high above and below the collapsed story, however access to stories above may be blocked.
  - ◆ The victims within the collapsed stories should be accessed by breaching from the story above. Also an access to the upper stories from below needs to be created in order to allow those trapped above the collapse to exit and rescuers to access the floor to be breached





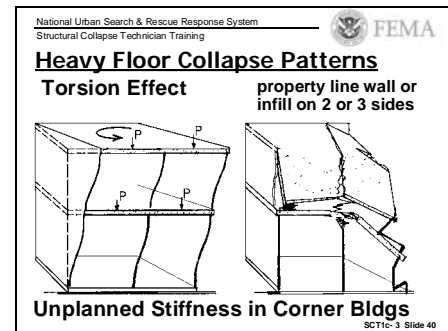


## Heavy Floor Collapse Patterns (continued)

- **Pounding** can cause a mid-story collapse, leaving a difficult problem to assess because the remaining floors are overloaded.
  - ♦ A pounding collapse normally occurs when two adjacent buildings have floors that are at different elevations.
  - ♦ The very stiff /strong edge of a floor in one building will cause the collapse of the adjacent building's column when they collide.
- The victim access issues are essentially the same as noted previously for Mid-Story Collapse
- **Torsion effects** occur in concrete frame structures when URM infill is placed within the concrete frames on the exterior property line walls for fire resistance. This occurs in corner buildings, where the street-side concrete frames have only light-transparent, infill – “Open Sides”

The property-line walls, prior to being cracked by earthquake motion, are stiffer than all the other moment resistant frames in the building. This can cause a temporary eccentric condition that can lead to collapse of the beam-column frames on the “Open”, street sides of the building.
- In most cases, only the structural bays next to the street sides will collapse, leaving a significant part of the structure relatively undamaged

The collapse zone will normally be some combination of a pancake and lean-to collapse, since some of the floor slab will be hanging off the uncollapsed area.
- Most of the victims will be found in these collapsed areas, adjacent to the two street sides
  - ♦ Search and the following victim access should be attempted by working from the uncollapsed area at each floor level, into the collapsed area
  - ♦ Voids will be created by pieces of structure and projecting structural elements, as well as the shape if slabs remain hanging from the uncollapsed structure
  - ♦ If viable victims are found, local and multi-story shoring may be used to reduce risk



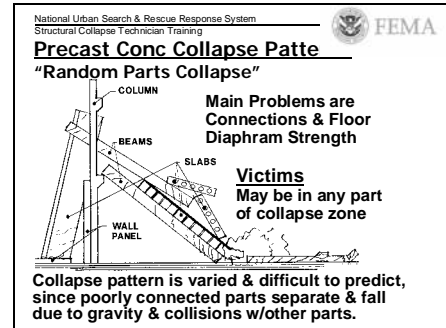
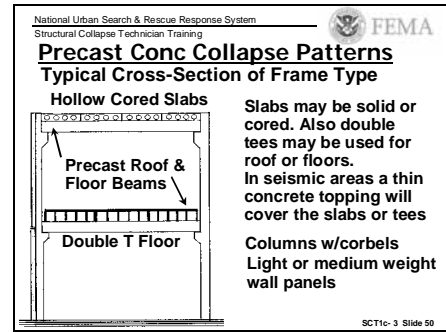


### **Pre-Cast Concrete Collapse Patterns**

- A pre-cast concrete collapse is usually caused when the pre-cast parts become disconnected from one another and the structure very rapidly loses stability.
- The collapse normally contains numerous layers of broken and unbroken pieces of slabs, walls, beams, and columns. The best description of this is **Random Parts Collapse**.
- It is difficult to predict how far the parts can be projected away from the original structure's position or if survivable void spaces will be created.

Gravity normally will drive parts downward without projecting them laterally away from the building, but they may form a relatively compact rubble pile.

- Victims are normally located within the rubble, but survivability has been low. Voids can be created, but there is not regular pattern.
- The voids can be difficult to access, but the slab can be removed, layer by layer, since interconnection is normally poor to non-existent.
- If the structure contained single or double tee floor members, they have two inch slabs through which access openings can be cut. If a topping slab originally covered the tees, breaching will be more difficult
- Precast Concrete Parking Garages have performed particularly badly.
  - ♦ They may be as very large as 400ft x 400ft and be as many as 8 stories tall.
  - ♦ Outside of California, most do not have a cast in place floor topping to help tie the structure together.
  - ♦ In some cases a cast in place slab may be installed that is supported by precast beams and columns. This configuration should perform better, especially if there are shear wall

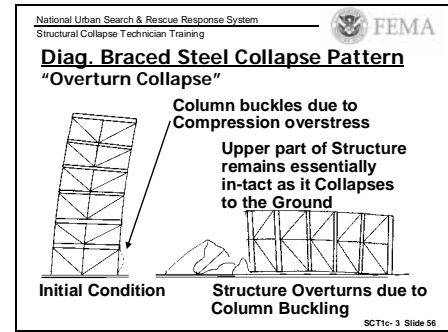




#### Steel Frame Collapse Patterns

- Collapse is usually caused when columns are not proportioned so that they are capable of receiving the combination of structure weight and all the vertical component of the quake load that can be delivered by the diagonal braces connected to them.
  - ◆ In this case the affected column or columns can buckle, causing a catastrophic, overturning failure.
  - ◆ This effect is attributed to the catastrophic failure of the Pino Suarez, 20 story tower during the 1985 Mexico City Earthquake.
  - ◆ The victims in this type of collapse should be found in the overturned part of the structure as explained in the discussion of Heavy Floor, Overturned Collapse.

The victims may be accessed within the open areas of the structure that are now laying nearly horizontal
- In some cases when tube type members are used for diagonals, sudden local crippling at cross-section corners has resulted. This can occur when cold rolled tubes are used, since high stresses are originally induced during forming.
  - ◆ Inadequate detailing or workmanship at connections has caused local failures, such as buckling of connection plates and roll over of beams.
  - ◆ The result of this type of failure rarely caused collapse, but damage can be caused to non-structural elements such as rigid wall panels, stairs, and interior finishes






## Windstorm/Flood Collapse Damage Patterns

### Windstorm Basics.

- They normally affect light, poorly, or non-engineered structures and generate both static and dynamic pressures on exterior surfaces and impact forces from missiles/debris.
- High winds can peel off light roof/canopies, and any type of "Open" structure is very vulnerable.
- Well-engineered structures are designed to resist wind forces by elastic action (in contrast to the inelastic response that is assumed in earthquake design); therefore, it is unusual to have this building class sustain significant wind damage.
- A very common occurrence is a **Wind Lift Collapse**, as shown in the adjacent slide.
  - ♦ If the roof is blown off the wall support is lost and the walls may collapse inward or outward, depending on what other elements (such as wall corners/intersections of intermediate floors) are available to provide redundancy.
  - ♦ As noted this type of collapse can even occur in heavy wall buildings, especially if large, metal doors are present.
  - ♦ Missile penetrates glass opening or doors blow in, structure changes from "closed" to "open type", roof and/or leeward wall are blown out.
  - ♦ Victims, if they have not evacuated prior to the hurricane, would not likely survive if caught beneath the heavy wall shown in the adjacent slide
- Storm Surge, associated with coastal windstorms, can produce collapse of lighter structures and even damage to engineered structures.
  - ♦ The destructive Tidal Surge of Hurricane Ivan Sep04 caused damage to freeway bridges and concrete buildings as well as lighter structures.
  - ♦ Windstorms often produce flooding – even if there is little "Wind Damage".

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### Windstorm Basics

- Light, poorly or non-engineered structures are most vulnerable
- High winds peel off light roof/canopies
  - Any type or open structure – very vulnerable
- Airborne missiles penetrate - cause collapse by impact or by creating open structure
- Storm surge/high waves can cause collapse/damage to engineered structures
  - Windstorms often produce flooding – even if no wind damage

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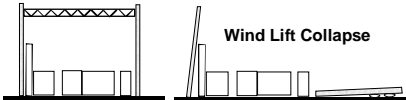
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### Common Windstorm Collapse Pattern

#### "Wind Lift Collapse"

- Roof blows off, and Walls Collapse due to lack of Lateral Support
- Missile penetrates glazed opening or door blows in, structure changes from "closed" to "open", roof blows off and walls fall (in or out)
  - Even tilt-up concrete, and other Heavy Wall Bldgs



SCT1c-3 Slide 61




- Tornadoes, with winds above 200 MPH, can damage all but the most well engineered and well constructed buildings.
  - ♦ The most destructive tornadoes have lifted as large of structures as Train Locomotives.
  - ♦ Light structures are extremely vulnerable to the lifting forces generated by tornadoes.
  - ♦ The most effective defense against loss of life, is to have some part of a structure be designed as a shelter.
- In some cases, tornado warning can be given, but they are only warning that the conditions are present in a general area, and not the precise location where one will occur.

### **Most Common Wind Collapse**

- Probably the most vulnerable structures are Light Metal Buildings and Mobile Homes.
  - ♦ Light metal bldgs are often penetrated by the wind and the skin and supporting roof members are compromised. Something as simple as not having a flutter resisting rubber grommet under the roof panel screw heads, can start a "Weak Link Behavior" collapse.
- Mobile Homes are often factory built at minimum cost. In older models the connection between the metal frame and wood walls were made using very light 24 gage straps and staples. More modern models use 16 gage straps and screws.
  - ♦ In any case, the "Tie-down Straps" need to be properly installed, not taken out of the way for convenience.
- Part or all of light roofs may be blown off and the walls, could then, collapse due to lack of lateral support.
- Very tall walls may be blown in or out causing the roof to collapse.

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**Common Windstorm Collapse Pattern**

**Most Vulnerable Structures**

- Light Metal Bldgs - collapse due to buckling or bending failure of long span roof, pull out of frame base
  - Weak Link Behavior – starts with something as simple as roof sheathing being blown off due to lack of rubber grommet under screw head
- Mobile Homes – collapse due to inadequate connection to base frame
  - Newer models use 16ga strap w/screws
  - Older models used 24ga. w/ staples

SCT1c-3 Slide 62

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**Problematic Building Types**

- Wood Houses
- Mobile Homes
- Other Frame, multi-residence condos
- Light Metal Buildings
- Commercial & Industrial - URM, RM, TU
- Aircraft Hangers
- Large, Long Span Structures

SCT1c-3 Slide 63



- Types of structures that are seriously damaged by hurricanes usually fall into three categories:
  - ◆ **Pre-engineered buildings** usually consist of moderate span steel framing with metal siding or masonry wall construction. They are usually commercial and light industrial buildings.
  - ◆ **Marginally-engineered buildings** have some combination of partly reinforced masonry, light steel framing, steel joist, wood trusses, and/or wood rafters. The exterior walls may be masonry, stucco, or siding, and there may be large truck-doors.
  - ◆ **Un-engineered buildings** such as homes and apartments.
- **Storm Surge** can damage large, heavy structures that have not been designed for adequate uplift.
  - ◆ Precast concrete highway bridge slabs and dock slabs can be displaced by this surge.
  - ◆ Second story flat slabs have been collapsed due to the uplift pressure causing a punching shear failure at supporting columns (upward punch).
  - ◆ Scouring has caused the undermining of foundations, leading to the partial collapse of multi-story structures.

### **Common Windstorm Damage**

Structural hazards created by windstorm damage include:


- The partial removal of the roof and/or wall skin in a light frame building. Partial loss of the lateral load resisting system.
- Peeling of outer layer of multi-layer, cavity-type, masonry bearing wall (lightly reinforced, eastern-type construction).
- Removal of masonry veneers on wood and metal frame walls.
- Removal of roofing materials: clay/concrete tile, shingles, gravel, etc.

All items can be destructive missiles.

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**Problematic S3, URM, RM, TU**

- Light Metal Buildings
- Commercial / Industrial Buildings
  - Walls of URM, RM, TU
  - ◆ Larger problem if large opngs are penetrated



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**Hurricane - Storm Surge Damage**  
Even to Larger Structures

- Surge/Buoyancy Lifts and Displaces PC Slabs & Highway Bridge Slabs
- Surge/Buoyancy Lifts and causes Uplift Failure of Flat Slabs
- Scouring Undermines Foundations and causes Partial Collapse

SCT1c-3 Slide 77

### **Common Windstorm Damage**

- Partial removal of roof/wall skin
- Masonry wall peel - older URM or modern, insulated, masonry cavity walls
- Removal of masonry veneers - low & high rise
- Loss of roofing material - tile, shingle, gravel
- All become destructive missiles



#### Common Flood Collapse Problems

Common flood collapse problems include:

- Structures move partly or completely off their foundations.
  - ◆ They can slide if moved completely off or tumble if one side stays attached. Structures that have been moved may be repaired but should initially be considered hazardous.
- Foundation and/or basement walls may have walls broken, offset, and/or badly cracked due to hydrostatic and/or hydrodynamic forces.
- Slabs on graded and shallow foundations can be undermined by swift moving water.

Undermined foundations may result in a hidden problem that would need to be carefully investigated.
- Wall, floor, and/or roof collapse may be caused by impact from objects as large as residential structures.

#### Common Flood Damage Problems

- **A high water mark will normally indicate the extent of flood damage in structures that have remained in place.**
- Buoyancy can cause parts of the structure to be lifted.

Wood floors and roofs can be lifted off their bearings by hydrostatic pressure, leading to a hidden hazardous support condition.
- Long-standing water can cause geotechnical problems, leading to subsidence.
- In addition to structural damage, wood floors that have been submerged may become warped.
- Flooding can cause black mold to occur, especially in hidden, enclosed spaces that are not dried rapidly.

**Black mold can cause severe health problems.**
- **Flooding may also lead to many HAZMAT problems.**

#### **Flood Damage Patterns**

- Riverine or Coastal Flooding
- Most damage is to light structures
- Moving water can impact & collapse or flow past & peel off the lt. walls of bldgs
- Waterborne debris - can cause collapse by penetrating structures
- Fast moving river or tidal surge can cause collapse/damage to engineered structures
- Slow moving water can produce buoyancy + standing water effects

#### **Common Flood Damage**

- Light frame structure shifted off foundation
  - Buildings can slide if free of foundation or will tumble if one side stays attached
- Broken and/or tilted foundation walls
- Undermined foundations & slab on grade
  - Potential for subsidence, geotechnical effects
- Buildings impacted by debris
- 1<sup>st</sup> & 2<sup>nd</sup> floor joist may be lifted off bearings, in unstable condition
  - Need to determine high water mark



## Explosion Effects on Buildings

### Basic Explosion Effects

These effects are very different from those caused by earthquakes where the collapse causing damage is the vertical elements (column connections & shearwalls). The pressures exerted on buildings by explosions may be many orders of magnitude higher (5000 psi+) than normal design pressures, but their duration is in milliseconds, and they are inversely proportional to the cube of the distance from the center of the source.

- Damage to structures may be severe, but it is only a fraction of what a proportional static pressure would cause.
- When large surfaces are engaged by blast pressures, they will be moved as the shock wave passes, but the direction of the net force (initial uplift – overpressure) will be determined by the complexities of the wave path and time.
- Heavy columns tend to survive but may have some of the floors that load and laterally brace them removed.
- Steel frames, beams, and columns may also survive but without all their intended bracing.
- The wall and floor planes in frame as well as box buildings have large surfaces that will receive most of the blast pressure. They likely will be ripped away from their connections, leading to the collapse of at least part of the structure.
- Occupants within the blast zone are usually killed or severely injured. There is little record of anyone surviving when they have been exposed to the direct blast pressure.  
However, if individuals are “shaded” from the blast pressure by concrete walls or other heavy-strong structure they may survive
- Since the floors of a structure are usually thrust upward, and then collapse into a dense rubble pile, survivability is very low  
If somehow protected from the direct effects of blast, victims may be injured by flying objects, especially glass shards

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**Blast Collapse Patterns**  
*Effect is different from Earthquake, where damage is to vertical elements.  
Blast has devastating effect on all surfaces especially uplift on floors*



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**Basic Explosion Effects**

- Large pressures exerted by explosions
  - Can be 5000 psi +
  - Short Duration - only Milliseconds
  - Inversely proportional to cube of distance from source (not exactly since hemisphere)
- Severe damage to structures
  - But not proportional to static pressure effects
- Effects of fast moving shock wave
  - May be very complex

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**Blast Effects on Buildings**

- W - Wood Structures
- S1 & S2 - Steel Frame Structures
- S3 - Light Steel Structures – Blown away
- C1, C2 & C3 - Concrete Frames
- PC2 - Precast Structures, Frame & Box
- Post-Tensioned Concrete Structures
- Heavy Wall Structures - TU, RM, & URM

**Few Survive within the Collapse Zone due to Blast and Crush Effects**

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#### Explosion Effects on Specific Buildings

The following is a brief description, by type, of the most predictable blast damage.

- **Wood frame – W:** The light wall and roof planes can be blown away and/or shredded. Leveling of all or at least a significant part of the structure can occur.
  - ◆ Occupants within light structures have little protection, and normally killed or severely injured
- **Steel frame – S1 and S2:** A well-designed steel frame may be relatively resistant since beams and columns have resistance to both upward and downward loads as well as tough connections and small dimensions.
  - ◆ Light floor framing such as metal deck with concrete fill or bar joist may be separated from beams since they have large areas and small connections that can be unzipped.
  - ◆ The most likely scenario is for at least part of the frame to remain, but beams may be twisted, with large areas of the floor diaphragm missing. This is called a **Lift and Drop Collapse**.

The occupants on the floors that are lifted and collapse have little chance of survival. They are normally found within the tightly packed rubble at the “ground” level.
- **Light metal – S3:** The light metal roof and wall panels can be easily blown away, leaving a bare, poorly braced frame.
  - ◆ Roof, purlins, and wall girts normally have relatively light connections and may be removed with the metal panels.
  - ◆ The frames may collapse from lack of lateral support and/or push from the blast pressure.
  - ◆ The result can be a completely collapsed pile of bent and twisted steel members (structural steel spaghetti).
  - ◆ Again, occupants within these light structures have little protection, and normally killed or severely injured. They may be found at some distance from their original position

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**Blast Effects on W & S Buildings**

- **W - Wood Structures**
  - Light wall/roof surfaces are blown away. Remainder collapses
  - End up with leveled structure
- **S1 & S2 - Steel Frame Structures**
  - Beams / columns have small dimensions and are very resistant to sudden forces.
  - Light floors may be blown away, leaving poorly braced beams & columns.
  - “Lift and Drop Collapse”

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**Blast Effects on W & S Buildings**

- **W - Wood Structures**
  - Light wall/roof surfaces are blown away. Remainder collapses
  - End up with leveled structure
- **S1 & S2 - Steel Frame Structures**
  - Beams / columns have small dimensions and are very resistant to sudden forces.
  - Light floors may be blown away, leaving poorly braced beams & columns.
  - “Lift and Drop Collapse”

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### Explosion Effects on Specific Buildings (cont.)


- **Concrete frames – C1, C2, and C3:** The lift pressures have had devastating effects on concrete slabs in gravity-type designs.
- One-way slabs hinge up because of the lack of top reinforcing at mid-span and continuity splices in bottom bars at supports.
- A critical location for flat slabs occurs at columns when the uplift pressure fails the slab column joint in upward punching shear, followed by a combination of gravity and positive overpressure that tends to drive the already damaged slab downward. **Lift and Drop Collapse Pattern.**
- The remaining structure may contain columns that are standing, exposed for several stories without the lateral bracing that the collapsed floors used to provide.
  - ◆ This occurred in both the 1993 World Trade Center and Murrah Federal Building disasters, large areas of several floors collapsed, leaving columns that extended as far as six stories without lateral support.
  - ◆ These columns, still heavily loaded were vulnerable to a sudden collapse and needed to be braced to reduce the risk to rescuers
- As previously stated, the occupants on the floors that were lifted and collapse had little chance of survival. They were found within the tightly packed rubble at the “ground” level, some as far as 50 feet from their original position.
- In the Murrah Building collapse several individuals were spared since they were standing and waiting for the elevator that had very strong concrete walls. The walls “shaded” them from the blast pressure, any the elevator walls kept the floors in that area from collapsing
- The adjacent slide discusses the low survivability that has been experienced in blast-caused collapses.
  - ◆ No one within the collapse area survived, and no live victims were removed from the rubble after the first 10 hours

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**Blast Effects on Concrete Structures**

**“Lift and Drop Collapse Pattern”**

- Lift forces have especially devastating effects on gravity designed slabs
  - When gravity force is overcome, slabs and beams can hinge where rebar is not continuous
    - ◆ At mid-span and at span ends
- This can result in multi story columns left standing w/o enough lateral bracing
  - Multi level collapse is then probable

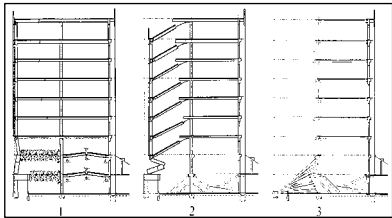


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**Probable Collapse Sequence**

**“Lift and Drop Collapse”**



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**Example of Blast Survivability**

**Oklahoma City Example**

- 359 people were in the building when the bomb was detonated
- 169 individuals were killed, including 19 children & 1 volunteer nurse
- No live person was removed after 1700hrs on Day 1
- Almost all of the deceased victims were within the collapse zone
- Very different from Earthquake Survivability

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#### Explosion Effects on Specific Buildings (cont.)


