



STUDENT MANUAL STRUCTURE COLLAPSE AWARENESS

Course Purpose

This course provides an easily accessible method for FEMA and other US&R team members of completing the NFPA 1670, Structural Collapse Awareness requirement.

Course completion will be of special benefit to US&R team members since the content exceeds the NFPA Awareness Level for the critical topics of Building Systems, Building Types and Characteristics, Collapse Patterns, and Hazard Identification

This manual is the companion to a CD-based and Internet based presentation. Its best use is for the student to have it available when he/she views the PowerPoint presentation, and to use it as a reference when completing the written examination.

This manual contains the same material in Sections II through VII as the FEMA Structural Collapse Technician Training, Student Manual, SCT01b

Acknowledgements

Most of Section I is based on information from the New York State Office of Fire Prevention & Control's Basic Collapse Operations Training. The principal author of that document was John O'Connell, New York Fire Department, Retired.

The principal author of this entire document was David J. Hammond, Structural Engineer, Retired, and FEMA CA-TF-3, Structures Specialist

Enabling Objectives

The student will become familiar with the topics shown in the adjacent slide

These topics are included in the following seven sections of this manual. They are:

- I. Introduction to Structural Collapse Response
- II. Building Materials, Systems & Redundancy
- III. Building Types and Characteristics
- IV. Causes of Collapse
- V. Collapse Patterns
- VI. Hazard Identification and Intro to Mitigation
- VII. FEMA Marking System

Enabling Objectives

The Student will become familiar with the following

- Introduction to Struct Collapse Response
- Structural Forces & Materials
 - Brittle vs. Ductile
- Building Systems + Redundancy
- Building Types and Characteristics
- Causes of Collapse
 - Focus on effects of Earthquake, Wind, Blast & Fire
- Collapse Patterns
 - Potential Victim Location & Survivable Voids
- Hazard I.D. – Collapse & Falling Hazards
- FEMA US&R Marking System



I. Introduction to Structure Collapse Response

We will discuss the topics in the adjacent slide to give an overview of the elements that go into conducting a Structure Collapse Response.

A successful rescue is highly dependent on having well trained individuals working within a properly structured response structure.

All responders must be familiar with the Incident Command System and how it has been adapted to a particular incident. ICS 100 and 200 can be completed as “on-line” courses and are required for all who expect to positively participate in rescue operations

NFPA 1670 – Operations and Training for Technical Rescue Incidents

This national consensus standard was developed by the 1670 committee of the National Fire Protection Association. It is designed to assist organizations in developing a technical rescue capability in their community. It is commonly referred to as an “organizational standard” because the organization as a whole (as compared to individual members) must comply with the requirements of the standard.

Designed as a core + (plus) standard, the core requirements have provisions for all specialties including: medical care, hazard analysis & risk assessment, incident response planning, equipment, safety, Safety Officer, incident management system, and fitness.

Specialty specific requirements are also included for: structural collapse, rope rescue, confined space, vehicle & machinery, water, dive, ice, surf, swift water, wilderness search & rescue and trench & excavation. Each one of these specialties includes 3 response levels: Awareness, Operations, and Technician.

All members of any type of emergency response organizations (EMS, Police, Fire, US&R) should have at least the awareness level of training. Fire departments that respond to emergencies should be trained at least to the Operational level.

Introduction to Structure Collapse Response

- NFPA 1670 Structure Collapse Awareness
- Discuss the Theme of US&R & Survivability
- Identify personal and on-scene safety issues
- Discuss Incident Size-Up
 - Remove Readily Accessible Victims
 - Collapse Warning Signs
- Discuss setting up Incident Command
 - 5 Stages of Collapse Rescue
- Understand the need for Team Ops and proper composition of a Team.
- Understand Basic Search Tactics

What is NFPA 1670?

- Standard on Operations & Training for Technical Rescue Incidents
 - Includes Urban Search & Rescue Ops
- Identify & Establish Levels of Operational Capability for Safe & Effective Operations at Technical Rescue Incidents
 - The purpose is to specify minimum job performance requirements for service as a rescuer in an emergency response agency.



- In structural collapse incidents, these response levels are broken down as follows:
 - ◆ Awareness level – includes: Size-up, site control, scene management, hazard identification and basic search & removal of readily accessible victims.
 - ◆ Operations level – includes: Rescue from light frame, ordinary, unreinforced and reinforced masonry construction.
 - ◆ Technician level – includes rescue from: Concrete tilt-up, reinforced concrete and steel construction.

The theme of Urban Search and Rescue is to save trapped victims while minimizing the risk to the victim as well as the urban search and rescue forces.

- **Survival Rates in Structure Collapse Incidents** - The faster we respond the better the survival rate. (Figures are affected by how people are trapped, such as are they crushed or trapped in a void.)
- The adjacent slide lists approximate survival rates, based on incidents caused by earthquakes, weather, impact load and structure aging/deterioration.

These do not apply to cases where explosions are involved

Personnel Safety

Emergency responders take risks on a regular basis and accidents do happen. Emergency scenes can be confusing and available resources taxed to the point where people need to do jobs with a minimum of personnel and equipment. Common sense often tells us when something is not safe, but a lack of training and incident confusion can lead to unsafe practices.

- Because of this, safety is everyone's job. Therefore, we need to review both personal and scene safety and how each individual is responsible for safety.

Teamwork

Teamwork is critical. Rescuers should always work in teams of a minimum of 2 people. US&R Rescue teams are comprised of 6 people which can be modified to meet different needs. This helps reduce "freelancing". One should always look out for teammates - know where they are. Keep an eye out in all directions - up, down & sides and immediately stop unsafe operations.

NFPA 1670 Levels of Capability

- **Awareness:** Size-up, Site control, Scene Management, Hazard Identification, Basic Search and Removal of Readily Accessible Victims.
- **Operations:** Rescue from Light Frame, Ordinary, Unreinforced and Reinforced Masonry Construction.
- **Technician:** Rescue from Concrete Tilt-Up, Reinforced Concrete and Steel Construction.

Theme of US&R

*To Save Trapped Victims while
minimizing the Risk to Victim as well
as the Urban Search & Rescue Forces*

Survival vs Time of Extrication

1 Hour	95 %
1 Day	80 %
2 Day	40 %
3 Day	33 %
4 Day	20 %
5 Day	7 %

Personnel Safety

- **Teamwork**
 - Minimum of Two on Team
 - US&R Squad = 1-Leader + 5 Rescue Spec
- **Personal Accountability**
 - Sign-out System
 - Immediate Supervisor
 - Escape Plan – Safe Haven
- **Identify Unsafe Areas**
- **Safety Officer**
 - Anyone can Stop an Unsafe Operation
- **Personal Protective Equipment**



Personnel Accountability

Use of an accountability system is critical in the typical confusion surrounding a structural collapse incident. An accountability officer is assigned and will track rescuers using one or more of a variety of methods including: tags, list, electronic systems, etc.

The purpose of an accountability system is to keep track of individuals for organizational and safety reasons.

- In any good accountability system one must know their immediate supervisor and have an escape plan that includes the route, where to re-assemble, and to whom one is to report

Identification of Unsafe Areas

Identification of unsafe areas is key to a successful and injury-free operation. When an unsafe area is found, everyone working in the area as well as operation supervisors need to be notified. The entrance should be blocked and the area monitored from a safe area.

Safety Officer

The Safety Officer is responsible for safe operations including the safety of firefighters and assigned rescue workers. **Anyone can stop a potentially dangerous operation**, but only the Safety Officer, Incident Commander or Operations Chief can restart it.

Personal Protective Equipment

Personal protective equipment includes:

- Rated helmet
- Gloves
- Eye protection
- Ear protection
- Safety boots
- Respiratory protection
- Long sleeved protective clothing
- Knee pads

Personnel Safety

- Teamwork
 - Minimum of Two on Team
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- Safety Officer
 - Anyone can Stop and Unsafe Operation
- Personal Protective Equipment



Scene Safety Precautions

General scene safety is everyone's concern and includes a wide variety of hazard types. Responders should adhere to the following general rules:

- Control Utilities: Electric, Gas, & Water
 - ◆ Eliminate shock or electrocution hazards and beware of alternate electrical systems; batteries, generators, solar electric systems, etc.
- Maintain proper monitoring: visual monitoring of building corners and racked openings may be effective.
- Water hazards: if flooded areas need to be searched, considerations include:
 - ◆ Undermining of structure foundations and bearing walls,
 - ◆ Be careful of ice in cold weather,
 - ◆ Have maps, specialists (such as utility companies) and specialized equipment readily available.
- Define & Observe Collapse Safety Zone:

Until a full assessment is made, allow the height of building exterior walls plus ten feet. High rise and odd shaped buildings require special consideration. Seek advice from Structural Engineers.

Rescue Shoring

The selection and placement of appropriate shoring provides safety from secondary collapse. To do this, you need a properly trained shoring team, equipment, and materials. Additionally, structural engineers are frequently used to ensure the systems being constructed will adequately hold the load.

Lighting

This is a critical resource needed for rescue operations. It allows for extended operations at night but you will still need portable & hand held lights for void search & interior operations. **Setup prior to time of need.**

Scene Safety Precautions

- Control Utilities
 - Electric Grid is off following Earthquake
 - You Must be Sure All Utilities are Turned Off
- Collapse Safety Zone
 - Collapse & Falling Hazards
 - Avoid & Minimize Exposure
- Rescue Shoring – depends on victim needs
 - Should be inspected every 12 hrs
- Lighting
 - Site and Personal
- Limit Vibrations & Rescue Overload
- Monitoring
 - Atmosphere and Structure



Limit Vibrations

Because of the weakened nature of collapsed structures, vibration from outside sources can cause secondary collapses. Every effort must be made to eliminate these sources. Examples include:

- Traffic - Shut down local traffic and reroute away from the scene. Make sure you leave open an in/out route for emergency vehicles & specialized equipment. Consider a shuttle for Rescue Personnel. Remote staging improves scene security and accountability.
- Public Transportation - Shut down trains, subways, busses etc.
- Construction Projects – This is a common source of vibrations and includes the use of heavy machinery for the rescue effort.
- Industrial & Commercial Operations – Machinery may cause vibrations that radiate a distance.

Atmospheric Monitoring

Atmospheric monitoring should be continuous to check for levels of oxygen, carbon monoxide, flammable gasses, as well as other hazards such as dust and asbestos. If possible, additional testing should be done for any other suspected (or even unsuspected) hazard.

Monitor Movement of the Structure

Monitoring may be set up remote from site (adjacent to the site with a good vantage point of the structure), or within the structure. Devices include:

- Theodolites & Total Stations (remotely measure movement),
- Wireless Bldg Monitoring Sys (tilt sensors placed on structure and read remotely),
- Electronic Levels (tilt measuring device placed on structure and read locally),
- Laser Levels (locally measure movement),
- Plumb Bob (locally measure movement, or measure vertical alignment)
- Crack Monitors (measure changes in cracks).

To be effective, these devices must be continually read and have the data recorded. There needs to be an effective alarm system that activates an efficient evacuation plan.

Scene Safety Precautions

- Control Utilities
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Hazard Evaluation & Size-up

Understanding the causes of collapse and the warning signs is critical during the incident size-up. This information will be critical in developing an operational plan that safeguards the responders.

Initial Size-up

When sizing up a structural collapse incident, the following factors should be taken into consideration:

- Survey Incident Area:
 - ◆ Move completely around the building – at a distance in order to stay in the Safe Zone.
 - ◆ Assess extent of collapse and falling hazard zones on sidewalks, streets and adjacent structures
- Building condition including:
 - ◆ Are corners straight? – will indicate if the building is plumb
 - ◆ Are openings racked? – this is also a very good indicator if building is not plumb, story by story. This is usually seen in the first story
 - ◆ Is it an old or new building? – older buildings are usually less reliable, and more susceptible to sudden collapse
 - ◆ Construction Type and Alterations? – as will be discussed later, heavy-weak building are the most dangerous. Also, structures with light roof trusses and heavy roofing can collapse suddenly
 - ◆ Collapse extent - localized or extensive? – A fully pancaked structure, may have less chance of secondary collapse, but may have entrapped many victims. A localized collapse may have trapped fewer victims, but may have greater potential for secondary collapse
 - ◆ How much Potential Energy remains? (heavy objects/parts of structure that can fall) This can help determine the potential for a secondary collapse. The remaining, heavy structure that is leaning or marginally attached could be triggered to collapse by small additional forces like winds, vibrations and aftershocks.

Initial Size-Up

- Survey Incident Area
 - Move completely around building
 - At a distance
 - From above if possible
 - Identify Collapse Extent
 - Identify potential Fall Zones
- Building Condition – Old – New, etc
 - Are Corners Straight?
 - Are Openings Racked?
 - What are Falling Hazards?
 - How much Potential Energy remains?
 - Elevated floors, walls, etc. that could fall/collapse.



Initial Size-up (continued)

- Remove readily accessible surface victims:
 - ◆ Need to gain as much information from these victims as possible.
 - ◆ Ask victims the following questions:

Are you OK or are you hurt?
If hurt, where?
Stabilize neck & spine if needed, then move victims to staging area away from hazards.

Do you take any medications?
Need to record this information and attach it to the victim for hand-off

What is your name? What happened here?
Where were you? What floor? What room?
Do you know of anyone else in the building?

These victims (and other bystanders) may be best source of info about what happened and possible number of remaining victims
 - ◆ Survey area for other victims and damage.
 - ◆ Determine the number of victims as early in the operation as possible
- Mutual Aid / Outside assistance
 - ◆ When in doubt call them out! You can always send them home. Should be pre-planned.

Includes: specialized rescue teams, other FD's, local contractors and engineers.

Using "FAST VOIDS"

Fast Voids is an acronym for items that should be addressed before entering any void in a building collapse. The following is an explanation of this check list of procedures.

- Fire Suppression - Small fires can become big fires in a very short time. Remember, smoke kills!
- Additional collapse potential - Is building or its components moving? What about loose / hanging debris?
- Structure type & condition – Is it old, new, maintained, under construction, or demolition?

Initial Size-Up (continued)

- Remove readily accessible surface victims
 - Determine condition of these victims & ask:
 - What is your name?
 - Are you OK or are you hurt?
 - If hurt, where?
 - Take care to stabilize neck & spine if needed
 - Move victims away from all hazards
 - Do you take any medications?
 - Need to hand-off that information
 - Where were you in building?
 - Do you know of anyone else in building?
 - Do best to determine number of victims & locations
 - Plan Search Tactics
- Is Mutual Aid/Outside Assistance Needed?

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FAST VOIDS

- Fire suppression
- Additional collapse potential
- Structure type & condition
- Trapped victim rescue
- Void types & location
- Occupancy type & hazards
- Immediate utility shutdown
- Day of night
- Situation – cause of collapse



Using “FAST VOIDS”(continued)

- Trapped victim rescue – Regarding the trapped victim: is it confirmed / unconfirmed? Are they crushed, impaled, pinned, dead or alive?
- Void Types & location – You need to size-up the location and number.
- Occupancy type / hazards – Examples include a private dwelling vs. commercial, nursing home etc.
- Immediate utilities shutdown - Who should handle this?
- Day or Night – Based on occupancy type, this may give indication of number of potential victims.
- Situation - Cause of collapse – an example; was it a gas explosion or a terrorist attack

This acronym was developed by the Fire Department of New York, and should be used by all those that find it helpful

Hazard Evaluation & Size-up

Understanding the causes of collapse and the warning signs is critical during the incident size-up. This information will be critical in developing an operational plan that safeguards the responders.

Causes of Collapse

Causes of collapse include:

(Most will be discussed in detail in Section IV)

- Explosions:
 - ♦ Accidental causes include: Natural Gas, industrial dust, clandestine drug labs, explosive storage, flammable liquids/gasoline tankers, malfunctioning utilities.
 - ♦ Intentional causes include: demolition (controlled), mining (below grade), road construction (blasting) and terrorism.
- Overloading of Structural Components
 - ♦ Primarily occurs with roofs and floors. Examples include: water (clogged drains, pooled water), snow, stacked building materials, HVAC equipment & water tanks, any additional material exceeding floor load capacity and change in occupancy.

FAST VOIDS

- Fire suppression
- Additional collapse potential
- Structure type & condition
- Trapped victim rescue
- Void types & location
- Occupancy type & hazards
- Immediate utility shutdown
- Day or night
- Situation – cause of collapse



Causes of Collapse (continued)

- Structural Aging/Deterioration
 - ◆ Considerations include: age of structure, quality of materials & workmanship, maintenance of the structure, occupied or vacant, weather exposure (water, wind, hot & cold), breakdown of mortar, rotting of structural members, expansion/contraction, undermining foundations, insect infestation, improper alteration, and removal of structural components.
- Natural Disasters
 - ◆ Includes: earthquake, flooding, undermining & floating of structure, mudslides, hurricane, tornado and windstorm surge.
- Collision Impact
 - ◆ Includes impact from: vehicles, aircraft, train, debris/materials (storm or explosion), construction equipment, etc.
- Security Measures
 - ◆ This factor is primarily found in urban/remote industrial areas. Typically, additional weight (i.e. steel sheeting on roof) is a primary reason. Additional considerations include: roll down gates covering large openings as well as grates, bars, sheeting, etc. causing access problems.
- Collapse by Fire
 - ◆ Flashover needing heat and back draft needing oxygen could both result in explosive force resulting in structural damage or collapse. Need a rapid determination if the fire is confined to contents or has extended to structural members.
 - ◆ Prolonged burning indicates that it is likely the fire has spread to structural members and collapse is possible.



Collapse Warning Signs

These include all the indications that may lead to a secondary collapse, including forces of nature and structural anomalies.

Remember that the gravity force in any leaning structure (including parts like walls) is acting to cause that structure to fall. It may be temporarily at-rest, but additional forces, caused by wind, aftershock, etc. may be enough to cause a secondary collapse

Collapse warning signs include:

- Aftershocks – that must be anticipated to occur following any earthquake
- High winds
- Heavy rain or snow
- Bulging walls & Separating walls
- Cracks in walls, columns or foundation
- Unusual sounds, wood crushing, etc.
- Falling/sliding plaster & falling dust
- Vibrations
- Sagging floors or roof
- Columns or walls out of plumb
- Swinging doors
- Racked doors or windows, also stuck
- Missing / broken structural elements

Structure should be monitored continuously and carefully investigated for warning signs. One should always proceed with caution and bring in competent assistance (such as engineers or other specialists).

Be careful of shifting loads and debris. Remember that partition walls may now be bearing walls and jammed doors could be supporting a load. These may need to be shored before being opened or removed.

Introduction to Team Operations

A technical rescue operation will run more effectively and safely when an Incident Command System (ICS) is utilized. By employing an incident command system to organize all rescue incidents, rescuers will gain the necessary confidence to organize even the most complex technical rescue incidents.

Collapse Warning Signs

(Causes of Collapse are covered later)

- **Extreme Forces**
 - Aftershock, High Winds, Rain or Snow
- **Out of Plumb/Racked - Columns/Walls/Opn'gs**
 - Gravity Rules
- **Excessive Loading on Floors/Roof**
 - Heavy Debris
 - Sagging/Un-level Floors or Roof
 - Missing or Broken Elements
- **Cracks In Walls, Columns & Foundation**
 - Separating or Bulging Walls
 - Falling Plaster & Airborne Dust
- **Unusual Sounds & Vibration**
 - Creaking or Groaning
 - Sounds of distressed wood



Overview of Collapse Operations

Five Phases of Rescue:

- Spontaneous rescues - victims are not pinned or trapped. Include the walking wounded - these rescues are made first.
- Light in-place rescues – victims are not pinned too badly. A quick air bag lift or cut to free those that are trapped. Typically involves patient packaging.
- Heavy careful removal – involves victims who are trapped or pinned in debris. Possible crush syndrome is setting in. Shoring, wall breaching and/or heavy lifting may have to be done. This type of rescue is going to take some time.
- Body recovery - usually when switching to this mode the operation is stopped and regrouped. Responders are no longer saving a life so rescue personnel should not take unnecessary risks.
- Demolition – the structure is taken down with heavy equipment, excavator, bulldozer or front end loader. Debris may be spread out for a final search. After that, it is put in some type of dump truck and hauled away. If the incident is a crime scene, the debris will be taken to a secure site for evaluation

Five Stages of Collapse Operations

- Reconnaissance and site survey
- Surface Victim Removal
- Void space exploration and removal of victims
- Selected debris removal and shoring operations
- General debris removal (supervised)

Incident Command Overview

A rescue scene can be one of confusion if a command system is not established early in the incident. The command system must be versatile, adaptable to any type or size of emergency or incident, and relatively familiar if it is going to be useable. It should also be expandable in a logical manner if changing conditions dictate. The majority of local, technical rescue operations may efficiently managed with a pared down version of the full blown ICS model. It will be the rare and overwhelming technical rescue incident that will require filling positions like Planning, Logistics, Finance, etc.

