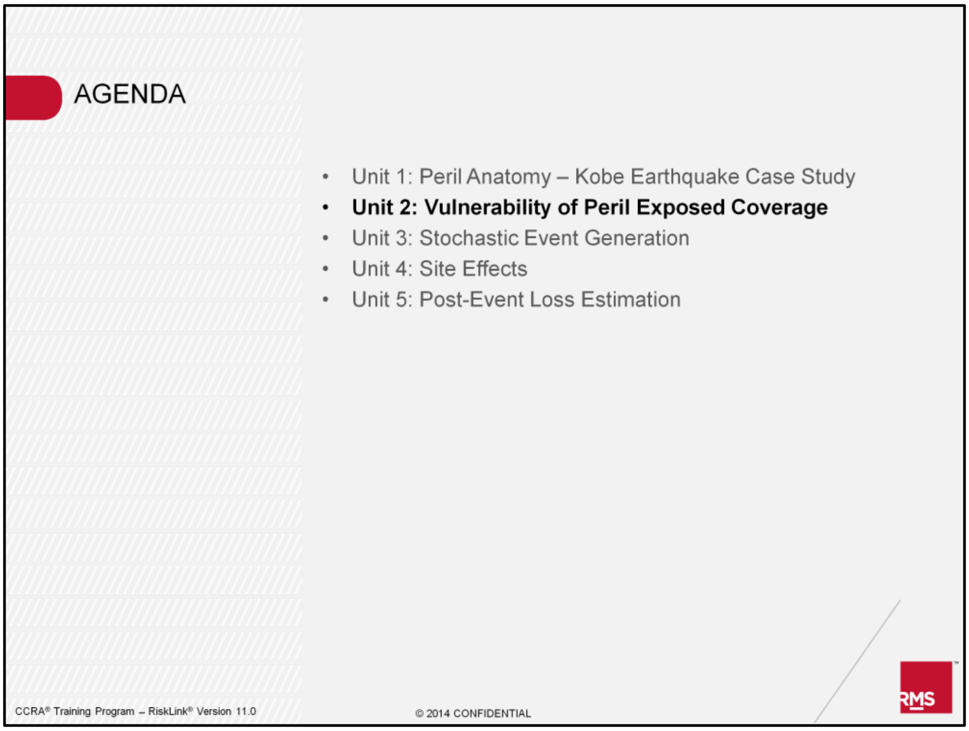
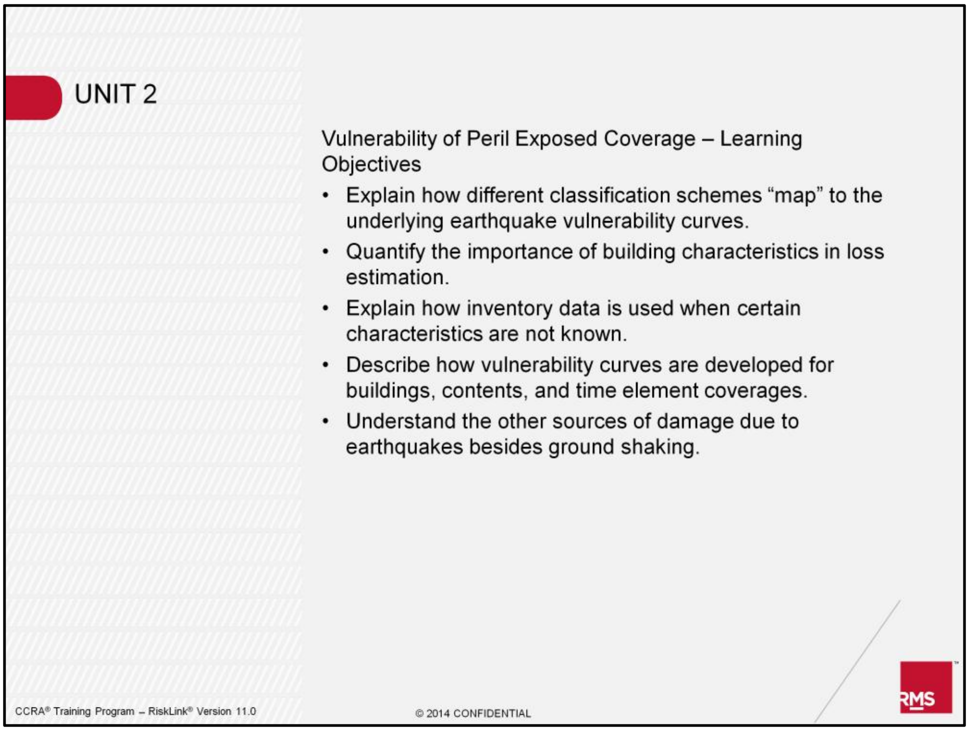
EARTHQUAKE MODELING UNIT 2

RMS® CCRA® Training Program

Certified Catastrophe Risk Analyst



This unit will discuss classification schemes, building characteristics, and inventory data as well as the development of vulnerability curves and sources of earthquake damage beyond ground shaking.

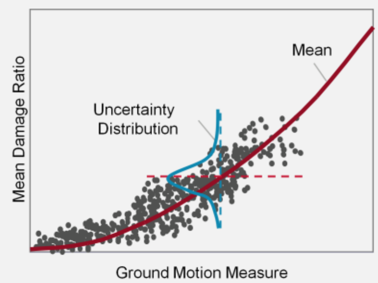


At the end of this unit you should have a good understanding of each of the five learning objectives listed on this slide.

VULNERABILITY MODEL

- Shows relationship between ground motion (MMI, PGA, Sa) and damage (MDR)
- Damage represented as percent of:
  - Building replacement cost
  - Contents value
  - Time element coverage
- Vulnerability functions are region-specific and vary by building class, age, and height.
- Vulnerability functions are calibrated with actual damage and loss data from past earthquakes.

Vulnerability Function for Reinforced Concrete (RC) Building



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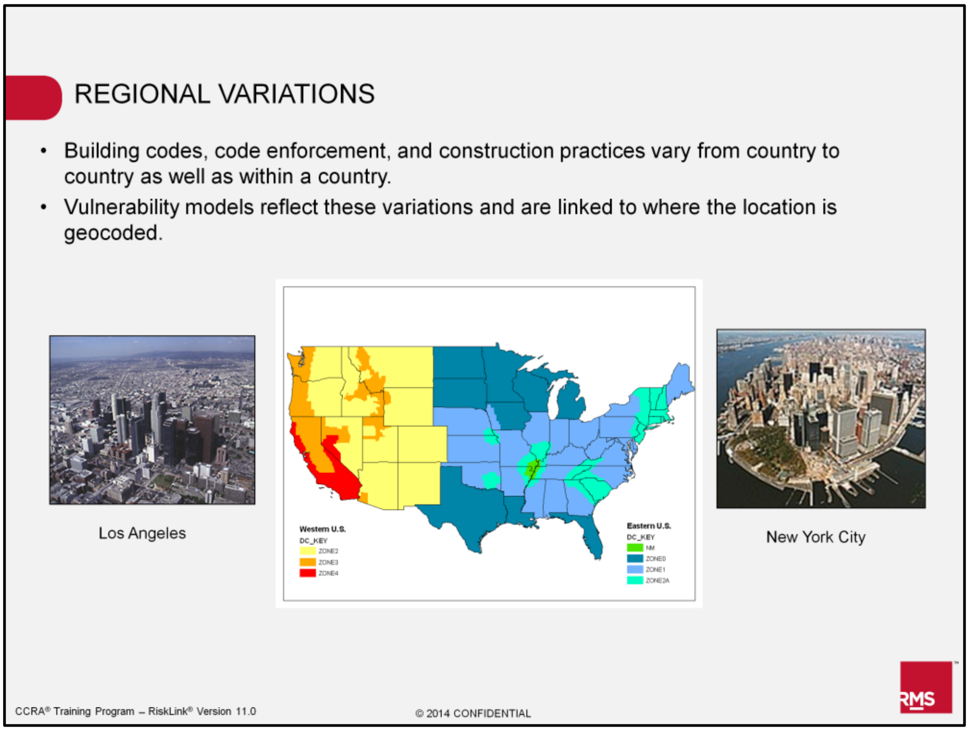
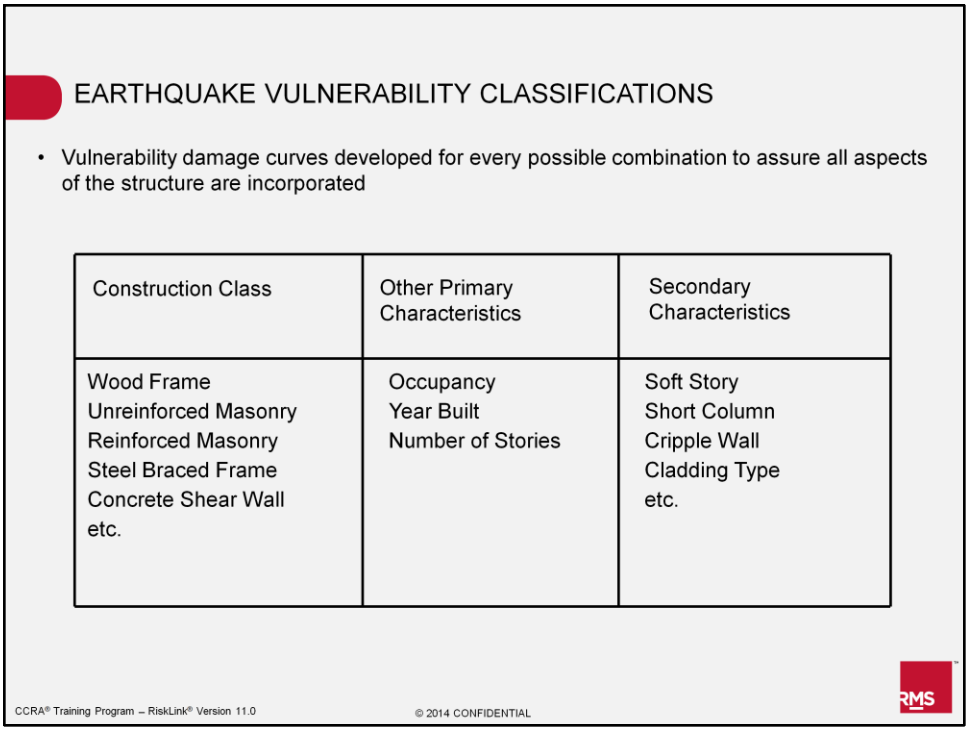
The vulnerability module is where we relate the ground motion observed to damage during an event at a location. Ground motions are usually modeled in either intensity, such as Modified Mercalli, in terms of observed ground motion, or in instrumentally measured ground motion, such as peak ground acceleration or spectral acceleration. We match these through a damage curve to a mean damage ratio for that ground motion. Damages are represented as a percent of the building replacement cost, the contents value, or the time element coverage. Note that for business interruption the damage ratio is the percent of the year in which the structure is not available. We will talk about this in more depth later in the presentation.

We build vulnerability curves or functions for many different sets or combinations of building classifications, building ages, and building heights. These vary on a regional basis. It is important to understand that from place to place there are different types of buildings, different age ranges, and different height ranges over which we calculate these curves. The curves are then calibrated against actual damage and loss data from past earthquakes. The plot on this slide shows observed data for reinforced concrete buildings in the Kobe earthquake. You can see that there is quite a scatter when we relate the mean damage ratio to the ground motion measure. It is important to understand that there is uncertainty around this mean damage ratio and that it is carried on through the financial calculation.



As was just mentioned, there are regional variations. Building codes, how well they are enforced, and construction practices in general vary from country to country and can also vary within a country. The vulnerability module reflects these variations. How we are able to pull these variations into the model and reflect it on the exposure is based on the level at which it is geocoded. Within each model, the vulnerability data is stored at different geocoding resolutions. The set of building curves the model accesses is based on how the locations are geocoded. For the U.S. these curves vary at the county level.



When incorporating exposure information within the databases, there are key pieces of information that help the model determine the most appropriate set of damage curves for each structure or location. The two most important primary characteristics are construction class and occupancy. Construction class determines the type of construction and the materials used to build the structure. Occupancy is also important because construction practices vary between occupancies. Year built and building height are also important primary characteristics that can have significant impacts on how a structure will respond to an earthquake. In addition to the primary characteristics, the vulnerability module allows for the inclusion of a set of secondary characteristics that modify the response of the standard primary characteristic combinations. The next few slides cover these different sets of characteristics in more depth.

EARTHQUAKE: CLASSIFYING STRUCTURES
PRE-READING

- Classifying Structures for Earthquake - A good reference guide
- Showed how to identify the primary and secondary structural characteristics that are most critical to earthquake modeling
- Indicated ways to recognize potential data quality problems, such as illogical combinations of primary and/or secondary characteristics

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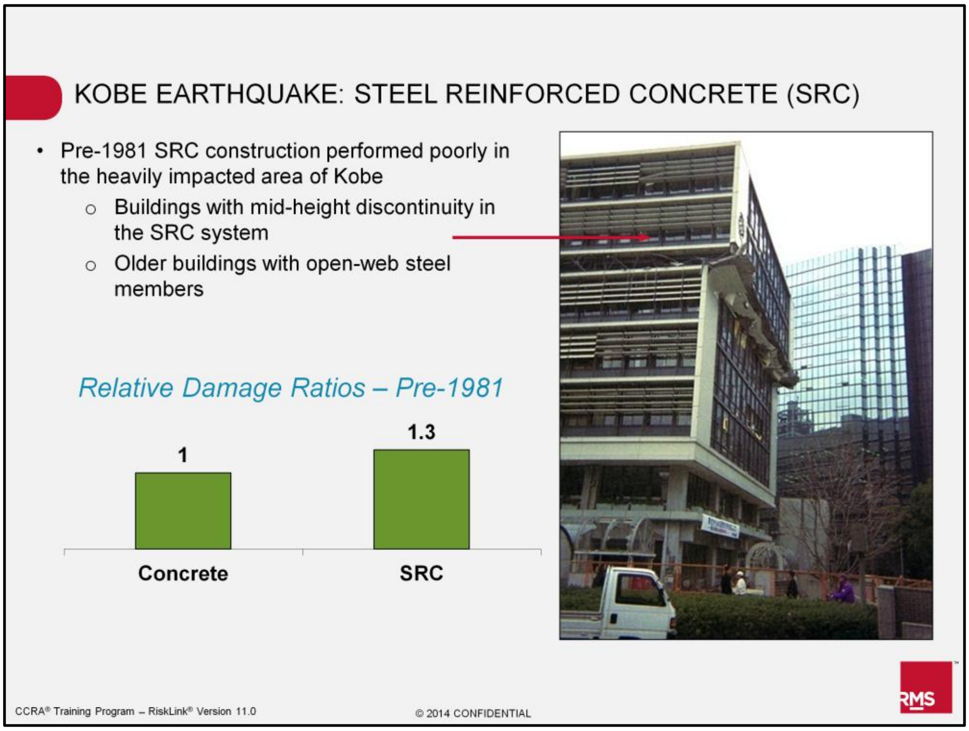
The pre-reading is a great tool for reviewing how to classify structures. It discussed most of the primary and secondary structural characteristics that are most important for earthquake. The pre-reading also walked through how these of the structural characteristics are damaged. Note that the model is intelligent enough to understand that certain combinations of primary and secondary characteristics are illogical and so cannot be combined. In these cases you will not be penalized nor will you receive credit for these secondary characteristics.