- In **C3 type Concrete Frames**, the URM infill is also particularly vulnerable to blast pressure (large areas and very little resistance to the lateral pressure).
- **Pre-cast concrete – PC2:** In pre-cast frame type structures, the lightly (gravity) connected floor slabs and wall planes can be blown away, leaving unbraced beams and columns.
  - ♦ If beam/column connections are minimal, entire sections of the structure could collapse.  
Progressive collapse has occurred when only one column was dislodged by a relatively small gas explosion in a multi-story, pre-cast structure.

- ♦ In Box type PC2 (such as the barracks in Saudi Arabia), the wall and floor slabs nearest the blast may be dislodged and broken loose at their joints.

The multi-cellular character of these structures (created from closely spaced bearing walls) will, however, tend to limit the collapse damage to those areas where the bearing capacity of wall panels is lost.

- The adjacent slide compares the survivability of the Murrah Bldg and Kobar Towers, to demonstrate that ductility really does make a difference. There were the same number of occupants and blast size for these structures.
  - ♦ The Murrah Bldg, even though it was a cast in place concrete structure, performed poorly due to brittle reinforcing steel configuration (few continuous bars) and anti-redundancy (all columns did not extend to the ground at the building face exposed to the blast).
  - ♦ Kobar Towers was a highly redundant, PC concrete multi-wall structure with reasonably ductile connections, and the collapse was limited for the blast facing walls.


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 **Blast Effects – Precast Concrete**

- **PC2 - Frame Type Structures**
  - Pressures can dislodge walls, slabs
    - ♦ Beams & columns then effected by lack of bracing.
  - Break/damage many connections
  - Progressive collapse possible.
    - ♦ Due to missing supports and discontinuous members.
- **PC2 - Box Type Structures**
  - Pressures can dislodge walls & slabs
    - ♦ Break/damage many connections
  - Better response in multi wall buildings

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 **Compare Murrah Bldg w/ Kobar Towers**  
*Similar size Bomb & Number of Occupants*



■ Brittle, Conc Details	■ Ductile Connections
■ Anti-Redundant	■ Highly Redundant
■ 45% Collapse	■ 10% Collapse
■ Collapse/Falling Haz	■ Falling Haz
■ 168 Killed	■ 19 Killed

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- **Post-tensioned concrete:** If the unbonded cables are damaged, becoming un-tensioned in only one small area of a floor slab, the entire length of the these cables can be affected, which can lead to the collapse of the full length of the floor.
  - ◆ This type of slab is also very susceptible to upward pressures since the cables are normally draped to lift the weight of the structure.

Therefore, the original structure will have less resistance to the blast uplift pressure than reinforced concrete. Also the concrete may break into very small pieces


- ◆ Pancake or some sort of draped slab pancake collapse can be formed in the floor structure adjacent to the blast zone.

Victim survivability within the blast area would be low, and access by breaching the concrete slabs, if pancaked, should be used to access victims.

However, in areas where these slabs are still in-tact there are special problems that should be address by a Structures Specialist.

- ◆ If the post-tensioned forces have been released, the slabs will act as brittle, un-reinforced concrete.
  - ◆ If the post-tensioning forces are still active, great care must be taken if any of the cables need to be cut
- **Heavy wall buildings – TU, RM, and URM:** Blast pressures will tend to engage the wall and roof surfaces, severing connections and blowing large sections away.
    - ◆ For interior blasts, walls will blow out, and roof sections will be lifted. Adjacent parts of the structure can also collapse from the loss of vertical and/or lateral support.
    - ◆ For blasts initiated outside the building, the near walls may be shattered or blown in, followed by roof sections being lifted, then dropped, and sections of the far side blown out.
    - ◆ Again victim survivability is very low within the blast affected area, as well as in the area where the heavy walls will fall

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**Blast Effects on Other Buildings**

- **Post-Tensioned Concrete - very vulnerable to Uplift Pressures.**
  - Progressive failure within entire slab due to loss of Tension in Unbonded Cable
- **TU, RM, & URM - Large Wall & Roof Surfaces are Effected.**
  - Lifted Roof and Blown-Out ,Far-Side Walls
- **Blast compared to Very Short-Term, High Velocity Wind w/Special Effects**

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**Blast Effects on Other Buildings**

- **Post-Tensioned Concrete - very vulnerable to Uplift Pressures.**
  - Progressive failure within entire slab due to loss of Tension in Unbonded Cable
- **TU, RM, & URM - Large Wall & Roof Surfaces are Effected.**
  - Lifted Roof and Blown-Out ,Far-Side Walls
- **Blast compared to Very Short-Term, High Velocity Wind w/Special Effects**

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In summary, the effects of explosions can be compared to those of a very short term, very high velocity wind. There may be special effects at corners and other discontinuities and shading of one part of a structure by another or one building by another.

#### KEY LEARNING POINTS


They are listed on the adjacent slide. The student is encouraged to review this section, since it contains information that forms a basis for understanding the performance of structures that will be encountered during US&R incidents.

#### Review of Enabling Objectives

- In this section, we have discussed:
  - ◆ Basic Collapse Patterns,
  - ◆ Earthquake Collapse Patterns,
  - ◆ Windstorm Collapse Patterns,
  - ◆ Flood Damage Collapse Patterns,
  - ◆ Blast Collapse Patterns.

We have focused on recognizing survivable voids and Potential Victim Locations.

- In the following section, Hazard Identification, we will focus more specifically on the US&R issues of how to deal with damaged and collapsed structures.

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#### Review Key Learning Objectives

- Quake, Wind and Blast produce Unique Effects on Different types of Structures
- Each of these produce Unique and Recognizable Collapse Patterns
- This Knowledge will allow us to Recognize the Survivable Voids and potential victim location

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## **Part 4 - Hazard Identification, Introduction to Assessment & Mitigation**

In this section, you will become familiar with the most common signs of distress exhibited by damaged structures. We have discussed material behavior and collapse patterns and will now apply this knowledge to the disaster site.

In this section, we will:

- Discuss concrete and masonry cracks and how to “read” the cracks to predict future performance of these structures.
- Identify the most common hazardous conditions that will occur in the five types of buildings that we have previously identified.
- Discuss the various tools and methods that are currently available to monitor buildings.


### **Cracks in Reinforced Concrete and Masonry**

A favorite statement in building design and construction is “if it’s not cracked, it’s not concrete” because cracks must form in concrete for the reinforcing steel to be stressed in tension. Most normal concrete develops cracks that are narrow (hairline) from shrinkage, temperature change, and predictable structural behavior.

#### Shrinkage Cracks

- Shrinkage cracks usually occur in slabs, beams, walls, and even in columns within 60 days of the pour, after the concrete is allowed to dry-out.
- Diagonal cracks will originate from most re-entrant corners in slabs and walls, that is, window, door, and floor openings.
- Straight cracks (more or less) occur often at 5 ft to 20 ft on center in long walls and/or floor surfaces, depending on the amount of reinforcing steel, numbers of pour joints, and curing conditions.
- The reinforcing steel within the structure is intended to hold the structure together as it shrinks and keep these cracks small.

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**Terminal Objectives**

- The Student shall understand the most common signs of distress exhibited by damaged structures.
- The Student shall understand to the most common Hazards found in damaged structures, and methods that have been used to used to Mitigate them

*We need to apply our knowledge regarding Structure Behavior & Collapse Patterns to the Disaster Site*

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**Key Learning Objectives**

**We will discuss the following**

- Crack patterns in Reinf Conc & URM
- Structure Hazard I.D. in five types of Bldgs
  - Light Frame
  - Heavy Wall
  - Heavy Floor
  - Precast Concrete
  - Steel Frame
- Introduction to Structure Hazard Assessment & Mitigation

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**Cracks in Reinforced Concrete & Reinforced Masonry**

- Shrinkage cracks
- Temperature cracks
- Tension cracks
- Diagonal tension cracks in beams
- Diagonal tension cracks in walls

**If it's not Cracked it's not Concrete**

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**Shrinkage & Temperature Cracks**

- Occur in slabs, walls, beams, & columns.
- Diagonal cracks originate at re-entrant corners in slabs & walls (openings)
- Transverse (more or less straight) cracks occur at 5 to 20 ft apart in long slabs & walls
- Nominal rebar normally keep cracks small

SCT1c-4 Slide 5



#### Temperature Cracks

- Temperature cracks occur in roughly the same pattern as shrinkage cracks and are difficult to differentiate from them.
- When the temperature of a concrete structure is decreased, it must shorten (shrink); therefore, it cracks, and the reinforcing steel attempts to hold it together.
- Reinforced concrete structures will, obviously, experience plainly observable temperature/shrinkage cracking when subjected to the winter cold.

#### Tension Cracks

- These cracks most often occur in concrete slabs and beams when bending-caused tension forces stretch the reinforcing steel.
- Cracks must form in the concrete in order to transfer the force to the steel, but the cracks are normally quite numerous, small, and undetectable (except to the trained eye).
- They form perpendicular to the long axis of the member, and as long as they remain hair like, the structure is behaving normally.

#### Diagonal Tension Cracks

Refer to explanation of Shear Forces in Sect II, pg 21

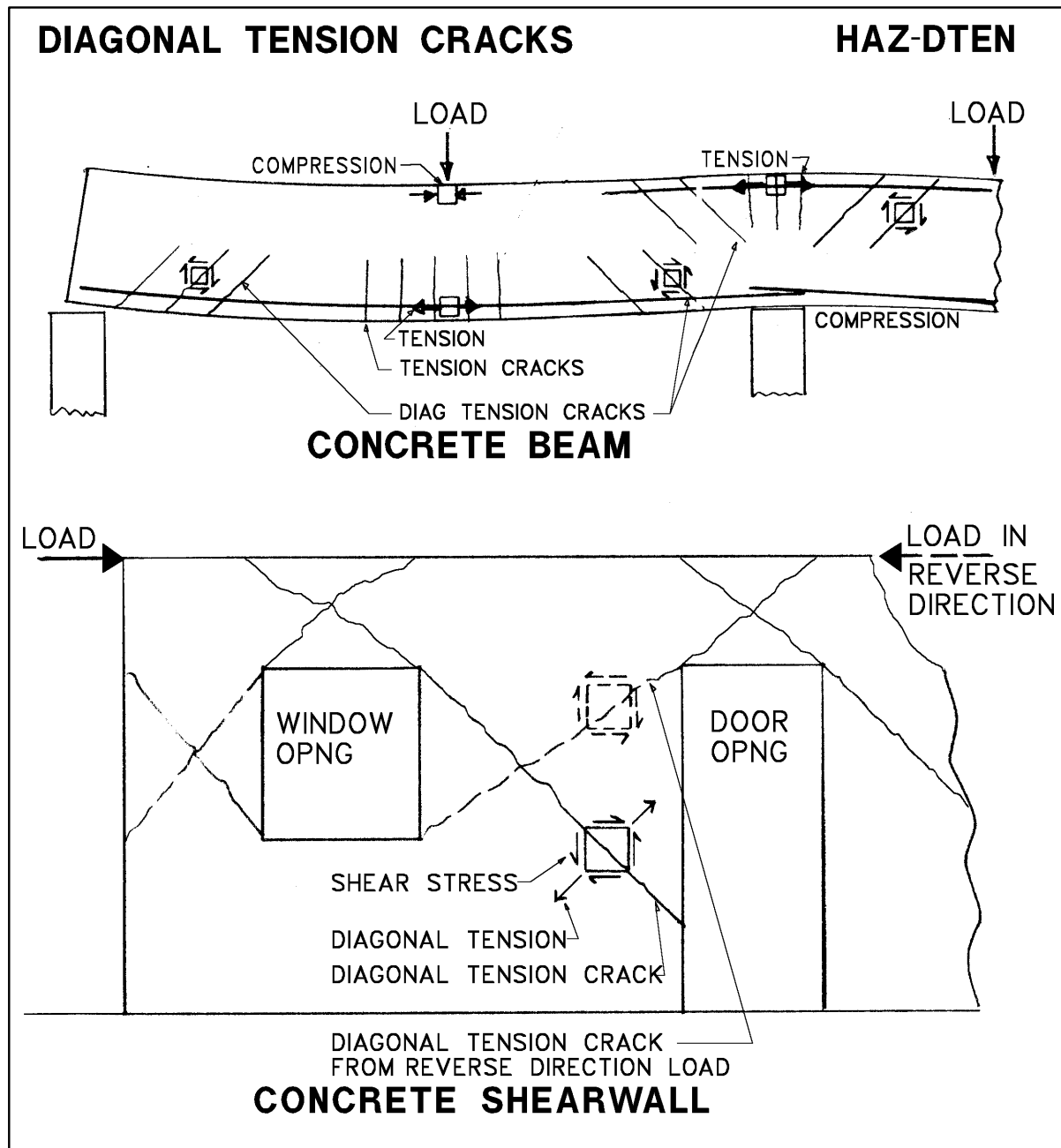
- Diagonal tension cracks occur in the high-shear stress zones of beams and girders in a typical pattern (HAZ-DTEN) under normal vertical load conditions.
- In shear walls, large diagonal tension cracks will form when the walls are heavily loaded by severe earthquake shaking (HAZ-DTEN).
- Earthquakes will normally cause a diagonal crack in each direction (cross cracking) in the highly stressed areas of shear walls (that is, between window openings and over-stacked door openings) since the shear force reverses, causing diagonal tension cracking in each direction.



#### Shrinkage & Temperature Cracks

- Occur in slabs, walls, beams, & columns.
- Diagonal cracks originate at re-entrant corners in slabs & walls (openings)
- Transverse (more or less straight) cracks occur at 5 to 20 ft apart in long slabs & walls
- Nominal rebar normally keep cracks small

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#### Cracks in Reinforced Concrete Walls

- The stability of concrete box buildings will probably depend on the post-cracked strength of the shear walls. Even with unsightly diagonal cracking, a shear wall may still have significant strength (HAZ-CK).
- The clamping action of the gravity loads, as well as the vertical rebar, will tend to hold the irregular surface of the cracks together, preventing the opposing surface from sliding. In addition, the rebar that cross the crack can act as dowels.
- Both these resistive actions are lessened when there is enough shaking or continued re-shaking from aftershocks. The crack widens, concrete chunks fall out, and the rebar can be seen in an offset curved condition. In this latter degraded condition, a shear wall has become unreliable and must be evaluated accordingly.

#### Cracks in Unreinforced Masonry Walls – URM

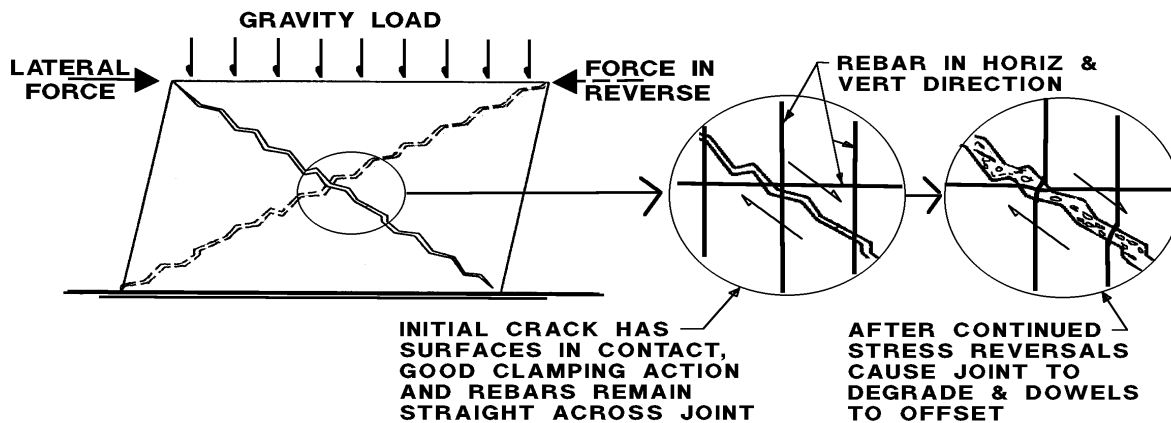
- Shrinkage, temperature, and diagonal tension/shear wall cracks occur in URM walls as well as unreinforced concrete walls. In these walls, however, cracking indicates a significantly degraded structure.
- Diagonal tension cracks form in these walls between openings, as they do in reinforced concrete walls because of earthquake shaking. In addition, cracks are often created at wall corners, with the bottom of the crack at the corner and the top extending up to the roof. These cracks are caused by the action of the disconnected roof diaphragm pushing against the corner, attempting to push it out. URM diagonal cracks tend to follow a stair step-pattern (HAZ-CK); that is, the crack follows the weaker mortar, rather than going through the bricks. This action results in cracked surfaces that are smoother than those in reinforced concrete.



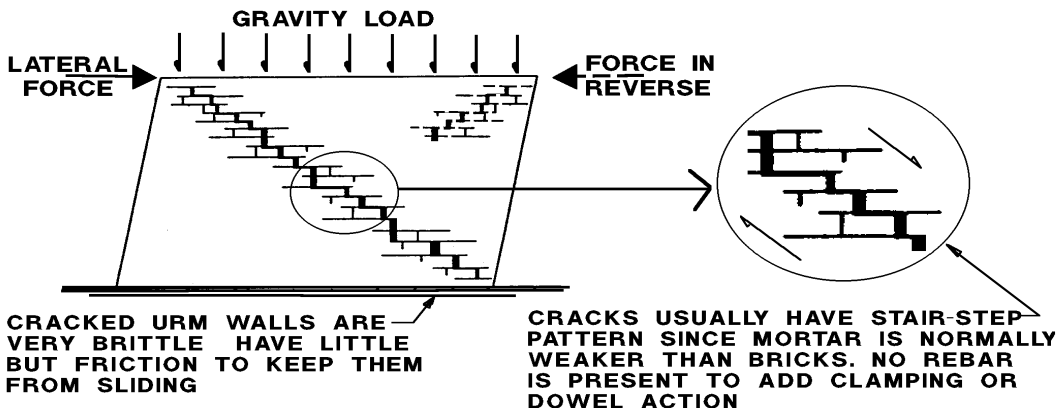
- **Masonry walls** with significant diagonal tension cracks must be considered capable of a sudden, brittle failure. Some clamping force on the horizontal steps of the cracks exists due to the gravity force, but no vertical bars exist to add clamping or dowel action. The greater smoothness of the joints also reduces the friction that could be developed by the clamping of the vertical force.
- **Unreinforced concrete walls** also perform poorly during quakes. They tend to break apart in pieces defined by whatever crack pattern existed before and/or according to the original pour joints. Fortunately, there are very few of these in earthquake areas.

## SHEARWALL CRACK PATTERNS

## HAZ-CK



## REINFORCED CONCRETE SHEARWALL



**URM SHEARWALL • UNREINFORCED CONCRETE = SIMILAR**



#### Hazard Identification in Damaged Structures

In damaged, partly collapsed and collapsed structures we can identify three types of hazards:

- **Falling**, in which part of the structure or its contents are in danger of falling;
  - **Collapse**, in which the volume of an enclosed space made by the structure will be reduced as stability is lost;
  - **Other**, which includes toxic gas, carbon monoxide, asbestos, and other hazardous materials (discussed in HAZMAT First Responder Course).
- 
- We will discuss falling and collapse hazards. The degree of hazard in both cases strongly relates to mass and how additional failure may occur. Brittle, sudden failure potential must be recognized as opposed to structures in which material ductility and redundant configuration could provide some warning of an additional collapse.
  - The problem of identifying, let alone properly evaluating, these hazards, is staggering. A well-trained engineer may, at best, be able to rate the risk of various hazards on some arbitrary scale like bad, very bad, and deadly. We must consider that:
    - ◆ Judgments cannot be precise.
    - ◆ We must try to identify brittle versus ductile behavior.
    - ◆ Partial collapse is very difficult to assess.
    - ◆ The cause of the condition is very important input (for example, earthquake with expected aftershock or windstorm).
  - In evaluating, if a specific structure is at rest, one could state, positively, that the structure that was moving had enough resistance to stop moving and come to an "At-Rest" condition. However, the damaged structure is difficult to assess, weaker, and more disorganized than the original.
    - ◆ Try to identify the load path and visualize what happens during an aftershock or wind gust.
    - ◆ Small, nonstructural elements and debris (loose materials) may be greater hazards than overall structural stability, especially in wind gusts and small aftershocks.



