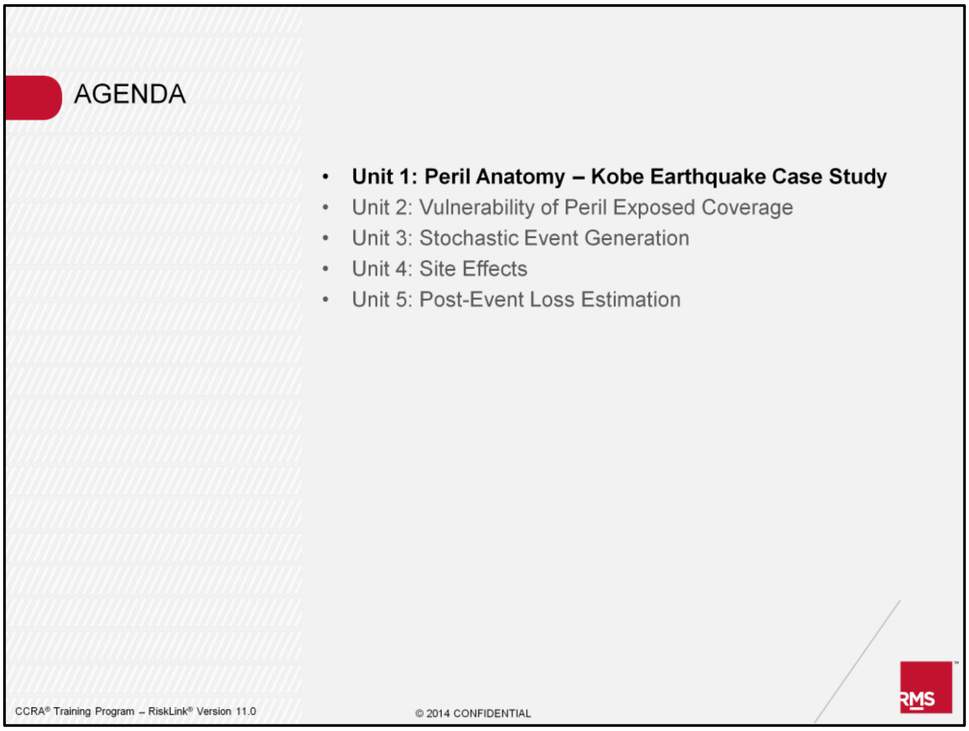
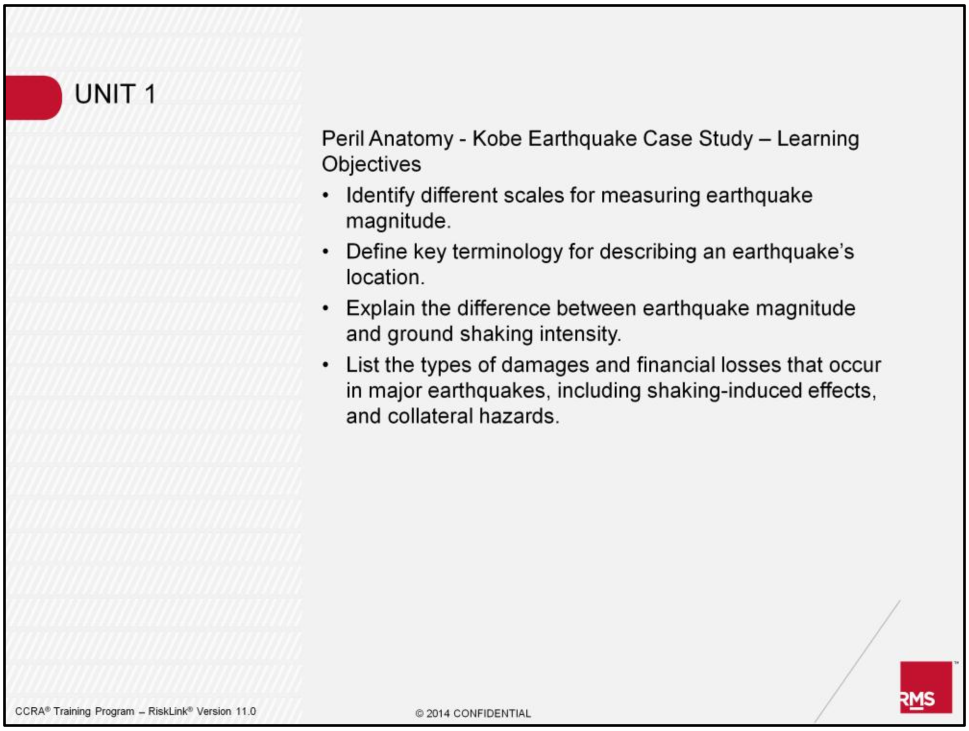
EARTHQUAKE MODELING UNIT 1

RMS® CCRA® Training Program

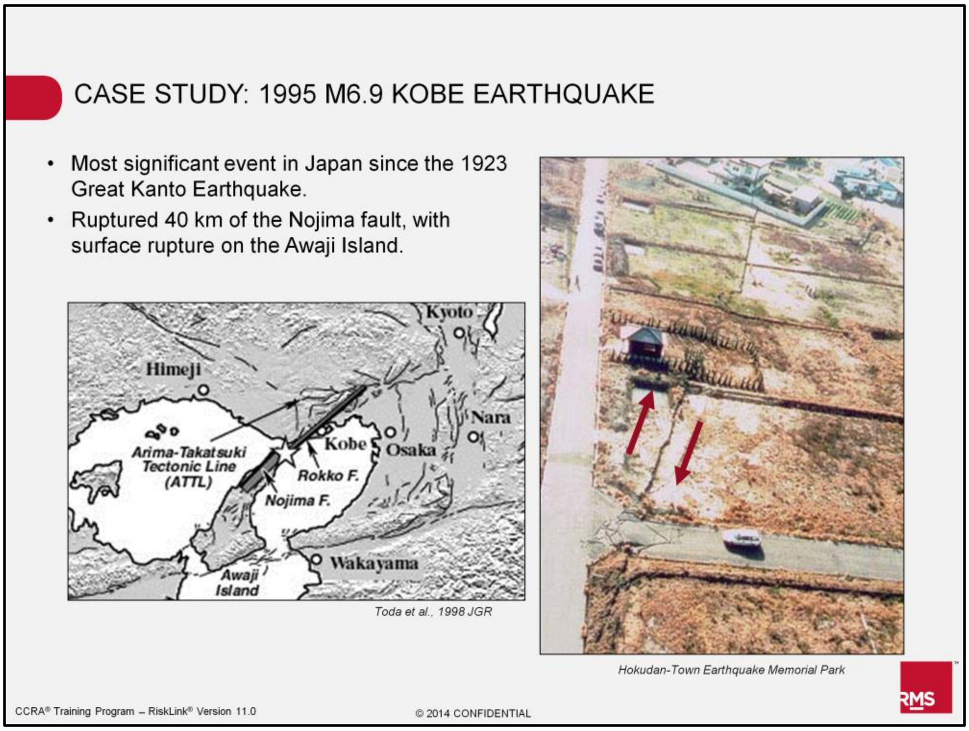


The objective of this course is to build on your prior knowledge. We appreciate that you have some background when it comes to earthquake modeling and risk assessment so we will begin at a high level and then look at each of the components of earthquake risk modeling in greater depth. We will look at how structures are damaged, building on the earthquake pre-reading that talked about the classification of structures. We will also look at seismic source characterization and the quantification of ground motion.