All participants should have completed some version of ICS 100 and 200 Training.

Overview of Collapse Operations

5 Phases of US&R

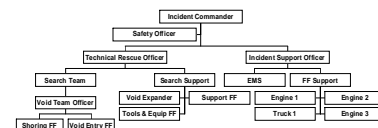
- Spontaneous Rescue
- Light, In-place Rescue
- Heavy Careful Removal
- Body Recovery
- Demolition

5 Stages of Collapse Operations

- Reconnaissance & Site Survey
- Surface Victim Removal
- Void Search & Rescue
- Selected Debris Removal
- General Debris Removal

Incident Command Overview

- Incident Command Sys (ICS)
 - Span of Control – Recommend 5 to 1
 - Unified Command – allows for many agencies
 - Well Defined Functions





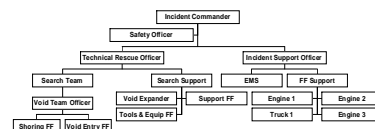
The ICS allows for a manageable span of control of people and resources. Utilizing an ICS takes much of the pressure off of the Incident Commander. The **maximum** span of control is 7 (seven) persons while the **recommended** effective span of control of 5 to 1 allows for the most effective management. The system is set up so that the IC is only **communicating to and receiving information from** a maximum of five people, rather than the whole assignment of personnel at the scene. Individual managers of personnel and resources within ICS are also working within a manageable span of control.

The **Incident Commander (IC)** or “command” is the individual responsible for the management of all incident operations. The IC does not need to be well versed in technical rescue, however he/she should be well versed in the ICS. The IC should be stationed at a command post outside the collapse zone. On large, complex, and or protracted incidents, the **I.C.** may delegate functional responsibilities by appointing an:

Liaison Officer (Liaison)

The **Operations Officer** is responsible for direction and coordination of all tactical operations. On modest sized rescue incidents, Operations may fulfill the functions of a Technical Rescue Officer (TRO). At large scale rescues, Operations may designate a TRO. Operations may also interface with the media and other appropriate agencies as necessary in the absence of the PIO and Liaison Officer.

- **Incident Command Sys (ICS)**
 - Span of Control – Recommend 5 to 1
 - Unified Command – allows for many agencies
 - Well Defined Functions





The **Safety Officer (SO)** is responsible for enforcing general safety rules and developing measures for ensuring personnel safety. When manpower is limited the SO position may be combined with the TRO and/or Operations positions. The SO can bypass the chain of command if necessary to stop unsafe acts immediately.

The **Technical Rescue Officer (TRO)** or “**Rescue Team Leader**” is responsible for the rescue operation. This person is normally the most experienced rescue technician on the team and assumes the lead role in designing, setting up, and checking of the necessary rescue systems. The TRO is the liaison between the rescue site and the command post and designates “tactical” level positions in the ICS as needed.

Sample Initial Response

NOTE: The following is what should occur at a local incident. Locally available equipment and personnel will dictate actual capabilities. Missing resources would be considered in determining mutual aid requests and pre-plans. (all incidents start as local incidents)

- Chief Officer (IC)
 - ◆ Assumes command
 - ◆ Identifies command post and main staging area
 - ◆ Identifies collapse zone & staging areas
 - ◆ Ensures utilities are made safe
 - ◆ Utilizes 6 sided approach to size-up - Top, Bottom, all 4 sides
 - ◆ Receives input from company officers
 - ◆ Divides structure (operationally) if necessary
 - ◆ Ensures ICS is utilized
 - ◆ Reviews 5 stages of collapse
 - ◆ Controls rescuers such as firefighters, police officers, civilians and others
- Rescue Officer
 - ◆ Directs & oversees actual rescue operation
 - ◆ Establishes rescue sectors
 - ◆ Makes assessment and size-up
 - ◆ Reports to IC for inclusion in overall assessment and size-up
 - ◆ Establishes rescue staging area(s)
 - ◆ Gathers information and provides progress reports plus uses operational check-lists.
 - ◆ Establishes backup plan for rescue operation
 - ◆ Communicates effectively up & down the chain of command.

Incident Command Duties

- Assume Command
 - Setup-up Command
 - Define Command Post Location
- Define Incident Boundaries
 - Collapse and Fall Zones ←
 - Staging Area
- Size-up
 - Survey Collapse
 - Utilities ←
- Begin and Define Stages of US&R
- Control Rescuers & Bystanders
- Determine need for additional resources



- First Due Engine
 - ◆ Establishes initial water supply
 - ◆ Attacks the fire with first line
 - ◆ Stretches a backup line if manpower permits
 - ◆ Operate front to rear of building
 - ◆ Leave space for the ladder (and Rescue)
- Second Due Engine
 - ◆ Establishes secondary water supply
 - ◆ Provide backup to first engine
 - ◆ Assists first engine with front to rear suppression
 - ◆ Checks exposures for extension and secondary collapse potential.
- Third Due Engine
 - ◆ Responds to the rear of structure
 - ◆ Establishes alternate water supply
 - ◆ Stretches a line if necessary
 - ◆ Looks for rescue access in rear
 - ◆ Reports to command post for further assignment
- First Due Ladder
 - ◆ Removes surface victims
 - ◆ Does site survey – reports to IC
 - ◆ Positions ladder for rescue effort & observation
 - ◆ Identifies location & type of voids
 - ◆ Identifies hazards & corrects them if possible
- Second Due Ladder
 - ◆ Shuts down utilities if possible
 - ◆ Positions ladder for rescue effort & observation
 - ◆ Begins void search
 - ◆ Identifies hazards & corrects them if possible
 - ◆ Reports to command post for further assignment
- Heavy Rescue
 - ◆ Establishes grid search to cover collapse areas
 - ◆ Void search in established victim locations
 - ◆ Performs shoring operations
 - ◆ Performs victim removal
 - ◆ Treatment and packaging according to local protocol.

This is just an example of how a local incident progresses. In cases where the FEMA National Response Sys is involved, local recourses are overwhelmed and a National Disaster is declared



Search Tactics

Search will determine the need and focus of any structure collapse incident. If viable victims are detected (or likely to be trapped) the rescue must be focused on locating and extricating them.

It is certainly the intent of all rescue operations to proceed as safely as possible. However when viable victims are detected, higher short term risks will be taken than in the case of body recovery

We have listed the several methods of search that are commonly used, and all have the intent of detecting and locating the viable victims:

- Physical Void Search
- Audible Call-out
- Technical Search using vibration detection
- Technical Search using extendable cameras
- Canine Search

The following is a short explanation of each

Physical Void Search

This method requires searchers to enter what may be relatively unsafe void spaces. It has the advantage of possibly finding an unconscious, viable victim, but it places searchers in potentially dangerous places. This type of search should only be done by highly trained teams that can mitigate some of the hazards

Physical Void Search is commonly the first choice of fire department units. Trained six-member void search team, consisting of one officer and five firefighters, are often used. The team is divided into two sub teams, the search team and the support team.

The primary function of the Void Search Team is to search any existing natural voids (voids that already have been created by the collapse) instead of trenching and tunneling the debris. These voids will be the fastest and easiest to explore and a significant number of viable victims may be trapped in them.

A support team is positioned at the mouth of the void. They will pass debris out of the void or pass tools and equipment in or out. They stay in direct contact with the entry team throughout the operation, widen the void opening when possible, assists the void entry team, and become the void entry team relief.

Search Tactics

- Determines **NEED** and **FOCUS** of US&R
 - Determines Risk vs. Reward Ratio
 - Need Detection and Location
- Physical Void Search
 - Should be performed by Trained Teams
 - May be dangerous, and may miss unconscious
- Audible call-out
 - Best as organized Grid Search w/ Hailing
 - Call for response, will miss unconscious
- Technical Search
 - Electronic & Camera
 - Need response to Hailing + Special Equip & Training
- K9 Search – limited resource



Audible Call-Out Search

Since frequently, one cannot hear the voice of the victim, this method of calling out to them with a request for knocking may be successful. The searchers/listeners should deploy in a grid pattern to help point to the victims' location. The searchers may also deploy in a line and walk across the collapsed area. A bull-horn, or hailing device, should be used to provide verbal directions to trapped victims. The area is then quieted and personnel will listen and attempt to pin-point the location of the responding noise.

This method is safer than a Void Space search, but it will miss unconscious victims. This method can provide **detection**, but may not be able to pinpoint location

Technical Search using electronic detection

The advent of state-of-the-art electronic listening devices has added a new dimension to the search function. The latest electronic devices can extend the range of the search (in case where the victim's scent may not reach the surface and therefore be inaccessible to canine) by detecting sounds from the victim.

This type of search will use hailing to request a response (usually tapping) from viable victims. The operator of this type of equipment needs to be highly trained in order to properly interpret the returning signals, and where best to place the several sensors.

This method is also safer than a Void Space search, but it will miss unconscious victims. However, it can detect victims that are buried so far in the rubble that their voice response cannot be heard. This method can provide very sensitive **detection**, but may not be able to pinpoint locations.

Tech. Search using extendable Video and Fiberoptic cameras

Cameras are available that have been designed specifically for search and rescue applications. Tactics used will make use of available holes and openings to look inside voids, or holes will be drilled to allow camera access.

These are very important tools for close-in search. They can be used for **Detection**, but are most often used to **Locate**, communicate with, and assess the condition of the victim.

Search Tactics

- Determines NEED and FOCUS of US&R
 - Determines Risk vs. Reward Ratio
 - Need Detection and Location
- Physical Void Search
 - Should be performed by Trained Teams
 - May be dangerous, and may miss unconscious
- Audible call-out
 - Best as organized Grid Search w/ Hailing
 - Call for response, will miss unconscious
- Technical Search
 - Electronic & Camera
 - Need response to Hailing + Special Equip & Training
- K9 Search – limited resource



Canine Search

A well trained canine search team can search large areas in a relatively short time. The dogs use their keen sense of smell to **Detect and Locate** victims buried under the debris. The primary function of the canine is to find those victims that are alive. However, most canines will give subtle indications of the dead, and when ever possible these areas should be noted for future recovery.

The search canine will indicate finding the scent of a buried human victim by focused barking and digging at the strongest scent source. The canine may also try to penetrate to the victim.

A canine team consists of a canine search specialist and a search canine. Two of these canine search specialist teams, a technical search specialist, and a search team manager should be assigned to search a site. The search team manager monitors handler safety, may be an observer (spotter), keeps track of and maps alerts, and coordinates the search operations.

The search team manager, technical search specialist, and the canine search specialists (handlers) will survey the site and decide the best search strategy for the operation.

- They will factor in the time of day, the temperature, size of area to be searched, and the type of collapse.
- The site will usually be divided into small search sectors. The search team manager should sketch the general features of the structure/rubble area, labeling each search sector, and noting all significant information (land marks, etc) on the sketch for future reference

Search Tactics

- **Determines NEED and FOCUS of US&R**
 - Determines Risk vs. Reward Ratio
 - Need Detection and Location
- **Physical Void Search**
 - Should be performed by Trained Teams
 - May be dangerous, and may miss unconscious
- **Audible call-out**
 - Best as organized Grid Search w/ Hailing
 - Call for response, will miss unconscious
- **Technical Search**
 - Electronic & Camera
 - Need response to Hailing + Special Equip & Training
- **K9 Search – limited resource**



Collapse Search Tips

- General Considerations
 - ◆ “Round the Clock” call out for victims - rescuers call out for victim one at a time and listen for an answer. This helps zero in on victims we can’t see trapped in debris.
 - ◆ Vertical access through floor - cutting through floors to get into voids.
 - ◆ Canine search potential - dogs can detect and locate victims at the same time, but are a scarce resource.
 - ◆ Avoid cutting walls - the wrong hole in the right wall can cause failure, extensive damage, and further collapse.
 - ◆ Roof/floor beam support should not be cut and should be re-supported/shored when necessary.
 - ◆ Consider the basement for access - Shore from below the collapse.
 - ◆ If a complete collapse has occurred, shoring should be started at the lowest level.
 - ◆ Falling Hazards - something small dropped from high up can take out a rescuer or victim. Something very heavy dropped only a few inches can also cause significant injuries.
- Initial First Aid Considerations
 - ◆ Follow local protocols.
 - ◆ Spinal immobilization.
 - ◆ Administer oxygen.
 - ◆ Use proper packaging techniques.
 - ◆ Be conscious of the possibility of crush injury syndrome.
 - ◆ Transportation
- Emergency signaling

Effective emergency signaling and evacuation procedures are essential for the safe operation of all personnel operating at a disaster site. The signal must be clear and must be universally understood by **ALL** involved in the rescue effort.

This signaling as well as the FEMA US&R Marking System will be discussed later in Section VII



II. Building Materials, Systems & Redundancy

Force Types

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

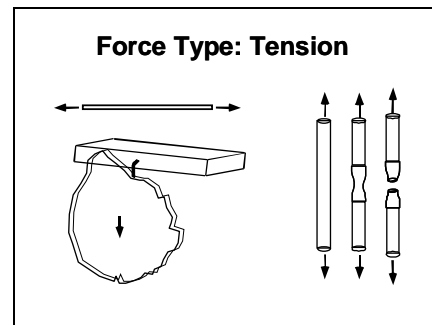
- When a **force** is applied to an individual member, it produces **stress**, which is defined as the force divided by the cross-sectional area on which it acts.
- **Example:** A 1000 lb **force** (also called 1 kip or 1k) acting in tension on a 2 in x 2 in steel bar produces a tension stress of 250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





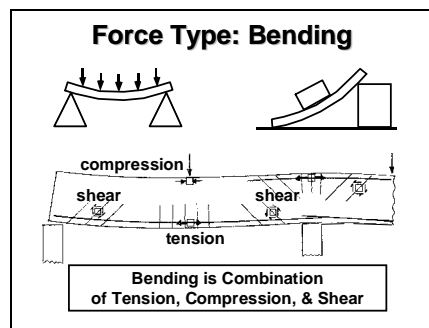
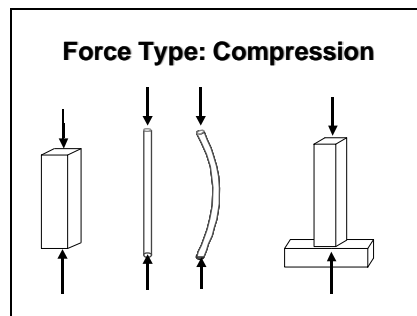
Compression Forces

- 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.

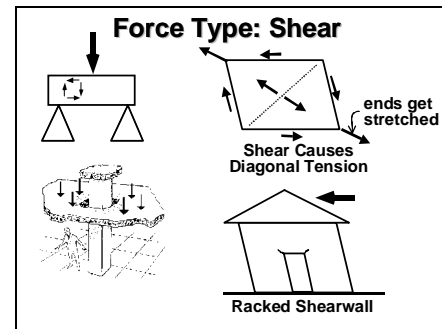
Example: Consider a beam made from a group of individual books as they sit on a bookcase, with a long threaded rod extending all the way through them, tightened with nuts at each end. If this beam is placed so that it spans the gap between two tables, and one attempts to push one of the books down to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

Material Properties Brittle vs Ductile

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



- 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.

Material Properties Brittle vs Ductile

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



- 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.

Material Properties Brittle vs Ductile

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



- 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.

Material Properties Brittle vs Ductile

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



- ◆ 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.

Material Properties Brittle vs Ductile

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



- 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

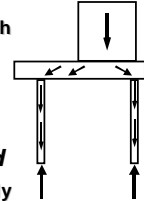
Structural members in these systems can be divided into two types, those that form horizontal (or sloped roof) planes and those that provide the vertical support for these planes.

Horizontal Members

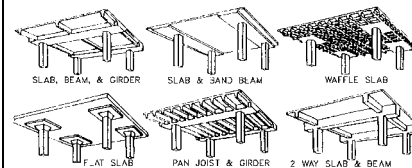
- Horizontal members support floor and roof planes and are normally loaded in bending, such as:
 - ◆ Wood: rafters, joists, purlins, beams, and girders;
 - ◆ Steel: corrugated sheets (filled with concrete), joists, purlins, beams, and girders.
- Reinforced concrete floor systems may be of many types. 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.

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



Concrete Floor Systems



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



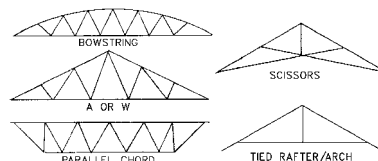
Trusses

- 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 the column and the 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).

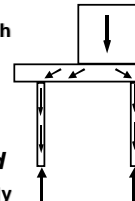
Typical Truss Configurations



- 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





- 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

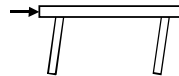
Lateral Load Resistant Systems

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.

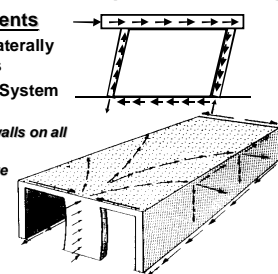
Lateral Load Resisting Systems

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

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

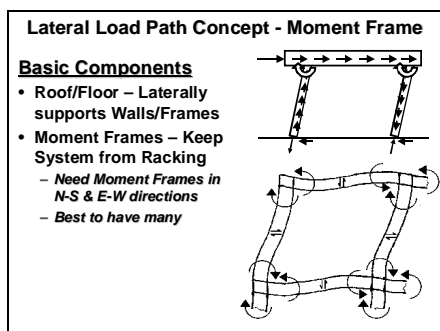
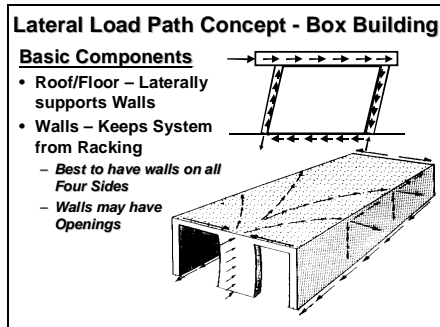




- The floor and roof planes (diaphragms) span horizontally between exterior (and sometimes interior) walls, which provides each horizontal plane with lateral support. The shear walls are in turn loaded by the floor diaphragm and must be capable of resisting both the shear stresses and bending stresses 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.





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).

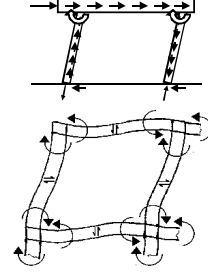
Frame Buildings—Diagonally Braced

- 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.

Lateral Load Path Concept - Moment Frame

Basic Components

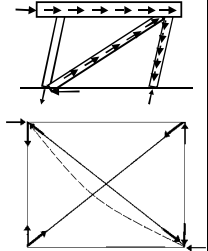
- Roof/Floor – Laterally supports Walls/Frames
- Moment Frames – Keep System from Racking
 - Need Moment Frames in N-S & E-W directions
 - Best to have many



Lateral Load Path Concept Diagonal Braced Frame

Basic Components

- Roof/Floor – Laterally supports Walls/Frames
- Diag Braced Frames – Keep System from Racking
 - Need Diag Br. Frames in N-S & E-W directions
 - May have combo of Mo. Frames and Diag Brace





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.

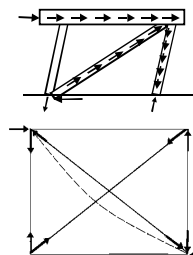
Redundancy

- 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.

Lateral Load Path Concept Diagonal Braced Frame

Basic Components

- Roof/Floor – Laterally supports Walls/Frames
- Diag Braced Frames – Keep System from Racking
 - Need Diag Br. Frames in N-S & E-W directions
 - May have combo of Mo. Frames and Diag Brace



Redundancy

- Multi - Elements
(at least 2 in every line of resistance)
 - Box Buildings
 - Diagonal Braced Frames
- Majority of Connections
 - Moment Frames
- Dual Systems
- Collapse Preventers

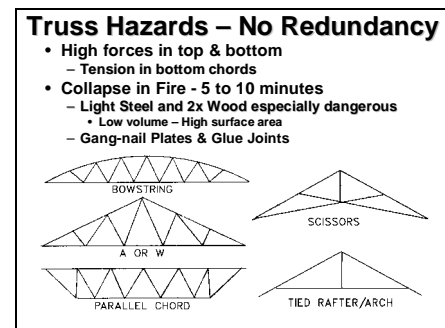
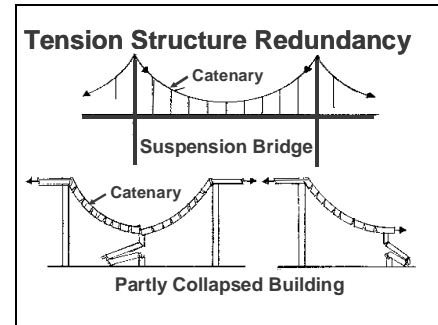


Suspension/Tension Structures

- 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.





