EARTHQUAKE MODELING PRE-READING

RMS® CCRA® Training Program

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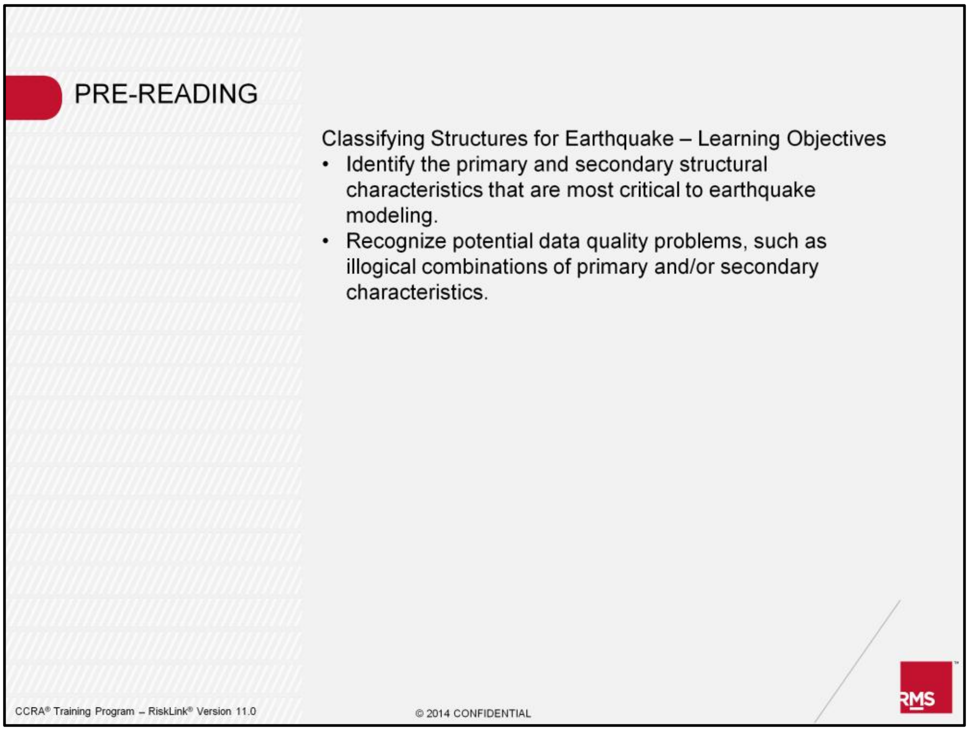
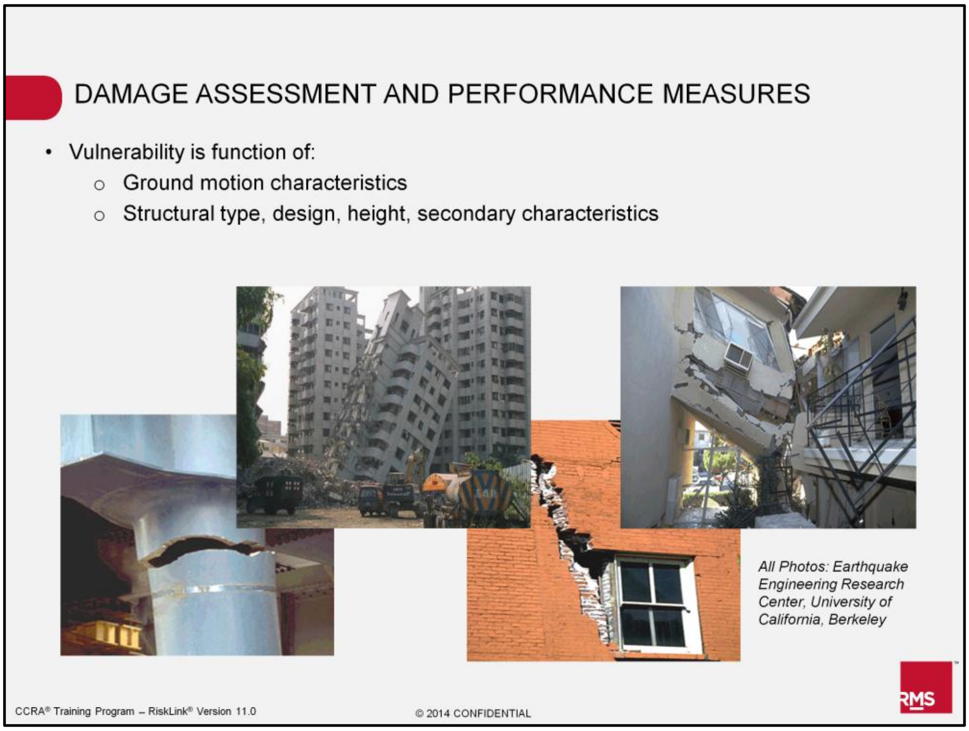


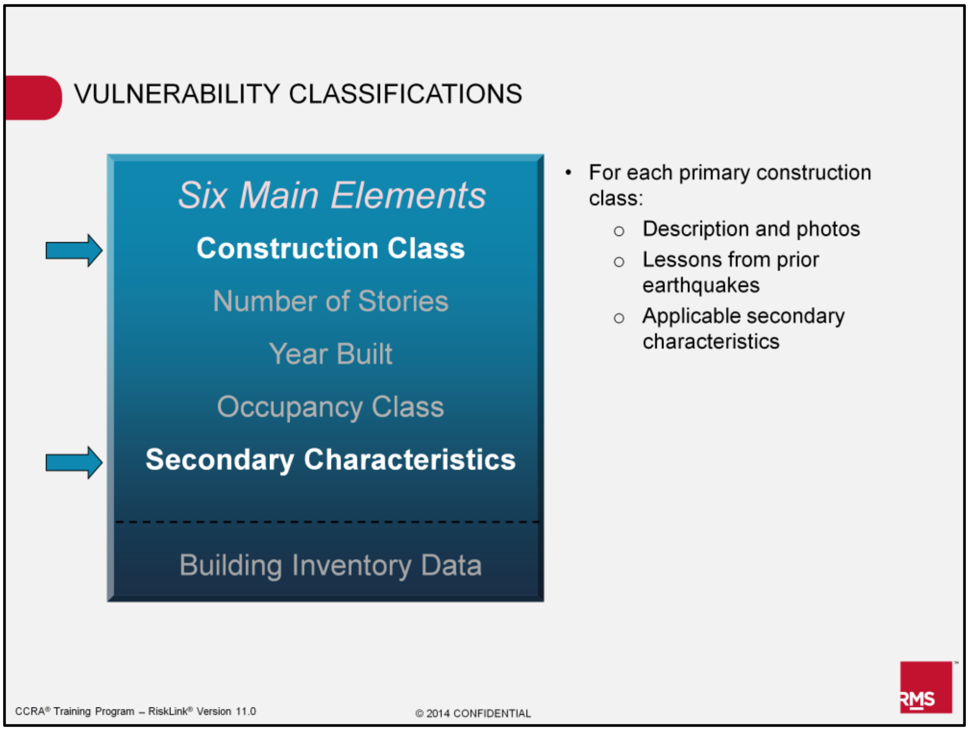
This presentation covers the proper use and identification of primary and secondary construction characteristics for earthquake exposed structures. In addition, it provides an in-depth treatment of the proper combinations of primary and secondary characteristics for buildings, thus improving data quality assessments as well as the accuracy of modeled loss results.
The presentation begins with the basics of primary structural systems and the secondary modifiers, followed by examples of the potential impact of earthquakes on these structures.



Shown here are different types of buildings (tall, masonry, wood, steel). The vulnerability for each of these structures is a function of ground motion characteristics as a result of earthquake waves traveling through the earth and impacting the site causing the structures to shake. Depending upon their construction, buildings will perform differently.

The top right figure shows the earthquake performance of a building with discontinuities, causing the damage seen at the top level. The next figure to the left shows a masonry building with a large crack around the window, which is a common failure mode for this type of building. The picture second from the left depicts a tall building that lost the first level causing it to collapse and tilt. This damage is related to the interaction between the structure and the soil it is built on. Joint failure is shown in the left-most picture for a structure built on columns. This was a common failure mode observed for similar structures in both the Kobe, Japan and Loma Prieta, California earthquakes.

These examples demonstrate the importance of accurately identifying building construction characteristics in order to correctly model potential damage states.



Vulnerability classifications include the six elements shown on this slide. In this presentation, only primary construction class and secondary construction characteristics will be addressed. For more information on the other classifications, refer to the “Vulnerability Classifications and Coding Construction Classes” Principles of Catastrophe Modeling presentation, available from the Training page of www.rms.com, as well as the DLM Reference Guide.

Each primary construction class can be classified based on descriptions in engineering or other documents, photographs, or site visits. Once the construction class is accurately described, then the performance of the structures is based on observations from the lab as well as past events. Finally, the performance of the building is modified given the presence of indicated secondary modifiers (or secondary construction characteristics) to more accurately assess the potential damage.