We will look at the Kobe earthquake to understand why building classification is very important. In Japan there is a special type of building called a steel reinforced concrete structure. These buildings use steel in their reinforcement. We have already talked about how 1981 was an important year for building codes, enforcement, and changes in how structures were built in Japan. Steel reinforced concrete buildings that were built prior to 1981 performed poorly in the Kobe earthquake. The arrow on the photo is indicating where a floor has been lost on this structure. There were a number of structures in the downtown area of Kobe that lost floors though they looked like new, well-built structures. These structures were actually built prior to 1981 and they had a fundamental flaw. Somewhere in their mid-height they had a discontinuity in how the steel reinforcement had been implemented. The steel reinforcement typically extends up to about five floors. The first five floors were often built first, and then more steel reinforcement was added above the fifth floor, but the connection between the first five floors and the floors above was very poor. As the photo shows, a floor has been lost in a building of this type. The bar chart on this slide shows the relative damage between the concrete buildings and the steel reinforced concrete buildings built prior to 1981. You can see there is a 30% increase in the damage ratio for these structures. It is important to be able to identify in detail what type of structure you are insuring in order to accurately estimate the potential damage.

EARTHQUAKE CONSTRUCTION CLASS SCHEMES

- A construction class scheme is an approach to organizing all of the various building construction types into a set of classes.
- A number of classification schemes are available with the earthquake peril:
  - Primary schemes: RMS and ATC
  - Others: ISO EQ, ISO Fire, User Defined (e.g., Canada Fire), and JPBldg
- Pre-reading discussed the ATC classification scheme

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One issue that can be confusing is that there are a number of different construction class schemes that have been developed within the structural engineering and insurance communities. There is no single construction scheme that is favored globally across these industries. The two primary schemes which are more closely related to the underlying engineering of structures are the RMS and ATC schemes but there are a number of others. In Japan in particular, there is a different scheme that is more specific to the structures built in Japan. The pre-reading discussed the ATC classifications and there is detailed documentation about all of the classifications available on www.rms.com.

EARTHQUAKE CONSTRUCTION CLASS SCHEMES

	RMS	ATC	FIRE	ISO	RMSEQ	RMSHU	RMSTH	USER	JPBLDG	EURO
Australia	P	X								
Canada	X	P	X	X				X		
Caribbean	P	X	X	X	X	X	X			
Central America	P	X								
China	P	X								
Europe	P	X								X
Greece	P									
Guam	P	X	X	X	X	X				
Hong Kong	P	X								
Indonesia	P	X	X	X						
Israel	P									
Japan	P				X	X			X	
Mexico	P	X								
New Zealand	P	X	X	X						
Philippines	P									
South America	P	X								
Taiwan	P	X								
Turkey	P									
United States	X	P	X	X						

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This slide shows the various construction class schemes used within the RMS earthquake models. A red P indicates the primary scheme used by the earthquake model for the region. Notice that the RMS scheme is the primary scheme used for all regions except Canada and the United States. The primary scheme used for these two regions is ATC. An X indicates that scheme is available in that region but the model will map to the primary scheme.

EARTHQUAKE CONSTRUCTION CLASS SCHEMES

ATC Class	Description	RMS Class	Description
1	Wood Frame	1	Wood
		1A	Light Wood
		1B	Heavy Timber
3	Unreinforced Masonry Wall	2	Masonry
		2A	Weak Masonry
		2B	Unreinforced Masonry
7	Reinforced Masonry Shear Wall	2C	Structural Masonry
5	Reinforced Concrete Shear Wall with Frame	3A2	Reinforced Concrete Moment Resistant Frame with Shear Walls
6	Reinforced Concrete Shear Wall without Frame	3A4	Reinforced Concrete Shear Wall
17	Mobile Homes	5	Manufactured/Mobile Homes
		5A	Without Tie Downs
		5B	With Tie Downs
21	Major Bridges (>500 feet)	8	Major Bridges (>500 feet)
24	Concrete Dams	11	Concrete Dams
37	Runways	24	Runways

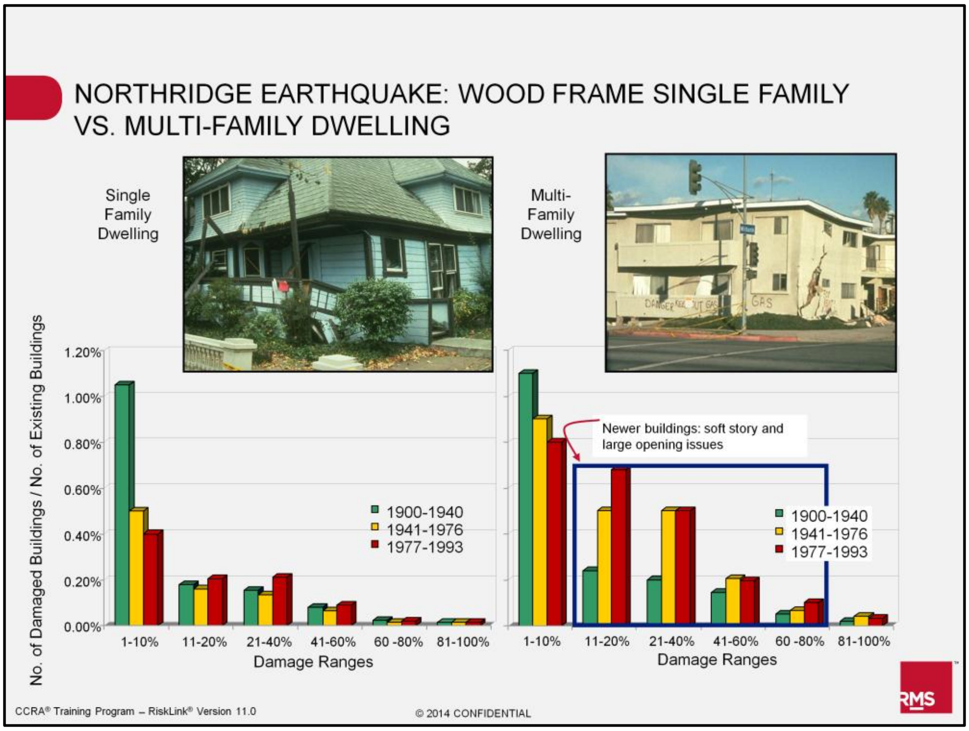
This table provides some insight into how these schemes map to each other by relating a few of the ATC classifications to the RMS classifications. The table shows ATC 1 is wood frame. RMS 1 is also wood frame but it is broken down further into wood, light wood, and heavy timber. There are additional sub-classes in the RMS scheme such as 1A1 and 1A2. Many classifications in different schemes map one to one, for example concrete dams and airport runways.

EARTHQUAKE OCCUPANCY TYPE

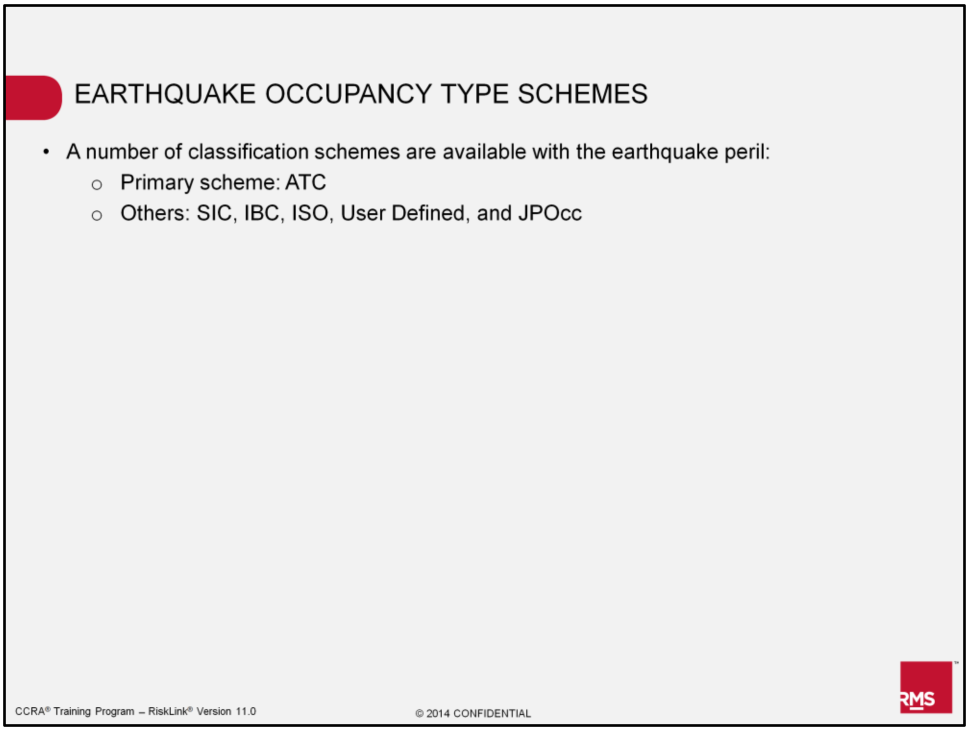
- An occupancy defines the type of activity that occurs within the structure and is used to differentiate between buildings of a particular construction class (e.g., wood frame: single family versus multi-family structures).

ATC Type	Name	Description
0	Unknown	
1	Permanent Dwelling (single family housing)	Owner-occupied detached dwellings
2	Permanent Dwelling (multi-family housing)	Owner-occupied attached dwellings, such as: Condominiums, Townhouses, and Apartments
3	Temporary Lodging	Hotels and lodging places
5	Retail Trade	Retail stores and other retail trade
9	Health Care Service	Doctors' and dentists' offices; Hospitals and clinics; Nursing and personal care; Other medical and health services
11	Parking	Parking Garages

Next we will look at occupancy type. Occupancy type reflects the kind of activity that occurs within the structure. Buildings of the same construction class but different occupancies will likely have very different losses. Occupancy type is tied directly to how we calculate damage to contents and how we look at business interruption so understanding the occupancy is very important for those coverages. The table on this slide shows some basic ATC occupancy types such as single family dwelling, multi-family dwelling, temporary lodging, and retail. So again, understanding how the structure is being used is critical to understanding how the structure will respond to ground motion.



This slide shows an example from the Northridge earthquake and examines the difference between how wood frame single family structures faired versus multi-family structures. On the left there is a heavily damaged single family structure that has come off its foundation. This happened to a number of structures. The chart on the lower left shows the damage ratios by year built in terms of the number of buildings damaged versus the number of buildings that exist. On the right there is an example of a multi-family structure that has been damaged. In a number of cases these multi-family structures in Southern California had parking on the first story and this soft story resulted in extremely high damage ratios for buildings. Interestingly, tuck under parking was a new feature after 1941 and was more prevalent after 1977. We actually see higher damage ratios for the newer multi-family structures. In this case it is important to understand the occupancy of the wood frame structure to better assess what kind of damage it experienced.



This slide points out that as with construction classes, there are a number of different occupancy type schemes. ATC is the primary scheme used by RMS but there are others available.

EARTHQUAKE OCCUPANCY TYPE SCHEMES

	ATC	IBC	SIC	NAICS	NCCI	ISO	WCOCC	EURO	EURO_FR	JPOCC
Australia	P		X	X		X	X			
Canada	P	X	X	X		X	X			
Caribbean	P		X	X		X	X			
Central America	P	X	X	X	X	X				
China	P		X	X			X			
Europe	P		X	X		X	X	X	X (FR only)	
Greece	P		X	X			X			
Guam	P		X	X		X	X			
Hong Kong	P		X	X			X			
Indonesia	P		X	X		X	X			
Israel	P		X	X			X			
Japan	X		X	X		X	X			P
Mexico	P	X	X	X	X	X				
New Zealand	P		X	X		X	X			
Philippines	P		X	X			X			
Taiwan	P		X	X			X			
Turkey	P		X	X			X			
United States	P	X	X	X	X	X	X			

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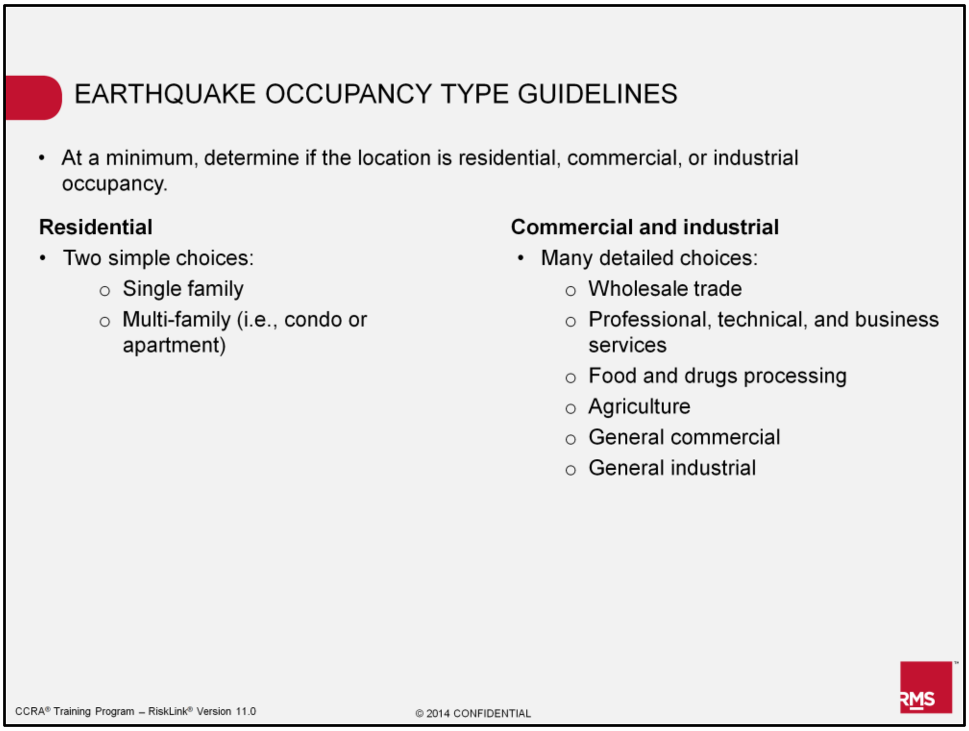
RMS

The table on this slide shows the occupancy types used across the earthquake peril countries and you can see that most are using ATC as the primary occupancy type. Japan is the one exception, using a Japanese scheme instead.



This slide discusses some guidelines when considering occupancy types. At a minimum, try to differentiate between residential, commercial, and industrial occupancy. Leaving the occupancy unknown requires RMS to make some assumptions about what the exposure might be, which may not best represent the exposure. Generally, it should be relatively easy to differentiate between single family and multi-family when looking at a residential occupancy. The Northridge example highlighted the importance of this distinction. It is acceptable with commercial and industrial to use the general options but there are a number of other choices. If you do know the type of activity that occurs in the structure, select the corresponding general commercial or general industrial occupancy type. This is particularly important when considering how contents are damaged or how business will be interrupted.