III. 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 13 specific building types based on how they respond to earthquakes. We have added Mobile Homes & Manufactured Units.
 - ♦ 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
- 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 Structure Recon and Structure/Hazard Eval 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.

Building Types & Characteristics

ATC-20 Building Types

- 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

SCA 30

ATC-20 Bldg Types - cont.

- 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

See Student Man. for Bldg Types & Characteristics

We will only discuss W1 & 2 + TU

SCA 31

Compare Brannigan to ATC

- ATC has more categories and relates to how structures respond to Earthquakes.
- Brannigan relates to how structures are effected by Fire
 - Wood Construction = W
 - Ordinary Construction = URM, RM, TU
 - Steel Construction = S1, S2, S3, S4, S5
 - Concrete Construction = C1, C2, C3
 - High Raise Constr. = S1, S2, C1, C2, C3
 - Garden Apartments = W



- 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 give the reader a real insight from the lessons that have been 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 multi-story wood structures.

Poorly connected W1 & W2 wood structures are also very vulnerable to wind damage.

- Mobile Homes & Manufactured Units are susceptible to damage by winds and earthquakes.
- Type S3 is listed since it is very susceptible to damage by wind.
- 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 often 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 due to earthquakes, but provide resistance to high winds

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

Problem Buildings

- W 1 & 2 1 to 3 story houses & 2 to 4 Story Apartments (especially pre 1970)
- S1 Frames w/brittle welded conns
- S2 Frames where column capacity is less than capacity of diag braces
- S3 Light structure vulnerable to Wind
- C1/C3 Pre 1971 bldgs (espec pre 1941)
- PC2/TU Factory built precast & tilt-up wall
- URM 1 to 8 story (most 3 story & less) + steel & conc frames w/URM infill
- Others Irregular - soft story, open front

SCA 32

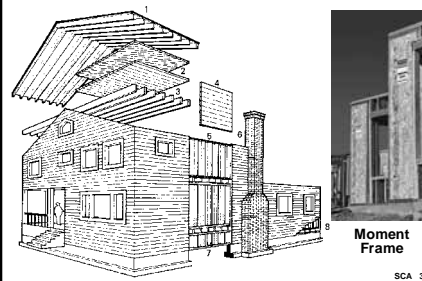


Wood Frame Buildings – W1 & W2

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

- The principle weakness may be in the lateral strength of walls or interconnection of the structure, especially at the foundation.
- The characteristics of wood frame structures are listed in the following slide
- 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
- Common problems in strong earthquakes are:
 - ♦ Walls that are weakened by too many 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. (mostly W1 Type)
- 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.

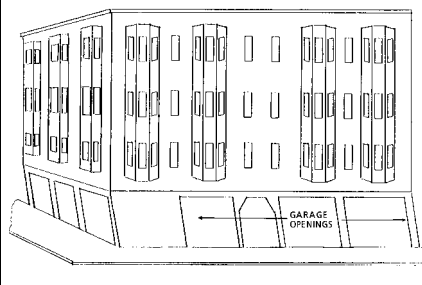
Wood Houses W1



W1 & 2 Type Characteristics

- Bearing Wall System
 - Light Frame (2X wood framing or light gage steel framing) Un-Framed System
- Typical Occupancies
 - Residential, light commercial – up to 4 stories
- Key Performance Aspects
 - Many walls create redundant structures w/ significant overstrength, generally ductile failure modes, depending on sheathing type.
- Combinations
 - May be built above R/C parking garage
 - Frequently used for interior partitions in residential and commercial masonry structure

Wood Frame Apartments W-2



W2 - 3 Story Apartments (also 4 story)

Over Conc Parking

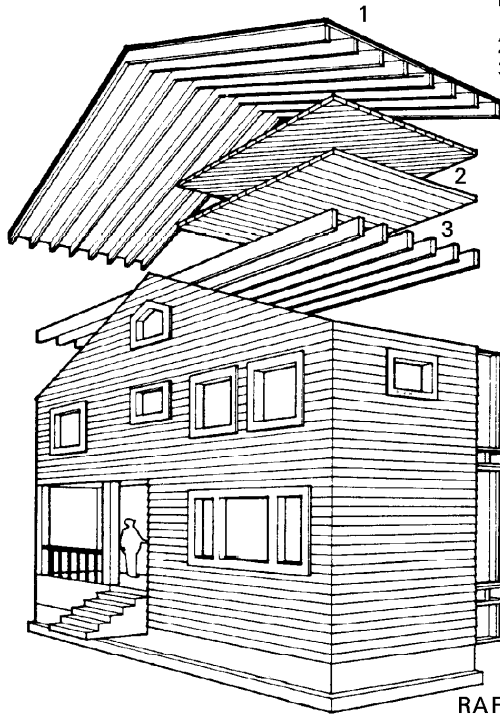


Over Weak
1st Story
Parking





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:

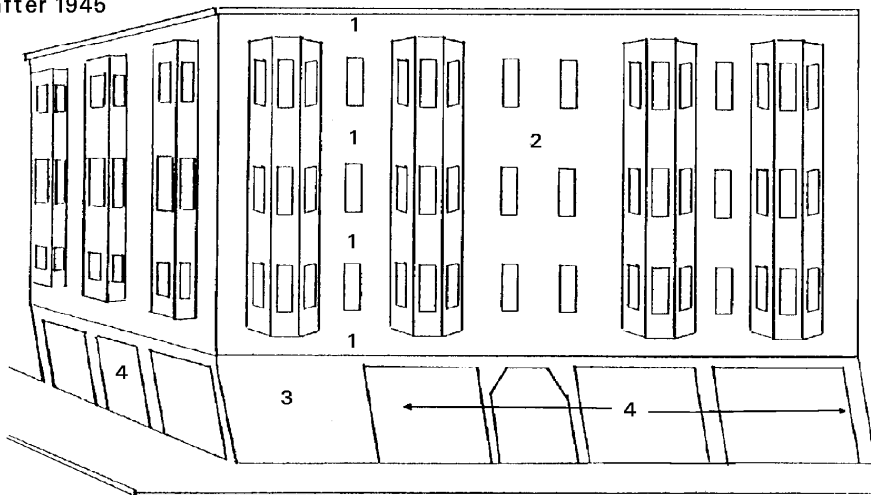
6. Masonry chimney
7. Cripple wall below 1st floor (often w/vent holes)
8. Floor joist may bear directly on footing.

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 .

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

SCA 38

Mobile Homes/Mfr'd Units- Characteristics

- **Structural Systems**
 - Very light, metal covered walls
 - Most all are built on a steel base framework
 - 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
 - Need to maintain ingress and egress
- **Combinations**
 - More than one unit may be interconnected to form larger space

SCA 39

Portable Classrooms – Seismic design

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



SCA 40

Temporary Office – for 30 years?

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

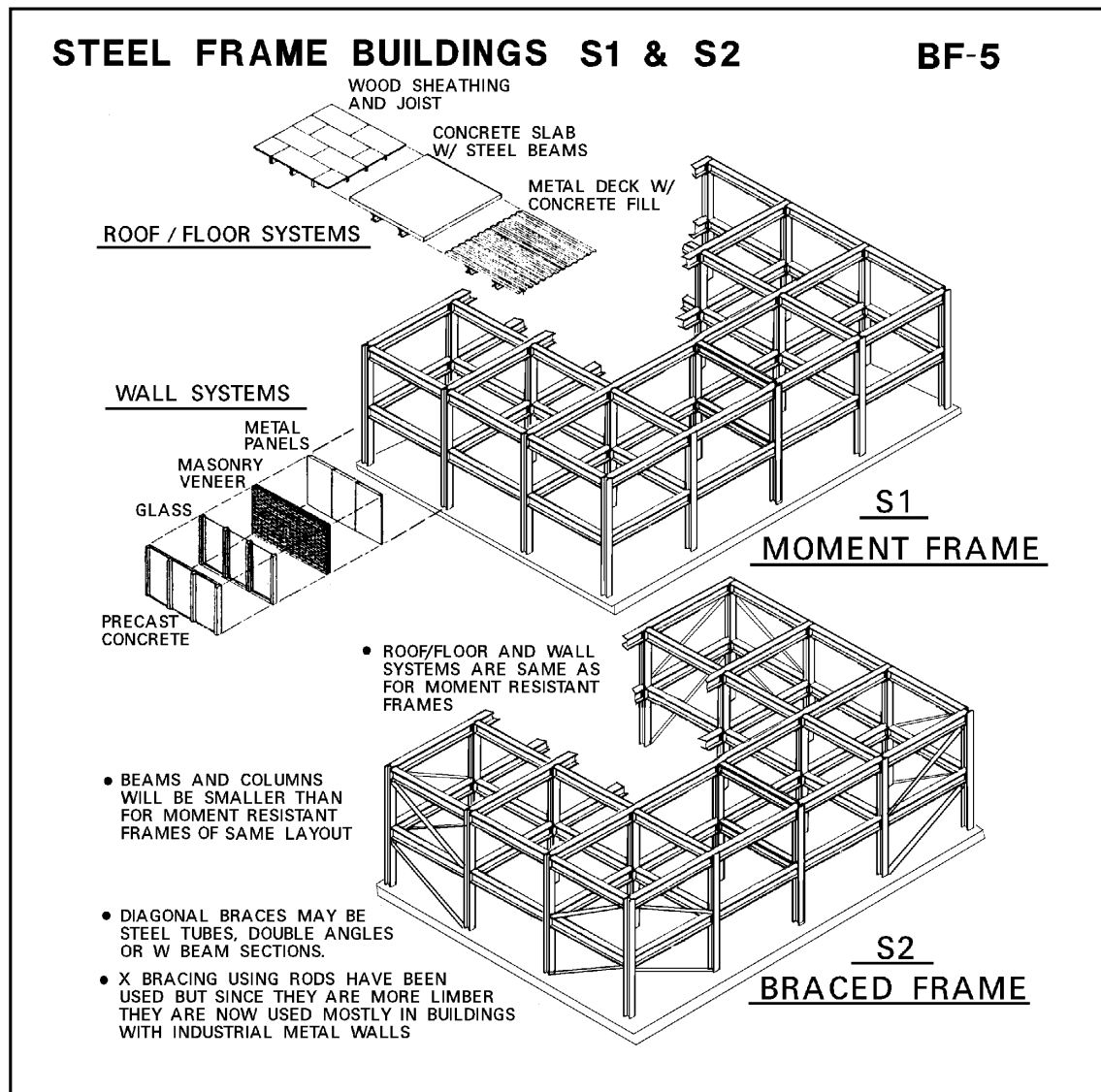


SCA 41



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 in general have performed well, but those with diagonal bracing have had the following 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 catastrophic failure of the 20-story Pino Suarez tower in Mexico City in 1985 is attributed to this effect.
- When tube-type members are used for diagonals, sudden 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.

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 partitions

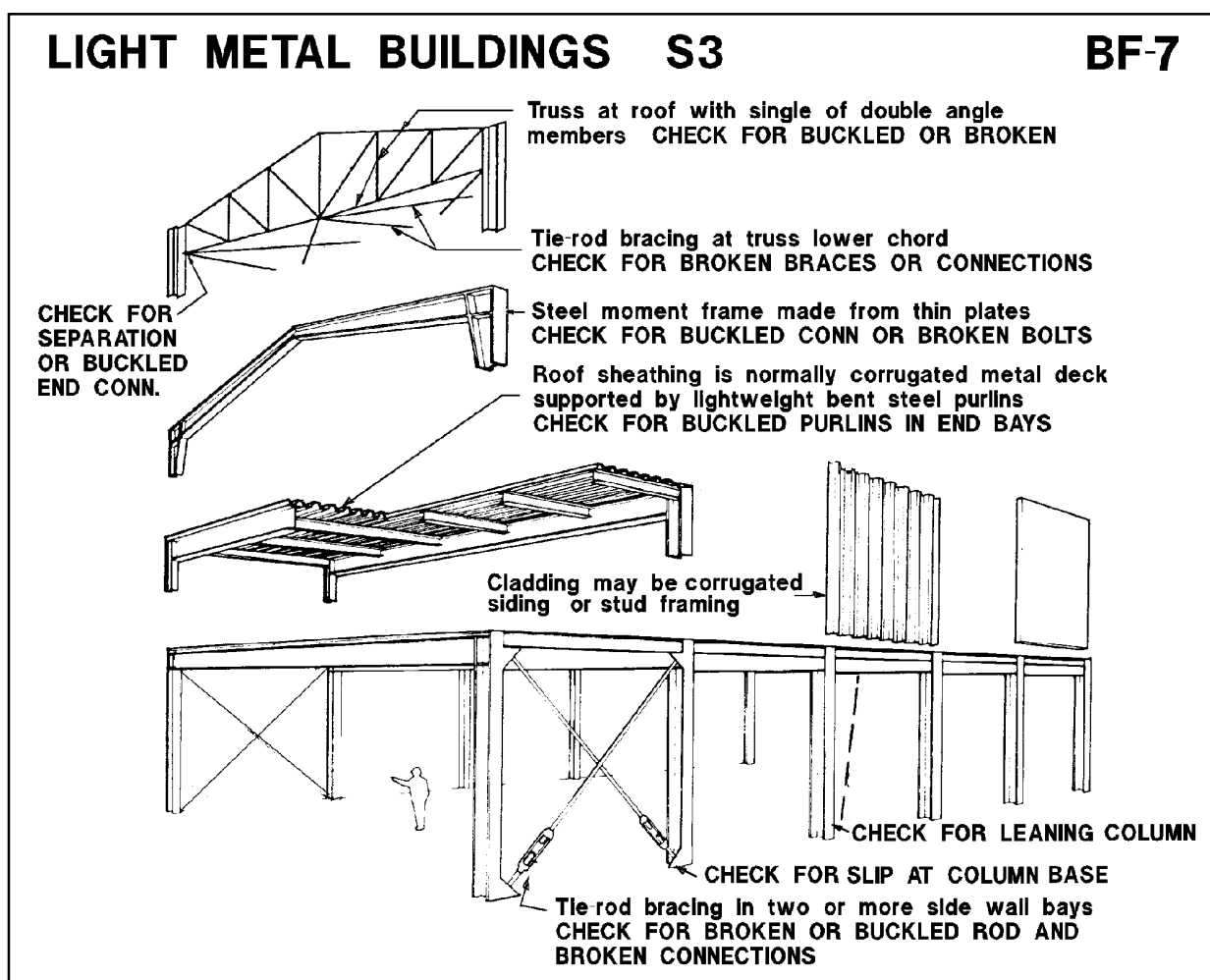
S2 Type Characteristics

- 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



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 adjacent 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 surrounding 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 and more likely to lead to larger collapse.

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 curtain/exterior walls

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



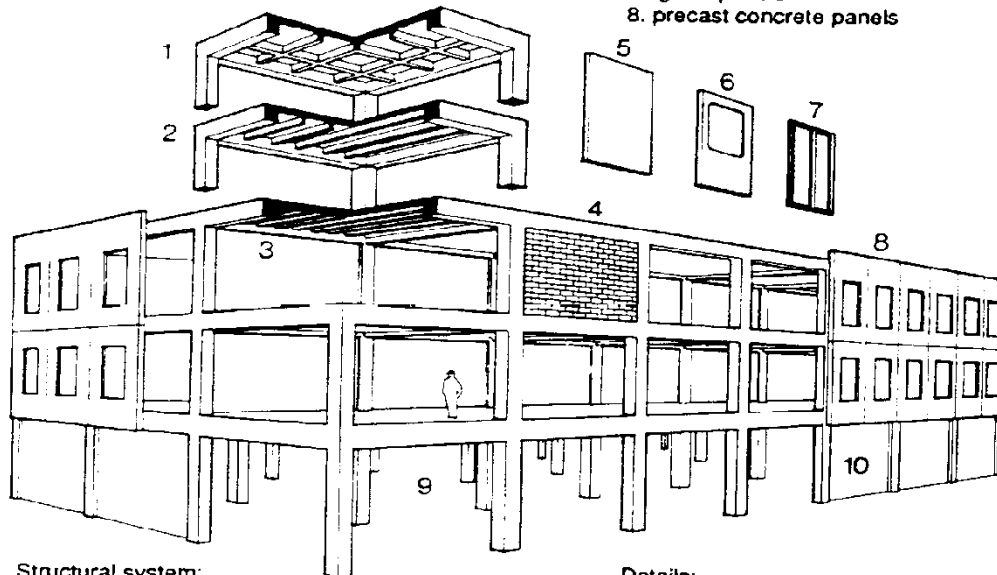
CONCRETE MOMENT RESISTING FRAME C1 BF-8

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)

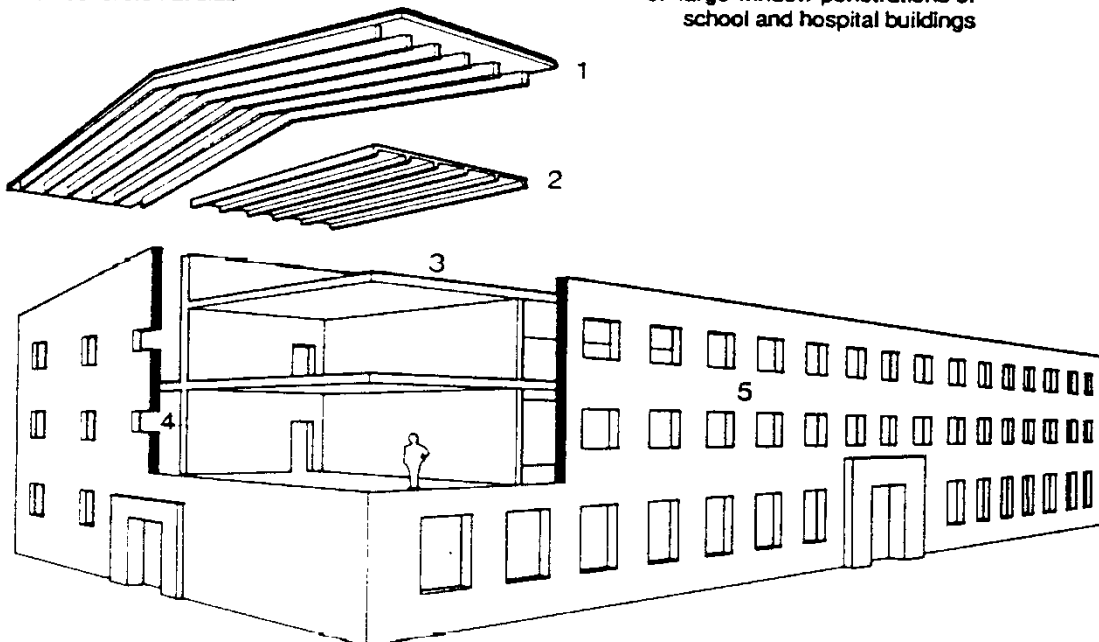
CONCRETE SHEARWALL BLDG C2 BF-9

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.

See adjacent slide for characteristics

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

- X-cracking of wall sections between punched-in 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).

See adjacent slide for characteristics, and following page for graphic.

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.