ATC EARTHQUAKE CONSTRUCTION CLASSES

ATC Class	Name
0	Unknown
1	Wood Frame
2	Light Metal
3	Unreinforced Masonry Wall
4	Unreinforced Masonry with Frame
5	Reinforced Concrete Wall with Frame
6	Reinforced Concrete Wall without Frame
7	Reinforced Masonry Shear Wall
8	Reinforced Masonry Wall with Frame
9	Braced Steel Frame
10	Moment Steel Frame (Perimeter)
11	Moment Steel Frame (Distributed)
12	Ductile Reinforced Concrete Frame (Distributed)
13	Non-Ductile Reinforced Concrete Frame (Distributed)
14	Precast Concrete
15	Long Span
16	Tilt-Up
17	Mobile Home

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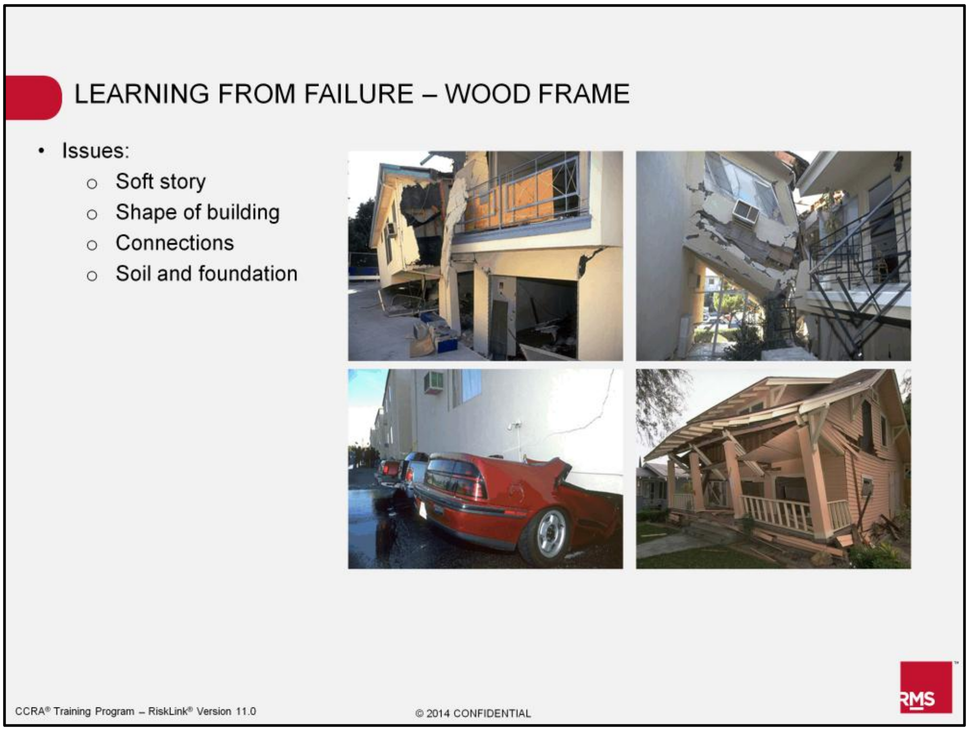
ATC is a widely used primary construction class scheme for earthquake in the U.S. Each of the construction classes shown here will be described in more detail in this presentation, starting with the classification ATC 0 (unknown construction) where there is no information known about the building.

When construction is unknown, an inventory database is used that assigns a vulnerability curve based on the prevalent construction type in the area in which the risk is located. RiskLink® will model losses based on this composite damage function (or vulnerability curve), which reflects the average construction for the occupancy type, region, and year built. As an example, given a residential building with unknown construction in the central U.S., the inventory will assign a classification of ATC 1 (wood).

The ATC classifications for 1 and greater are based on the type of construction material. For each main construction class there is also a subset of classifications defined that describe the main classification in more detail.

Wood frame is widely used in residential single family and multi-family structures as well as for some commercial structures. Earthquake forces are dampened by shear walls through which lateral earthquake loads are transferred to the foundation of the structure if proper connections exist, such as anchor bolts. These types of structures generally are one to three stories. Building loads are light and the framing span is usually very short. Floor and roof framing consists of wood bracing with rafters that are placed about 24 inches apart.



This slide shows the performance of a wood frame building in an earthquake where damage occurred. Wood structures are very light from an earthquake perspective, and are thus an excellent material for low story earthquake exposed structures. However, if they are not built correctly they can be subject to severe damage.

Soft story, shape of the building, connections, and the soil and foundation underneath the structure are characteristics that have a significant impact on the structure's performance during an earthquake.

The photo on the upper right shows the impact of irregular shape configuration. There is a discontinuity between the upper and lower levels. This causes the structure to respond differently at each level, resulting in significant damage to the upper level of the building.

The upper left photo depicts foundation failure and sub-story failure.

The lower left photo is a classic example of soft story failure, which in this case is the failure of tuck-under parking, causing damage not only to the building but also to the cars parked underneath. Collapse is due to the discontinuity between the first floor structure and the building on top.

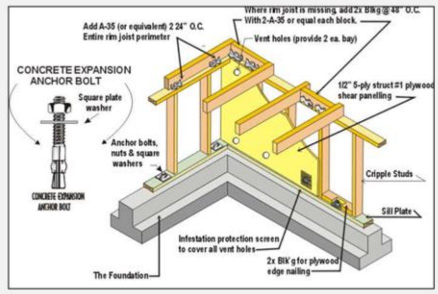
The photo on the lower right shows the failure where the connections of the roof to the vertical element (in this case columns) is not sufficient to transfer the loads properly during an earthquake from the roof, through the walls and/or columns, to the base of the structure.

Identifying structural problems such as these will provide information on potential losses during an earthquake. The next few slides will discuss in more detail each of the structural elements (secondary modifiers) that impact the performance of a wood structure in an earthquake.

SECONDARY MODIFIER – CRIPPLE WALLS

- Common in older wood frame houses with tall crawl spaces
- Crawl space walls (also known as cripple walls) connect the foundation to the floor joists
- Can fail under lateral loads, unless reinforced with plywood

Wood cripple wall failure in frame house – 1989 Loma Prieta Earthquake



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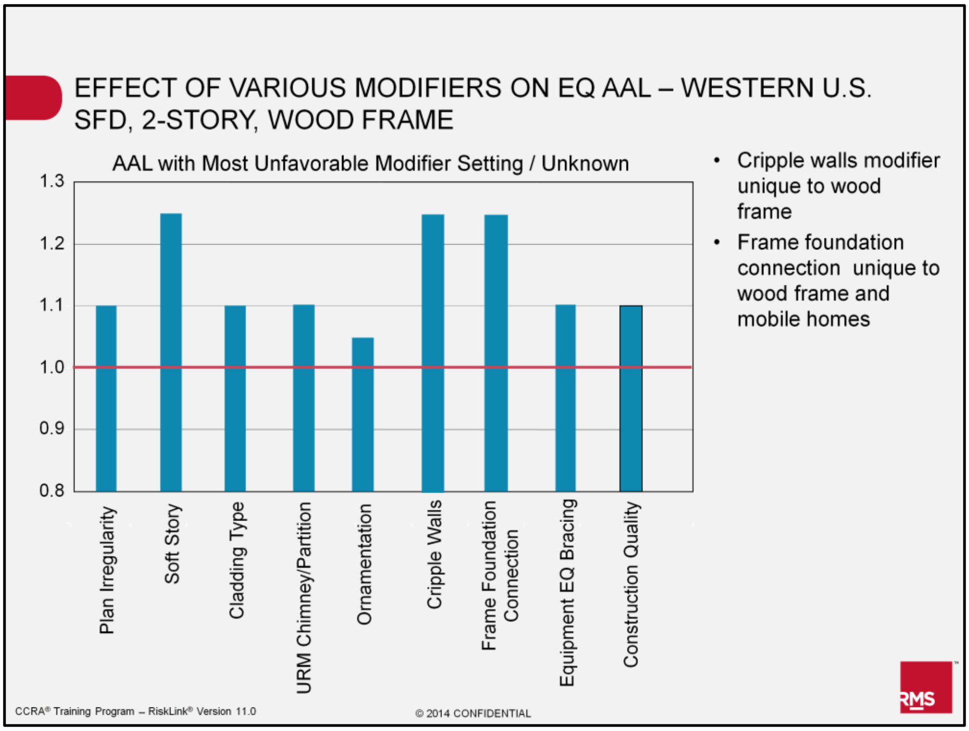
One of the most important failure modes seen in older buildings is cripple walls, which are common in wood frame houses. Cripple walls connect the building foundation to the floor trusses. If these walls are not connected or reinforced properly to the floor system, then the motion of the structure during an earthquake will not be transferred properly to the foundation. The picture on the left shows the poor performance of a structure with a cripple wall in the Loma Prieta earthquake. This structure was moved off of its foundation because the cripple wall was not able to transfer the upper level forces to the foundation. How can this problem be fixed? It is necessary to provide reinforcement to the cripple wall or add rigidity to the wall to allow transfer of earthquake forces from the floor to the structure. In the figure on the right you will note a yellow element that depicts plywood panel. That is the type of element that will add to the vertical strength by improving the vertical rigidity, which allows continuous transfer of ground motion through the structure. Alternatively, if you use cripple wall bracing, then the building will experience similar transfer of ground motion to the structure during an earthquake.



Next we will look at the relative impact of various secondary construction characteristics (construction modifiers), such as cripple walls on wood frame buildings. The horizontal axis identifies secondary modifiers that are applicable to earthquake modeling. The vertical access is the ratio between modeled loss from a location with an unknown secondary modifier setting and the modeled loss when the most unfavorable (most damageable) modifier setting is chosen. To create the bar chart, an analysis was run on one location with all construction characteristics set to unknown. This result was then compared to the individual average annual loss results for each of the secondary modifiers set to a known value. As you can see, the soft story, cripple walls, and frame foundation connection show about a 25% increase in average annual loss as compared to the unknown case (based on the average building inventory). The option chosen for each of these is the one that would increase losses (e.g., poor frame foundation connection, existence of cripple walls, existence of soft story, etc.).

As a side note, soft story, while important, should not have as much of an impact on newer structures due to stricter code requirements in more recent years. However, for older buildings the existence of a soft story could increase the loss more dramatically.

MOBILE HOME (ATC 17)

Mobile home damaged in 1994 Northridge Earthquake

Failure at pier supporting mobile home

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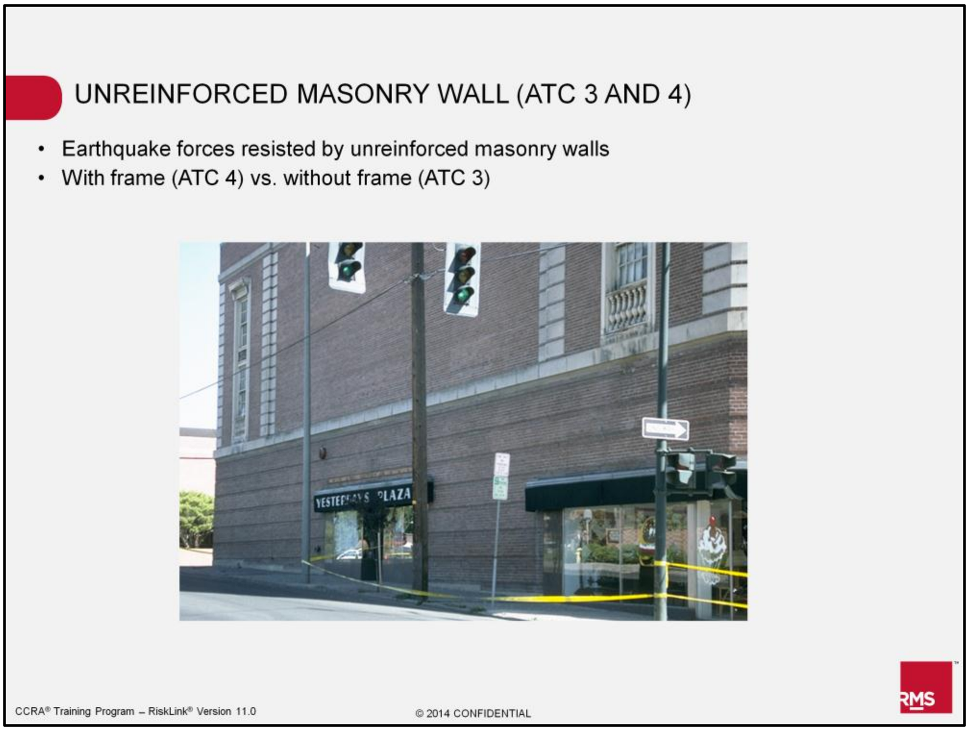
Mobile homes are manufactured homes taken to the job site and placed on a foundation. The foundation is usually very simple with a limited connectivity between the home and foundation (as shown in the photo on the right). During an earthquake, the mobile homes are easily separated from the foundation and collapse.