PRIMARY CHARACTERISTIC: YEAR BUILT

U.S. Earthquake
Year Built Ranges By Region

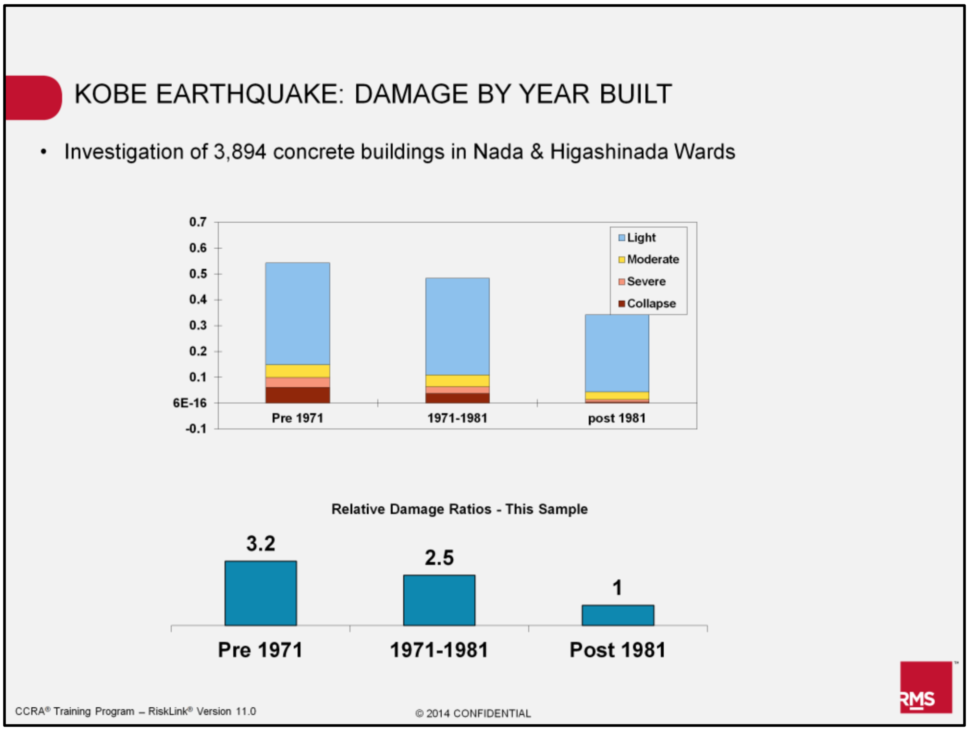
Steel Moment Resisting Frame	
Eastern U.S.	**Western U.S.**
Pre-1937	Pre-1937
1937 - 1991	1937 -1973
1992-1995	1974 - 1988
Post-1995	1989 - 1995
	Post-1995

All Other Construction Classes	
Eastern U.S.	**Western U.S.**
Pre-1937	Pre-1937
1937 - 1991	1937 -1973
1992-2000	1974 - 1988
Post-2000	1989 - 2000
	Post-2000

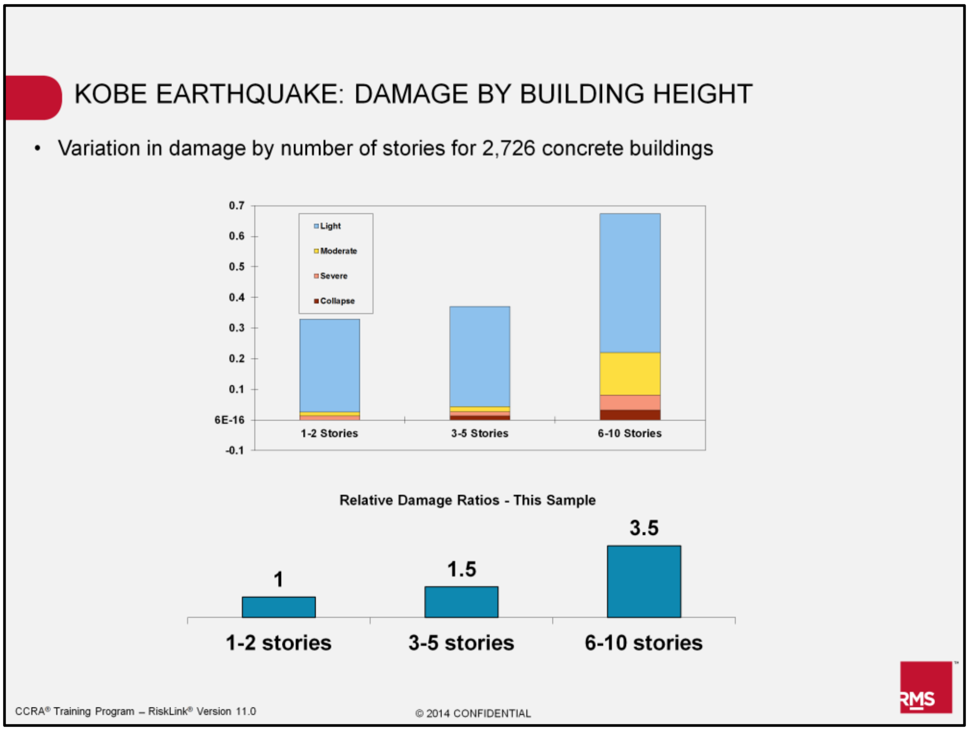
- Construction practices change over time.
- Vary regionally to account for these variations in building practices and codes
- For unknown year built, the model refers to the inventory data.

Next we will discuss the other primary characteristics. This slide details year built. Construction practices change over time and this is true worldwide. There are also variations in how the codes are implemented and how well they are practiced. Leaving the year built unknown means the model will revert back to the inventory data in order to have some information about when the structure may have been built based on the occupancies and construction class selected. Knowing exactly when the structure was built or when it was last mitigated can have a significant impact on the losses that may be experienced.

The table shows the important year ranges within the earthquake model in the U.S. which vary based on the construction class and region. You can see there were some changes in construction practices in the Eastern U.S. in the 1930s and the 1940s and there were additional changes in the 1990s. The year ranges for the western U.S. are really driven by significant earthquakes. The 1933 Long Beach earthquake impacted how structures were built post 1937. The 1971 San Fernando earthquake impacted how structures were built post 1974. There were some building code changes around the 1989 Loma Prieta earthquake and there were also some changes after the Northridge earthquake in 1994. When you look globally at how the year built ranges are defined, they are driven by how large earthquakes have impacted the region and how codes have changed due to that impact, and they are also driven by how building practices have changed. So it is helpful to be able to determine the year a structure was built, which in turn will allow a better assessment of how it is likely to perform in an earthquake.



This slide shows an example from the Kobe earthquake. The pale blue represents buildings that were lightly damaged, yellow represents buildings moderately damaged, pink represents buildings that were severely damage, and red represents buildings that completely collapsed. The graph shows that buildings built prior to 1971 faired poorly and buildings built between 1971 and 1981 also did not fair very well. Few buildings built after 1981 sustained severe damage and very few collapsed. This graph makes it clear that knowing whether a building had been built before 1981 or before 1971 would help better assess what its damage level might be. When you look at the relative damage ratios chart at the bottom of the slide it is clear that structures built between 1971 and 1981 had two and a half times higher damage ratios than structures built after 1981. Structures built before 1971 saw 3.2 times higher damage ratios compared to post-1981 structures. This highlights, again, the importance of knowing when a structure was built or when it was last mitigated.

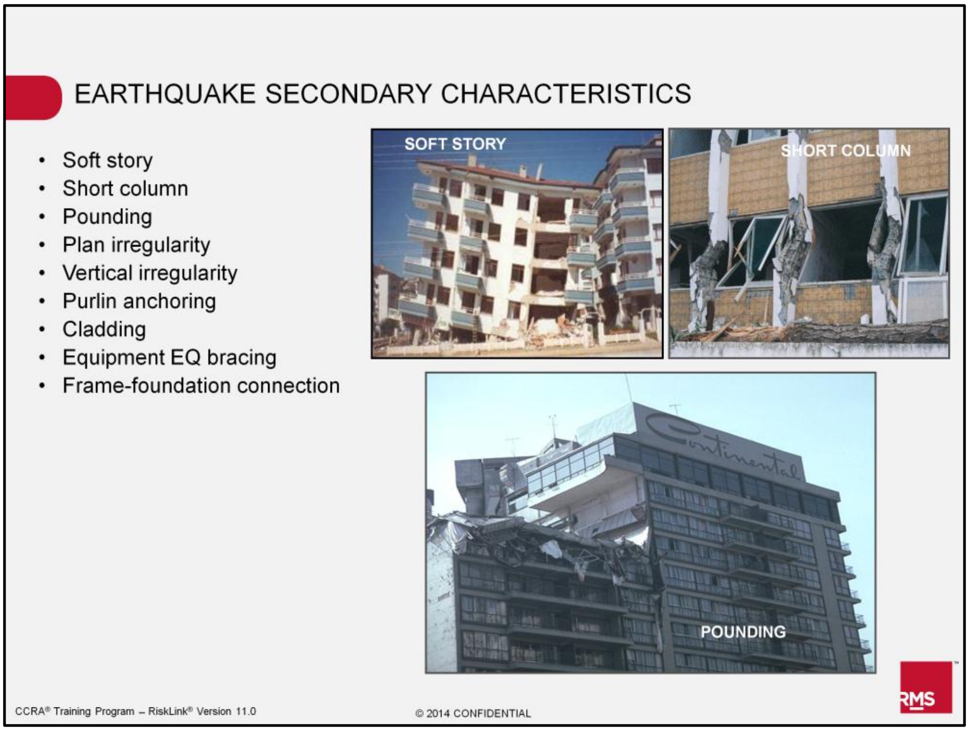


This slide shows another example from the Kobe earthquake. You can see that very few of the one to two story buildings collapsed and they also had the lowest level of overall damage. The three to five story buildings have higher damage and the six to ten story buildings have much higher damage ratios. The damage ratios are on the order of 3.5 times higher in the six to ten story buildings than for the shorter story buildings. This reinforces the importance of knowing the height of the structure.

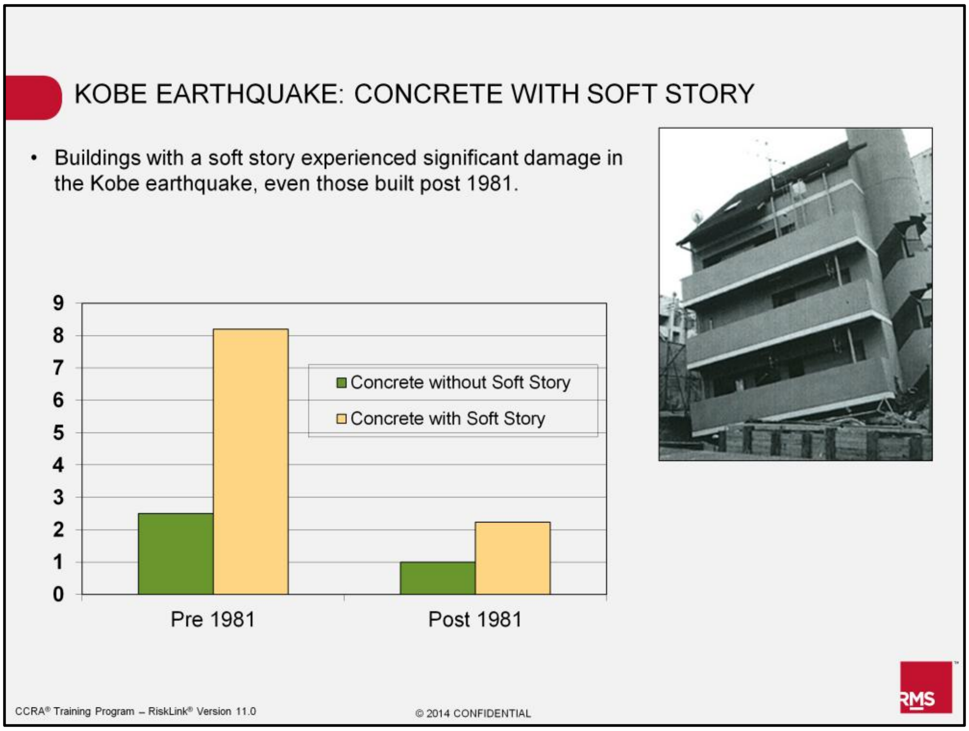
EARTHQUAKE SECONDARY MODIFIERS

- Modifier values are intended to quantify the “average” impact of the secondary modifier.
- Values are largely based on engineering judgment/analysis.
- Actual loss data related to building specific characteristics is often not available, impacts in past EQ events is anecdotal.
- Nevertheless, the impacts of building characteristics are fairly well understood based on actual building performance.

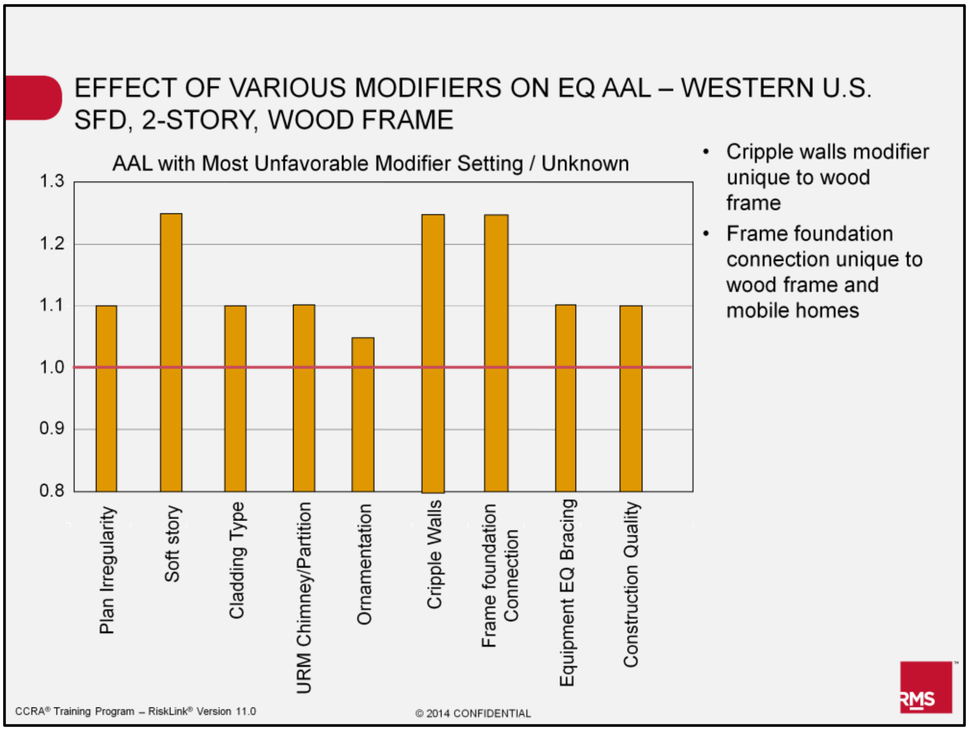
Next we will discuss secondary modifiers. Secondary modifiers take the damage curves based on the primary characteristics and makes adjustments based on the expected impact of the secondary characteristic. Both positive and negative adjustments are possible. How these impact the damage ratios is based primarily on engineering judgment. When looking at the damage statistics that have been collected for earthquake, detailed information about the primary characteristics are typically collected, but the secondary modifiers are typically underrepresented in the loss data. Nonetheless, the impact of these secondary building characteristics is fairly well understood based on building design principles.