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

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**
 - Parking Garages, Office, Residential, & Commercial
 - 1 to 12 stories
- **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**
 - Precast panels used for floors and roofs of masonry and steel frame structures.
 - Commonly used for curtain walls



PRECAST CONCRETE BUILDINGS PC2

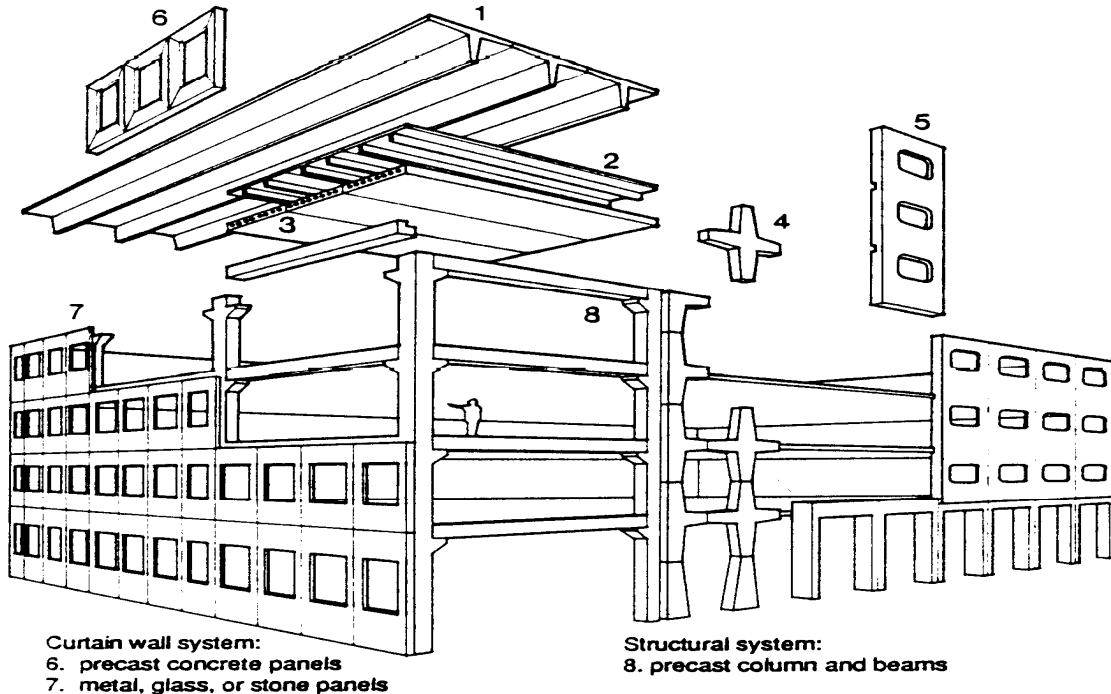
BF-10

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



TILT-UP CONCRETE WALL BUILDING

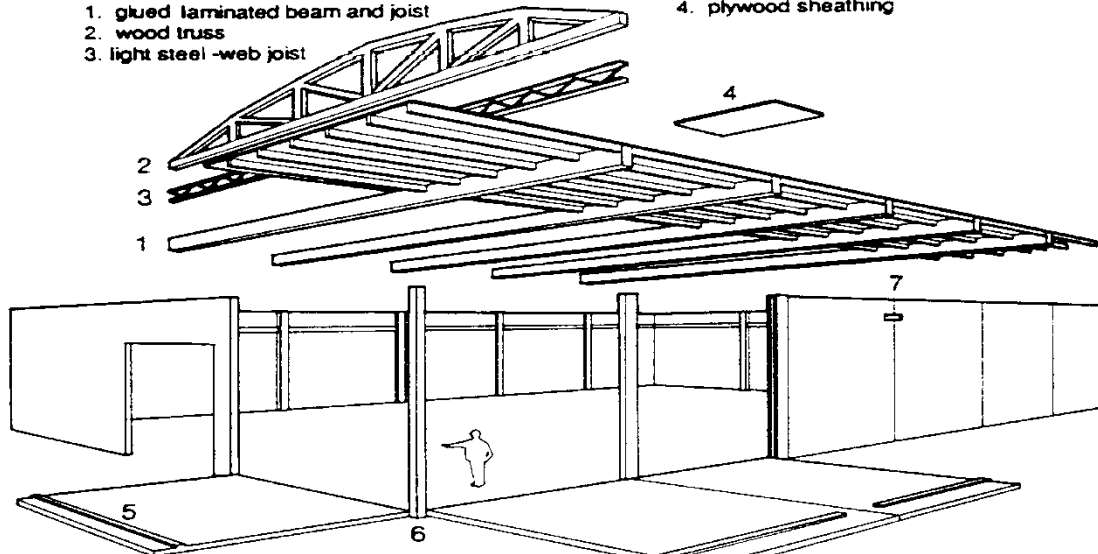
BF-12

Roof/floor span systems:

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

Roof/floor diaphragms:

4. plywood sheathing



**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.

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

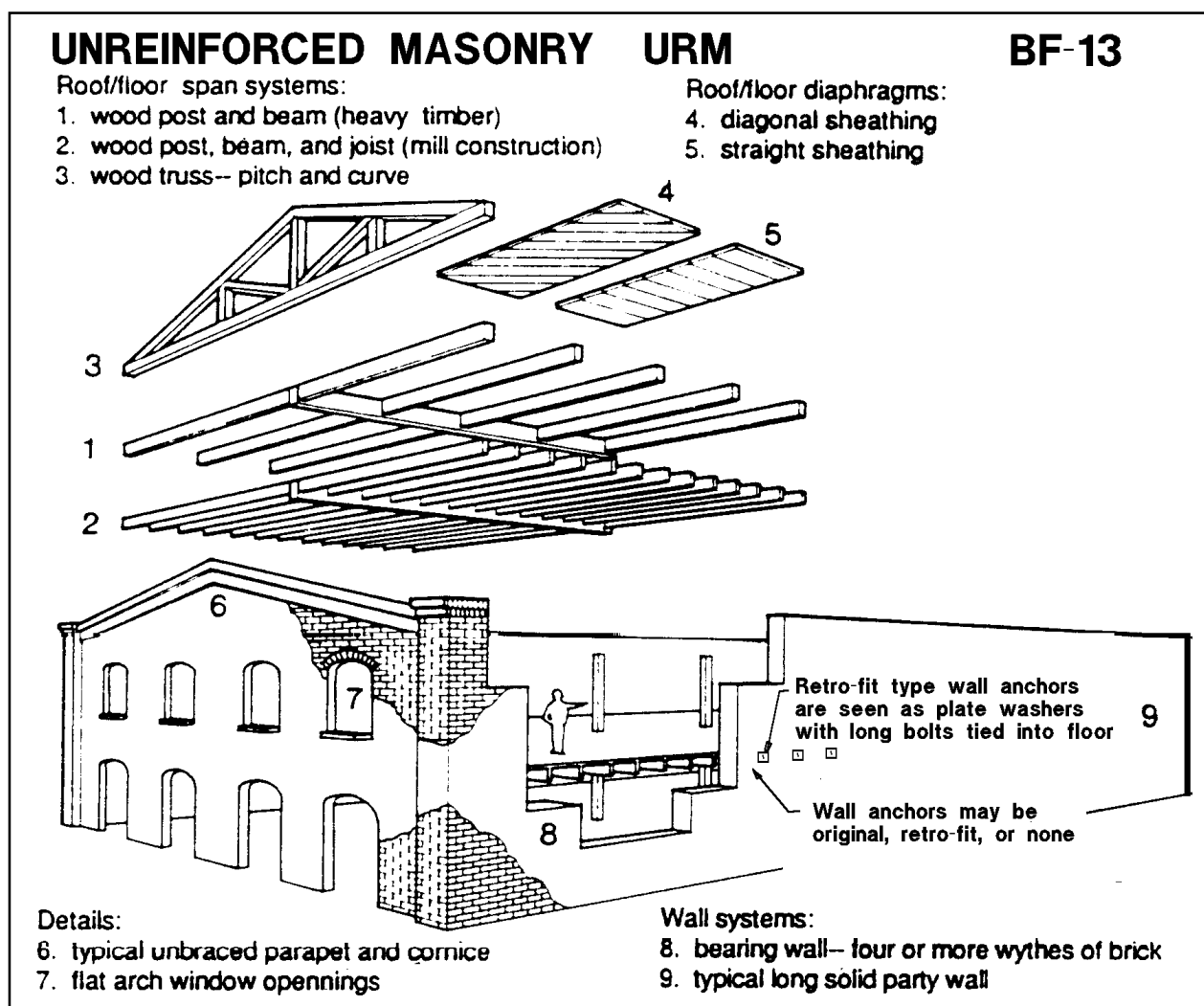


Unreinforced Masonry Buildings—URM

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 the earthquake has a long enough duration.
 - ♦ 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.

URM Type Characteristics

- **Bearing Wall System**
 - Heavy Wall Structure Unreinforced Masonry (includes unreinforced brick and CMU used for low-rise bldgs)
 - Older “red brick” with bond/header courses
 - Lack of strap anchors & ties (except Retrofit in CA)
- **Typical Occupancies**
 - Residential, commercial, and industrial
 - 1 to 8 stories
- **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.

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 opngs

Types of URM Buildings

- **UR or Under-reinforced Brick cavity walls.**
 - Insulation layer between masonry layers
 - May be used as infill or as bearing walls with bond beams.
- **Masonry veneer on wood/steel studs**
 - Anchorage is all important due to interaction of brittle wall covering on flexible structure.
- **Native stone, adobe, mud, etc. bearing wall buildings.**



IV. 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 an earthquake with a larger magnitude, the following can be said:

- The maximum intensity of the 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.

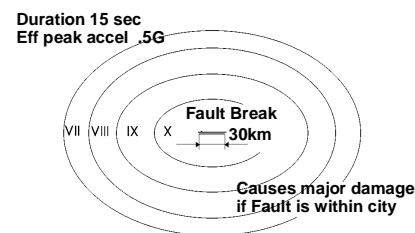
Terminal Objectives

- 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

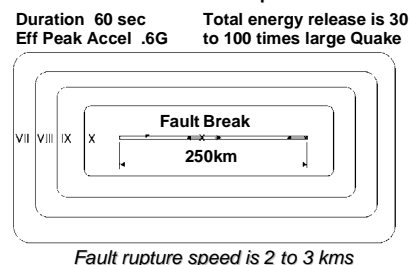
Earthquake Basics

- Extent of damage is determined by
 - type of shaking that occurs at site
 - coupled with the structures response
- Magnitude (energy release)
 - determines POTENTIAL number of effected structures
- Aftershocks
 - Earthquakes are unique type of Disaster
 - just keeps on giving

Plan of Large Earthquake - M 7



Plan of Great Earthquake M 8+





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).

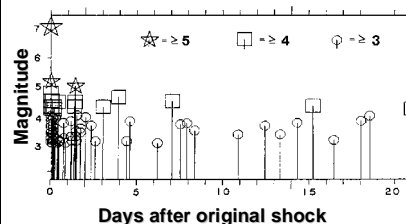
Aftershocks

- Smaller quakes that occur on same fault as original quake.
 - Minor fault adjustments
- Occur after most quakes regardless of size of original shock
- 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.

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

1989 Loma Prieta Aftershocks

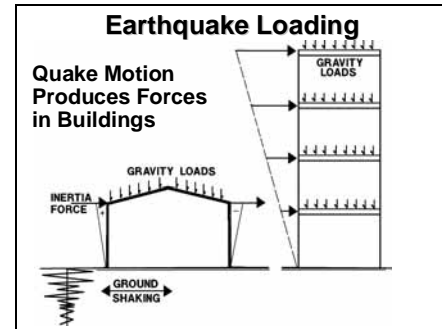




Basic Structural Loading

Earthquakes

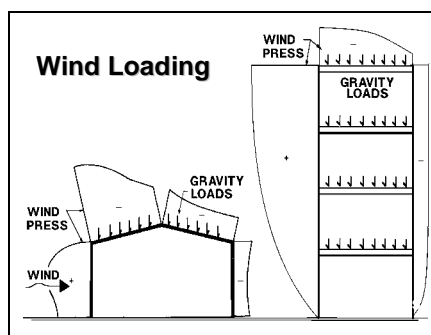
- Some of the most destructive effects caused by earthquake shaking are those that produce lateral loads in a structure. The input shaking causes the foundation of a building to oscillate along a more or less horizontal plane. The building mass has inertia and wants to remain where it is. Therefore, 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 Speed². 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 Speed²
 - 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 (floor diaphragms, 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 18th 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.

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)

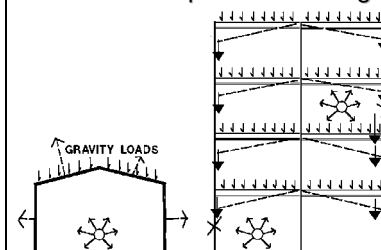
Explosion Basics

- 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

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 and 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

Interior Explosion Loading



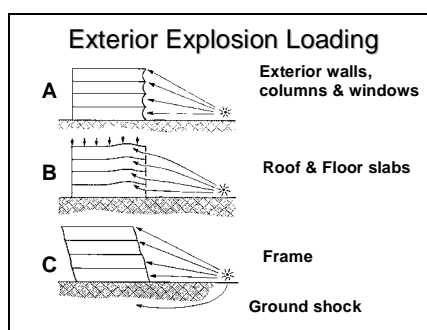
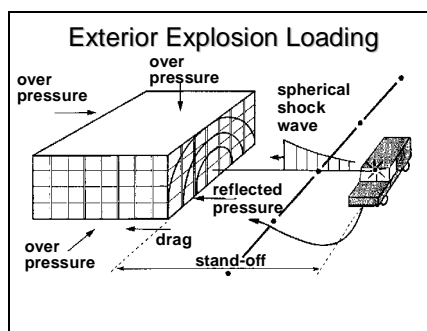


- In the case of an exterior explosion from a bomb, the shock wave is initially reflected and amplified by the building face and then penetrates through openings, subjecting floor and wall surfaces to great pressure.
 - ◆ Diffraction occurs as the shock propagates around corners, creating areas of amplification 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.

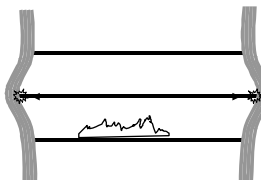


Fire Effects on Steel Structures

- Expansion
 - About 10" in 100ft from ambient to 1100°
- Loss of flexural rigidity
 - Significant above 800°
 - Both Yield Point & Stiffness are reduced
 - Deflected Floor is Warning Sign
- Significant loss of strength above 1000°
 - Strength OK up to approx 700°
 - Drops below Design Strength at 1100°
 - At 1000° both Stiffness and Strength are 50%

Effects of Fire – Expansion (10 " in 100 ft)

Can cause restrained connections to fail
Can destabilize columns





- **Loss of Structural Rigidity**

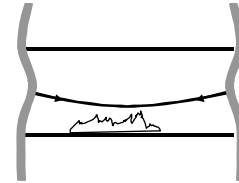
- ◆ Both the yield strength and modulus of elasticity of steel drop to about 75 percent of normal values when the temperature reaches 800° F. They drop at an increasing rate at greater temperatures.
- ◆ In fires, this drop results in the formation of “draped” or “bellied” beams and girders that generate 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 be able to avoid a deadly collapse.

- **Loss of Strength**

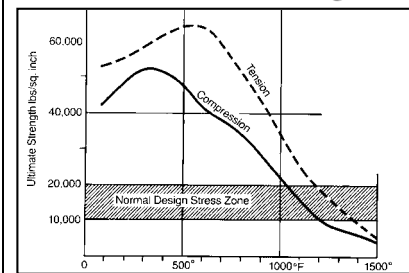
- ◆ Steel actually gains strength when the temperature is raised from ambient to about 700° F.
- ◆ For the normal structural steel used in buildings (A-36), both the strength and stiffness are reduced to about 50 percent at 1000° F.
- ◆ Steel drops below the “design” strength at about 1100° F, and failure 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.

Effects of Fire – Loss of Rigidity

Catenary forces can cause connections to fail and then destabilize columns
Deflected floor can warn of collapse

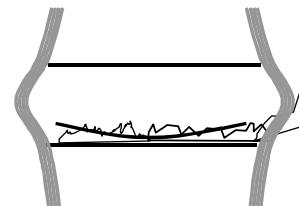


Heat Effects on Steel Strength



Effects of Fire – Strength Loss

Can lead to floor collapse and eventually collapse columns



Effects of Fire – Strength Loss

- Worst effects on Joist, Beams, & Girders
 - Heat Concentrates and is Trapped on Horizontal Surface
- Less effect on Columns
 - Usually have some Protective Covering
 - Columns are thicker members
 - Heat dissipates into Continuous Column Sections in Floors, Above & Below



- **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 with a loss of \$154 million.
 - 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.

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 4**
 - Lower Fire Protection Requirements
- **Type 5 - Wood or Lt. Metal frame**
 - May require 1 hour Exterior and Dividing Walls

Fire Effects on Steel Structures

- **Type 1 Steel Buildings**
 - Prior to 9/11 no Type 1, Fire Protected 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/warning requirements

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 5th floor.
 - ◆ Emergency generators and 275 gal fuel “day tanks” were placed on the 5th, 7th and 9th floors.
 - ◆ Pipes from a 6,000 gal tank on the 2nd 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).

Fire Effects on Steel Structures

- Unprotected Steel Building problems
 - Long span, low rise truss and bar joist structures had spectacular collapses
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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

Collapse of WTC - 7

- Potential Configuration Problems
 - WTC 7 built over Electrical Substation
 - Used 3 Transfer Trusses at 5th to 7th Fl Level
 - 6 locations of generators & 4- 275 gal fuel, “Day Tanks” - on 5th, 7th, 8th & 9th floors
 - Some Generators & Tanks were near Trans Trusses
 - Most day tanks were resupplied through pipes from one-6000 g tanks on 2nd fl & 36,000 g in four tanks under ground level loading dock
 - Fuel from tanks or broken pipes MAY have contributed to the fire – NO CONFIRMATION



- **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 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).

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

Fire Effects on Other Structures

- Type 3 & 5 Buildings with light wood trusses have been a deadly, sudden collapse problem
 - 34 Firefighters killed in 19 incidents - 1977 thru 1999
 - Prior to 9/11 were the most deadly building types
- Type 3 Bldgs – Conc/Masonry walls, wood roof
 - Burnout of wood roof/floors creates dangerous, unbraced heavy walls
- Type 5 over Type 1 Concrete Garage
 - Firestorm consumed Wood Apartment which caused Expansion Damage to RM Garage Shearwalls



- ◆ 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.

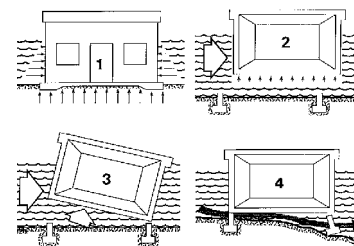
Flood – Storm Surge & Tsunami

- 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.

Fire Effects on Other Structures

- Type 3 & 5 Buildings with light wood trusses have been a deadly, sudden collapse problem
 - 34 Firefighters killed in 19 incidents - 1977 thru 1999
 - Prior to 9/11 were the most deadly building types
- Type 3 Bldgs – Conc/Masonry walls, wood roof
 - Burnout of wood roof/floors creates dangerous, unbraced heavy walls
- Type 5 over Type 1 Concrete Garage
 - Firestorm consumed Wood Apartment which caused Expansion Damage to RM Garage Shearwalls

Typical Flood Loading



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).

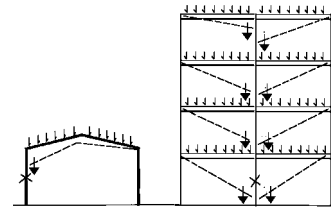
Vehicle Impact Loading

- 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.

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.

Construction Bracing, Overload



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

Key Learning Points

- Earthquakes will produce Aftershocks during US&R Operations – They require Planning
- Hurricanes produce destructive Winds & Tidal Surge
 - General Area Warnings can be given
 - Specific Target of Storm Center is difficult to predict
- Tornadoes produce very destructive Winds
 - Damage Band may be relatively narrow
- Blasts produce very Intense Pressures
 - They may be Localized and will Dissipate with Distance
- Fire Effects Structures in 3 ways
 - Expansion, Loss of Rigidity and Loss of Strength
- Floods Damage depends on how High and how Swiftly the Water Moves
- Construction Accidents and Vehicle Impacts occur due to Human Failures



V. 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 the gravity load is offset a distance that is large enough to overcome the shear capacity of walls at a particular level, usually on the 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**.

Terminal Objectives

- The Student will be able to recognize the Collapse Patterns that are unique to the common types of buildings when subjected to different types of extreme loading
- The Student will be able to use this knowledge to assist US&R in determining locations of Potential Victims

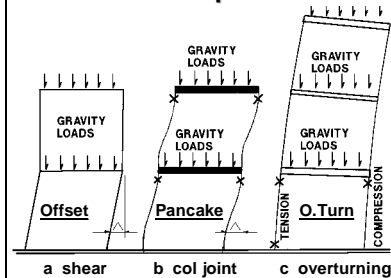
Enabling Objectives

the Student will understand the following:

- Basic Collapse Patterns
- Earthquake Collapse Patterns
- Windstorm Collapse Patterns
- Flood Damage Patterns
- Blast Collapse Patterns

Focus on Survivable Voids & Potential Victim Location

Basic Collapse Patterns





b. Inadequate Beam/Column Joint Strength

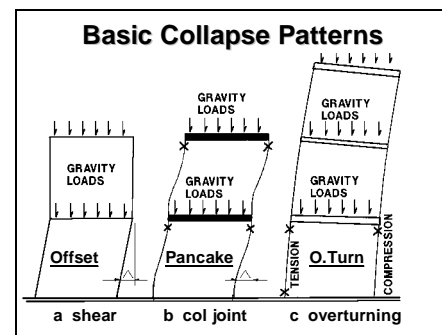
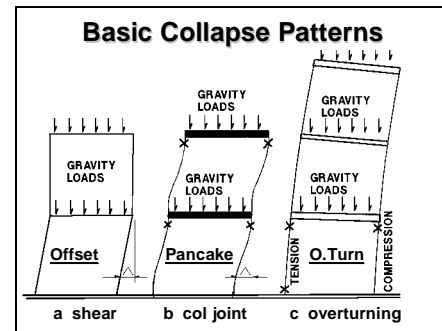
Inadequate beam or column joint strength failures are caused mostly by earthquake shaking of buildings that have joints with poorly confined concrete.