Unreinforced masonry walls may or may not have framing systems. In this photo, the perimeter of the building walls are unreinforced masonry (URM) and the interior is also masonry. The buildings are heavy, so there is more mass to experience larger shaking and a greater degree of damage will result if not properly built. Due to the large mass of the building, most of the earthquake forces are exerted from the roof to the foundation.

This slide shows the different failure modes of URM construction buildings. The figure on the left shows a massive crack due to the Northridge earthquake in 1994. The middle figure shows failure in a URM building during the Seattle-Olympia 2001 earthquake, which consists of a continuous crack in the wall. The figure on the right shows damage from the 1994 Northridge earthquake. The upper part of a brick wall moved in a different direction than the rest of the building and eventually crashed into the street.

While the three photos above show failure to different types of URM buildings in two separate events, the failure is due to the same problem related to URM walls not having sufficient confinement and reinforcement. The other issues are improper connections between the roof and the top of the wall, which can allow out-of-plane failure. In other words, the wall is allowed to move in a different direction from the roof during an event, causing the wall to fail and collapse as shown in the figure on the right.

So how can these structural problems be fixed? The next slide shows a retrofit that will impede the types of failure shown here.

SECONDARY MODIFIER – URM RETROFIT

Many masonry buildings can be made more resistant to earthquakes by adding an internal frame, such as the one shown here, and bolting the walls to the frame.

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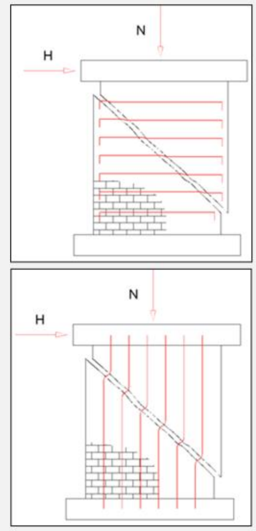
This slide depicts one of the possible secondary construction modifiers – URM retrofit. By using the internal frame shown here, the design engineer is now allowing for the continuous transfer of earthquake loads via the lateral bracing from the roof through the walls and to the foundation. This shows one approach, which is to isolate the walls responsible for carrying the lateral forces. If this type of internal framing is implemented, then the URM retrofit modifier should reflect that structural credit.

REINFORCED MASONRY SHEAR WALL (ATC 7 AND 8)

- Reinforced masonry provides the structure and the skin at the same time.
- Fire and sound resistance are built right into the wall.
- Vertical and horizontal reinforcement resist earthquake loads.



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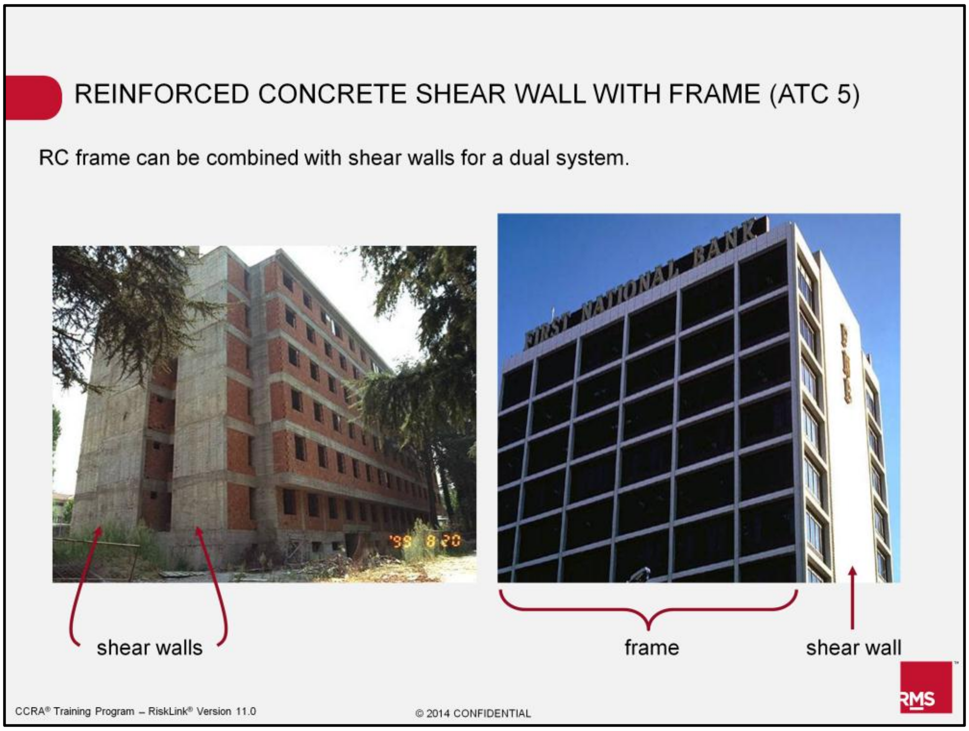
This slide shows a reinforced masonry (RM) building. The RM construction provides both reinforcement for the structure (thus improving the strength) and an outer surface covering (or skin) on the structure. Other advantages to reinforced masonry structures are their inherent sound and fire resistance. Finally, they provide both vertical and horizontal resistance to earthquake loads. The two pictures on the right show the failure modes of masonry walls. The cracks similar to those shown in the previous slides can be prevented by installing horizontal bars and vertical posts or reinforcement, shown as red lines in these figures. When these types of reinforcements are put in, together they increase rigidity, thus preventing the structure or material from moving. The confinement of the masonry diminishes or stops damage to the structure.

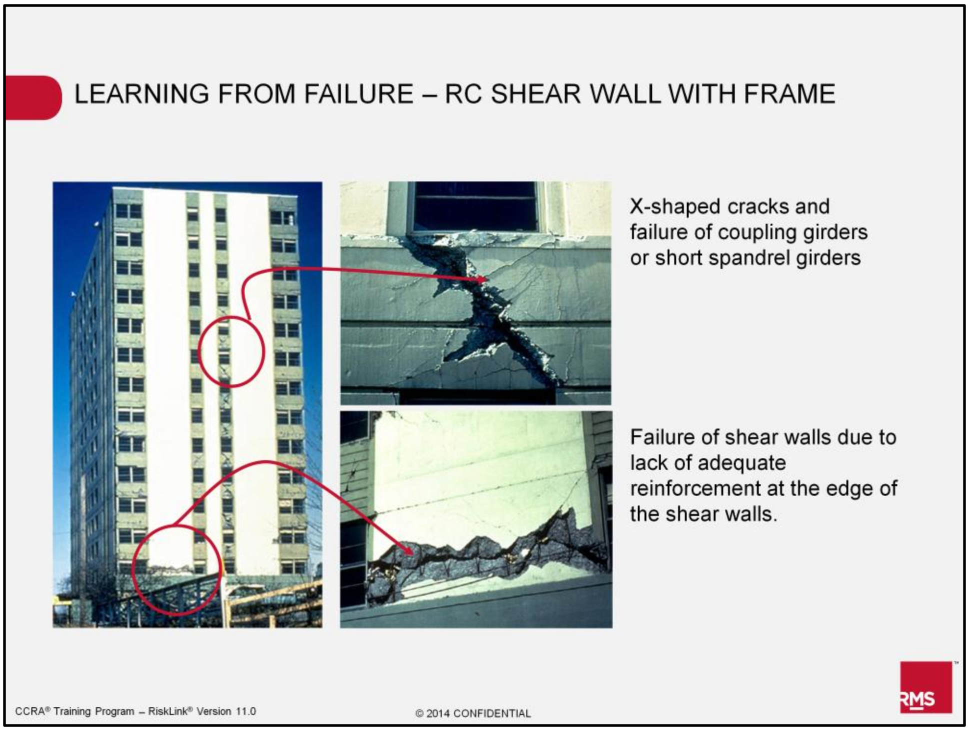
REINFORCED CONCRETE SHEAR WALL WITHOUT FRAME (ATC 6)

Earthquake forces are resisted by reinforced concrete (RC) shear walls.

In the next couple of slides we will focus on reinforced concrete shear wall structures with and without frames. Reinforced concrete buildings are usually constructed with a combination of shear wall, framing, and pre-cast concrete. This photo shows a shear wall building (ATC 6). In a shear wall building, lateral loads (which make up the majority of earthquake loads) are transferred from the shear wall to the floor and then to the foundation. These types of structures are very rigid and in terms of life safety, they perform very well. However, if the walls are not confined, they will experience damage. The picture above shows cracks in the walls that can be fixed, the integrity of the structure has not been damaged.