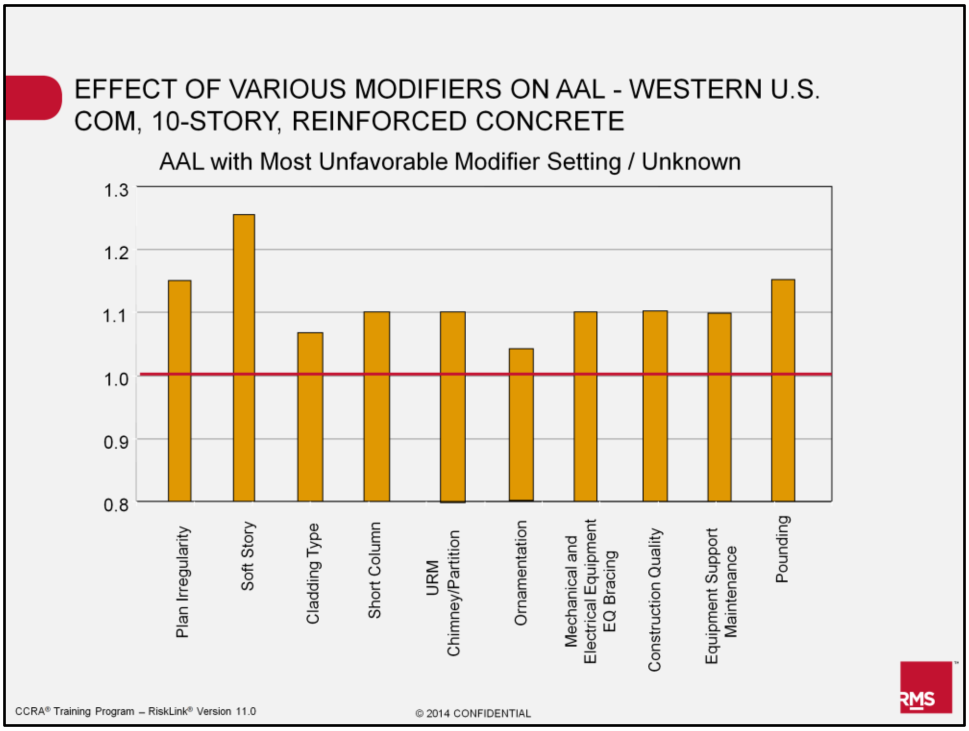
There is a series of secondary characteristics available within RiskLink. The pre-reading looks at each of the primary building classifications and several of the most important secondary characteristics that relate to them. Some of the more important secondary characteristics for earthquake are listed on this slide. You will notice soft story is on the list as well as short column and pounding. The pre-reading contains more details about each of these.



Here is an example of a concrete building with a soft story from the Kobe earthquake. Soft stories were mentioned earlier in the presentation when we discussed examples of occupancy for wood frame structures from the Northridge earthquake. A soft story is generally a first floor that does not have much lateral support, typically either parking or a large area with no walls to prevent the building from torquing during an earthquake. These kinds of structures often collapse. The chart at the bottom of the slide shows concrete buildings without soft stories in green and concrete buildings with soft stories in yellow. You can see that the buildings with soft stories built prior to 1981 faired more poorly than those built after 1981. You can also see that buildings with soft stories built after 1981 saw significantly higher damage than those built after 1981 without soft stories.



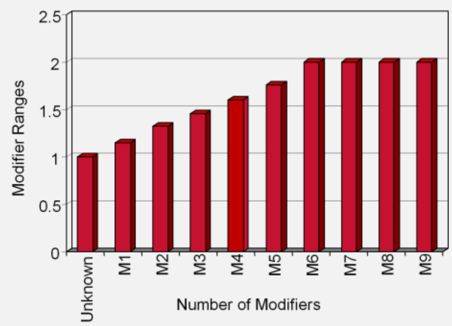
This slide also comes from the pre-reading and looks at how wood frame structures are impacted by modifiers. These are the most unfavorable modifier settings for each of the various classifications. You will notice that in general the variation in the damage ratio is on the order of about 5% to about 25%. Looking at the chart, we see that when looking at wood frame structures, cripple walls are important as is whether a building has been bolted to its foundation and the existence of a soft story.



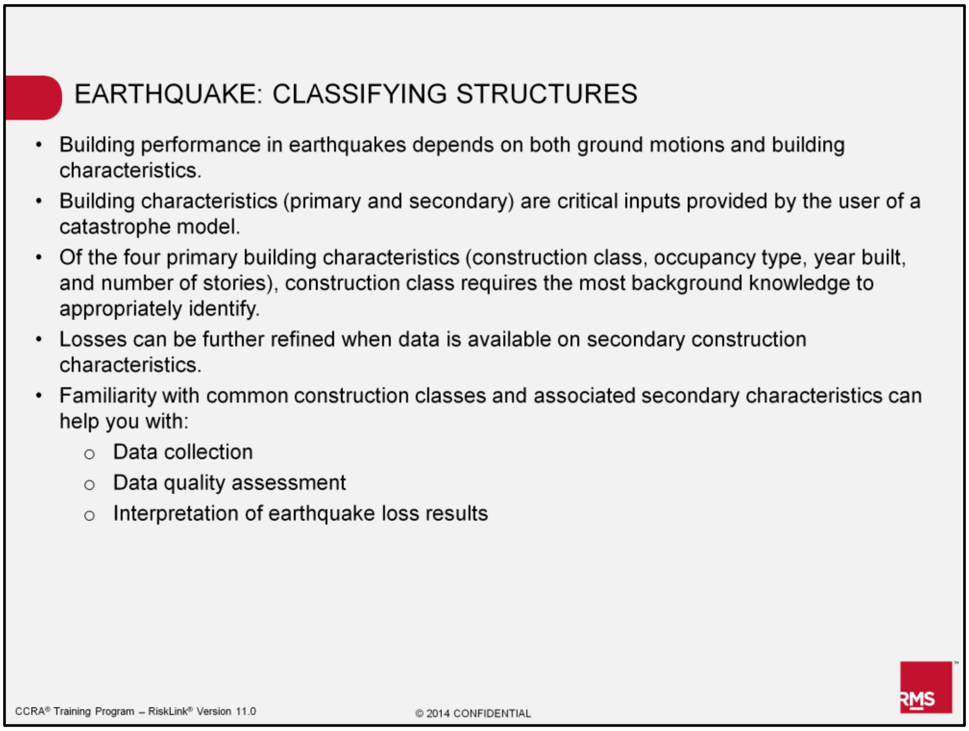
This next slide looks at reinforced concrete structures, which we have already discussed in some detail. The unfavorable modifiers for these structures center around plan irregularity, soft story, and pounding. The more detailed information you can gather the more accurate the classification of the risk.

SECONDARY MODIFIERS: USING MULTIPLE MODIFIERS

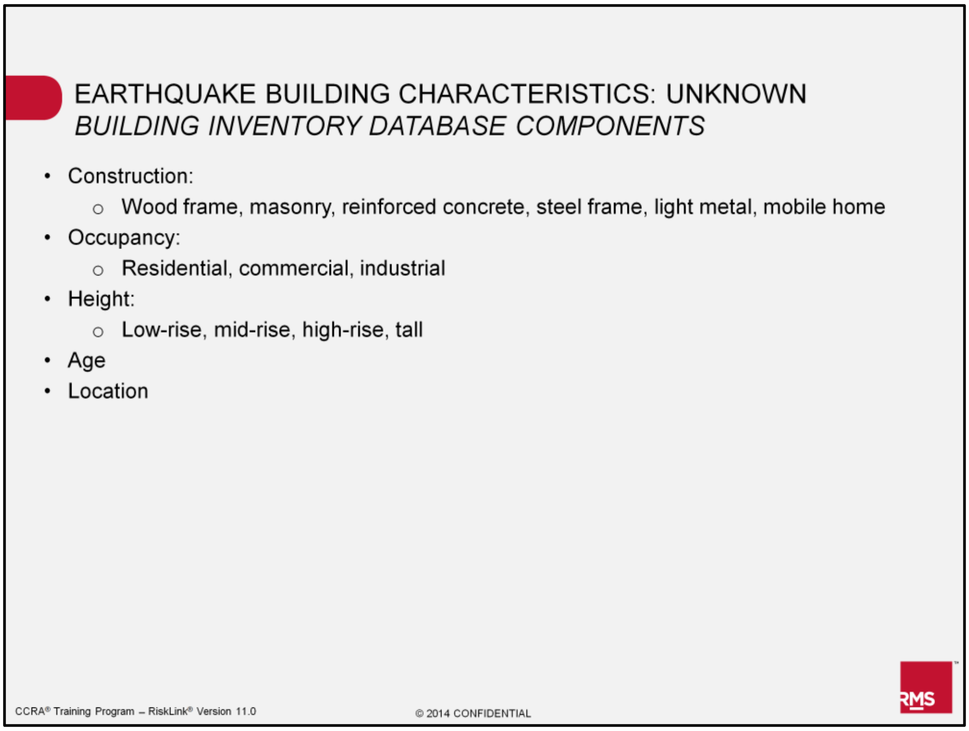
- Capped potential impacts resulting from use of multiple modifiers
  - Maximum increase 2.0 x mean damage ratio
  - Maximum decrease 0.5 x mean damage ratio
- Limitation on reduction of CV for use of multiple modifiers



One point of clarification is that you cannot overdo the secondary modifiers. There is a limit to how many secondary modifiers you can implement in terms of their overall effect. You cannot increase the damage ratio by more than 100% using secondary modifiers, and you cannot decrease the damage ratio by more than 50% by using favorable modifiers. Also note that by using secondary modifiers you are indicating you know more about the structure, which in turn reduces the uncertainty associated with the damage ratio. There is also a limitation in the amount of uncertainty that can be reduced due to the secondary modifiers. The limit on CV reduction is 50%.



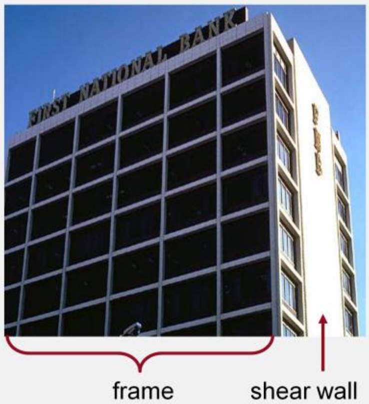
This slide comes from the pre-reading and reiterates some of the highlights from that presentation. As discussed, the building characteristics clearly are important input when quantifying the risk to a structure. Knowing the construction class, the year built, and the number of stories will get you a better answer with less uncertainty. Familiarity with the classifications and understanding what data is available in terms of classifying a structure is very helpful. Secondary modifiers are really a refinement to the combination of the primary building characteristics. We appreciate that understanding the secondary modifiers, how they affect the structures, or how to classify the structures does takes a certain level of sophistication and requires additional effort to collect. Regardless, the more correct information you can collect, the more accurate the analysis.



What if a piece of information is unknown? In these cases, we refer to the inventory database. The inventory database takes into account for a particular geocoding resolution all the different construction classes that are likely to be observed in that geocoding unit. It weighs those different construction classes in terms of what the insured exposure is likely to be made up of within that geocoding resolution. It also looks at what different occupancies occur in that geocoding resolution, the different building heights, and the ages of the structures. Essentially the building inventory databases creates, by geocoding resolution, an understanding of what the structure might be if there is a piece of information you do not have.

BUILDING INVENTORY DATABASE: DATA EXAMPLE

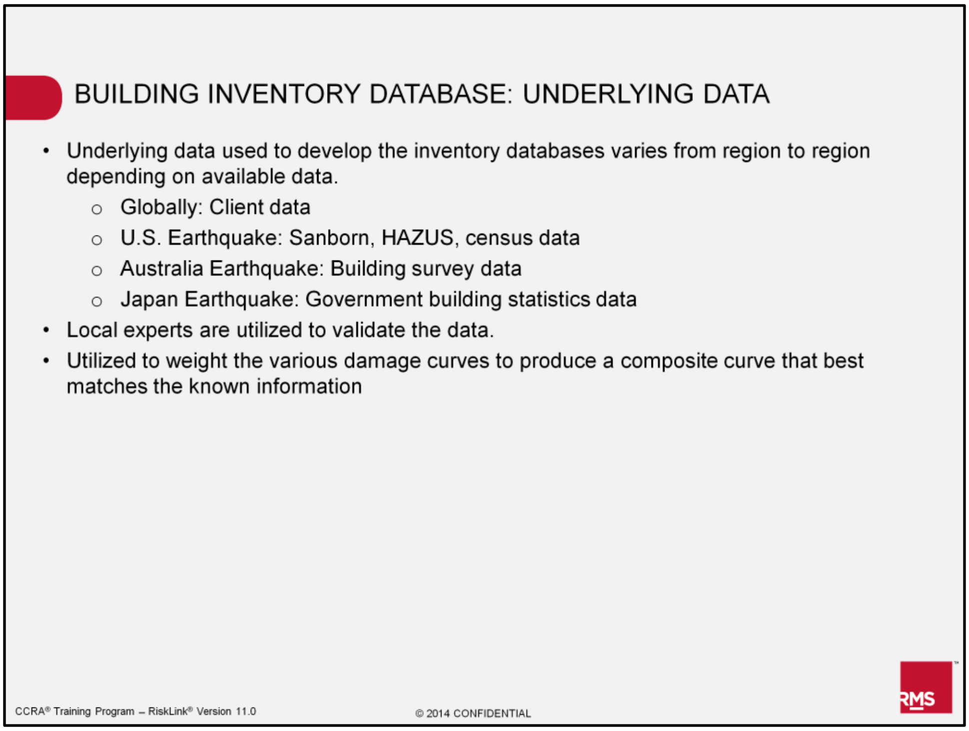
Reinforced Concrete Shear Wall With Frame (ATC 5)



- The better the information about the building, the better the match to the damage functions.
- Each additional piece of information brings you closer to an appropriate risk assessment.

Input Information	Weight for ATC 5
Gen Com	3.5%
Gen Com, 10 stories	13.2%
Gen Com, 10 stories, ATC 5	100%

This slide shows an example of the importance of knowing more information about a structure. The photo is of a reinforced concrete structure with sheer wall and a frame. This is a ten story structure with a rigid frame on one side and some sheer wall on the other side. The labels on the photo point to these characteristics. The more information you know about a structure, the more likely we are to pull the correct information from the database. If this building was coded as general commercial, only 3.5% of the general commercial inventory is thought to be reinforced concrete sheer wall with frame, or ATC 5. If this building was coded as general commercial with ten stories, 13.2% of the buildings in that classification are ATC 5. But if you know the building is ATC 5 then you will have a better classification.



So where do we get this underlying data? The data comes from a number of different sources. The first source is global client data. Within the U.S. we also look at Sanborn data, HAZUS data, and Census data. For a number of countries there is a lot of building survey data that is not typically available in the U.S. In Australia and Japan, detailed information about individual structures in terms of construction class, age, and number of stories is available. This allows us to build an extensive inventory database for these regions. When we build these databases it is important to consult local experts in these regions because they have a better understanding of what is being built in terms of newer structures. Additionally, they help us narrow in on what kinds of structures are likely to be insured. For example, in Chile there are a lot of unreinforced masonry structures that are often residential and are not being insured. So while they make up a large component of the number of residential structures in certain parts of Chile, they are not part of the insured exposure. This is a consideration we must take into account when developing the inventory data.

Once the inventory data is developed and we begin trying to develop a damage curve, the various damage curves that could possibly represent a structure are considered and a composite curve is developed. We do not say a building is 50% wood frame and 20% unreinforced masonry and try to build a curve based on these pieces of information for the structure. Rather, we actually weigh the different damage curves to come up with a composite curve based on the inventory data.

EARTHQUAKE: BEYOND BUILDING SHAKE DAMAGE

- Other Coverages:
  - Contents
  - Business interruption
- Loss Amplification:
  - Economic demand surge
  - Claims inflation
  - Super Cat impacts
- Collateral Hazards:
  - Fire following earthquake
  - Earthquake sprinkler leakage
  - Tsunami

One of several large relief camps established by the U.S. Army at the Presidio of San Francisco after the 1906 earthquake. (from Museum of the City of San Francisco, Picture Presidio 2).