#### Hazards in Damaged Structure

- Falling hazards
- Collapse hazards
- Other hazards

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#### Identification Problems

- Judgments Cannot be Precise
- Partially Collapsed Structures are Difficult
- Collapsed Structure has "Come to Rest", but is weaker & more disorganized than Original Structure
- For Earthquake caused Partial Collapse, Building remainder is Weakened & More Likely to collapse in an Aftershock.
- Structures Collapse in Aftershocks
- See SOG (or StS FOG), Sect 1 for following

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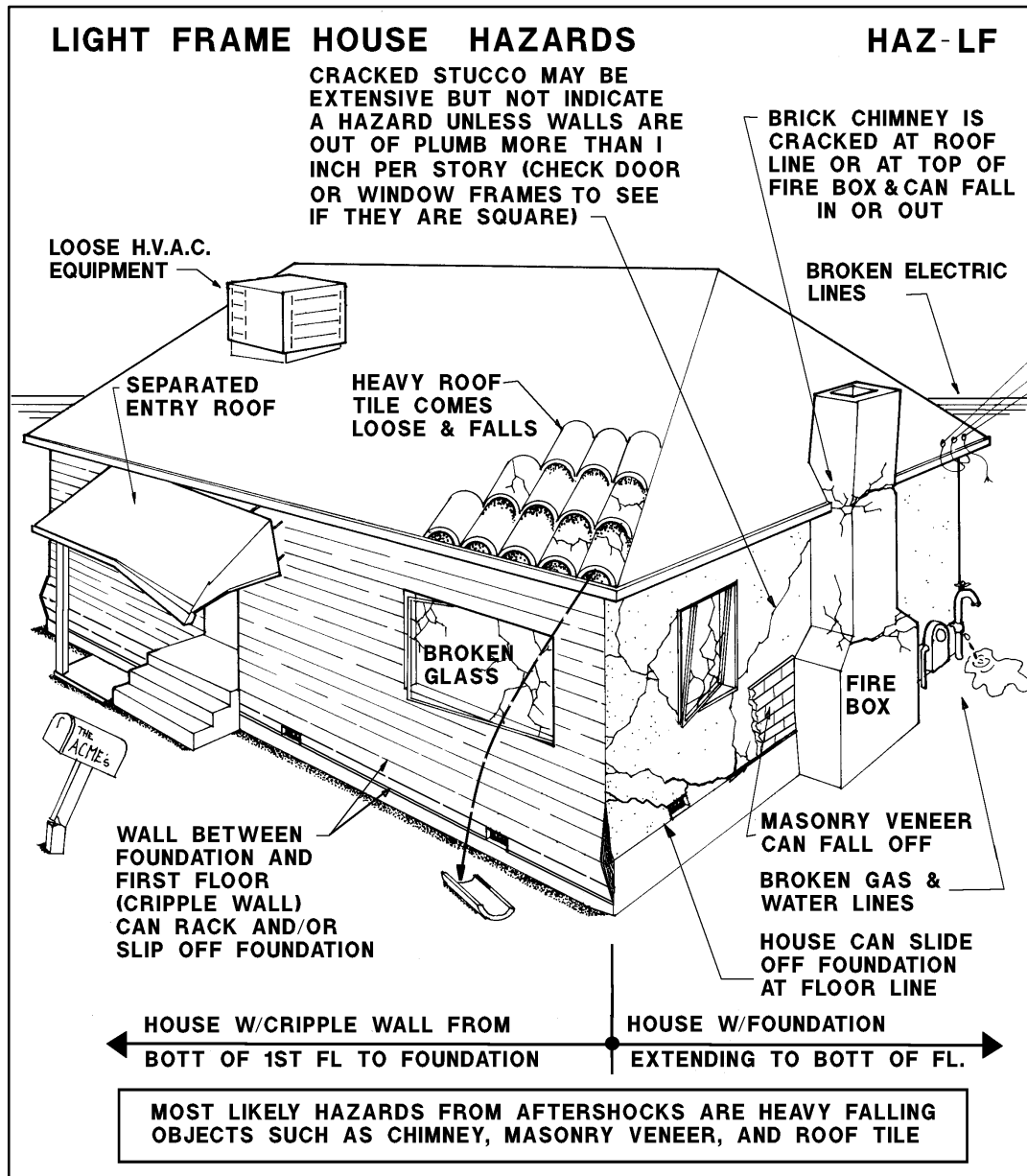


### Light Frame Building Hazards

The principal weakness is in the lateral strength of walls and connections.

- **Check Points: (HAZ-LF):**

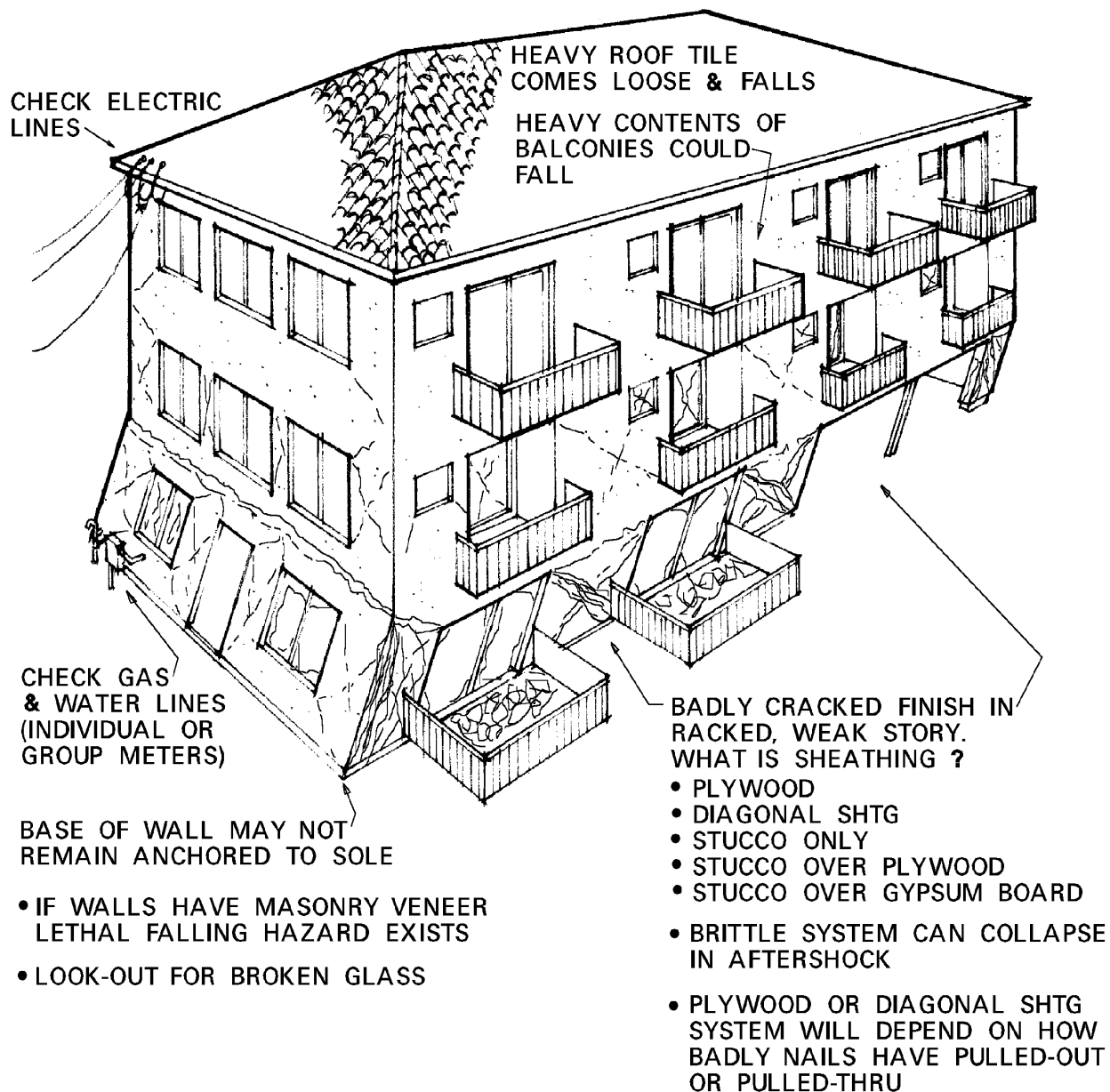
- ♦ Badly cracked or leaning walls;
- ♦ Offset residence from foundation;
- ♦ Leaning first story in multi-story buildings;
- ♦ Cracked, leaning masonry chimney or veneer;
- ♦ Separated porches, split level floors/roof.





- In structures of less than three stories, additional collapse is unlikely because of the light weight of this type of construction.
  - ♦ Collapse of this type is often slow and noisy.
  - ♦ Falling masonry chimneys and masonry veneers are the most brittle types of behavior for these structures.

## LIGHT FRAME • MULTI-STORY HAZARDS HAZ-LF3

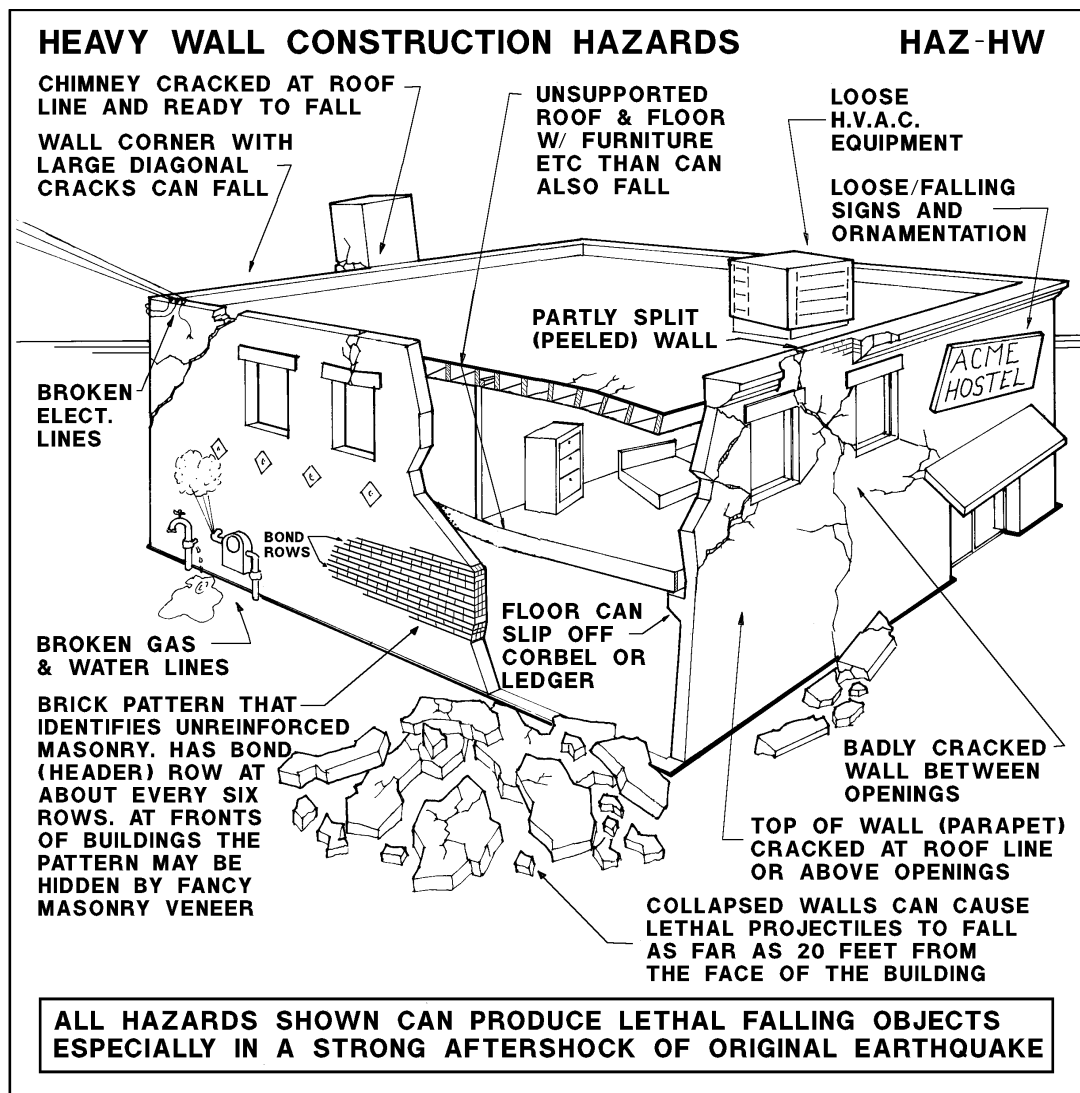




### Heavy Wall Building Hazards

The principle weakness is in the lateral strength of walls and their connections to floors/roof.

- **Check points: (HAZ-HW):**
  - ◆ Loose, broken parapets and ornamentation;
  - ◆ Connection between floor and wall;
  - ◆ Cracked wall corners, openings;
  - ◆ Peeled walls (split thickness);
  - ◆ Unsupported and partly collapsed floors.
  - ◆ **All failure will probably be brittle.**
- Falling hazards are very common in unreinforced masonry buildings because of the combination of weak and heavy wall elements. Collapse of adjacent buildings can occur as a result of the falling hazard of party walls.

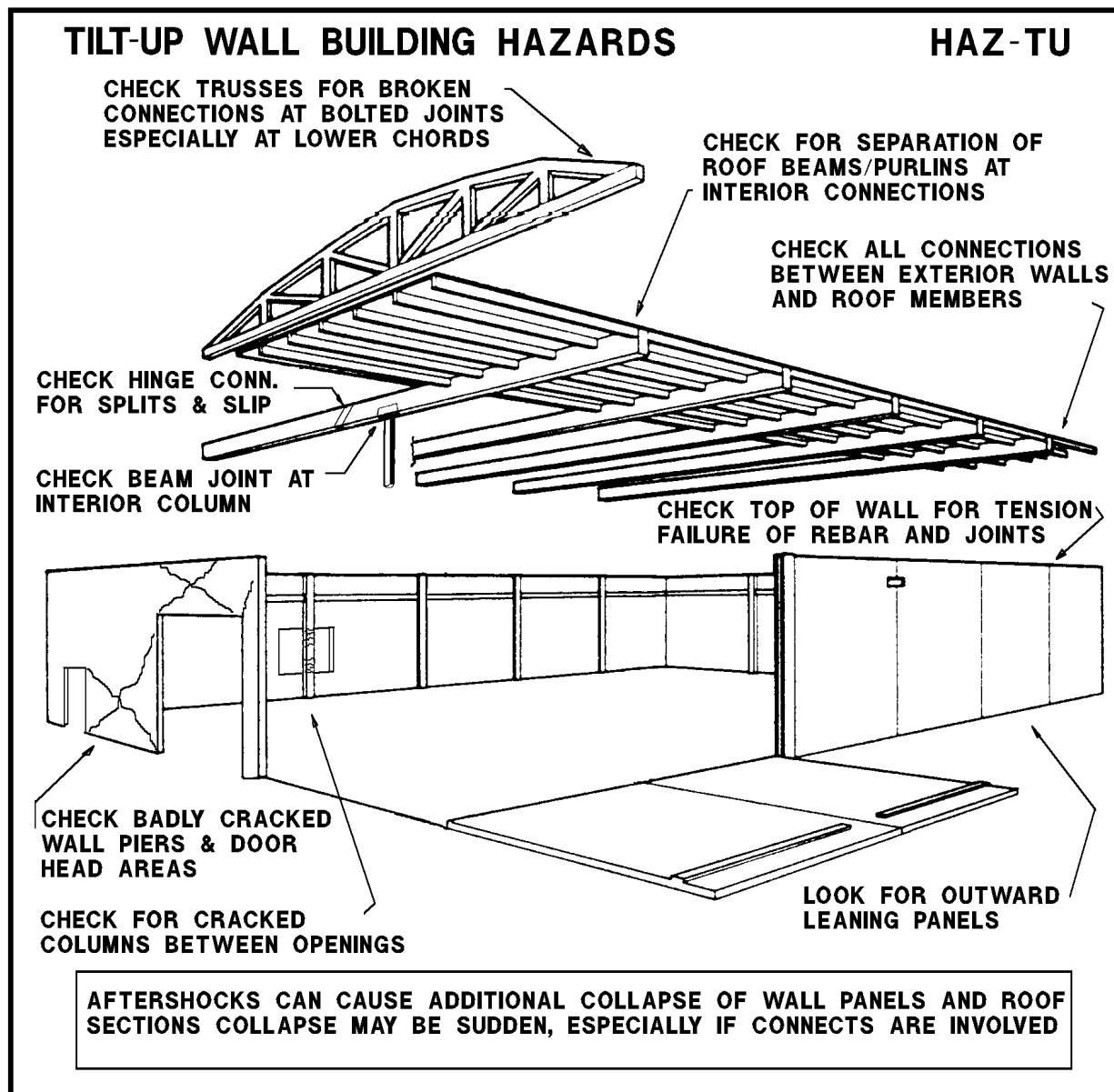




## Heavy Wall Building Hazards – Tilt-Up

(Low-rise, reinforced masonry wall buildings with light roofs are similar.) The principle weakness is in the connections between the wall and floor/roof.

- **Check Points: (HAZ-TU):**
  - ◆ Connection between floor/roof and exterior wall;
  - ◆ Connection between beams and columns, both exterior and interior;
  - ◆ Badly cracked walls and/or columns.
- The connection failure will often be brittle. The wall/column failure and shear failure may be more ductile, but single curtain wall reinforcing provides little confinement.