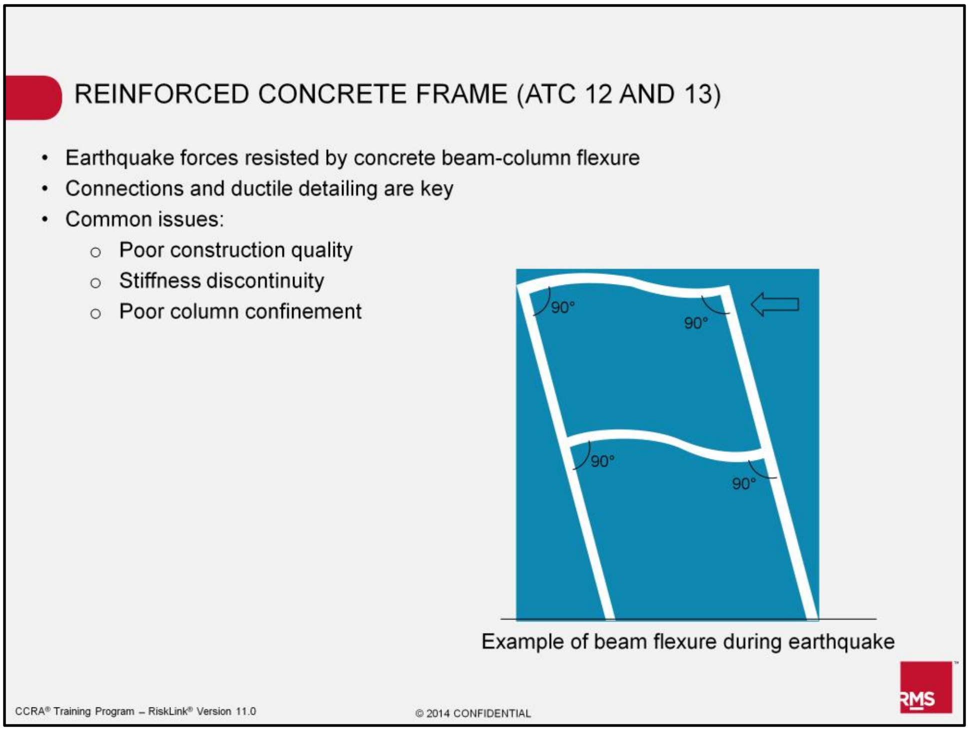
This slide shows the combination of shear wall with frame. We call the system a dual system. That means that the shear wall not only carries the force, but the framing and beams are also responsible for carrying earthquake loads. The picture on the right shows the external frame system as well as the shear wall on the right side. This is a type of redundant system, so that if the earthquake causes the shear wall to fail, then the framing system will be able to handle the earthquake forces. This is a very common type of commercial structural system and historically they perform well.



This slide depicts historical failure modes for shear wall frame. Shown is a high rise building with shear walls that are visible as panels extending the length of the building from the second floor to the roof. The frame is between the shear walls and contains windows.

At the connection between the two big walls there was a failure of earthquake load transfer causing a very wide crack in the shape of an "X." This type of cracking is very common. If an xbar or reinforcement is not there, then a crack will occur at that location.

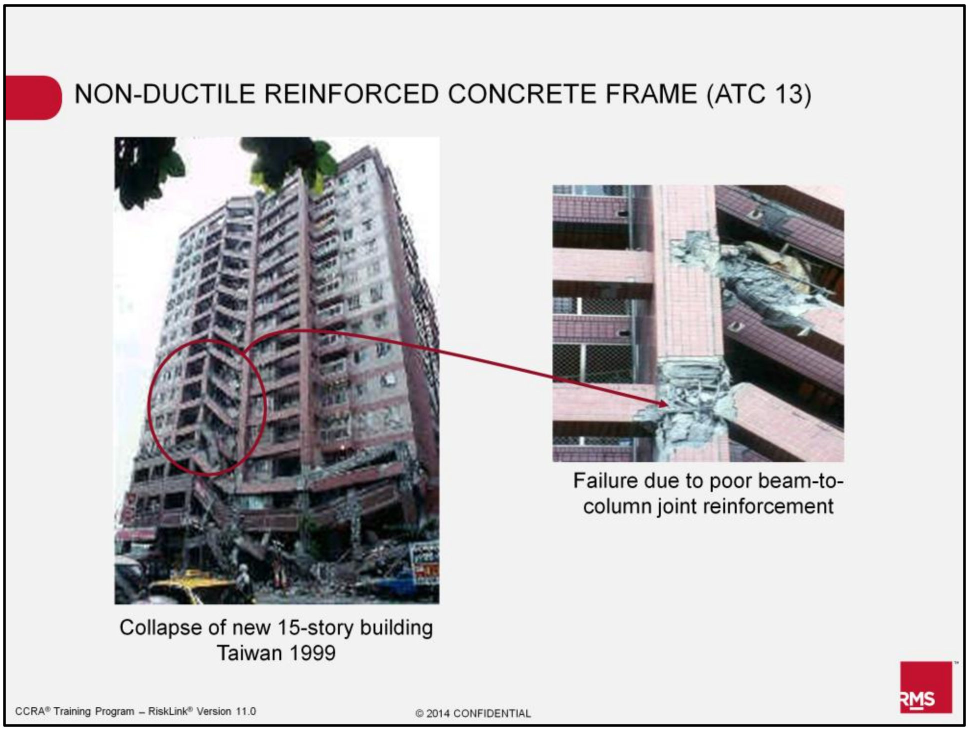
At the base you can see there is a continuous crack along the width of the shear wall. This crack is the result of excessive forces being exerted downward along the shear wall and not properly transferred to the foundation. Without sufficient capacity to handle the loads, the force cannot be properly transferred to the foundation and a crack appears.



In some cases buildings must be constructed with only frames to accommodate architectural designs. In this case engineers have to take up the lateral motion via a "moment frame" construction.

To illustrate, the figure on the right is being pushed in one lateral direction. The structure starts to deform and the lateral load resistance is taking place at all of the joints. If one or more joints fail, then the column and the beam will not be joined correctly and the loads will not be transferred. The seismic performance of this type of structure depends on the proper detailing of the beam/column connection to make sure flexural behavior of joints is maintained. For reinforced concrete structures, it is required that beams and columns have sufficient reinforcement around the joint to provide confinement and ductile behavior. For steel structures, the beam/column connections are critical, and sufficient welding and additional plates are required. Older buildings may not have sufficient ductility of proper welding requirements.

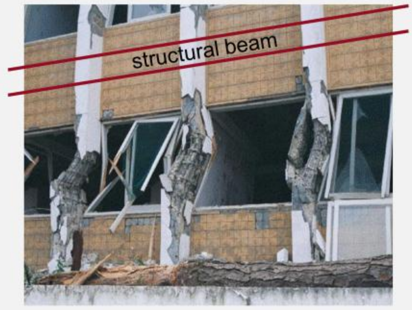
There are some poor construction quality issues related to these types of structures. Improper construction, such as the inclusion of a wall that causes some type of discontinuity, or poor column confinement, will compromise the lateral load response. Illustrated in the next few slides is the building response to an earthquake in both of these cases.



This is an excellent example of the failure of joints in a non-ductile reinforced concrete frame high rise. The joints in this building are responsible for the transfer of loads from the top to the bottom of the structure. If these joints or connections are not properly built, or do not have sufficient reinforcement, then they can fail as shown in the photos above for a building that collapsed in the 1999 Taiwan earthquake. This is a common building failure, especially in Taiwan where this type of building is popular for high rise structures. These types of buildings are classified as non-ductile, which causes the damageability of this type of building to be much higher than the ductile building construction that allows the building to respond to lateral earthquake forces in a less rigid manner.

SECONDARY MODIFIER – SHORT COLUMN

- Definition/condition:
    - Condition where concrete columns are effectively shortened in height, changing location of maximum load relative to design.
    - Applies to reinforced concrete structures only.
- Examples:
    - Deep exterior spandrel beams
    - Partial height nonstructural exterior walls
- Possible consequences:
    - Excessive cracking of concrete columns



Failure of reinforced concrete column due to its shortening because of the effect of the masonry wall.

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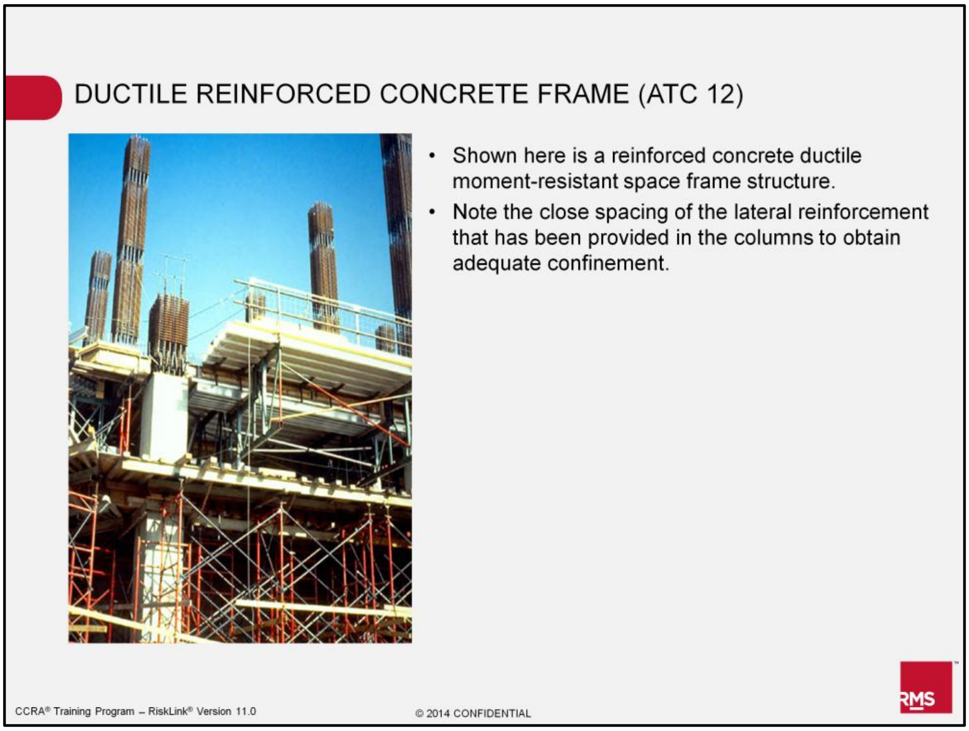
This example is from a building containing short columns that was exposed to an earthquake in Turkey. A short column failure will cause the height of the building to effectively shorten. In this photo there is a wall between the columns that stopped total collapse of the floor. The columns were designed to separate one level from the other, and they fail when they do not have the capacity to bear the earthquake loads. This failure is always a 100% failure accompanied by excessive cracking in each of the concrete columns. This failure can be prevented by providing a gap between the walls and the column. In this manner, the columns become a non-structural element and should not participate in the structural behavior of the building.