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Now that we have discussed building shaking, we will look at some of the other coverages. We will start by looking at contents and business interruption. Next, the subject of loss amplification during catastrophic and “super catastrophic” events will be covered. Finally we will move onto the topics of earthquake collateral hazards, including fire following earthquake, sprinkler leakage, and tsunami.

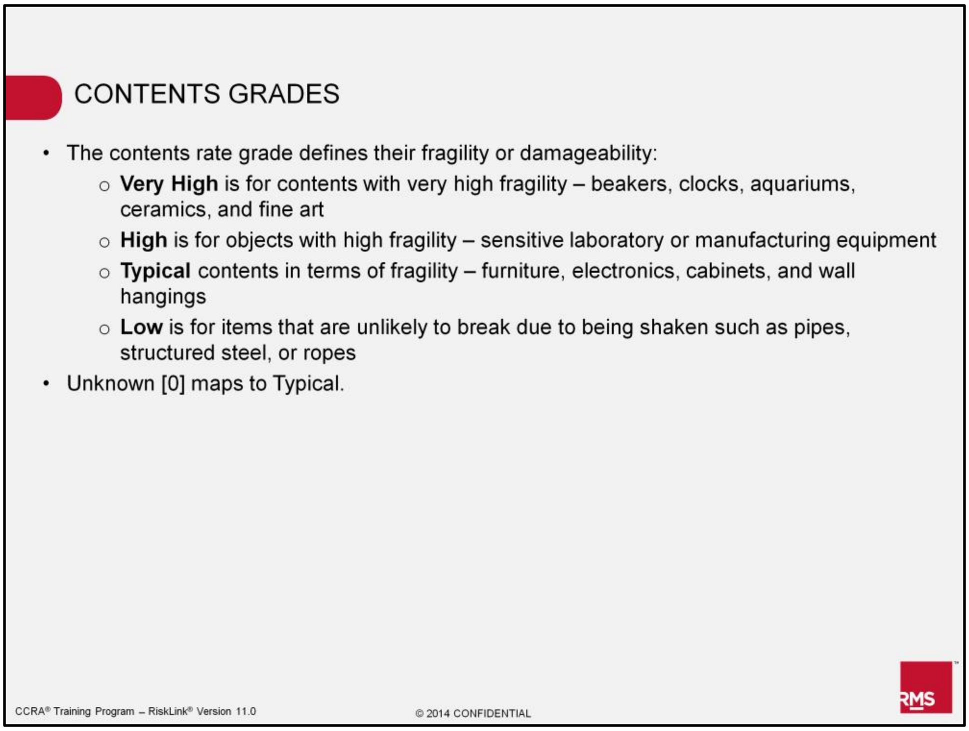
EARTHQUAKE: CONTENTS DAMAGE

- Contents susceptibility to damage is a function of:
  - Damageability of the contents
  - Storage of the contents which is correlated to building occupancy
  - Integrity of the structure following the earthquake

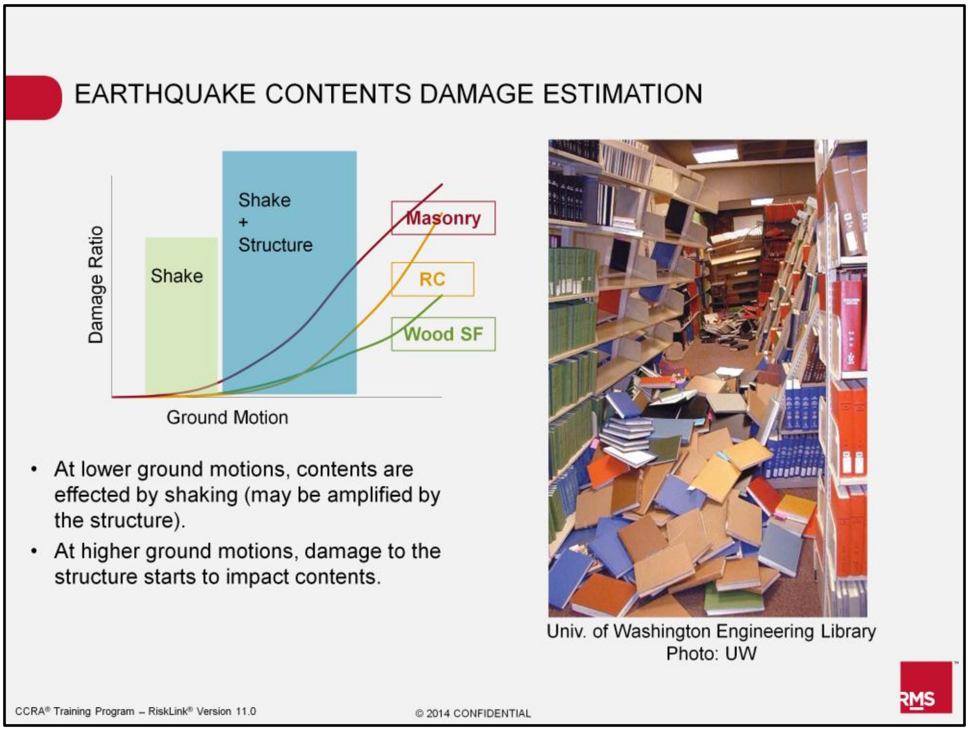
Fallen grocery stocks
Santa Barbara Earthquake, 1978

Contents damage is rather complex. Clearly one of the first considerations is how damageable the contents are, but how it is stored is also critical. The photo on this slide shows the results of the Santa Barbara earthquake in 1978. The photo shows the liquor section of a grocery store and you can see that almost all the bottles have fallen off the shelves and have broken, so we have extensive contents damage. If these bottles had been stored in boxes, however, or had been stored on a shelving system which could have kept them from falling, the risk could have been mitigated.

The integrity of the structure is also important in terms of risk to the contents. In this case it looks like the structure is well intact but if the structure had collapsed it would have crushed the contents regardless of how they had been stored.



Contents grades are classified into four levels. Very high refers to very fragile contents, such as the wine bottles in the previous slide, glass, clocks, aquariums, ceramics, or anything that is likely to be destroyed if it is dropped. High contents refers to high fragility such as sensitive laboratory equipment; contents that may be damaged if dropped but may not be destroyed. The typical contents grade refers to items you would see in a residential structure. For example, furniture, large appliances, electronics, cabinets, and wall hangings; items that you would not want to drop but that may not be damaged if they do drop. Finally we have the low contents grade. This refers to items that are very hard to break and items that if dropped probably would not be damaged. For example, pipes, steel, and ropes. The building would have to collapse on them to destroy them.

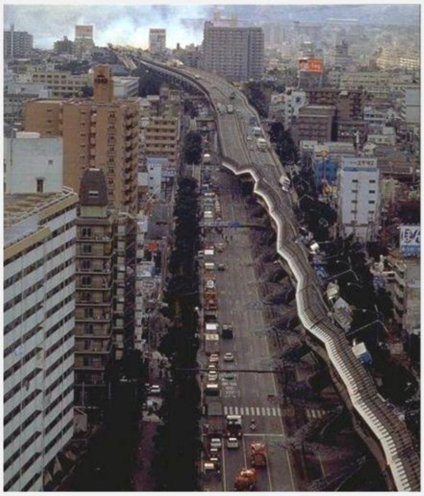


How do we estimate contents damage losses? At very low ground motions the contents are affected by shaking. For example, items stored on shelves may be knocked off. Keep in mind that the structure may amplify the ground motion causing contents to fall more readily then they would in a different structure.

The photo on this slide is of a library after the Nisqually earthquake. Though books do not get heavily damaged, they have fallen off the shelves and the shelves themselves have started to give way, though the building itself has probably not been damaged.

At higher ground motions we start to see damage to the structure and ultimately structural damage will impact contents regardless of what the contents are, particularly if the structure collapses.

BUSINESS INTERRUPTION AND EARTHQUAKES



- Direct losses are related to physical damage to a structure or critical lifeline.
- Indirect losses result from disruption of key suppliers or locations outside of the location suffering physical damage.
- Induced losses result from the depression of the economy due to a loss event (earthquake, hurricane, flood, etc.).

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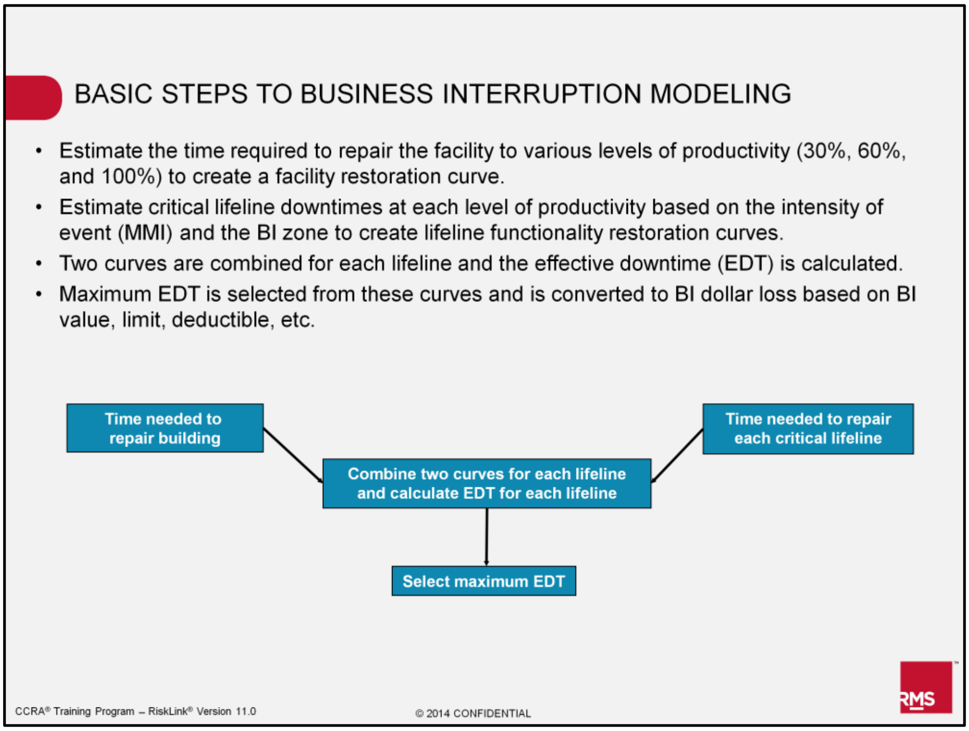
Next we will look at business interruption. There are three parts to how we look at business interruption losses . There are the direct losses, which are related to physical damage to the structure that is insured or to some critical lifeline that supports the structure, such as electricity or water. These direct losses are where most of the loss estimations are focused. There are also indirect losses, such as a key supplier who has been taken offline and cannot supply some product that needs to be utilized in the facility or there is some type of physical damage that impacts the structure more indirectly. And then there are induced losses, which refers to large scale economic depression of a particular line of business. This was the case with the port facilities in the Kobe area. Though some individual structures may have come online quickly, because of the extensive damage to the port facilities, the shipment and movement of materials was heavily impacted and limited the ability of many businesses to return to the productivity levels they had prior to the event.

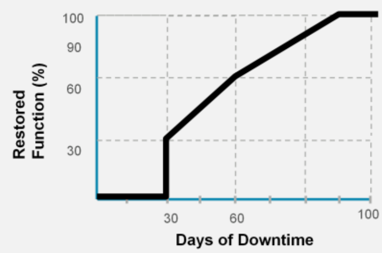


The standard approach for the calculation of business interruption losses for an individual structure is to develop a facility restoration curve. We look at how long it will take that facility to recover from structural damage based on its damage ratio. We also look at how long it will take the major lifelines that impact that structure to be restored. In some cases, the facility restoration may take longer, in others the lifeline functionality restoration may take longer. We look at these two curves and calculate an effective downtime. Using that piece of information we then go on to calculate a damage ratio. We will look at this in more depth on the next slide.

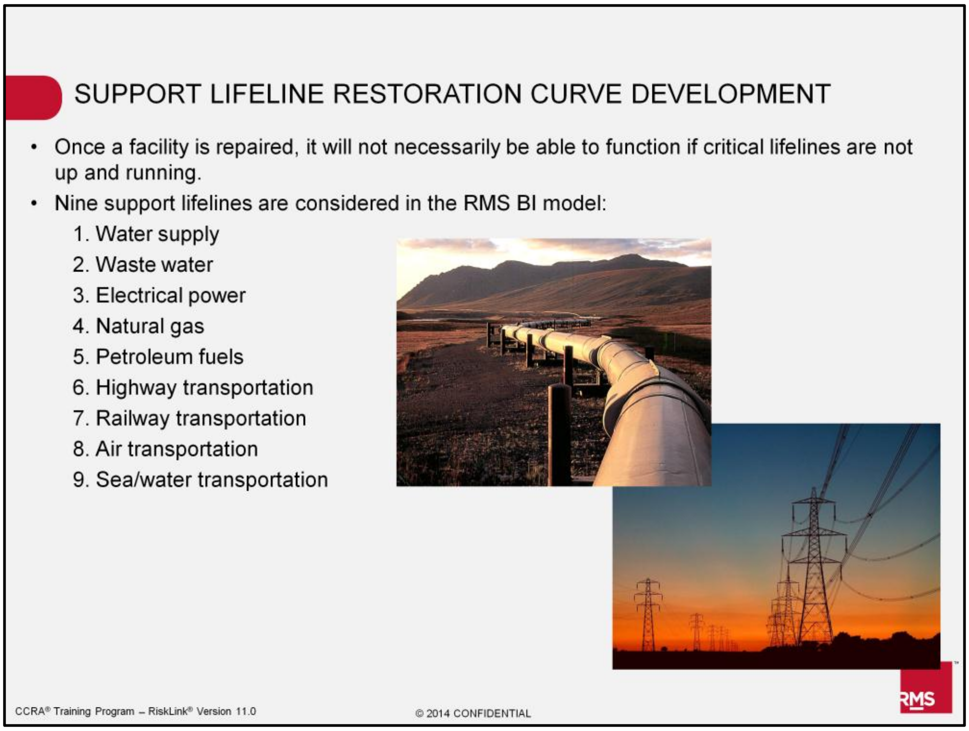
FACILITY RESTORATION CURVE DEVELOPMENT

- Earthquake building damage ratio mapped to seven damage states
- To account for uncertainty, beta distribution used to calculate the probability that the damage ratio (DR) may correspond to any of the seven damage states
- For each combination of occupancy type and damage state, a facility restoration curve is created.

Damage State	Mean Damage Ratio Range (%)
1 - None	0
2 - Slight	0 – 0.5
3 - Light	0.5 – 5.5
4 - Moderate	5.5 – 20
5 - Heavy	20 – 45
6 - Major	45 – 60
7 - Destroyed	60 - 100



The damage ratio for the facility is then mapped to a particular damage state. To account for the damage ratio uncertainty, a beta distribution is used to weight a set of possible damage sets. For each damage state there is a different restoration curve and these are then weighted to determine the facility restoration curve. We then look at how long it takes the structure to go from completely inoperable to 30% back online to 60% back online to 100% back online. The curve on the bottom right of the slide shows this for a particular structure. We have 30 days of complete downtime, 30 days at 30%, and so on, as the facility works its way back up to 100% operation. We take all of the fractional days – the days at which it is at 100%, 60%, 30% – and calculate a total number of days the facility is offline. We then divide the total number of days it is offline by the number of days in the year to arrive at the damage ratio for a structure in terms of business interruption.