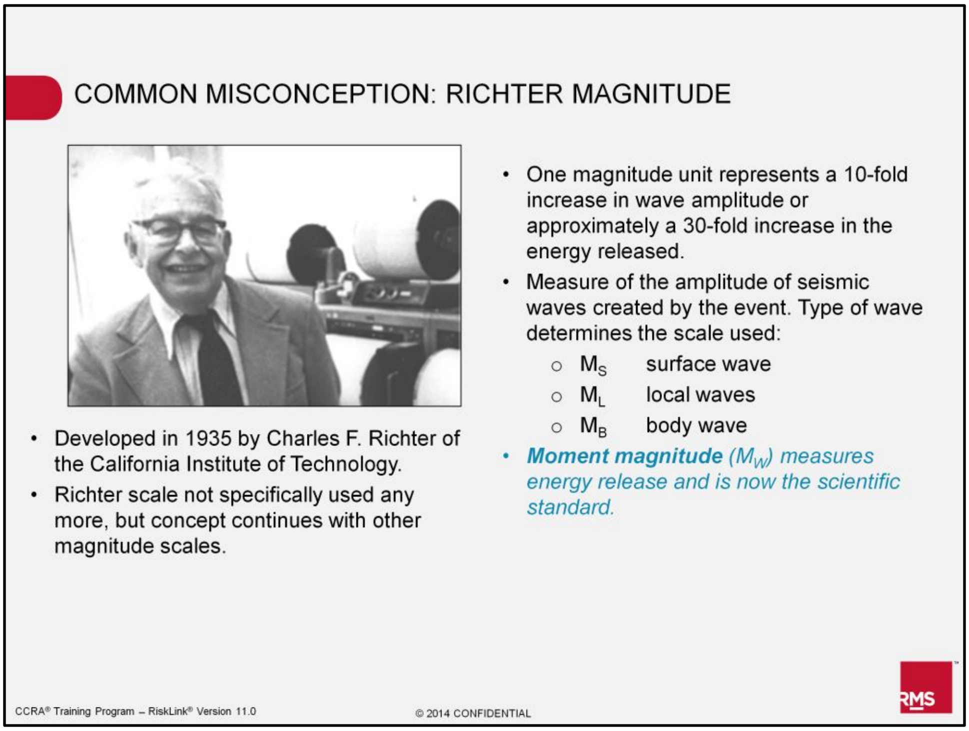
Unit 1 covers the Kobe earthquake case study. We will discuss a number of definitions in this unit. We will start by looking at how earthquakes are measured, some terminology around how we discuss earthquake locations, the difference between magnitude and intensity, and finally we will talk about the Kobe earthquake in terms of damage and losses and how earthquakes affect exposures.



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



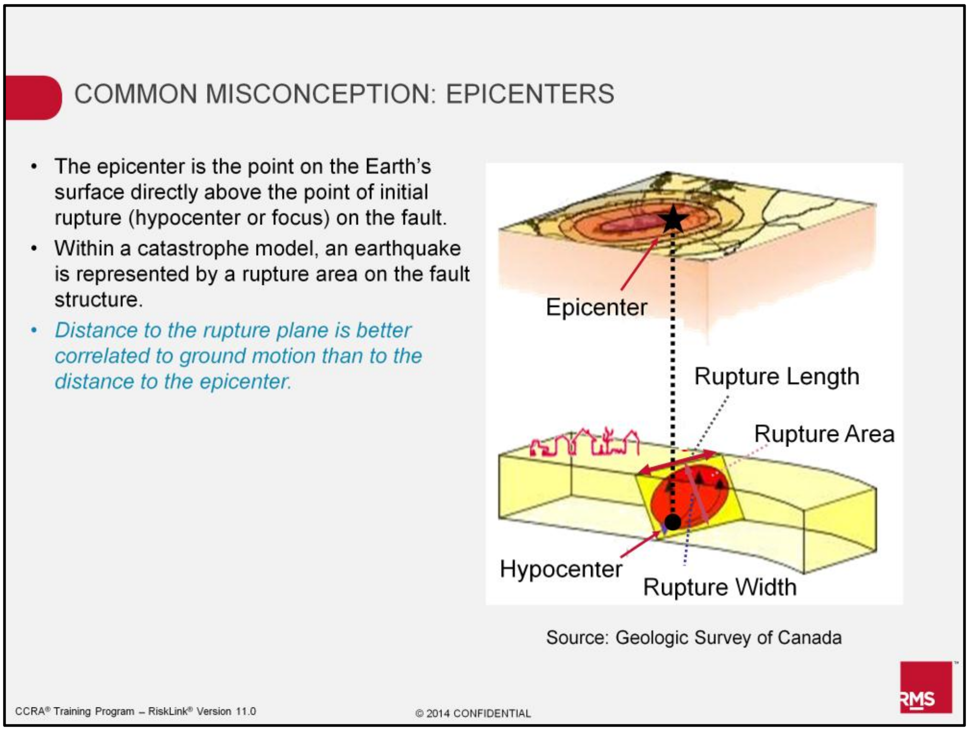
The Kobe earthquake in 1995 had a moment magnitude of about 6.9. This was the most significant earthquake to impact Japan after the 1923 Kanto earthquake until the M9.0 Tohoku earthquake in 2011. The Kobe event struck the Osaka-Kobe area, as you can see in the map on the lower left. The solid lines represent the rupture area for the fault. There were a total of about 40 kilometers of rupture on the Nojima fault on the island of Awaji, and this extended into the Kobe area. The star represents the epicenter of the earthquake. This region covers significant exposure in a very heavily industrialized area.