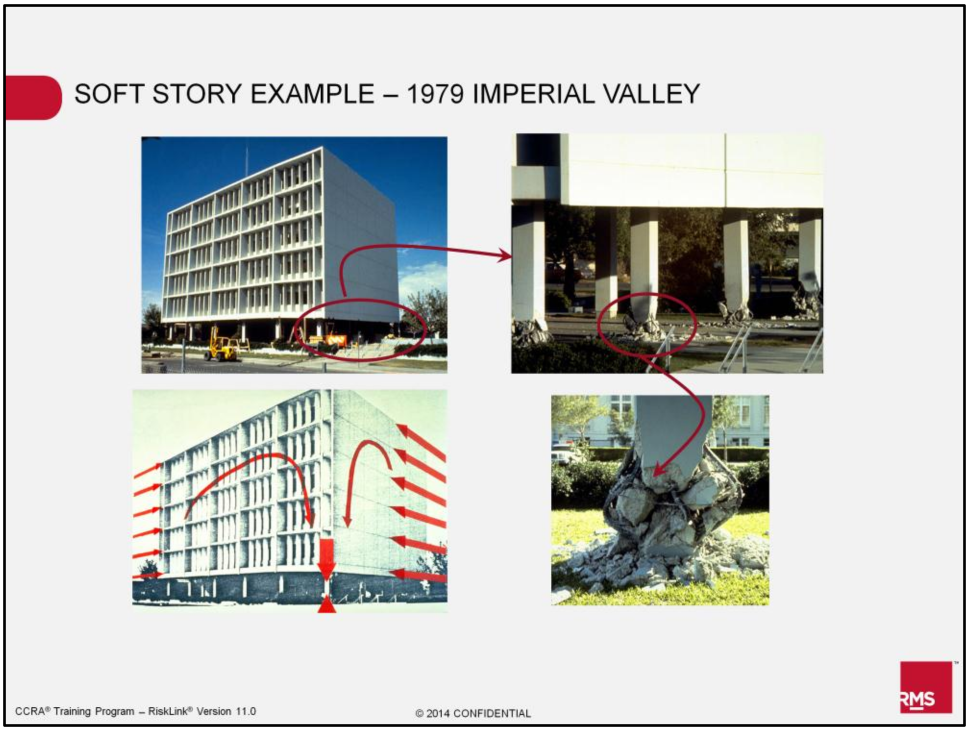


Next we will define the concept of confinement or ductile reinforcement of a structure. The photo on this slide is of a ductile reinforced concrete structure under construction showing the rebar prior to pouring the concrete in the upper level. The columns and the horizontal structures are confined by vertical reinforcements (columns and rebar) so that when the concrete is poured, it is constrained and strengthened by the reinforcements. In this case, the frame will be able to adequately transmit the earthquake forces through the structure.

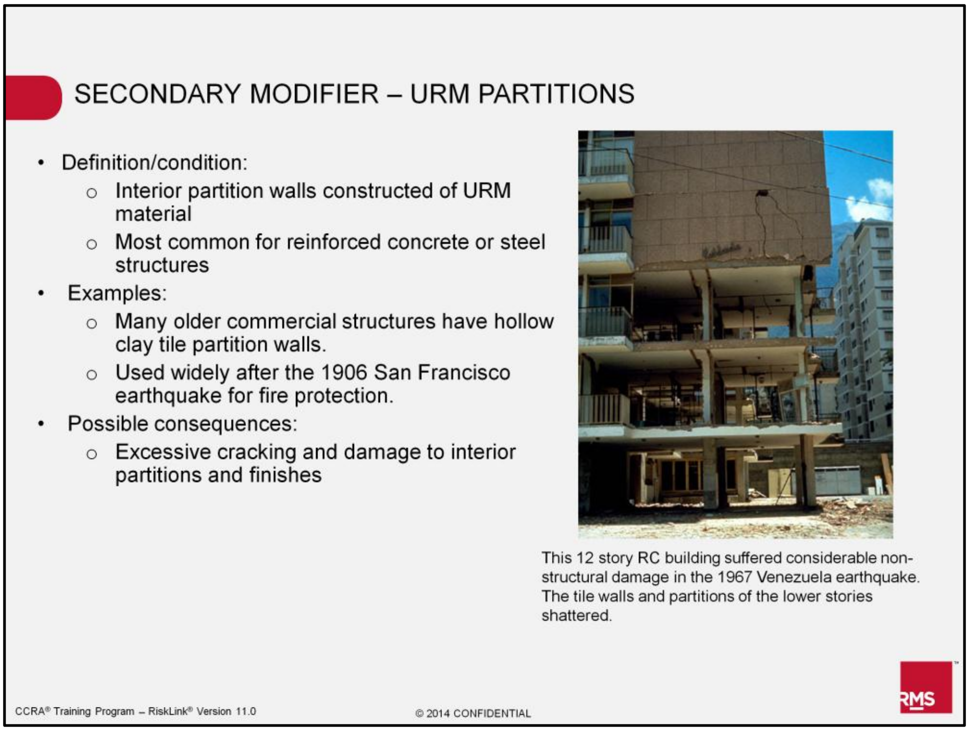
SECONDARY MODIFIER – SOFT STORY

- Definition/condition:
  - A discontinuity in the building structure system where stiffness of one story is dramatically less than the story above or below.
  - Can apply to various structural types (including RC, wood, steel)
- Examples:
  - Tuck-under parking
  - Open storefronts
- Possible consequences:
  - Excessive deflection and damage to soft story

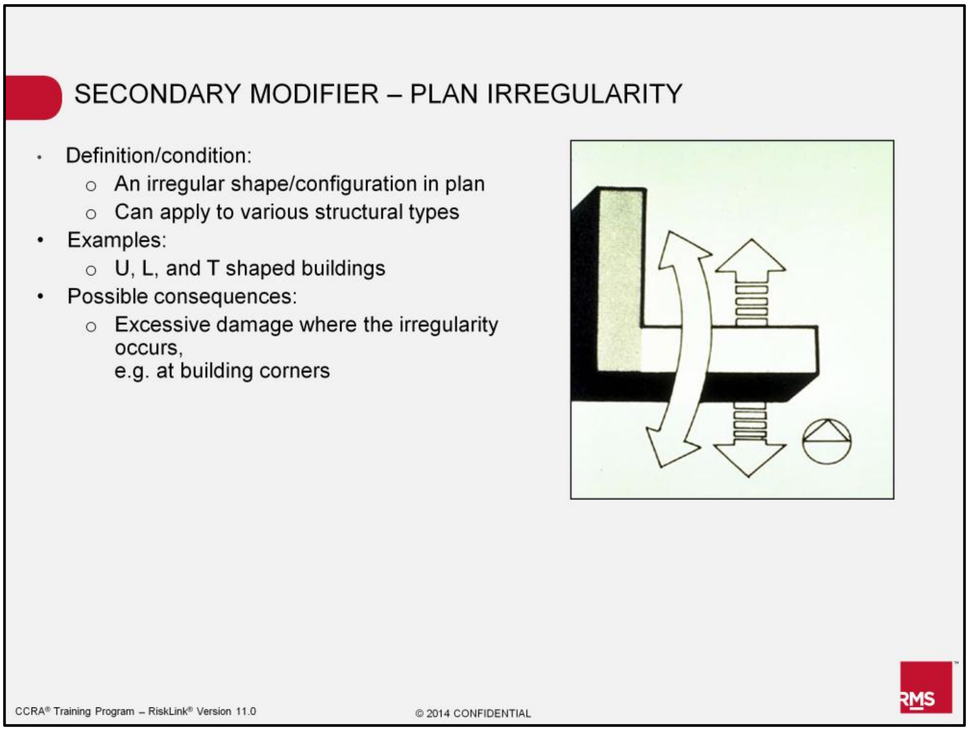
A very common issue outside of the U.S., and in older buildings in the U.S., is a soft story condition. A soft story is an area where there is a discontinuity in building structural stiffness. The top photo shows a solid concrete structure built on small columns. In this case, the lower level of the structure occupies a much smaller volume than the upper level, so they do not have sufficient resistance to prevent the structure from collapsing. The bottom photo shows a similar problem. The main rigid structure sits on top of columns that failed, causing the structure to be lowered where the columns were flattened. This is a very common problem for buildings with parking garages underneath (e.g., tuck-under parking) or for open retail space at the base of a residential or commercial high rise structure.



Every earthquake provides additional experience with regards to the structural response of buildings to ground motion. This leads to new building codes which are then implemented by structural design engineers in the building and retrofitting of structures. The 1979 Imperial Valley, California earthquake was no exception. It was the first event where soft story failure was brought to the attention of the engineering community. The top photos show a rigid building built on columns that failed during the earthquake. The red arrows in the bottom left photo depict the structural loads due to the earthquake in two directions. All of these forces converge on the corner column. This corner column does not have the capacity to carry the entire weight of the building during an earthquake. As you can see in the picture on the lower right, because the column does not have sufficient confinement, or redundancy, the column fails or explodes. One solution to prevent this type of failure is to install a retaining wall from the lower level to the upper level of the building.



Another modifier that is not only applicable to concrete buildings but also to steel structures, are URM partitions. This is covered cladding, or partition walls, constructed with URM. If these elements are not properly connected to the structural frame, they can crack and detach from the structure, as shown in this example. This is a very old structural practice that is common in some areas of the world such as Taiwan, but it is not prevalent in the U.S.

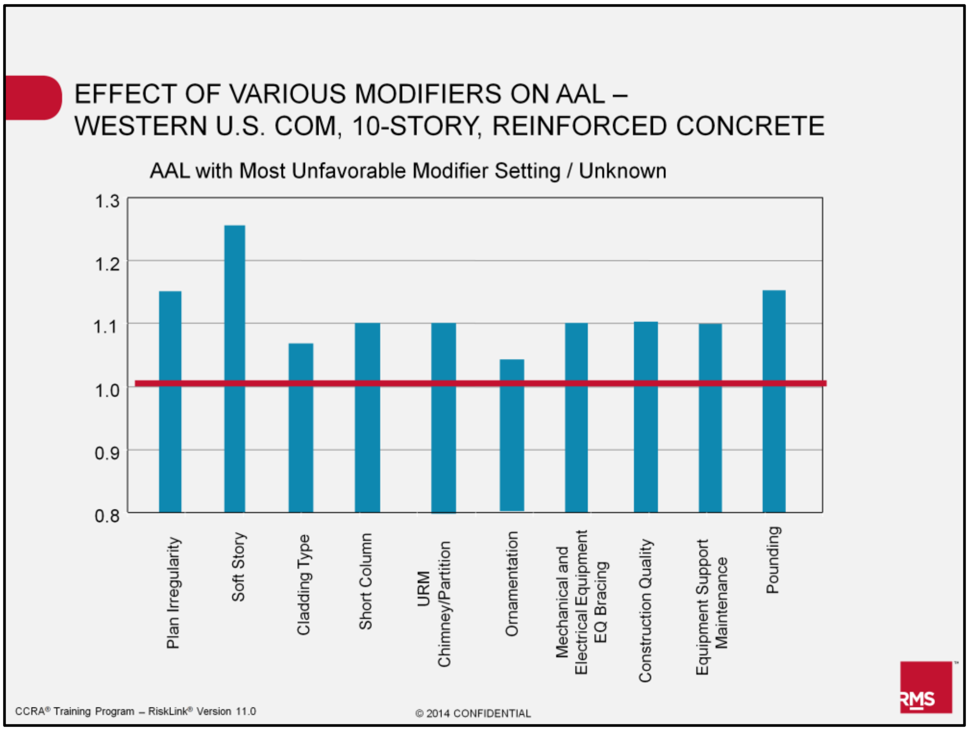


Another issue is the impact of an irregular shape configuration such as U, L, or T shaped buildings. As you can see in this example, the vertical part of the structure is relatively rigid since it is parallel to the predominant ground motion, whereas the horizontal part of the structure is subject to back and forth motion perpendicular to the width of the building, causing more damage.