This slide highlights some of the important lifelines that support facilities including water, waste, power, natural gas, and petroleum. There is also accessibility to the facility based on the different types of transportation; highway versus air versus railway, depending on what type of business takes place. This is a good point at which to reiterate how important it is to know what kind of activities are occurring in the structure and mapping it to the appropriate occupancy. Different types of occupancies will have different lifeline restoration curves based on their needs.

PRIMARY POST EVENT LOSS AMPLIFICATION FACTORS
MAJOR COMPONENTS

- **Economic Demand Surge** (EDS) – Increase in the cost of building materials and labor costs as demand exceeds supply.
- **Claims Inflation** (CI) – Difficulties in fully adjusting claims following a cat event.
- **Super Cat Loss Amplification Behavior** – Loss expansion due to secondary or tertiary events (evacuation effects, containment failures, systemic economic downturn) in metropolitan areas.

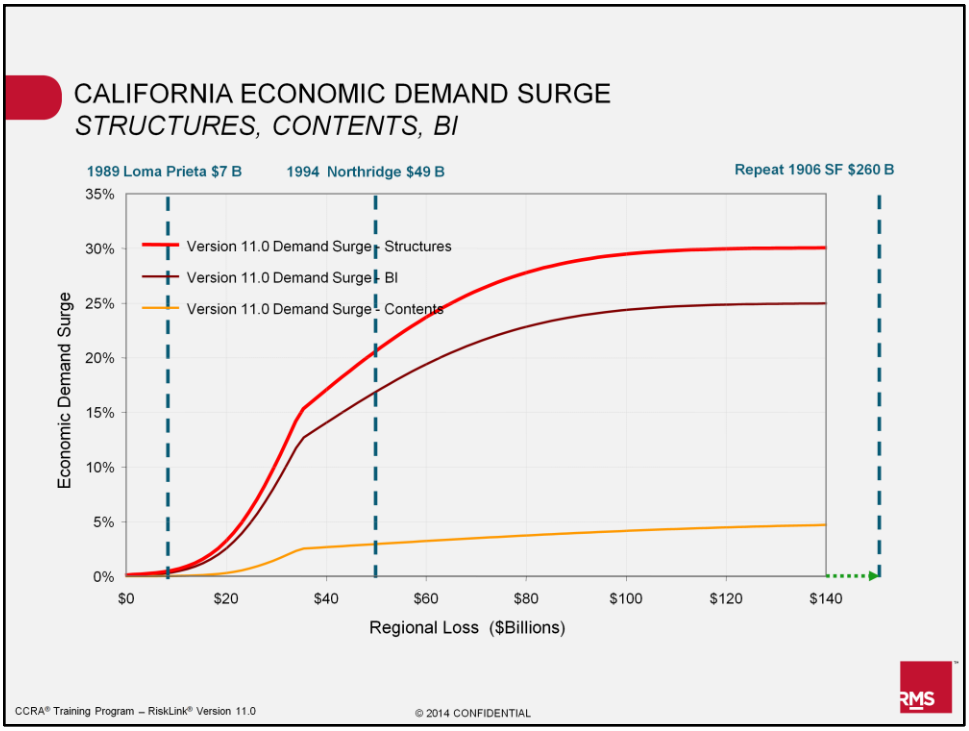
Research into primary loss amplification (PLA) has resulted in an expanded modeling component methodology that quantifies three major components that escalate loss following major catastrophic events:

1. **Economic demand surge (EDS):** Increase in the costs of building materials and labor costs as demand exceeds supply. This factor has the biggest overall impact.
2. **Claims inflation (CI):** Cost inflation due to the difficulties in fully adjusting claims following a catastrophic event. For example, shortcuts (such as setting a threshold loss amount under which claims are simply paid with little to no investigation) are practices historically taken by insurers who are overloaded with claims following a catastrophic event. Intuitively, the impact of this factor varies with the estimated number of claims occurring for an event. Overall, CI has a minor impact compared to the other two PLA components.
3. **Super Cat scenarios:** Coverage and loss expansion due to a complex collection of factors such as containment failures, evacuation impact, and systemic economic downturns in selected urban areas. This factor has an impact for high return period events striking earthquake and hurricane exposed metropolitan areas.

There are also two other secondary loss amplification components worth mentioning:

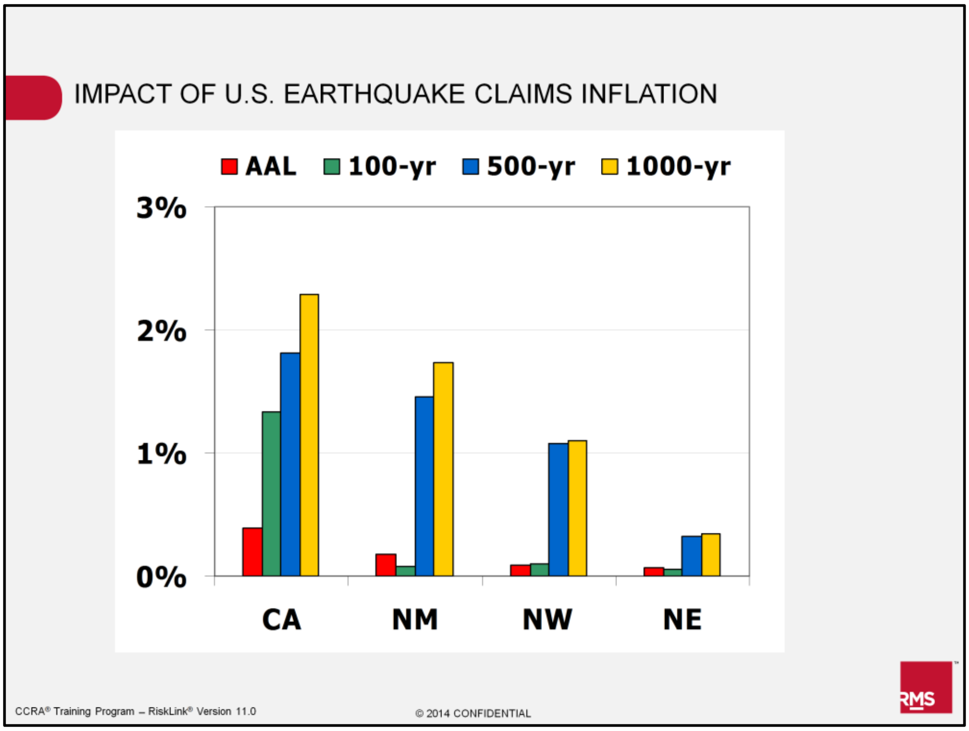
Repair cost delay inflation: This is the time dependent damage escalation caused by delays in making repairs.

Coverage expansion: This refers to the expansion of insurance terms and coverages, often as a result of political pressure. Both of these components are not well documented from claims records, and are thus not currently modeled in RMS applications.

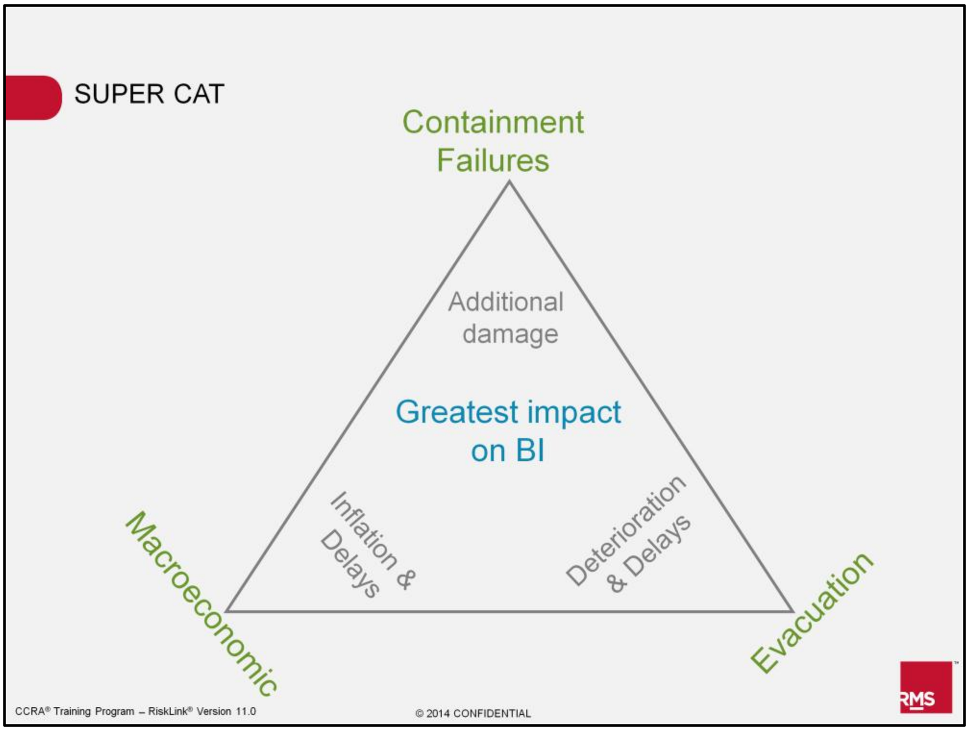


On this slide, the economic demand surge (EDS) functions for the California earthquake region are displayed for building (structure), business interruption, and contents coverages. Note that the relationships follow an S-curve over the course of the entire EDS function with inflection points at 2%, 50%, and 97% of the maximum EDS. This is the observed behavior of actual EDS following events as tracked by RMS.

The threshold or trigger point for the initiation of demand surge is determined by the capacity in the repair sector by region as estimated by RMS. For the earthquake model in the U.S., the basic calculation of EDS is identical to that of the hurricane peril; however, the trigger points to initiate EDS will differ by region versus for the entire U.S. with hurricane.



This figure shows the impact of claims inflation (the second component of PLA) by region for U.S. earthquake analyses performed on the RMS Industry Exposure Database. Note that while the maximum impact for any U.S. earthquake peril is 6%, the impact is never higher than 3% for the U.S. earthquake regions. As such, the impact of claims inflation on overall loss amplification is very small.



We now address the third component of PLA – earthquake super catastrophes, or "Super Cat." These are extremely high severity events characterized by:

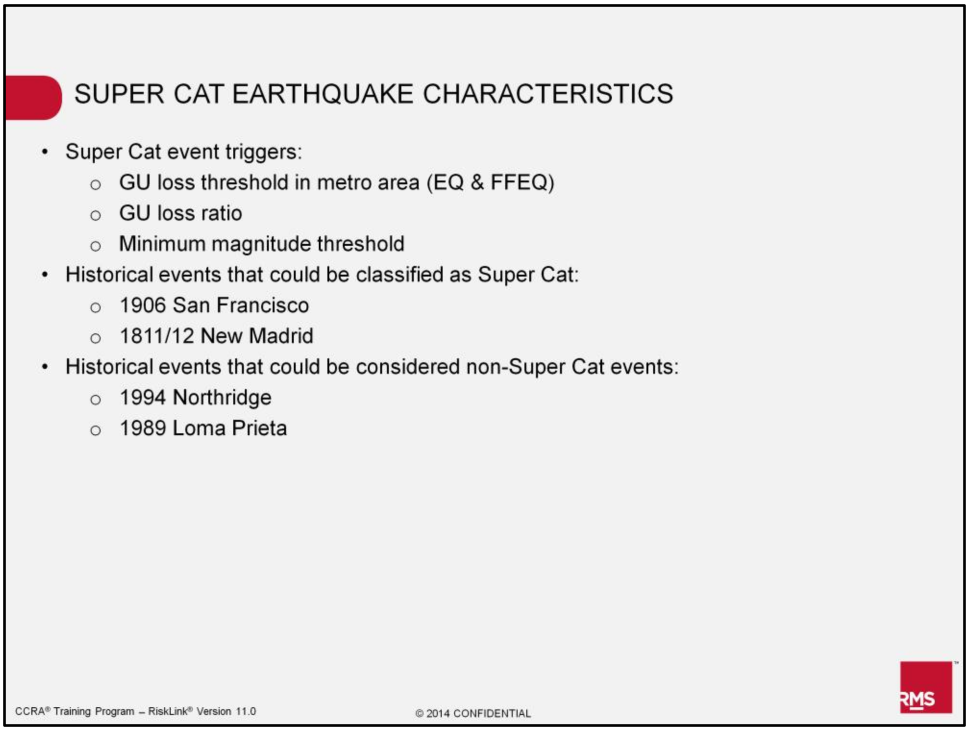
- Containment failures (e.g., levee breaks)
- Widespread long term evacuation
- Systemic macroeconomic impacts (e.g., hotels/stores staying closed because there are no customers and absence of labor force to make repairs)

These non-modeled (or secondary consequence) event losses are a major proportion of loss in Super Cats. At the extreme, the non-modeled loss can become larger than the original event. The largest escalation of loss for Super Cat earthquake events occurs with respect to business interruption coverage.

EARTHQUAKE SUPER CAT
AREAS AFFECTED

- High concentration of population and exposure
  - Metro areas with larger than one million inhabitants
  - Areas of high concentration of exposures
- Areas that have potential for escalation of effects other than ground shaking and fire following earthquakes
  - Underground utilities, pipeline, and tank breakage/damage
  - Limited access due to collapsed/damaged bridges, highways, ports, airports, and limited communication with the affected area
  - Tsunamis and flooding from failures of dams, levees, landslides etc.
  - Release of toxic chemicals/contaminants
  - Shut-down of nuclear power plants and other power failure related problems

The selected urban areas where earthquake Super Cats will occur are defined as containing more than one million inhabitants with high concentrations of insured exposure. These metro areas will be exposed to significant loss escalation due to both modeled perils (ground shaking and fire following earthquake) and non-modeled earthquake related losses listed on this slide. The Super Cat impact for the metropolitan areas incorporated into the model was determined by using RMS-modeled results and a case-by-case analysis of the impact of the key elements of Super Cat behavior.



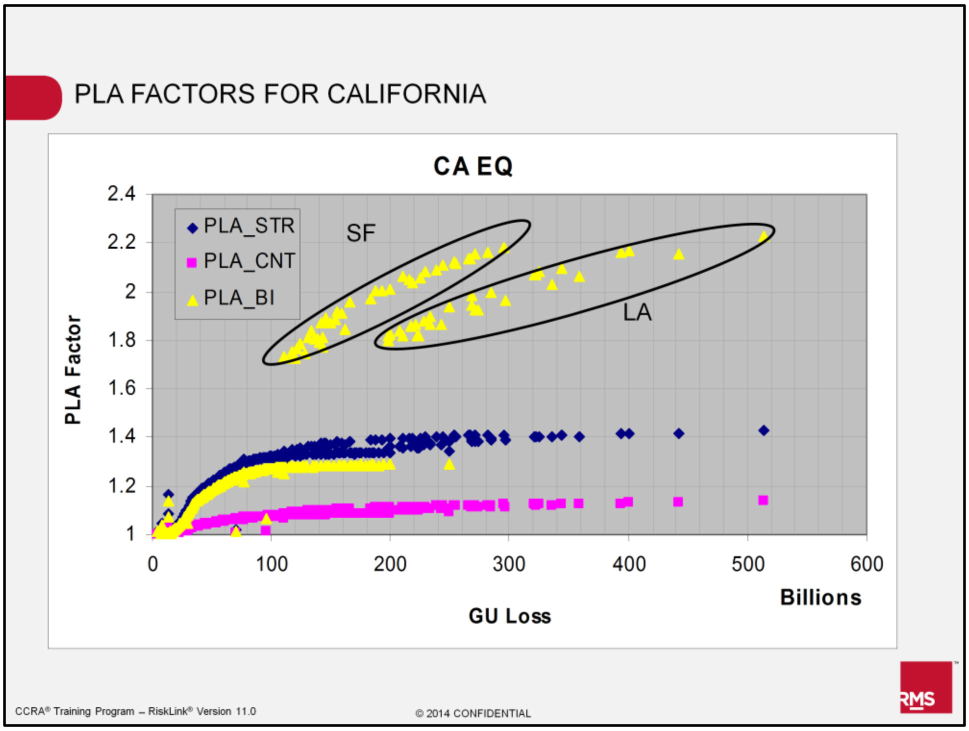
There are three metric thresholds that were used in combination to identify earthquake Super Cat events in the RMS stochastic event database: A ground up loss threshold, a ground up loss ratio (Loss Ratio [LR] = Regional Loss/Gross Regional Product) threshold, and an earthquake magnitude threshold.