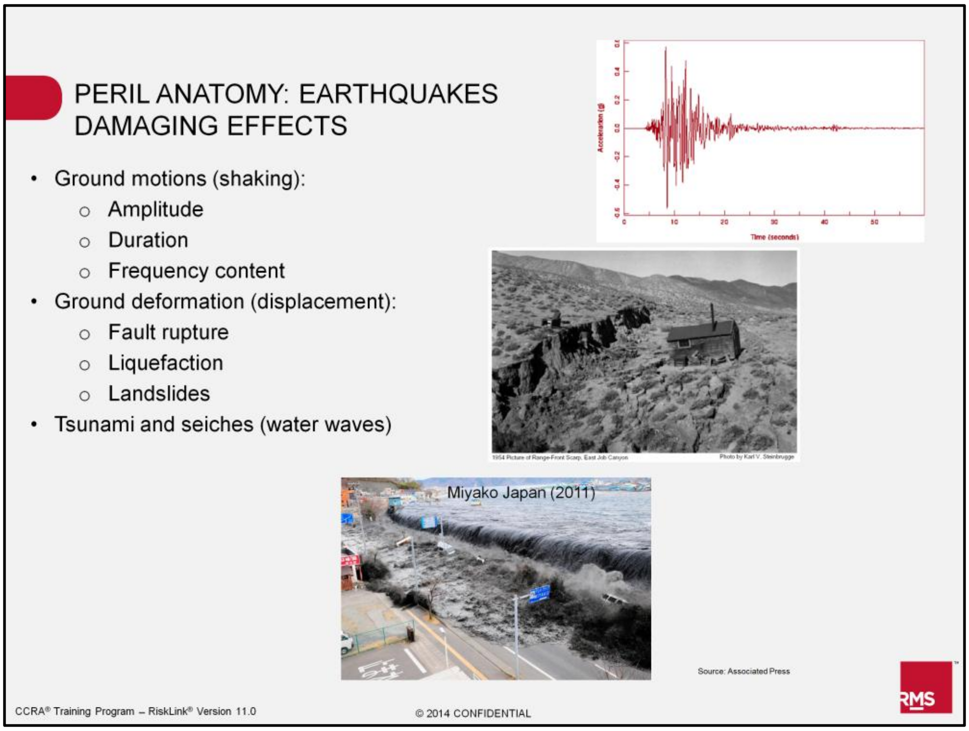
As we go through the presentation there will be a few slides addressing common misconceptions. Some of the issues related to earthquake risk that can be confusing will be discussed. You will also notice text on some slides will be in blue; this is to highlight the most important content.

We will begin by discussing magnitude scales. One common misconception is that people often report magnitude scales in terms of Richter magnitude. Dr. Charles Richter was a very important person involved in the early development of the field of seismology. He did some very instrumental work and was the first to identify this idea of a magnitude scale where one unit represented a 10-fold increase in the amplitude of the ground motion, but the Richter magnitude scale was specifically designed for observation on a particular type of instrument called a Wood Anderson seismogram. This instrument is no longer being used. As a result, there are no Richter magnitude scale measurements being made today. Local magnitude is a measurement used today that is the most similar to the Richter magnitude scale. Local magnitude is measured in the immediate area of the earthquake looking at the amplitude of the ground motions there, and is often reported in the initial time period after the earthquake. There are other magnitude scales that look at other seismic waves including surface wave magnitude, which is another common way magnitudes are published. Body wave magnitudes are often used in the eastern U.S.

Recently, there has been a move within the scientific community towards the moment magnitude scale, which measures the amount of energy released. As we step one unit of magnitude in the moment magnitude scale, we have a 30-fold increase in the amount of energy released. The energy released is a much better way of scaling or understanding the magnitude, so the moment magnitude has now become the scientific standard.



Another common misconception is the idea of epicenters. Epicenter is the point on the Earth's surface directly above the point on the fault where there is an initial rupture. This point on the fault is often called the hypocenter, or focus. We often receive requests for the epicenters of the events in our seismic risk models. While it is helpful from a scientific point of view to give coordinates to where the earthquake has happened when it initially occurs so we have an idea of its location, it is much more important to know what part of the fault ruptured. When an earthquake occurs, it starts at a point but then it ruptures over the plane of the fault. The distance to that rupture plane is a much better correlation of the ground motions than the distance to the epicenters. While we often get requests from clients for the epicenters for our stochastic event sets, this is not the most useful piece of information. What you really need to know is where the rupture planes are so you can better correlate distance to the highest ground motion.

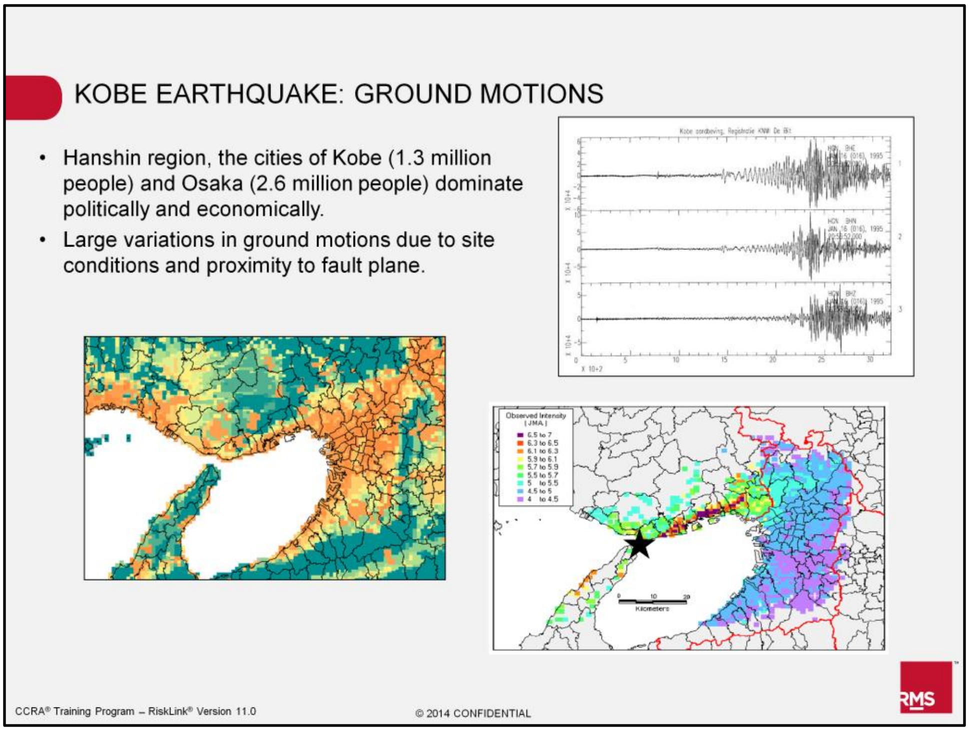


Let's take a look at earthquakes as a whole. How do they cause damage? There are three different ways earthquakes cause damage. Most obvious is ground shaking, which has several components to it. One component is the intensity of the ground motion, or how high the amplitudes of the ground motion are. Other components are the length or duration of the ground shaking, and the frequency content. The frequency content is an important link to exactly how structures of different construction and heights will be impacted. We will talk about this more when we talk about how damage is calculated.