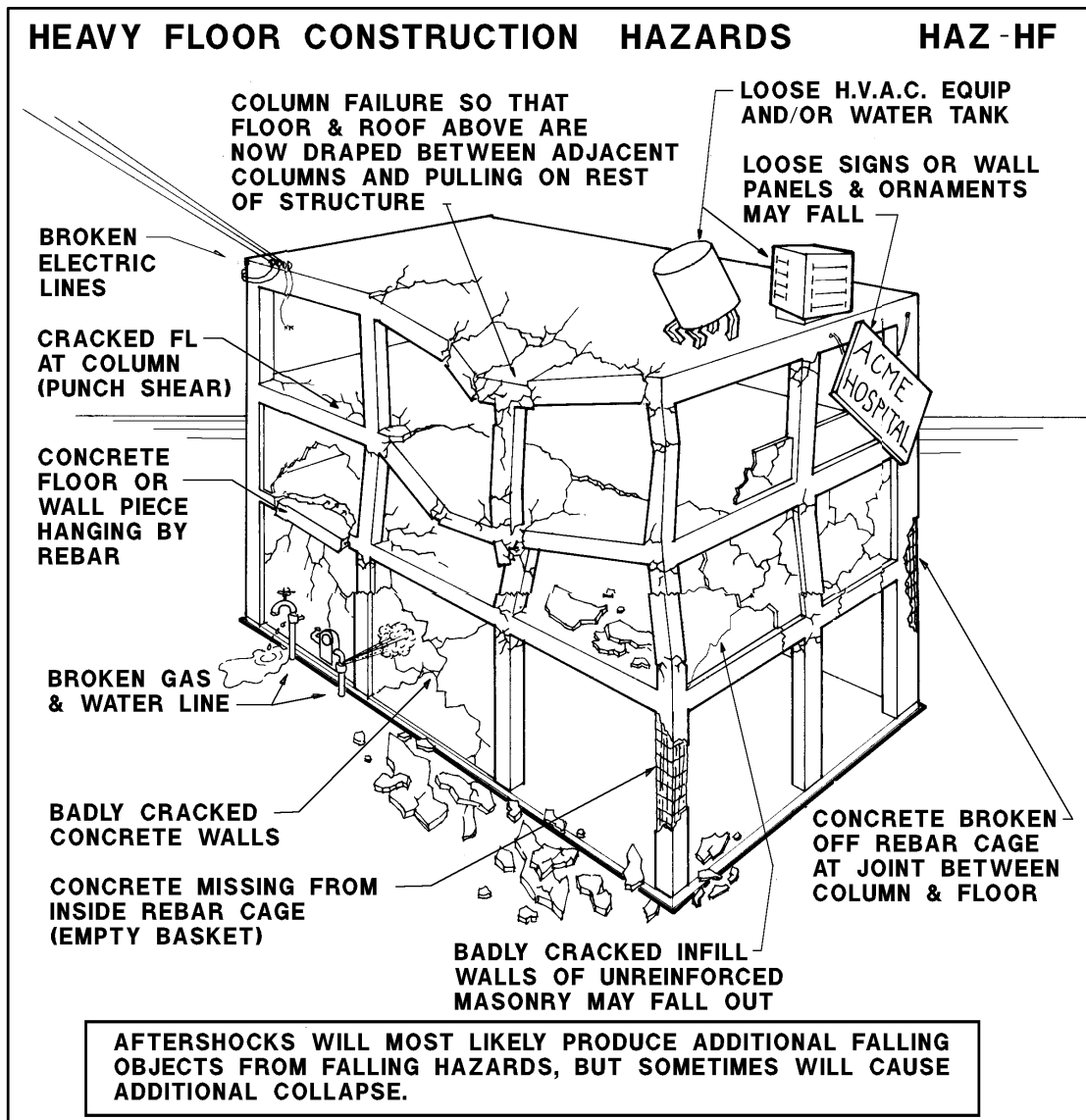




### Heavy Floor Building Hazards – Concrete Frames

The principle weakness is both a lack of adequate column reinforcement that can properly confine the concrete and an inadequate connection between slabs and columns.

- **Check Points: (HAZ-HF)**
  - ◆ Confinement of concrete in columns (empty basket).
  - ◆ Cracking of columns at each floor line (above and below floor).
  - ◆ Diagonal shear cracking in beams adjacent to supporting columns and walls.
  - ◆ Cracking in flat slabs adjacent to columns.
  - ◆ Attachment of heavy non-structural, unreinforced masonry walls (infill walls).
  - ◆ Cracks in concrete shear walls and/or stairs.
- Ductile behavior may still be possible if the concrete is confined by reinforcing and the reinforcing is still within a lower yielding range.



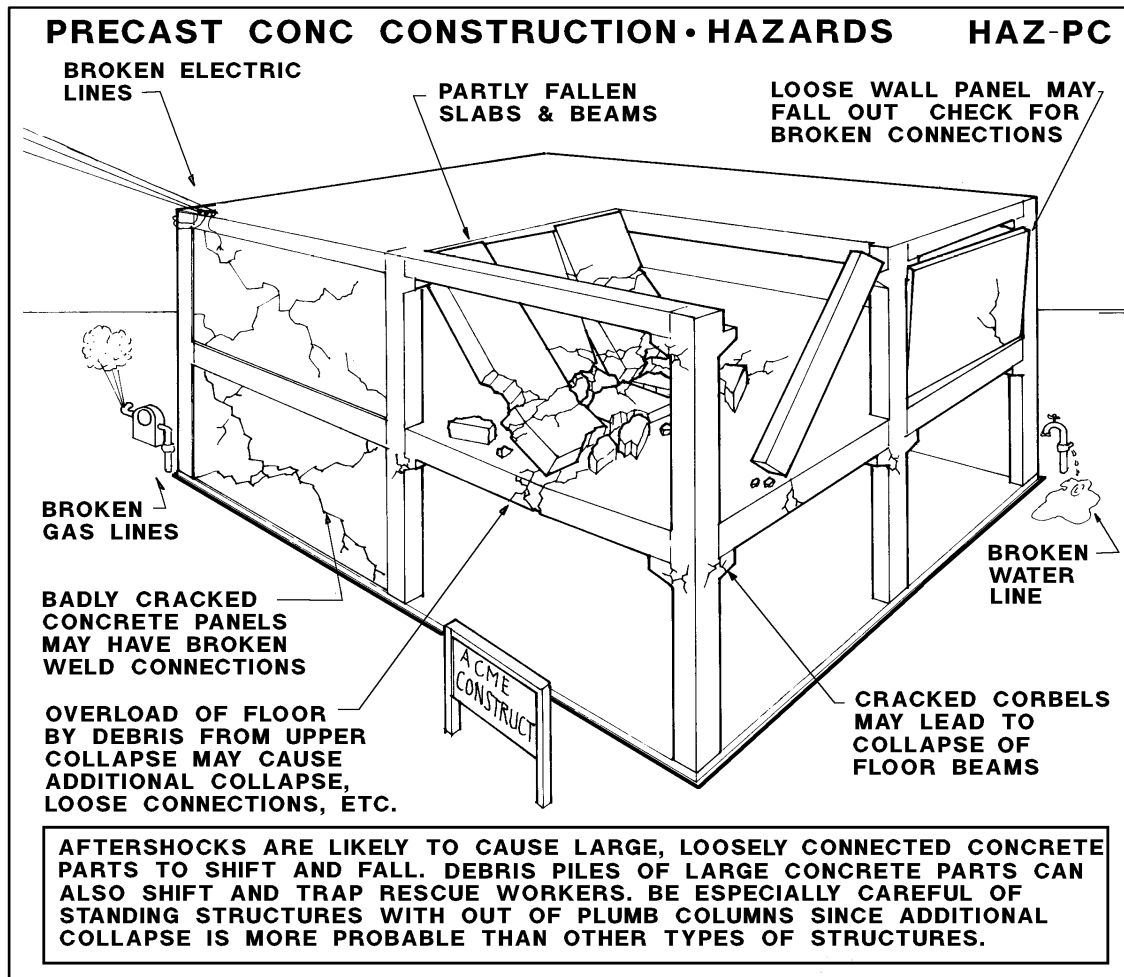




## Pre-Cast Building Hazards

The principle weakness is the interconnection of parts: slabs to walls/beams, beams to columns, walls to slabs, etc. It is very difficult to make connections adequate enough to transfer the strength of parts, connections necessary to survive a maximum earthquake. These buildings can have fairly heavy walls and floors, but neither is as heavy as heavy wall or heavy floor types.

- **Check points: (HAZ-PC)**
  - ◆ Beams to column connections, broken welds, and cracked corbels.
  - ◆ Column cracking at top, bottom, and wall joints.
  - ◆ Wall panel connections.
  - ◆ Shear wall connections at floors and foundation.
  - ◆ Badly cracked walls.
- These structures are often made from lightweight concrete. It should be noted that lightweight concrete splits more easily than normal weight concrete.
- Most failures that occur due to broken connections will be brittle.
- Since individual building parts may be quite strong, cracked concrete failures may be ductile if adequate bonded reinforcing is present.
- Depending on extent of collapse, many falling hazards may be present.





## HEAVY STEEL FRAME BUILDING HAZARDS

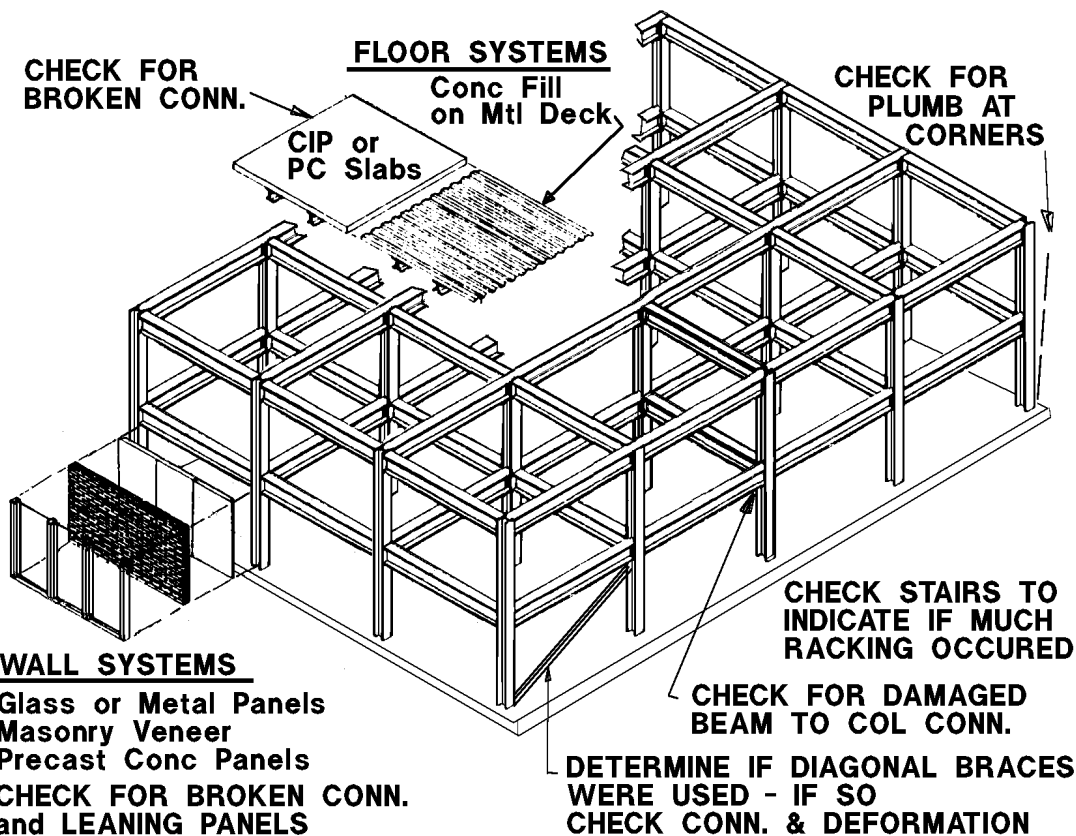
Principal concerns are the potential for building cladding to become Falling Hazards, and the cracking of welds in the main, moment resistant connections. Both of these hazards have occurred during earthquakes. Following earthquakes in 1985, 89, 93 and 94, building codes now require improved ductility in both the cladding attachments and the moment resistant connections.

- **Check points: (HAZ-HS)**

- ◆ Exterior Cladding for leaning or broken connections.
- ◆ Indications of movement – plumb corners, stair and non-structural damage – as clues to potential structure damage.
- ◆ Main Beam-Column connections – may need to remove finishes or fireproofing.
- ◆ Broken/damaged floor beam connections and, if present, broken PC slab connections.

### HEAVY STEEL FRAME - HAZARDS

### HAZ-HS



SINCE MOST MEMBERS AND CONNECTIONS ARE HIDDEN, BEST INDICATION OF FAILURE IS EXCESS MOVEMENT CAUSING DAMAGE TO NON-STRUCTURAL ELEMENTS AND OUT OF PLUMB CONDITIONS



#### **Post-tensioned Concrete Slab Hazards**

- There are many types of structures that have floor slabs that are reinforced by high strength cables that are cast in place in a sheath, then stressed after the concrete is cast and cured (Post Tensioned).

These structures can perform very badly when subjected to extreme loading, and most always exhibit brittle behavior. Most common examples of structures where P.T. slabs may be found are:

- Multi-story Parking Garages.
- First floors of apartment houses that are built over parking.
- Since the cables often extend the full length of these slabs, if it becomes damaged at one end or section, it will become “unstressed” over the entire length of the structure.
  - ◆ Therefore this type of slab has the very undesirable characteristic of being “Anti-Redundant”.
- It may become necessary, during a US&R Incident, to cut through a P/T. slab that still has stressed cables. This takes proper care and protection.

#### **Summary, Hazard Identification**

The problems of identifying hazards after a structural collapse are extremely difficult.

- Buildings are often complicated, and there are many different types and configurations.
- What remains after the triggering event may have come to rest, but the danger of further collapse and/or falling objects is often present.
- As shown in the adjacent slide, damaged structure may be “At-Rest”, but that does not mean that they are “Stable”.
- A properly trained US&R engineer (Structures Specialist) should help identify these hazards.
  - ◆ Hazards should be have probable risk factors assigned to them.
  - ◆ Measures to mitigate the danger can then be factored into the overall search and rescue effort.
  - ◆ Brittle conditions pose the greatest threat because of the possibility of sudden failure.



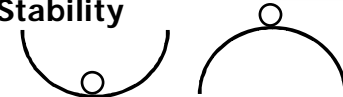
#### **Other Hazard I. D.**

- PostTensioned Concrete Slabs present unique Hazards
  - After cables become loose, slabs act more like unreinforced concrete.
  - Cables normally extend full length/width of slab .  
(? loose full length of cable)
  - If cables are still stressed, must cut with great care.
- Geologic Hazards - effect structures

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#### **Stability**



**By Definition Stable System will come back to Original Position**

**In US&R, we need to deal with Structures that are “At Rest” & just barely in “Equilibrium”**

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#### **Hazard Identification Summary**

- Structure has come to rest but many hazards may remain
- Aftershocks & strong winds may cause falling objects & additional collapse
- Hazards need to be identified & relative risk factors assigned
- Mitigation measures then need to be designed in concert with the SAR effort

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## **Hazard Assessment for US&R**

Based on the previous section on Hazard Identification, we need to add some additional considerations for US&R, since we may need to enter damaged structures.

- Assessment applies to building structural system and individual void systems. (global vs. local)
- The first question should be “do we need to be in this area at all?”
  - ◆ Hazard avoidance is the preferred option
- What caused the collapse?
  - ◆ Quake, Wind, Explosion, unknown?
- Has the structure collapsed to a stable condition?
- What if there is an aftershock?
  - ◆ What is the plan?
  - ◆ What are the escape routes and/or safe havens?
- **Look up first!** Small, nonstructural elements may be the greatest hazards.
- Debris and other loose materials can fall in wind gusts and aftershocks—these are hazards during hazard assessment.
- Identify how the load paths have been changed due to the collapse.
  - ◆ Can we add mitigation to better stabilize without significant risk
- Identify vertical and lateral load systems.
  - ◆ How have the load carrying systems been changed?
  - ◆ Will the structure exhibit brittle or ductile behavior?
- What redundancy is present?
- Can the hazards be mitigated to an acceptable level?
  - ◆ What is the risk during the mitigation?
  - ◆ Before changing the existing configuration, evaluate the effect of the change on the load paths.
- Check for potential instabilities: building stability and rubble stability.

### **Intro to Hazard Assessment**

- Applies to building structural systems and individual void systems (global vs local)
- First question should be
  - Do we need to be in this area at all?
  - Hazard avoidance is the preferred option
- What caused the collapse?
- Has structure collapsed to a stable condition? Usually answer is NO
- What if there is an aftershock - what is the plan? (Safe haven areas / escape routes)

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### **Hazard Assessment - 2**

- Look up first! Small nonstructural elements can be the greatest hazard
- Debris and other loose materials
  - Wind, aftershocks, etc. can knock off loose materials
  - These are hazards during Hazard Assessment
- Identify load path

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### **Hazard Assessment - 3**

- Identify vertical & lateral systems
- Brittle or ductile behavior?
- Check for redundancy
- Can the hazards be mitigated to an acceptable level?
  - What is risk during mitigation?
  - Before changing the existing configuration evaluate the effect on the load path
- Check for potential instabilities
  - Building stability & rubble stability

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## Hazard Mitigation

The basic alternatives to deal with structural collapse or falling hazards are as indicated below.

- **Avoid:** Plan the direction of SAR activities as far away as possible from a hazard and its effects.
  - ◆ Access of a badly collapsed structure should start from the top rather than from the edge (between layers) or by tunneling.
  - ◆ The use of mining techniques of tunneling and shoring with individual vertical posts has led to aftershock-caused shore failures. Consider alternatives, consult with others, and be as resourceful as possible.
- **Exposure reduction:** One of the most efficient methods of hazard reduction is to limit the time of exposure of rescuers exposed to a potentially dangerous situation.
  - ◆ Because of the natural tendency of rescuers to be helpful and to be **part of the action**, one will often find more than the minimum required number in a confined space especially when a live rescue is nearing completion.
  - ◆ Risk is a function of both severity and exposure.
- **Remove:** Removal may be more efficient than shoring.
  - ◆ Parts of URM walls may be removed by hand using aerial ladders for upper portions or in larger pieces using crane and clamshell.
  - ◆ Pre-cast concrete sections are more easily removed by small cranes or other concrete removal machines because of their moderate size and lack of interconnections compared to cast-in-place concrete.
  - ◆ If at all possible, Lift Off, Push Over, or Pull Down (safely of course) should be a first choice.

### Intro to Hazard Mitigation

- **Avoid**
  - Need effective barrier system
- **Removal**
  - Lift off, push over, pull down
- **Exposure reduction**
  - How long do we need to be in the area?
  - Risk is a function of severity and exposure
  - Limit time exposed to hazard
  - Limit number of personnel exposed
- **Similar to Time, Distance, & Shielding Rule used in Hazmat**

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- **Shore:** Provide both vertical and lateral support; build safe haven areas. This topic will be discussed in detail in its own section, with special emphasis on slow/forgiving failure modes. The lateral bracing of damaged columns, beams, and entire leaning buildings may be required. Tension tieback bracing can also be effective for holding walls, and cranes have been used to temporally suspend parts of damaged buildings.
- **Monitor:** Methods include the use of crack measuring devices, Theodolites & Total Stations, and other tilt measuring devices (Change in Tilt) to monitor damaged structures. To be effective, these devices must be continually read and have the data recorded. There should also be an effective alarm system that activates an efficient evacuation plan.
- **Recognize** and refer hazardous materials to HAZMAT Specialists. Eliminate/shut off all possible fire hazards.

### Summary, Hazard ID and Intro to Mitigation


- We discussed “READING” concrete and masonry cracks in order to predict structural behavior.
- We then learned to IDENTIFY the most common hazardous conditions for simple buildings.

We have completed our discussion of Hazard I.D., and introduction to Assessment and Mitigation. The Key Learning Points are listed on the adjacent slide.

US&R operations will need to be carried out in partially collapsed and badly damaged, uncollapsed structures that pose the greatest threat of additional collapse and entrapment of rescue workers. Using the suggested monitoring methods, it is possible, in most cases, to recognize when further collapse is likely.

We will now discuss the FEMA US&R Marking System.

National Urban Search and Rescue Response System  
Structural Collapse Technician Training




#### Other Hazard Mitigation

- Vertical & Lateral Shoring
  - System with slow failure mode
- Lateral Bracing
- Lateral Tieback
  - When shoring isn't practical
- Vertical Tieback
  - Use cable to hang or tie-back structure
- Monitor - with alarm & escape system
- Recognize & Refer Hazard (hazmat)

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#### Key Learning Points

- Cracks in Reinf Conc & URM create an opportunity to Monitor Structures
- Potential Hazards have been summarized for each of the four main types of Buildings
  - Light Frame, Heavy Wall, Heavy Floor, Precast Concrete & Steel Frame
  - Become familiar with these summaries in the StS FOG and in SOG
- Hazard Assessment and Mitigation are important tasks that are performed by the Structures Specialist – we have introduced the basic concepts

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## METHODS TO MONITOR STABILITY

The fundamentals of structural monitoring for SAR include: a Monitoring Plan; effective Emergency Communication Plan; Monitoring Tools, and Trained Monitoring Personnel

**Monitoring Plan:** Similar to a design performance memorandum, the monitoring plan establishes the expected performance levels for the structure being monitored.

### Monitoring Plan:

- Identifies what structure or component is being monitored, why, and for how long monitoring, should continue.
- Establishes control and reference points ensuring the accuracy of the monitoring. Identifying survey targets on a damaged structure may not be possible so finding appropriate targets that will telegraph incipient movement is critical.
  - Control points should be visible in various conditions and from at least two monitoring locations (to observe movements in X-Z and Y-Z directions).
- Must establish the tolerances, which create a "CAUTION" or an "ALARM" notification.
  - Caution levels might include movements that are out of the expected, but not large enough to warrant evacuation.
  - Alarm levels would include movements that telegraph impending collapse and evacuating rescue personnel is appropriate.
  - NOTE: Expected movements due to thermal expansion/contraction shouldn't initiate a "CAUTION".
- Must utilize an effective emergency communication system used to inform command of changing site conditions and the potential for site evacuation.