- 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

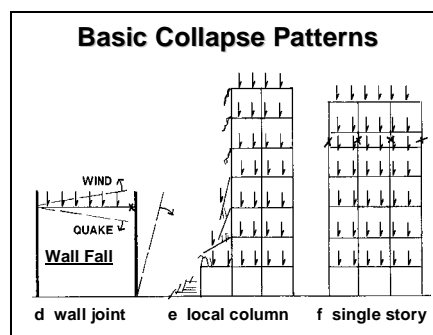
Single floor collapse has occurred in earthquakes due to pounding or vertical irregularities that focus the damaging effects on a single story.

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

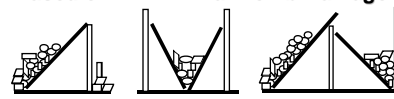
- Earthquake shaking causes damage to structure.
- Gravity causes collapse.
- Redundancy and ductile behavior can prevent or reduce the extent of a collapse.
- Brittle behavior enhances the possibility and increases the extent of a collapse.

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

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

BASIC PRINCIPLES

Earthquake Caused Collapse

- 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

Earthquake Survivability

Survival vs Time of Extrication

1 Hour	95 %
1 Day	80 %
2 Day	40 %
3 Day	33 %
4 Day	20 %
5 Day	7 %

Individuals have survived for as long as 14 days in confinement



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.

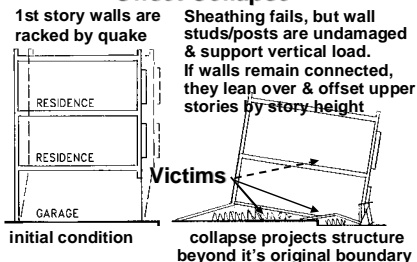
Light Frame Collapse Patterns

- 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.

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
- **Diag. Braced Steel Frame**
 - Overturn Collapse Pattern

Light Frame Collapse Pattern "Offset Collapse"





- 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 bldgs, 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 were not properly strengthened with 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

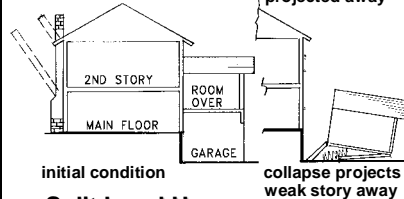
Mobile homes are a problem in quake and just about any disaster type. Base connections are usually critical. These are the common problems:

- 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

Lt. Frame, Offset Collapse Pattern

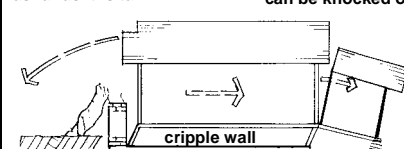
chimney breaks at roof or fire box
roof & floor over weak garage are projected away



Split Level House

Lt. Frame, Offset Collapse Pattern

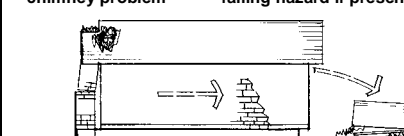
chimney can fall as far as it is tall
discontinuous roof can be knocked off



1 to 3 Story House with Cripple Wall

Lt. Frame, Offset Collapse Pattern

typical masonry chimney problem
brick veneer is typical falling hazard if present



1 to 3 Story House or Apartment

Mobile Homes & Manufactured Units Typical quake issue at base

- On Jack stands
- About 2 ft off ground
- Vulnerable to racking & utility connection issues

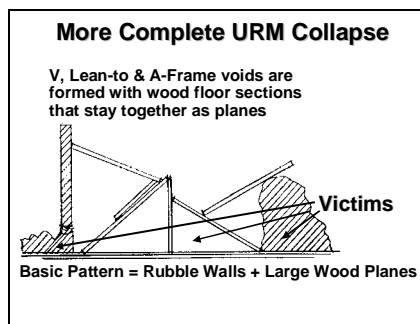
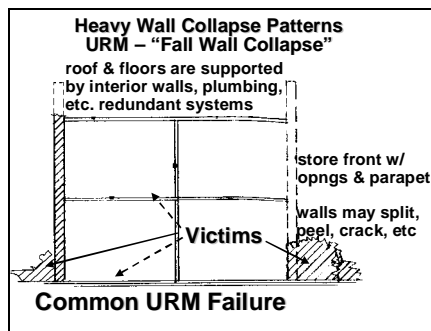
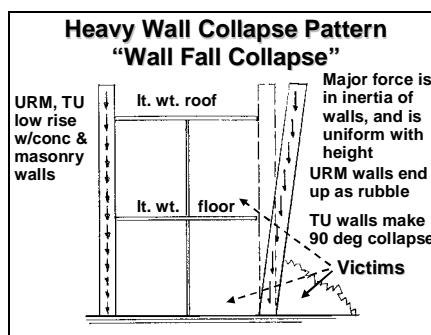


SCA 89



Heavy Wall Collapse Patterns URM

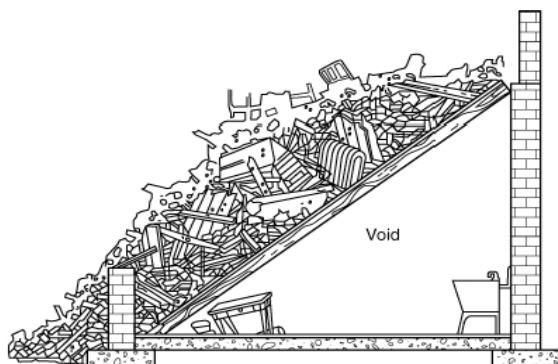
- Collapse is usually partial and is strongly related to the heavy, weak bearing walls falling away from the floors. This is the **Wall Fall Collapse Pattern**.
- In URM buildings, the walls normally fall away from their original position but most often do not project out as far as their height.
- The 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





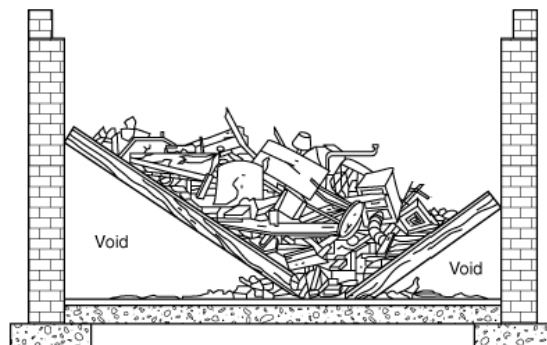
FIVE COLLAPSE PATTERNS DEFINED BY NFPA 1670

(taken from WW2 Civil Defense Publications)



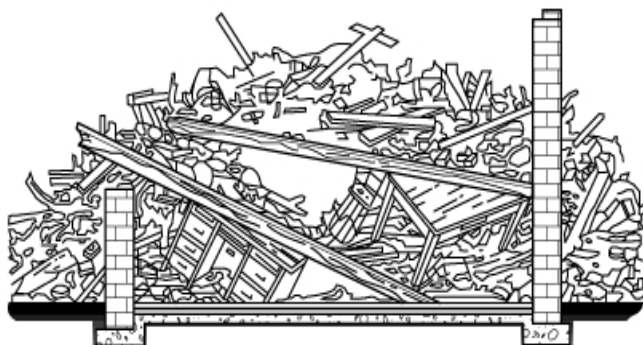
LEAN-TO

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



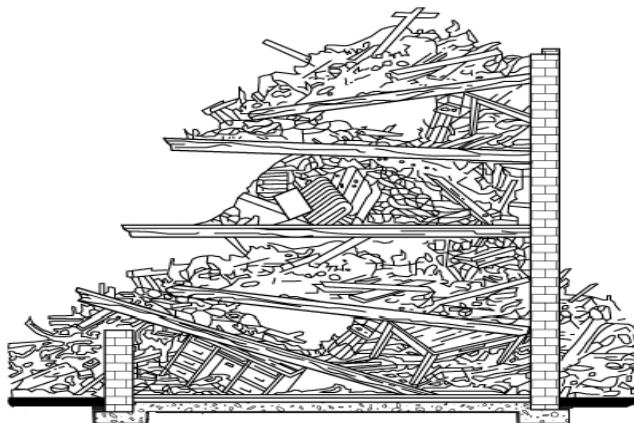
VEE

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



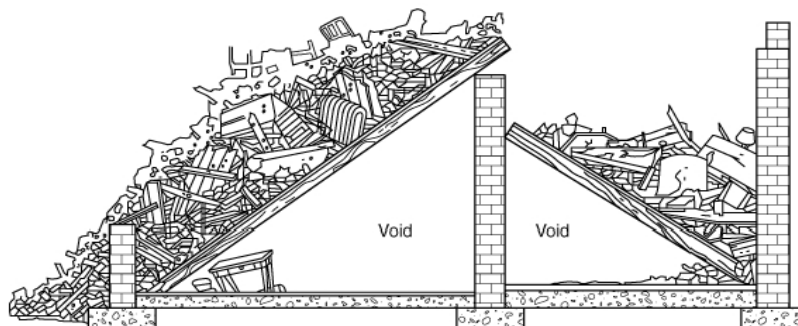
PANCAKE

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.

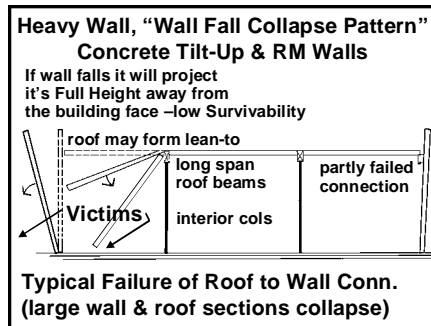
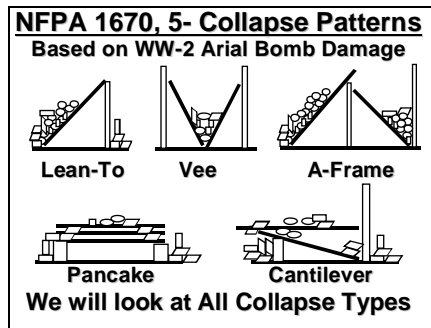
In this type of collapse, victims may also be trapped below the sloped floor at the shallow end. In this case access may be made by cutting through the floor. Unless it has been carefully evaluated by a Structures Specialist, the URM walls should not be breached

- 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

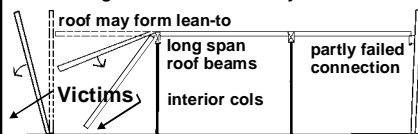
Heavy Floor Collapse Patterns

- 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

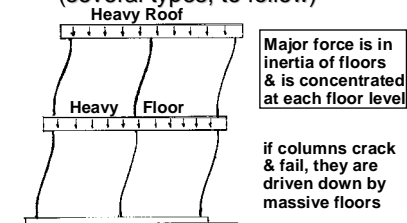
Heavy Wall, "Wall Fall Collapse Pattern" **Concrete Tilt-Up & RM Walls**

If wall falls it will project
 it's Full Height away from
 the building face –low Survivability



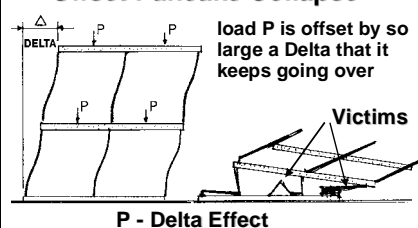
Typical Failure of Roof to Wall Conn.
 (large wall & roof sections collapse)

Heavy Floor Collapse Patterns (several types, to follow)



Types C1, C3, & Highway Bridges

Heavy Floor Collapse Patterns **"Offset Pancake Collapse"**



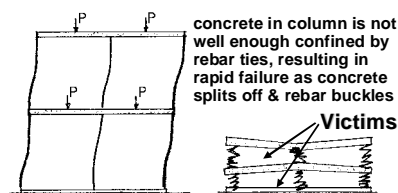


Heavy Floor Collapse Patterns (continued)

- 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
- **Overtured 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.

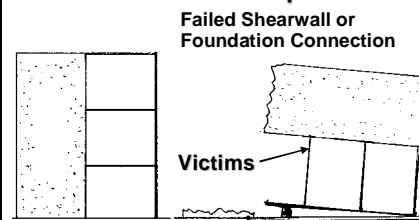
The victims in the upper stories may have been thrown about and injured, but they can be easily accessed using ladders, man lifts, etc. There were many collapses of this type following the Taiwan Earthquake in 1999, and most of the occupants survived

Heavy Floor Collapse Patterns "Pancake Collapse"



Caused by Column Joint Failure

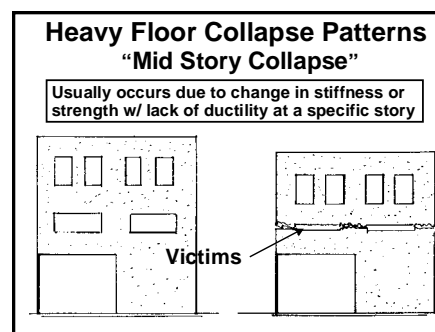
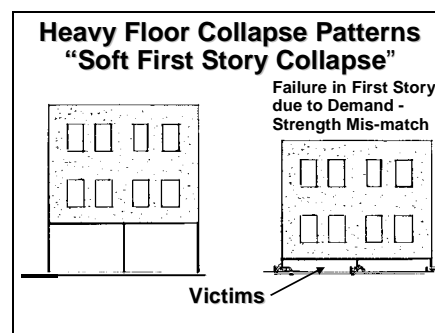
Heavy Floor Collapse Patterns "Overtured Collapse"





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

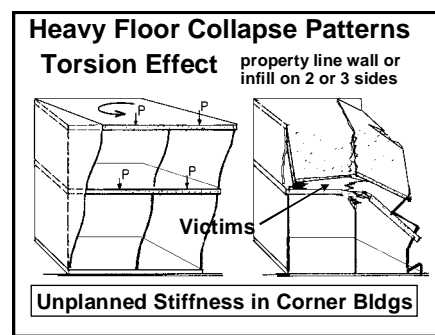
- **Torsion effects** occur in concrete frame structures when URM infill is placed within the concrete frames on the exterior property line walls for fire resistance. This occurs in corner buildings, where the street-side concrete frames have only light-transparent, infill – “Open Sides”

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



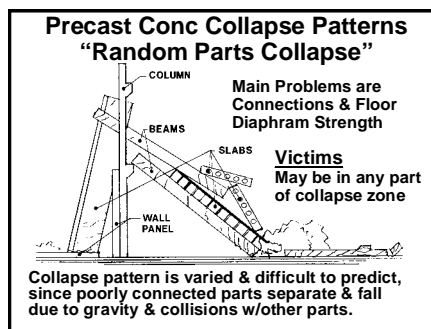
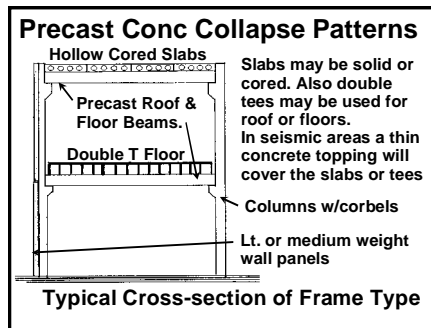


Pre-Cast Concrete Collapse Patterns

- 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





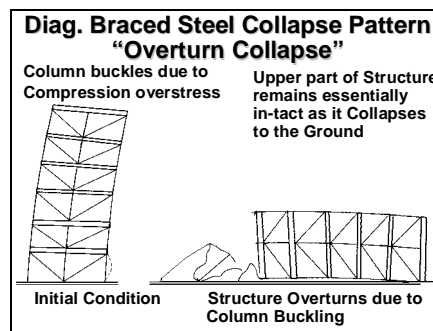
Steel Frame Collapse Patterns

- 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.

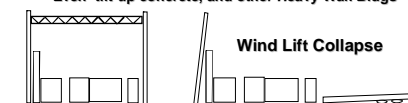
- They normally affect light, poorly, or non-engineered structures and generate both static and dynamic pressures on exterior surfaces and impact forces from missiles/debris.
- High winds can peel off light roof/canopies, and any type of “Open” structure is very vulnerable.
- Well-engineered structures 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”.

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

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





- Tornados, with winds above 200 MPH, can damage all but the most well engineered and well constructed buildings.
 - ♦ The most destructive tornados have lifted as large of structures as Train Locomotives.
 - ♦ Light structures are extremely vulnerable to the lifting forces generated by tornados.
 - ♦ 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.

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

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



- 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.

Problematic Special Buildings

- **Aircraft Hangers**
 - very high winds lifted roof which released top attachment of large sliding doors
 - aircraft inside were destroyed by swinging or falling doors
- **Large, Long Span Structures**
 - under engineered Precast Concrete

Hurricane -Storm Surge Damage 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**

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
- 1st & 2nd 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

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

Basic Explosion Effects

- Large pressures exerted by explosions
 - Short Duration - only Milliseconds
 - Rapidly dissipates with distance
- Severe damage to structures
 - Effects surfaces in all 6 directions
- Effects of fast moving shock wave
 - May be very complex
 - Lift from Inside then Push Down from Outside
 - Pull-out Walls then Push them IN

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

Less Survivable Voids & Blast Effects



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

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”

Blast Effects on S3 Buildings

- Wall & roof panels are easily blown away. and steel framing may be pushed over
- Blast at Explosives Manufacturing Plant near Reno NV, 1998.
 - First explosion was in primer mixing room
 - Set off 2nd blast and completely disintegrated structures.
 - Miraculously 12 of 16 workers escaped



Explosion Effects on Specific Buildings (continued)

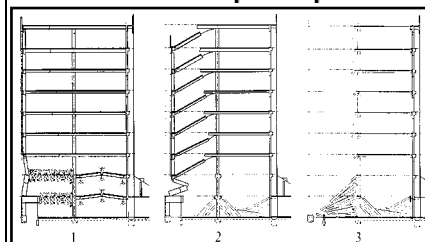
- **Concrete frames – C1, C2, and C3:** The lift pressures have had devastating effects on concrete slabs in gravity-type designs.
- One-way slabs hinge up because of the lack of top reinforcing at mid-span and continuity splices in bottom bars at supports.
- A critical location for flat slabs occurs 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 elicitor 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

**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



**Probable Collapse Sequence
“Lift and Drop Collapse”**



**Example of Blast Survivability
Oklahoma City Example**

- 359 people were in the building when the bomb was detonated
 - 517 persons were injured, Total in area
 - 169 individuals were killed, including 19 children & 1 volunteer nurse
- Final live person (15 y.o.) was found at 1700hrs and removed by 2030hrs on Day 1
 - Many were accessible by remaining stairs or aerial ladder
- Almost all of the deceased victims were within the collapse zone
 - 6 were in adjacent buildings, 1 in street



Explosion Effects on Specific Buildings (continued)

- 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.

Blast Effects on PC2 Buildings

- **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 dis-continuous members.
- **PC2 - Box type structures**
 - pressures can dislodge walls & slabs
 - break/damage many connections
 - better response in multi wall buildings

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 |



- **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

Blast Effects on Buildings

- Postensioned 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 effected. Lifted roof and blown out ,farside walls

Blast compared to very short term - high velocity wind w/special effects

Blast Effects on Buildings

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Blast compared to very short term - high velocity wind w/special effects



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.

Key Learning Points

- Extreme Loading has Predictable Effects on Different Types of Structures
 - Specific Collapse Patterns are created
- The StS must be able to recall this knowledge when assessing distressed structures
 - Ductility and Redundancy are very important
 - Secondary collapse/movement must be anticipated
 - Potential location of victims and Survivable Voids must be recognized
- The survival of Victims and Fellow TF members may depend on our Judgment

Enabling Objectives the Student will understand the following:

- Basic Collapse Patterns
- Earthquake Collapse Patterns
- Windstorm Collapse Patterns
- Flood Damage Patterns
- Blast Collapse Patterns

Focus on Survivable Voids & Potential Victim Location



VI. Hazard Identification and Introduction to 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.

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

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

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

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



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.