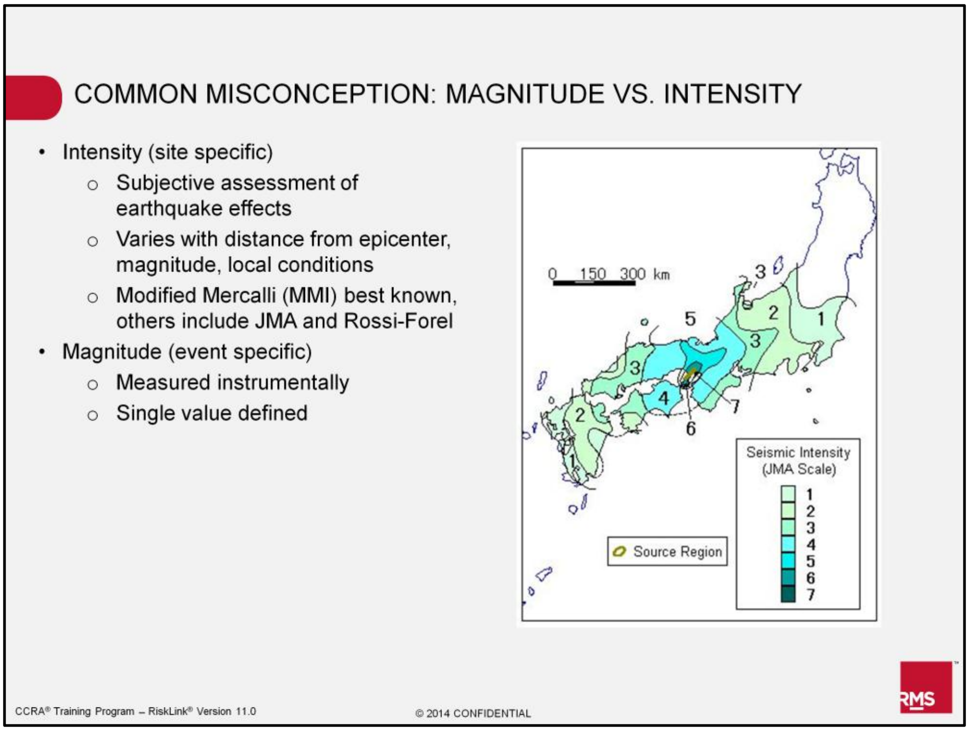
Beyond how shaking affects structures, it is important to understand that ground deformation is a contributor to how buildings are damaged. The picture in the middle shows surface rupture from the Dixie Valley/Fairview Peak, Nevada earthquakes of 1954. You can see there has been about 10 to 12 feet of displacement on the fault. It actually occurred between this small building and its outhouse, which is sitting perched on top of the fault rupture. Fault surface rupture, however, is an extremely isolated problem. It is more of an issue if your structure straddles the fault, and in many places there have been codes designed to prevent structures from being built across a fault. Fault rupture only occurs in shallow earthquakes. Other ground deformations that can occur in an earthquake include liquefaction and landslide. We will talk about these in more detail later but they essentially impact the ground where the building is situated. Either the building loses its stability, as in liquefaction, or it physically moves down slope, as in a landslide. Both of these hazards can cause significant damage to a structure if they happen in the immediate area.

Earthquakes can also generate water waves as we saw in the Indonesian earthquake in December 2004 and Tohoku, Japan earthquake in March 2011. Very large tsunamis can be generated as well as seiches, which are water waves produced in isolated or enclosed bodies of water. Seiches can occur within harbors or within lake bodies. There are also collateral hazards that happen with earthquakes, such as fire following earthquake and earthquake sprinkler leakage. These are linked primarily to ground shaking but ground deformation can also cause ignition sources for fire and can impact sprinkler systems.

We will now walk through the impacts of the Kobe earthquake, looking at examples of both ground shaking and ground deformation.



Looking at the Kobe earthquake ground motion, the map on the lower left shows the site conditions throughout the Kobe Osaka region. The better site conditions are represented by dark green; as the soil becomes poorer, the colors change to paler green, yellows, and oranges. More than four million people live in this region, and most of the exposure is on the poorer soils, represented by the orange and yellow. The map on the right shows the observed ground motion. The really high intensity values are represented by the red, orange, and yellow. The lower intensities are represented by the blues and purples. The epicenter is represented by a star. The reds and oranges in the immediate area of Kobe show very high ground motions and highlight the location of the fault. The large variation in ground motion is due primarily to site conditions and proximity to the fault plane.

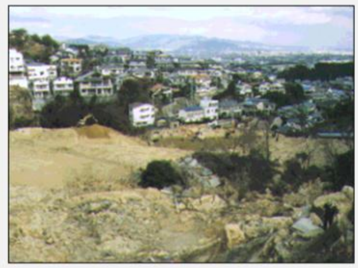


Another common misconception is the difference between magnitude and intensity. Intensity is a very subjective scale based on observations of either how buildings are damaged or how people felt or experienced the earthquake. It varies with distance from the epicenter and it is influenced by the magnitude of the earthquake and the site conditions at the location where the intensity is being observed. This map shows the JMA intensities for the Kobe earthquake. Japan uses the JMA scale, rather than the Modified Mercalli scale. The scale ranges from one to seven with one representing lower ground motions or intensities, and seven representing the highest ground motions or intensities. At JMA intensity five, unreinforced masonry walls start to fail so it is at this intensity that we begin to see damage to structures. At JMA intensity seven there will be very high losses.

In contrast, the magnitude scale which is instrumentally measured, is a single value for an earthquake, and it does not vary by location. A good analogy for explaining the difference between intensity and magnitude is a light bulb. Think of the wattage of the light bulb as the magnitude and how bright the light is for you depending on how far away you are from the light bulb as the intensity you experience.