SECONDARY MODIFIER – POUNDING

- Definition/condition:
  - A condition where two adjacent buildings collide during an earthquake.
- Examples:
  - Adjacent commercial buildings with little space between them.
  - Most common for reinforced concrete or steel structures.
- Possible consequences:
  - Damage where the two buildings collide, of particular concern if floors are not at the same elevation.

A common modifier in urban commercial areas with buildings built very close to one another, is pounding; where one building is impacted by a neighboring structure that is moving at a different frequency or direction during an earthquake. When the structures are the same height, pounding between the structures should not be as much of an issue. If neighboring structures are different heights, they will both move with different modes of vibration and impact each other. At the point of impact you see significant damage and deformation to the building. This can happen to both steel and concrete buildings. According to newer building codes, there must be a sufficient gap between the two buildings, so this should not be as significant a damage issue for newer buildings.



This slide shows the impact of various earthquake modifiers on AAL for a 10-story reinforced concrete building in the western U.S. Similar to the earlier example, an analysis was run on one location with all modifiers set to unknown. Then one modifier at a time was set to a value for that location, and the resulting average annual loss analysis was compared to the unknown case. The ratio of the AAL for known vs. unknown modifiers is shown in this bar chart. The range of the impact varies up to about 15%, with soft story impacting the AAL about 25%.

The second group of concrete structures is pre-cast concrete. The girders (i.e., crossbeams) and columns of these buildings are created separately and assembled at the work site. The builder provides sufficient connection as well as the shear wall.

The pre-cast concrete should not be responsible for carrying the load of the building. The shear wall is the load-bearing wall, and the pre-cast concrete carries the gravity load.

However, if sufficient connections are not provided, the building will fall apart, as seen in the picture on the lower right. This photograph is from Turkey, and represents a very common type of failure of this kind of building in the area.

These buildings are common because they are economical and can be built very quickly.

LEARNING FROM FAILURE – PRE-CAST CONCRETE

- 1994 Northridge Earthquake

Three story pre-cast concrete parking structure

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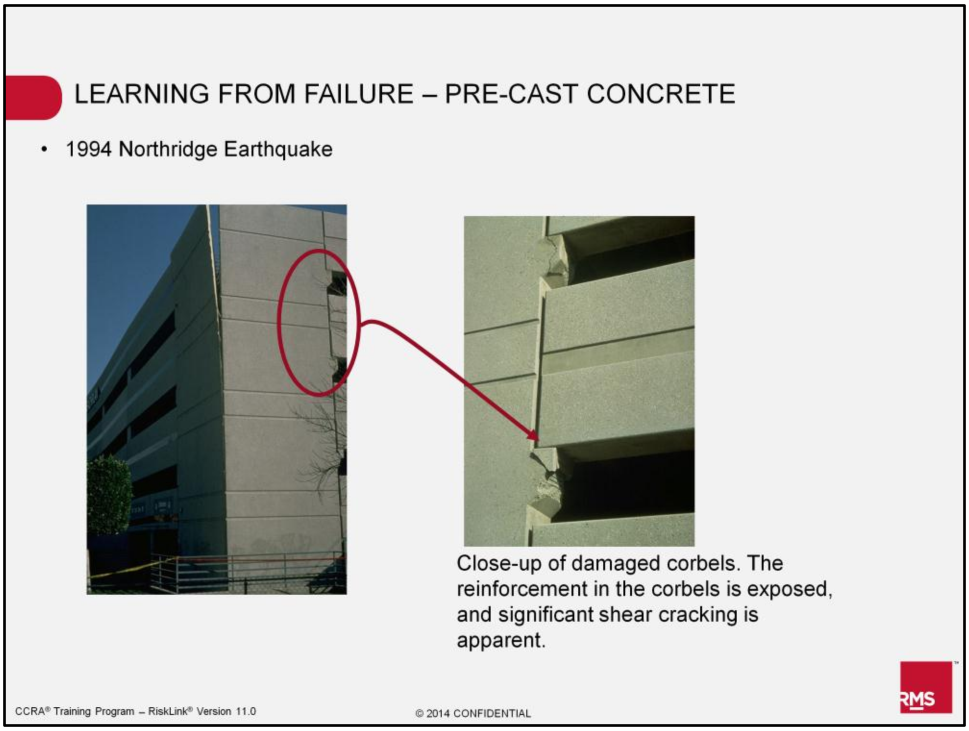
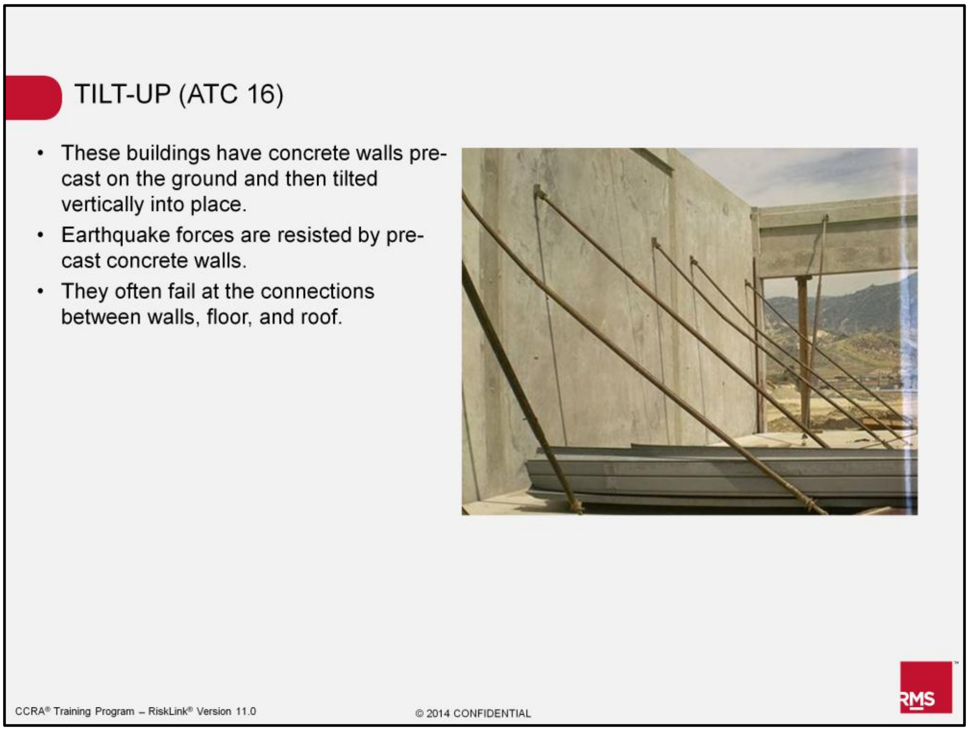
This is a parking garage after the Northridge earthquake in 1994. From the standpoint of life safety, these columns have actually done quite well - there was no one hurt in this building. Part of the roof came down and caused damage to some of the structure.

There was not much of a connection issue with this structure. The structure had no lateral system – if there had been a shear wall in place, the columns would not have experienced this type of deformation.



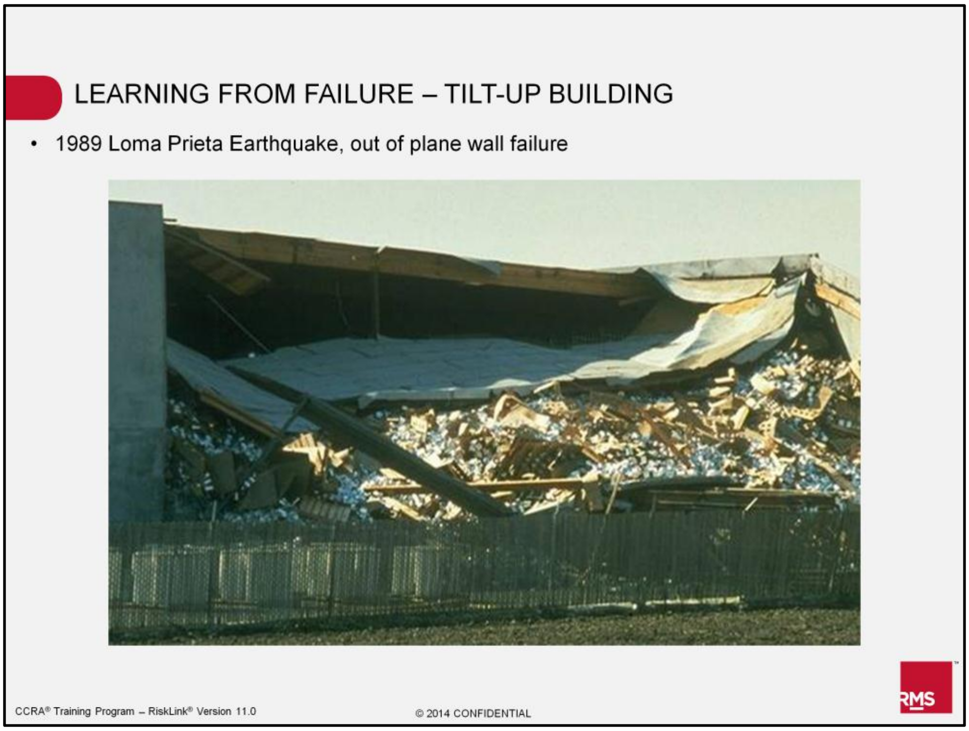
This is another example from the 1994 Northridge earthquake. These pre-cast pylons hit the top of the corbels. If there is sufficient impact due to the movement back and forth, they can cause cracks at the location where the pylons are sitting, which is actually the weakest point on this type of structure. A corbel is defined as an architectural member that projects from within a wall and supports a weight, especially one that is stepped upward and outward from a vertical surface.