### Elements of Monitoring

- Monitoring Plan
- Record Keeping
- Emergency Communication Plan
- Monitoring Tools
- Properly Trained Personnel

### Monitoring Plan

- Where and how
- Control/Reference Points
- Directions of movement
- Caution vs Alarm
- Record Keeping
- Report Info in Incident Action Plan
  - Info gets to those who need it



### **Monitoring Plan (continued)**

- Must document all readings, expected direction of movement(s), potential failure-modes and effects, observations, and readings.
  - An effective record keeping system is well organized and keeps the Task Force Leader and Incident Command informed of site conditions
  - Typically, the documentation is included in the Operational Action Plan.

**Emergency Communication Plan:** Effective monitoring must utilize an effective **warning system** that informs Incident Command of potential structural movement (CAUTION) and includes a signal system to communicate **site evacuation** (e.g. three long horn blasts).

- The FEMA Incident Support Team and Task Force Leader(s) must persuade the Local Incident Command to integrate the local monitoring plan into the overall site safety plan.
- All rescue personnel must understand and be able to hear the warning device.
- All must know their evacuation route, and to whom they are to report –Accountability

**Monitoring Tools** - The following indicators have been used to monitor damaged structures in an attempt to warn of change in stability:

- Engineers Transit and/or Total Station.
- Electronic Tilt-meter Systems
  - Wireless Building Monitoring System
- Electronic Levels
  - SmartTool and SmartLevel
- Laser pointers or Level
- Plumb bob.
- Crack measuring device
- Wind Speed Measuring Devices

### **Record Keeping**

- Written Records need to be kept of all Monitoring Devices (forms shown next)
  - Record at least Hourly during first 5 days
  - All Monitoring Devices, inc Crack Monitors
- Recording System could be setup and kept by IST Structure Spec Staff
  - Each TF Structure Spec should keep own Unit Log (ICS 214) including Monitoring Data
  - Need to share data at every shift change, assuming no significant movement
    - Part of normal Hand-Off
  - Report info in Operational Action Plan (OAP)
  - OAP is generated by the IST, TAP by the Task Force

### **Emergency Comm. Plan**

- Effective Warning System
  - For Caution and Alarm Warnings
- Involves Coordination
  - FEMA Task Force Leaders
  - FEMA Incident Support Team
  - Incident Command
- All must understand, and be able to Hear Warning Signals
- All must know their Evacuation Routs, and to Whom they Report

### **US&R Monitoring Devices**

- Theodolite and Total Station
  - Reflectorless Total Station
- Electronic Tilt Meter
- Electronic Level
  - SmartLevel & SmartTool
- Laser Levels
- Plumb bob
- Crack measuring devices
- Wind Speed Measuring Devices





**Theodolites and Total Stations** have been successfully used to monitor damaged structures, including Falling and Collapse Hazards.

- They are capable of very remote sightings on damaged structures that allow the observer to operate without significant risk.
- It is not required that the monitoring point be able to be physically accessed (only clearly observed).
- For reliable and repeatable results it is necessary to establish control points, such as back sight lines, that allow for re-setup of the instrument.

This may be problematical following earthquake Aftershocks when many structures and ground surfaces have been moved and possibly disrupted

**Theodolite/Total Station Surveying Methods:** There are at least three methods that may be used when operating a Theodolite

- **Method One** is to establish a vertical control line that will compare a point on the structure to a fixed point on the ground, in order to monitor any changes in a leaning column or wall.
  - This method is simple and provides reliable control and repeatability – **Especially post Aftershock**
- **Method Two** is to use the Theodolite is to establish a reference point on an adjacent, stable structure, and then turn a series of horizontal angles to locations of interest on the damaged structure.
  - In this case we may be limited by the angular accuracy of the Theodolite.
  - This method requires the additional step of crosschecking the reference point, to assure that an observed movement has been accurately measured.
- **Method Three**, the Theodolite may be used to spot check a single point on a structure, measuring any movement using the telescope crosshairs.
  - This method is inefficient, not repeatable, and not normally recommended.
  - There may be instances where quick, short term monitoring of this type is all that is required, based on short term risk

#### Use of Devices

##### Theodolite/Total Station

- Theodolite/Total Station may be used to detect small movement in remote structures

Method 1 - Establish a vertical line that will compare a point on a dangerous building to a point on the ground to detect additional tilt / movement

Method 2 - Use a Reference Point on an adjacent building, and turn an angle to several locations of potential movement on a questionable structure

Method 3 - Just do a spot check on an individual point on a damaged structure, such as Falling or Collapse Hazards (Total Station could measure X, Y, & Z)



## **Theodolite Advantages and Disadvantages**

**Advantages:** Allows for observation w/o making contact w/structure, and very distant observation with ability to zoom in on structure

**Disadvantages:** Expense, Need well trained personnel, subject to false readings when instrument is accidentally bumped, reading are not as intuitive to unfamiliar personnel

**Theodolites** have been often been used poorly and without reference marks, as well as proper records and warning systems.

- As a result erroneous readings have caused false alarms to be sounded.
- This is, obviously, an intolerable condition that can undermine the creditability of a monitoring system
- The most common cause of false readings is inadvertent moving of the tripod.
  - One needs to establish effective barrier systems around Theodolite monitoring stations.
  - Previously established, back sights and reference points can minimize these problems.
  - At earthquake caused incidents, one must also plan for Aftershocks by setting up the instrument and the reference points properly

**A Wireless Building Monitoring System** is available from: Exponent Technology Development - (602) 206-4126 [www.Exponent.com](http://www.Exponent.com)

- A full-system consists of four, bi-directional sensors that can be read by either one of two iPAQ Pocket PC (or a laptop computer) A full-system has 2 spread spectrum receivers.
- Receivers have range to 1000ft with clear sight line, but is less if signal is obstructed by heavy structures and/or metal
- The software is set to poll each sensors at 10 sec intervals. It checks the signal for interference, and a audible ping is heard as each sensor "reports" good data
  - A lower frequency "clunk" is heard if a sensor is not operation properly or turned off

### **Use of Devices Theodolite/Total Station**

- **Advantages**
  - Observation w/o contacting structure
  - Make Distant Observations
  - Ability to Zoom - In on structure
  - Observe many points from One Location
- **Disadvantages**
  - Cost of instrument
    - 20sec Theodolite = \$2000
    - 5sec Reflectorless Total Sta = \$6500
  - Need Trained Operators
  - Readings not Intuitive
  - Need stable Reference/Control points
    - Difficult establishing post aftershock control?
  - Can't Use w/Face Mask

### **Use of Devices Theodolite/Total Station**

- Theodolite have often been used Poorly and without Reference/Control
- **False Movements have been reported at several major incidents**
  - Most often as a result of someone inadvertently bumping the tripod, without having an adequate Reference/Control mark system
  - This can lead to a lack of confidence in this very important system
- This is a very effective device that must be used properly

### **Use of Devices – WBMS**

- **Wireless Building Monitoring Sys (WBMS)**
  - System uses up to 4 Sensors, placed structure(s), to measure & transmit movement as an angle change.
    - Measures angle change of 0.05 degree (repeatable)
  - Signal is sent to 900mhz Spread Spectrum Receiver
    - Range is up to 1000 ft. (clear sight)
    - Not as far thru Heavy Concrete & Metal Structures
  - Receiver is linked to MS Pocket PC PDA or a Laptop by wireless, blue-tooth connection
    - PDA software polls sensors at 10 to 15 sec interval
    - PDA chirps for each coherent signal received
    - May set software to alarm for any amount of angle change
  - USACE purchased 7- Sys in 2004 (6-deploy & 1-Train)
  - FEMA purchased 6 - Sys for IST in 2005
  - Mount using Hat Channel, screwed to concrete.
    - Strap Sensor to Hat Channel – Cargo Strap & Bungee



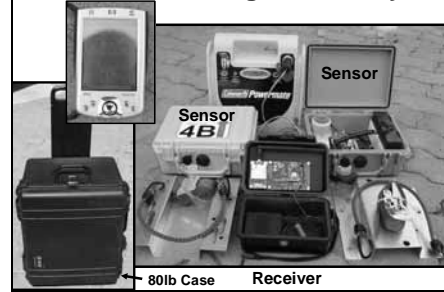
### Wireless Building Monitoring System (continued)

- The software can be set to trigger an alarm at any preset angle change (alarm can be sounded through an earpiece)
- The tilt meters are sensitive to angle change of .05 degrees
- WBMS units are packaged in Pelican Cases, each having:
  - Two Sensors with 7 day, 12v. batteries & cables
  - One Receiver w/ Blue Tooth communication
  - One PDA with Pocket PC 2003 or Mobile 5 Op System
  - Software, Manuals & connecting hardware
- In 2005, FEMA purchased, two full systems for each IST (Four Pelican Cases + small case with drill-driver, etc)
- Advantages and Disadvantages of WBMS are shown in adjacent slide

**Electronic levels**, sensitive to an angle change of 0.1 degree, with digital read-out, can be purchased at Home Depot type stores and tool mail order houses for about \$100 (2005).

- They can be mounted on a structure, the angle recorded, and any subsequent change would then need to be read by a TF member.
- In order to mount the SmartTool on a concrete structure, one may do the following:
  - Place a 1 x1x1/8 x 0'-9" steel angle that has been attached to the structure with putty type epoxy or 1/4" concrete screws placed thru 5/16" holes that have been drilled in the angle (angle may be left in place)
  - One should then use a 2 1/2" C-clamp to make a removable, but positive connection

### Wireless Building Monitor Sys



### Use of Devices – WBMS

- **Advantages**
  - Monitor 4 or more locations at once
  - Very accurate and can set Alarm for any amount of movement
  - Portable Receiving/Alarm System
  - Remote Observation (up to 1000 ft )
  - Can Use w/Face Mask
- **Disadvantages**
  - High cost (\$18,000 per full-system, 2005)
  - Need Qualified, Techno-Operator
  - Need planned, periodic battery recharge system
  - Need to place Sensors on Structure
    - They have remote, 7-day, 12v batteries

### Use of Devices – Electronic Levels

- **Electronic Levels should be placed in pairs on structure to measure change in any angle (Vertical or Horizontal)**
  - Measures angle change of 0.2 degrees
  - Cost is in \$100 range, each
  - **Must be continually read (no alarm)**
    - New lower cost model cannot be set on zero when placed in vertical position
  - Use binoculars for remote reading
  - Must alter device to turn battery saver off
  - Mount on steel angle using magnetic tape and/or a C-clamp



### **Electronic levels (continued)**

- They are supplied with a battery saver feature that turns them off in 5 min. if no change in angle is sensed.
  - This feature can be defeated by a modification:  
contact [djhammond@sbcglobal.net](mailto:djhammond@sbcglobal.net)
- Made by: MACKLANBURG-DUNCAN  
[www.amazon.com/toolcrib](http://www.amazon.com/toolcrib)
- Advantages and Disadvantages of Electronic levels are shown in adjacent slide

**Laser Levels**, may also be used to measure an angle change of about 0.2 degrees.

They may be purchased at Home Depot stores for less than \$100 (RoboToolz) in a 3-beam or single beam configuration, and come with magnets embedded in their bottom surface.

There are also more versatile models, such as the Hilti PMP-34 that are sold in kit form. It can be configured as a 3-beam, 2-beam or 1-beam tool. It also is self leveling, but one may cancel this feature

- The RoboToolz may be mounted on a structure using the same steel angles as for the SmartTool, however they have a strong magnet, so the C-clamp is not required
- The Hilti PMP-34 also has magnets, plus several mounting devices
- One would then need to place a target within 75ft of the device with an **X** on it to observe the structure's movement
- One could use the 3-beam laser level with 2 targets to observe movement in two directions. Otherwise it would require that two single beam lasers be mounted in a mutually perpendicular orientation (same as SmartTools)
- The RoboToolz use AAA batteries that last only 12 hours, but the Hilti PMP-34 uses 4-AA batteries that last 40 hours
- The advantages and disadvantages of Laser Levels are listed on the adjacent slide

#### **Use of Electronic Levels**

- **Advantages**
  - Low cost
  - Long battery life (about 40 hours)
  - Easy to read
- **Disadvantages**
  - Not as accurate as Tiltmeter
  - Need to place on structure
  - Need to place 2 in each location to measure angle change in N-S + E-W direction
  - Need to dedicate someone to read them – line of sight
  - Need to modify Battery Saver Function

#### **Use of Devices – Laser Levels**

- **Laser Levels** - placed on structure to indicate movement by changed position of the light beam on a specified target
  - May measure angle change or lateral/vertical movement
    - Accuracy depends on setup – maybe 0.2 degrees,
    - 1/8" Must be continually read (no alarm)
    - Target should be set in safe area
  - **RoboToolz Laser Level**
    - Low cost, but less useful
  - **Hilti Laser Level - PMP-34**
    - Moderate cost w/ lots of extras

#### **Use of Laser Levels**

- **Advantages**
  - Low cost
  - Easy to read
- **Disadvantages**
  - Not as accurate as WBMS
  - Need to place on structure
  - Need to place 2 targets for each location to measure angle change in N-S + E-W direction
  - Someone to read them – line of sight
  - Need to replace batteries
    - Every 12 hrs for RoboToolz
    - Every 40 hrs for Hilti



**Plumb Bob** and string can be used for moderate structures to determine changes in position of one story from another, between a story and the ground, or between an upper part of the wall and the ground.

- This can allow one to measure and record the changes in a leaning structure when no other device is available.

**Benefits:** inexpensive and simple to use. No special skills are required

**Disadvantages:** Personnel must attach plumb bob to structure and constantly observe it

Crack Measuring Devices can be used to monitor cracks in concrete or masonry shearwalls or concrete moment frame in several ways. It is important to know if the cracks in a damaged building are of a constant width or enlarging.

Methods that have been used include:

- Marking an "X" across the crack with the center on the crack. Significant lateral movement changes can be observed.
- Placing folded paper in cracks or use automobile thickness gages (.004" to .025") to measure a specific location.
- Adhesive or other tape may be placed across the joint to measure change, but dusty conditions may prevent tape from adhering.
- Two parallel sticks (rulers) can be taped across a crack with a perpendicular line being drawn across both of them (or existing lines on two rulers can be aligned). If the crack changes width, then the originally straight line will be offset.
- Plastic Strain gages (about \$16 ea. in yr. 2000) may be placed across cracks to also indicate change. (mount with paste type, quick set epoxy or concrete screws)

Made by: Avongard, ([www.avongard.com](http://www.avongard.com))

- One may epoxy inexpensive glass slides across a crack. If the crack moves the slide will crack

#### Use of Devices - Plumb Bob

- Use a Plumb bob hung from small structure to compare to a point on the ground/pavement
  - Allows one to observe change in a leaning structure
- Advantages
  - inexpensive, easy to use, no special skills (a rock on a string will suffice)
- Disadvantages
  - requires one to attach to structure, constant observation, not too accurate

#### Crack Monitoring

- Draw or sawcut 'x' centered on crack
- Use inexpensive (\$15) plastic strain gage can be placed at crack
- Spray paint cracked area
- Place shims/cards in cracks
- Inexpensive, easy to read change, but need to be checked (up close) periodically

Note that if a structure has significant changes in temperature, the cracks will change width, due to the temperature change. The larger the structure the larger the change.



### **Method to Monitor Disaster Site**

**Seismic Trigger Device** can be installed at the site to sense the initial **P** waves of strong aftershocks. Since the **P** waves travel at 5 km/sec max. and the damaging **S** waves follow at approx. 3 km/sec, a warning signal could be triggered at a building site prior to the damaging effects of the **S** wave.

- The device comes in a portable carrying case and would need to be bolted to a solid slab/foundation, etc. somewhere near a damaged building.
- For sites within 10 km of the aftershock origin there would not be enough warning to be useful.
- For sites over 50 km away there would be time to escape to cover etc. (seven seconds + )
- A device of this type was used at a site after the Loma Prieta Earthquake. The current cost of the device is approximately \$6000.00 and is manufactured by:

Earthquake Safety Systems  
2064 Eastman Ave., Ste 102 Ventura, CA 93003  
(805) 650-5952

### **Aftershock Warning System**

The U.S.G.S., and others, have discussed making an aftershock warning system available to US&R Task Forces during the first week after an earthquake.

- The system uses an array of sensors near the fault to detect aftershocks.
- A warning signal is relayed by repeaters to individual pagers that will be given to each task force that is involved in rescue operations.
- For sites that are about 10 km from the active fault, there will be only 3 seconds warning.
- For sites that are 50 km away there will be 12 seconds warning (proportionally greater warning for greater distance from aftershock origin).

### **Method to Monitor Disaster Site**

- **P vs S wave - time delay**
  - P wave travels faster than S waves
  - If distance from Fault to Site is more than 50km there is opportunity to warn of Aftershocks
- **Seismic Trigger deployed at Disaster Site**
  - Warns when P wave arrives
  - Destructive S wave arrives later
- **Pager System**
  - Pagers at disaster site are signaled from sensors at fault that measure Aftershocks



#### Summary Of Hazard I.D. & Monitoring Methods

- We discussed to “**READ**” Concrete and Masonry cracks in order to predict structural behavior
- We then learned to **IDENTIFY** the most common Hazardous Conditions for simple buildings
- And finally it should be understood that US&R operations will need to be carried out in partially collapsed and badly damaged, uncollapsed structures.

These pose the greatest threat for additional collapse and entrapment of rescue workers. Using the suggested Monitoring Methods, it is possible, in most cases, to recognize when further collapse is likely.

#### Key Learning Points

- Structure Mitigation requires initially rapid and then continuing Prioritization & Planning
  - Creative Alternatives are what is needed
- Monitoring needs careful planning & the reporting of reliable information
  - The StS must become familiar with the Operation and Care of all Monitoring Tools in the Task Force Cache



## **Part 5 – US&R Strategy & Structure Size-up**

**Strategies** will be presented from a Structures Hazards point of view. Other input such as medical urgency, availability of special equipment and/or trained personnel, other hazardous conditions will also need to be considered.

### **THE THEME OF US&R MUST BE TO SAVE TRAPPED VICTIMS WHILE MINIMIZING THE RISK TO THE VICTIM AND THE US&R FORCES**

The Terminal Objectives are:

The Student shall understand the phases of a large disaster, and how the FEMA US&R Task Force could be deployed to perform its initial tasks.


The Student shall understand the FEMA US&R Marking System

The Student shall understand the most appropriate strategies to be used in order to effect rescues in various types of structures.

We will discuss the following:

- Phases of a Large Disaster
- Information Gathering
- Rapid Recon/Triage and Search Process
- Identification of Individual Buildings
- Structure/Hazards Evaluation and Marking
- Search and Rescue Assessment Marking
- Victim Marking
- Example of Search and Victim Marking
- Basic Building Search & Rescue Strategy (Student Manual only)
- Metal Detector & Cutting of Post-Tensioned Concrete, Cables (Student Manual only)

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Structural Collapse Technician Training




### **Terminal Objectives**

- The Student shall understand the phases of a large disaster and how the FEMA US&R Task Force could be deployed to perform its initial tasks.
- The Student shall understand the FEMA US&R Marking System

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### **Enabling Objectives**

The student will understand the following

- What normally occurs during the initial phases of Task Force Deployment
  - Recon and Search Process
  - Building I.D. and other Marking Systems
- See Student Manual for US&R Strategies that should produce best results for specific types of buildings.

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### Phases of a Large Disaster

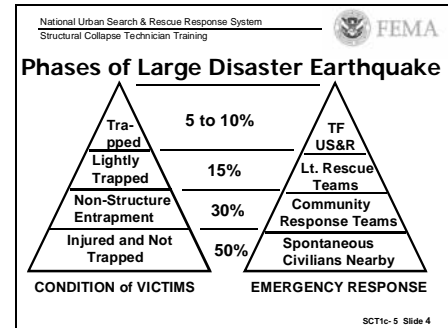
It is important for all to understand the typical chronology of a US&R incident, especially one caused by a devastating earthquake. The emergency response normally occurs in the following phases:

**Initial spontaneous response** unskilled, neighbors, community response teams, passers-by will heroically help remove lightly trapped and/or injured victims. These rescuers have often acted far beyond their normal skill level and often save three-fourths or more of the total. Survival rates are relatively high, since victims are normally not entrapped. Professional firefighter, law enforcement officers, and emergency medical personnel may participate and better organize the response. This phase will often end during the first night.