KOBE EARTHQUAKE: GROUND DEFORMATION

- The Port of Kobe, the third busiest in the world, was shut down by damage to port facilities due to extensive liquefaction.
- About 95% of the berths in the port were inoperable.
- Landslide was a more localized issue.
- Most significant landslide occurred at Nikawa-Yurino town in Nishinomiya City and killed 34 people.



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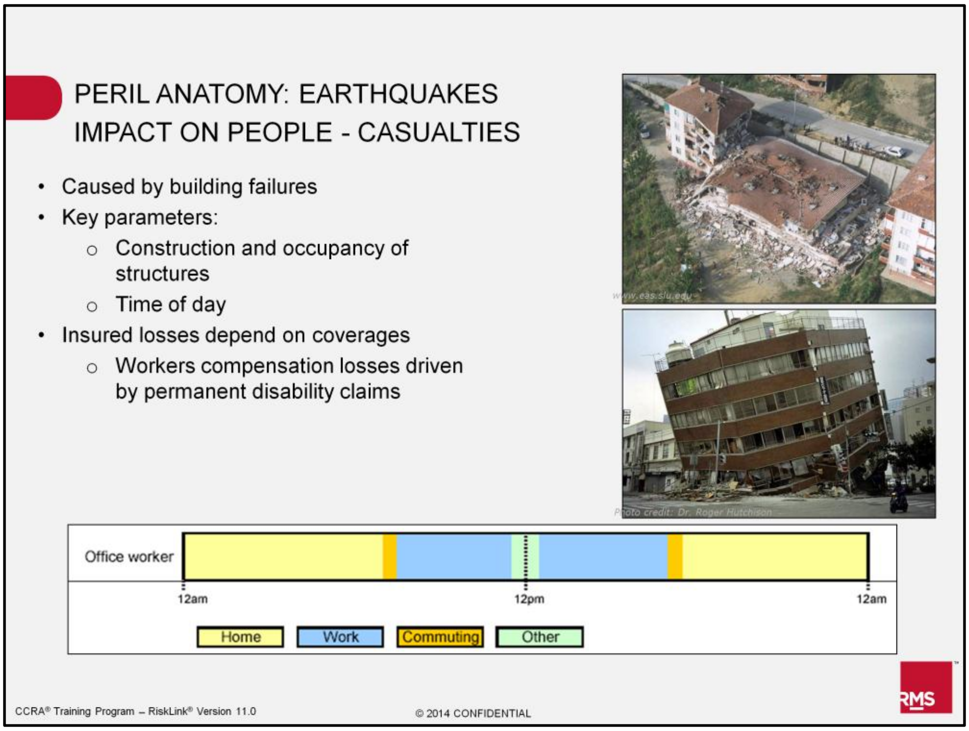
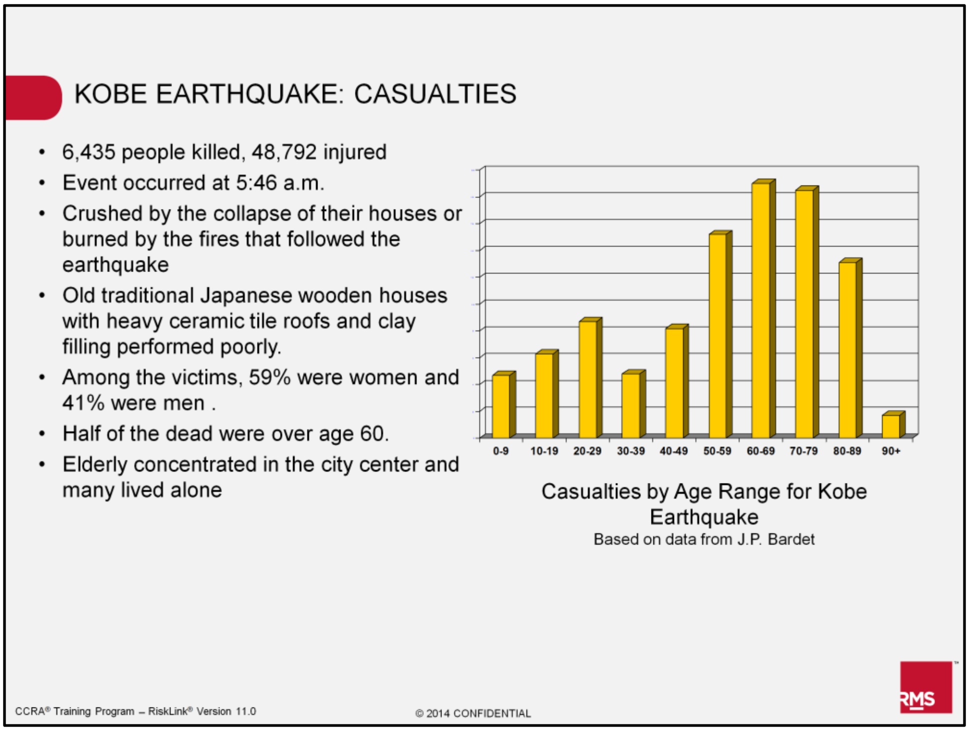
Next we will discuss ground deformation with results from the Kobe earthquake. There was very little surface rupture with the Kobe earthquake. You will recall a picture at the beginning of this presentation showing surface rupture as a result of the Kobe earthquake. That surface rupture was on the island of Awaji in the town of Hokudon. While there was some surface rupture and it did affect structures, most of the damage observed was not directly related to surface rupture. Much more important was liquefaction. The port of Kobe prior to the earthquake was the third busiest port in the world. The port had to be shut down after the earthquake due to the extent of liquefaction. Most of the port structures were completely undermined by extensive liquefaction. In the picture on the upper right, you can see that there has been a lot of lateral spreading, there has been sinking, and these large cranes can no longer be used because they are not stable. About 95% of the berths were rendered inoperable. Eighteen years have passed since the Kobe earthquake and the shipping in the area still has not returned to the level it was before the event. The earthquake had a very significant economic impact on the shipping business in this area.

Landslide was a more localized issue with the Kobe earthquake, but there was one significant landslide in the Kobe area that buried a community and killed 34 people. As a whole, liquefaction was extensive in the Kobe earthquake whereas landslide was not as important an issue. With each earthquake you will see a different balance of these perils and how they relate to each other.