The ground up loss threshold to trigger Super Cat earthquake events varies based on:

1. Whether or not the earthquake epicenter is directly beneath an urban area.
2. The susceptibility of the metropolitan infrastructure (transportation, communications, utilities, etc.) to earthquake damage that could lead to Super Cat effects.

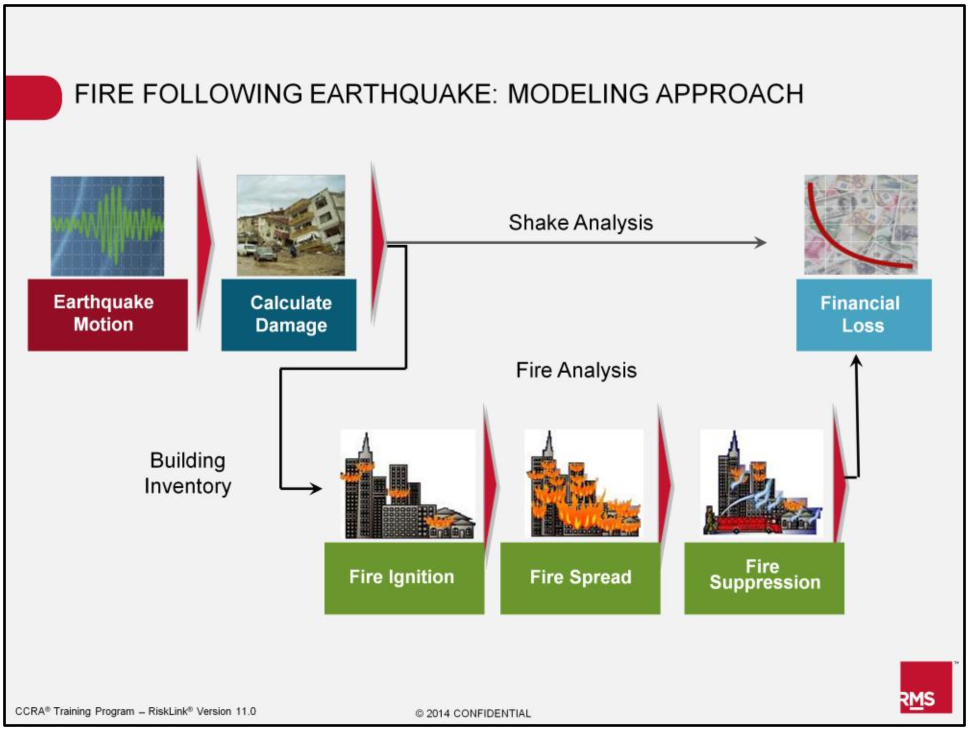
It is generally assumed that earthquakes below a certain magnitude would not result in Super Cat effects.

Listed on this slide are examples of historical U.S. earthquakes classified as Super Cat or non-Super Cat based on the metric thresholds just discussed.



To further exemplify the difference between Super Cat and non-Super Cat events, we take a further look at calculated primary loss amplification (PLA) factors for California earthquake. Each triangle on this graph represents a separate event for which there is a modeled ground up loss and PLA factor. To arrive at these numbers, an earthquake and fire-following earthquake analysis was run for each ZIP Code in an urban area in California. You will note that after the $150 billion loss, the PLA factor/GU Loss relationship separates into two trends for the building/structure coverage. The same is much more dramatic for the business interruption coverage, which is a primary characteristic of Super Cat events. Thus, the events circled on the graph represent 70 Super Cat stochastic events in California. All are located in either the San Francisco Bay Area or the Los Angeles Basin and pass the loss, loss ratio, and magnitude (6.9 in S.F. and 6.8 in LA) thresholds. Listed on the next two slides are stochastic event ID ranges, magnitudes, and fault source names for these events.

For more information on primary loss amplification, please refer to the *RMS Post-Event Loss Amplification Methodology* document on www.rms.com.



Next we will discuss collateral hazards. We will start with fire following earthquake. The fire following model works in parallel with the shake model. You can model a shake analysis, a fire analysis, or the shake and fire combined. The shake analysis results in a mean damage ratio while the fire analysis results in the chance of conflagration or the chance the structure will be completely destroyed by fire. There are three components of the fire analysis. The first component is fire ignition. Shaking can result in a number of ignitions so the higher the shaking, the more ignitions. The second component looks at how those ignitions will spread. Are they in places where fires can propagate? Finally, we look at how the fires are suppressed in terms of fire equipment. Next we will walk through the parameters that govern each of these components.

FIRE IGNITIONS: GOVERNING PARAMETERS

- Ground motion
- Building material
  - Wood vs. others
- Building occupancy
  - Residential, commercial, industrial
- Time of the day
  - Morning, evening
- Time of the year
  - Summer, winter

1994 Northridge Earthquake CA

The single most important thing to understand with fire ignition is that you need high ground motions to result in fire ignition. How high the ground motions need to be in order to trigger ignitions varies from place to place. In Japan, the older buildings have a lot of fire sources because they are typically heated with kerosene heaters. If a heater tips over or if materials fall on them, it can cause an ignition. In the U.S., buildings typically have internal furnaces, which is a furnace system within a structure, so the sources of ignition are very different in these environments. To get a significant number of ignitions in the U.S., you typically need a ground motion up in the intensity seven range. You also need something to burn so we look at what the building materials are; is it a wood building or a non-wood building? Different occupancies are more likely to be combustible than others. Residential is highly flammable compared to some commercial and industrial exposures. Time of day is also important. It was mentioned earlier that the Kobe earthquake occurred early in the morning. Many people had just gotten up and turned on the heat so there were a lot of ignition sources available. In the evening and in the early morning people are at home cooking so there are more sources of ignition at those times of day. Time of year is also a consideration. In the summer there is less likely to be heat sources so there are more ignition sources in the winter than in the summer.

Another point to mention is the importance of ground deformation. The photo on this slide shows a gas line that has ruptured probably due to some sort of ground deformation, either liquefaction or differential settling in the area that has ruptured this pipeline and resulted in a fire. In terms of exposures affected, this individual fire did not cause extensive damage, but you can see that many of the structures in the immediate area have burned. Emergency services were able to suppress the fire and to keep it from spreading.

FIRE SPREAD: GOVERNING PARAMETERS

- Building fire resistance (wood vs. others)
- Building density
- Wind speed
- Wind direction
- Humidity
- Fire breaks
  - Streets, roadways, and freeways
  - Parks, undeveloped areas, and water bodies

1995 Kobe Earthquake Japan

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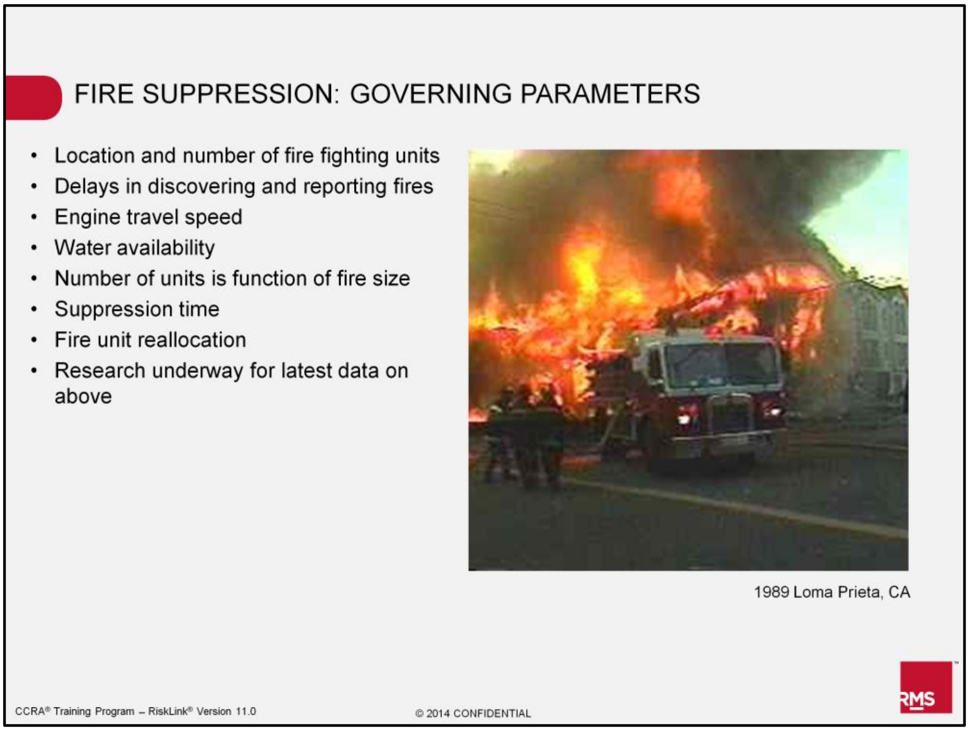
What governs how much a fire will spread? We need to look at how resistant the buildings are to fire. Building density is also important. This was particularly a problem in the Kobe earthquake. Wind speed and wind direction are also a problem. The photo shows smoke going straight up so we can see that wind is not a critical issue in this example. But in a place like San Francisco, where there can be very high winds much of the time, a fire can spread very quickly and be harder to suppress. Humidity is also an issue. In very dry environments fires are harder to put out. Finally, we look at how the cities have been developed. Have they been developed in such a way that there are major fire breaks? Are there wide streets, roadways, and freeways that can serve as fire breaks? Are there undeveloped areas? Are there bodies of water or parks that will stop fires? In San Francisco there are some major parks that do actually serve as important fire breaks.



So how are fires suppressed? It really comes down to how much fire suppression equipment there is and the availability of water. Major liquefaction will impact the water supply. The number of vehicles available to travel to the fire will also have an impact. In addition to water availability and the length of time it takes the fire trucks to get to the fires, the number of ignition sources and whether there are enough fire trucks for all of them will also define the length of time it will take to suppress the fires. This is an area where there is still a lot of ongoing research to try to really understand how fire suppression can best be quantified. The photo on this slide shows some of the fires in the Marina district following the Loma Prieta earthquake.

To summarize the fire following methodology, when we look at fire there are three pieces: ignition, spread, and suppression. Through a detailed simulation process, we determine for a particular location and for a certain ground motion level the likelihood of conflagration. This works in conjunction with the shake calculation and the losses are combined within the financial model.

EARTHQUAKE SPRINKLER LEAKAGE (EQSL)

Event	Year	# Systems Damaged
Long Beach EQ	1933	90
Alaska EQ	1964	14
San Fernando EQ	1971	68

Alaska EQ, 1964

- 1994 Northridge Earthquake – 2,014 systems damaged
  - First (and only) major EQSL loss event
  - EQSL exceeded EQ loss for many commercial carriers
- Primary occupancies suffering EQSL losses
  - Department stores, office buildings, electronics, warehouses, and hospitals
- Contents is the main issue

San Fernando EQ, 1971

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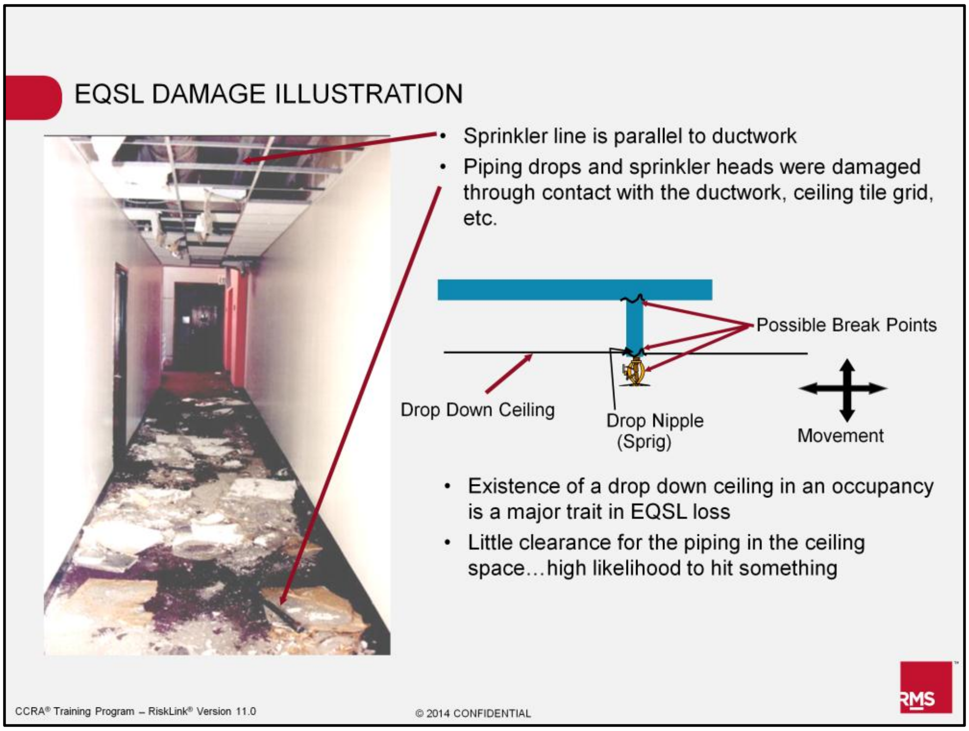
Next we will look at earthquake sprinkler leakage. This was not really perceived as a significant risk until the mid-1990s. There were some examples of sprinkler systems that were damaged in the 1933 Long Beach earthquake and the 1964 Alaska earthquake, but not until recently were these kinds of systems routinely installed in structures. It was really the Northridge earthquake in 1994 that brought home the importance of understanding the exposure to earthquake sprinkler leakage. There were more than 2,000 sprinkler systems damaged in that earthquake. It was really the first example of an earthquake sprinkler leakage loss and it accounted for 3% of the total gross losses. The primary occupancies that were impacted were department stores, office buildings, electronic warehouses, and hospitals. The primary issue with earthquake sprinkler leakage is contents damage.



One of the problems is how the sprinkler systems are installed. In this example we see there is a drop-down ceiling so the sprinkler system is running parallel to the duct work above the ceiling. The sprinkler heads come down through the ceiling tiles. As the ceiling in the structure moves, these pipes that drop down through the ceiling often get snapped off resulting in major leakage. The earthquake sprinkler community is working on finding a better way of installing these to prevent these problems.