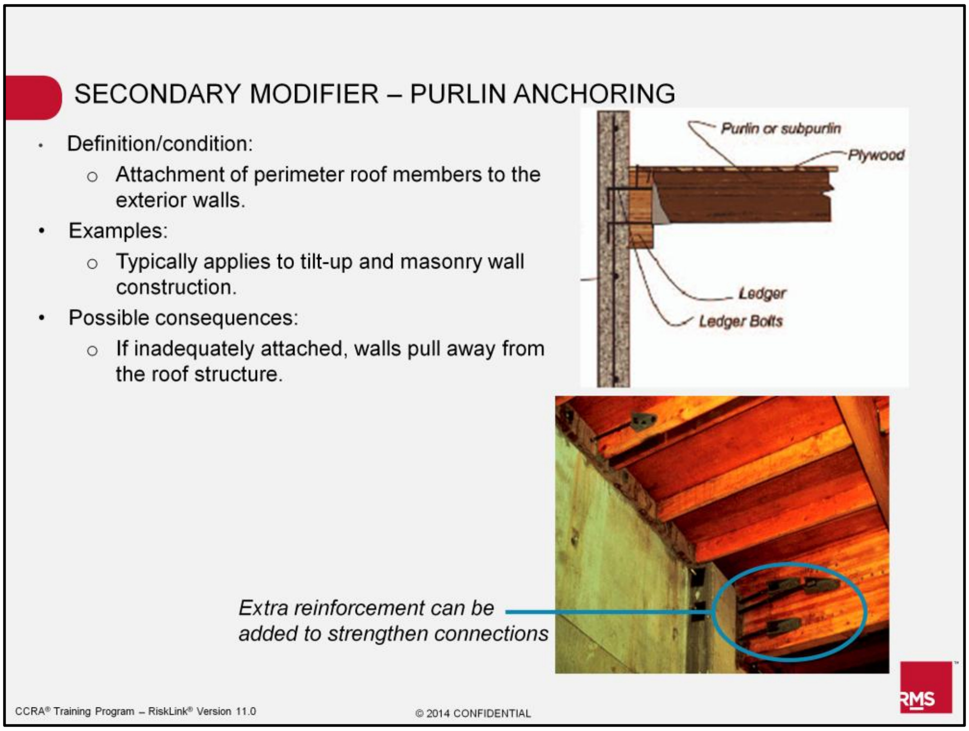
Another group of pre-cast concrete structures are tilt-ups. These buildings are typically single story structures. They may build another level on the interior of the building, but in terms of the construction, they are only one story.

The walls are built on site and then tilted upward to create the exterior of the building. The roofing system is then built. If the roofing system is not properly connected to the walls, these walls could fall apart.

The main cause of failure to tilt-up buildings is out-of-plane failure, due to insufficient connectivity between the roof and the walls.



This is an example from the Loma Prieta earthquake in 1989. The walls were not connected properly to the roof. They were out of plane; part of the roof did not have sufficient support and ultimately came down.

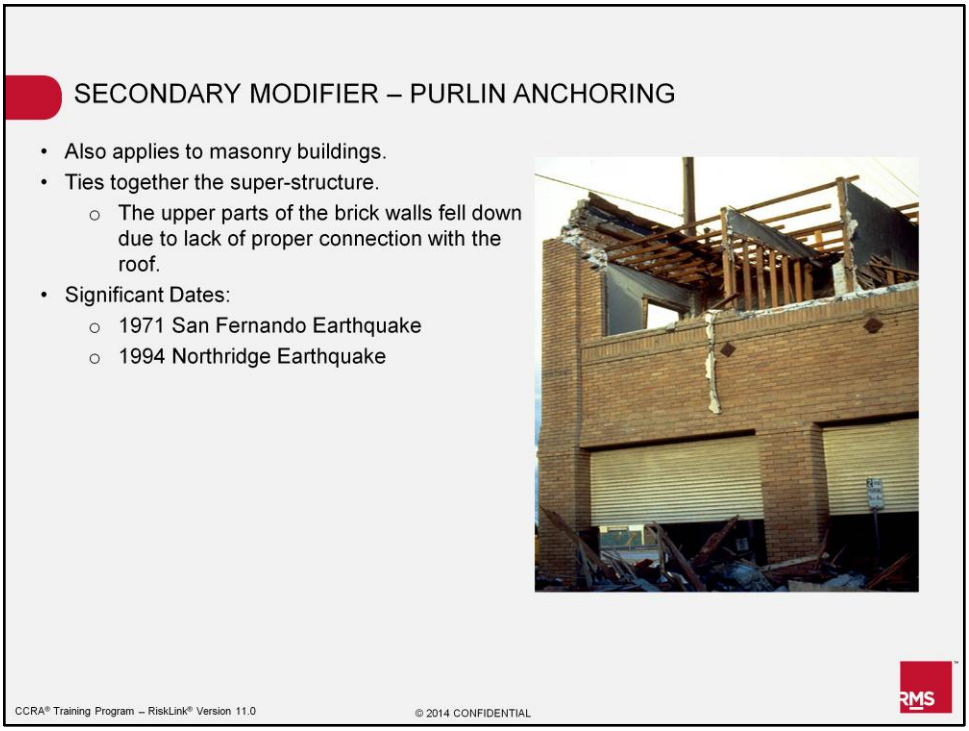


As mentioned earlier, every earthquake provides examples or lessons to learn.

Tilt-up buildings performed differently in the 1971 San Fernando earthquake than they did in Loma Prieta in 1989 and Northridge in 1994, because of a change in building codes after 1971. We expect that the new tilt-up buildings will perform much better in future earthquakes than they did in 1989 or 1994 for the same reasons.

In order to provide connectivity between the walls and the roof, the purlin anchor can be used. This is actually connecting the beam to the walls and making the assembly more uniform. When shaking occurs, the structure will then move together as a unit – roof and walls.

During the Northridge earthquake, RMS found that even though the roof is connected properly to the walls, there can be another type of failure. The picture at the top shows the connection of the purlin to the wall using a ledger. Even though you have a purlin connection, you have to have sufficient nailing from the deck to the ledge.



Purlin anchoring is not only applicable to tilt-up buildings, it is also applies to masonry buildings. As we discussed earlier, this type of failure is very common. If the URM (unreinforced masonry) is not properly connected to the roof, there can be out-of-plane failure.

Using purlin anchoring will reduce this type of failure by properly connecting the walls to the roof. The significant dates for seeing this are the 1971 San Fernando earthquake and the 1994 Northridge earthquake.

LIGHT METAL (ATC 2)

- Light metal structures are pre-engineered and prefabricated with transverse rigid steel frames.
- They are one story in height.
- The roof and walls consist of lightweight metal.

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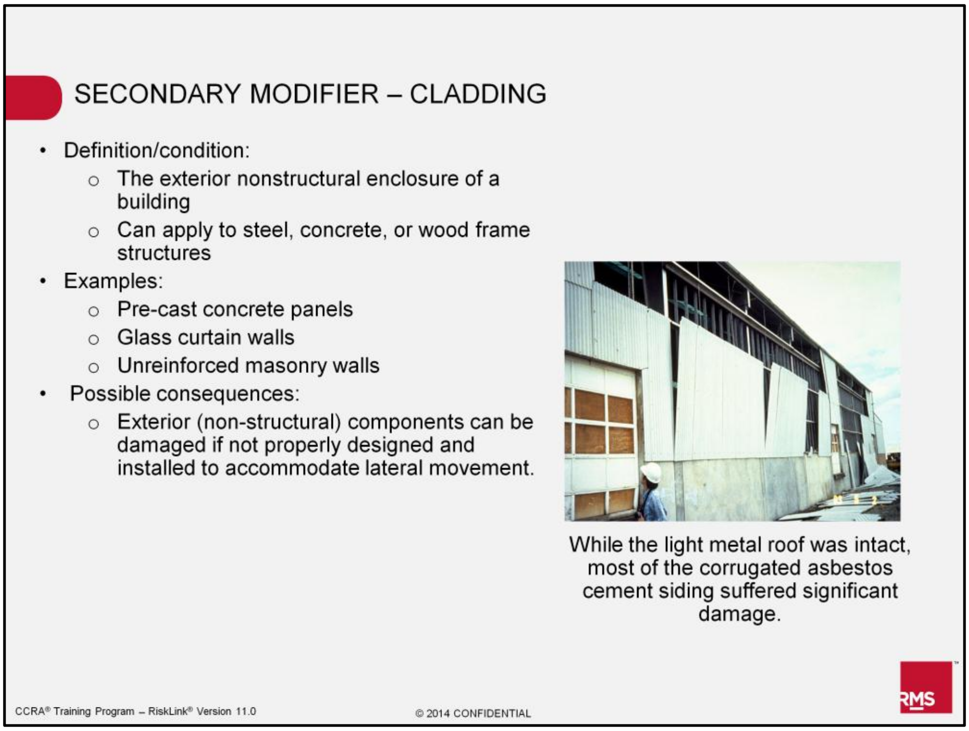
Now we move to a new group of structures – steel structures. We will start with light metal.

Light metal structures are engineered and prefabricated somewhere other than the job site. All the parts are brought together and the builder assembles the building and provides the appropriate connections.

These types of structures are commonly used to build warehouses, workshop areas, and storage units. They are very efficient and good performers during an earthquake because they are very light. They are typically only one story in height and the roof is constructed of light-weight metal.



Cladding, which is a secondary modifier, is a material applied to the exterior of a structure. It is not part of the structural enclosure of the building.

Cladding is often not properly connected to the main structure. As we have referenced many times during this presentation, if a structure is not connected properly it will move out-of-plane. That is, when the building experiences shaking, the poorly connected part of the structure will move separately from the remainder of the building. If a building is well constructed and connected, it will move together as a unit and, therefore, damage will be minimized.

Light metal is one common type of cladding. However, pre-cast concrete panels, glass, and unreinforced masonry can also be used as cladding. Again, if these materials are not properly connected they can move out-of-plane and earthquake damage may be significant.

BRACED STEEL FRAME (ATC 9)

- Earthquake forces are resisted by steel braces.

Shear bracing on the outside frame of the building down to the first floor.

Below the first floor, horizontal shear force is transferred to a central core.