Next we will discuss how earthquakes impact people. When looking at earthquake casualties, it is almost exclusively caused by building failures. The key issues with respect to building failures and casualties include the construction and occupancy type of the structure, and the time of day the earthquake occurs. The picture on the upper right shows a five story unreinforced non-ductal concrete structure which is completely collapsed. This picture is from the Ismit earthquake in Turkey. There were a number of these five story residential buildings that failed in the Turkey earthquake because buildings five stories or shorter did not need to be reviewed by an engineer so many of these structures were poorly built. Because of this, a lot of people were killed in their homes. The lower picture shows a commercial structure that was significantly damaged by the Kobe earthquake. In an earthquake, you can be injured at home or at work. When we look at the timeline at the bottom of the slide we see where an office worker is during the day. They are at home during most of the evening hours and they are at work during the mid-day hours. They can also become casualties while they are commuting. In the Kobe earthquake a lot of the highways collapsed. When looking at insured losses for casualties, we see that the workers compensation losses are driven by permanent disabilities. So it is not so much the people who are killed but the people who are seriously injured and become permanently disabled that drive the insured losses for earthquake casualties.

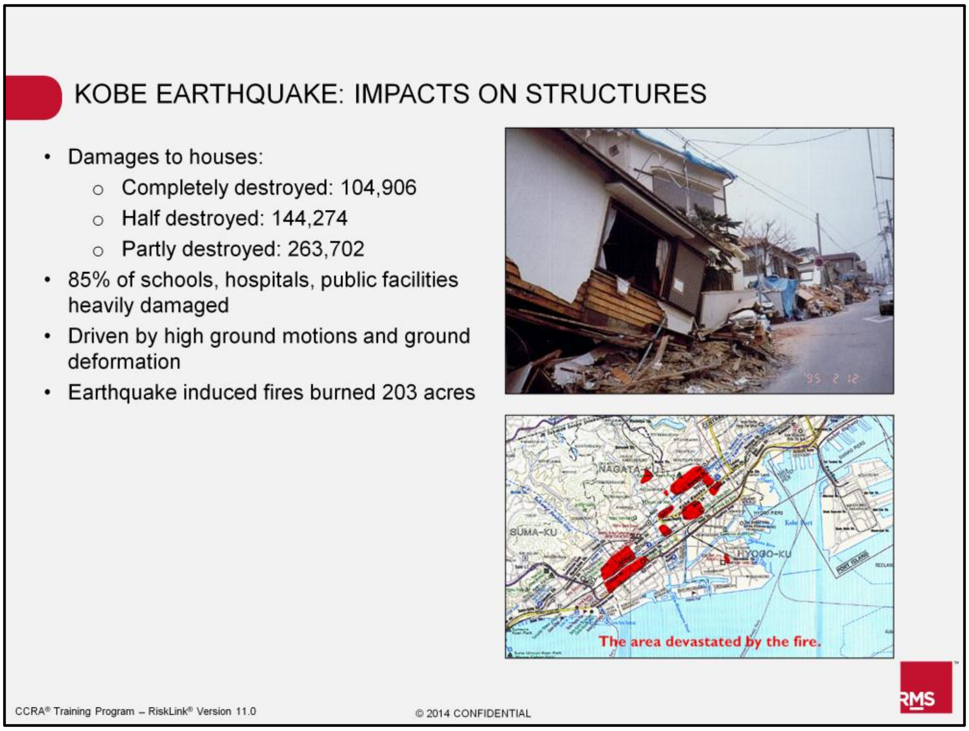


The casualties for the Kobe earthquake are very extensive considering the magnitude of this event, and the fact that it happened in Japan where there is an appreciation of earthquake hazard. In all there were more than 6,400 people killed and nearly 50 thousand people injured. This is primarily driven by the fact that the event occurred at 5:46 a.m. when everyone was at home. Most of the people who were killed were crushed in their homes or burned by the fires. One of the key factors in this was the old traditional Japanese wooden homes. These buildings are built with extremely heavy ceramic tile roofs because Japan is prone to typhoons and these heavy tile roofs stay in place in high winds. Unfortunately these roofs make the buildings very heavy and there is not enough lateral support within these older homes. When earthquakes shake them, they are very prone to collapse. When we look at the victims of the earthquake, we find that 59% of them were women and 41% were men. Another interesting note is that half of those killed were over the age of 60. The elderly were concentrated in these older traditional homes in the city center, a very high density area. Also, many of them lived alone. When the building collapsed and they were injured, they were unable to escape their homes. Then the fires began and they were trapped.

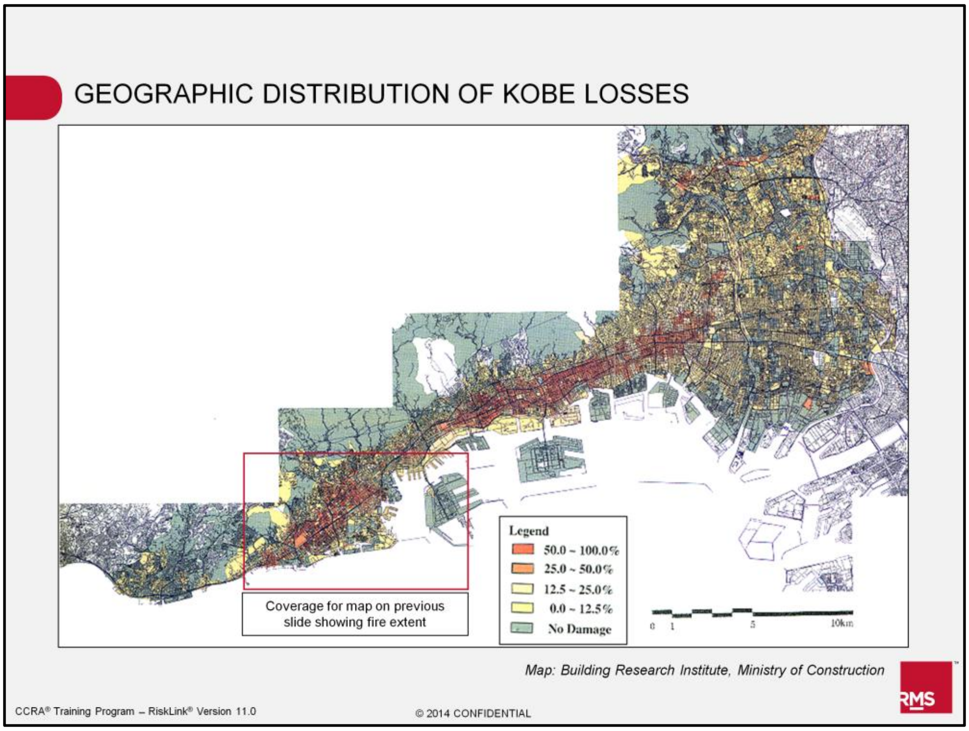
PERIL ANATOMY: EARTHQUAKES IMPACTS ON LOCATIONS