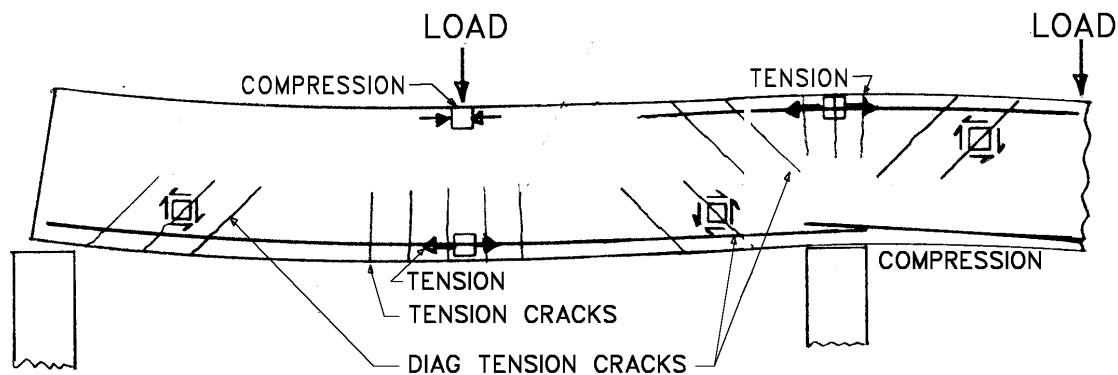
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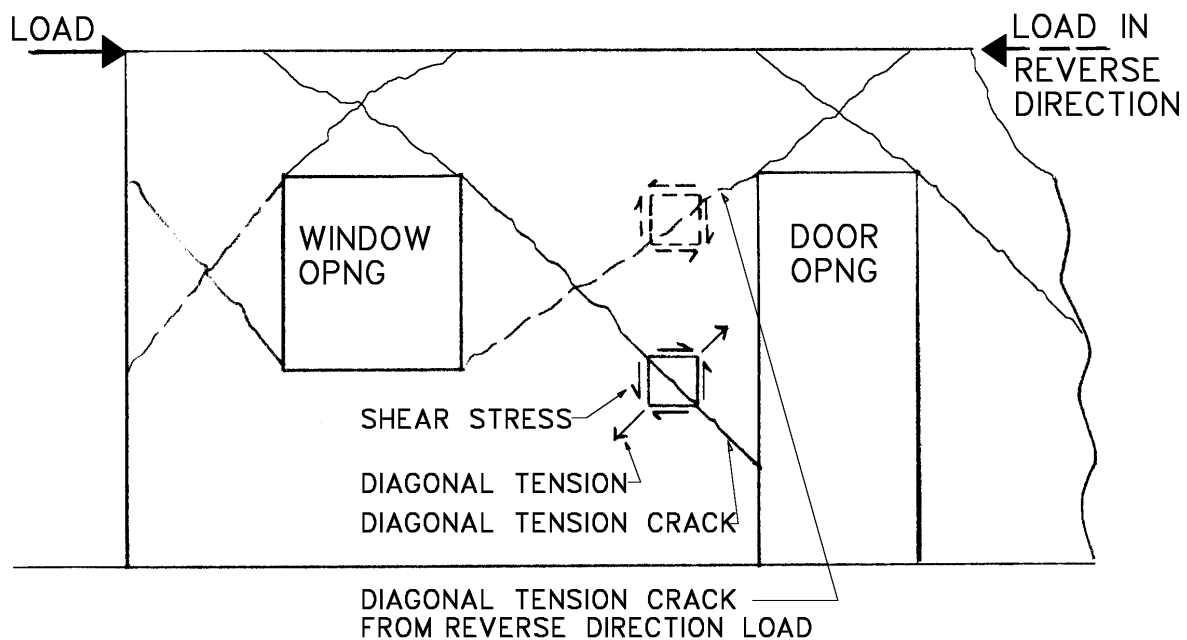


DIAGONAL TENSION CRACKS

HAZ-DTEN



CONCRETE BEAM



CONCRETE SHEARWALL



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

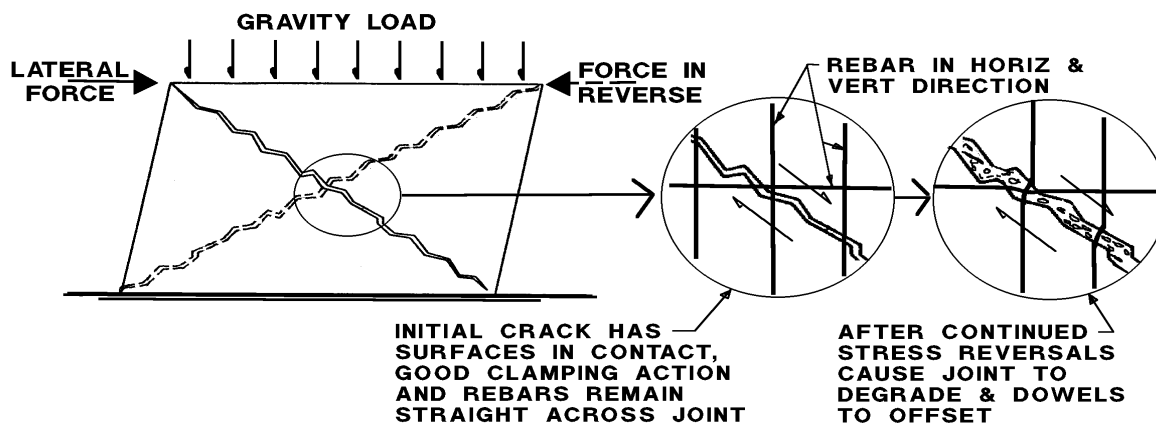
- Shrinkage, temperature, and diagonal tension/shear wall cracks occur in URM walls as well as unreinforced concrete walls. In these walls, however, cracking indicates a significantly degraded structure.
- Diagonal tension cracks form in these walls between openings, as they do in reinforced concrete 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.



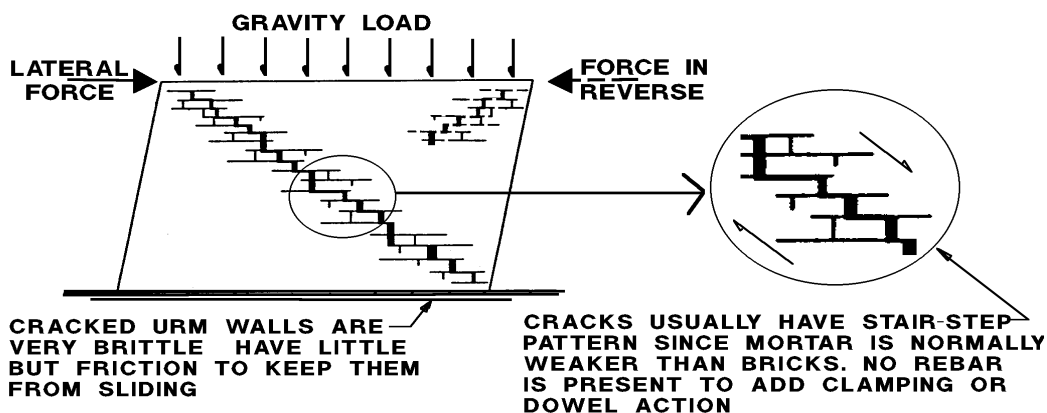
- **Masonry walls** with significant diagonal tension cracks must be considered capable of a sudden, brittle failure. Some clamping force on the horizontal steps of the cracks exists due to the gravity force, but no vertical bars exist to add clamping or dowel action. The greater smoothness of the joints 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

- **Hazard Types**
 - Falling Hazards – heavy objects that fall
 - Collapse Hazards – voids are reduced
 - Other Hazards – mostly health hazards
- **Basis of making judgments**
 - Partially collapses are most unpredictable.
 - Remaining Potential Energy.
 - High impact collapse expends most energy.
 - Much energy is absorbed as collapse stops.

Identification Problems

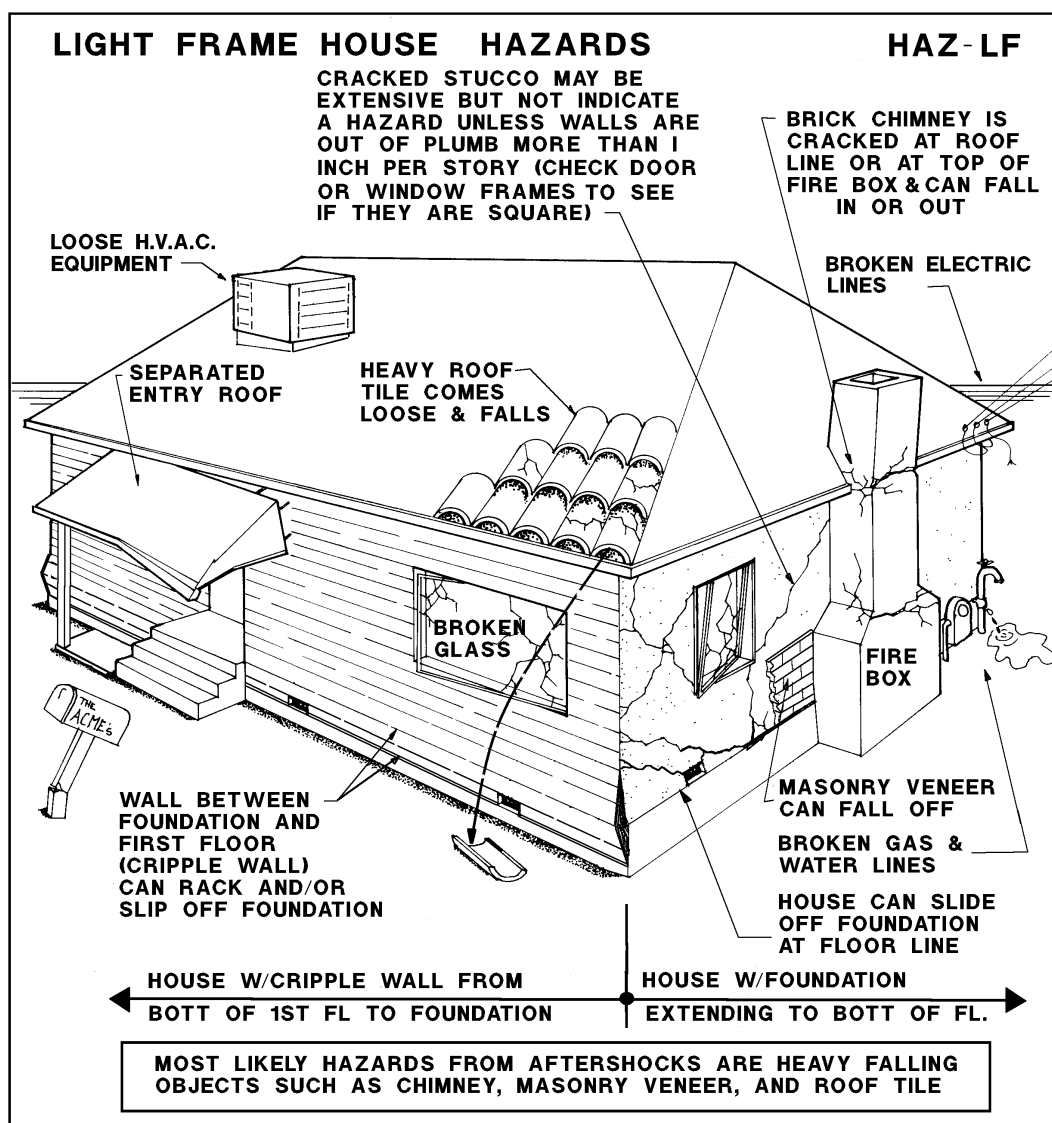
- Judgments cannot be precise.
 - What is chance of secondary collapse?
- Collapsed Structure has “Come to Rest”.
 - But it is weaker and less organized.
 - Heavy, brittle parts still have potential energy.
- Aftershocks, high winds, etc will add additional lateral forces.
 - Identify most susceptible part of remaining structure.
 - All types of buildings have collapsed in aftershocks.
- See SOG (or StS FOG), Sect 1 (& following slides)
 - Lists of typical issues for various building types.



Light Frame Building Hazards

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

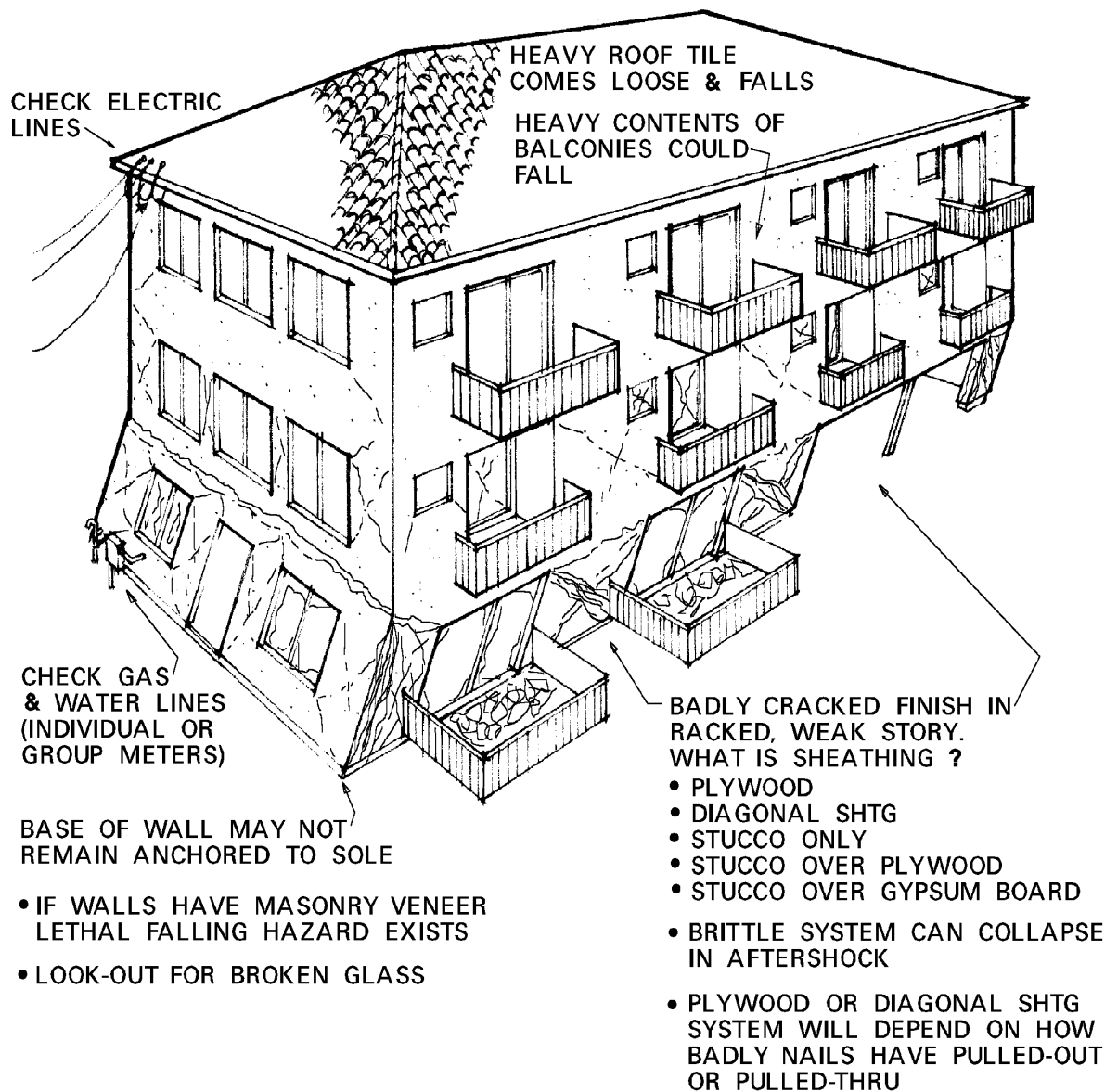
- **Check Points: (HAZ-LF):**
 - ◆ Badly cracked or leaning walls;
 - ◆ Offset residence from foundation;
 - ◆ Leaning first story in multi-story buildings;
 - ◆ Cracked, leaning masonry chimney or veneer;
 - ◆ Separated porches, split level floors/roof.





- 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

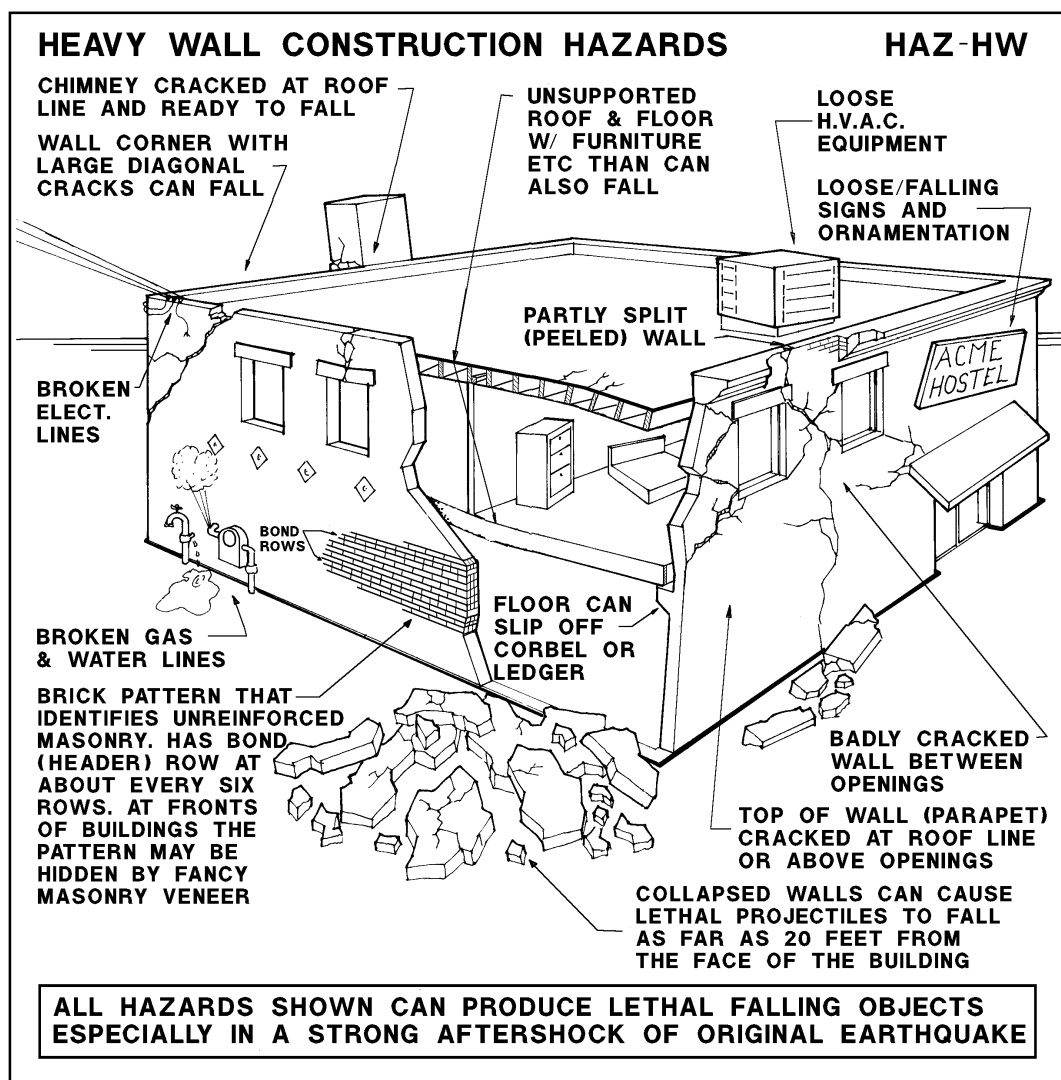




Heavy Wall Building Hazards

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.