EQSL DAMAGE CHARACTERISTICS

- Most damage occurs to materials in contact with the floor and not water falling from above.
- Water runs for hours on average.
- Damage to water supply or pressure has no quantifiable effect on reducing damage since:
  - Supply typically has less pressure, not zero pressure
  - Water in system cannot drain due to alarm valve and backflow preventer
  - Even under low pressure, substantial EQSL damage can occur

Palletized storage (top photo) less damaged than storage directly on floor (bottom photo)

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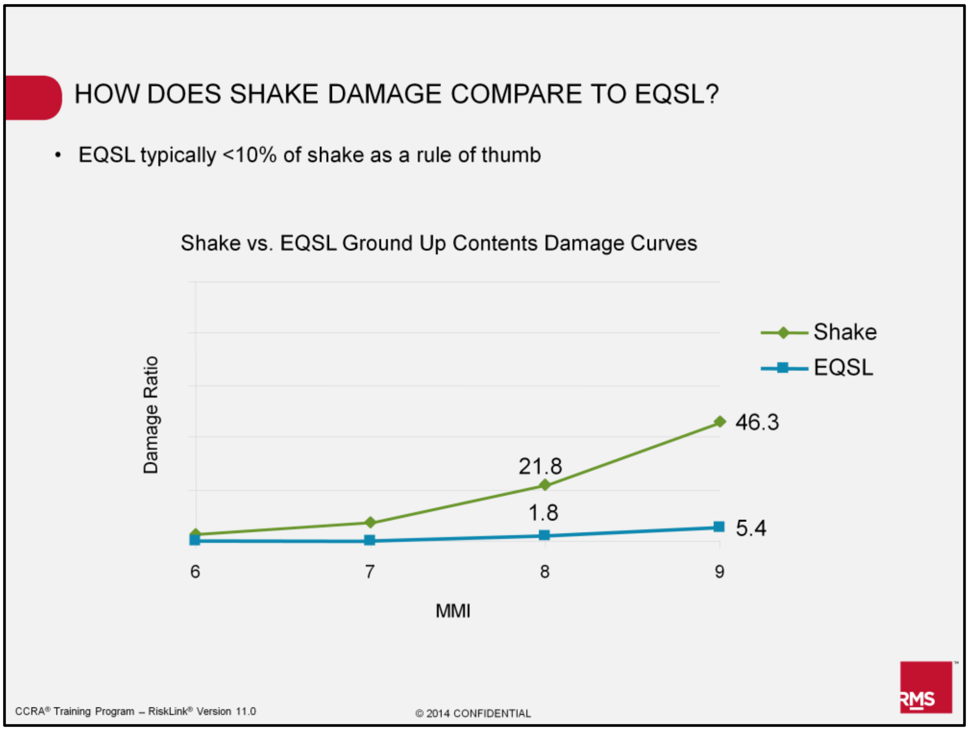
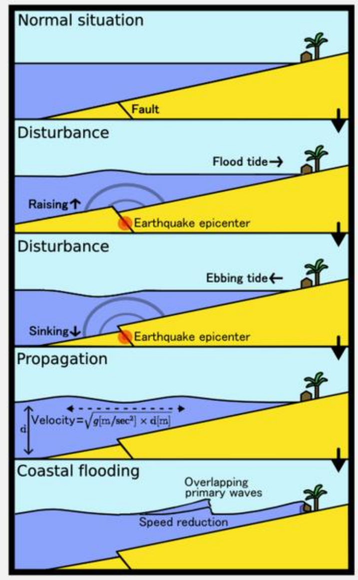
Again, earthquake sprinkler leakage is predominately a contents issue. Whether the contents are in contact with the floor is going to dictate whether there is damage. The water in these systems typically runs for a very long period of time so even though the system has been compromised, there is often still some water pressure left. There is either no way to disconnect the structure from the water system or it has not been turned off. Even if there is very low water pressure you can still have extensive water damage. How contents are stored in buildings with sprinkler systems has a big impact.



When we look at how sprinkler leakage damage relates to shake damage we can see that the rule of thumb is that sprinkler leakage damage will typically be less than 10% of the shake damage. It is important to understand, however, that sprinkler damage is not typically covered by the earthquake policy but is covered by a more general policy such as a homeowner's policy. This means that the deductible for the coverage for the sprinklers may be much lower and result in much higher losses to the insurers than the shake damage.

TSUNAMI BASICS

- Japanese term meaning “harbor wave”
- Occur when there is a large displacement of water due to an undersea earthquake, volcano, or landslide
- Subduction zone earthquakes are a common cause for tsunami, not all of these earthquakes generate tsunami



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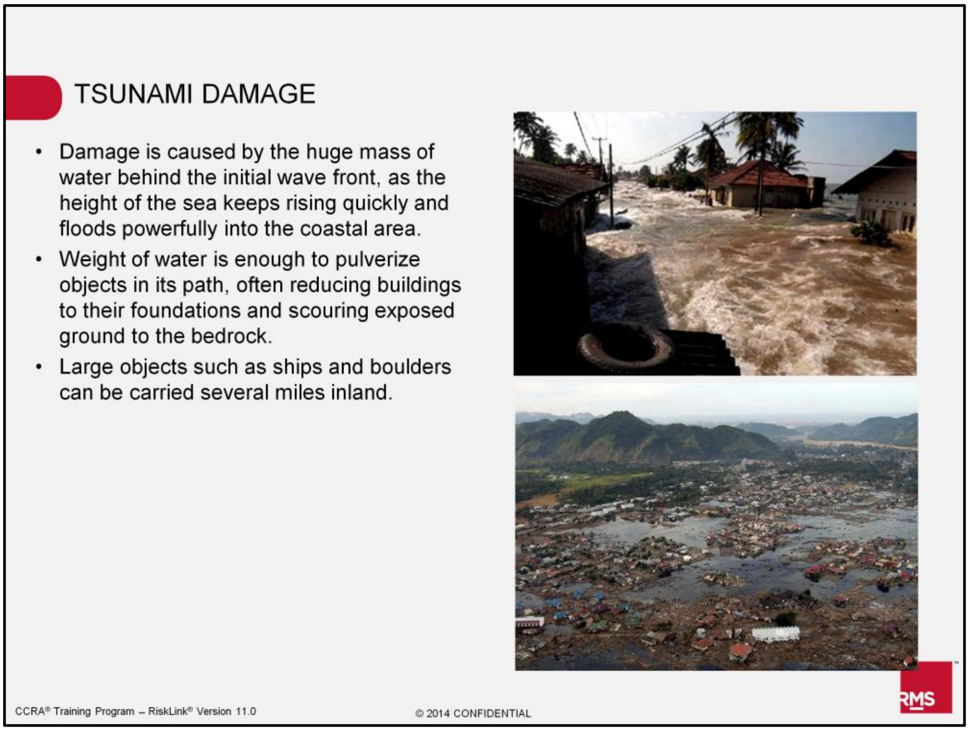
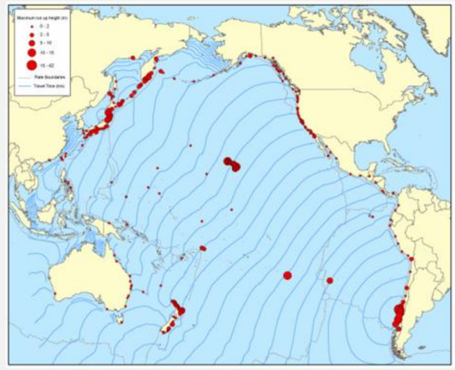
The last topic for this unit is tsunami. The tsunami risk was really brought home by the Indonesian earthquake in December 2004 and the Tohoku, Japan earthquake in March 2011. Tsunamis occur when there is a large displacement of the ocean floor. This can be the result of an earthquake, a volcanic eruption, or a large landslide underwater. It is the very large earthquakes associated with subduction zones that generate tsunamis but it is important to understand that not all major subduction zone earthquakes are going to generate tsunamis. This is why it is more difficult to quantify the risk due to tsunamis.



There is often a misconception about exactly what a tsunami is. It is not really a series of waves but is actually a change in the sea level. It is a mass of water that comes in at a much higher level than is typical and the water level also rises very quickly, acting very much like a flood. The photo on the upper right shows some buildings on the coast and you can see that the sea level has risen ten to 15 feet and is now moving through these structures at a very high velocity. The weight of the water is enough to destroy any structure in its path and often reduces buildings to their foundations. In some cases, it will remove even the soil and bring the ground back to its bedrock. In many cases, large ships and boulders are carried inland several miles showing just how powerful these events can be. The photo on the lower right shows the aftermath of a tsunami. You can see that the structures at the lower elevations have been completely scoured away and the buildings at slightly higher elevations have been spared to some degree but have still experienced damage.

TSUNAMI: BASIN-WIDE WAVES

- Far-field, or "teletsunamis," are those which occur hundred to thousands of kilometers from the causative source.
- Most likely to be caused by great earthquakes (Mw 8.5+) and can be global catastrophes.
- Are often accompanied by major local tsunamis closer to the source.



Map of 1960 Chile earthquake-induced tsunami with travel times (in one hour increments).

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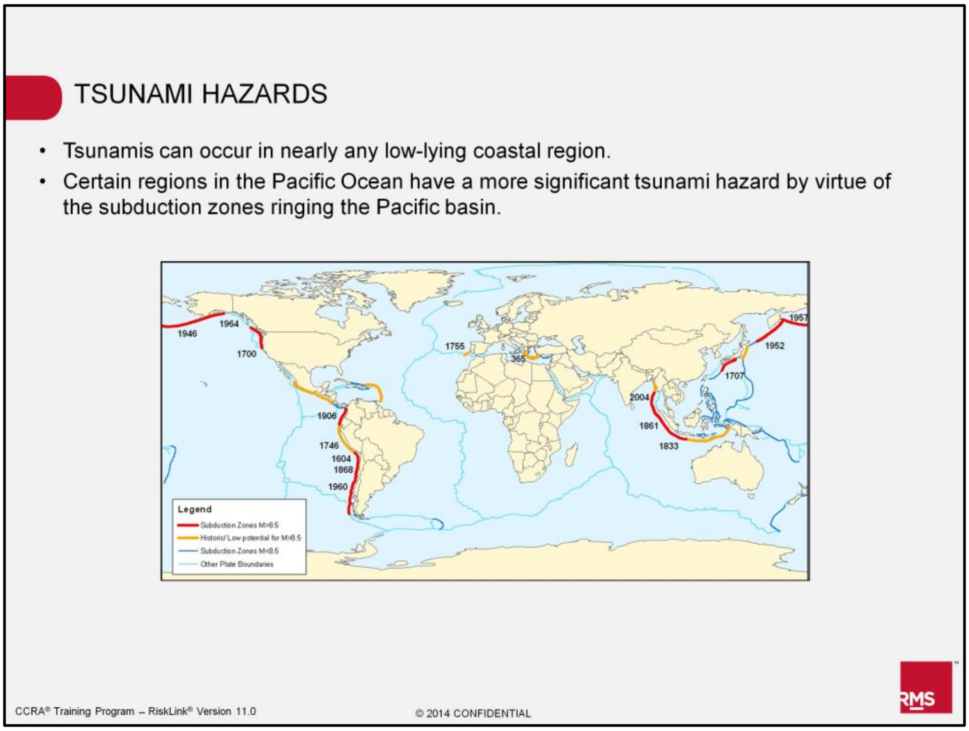
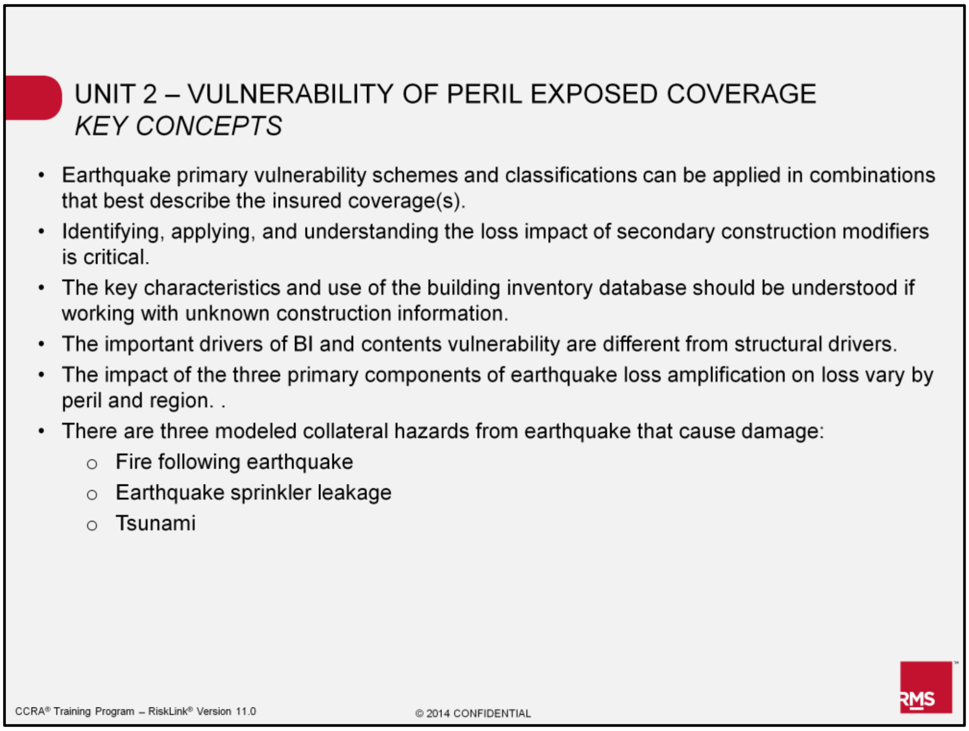
There are two different types of tsunamis. There are basin-wide tsunamis and local tsunamis. Localized tsunamis occur in the immediate area of the earthquake or the source of the event while basin-wide tsunamis, also called tele-tsunamis, travel great distances. The map on this slide shows the advance of the 1960 Chile earthquake tsunami. The 1960 Chile earthquake was one of the biggest earthquakes to have occurred, with a magnitude in the 9.5 range. It happened along the southern coast of Chile. The blue lines represent the tsunami waves as they progressed across the basin, and each line represents a one hour increment. In other words, these are hourly bands of how the waves propagated across the Pacific. You can see that though they move quickly, they move slowly enough that there is enough time to warn people in places like Hawaii and Japan. Casualties should be relatively low in tsunamis and some contents may be moved but structures are still going to be impacted. It should be noted that when the 1960 Chile earthquake and subsequent tsunami occurred, people in Hawaii informed that the tsunami was coming actually went down to the coastline to see it and many, many people were killed in the Hilo area because of their curiosity. They did not really understand that the warning meant they should go to higher ground. There is a much better appreciation of the risk due to tsunamis now across the globe due to the Indonesian earthquake in 2004. More than 280,000 people were killed by this earthquake with the vast majority killed by the tsunami. The levels of casualties in that event are unlikely to occur again.



In terms of tsunami hazard, any low lying coastal area in the world can potentially experience a tsunami. The return periods in some areas are fairly low, particularly in the Atlantic. When we look at the Pacific, we see that there are a number of sources of major subduction zones that can produce tsunamis. The subduction zones are highlighted in red and orange on the map shown. The ones in red are subduction zones that can generate events greater than 8.5. Events of moment magnitude greater than 8.5 are events that could generate a tsunami that would affect the entire basin and potentially large portions of the globe. You can see there are a number of these sources around the Pacific Rim so it is important to understand when we look at tsunami hazard that the Pacific Ocean is the area where this is highest. Clearly the Indian Ocean has the potential for tsunamis and the Atlantic Ocean is not immune.



This slide highlights the key points from Unit 2 of this presentation. We encourage you to review these topics to ensure that you have a good understanding of each bulleted item before proceeding to Unit 3.