**Planned Community Response** by local trained community response teams. Call-out and visual search would be used to locate and rescue the non-structurally trapped. Some lifting of objects (furniture, bookcases, etc.) would be done as well as mitigation of hazards (extinguish small fires, turn off gas, observe/refer hazardous materials).

**Void Space Rescue** by local emergency services rescue forces. Search elements would help prioritize site to make better risk vs. benefit judgments. Rescue would proceed using existing cavities, duct/plumbing shafts, basements, and/or small cut openings in easily breachable floors and walls. Some shoring might be done to provide safe haven areas and otherwise protect emergency responders and/or victims. This phase may start the first day, but often, not until after some organizing efforts have taken place, requiring at least one hour.

**Technical, Urban Search & Rescue** by trained US&R forces, aided by equipment. Site or sites would be re-evaluated, re-searched, and prioritized for the ten-daylong effort. Extensive cutting, shoring, etc. may be done to penetrate the structure. Cranes may be used to remove layers of structural debris or parts of the structure that are hazardous.





**Typical First Hours Deployment** – for large, sudden incidents, like an earthquake.

There are many possible scenarios to which a US&R Task Force or a number of Task Forces could respond. However, our Operating System Description envisions that, during initial setup, a decision needs to be made as to the most appropriate deployment of TF Structure Recon and Search components. Some initial questions that need to be answered are:

Is Recon/Rapid Triage needed or have others established initial priorities?

- Will Task Force deploy the Recon Team(s) in order to pre-prioritize the structure?
- What sort of Search Team configuration will be used? ( Detection Team(s), Location Team(s))

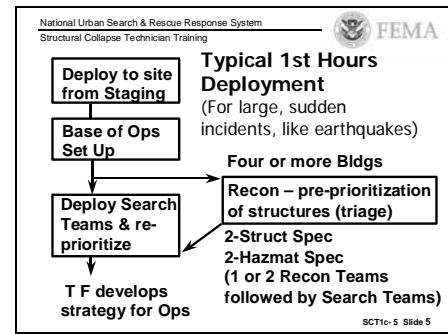
How many building have been assigned to the TF, and does Search and Recon need to be carried out at one or more locations?

How remote are the buildings assigned to TF?

### **Initial Information Gathering**

Information gathering techniques will be crucial to the efficient transition of the US&R forces into the incident. It is important for these incoming forces to carefully verify information obtained from the first responders and other individuals at the disaster site. By the time the information exchange takes place, the first responders will probably be subjected to the following:

- A many hour period of physically and emotionally draining work. Feelings that it's not possible that other victims have survived within a badly collapsed structure.
- A need to experience closure; that the incident is over.
- Feelings by relatives/friends of the missing that they have surely survived and are entrapped.
- The information gathering must therefore, proceed as swiftly and unemotionally as possible, while testing all current assumptions.





#### **Recon (Formerly called Structure Triage)**

The intent of pre-prioritization and identification of structures for a large, earthquake-like incident is to make more efficient use of search teams.

This can be done immediately after a suddenly occurring disaster by special assessment teams or local responders.

It can also be done by FEMA US&R Task Force(s) after they have been assigned to a specific area

- The assumption in this case is that local responders have been overwhelmed, and a rapid recon process will help focus the task forces on their life saving work.

#### **Rapid Recon Process**

A more rapid method for pre-prioritization and identification of structures for a large, earthquake-like incident was adopted in 2008.

Previously, it was envisioned that a Structure Triage would be accomplished by the Structures Spec.(StS) and Hazmat Spec.(HMS) during the first hour or more of a deployment. In this process, Search Teams would not be deployed until the triage was completed. This would be too time consuming, and the newly adopted process proceeds as follows:

- The Recon Team (explained next) would be sent-out first to quickly assess and identify the first two or three structures.
- They would report their findings to the Search Team Manager (or other designated leader).
- Search teams would re-prioritize these 2 or 3 structures, based on viable victim finds, and rescue could be started in the highest priority structure
- The Recon Team would have moved-on the next two or 3 structures, and report those findings.
- The process would continue until all assigned structures had been searched, and task force was clearly focused on rescue operations in the highest priority structures.



#### **Recon - (formerly structure triage)** Pre-Prioritization & I.D. of Structures

- Done immediately after disaster by special assessment team or by local emergency responders - or
- Done immediately after deployment of US&R Task Force - all structures in assigned area
  - Rapid assessment w/ scoring system and sketch map of area w/ bldg I.D.
  - TF Recon Team(s) would be followed by Search Team(s) within 15-30 minutes

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#### **Rapid Recon Process**

- Recon Team to rapidly assess & I.D. first 2 or 3 structures – (all in 15 to 30 minutes)
  - Pre-prioritizes these structures and reports findings for the follow-on Search Team(s)
  - Search Team(s) re-prioritize based on viable victim finds
- Recon Team moves-on to next 2 or 3 structures
  - Process continues until all assigned structures have been assessed
  - Recon Team continues to record and report findings

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### **Recon and Search Team Configuration**

Although this rapid recon process is intended to be flexible and incident dependent, the teams are most likely to be staffed by the following:

**Recon Team** – Search Team Manager (STM), StS., HMS., & Technical Information Spec.

**Search Detection Team** – STM, Canine Search Spec, Tech Search Spec, Medical Spec, Rescue Spec, StS.

**Search Location Team** – Similar to Detection Team

### **Team Tasks**

**Recon Team(s)**- provide initial hazard assessment and detection, with a scoring system based on expert judgment. They would then provide feedback of initial prioritization.


**Search Detection Team(s)** – provide victim detection that could re-prioritize the structures for the Search location Team(s). They would also provide detailed hazard assessment, and mark the structure with appropriate Search and or Structure Hazard Marks.

**Search Location Team(s)** – would locate victims, assess their condition, and start rescue. They would also mark the appropriate areas with Victim Marking.

**Recon** - the following information needs to be considered in determining risk/benefit that will aid in prioritization.

- **Disaster Type** The type of disaster would determine several things such as:
  - Potential for aftershocks following earthquakes
  - Severity of damage from blasts.
  - Unknown existing deficiencies for sudden collapse without apparent cause
- **Occupancy** the type of activity done in the building, and where most individuals would have been located. May be time of day dependent.
- **Time of Day** refers to the time of the event which caused the collapse. This is a critical factor when combined with the occupancy.
- **Structure size/type** indicates potential number of victims, plus difficulty of access and hazards
- **Collapse Type** – indicates type(s) of voids and potential for victim survival.

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**Team Configuration**  
(Incident dependent, emphasize flexibility)

- **Recon Team**
  - Struct Spec, Hazmat Spec, Tech Info?, Search Team Mgr?
- **Search Teams**
  - Detection
  - Location

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**Team Tasks**

- **Recon Team**
  - Hazmat Evaluation and Detection
  - Rapid Structure Triage/ Assessment
    - Scoring based on "Expert Judgment"
    - Provides initial prioritization
- **Search Detection Team**
  - Victim Detection, Search Marking & re-prioritization
  - Detailed Hazards Assessment & Marking
- **Search Location Team**
  - Victim Location & Start Rescue

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**Recon – Critical Information**  
Info considered to determine Risk / Benefit

- **Disaster Type** - possible after-forces
- **Occupancy** - type of activity and where the most individuals would have been located.
- **Time of day** - when disaster occurred
- **Structure size & type** - potential no. of victims + difficulty of access & hazards
- **Collapse type** - indicates type of voids & potential for victim survival

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#### Other Considerations

**Prior Intelligence** information from the general public, local authorities, first responders, etc. relating to known trapped victims.

**Search and Rescue Resources Available** does the particular building require resources beyond what is readily available to the task force (i.e., is heavy equipment required to gain access).

**Structural Condition of the Building** generally, can search and rescue operations proceed with a minimum of stabilization effort.

#### Recon Scoring Criteria

The following will be evaluated in assessing the **Probability of having Viable Victims**:

- Potential number trapped - low medium high
- Time required to access victims - 12hrs 6hrs 1hr
- Type of voids - compact separated open

The following will be evaluated in **Assessing Risk**:

- Chance of further collapse - low medium high
- Number. of Falling Hazards - low medium high
- Void support condition - good poor unknown

#### Recon Structure Classifications

Each structure would be given a two letter Classification to indicate the probability of being able to rescue viable victims, and a two letter Classification for Assessment of Risk.

These Classifications would be based on the Scoring Criteria presented above, and require "Expert Judgment" to be applied by the StS and HMS


**For probability of being able to rescue viable victims:**

- **LP** indicates Low Probability
- **MP** indicates Moderate Probability
- **HP** indicates High Probability

**For Assessment of Risk**

- **LR** indicates Low Risk
- **MR** indicates Moderate Risk
- **XR** indicates High Risk (HR = Human Remains)

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### Recon Scoring Criteria

- **Criteria for Probability of Viable Victims**
  - Potential number trapped - low med high
  - Time req'd to access victims - 12hr 6hr 1hr
  - Type of voids - compact separated open
- **Criteria for Assessment of Risk**
  - Chance of further collapse - low med high
  - Number of Falling hazards - low med high
  - Void support condition - good poor unknown

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### Recon Structure Classifications

- **For Probability of Viable Victims**
  - LP = Low Probability
  - MP = Moderate Probability
  - HP = High Probability
- **For Assessment of Risk**
  - LR = Low Risk
  - MR = Moderate Risk
  - XR = High Risk (HR used for Human Remains)

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### **"No Go" Conditions.**

These would include structures that are on fire, have significant hazmat spills or otherwise have conditions that would make search and rescue operations too risky. Buildings with **"No Go"** conditions would be expected to be re-evaluated when those conditions were mitigated, and some comment would be made regarding this should be communicated to the STM or other designated leadership.

A better term for these conditions would be **"Slow-Go"**, since that would better indicate that after the extreme hazard has been eliminated, the building might be searched

### **How Classifications are applied**

After assessing each of the three Criteria for Victim Probability, each structure would be given a Classification of LP, MP, or HP

After assessing each of the three Criteria for Risk, each structure would be given a Classification of LR, MR, or XR

- This process required the StS & HMS to make rapid, value judgments in a very short time
- Victim probability should include considerations such as potential numbers and ease/difficulty/risks involved with their extrication.
- It should be understood that it is possible to have more than one structure with the same classification.


### **Examples of Risk Level**

The companion recon form Recon-2 will provide a list of collapsed structure conditions that could be considered low, moderate and high risk.

This will provide the StS some backup information to aid in making the difficult judgments that are required in this rapid Recon Process

The adjacent slide lists some of those conditions

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### **No-Go Conditions**

(Really Slow-Go or Delayed-Go)

- **FIRE**
- **HAZMAT**
- **Need to add information as to when Slow/Delayed-Go is to be re-evaluated and/or revisited**

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### **How Classifications are applied**

- **Each structure would be classified for Probability and for Risk.**
  - Requires StS and Hazmat to make rapid, value judgments.
  - Probability includes considerations such as potential number of victims and ease of extrication
  - More than one structure could have the same classification.
- **Examples**
  - HP, LR and LP, XR

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### **Examples of Risk Level**

- **Low**
  - Pancake concrete slabs
  - Soft 1<sup>st</sup> story collapse
  - Wood 1 & 2 story
- **Moderate**
  - Partly collapsed concrete
  - Racked wood 3 story+
  - Free standing URM/Conc walls – plumb
  - URM w/ Lean-to, V, Wall Fall collapse
- **High**
  - Partly collapsed PC or PT conc.
  - Uncollapsed & leaning
  - Free standing URM/Conc walls – leaning
  - Many falling hazards

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#### Information to be used to determine potential number of victims

**Number of Potentially Trapped Victims.** Would be assessed knowing the type of occupancy, the floor area of collapsed structure, the time of day the incident occurred, and the type of collapse.

The following are the average total number occupants for various occupancies that were used in the Triage Process:

#### **Based on units other than area:**

Schools	25 to 35 students per classroom
Hospitals	1.5 occupants per bed
Residential	2.0 occupants per bedroom
Others	1.5 occupants per parking space

#### **Based on area: Variation**

Schools, Library	1 per 70 SQ. FT.	50-100
Hospitals	1 100	80-150
Multi Residential	1 200	100-300
Commercial	1 100	50-200
Office, Inc Govt.	1 150	100-200
Public Assembly	1 25	10-050
EOC, PD, FD	1 125	100-150
Industrial	1 200	100-300
Warehouse	1 600	400-900

**Other methods** to estimate the number of occupants in a building would be either of the following:

- Number of cars in the parking lot for assembly, office, and commercial occupancies
- Number of bedrooms in residential occupancies, that are involved in the collapse

#### **New Recon-1 Form**

New forms Recon-1 and Recon-2 have been developed to replace the Triage Forms, TRI-1 & TRI-2

Form Recon-1 is shown on the next page. Recon-2 is similar, and has instructions for using the new recon forms

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**FEMA**

Recon Form - Recon-1      Date/Time: \_\_\_\_\_ By: \_\_\_\_\_ Page \_\_\_\_\_ of \_\_\_\_\_

Task Force: _____		Date/Time of Disaster: _____		See Form Recon-2 for Instructions	
<b>AREA MAP</b>					
<b>BLDG. ID:</b> _____  FLOOR AREA: _____ No. STORIES: _____ OCCUPANCY: _____  MATERIAL: (Circle all that apply) WOOD   CIP CONCRETE   STEEL URM   TILT-UP   PT CONC   PC CONC OTHER: _____		<b>Criteria for Probability of Viable Victims</b> (check one in each line)  POTENTIAL NUMBER TRAPPED      LOW _____ MEDIUM _____ HIGH _____ TIME REQ'D TO ACCESS VICTIMS      12 Hrs _____ 6 Hrs _____ 1 Hr _____ TYPE OF VOIDS      COMPACT _____ SEPARATED _____ OPEN _____  <b>Criteria for Assessment of Risk</b> (check one in each line)  CHANCE OF FURTHER COLLAPSE      LOW _____ MEDIUM _____ HIGH _____ No. OF FALLING HAZARDS      LOW _____ MEDIUM _____ HIGH _____ VOID SUPPORT CONDITION      GOOD _____ POOR _____ UNKNOWN _____		<b>CLASSIFICATION</b> (Circle one each line)  LP   MP   HP   LR   MR   XR	
GPS Coordinates _____ _____ _____		SLOW- GO (circle if applies)    FIRE    HAZMAT    OTHER: _____ Notes: _____ _____			
<b>BLDG. ID:</b> _____  FLOOR AREA: _____ No. STORIES: _____ OCCUPANCY: _____  MATERIAL: (Circle all that apply) WOOD   CIP CONCRETE   STEEL URM   TILT-UP   PT CONC   PC CONC OTHER: _____		<b>Criteria for Probability of Viable Victims</b> (check one in each line)  POTENTIAL NUMBER TRAPPED      LOW _____ MEDIUM _____ HIGH _____ TIME REQ'D TO ACCESS VICTIMS      12 Hrs _____ 6 Hrs _____ 1 Hr _____ TYPE OF VOIDS      COMPACT _____ SEPARATED _____ OPEN _____  <b>Criteria for Assessment of Risk</b> (check one in each line)  CHANCE OF FURTHER COLLAPSE      LOW _____ MEDIUM _____ HIGH _____ No. OF FALLING HAZARDS      LOW _____ MEDIUM _____ HIGH _____ VOID SUPPORT CONDITION      GOOD _____ POOR _____ UNKNOWN _____		<b>CLASSIFICATION</b> (Circle one each line)  LP   MP   HP   LR   MR   XR	
GPS Coordinates _____ _____ _____		SLOW- GO (circle if applies)    FIRE    HAZMAT    OTHER: _____ Notes: _____ _____			
<b>BLDG. ID:</b> _____  FLOOR AREA: _____ No. STORIES: _____ OCCUPANCY: _____  MATERIAL: (Circle all that apply) WOOD   CIP CONCRETE   STEEL URM   TILT-UP   PT CONC   PC CONC OTHER: _____		<b>Criteria for Probability of Viable Victims</b> (check one in each line)  POTENTIAL NUMBER TRAPPED      LOW _____ MEDIUM _____ HIGH _____ TIME REQ'D TO ACCESS VICTIMS      12 Hrs _____ 6 Hrs _____ 1 Hr _____ TYPE OF VOIDS      COMPACT _____ SEPARATED _____ OPEN _____  <b>Criteria for Assessment of Risk</b> (check one in each line)  CHANCE OF FURTHER COLLAPSE      LOW _____ MEDIUM _____ HIGH _____ No. OF FALLING HAZARDS      LOW _____ MEDIUM _____ HIGH _____ VOID SUPPORT CONDITION      GOOD _____ POOR _____ UNKNOWN _____		<b>CLASSIFICATION</b> (Circle one each line)  LP   MP   HP   LR   MR   XR	
GPS Coordinates _____ _____ _____		SLOW- GO (circle if applies)    FIRE    HAZMAT    OTHER: _____ Notes: _____ _____			





### FEMA Building Marking System

What follows is a discussion of the FEMA building marking system. The marks are as follows:

- Building Identification Marking
- Structure/Hazards Evaluation Mark
- Search Assessment mark
- Victim Location Mark

Following the explanation of the marks, is an example of how the Search and Victim marks are applied.

### Identification of Individual Buildings


The standard system for locating a building on any block involves the following considerations:

- Use existing numbers and fill in unknowns.
- If the numbers are all unknowns, keep numbers small, on odd and even sides.

The standard system for building layout is as follows:

- Sides A, B, C, and D start at the street and go clockwise.
- Stories are designated as 1 (or ground), 2, 3, 4. Make sure that everyone understands where the 1<sup>st</sup> (or ground floor) is and whether there are any basements.
- Basements are designated as B1, B2, and B3.

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### FEMA Bldg Marking Sys

- Building I.D. Marking
- Structure / Hazards Evaluation & Marking
- Search Assessment Marking
- Victim Location Marking
- Search Marking Example

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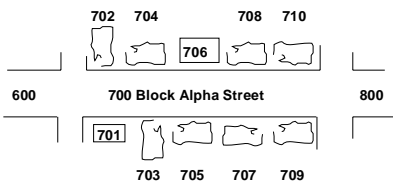
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### FEMA Building I.D. System


#### I. D. by Street & Number

- Case 1 - If some numbers are known, fill in




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### I. D. by Street & Number

- Case 2 - No numbers known, use low no's



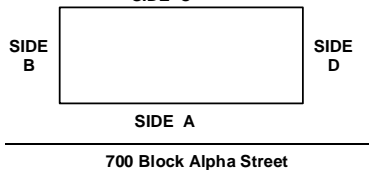
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### Sides of a Structure

- If more than one side, use more letters



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### **Identification of Individual Buildings (continued)**

Quadrants within a building are marked according to the following system:

- Mark A, B, C, D, etc. on the long side, and 1, 2, 3, etc on the short side.
- It is more helpful to mark an appropriate number on each column for structures with a regular (or irregular) layout.
- Column numbers should be large enough to be read from a distance (such as by a crane operator).
- Use existing column numbers if known.
- If designation is unknown, best to use letters on long side & numbers on short side, starting at left-front corner.

### **Structure/Hazard Evaluation and Marking**

This mark would normally be drawn on structures in a large incident with many damaged buildings, when the Struct. and Hazmat Specs need to leave a particular site, and assess another. In single structure incidents, when the Struct. and Hazmat Specs remain at the site, there would be no need to draw the mark .

This mark may be made using spray paint, crayon, or by placing a placard as shown on following pages.

The explanation of what this “Open Box” means is being clarified in this 2008 document.

The “Open Box” indicates a structure with low risk for US&R Operations. It may be significantly damaged, but is a low probability of further collapse.

The previous versions of this mark said “Structure is accessible and safe for search and rescue operations. Damage is minor with little danger of further collapse”

The term “Safe” was inaccurate, since all structures that would be the focus of US&R would be hazardous. The new term “Low Risk”, is more appropriate

The graphic on the following page contains, new, more appropriate explanations for the three levels of hazard that are intended for the three different boxes.

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**Quadrants within Structure**

■ Also use and **MARK** column grid

Quad. B	Quad. C
E	
Quad. A	Quad. D

700 Block Alpha Street

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**Column Grid Layout**

■ Use existing column grid - If Known

4							
3							
2							
1	A	B	C	D	E	F	G

700 Block Alpha Street

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**Structure / Hazards Mark**

■ Struct & Hazmat Spec make a 2' x 2' box on building adjacent to accessible entry.

■ Done after doing Hazards Assessment and filling out Structure / Hazards Evaluation.