- Ground shaking and displacement damage buildings
- Damage to contents caused by shaking and structural failure
- Fires following the earthquake
- Sprinkler system failures (leakage)
- Lifelines and business interruption

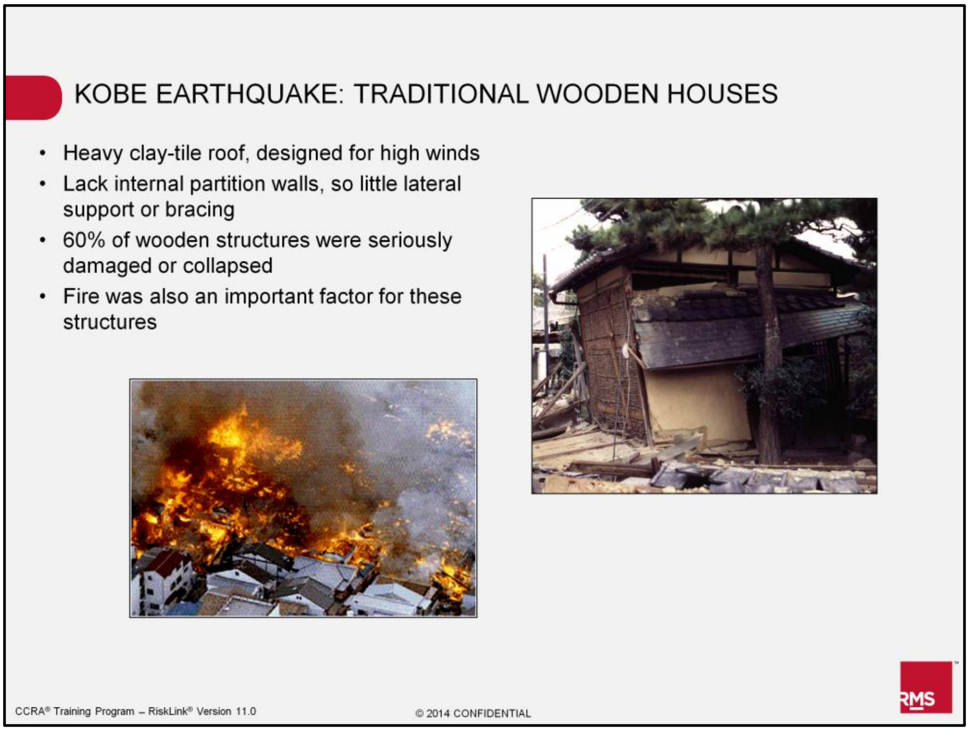
Thus far we have talked about how earthquakes affect locations. The ground shaking and the ground deformation or displacement causes damage to structures. But contents are also damaged by shaking and structural failure, by fires initiated by the ground shaking, and by sprinkler leakage when the sprinkler systems within a structure are undermined by the ground shaking. They either snap or crack and then water leaks out of them onto the contents of the building. There are also business interruption and lifeline issues as well.



The impact on structures from the Kobe earthquake was significant. Nearly 500,000 buildings damaged. The photo on the upper right shows a residential area in Kobe. You can see that a lot of the structures have fallen over. There was complete destruction of more than 100,000 buildings, 150,000 buildings that were half destroyed, and 250,000 structures sustaining partial damage. In all, 85% of schools, hospitals, and public facilities were heavily damaged. Most of the damage to structures occurred in areas with very high ground motion where the ground motion was amplified by poor site conditions, and by ground deformation such as liquefaction. We also cannot negate the importance of the fires that were induced by the ground shaking. More than 203 acres were burned. The map on the lower right shows the areas where the fire was particularly devastating. Because the area was contiguous, large areas burned.



The red box on this image identifies the area shown on the map on the previous slide. This image also shows the geographic distribution of the losses in the Kobe area. Pale green represents areas with no damage, while orange represents damage levels from 50% damage to complete damage. We can see on this image that the immediate area that was most closely associated with the fault that ruptured underneath Kobe has the highest damage. The rupture did not come to the surface but the fault runs under the Kobe area. There is also extensive damage farther to the east due to the poor site conditions in that region.



The pictures on this slide are of the traditional wooden homes mentioned earlier. You can see the heavy tile roofs with very little lateral support. Again, they were built to withstand high winds. While there was an appreciation for the earthquake hazard in this area, the level of risk was not very well understood. Sixty percent of the wooden structures were seriously damaged or collapsed. The fires were also very important because fires were initiated in these structures. Because these homes are poorly insulated, it was common to keep a kerosene heater in every room of these homes in the winter, which provided numerous sources of ignition within these structures.

KOBE EARTHQUAKE: NON-DUCTILE CONCRETE MULTI-FAMILY DWELLING

- Built prior to 1981, sustained heavy damage
- Building codes updated in 1981, newer buildings fared better

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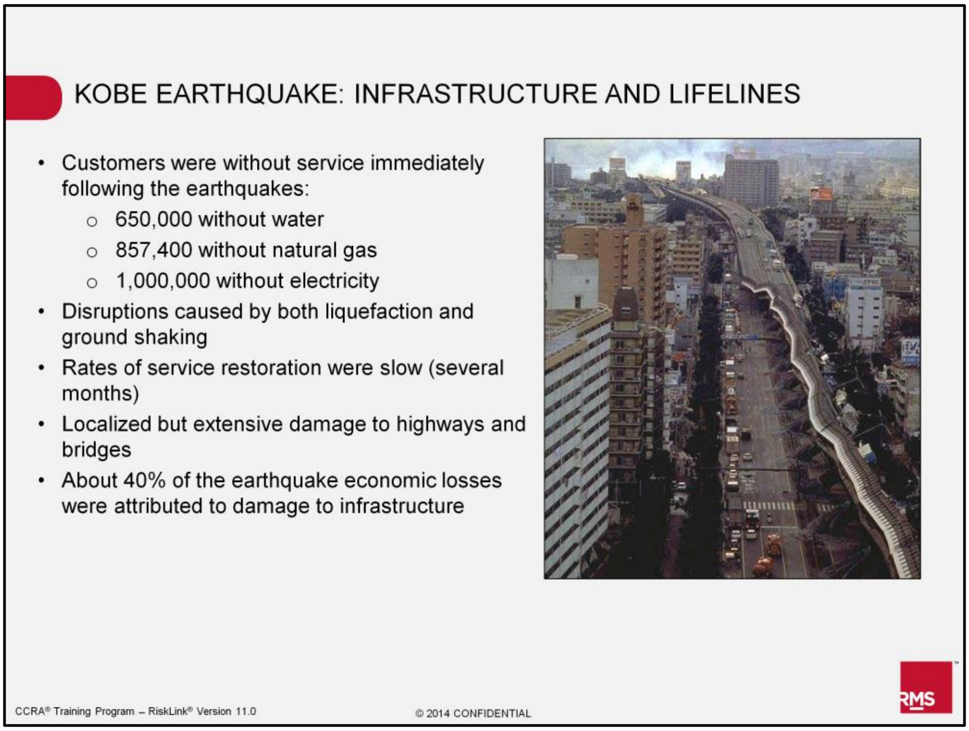
Another structure that faired rather poorly in this earthquake were the non-ductal concrete multi-family dwellings. The structures built prior to 1981 sustained heavy damage. In the photo on the lower left you can see the second story is missing. The photo on the right shows the bottom story missing. These structures were known to be an issue. When the building codes were revised in 1981 this issue was addressed so that these types of buildings built after 1981 performed better. There were also building code adjustments in 1971, which made a slight improvement on these structures but it was not until 1981 that they were better assessed and the ways to mitigate the hazard were better defined.