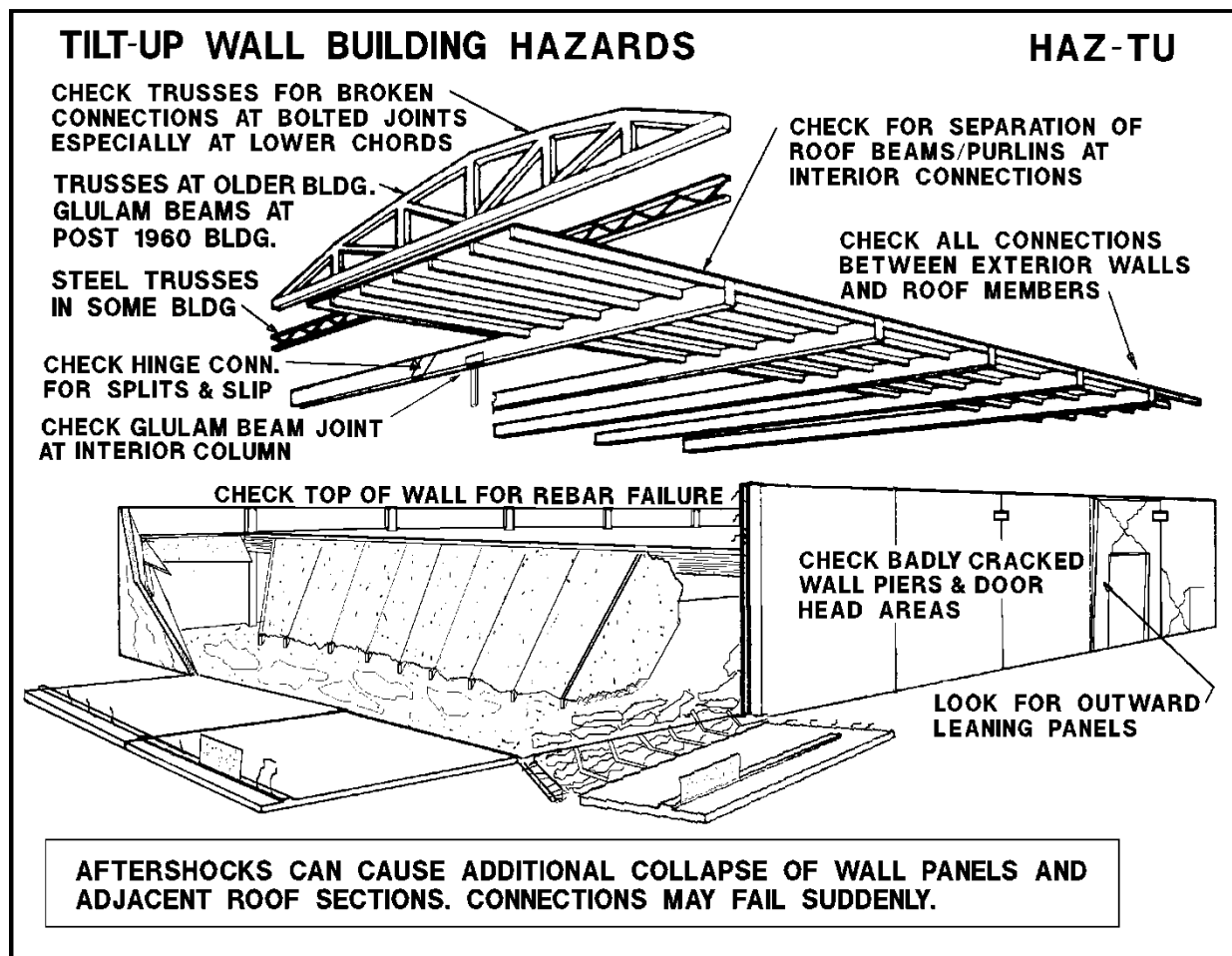




Heavy Wall Building Hazards – Tilt-Up

(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;
 - ◆ Hinge connectors at cantilevered glulam beams.
 - ◆ Cracks in wood at bolted joints of trusses, especially at lower chords.
 - ◆ Badly cracked walls and/or columns.
 - ◆ Out-leaning wall panels.
 - ◆ Rebar tension failure at tops of walls, especially at joints.
- 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.

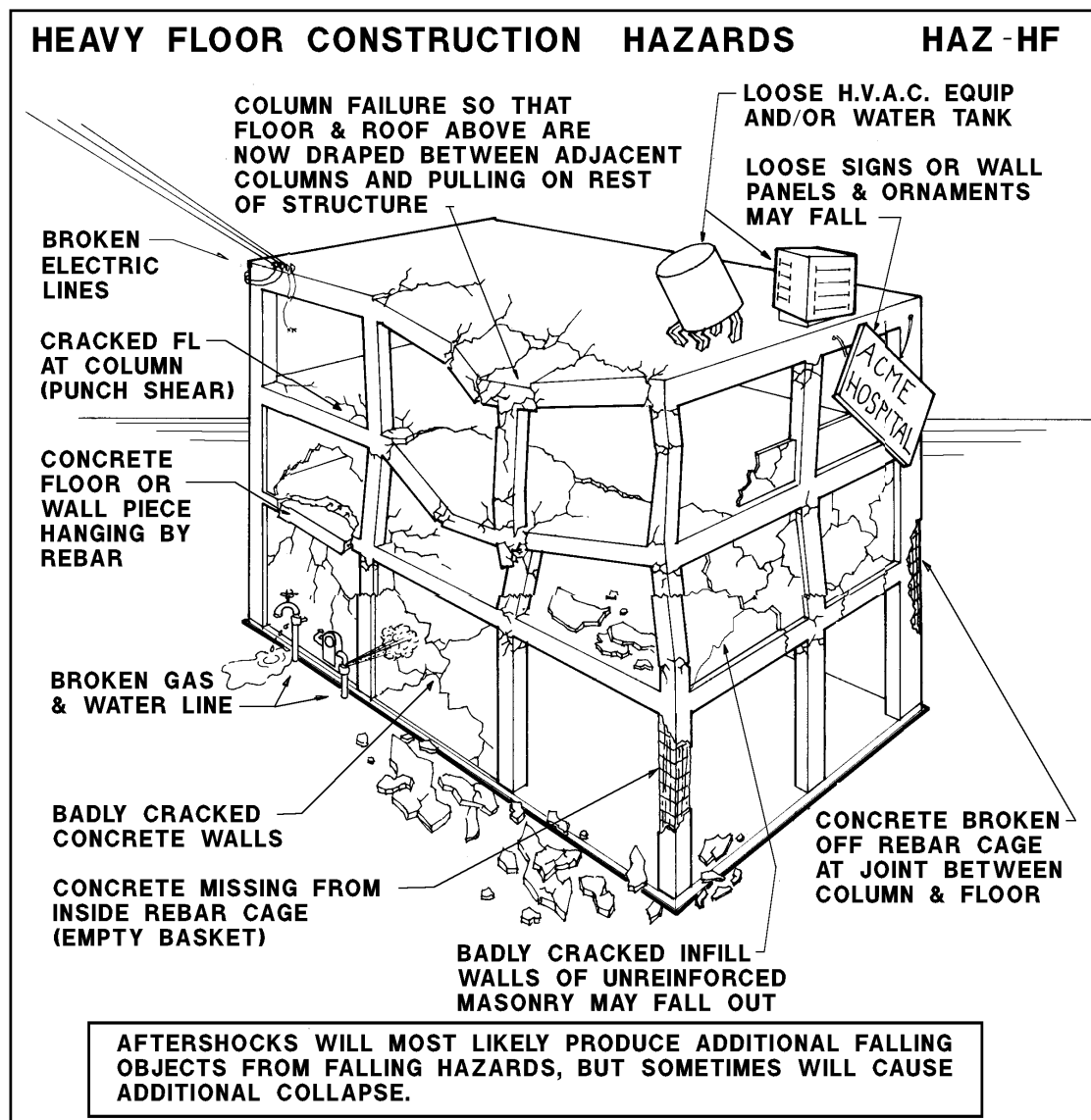




Heavy Floor Building Hazards – Concrete Frames

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 major 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.

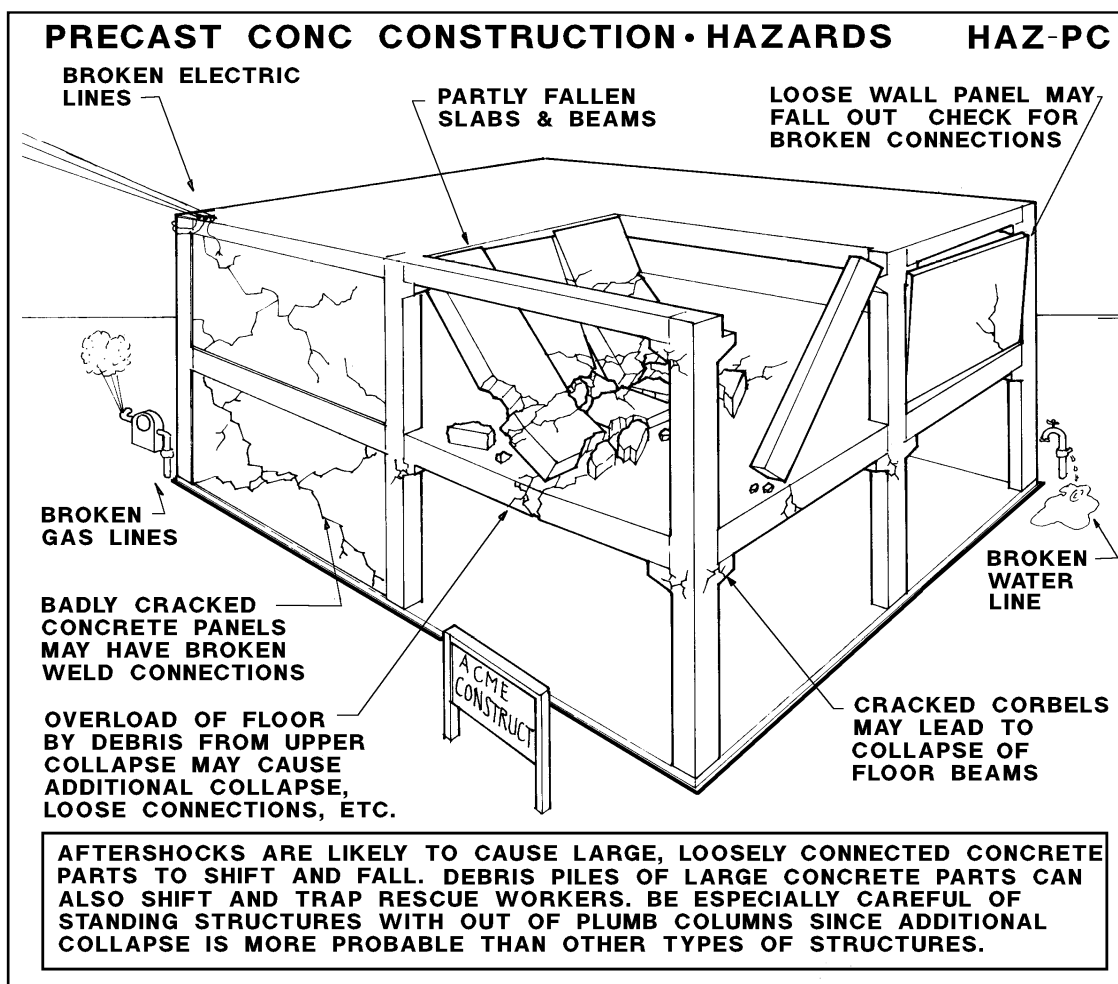




Pre-Cast Building Hazards

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.

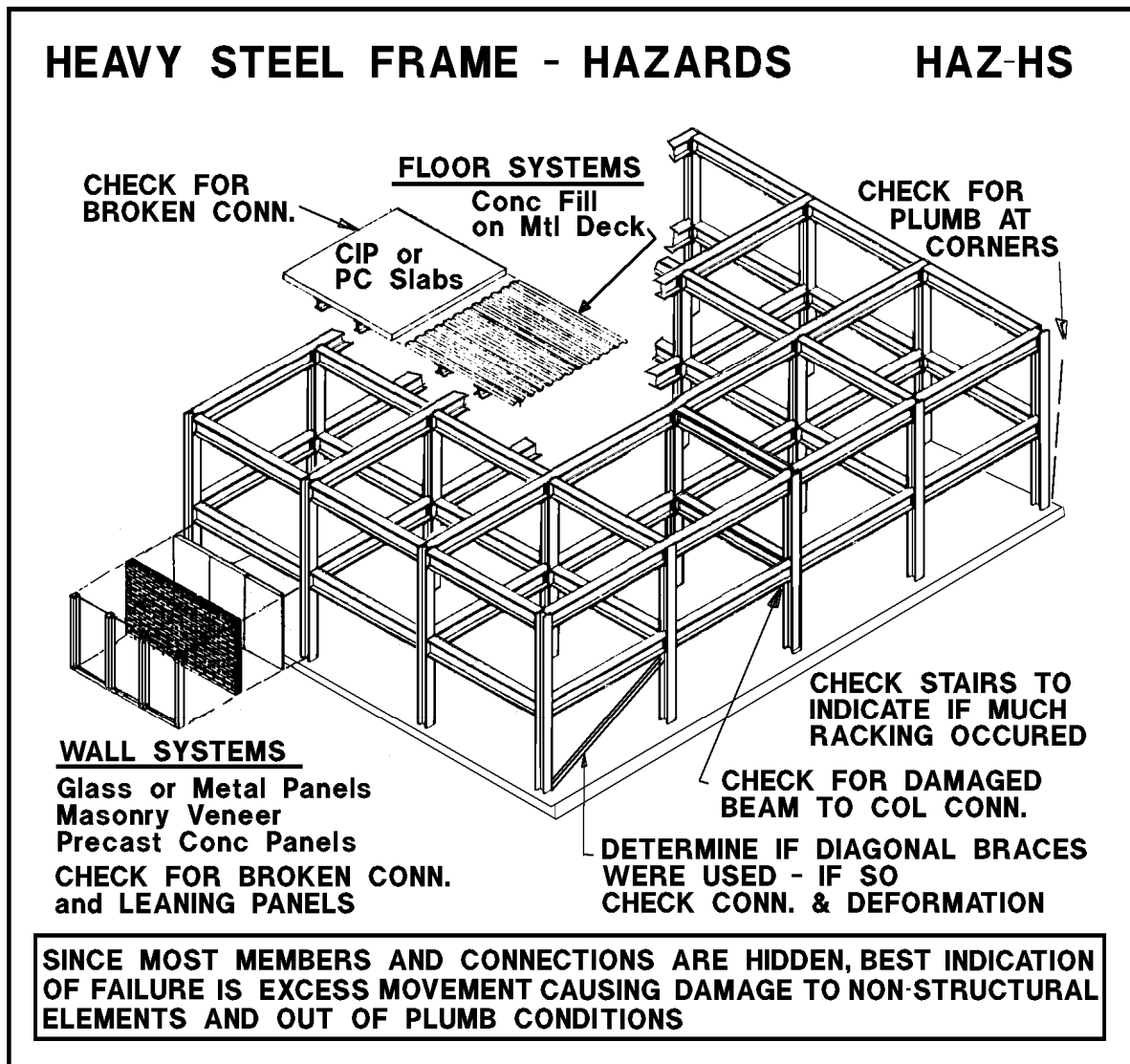




HEAVY STEEL FRAME BUILDING HAZARDS

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.





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

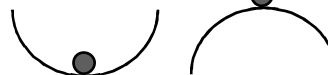
The problems of identifying hazards after a structural collapse are extremely difficult.

- 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

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”

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



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.
- The first question should be “do we need to be in this area at all?”
- Hazard avoidance is the preferred option.
- What are the global versus local hazards?
- **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 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?
- Check for potential instabilities: building stability and rubble stability.
- What caused the collapse?
- 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?
- Before changing the existing configuration, evaluate the effect of the change on the load paths.

Intro to Hazard Assessment

- Applies to building structural systems and individual void systems
- First question should be
 - Do we need to be in this area at all?
- Hazard avoidance is the preferred option
- Local vs global hazards

Hazard Assessment – cont.

- 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

Hazard Assessment – cont.

- What caused the collapse?
- Has structure collapsed to a stable condition?
- What if there is an aftershock - what is the plan? (Safe haven areas / escape routes)
- Visualize what could happen during an aftershock or wind gust
- **Before** changing the existing configuration evaluate the effect on the load path



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***



- **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.

Other Hazard Mitigation

- **Vertical & Lateral Shoring**
 - system with slow failure mode
- **Lateral Bracing**
- **Lateral Tieback**
 - when shoring isn't practical
- **Vertical Tieback**
 - use crane to hang structure
- **Monitor - with alarm & escape system**
- **Recognize & Refer Hazard (hazmat)**

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
- **Hazard Assessment and Mitigation are important tasks that are performed by the Structures Specialist – we have introduced the basic concepts**



VII. FEMA US&R Marking System

In this section we will discuss the following topics that involve structure marking and location:

- Identification of Individual Buildings,
- Structural/Hazard Evaluation and Marking,
- Search and Rescue Assessment Marking,
- Example of Search Assessment & Victim Marking,
- Disaster Site Audio Signaling/Alerting.

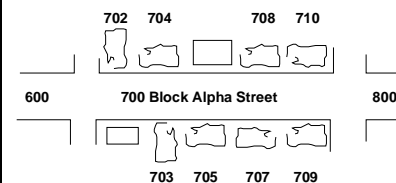
These are important communication methods that are used to designate what operations have been performed. It is extremely important that these standards be followed, so that critical information can be shared with all responders that may be working the same incident. Standard nomenclature is critical for efficient US&R operations.

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.

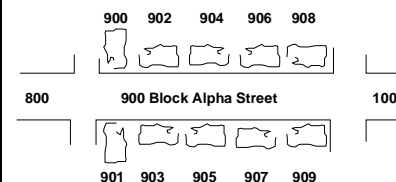
I. D. by Street & Number

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



I. D. by Street & Number

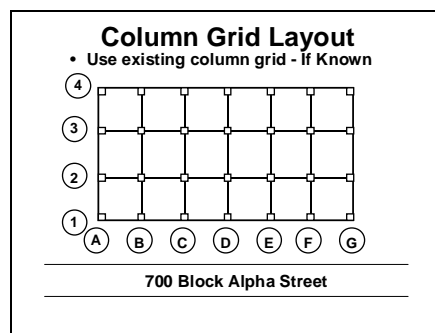
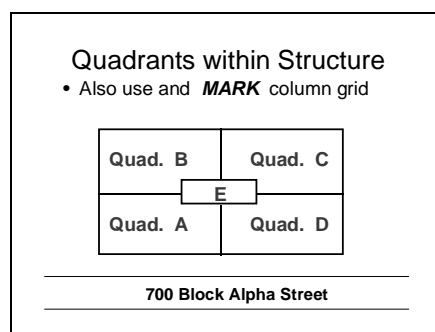
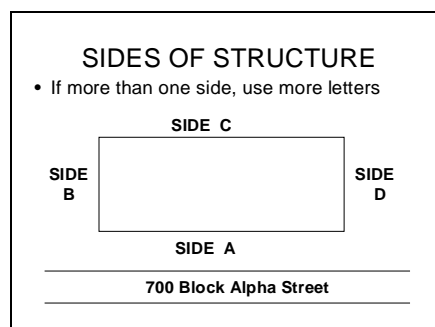
- Case 2 - No numbers known, use low no's





- 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 1st (or ground floor) is and whether there are any basements.
 - ◆ Basements are designated as B1, B2, and B3.
- 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.






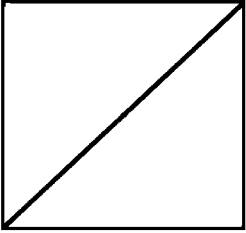
- ◆ It is more helpful to mark an appropriate number on each column for structures with a regular (or irregular) layout.
- ◆ Column numbers should be large enough to be read from a distance (such as by a crane operator).
- ◆ Use existing column numbers if known.
- ◆ If designation is unknown, best to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





Structure/Hazard Evaluation and Marking

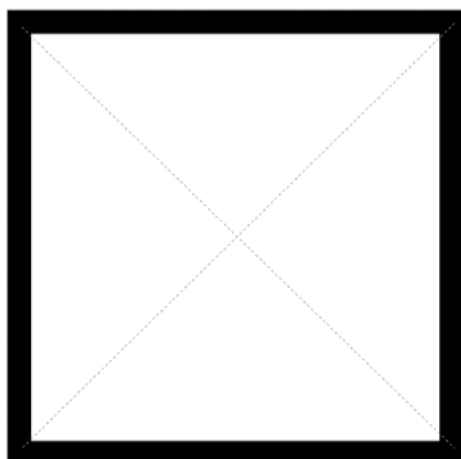
Structural/hazard evaluation should take place after a priority list of structures has been established by the leadership using Rapid Structure Triage (RST) or just common sense if only a few structures are involved. The Structure/Hazards Evaluation form is intended to facilitate this process, and has, deliberately, been made different from the ATC-20 "Safety Assessment" placards and forms. It is assumed that the US&R task force will be dealing with buildings that have or would have received a red tag (using ATC-20). 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 Forms, identifying structure type, occupancy, hazards, etc. In addition, the Structures Specialist will generate notes and diagrams regarding search operations (locations of voids, shafts, shoring, etc.). However, in some cases, the assessment will indicate that the building is too dangerous to safely conduct US&R operations until time-consuming mitigation is completed.