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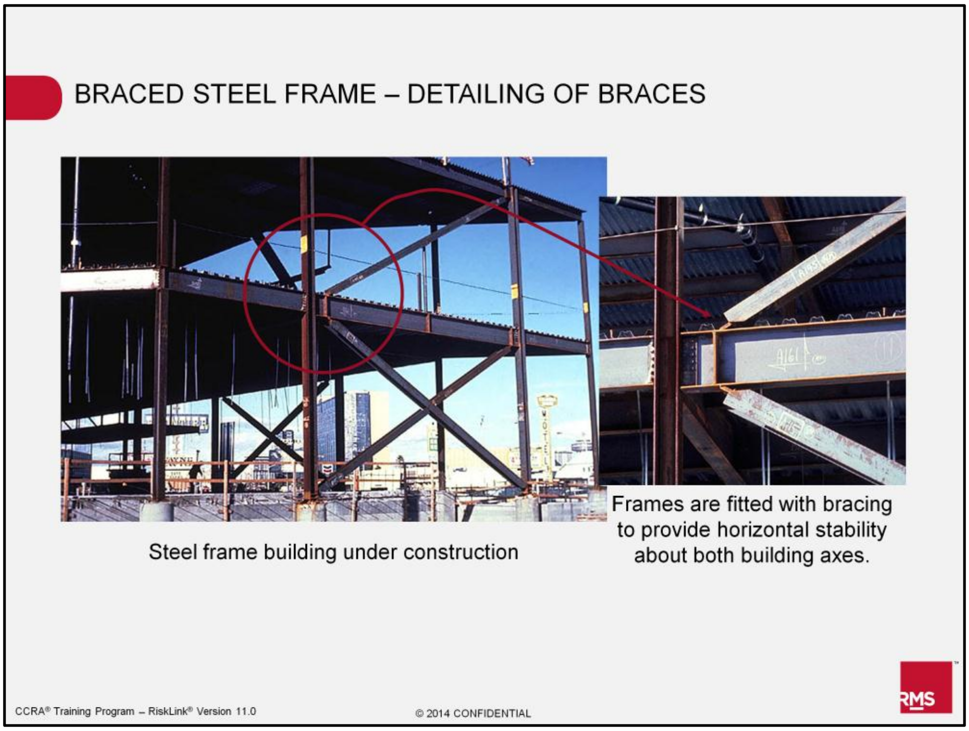
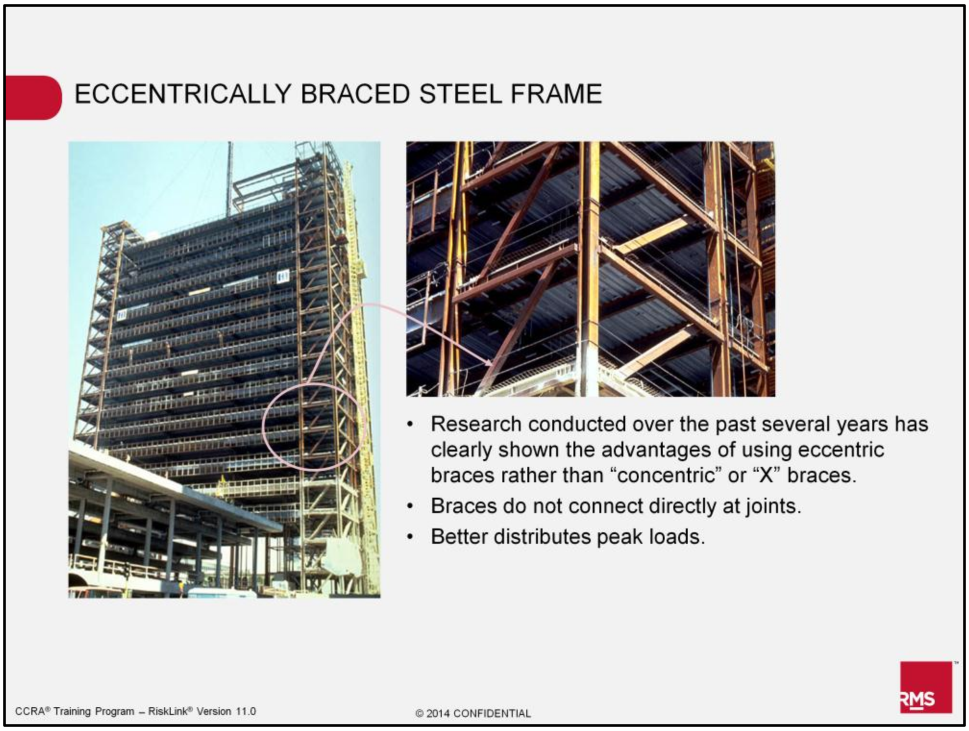
The next group of structures are steel structures with a frame. These are used mostly for high rise buildings.

The example that is shown here is braced steel frame. It is taking the forces from each level and carrying it from top to bottom to the foundation. The picture on the right shows that for this building, the shear force is transferred to a central core column in the middle or interior of the building. As a result, all of the forces are taken from the top of the building and transferred to the foundation. This building has a good lateral system and this type of structure has performed very well in past earthquakes.



This type of bracing is known as an “X-brace” and is connected at the location where the beam intersects the column by connecting a joint on one corner of a floor to the opposite joint on an upper or lower floor. This allows loads from the joints to be transferred to the foundation.

If the vertical bar between both floors is too long, the result could be a buckling of the bar during an earthquake. Using an X-brace means you are reducing the effective length of the vertical brace by half (from an engineering standpoint), thus making the structure more rigid and able to transfer the lateral earthquake forces better.



In this example of an eccentrically braced steel frame building, the braces are not connected from joint to joint as they were in the X-braced building. They are slightly offset from the joints. That means that they are taking the force away from the joints, which is critical. This type of brace will perform even better than an X-brace in the event of a large deformation.

In this example, the braces are connected to the middle of the beam (again, not from joint-to-joint as was the case with the X-brace). In 2001 we saw failure to this type of building. However, it was not actually a failure – the joint started buckling, which was easy to repair at minimum cost, and the structure was immediately functional afterwards.

MOMENT STEEL FRAME (ATC 10 AND 11)

- Earthquake forces are resisted by steel beam-column flexure.
- Perimeter (ATC 10): earthquake forces resisted by perimeter columns only.
- Distributed (ATC 11): design distributes earthquake forces among all columns.
- Differences not discernible by visual inspection.

This six story frame consists of I-beams for horizontals and verticals, and uses all-welded construction.

The function of the brace is the same as the function of the shear wall. It makes a structure more rigid and transfers forces from the top of the building to the bottom.

In moment steel frame (ATC 10 and 11) the earthquake forces are resisted by steel beams and columns. The joints are responsible for carrying the earthquake load. As a result, these joints have to be well defined, well connected, and welded properly to transfer the forces.

Many of the joints in these structures experienced damage during the Northridge earthquake. Since then, the codes have changed and builders are now providing sufficient redundancy in these types of structures so that they will perform better in the future.

MOMENT STEEL FRAME – CONNECTIONS

14-Story steel moment-resisting frame (MRF) building under construction

Typical moment frame connection details

The steel frame connections can be provided by welding or by bolts.

In this example we have a close up of one connection from both directions, which are connected by bolts. As mentioned, many of these connections failed during the Northridge earthquake. As a result, extensive research was conducted and the codes have now changed to provide sufficient redundancy in this type of structure system.

We have a different damage function for post-1994 moment steel frame construction to reflect the improved construction of these buildings. The damage is significantly less in these buildings than in pre-1994 moment steel frame buildings because of the much stricter building code requirements.

These connections are sometimes easier to prefabricate and then complete the connection at the job site. The pre-constructed elements are brought to the job site and then connected to the beam.

These pictures show that the critical building for the beam-to-column connection is done, and then the builders bolt them together at the job site. This has become very efficient, and is very accurate. The end result is a high quality structure.

SECONDARY MODIFIER – EQUIPMENT EQ BRACING

- Definition/condition:
  - Bracing of architectural finishes and utility systems that are not a part of the lateral load resisting system.
- Examples:
  - Piping, A/C units, ceilings, walls, etc.
- Possible consequences:
  - If inadequately braced, can result in extensive damage, including water leakage.

So far, all of the secondary modifiers we have discussed have been structural elements. However, non-structural elements, such as the bracing of architectural finishes, will experience much movement during an earthquake. If they are not properly connected to the structure, then we may see extensive damage to ceilings, walls, etc. Also, it may result in failure of pipelines or sprinkler systems, which will cause water damage to both contents and structures.

STEEL AND REINFORCED CONCRETE (SRC) BUILDINGS

- Earthquake forces are resisted by steel beam-column flexure.
- Common in Japan.
- A light structural steel frame is built first then, to avoid the buckling of steel members, they are covered with confined reinforced concrete.

Composite structural steel and reinforced concrete earthquake-resistant building under construction in Japan.

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There is a special type of building that is mostly made in Japan – it is not common in the U.S. The first five to six levels of the building are built using light steel frame and then concrete is added to reinforce the frame (the process shown in the picture). Another six to seven levels are then built on top, however these levels of the structure would continue all the way to the top as a steel only structure. In other words, concrete is not added to these upper levels as it was to the lower levels.

If the upper levels are not connected properly with the five or six stories below – that is, if there is a discontinuity– that can cause significant damage in an earthquake. This was a common cause of failure to these structures in the earthquake in Kobe, Japan and there are numerous publications on this failure.

SUMMARY

- Building performance in earthquakes depends on both ground motions and building characteristics.
- Building characteristics (primary and secondary) are critical inputs provided by the user of a catastrophe model.
- Of the four primary building characteristics (construction class, occupancy type, year built, and number of stories), construction class requires the most background knowledge to appropriately identify.
- Losses can be further refined when data is available on secondary construction characteristics.
- Familiarity with common construction classes and associated secondary characteristics can help you with:
  - Data collection
  - Data quality assessment
  - Interpretation of earthquake loss results

To summarize, the performance of a building is dependent on two things: the ground motion and the construction of the building. The degree of damage is dependent on the primary and secondary characteristics of the building. A clear understanding of the primary and secondary characteristics of the building could help you to better capture the necessary data for modeling, and to differentiate the loss potential of one building from another. Losses can be further refined when data is available on secondary construction characteristics. Familiarity with the common construction data can help you understand what data needs to be collected, the quality of the data that you are receiving, and ultimately, it will help you with the interpretation of modeled earthquake losses.

This concludes the Earthquake Pre-Reading presentation.