■ Box is spray painted with using International Orange (in TF Cache)

■ An paper/cardboard placard may be used as an alternate – later slide

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**Structure / Hazards Mark**

■ **Low Risk** for US&R Ops, with low probability of further collapse.

■ Victims could be trapped by contents

■ Bldg could be completely pancaked or soft 1<sup>st</sup> story collapse

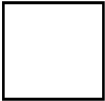
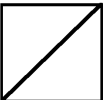
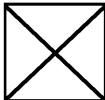
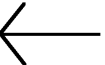

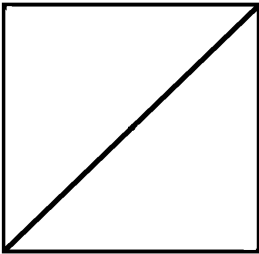
■ Bldgs could be up to 2-story wood construction

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## Structure/Hazard Evaluation and Marking (continued)

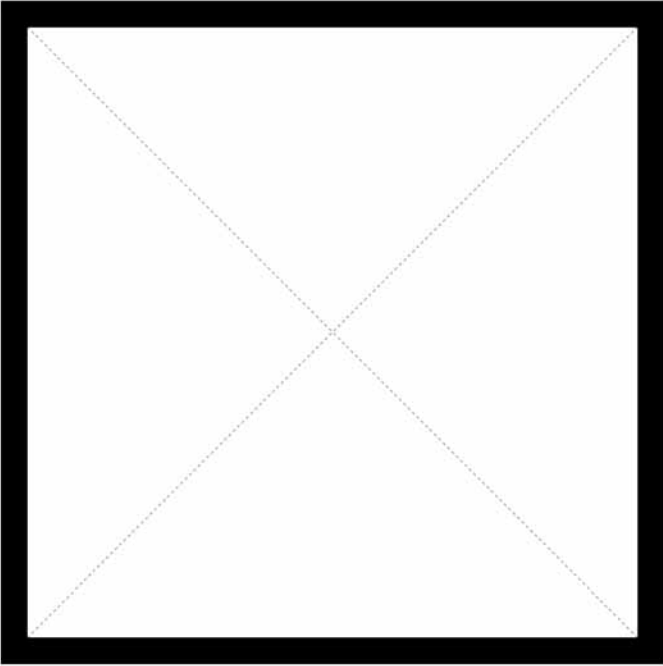
Detailed Structural/Hazard Evaluation should take place **after** a priority list of structures has been established by the leadership using recon or just common sense if only a few structures are involved. The Structure/Hazards Evaluation Form has been made deliberately different from Search and Victim Marks. The greatest area of concern is not with the fully collapsed structures but with those that have only partly collapsed. The Structures and Hazmat Specialist should be prepared to fill out the US&R Structure/Hazard Evaluation Form, identifying structure type, occupancy, hazards, etc (probably at the beginning of search operations). In addition, the Structures Specialist will generate notes and diagrams regarding search operations. However, in some cases, the assessment will only indicate that the building is too dangerous to conduct US&R operations until significant, and time-consuming mitigation is completed.

<b>TASK FORCE BUILDING MARKING SYSTEM</b>	
<b>STRUCTURE/HAZARDS EVALUATION</b>	<b>UHR-4 08</b>
<b>STRUCTURAL SPECIALIST MAKES A 2'x2' BOX ON BUILDING ADJACENT TO MOST ACCESSIBLE ENTRY. THIS IS DONE AFTER DOING HAZARDS ASSESSMENT AND FILLING OUT HAZARDS ASSESSMENT FORM. BOX IS SPRAY PAINTED WITH INTL ORANGE AND MARKED AS FOLLOWS:</b>	
	<b>LOW RISK</b> FOR US&R OPERATIONS (BUT NOT SAFE) DAMAGE IS SUCH THAT THERE IS A LOW PROBABILITY OF FURTHER COLLAPSE. (may be pancaked bldg, soft 1st story, or up to 2-story wood construction)
	<b>MODERATE RISK</b> FOR US&R OPERATIONS STRUCTURE IS SIGNIFICANTLY DAMAGED. SOME AREAS MAY BE LOW RISK, BUT OTHER AREAS MAY NEED SHORING, BRACING, MONITORING, OR REMOVAL OF HAZARDS.
	<b>HIGH RISK</b> FOR US&R OPS AND MAY BE SUBJECT TO SUDDEN COLLAPSE. REMOTE SEARCH OPS MAY PROCEED AT SIGNIFICANT RISK. IF RESCUE OPS ARE UNDERTAKEN, SIGNIFICANT, TIME CONSUMING MITIGATION SHOULD BE DONE.
	ARROW LOCATED NEXT TO THE MARKING BOX INDICATES THE DIRECTION OF SAFEST ENTRY TO THE STRUCTURE.
<b>HM</b>	INDICATES HAZMAT CONDITION IN OR ADJACENT TO STRUCTURE. S&R OPERATIONS NORMALLY WILL NOT BE ALLOWED UNTIL CONDITION IS BETTER DEFINED OR ELIMINATED.
	 <div><b>15JUL92 1310 HRS</b> <b>HM - NATURAL GAS</b> <b>OR-1</b>  (DO NOT ENTER BUILDING UNTIL GAS IS TURNED OFF)</div>



**Structure/Hazard Evaluation and Marking (continued)**

- As noted the three different marks indicate the level of risk, and are consistent with the terms used during Recon. For a large, multi-structure incident, this detailed assessment would most likely be completed by a Structures and Hazmat Spec assigned to the Search Detection Team (as they are starting search operations). The StS and Hazmat Spec. that are part of the Recon Team would only have time to complete the Recon Forms, and a rapid assessment
- Following this evaluation, the Structure/Hazard Evaluation Marking would be placed on the building near each entry (as noted on the previous page).
- As an alternative to the painted marking, a paper or cardboard placard may be used. It is illustrated below and is intended to be in 8.5" x 11" (portrait) , and made with black ink on white paper (Stick-on, Rite-in-Rain, or light cardboard).



Structural / Hazard Evaluation		
DATE	TIME	TF
HAZARDS:		
<div style="border: 2px solid black; width: 40px; height: 40px; margin: 0 auto;"></div> <p style="margin: 5px 0;"><b>LR</b></p> <p style="font-size: 0.8em; margin: 0;">Low Risk for US&amp;R Operations, with low probability of further collapse. Victims could be trapped by contents, or building could be completely pancaked or soft 1<sup>st</sup> story</p>	<div style="border: 2px solid black; width: 40px; height: 40px; margin: 0 auto; position: relative;"> <div style="position: absolute; top: 0; right: 0; border-left: 2px solid black; border-top: 2px solid black; width: 100%; height: 100%;"></div> </div> <p style="margin: 5px 0;"><b>MR</b></p> <p style="font-size: 0.8em; margin: 0;">Moderate Risk for US&amp;R Ops, and structure is significantly damaged. May need shoring, bracing, removal, and/or monitoring of hazards. The structure may be partly collapsed.</p>	<div style="border: 2px solid black; width: 40px; height: 40px; margin: 0 auto; position: relative;"> <div style="position: absolute; top: 0; right: 0; border-left: 2px solid black; border-top: 2px solid black; width: 100%; height: 100%;"></div> </div> <p style="margin: 5px 0;"><b>XR</b></p> <p style="font-size: 0.8em; margin: 0;">High Risk for US&amp;R Ops, and may be subject to sudden collapse. Remote search operations may proceed at significant risk. If rescue operations are undertaken, significant and time-consuming mitigation should be done</p>
Should the marking box need to be made remote from the indicated entrance, place an arrow next to the marking box to indicate the direction to the lowest risk entrance to the structure.		



### Structure/Hazard Evaluation and Marking (continued)

- The US&R Structure/Hazards Evaluation Form is filled-out by the StS during the detailed assessment. It provides places to quickly record the critical information, and acts as a check-list. It is shown below:

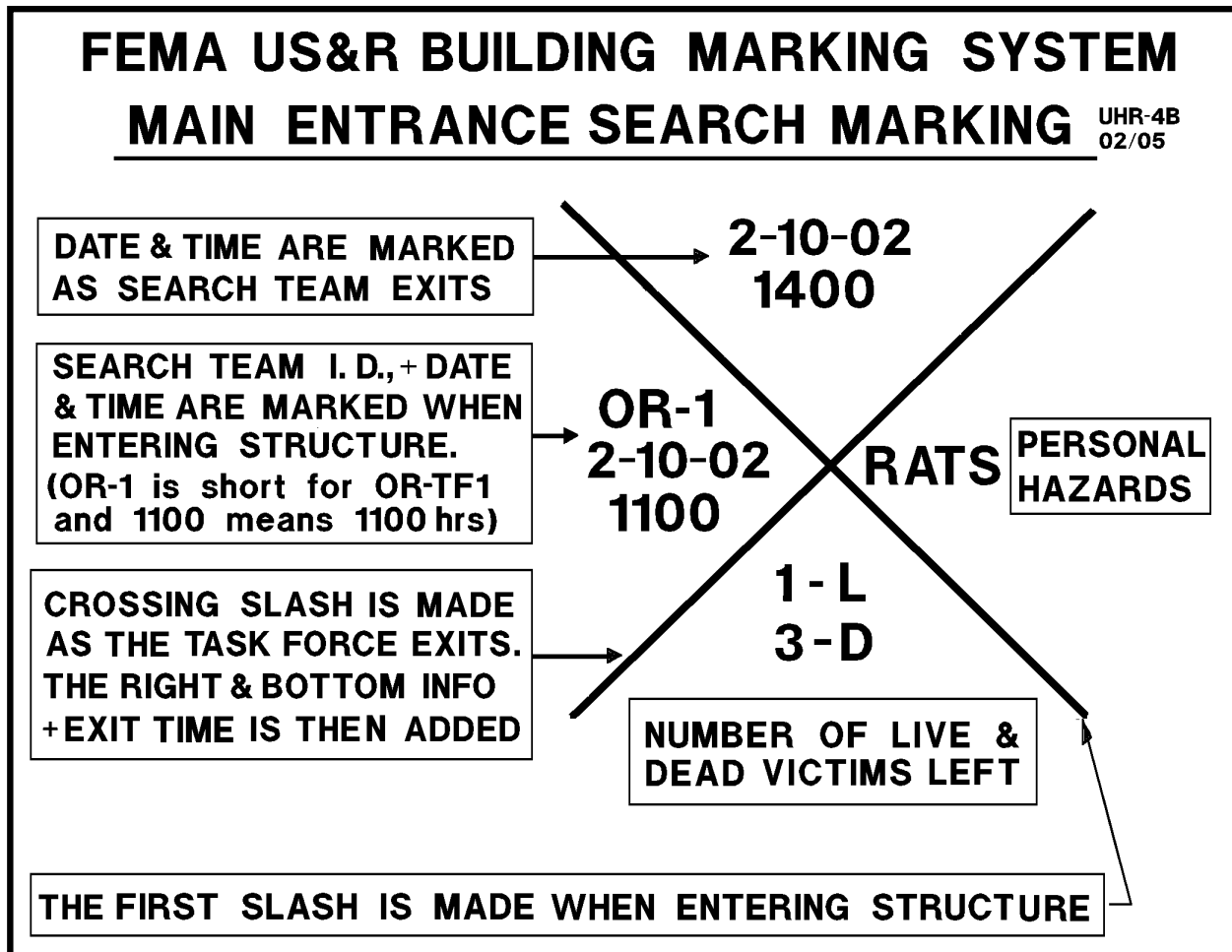
US&R STRUCTURE / HAZARDS EVALUATION FORM - HAZ-1		BY: _____
<small>Where required, circle all the information or items that apply. NOTE: AFTERSHOCKS MAY CAUSE ADDITIONAL DAMAGE OTHER THAN NOTED.</small>		
<b>STRUCTURE DESCRIPTION:</b>  Bldg ID: _____  No. Stories: _____ No. Basements: _____	<b>BUILDING MARKING:</b>  <div style="display: flex; align-items: center;"><div style="border: 2px solid black; width: 40px; height: 40px; margin-right: 10px;"></div><div><div>Date/Time of Evaluation: _____</div><div>Date/Time of Catastrophe: _____</div></div></div>	
<b>MATERIALS:</b> Wood    Concrete    Steel    URM    PC Concrete  Other: _____	<b>TYPE OF COLLAPSE:</b> Pancake    Soft 1st Floor    Wall Failure Torsion    Middle Story    Overturn  Other: _____	
<b>FRAMING SYSTEM:</b> Shearwall    Moment Frame    Braced Frame  Other: _____	<b>LOCATION OF VOIDS:</b> Between Floors    Basement    Shafts  Other: _____	
<b>OCCUPANCY:</b> Hospital    Police Station    Fire Station Emergency Operations Center    Office Building    School Public Assembly    Industrial    Hotel Apartment    Retail Store    Other: _____	<b>DESCRIPTION OF UNSAFE AREAS &amp; HAZARDS:</b> _____ _____ _____ _____ _____	
<b>VICTIM &amp; OTHER INFORMATION:</b> _____ _____		
<b>LOCATION OF BEST ACCESS &amp; SAR STRATEGY:</b> _____ _____		
<b>SKETCH:</b> <div style="border: 1px solid black; height: 250px; width: 100%; background-image: linear-gradient(to right, black 1px, transparent 1px), linear-gradient(to bottom, black 1px, transparent 1px); background-size: 20px 20px;"></div>		



### Search and Rescue Assessment Marking

Standard SAR assessment marking is designed to perform two functions:

- First, when SAR personnel enter the building or parts of the building, they draw an initial line so that others will be informed of **ongoing operations**. In addition, they mark in the left quadrant the Task Force identifier, plus date and time they have entered. The time, date and I.D. will inform others as well as provide critical data should there be a question regarding the Task Force's safety in the event of a secondary incident.
- Upon entering, the searcher(s) should proceed in a consistent pattern in order to assure that all areas are searched. Go to the right and always keep to the right in every room is a common method, but go left, stay left is also used. Be consistent and search all areas.
- When operations are completed in the building (or parts of the building), the crossing diagonal line will be drawn and information in the remaining three quadrants will be added to indicate what was found and accomplished. **This marking will also indicate that the Task Force has exited safely.**
- The finished mark can then indicate to other SAR forces the outcome of previous operations.





### Incomplete Search Assessment Mark

- The slide shows the new mark to provide a method for a task force to indicate it has performed and incomplete search. The TF may have entered the structure and only completed some of the floor or, as in the case of Hurricanes; the Search may have been of the exterior only.
- The extent of the search should be determined by information that is placed in the box below the Search Mark.

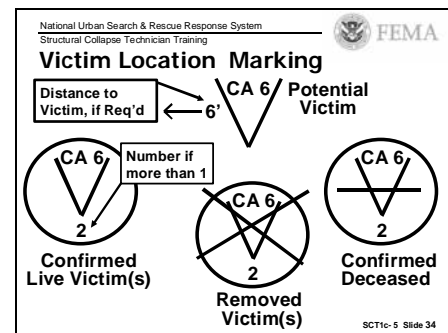
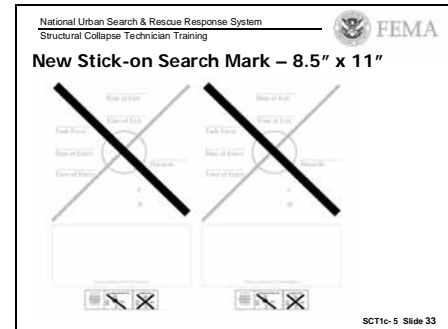
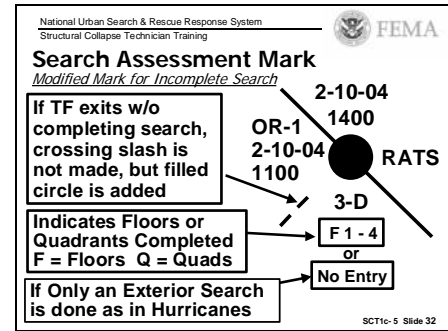
### Stick-on Search Assessment Mark

In Sep06 a Stick-on Search Mark was approved, in order to reduce the use of paint in incidents like Hurricanes where many structures are involved. The Stick-on Template is shown in adjacent slide.

### Victim Marking System

This series of marks is used to indicate the location of each victim discovered on the US&R site.

- The marks are made with orange spray paint or crayon.
- Marks will normally be initiated after a search is performed unless the victim is immediately removed.
- The **V** is intended to be about 2 feet high and located as near to the victim as practicable.
- It could be painted on a nearby wall surface or directly on a piece of rubble.
- An arrow may be added to indicate the exact victim location.
- The TF identifier example "**CA 6**" should be included as shown.
- The circle is added when the victim is **confirmed**.





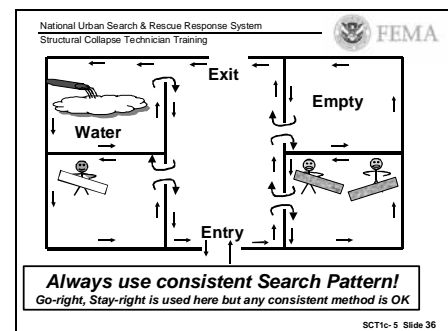
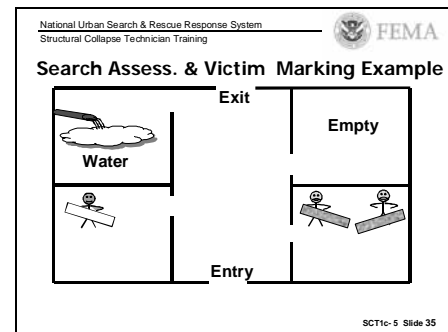
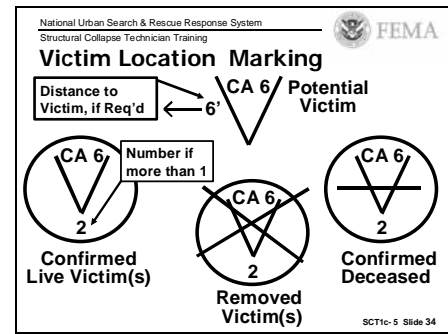
- ◆ As an example, the **V** could be placed when only one K9 has indicated that a victim has been located. The circle could be added when the initial **find** is **confirmed** by another K9 or some other search tool.
- ◆ However, when K9s are working in pairs, no mark should be made after the first dog indicates a victim because it may influence the second dog.

- A horizontal line is added if the victim is confirmed to be dead.

An large **X** is drawn completely through the circle after the victim has been removed.