TASK FORCE BUILDING MARKING SYSTEM	
STRUCTURE/HAZARDS EVALUATION UHR-4 08	
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:	
	LOW RISK 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)
	MODERATE RISK 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.
	HIGH RISK 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.
HM	INDICATES HAZMAT CONDITION IN OR ADJACENT TO STRUCTURE. S&R OPERATIONS NORMALLY WILL NOT BE ALLOWED UNTIL CONDITION IS BETTER DEFINED OR ELIMINATED.
	<div><div>15JUL92 1310 HRS HM - NATURAL GAS OR-1 (DO NOT ENTER BUILDING UNTIL GAS IS TURNED OFF)</div></div>

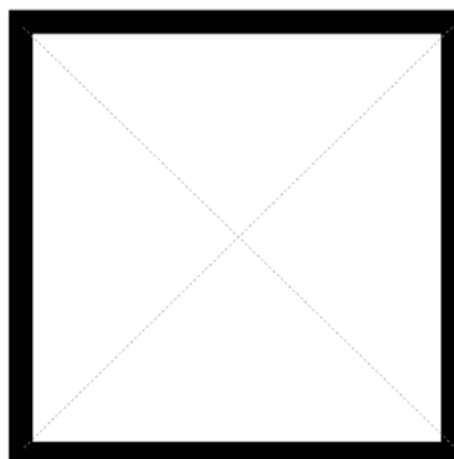


Structure/Hazard Evaluation and Marking (continued)

- As noted the three different marks (Open Box, Single Diagonal, and Cross) indicate the level of risk, and are consistent with the terms used during the RST Process. For a large, multi-structure incident, this detailed assessment would most likely be completed by a Structures and Hazmat Spec assigned to the Search Team (as they are starting search operations). The Structures and Hazmat Spec. that are part of the Rapid Structure Triage (RST) Team(s) would, initially, only have time to complete the RST Forms, and a rapid assessment. However, it is strongly suggested that the StS attached to the SearchTeam, perform an independent analysis and not be overly influenced by the RST Ratings
- The Structure/Hazard Evaluation Marking is then placed on the building near each entry.
- As an alternate to marking the structure with paint or crayon, a paper or cardboard placard may be used. The Structure/Hazards Mark Placard is illustrated below and is intended to be in 5.5" x 8.5" (portrait) format , and made, 2 per sheet, with black ink on white paper (Stick-on, Rite-in-Rain, or light cardboard).



Structural / Hazard Evaluation		
DATE	TIME	TF
HAZARDS:		
<p>Low Risk for US&R Ops. Low probability of further collapse. Victims could be trapped by contents, or building could be completely pancaked or soft 1st story</p> <p>LR</p>	<p>Medium Risk for US&R Ops. Structure is significantly damaged. May need shoring, bracing, removal, and/or monitoring of hazards. The structure may be partly collapsed.</p> <p>MR</p>	<p>High Risk for US&R Ops. May be subject to sudden collapse. Remote search operations may proceed at significant risk. If Rescue Ops are undertaken, significant and time-consuming mitigation should be done</p> <p>XR</p>
Should the marking box need to be made remote from the indicated entrance, place an arrow next to the box to indicate the direction to the lowest risk entrance to structure.		



Structural / Hazard Evaluation		
DATE	TIME	TF
HAZARDS:		
<p>Low Risk for US&R Ops. Low probability of further collapse. Victims could be trapped by contents, or building could be completely pancaked or soft 1st story</p> <p>LR</p>	<p>Medium Risk for US&R Ops. Structure is significantly damaged. May need shoring, bracing, removal, and/or monitoring of hazards. The structure may be partly collapsed.</p> <p>MR</p>	<p>High Risk for US&R Ops. May be subject to sudden collapse. Remote search operations may proceed at significant risk. If Rescue Ops are undertaken, significant and time-consuming mitigation should be done</p> <p>XR</p>
Should the marking box need to be made remote from the indicated entrance, place an arrow next to the box to indicate the direction to the lowest risk entrance to structure.		



FEMA

National Urban Search and Rescue Response System

Structure Collapse Awareness Training

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:

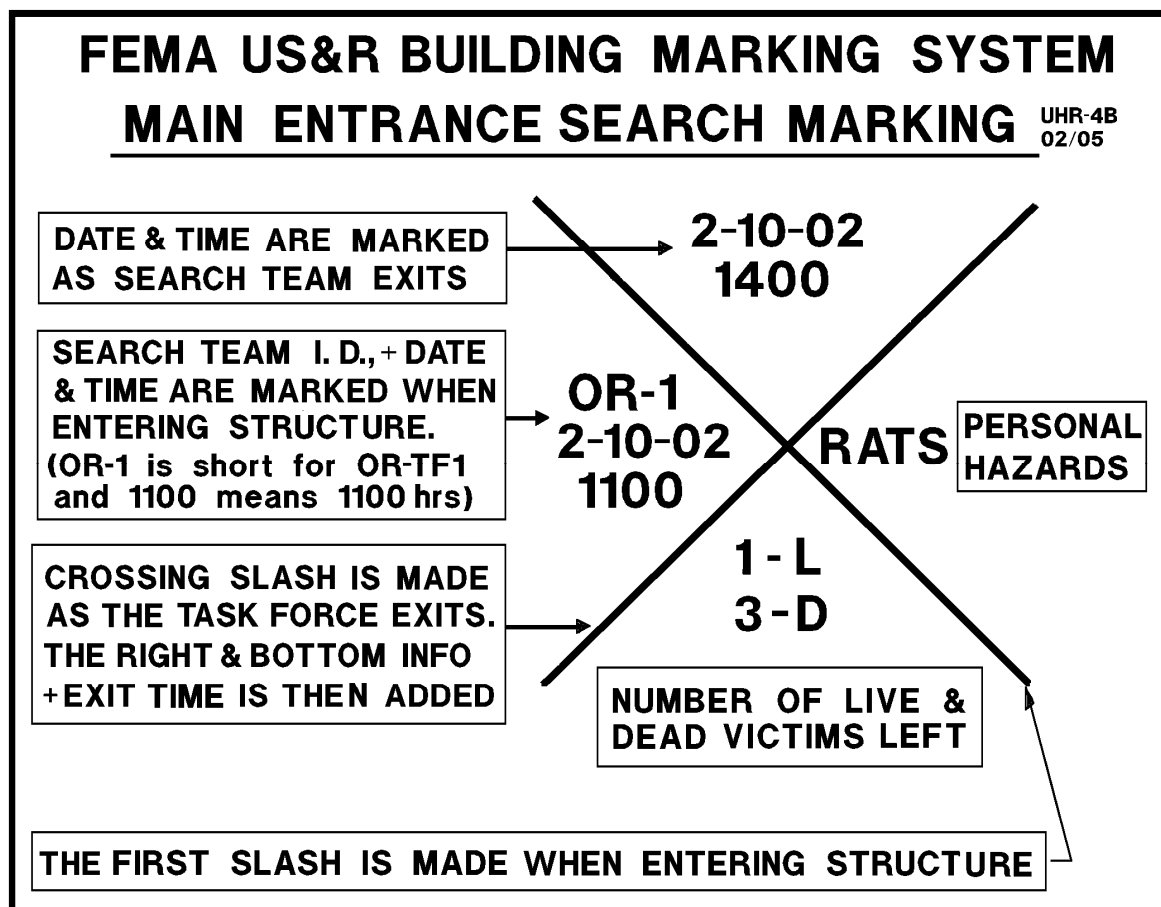
US&R STRUCTURE / HAZARDS EVALUATION FORM - HAZ-1		BY: _____
<small>Where required, circle all the information or items that apply. NOTE: AFTERSHOCKS MAY CAUSE ADDITIONAL DAMAGE OTHER THAN NOTED.</small>		
STRUCTURE DESCRIPTION: Bldg ID: _____ No. Stories: _____ No. Basements: _____		BUILDING MARKING: <div style="display: flex; align-items: center;"><div style="border: 1px solid black; width: 30px; height: 30px; margin-right: 10px;"></div><div>Date/Time of Evaluation: _____ Date/Time of Catastrophe: _____</div></div>
MATERIALS: Wood Concrete Steel URM PC Concrete Other: _____		TYPE OF COLLAPSE: Pancake Soft 1st Floor Wall Failure Torsion Middle Story Overturn Other: _____
FRAMING SYSTEM: Shearwall Moment Frame Braced Frame Other: _____		LOCATION OF VOIDS: Between Floors Basement Shafts Other: _____
OCCUPANCY: Hospital Police Station Fire Station Emergency Operations Center Office Building School Public Assembly Industrial Hotel Apartment Retail Store Other: _____		DESCRIPTION OF UNSAFE AREAS & HAZARDS: _____ _____ _____ _____ _____ _____
VICTIM & OTHER INFORMATION: _____ _____		
LOCATION OF BEST ACCESS & SAR STRATEGY: _____ _____		
SKETCH: <div style="border: 1px solid black; height: 300px; width: 100%;"></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.



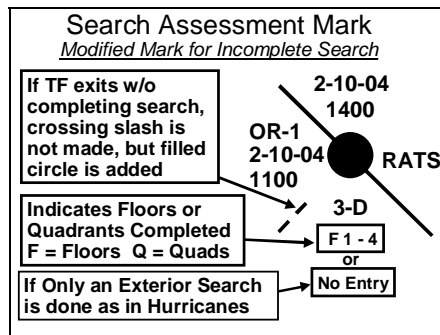


Incomplete Search Assessment Mark

- 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.

Search Mark Placard

- In Sep06 an adhesive backed, stick-on Search Mark Placard was approved, in order to reduce the use of paint at incidents like hurricanes where many structures are involved.
- In 2011 it was modified to add information regarding the type of search. This information is to be added in the box below the main part of the Search Mark. See below



Adhesive-backed Search Mark Placard (8.5" x 11.5" - cut sheet in half)

Date of Exit
Time of Exit
Task Force
Date of Entry
Time of Entry
Hazards
-L
-D

Additional Information

Primary No Entry Secondary

Additional Information New in 2011

Primary No Entry Secondary

Rev 6/8/11

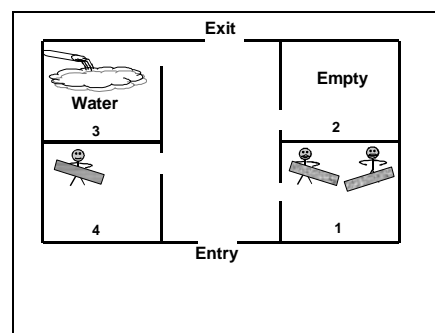
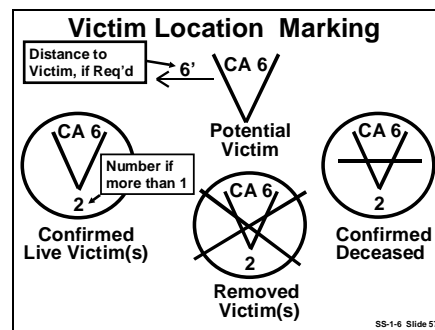
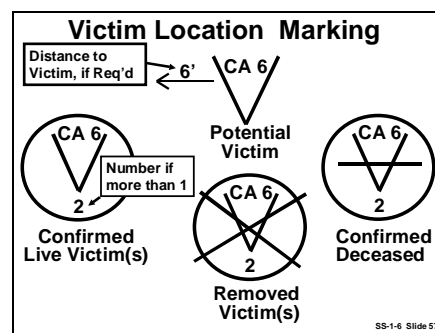
- 2011 version
- With search type shown within Additional Info Box
- 11" x 8 1/2"
- On bright orange paper
- Peel & stick



Victim Marking System

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

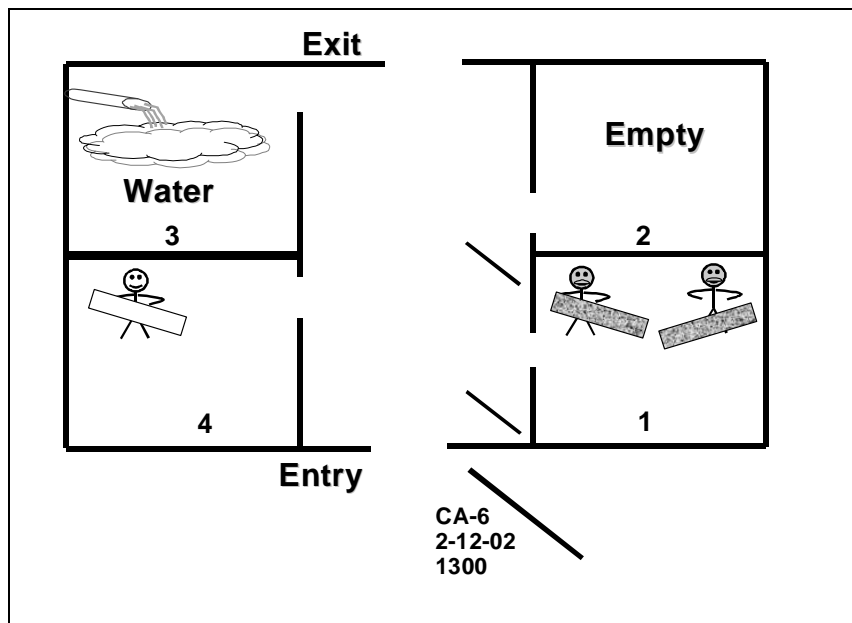
- The marks are made with orange spray paint or crayon.
- Marks will normally be initiated after a search is performed unless the victim is immediately removed.
- The **V** is intended to be about 2 feet high and located as near to the victim as practicable.
- It could be painted on a nearby wall surface 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.
- A large **X** is drawn completely through the circle after the victim has been removed.
- 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.



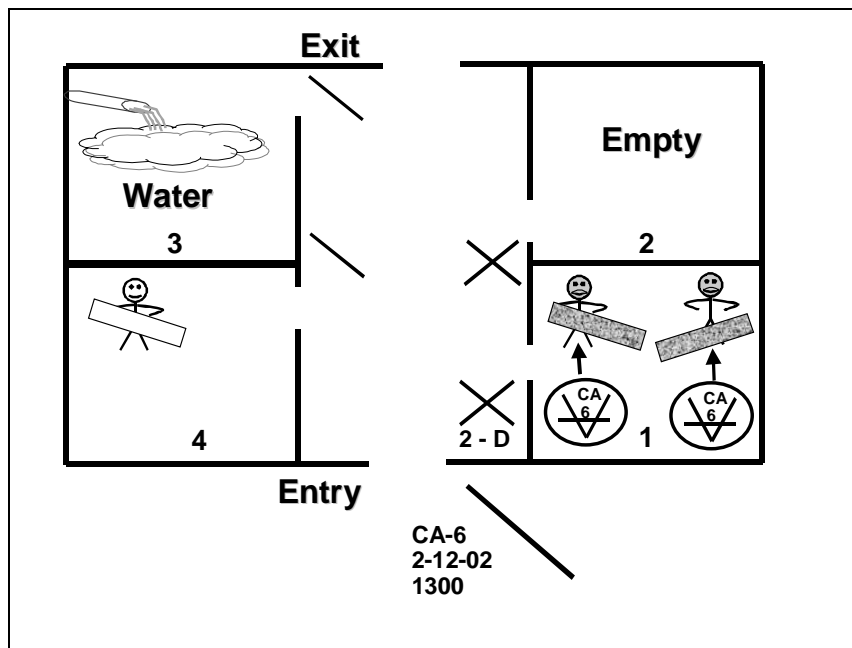


Search Assessment and Victim Location Mark: Example

- 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.

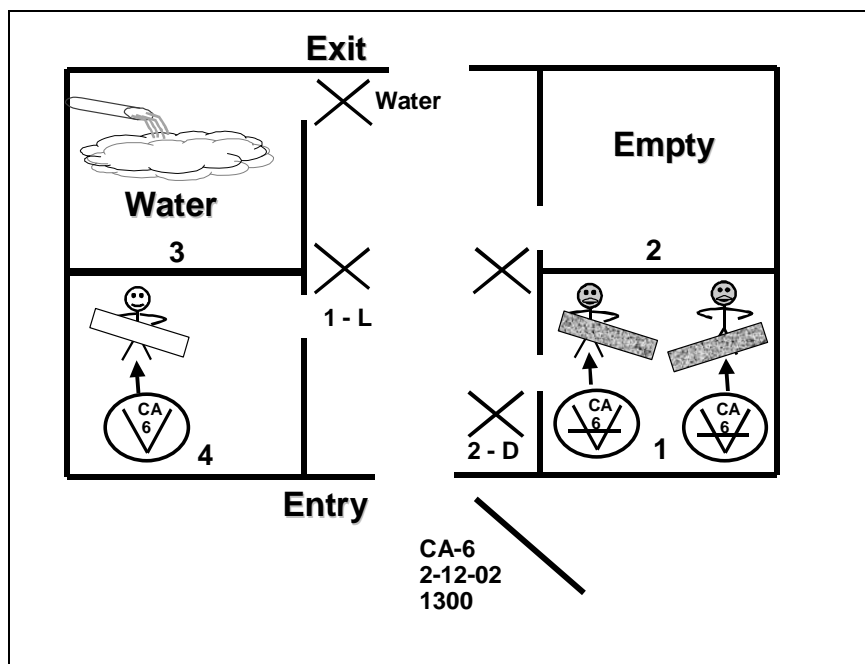


- Exit Rooms 1 and 2; draw a second slash and record findings. Then enter Rooms 3 and 4.

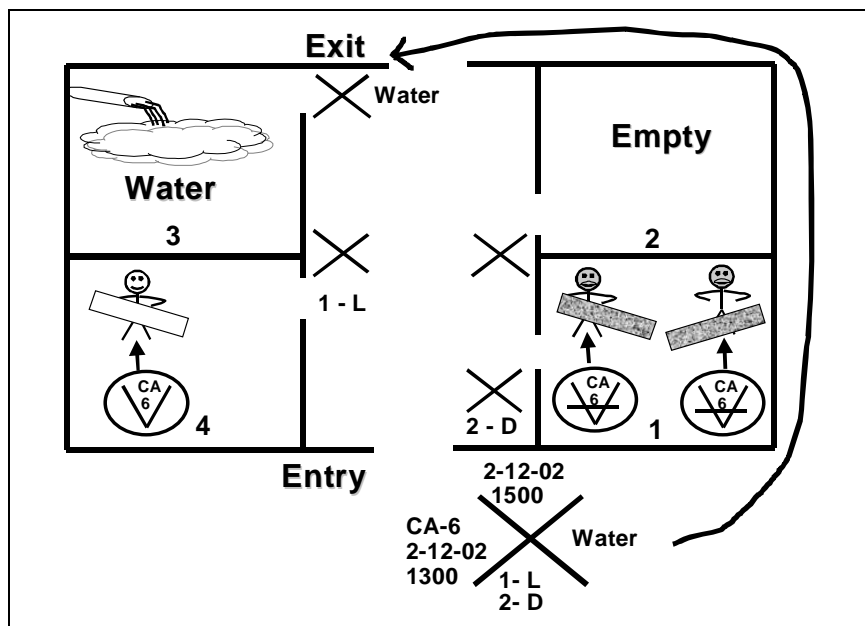




- Exit Rooms 3 and 4; draw a second slash and record findings.



- 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.

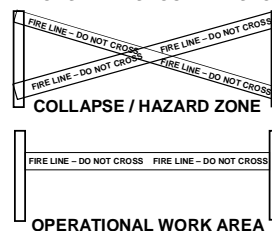
DISASTER SITE AUDIO SIGNAL/ALERTING

(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.

RESCUE SITE SET UP

- OPERATIONS AREA SHOULD BE SECURE



Marking System Summary

- Building Identification System
- Structure / Hazards Evaluation & Marking
- Search Assessment Marking
- Victim Marking
- Search Marking Example
- ICS & Other Map Symbolology
- Disaster Site Audio Signal/Alerting



VIII. Structure Collapse Awareness Summary

In this manual, we have discussed:

- Introduction to Structure Collapse Response,
- Building Materials, Systems & Redundancy,
- Building Types & Characteristics,
- Causes of Collapse,
- Collapse Patterns,
- Hazard Identification & Introduction to Mitigation,
- The FEMA US&R Marking System.

In the first section of this unit, we discussed the types of forces that load structures, the method used to classify structures, the types of problems that various building types have experienced in the past, and the various collapse patterns that have occurred that will give us some insight as to how structures will behave in future disasters.

We then focused more specifically on the US&R issues of how to deal with damaged and collapsed structures. Remember, the issue in US&R is not the academic one of how the structure collapsed but what additional collapse is possible and how stable is the existing configuration. **Our goal is to be ready to recognize the most probable location of victims. Where were most of the building occupants prior to the collapse, and where are the survivors most likely to be located.**

In the hazard identification section, we discussed the difficulty of identifying hazards after a structural collapse and the need to use monitoring methods to recognize when further collapse is likely.

We 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. In addition, we reviewed the US&R Structure triage.

Enabling Objectives

- Introduction to Struct Collapse Response
- Structural Forces & Materials
 - Brittle vs. Ductile
- Building Systems + Redundancy
- Building Types and Characteristics
- Effects of Earthquake, Wind, Blast & Fire
- Collapse Patterns
 - Potential Victim Location & Survivable Voids
- Hazard I.D. – Collapse & Falling Hazards
- FEMA US&R Marking System