In terms of economic impact, infrastructure and lifelines were significantly impacted by the Kobe earthquake. The number of people who lost service to their major utilities such as water, natural gas, and electricity were on an unbelievable level. Six hundred and fifty thousand people were without water, nearly a million people were without natural gas, and a million people were without electricity. It took several months for these services to be restored. The disruption of these utilities was driven both by the liquefaction and the ground shaking. The photo on this slide shows the Hanshin highway, which has fallen over. This is just one example of the very extensive localized damage to highways. There were parts of the city that were basically impassable. You can also see the fires burning in the background of this photo. The damage to these lifelines and utilities caused about 40% of the economic loss attributed to the earthquake.

KOBE EARTHQUAKE: FINANCIAL IMPACT

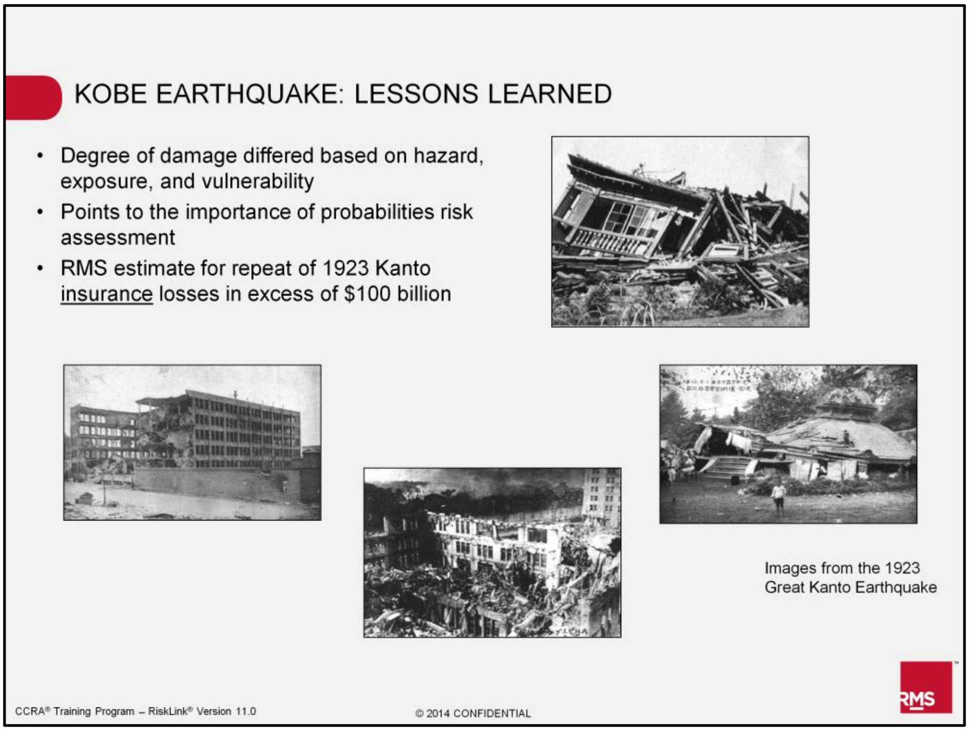
Economic Losses ($USD)

- Total economic losses estimated at $150 billion
- $100 billion in infrastructure and property losses
- $50 economic disruption

Insured Losses ($USD)

- Domestic carriers saw losses of $3 billion
- International market also $3 billion due to additional shipping costs, business interruption, and inventory losses
- Japan's central government paid over $780 million in residential claims

When we look at the final impact of the Kobe earthquake, overall we see the economic impact was on the order of $150 billion USD. Of this, $100 billion was due to infrastructure and property losses. There was also $50 billion due to economic disruption. Overall, the insured losses were much lower. The domestic carriers saw losses on the order of about $3 billion. The international market did absorb about $3 billion due to additional costs from shipping, business interruption, and inventory losses. On the residential side, the Japanese central government covered about $780 million worth of loss.



There are a many lessons learned from the Kobe earthquake. Clearly we saw that there is a link between the location and its proximity to the fault that ruptures, as well as to the site conditions. We see that certain types of structures, such as the traditional Japanese wooden homes and the non-ductal concrete multi-family structures that were built prior to 1981, performed poorly. So the degree of damage differs based on the hazard, exposure, and vulnerability. This event really emphasized the importance of looking at a probabilistic risk assessment for this type of region, taking into account the best information we have about structures and about where the seismic forces are located. It is important to realize, however, that while the Kobe earthquake was the largest event to affect Japan since the Kanto earthquake in 1923, events like the 1923 Kanto earthquake can cause significantly higher losses. The Kanto earthquake in 1923 occurred off the shore of Tokyo. It was on the order of a high M7, low M8. It resulted in JMA intensity seven over a very large area of the Tokyo metropolitan area. RMS estimates that a repeat of the Kanto earthquake would cause insured losses in excess of $100 billion - a much more significant event than was seen in the Kobe earthquake.

UNIT 4: PERIL ANATOMY – KOBE EARTHQUAKE CASE STUDY KEY CONCEPTS

- Earthquakes are measured by different methodologies, resulting in several different magnitude scales.
- Earthquake locations are designated by epicenter, hypocenter, and rupture area (length and width).
- There is a difference between earthquake magnitude and intensity.
- The three modeled damaging effects of earthquakes on insured coverages are ground motion, ground deformation, and tsunamis.
- Historical earthquakes, such as the Kobe earthquake, offer critical insight into financial and human impacts for model input and calibration.

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This slide highlights the key points from Unit 1 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 2.