### Search Assessment & Victim Marking Example

- An **example** that illustrates the use of the **Search Assessment** and **Victim Location Marks** is illustrated on the following two pages.
- The basic information is as follows:
  - ◆ It has a front entry and a rear entry/exit.
  - ◆ There are four enclosed rooms in the building.
  - ◆ Room 1 has four dead victims.
  - ◆ Room 2 is empty except for normal contents.
  - ◆ Room 3 has a broken water pipe and is flooded.
  - ◆ Room 4 has one live victim.
- The search team will need to decide what search pattern to use, as they search the building
  - ◆ The pattern that is illustrated here in the “Go Right, Stay Right Pattern
  - ◆ Any pattern may be used, as long as it is consistent and covers all areas of the building
  - ◆ The Search Team Manager should determine the most appropriate pattern, no later than when the search team is planning to enter the building

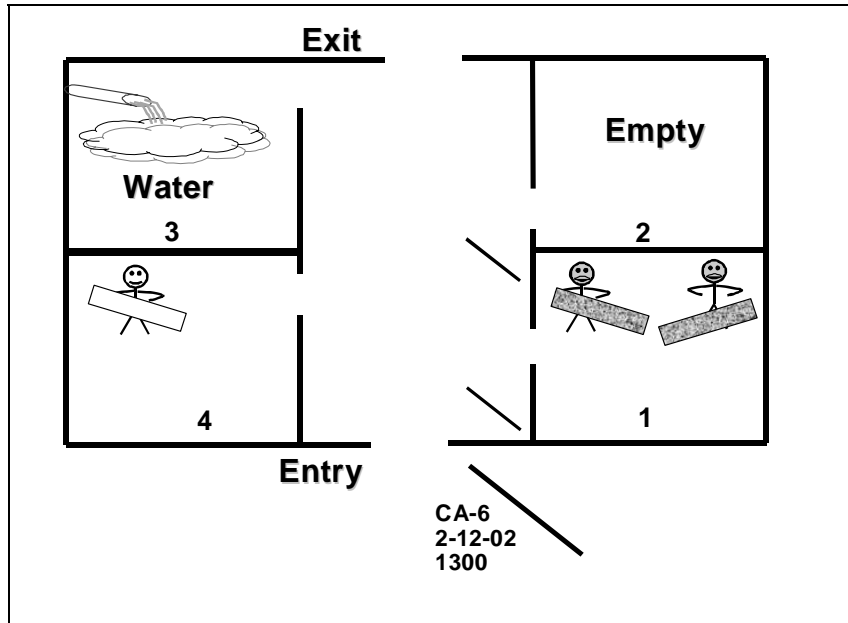




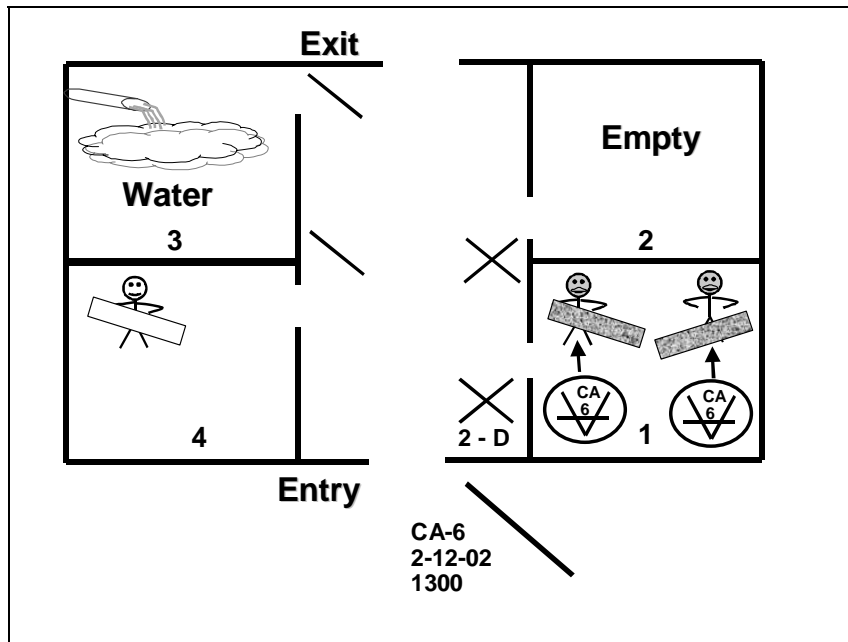


### Search Assessment and Victim Location Mark: Example

- In this example, we will search in a Go-right, Stay-right Pattern. It should be noted that any consistent search pattern is acceptable, as long as all areas are searched.
- Enter the building, make first slash, TF ID, date and time, and enter Rooms 1 and 2 after making a single slash by each door.

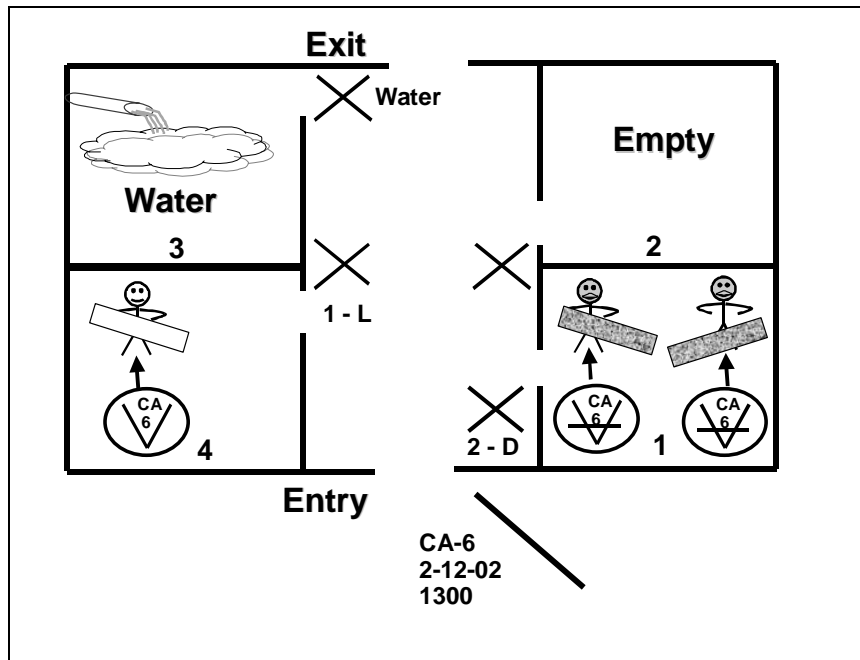


- Exit Rooms 1 and 2; draw a second slash and record findings. Then enter Rooms 3 and 4.

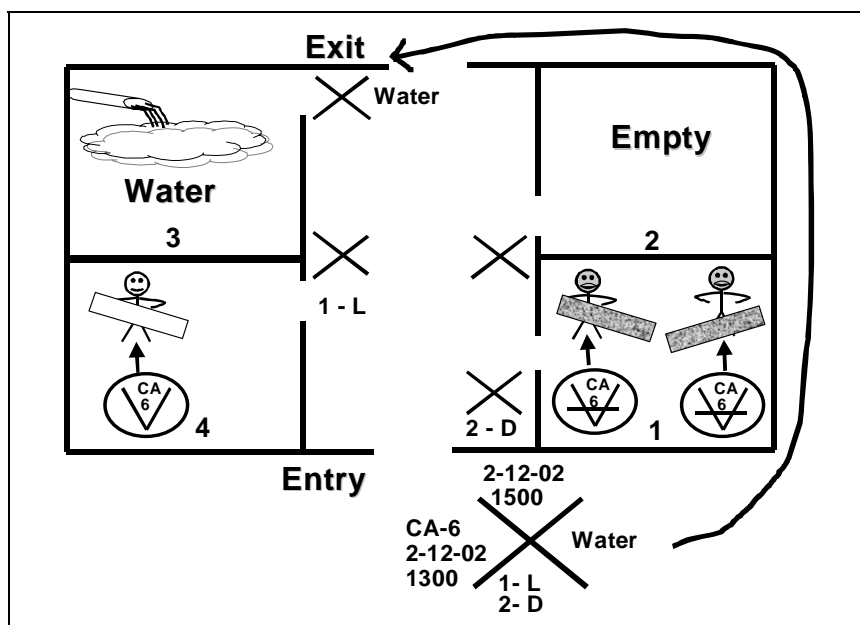




- Exit Rooms 3 and 4; draw a second slash and record findings.



- Exit the building, draw a second slash, complete all data, and prepare to go to the next building or assist Rescue at this building. If the exit might be approached by another SAR unit without seeing the front entry, repeat the marks at the exit location.





### Disaster Site Signaling and Barricades

#### General Requirements

- Effective emergency signaling is essential for the safe operation of SAR Team personnel operating at a disaster site.
  - ◆ These signals must be clear and universally understood by all SAR Team personnel.
  - ◆ These signals are used throughout the world.

#### Disaster Site Audio Signaling/Alerting

Air horns or other appropriate hailing devices shall be used to sound the appropriate signals as follows:

- Cease Operation/All Quiet:  
1 long blast (3 seconds) = **STOP**
- Evacuate the Area:  
3 consecutive short blasts (1 second each)  
= **OUT, OUT, OUT**

Conduct a radio roll call to account for all personnel. When all are accounted for, the radio signal “all clear” will be broadcast on the command channel.

- Resume Operations:  
1 long and 1 short blast = **O, KAY**

#### Disaster Site Barricades


- General cordon markings (cordon banners, flagging, etc.) are used for a small, defined area. They can be enlarged to include other non-buildings (for example, a bridge, dangerous zones, NBC, or security). Large areas may require fences and/or patrol.
  - ◆ Operational Work Zone—see slide at right.
  - ◆ Collapse/Hazard Zone—see slide at right.

### Summary, FEMA US&R Marking System

In summary, we have discussed the FEMA US&R marking system that US&R Task Forces and others involved in urban search and rescue should use to document the actions they have taken at a particular disaster site.

Please review this system to make sure you are completely familiar with it


National Urban Search & Rescue Response System  
Structural Collapse Technician Training

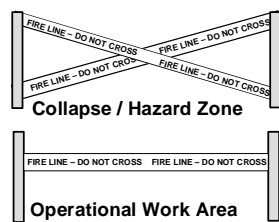
 **Disaster Site Audio Signal/Alerting**  
(Use Air horn or / Loud Whistle)

- Cease Operations/All Quiet
  - 1 long blast = STOP
- Evacuate the Area
  - 3 short blasts = OUT, OUT, OUT
- Resume Operations
  - 1 long & 1 short blast = Oh. K.

SCT1c-5 Slide 39


National Urban Search & Rescue Response System  
Structural Collapse Technician Training

 **Rescue Site Set Up**  
■ Operations Area should be Secure



SCT1c-5 Slide 40

National Urban Search & Rescue Response System  
Structural Collapse Technician Training

 **Summary of Discussion**

- Initial Phases of Task Force Deployment
- Recon Process
- Structure / Hazards Evaluation & Marking
- Search Assessment Marking
- Victim Marking
- Search Marking Example
- Disaster Site Audio Signal/Alerting

SCT1c-5 Slide 40



## **Basic Search & Rescue Plans**

### **Basic Plan – for Individual Buildings**

**Reconnoiter Site** collecting as much information as possible

- Determine structure type - to better assess type of failure, type of hazards, ease of entry and cutting.
- Interview neighbors, survivors, interested people (how many potential victims; where last seen, location of stairs, elevators, basement, etc.).
- Obtain building plan an/or draw crude plan with special emphasis on probable location of voids, existing shafts, basement.
- Search Specialists re-assess building in detail to re-identify hazards.

**Prioritize site** use collected data to obtain best risk/benefit ratio.

- Conduct callout/listen search.
- Plan shoring at access, and/or use most efficient access.
- Determine condition of basement.
- Avoid falling hazards unless they can be removed and/or shored.

**Initial Search** Properly trained search dogs and electronic locators can be used successfully to locate deeply buried victims.

Even properly trained dogs may only be able to indicate direction of scent, which is not necessarily the direction of the victim.

Electronic devices, operated by trained personnel, can detect victims that are instructed to make tapping noises.

- "Send out" search dogs as far as possible. Check alerts with second dog/observer/handler.
- Use listening/seismic finders to hear victim noise.
- Explore all existing vertical shaft openings.
- Explore horizontal openings with great care (send dog in and keep people out ).
- Search from safe, stable areas into unstable.
- Re-prioritize site vs. location of potential live victims.

**Selected Cutting & Removal** based on priorities of initial search vs. probable hazards.

- Cut vertical openings and re-search, re-check with dogs and/or listening/viewing devices.
- Initial shoring for access.
- Avoid un-shored overhead structures.
- Recheck all shoring after cutting and removal, loading can change.
- Continue process of cutting layers, re-searching, and re-prioritizing.
- Stabilize area at victim to give medical aid.



## **Heavy Search & Rescue**

- Continue search after prolonged cutting and/or removal.
- Give victim aid and gain information regarding additional victims.
- Re-check all shoring after cutting and removal, since loading can change

We will now discuss how these strategies should be adapted to the following construction types

- Light frame
- Heavy Wall – URM & Tilt-up
- Heavy Floor- Concrete Frame
- Precast Concrete

## **SAR Plan – Light Frame**

### **Search Items**

- Callout/listen search may be effective due to lower density of wood floors.
- Acoustic listening devices will probably be more effective than seismic type sensors in these buildings that have wood floors and walls. Broken wood is relatively poor transmitter of vibrations.
- Dogs may be able to sent through cracks in wood floors if they are not heavily covered.

### **Hazard Reduction Items**

- Shut off gas (and electricity) and reduce other fire hazards. (**This applies for all types of buildings**)
- Assess / refer chemical hazards. (**What's in the typical kitchen?**)
- Remove / avoid or topple leaning chimney
- Place vertical and / or lateral shores as required

### **Victim Access Items**

- Use horizontal entry thru cavities or thru walls.
- Make vertical access thru holes cut in roof / floor
- Remove / shore hazards as required.



### **SAR Plan – Heavy Wall – URM & Tilt-up**

#### **Search Items**

- Callout / listen search may be effective due to lower density of wood floors.
- Acoustic listening devices will probably be more effective than seismic type sensors. Most of these structures will have wood floors that have collapsed in large planes and badly broken masonry, both of which are relatively poor transmitters of vibrations.
- K9 may be able to scent through cracks in wood floors if they are not heavily covered.

#### **Hazard Reduction Items – URM**

- Shore hazardous floors with vertical shores.
- Remaining uncollapsed URM walls are brittle, aftershock / wind falling hazards. Either avoid, remove, tieback, or raker shore them. May need to shore in both IN and OUT direction.
- Beware of all falling hazards - peeled, cracked, & split URM walls are very brittle. High potential for falling & collapse hazards.

#### **Hazard Reduction Items – Tilt-up & Low Rise**

- Use diagonal or raker shores for hazardous walls.
- Shore hazardous roof / floor beams, etc.

#### **Victim Access Items – URM**

- Use horizontal entry thru existing openings with great care.
- Vertical access through wood floors should be easy and least dangerous.
- Avoid cutting large beams and more than two joists in a row.
- Avoid cutting walls. Holes can greatly reduce strength of poorly cemented walls - most are important bearing walls
- Beware of roof / floor joist / beams that are not sitting on their original flat bearings or ledges, they can slide down walls and produce outward forces as they move to find next stable position.
- Basement may provide good access, but should shore for safety. Failure of wood column or beams can be sudden.
- Hand removal of bricks may be required.
- Large pieces of wall may be removed by clamshell or other bucket with thumb. ( need to prevent parts from falling)

#### **Victim Access Items – Tilt-up & Low Rise**

- Use horizontal entry thru existing openings with great care.
- Vertical access through wood roof / floors should be easy and least dangerous.
- Holes in wall panels should be made 2 ft minimum away from joints. If wall has concrete pilaster / column, one may cut opening next to column on side away from joint.
- Wall panels and large pieces of roof may be lifted by crane or other equipment.



#### **SAR Plan – Heavy Floor, Concrete Frames**

##### **Search Items – Heavy floor**

- Not likely to hear callout of victims through floors due to high density of concrete.
- Seismic listening devices can be most effective in these, heavy structures, especially when floor slabs remain intact and form thin void spaces as in pancake type collapse.
- K9 will indicate direction of scent that may be flowing around large slabs, back and forth across the building. (**Location of victim must be interpreted from conditions**) Area should be re-checked by dogs after layers have been removed. The best time to use dogs is in early morning and at dusk when scent is rising.

##### **Hazard Reduction Items – Heavy Floor**

- In partly collapsed building (upper floors, etc.) is very important to check floors that support debris load.
  - ♦ Read cracks to determine if more and progressive collapse is probable.
  - ♦ Multi-story shoring may be only safe procedure.
  - ♦ It normally takes at least three un-damaged floors to support shores from one damaged floor that contains little debris (if heavy concrete debris from upper floors is present, shores need to extend down to additional, undamaged floors - two more floors per 12" of debris)
- Shore / avoid badly cracked beams.
- Shore / avoid hanging slabs / beams.
- Shore heavily loaded flat slabs (beamless slabs) - punching shear.
- Beware of all falling hazards - parts of slabs, walls, etc. May be hanging from exposed rebar - how well is rebar embedded?
- Monitor structure for Lateral Movement with Theodolite or other tilt measuring device

##### **Victim Access Items – Heavy Floor**

- Use any existing vertical shaft.
- Basement may be good access, but need to evaluate floor slab above and possibly shore. How many basement levels?
- Preferred access is usually made by cutting thru slabs from above collapse.
- Best to cut slabs mid-way between beams & columns.
- Check for thinnest slab area. Pan joist and waffle slabs have ribs spaced 3 ft or so with 3 to 4 inch thick slab between.
- Do not cut columns - usually do not need to.
- Avoid cutting concrete / masonry walls. They may be bearing walls. If have masonry infill wall in concrete frame cutting is possible - check first to see if frame is loading wall due to collapse.
- Remove concrete slabs with Crane after all rebar is cut



## **SAR Plan – Precast Concrete**

### **Search Items – Precast Concrete**

- Callout / listen search may be effective. It depends on size of voids between larger pieces of concrete.
- Effectiveness of listening devices will depend on the interconnection of the collapsed, structural parts. Acoustic sensors may not be effective in compact rubble, and seismic sensors may not be effective due to poor transfer through badly broken concrete parts.
- K9 search may be effective - again depending on compactness of concrete rubble.

### **Hazard Reduction Items – Precast Concrete**

- Remove / avoid hanging pieces of structure. There may be many loose or poorly connected pieces of precast concrete. Use cranes and other equipment.
- Shore beams adjacent to badly cracked columns.
- Remove / shore tilted wall panels or pieces.
- Partly collapsed buildings may have adjacent slabs and/or wall panels that have damaged connections that may break loose in aftershocks or if loading shifts.

### **Victim Access Items – Precast Concrete**

- Cutting of cored slabs & tee slabs should be done at edges (Thinnest part of section, away from ribs).
  - ♦ Cut half of hole in each of two adjacent precast pieces.
- Don't cut ribs in Tees or walls & do not cut columns.
- Walls may be cut with care.
  - ♦ Cut holes at least 2 ft away from joints.
  - ♦ Consider problems of shoring vs. removal (removal may be more efficient).
  - ♦ Check wall welded joints for signs of movement.
- Some walls may be infill URM and may be cut if not loaded by collapsed concrete pieces.
- Basements may not be good access unless basement walls and first floor slab are cast in place concrete. Shoring may be required in any case.
- Use horizontal access thru existing cavities - use great care
- Lift off loose concrete pieces with cranes or other equipment
- Great care must be taken when lifting and/or shoring large concrete pieces, since adjacent pieces may shift.
- Precast concrete will often weigh about 75% of normal (150 PCF) concrete. It also splits more easily.





## **Metal Detector**

Metal detectors should be used to locate rebar or prestress cables prior to cutting slabs and walls. This can keep from dulling bits and inadvertently cutting cables.

Metallescanner Pro by Zircon is magnetic type that is small and can determine location of rebar as much as 4" deep. Cost \$100

- Devices are available with costs from \$400 to \$2000.

## **Cutting Post Tensioned Concrete – Cables**

Post-tensioned concrete contains steel cables ( ½" dia.) enclosed in a long plastic casing. They are placed in the forms prior to the pour, and when the concrete hardens, the cables are tensioned using a special hydraulic jack assembly.

Post-tensioning Cables (P.T.) are then anchored in special steel fittings at each edge of the concrete floor, but remain separated from the concrete by the plastic casing. (Unbonded) . This is discussed in SCT03

- When P.T. cables need to be cut during US&R Ops, special care needs to be taken to deal with the tension force that will be released.
- Cables are most often placed in a Draped Configuration within the concrete. The cable is placed near the bottom of slab / beam near mid-span, and near the top where cables pass over supporting columns or beams.
- It is best to use a Torch to cut the P.T. cables, since the tension should be released slowly. A carbide saw could be used to carefully cut the cables, one wire at a time.
- If the cable is not cut slowly so that the force can be gradually released, parts of the cable may violently project out of the concrete structure.
- Depending where the cable is cut it may project above the floor walls or columns, below the floor near mid-span, or project out of the concrete slab edges like a spear.

The TF can mitigate this problem by clearing an area that measures, at least, 10 feet either side of the cable for the full length of the slab / beam. In addition the area outside the building should be cleared for 100 feet and barricaded to deal with the threat.

- See SCT03 for more information, including pictures of the cables, their anchorages, as well as methods to recognize concrete structures that may contain PT cables.



## **Summary for Part 5 US&R Strategy & Structure Size-up**

We have discussed the following:

- Phases of a Large Disaster
- Information gathering
- Rapid Recon/Triage and Search Process
- Identification of Individual Buildings
- Structure/Hazards Eval. Marking, Search Assessment Marking, and Victim Marking
- Basic Building Search & Rescue Strategy (Student Manual only)
- Metal Detector & Cutting of Post-Tensioned Concrete, Cables (Stu. Man. Only)

It is important for all Rescue Specialists to remember this information. During an incident the safety and efficiency of the rescue operation depends on everyone involved being able to quickly respond to common terms, marking systems, and warning signals.

The information regarding search, hazard reduction and victim access for the different types of construction should lead to finding ways to most effectively approaching Search and Rescue in Collapsed Structures