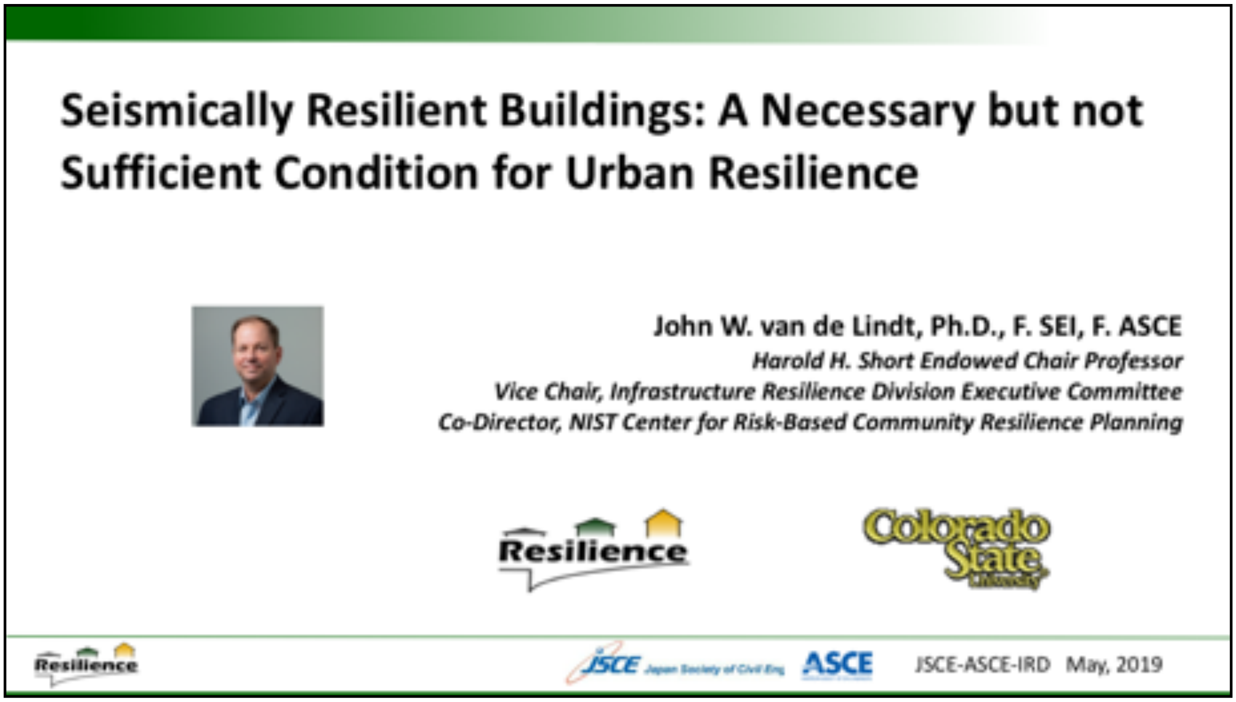
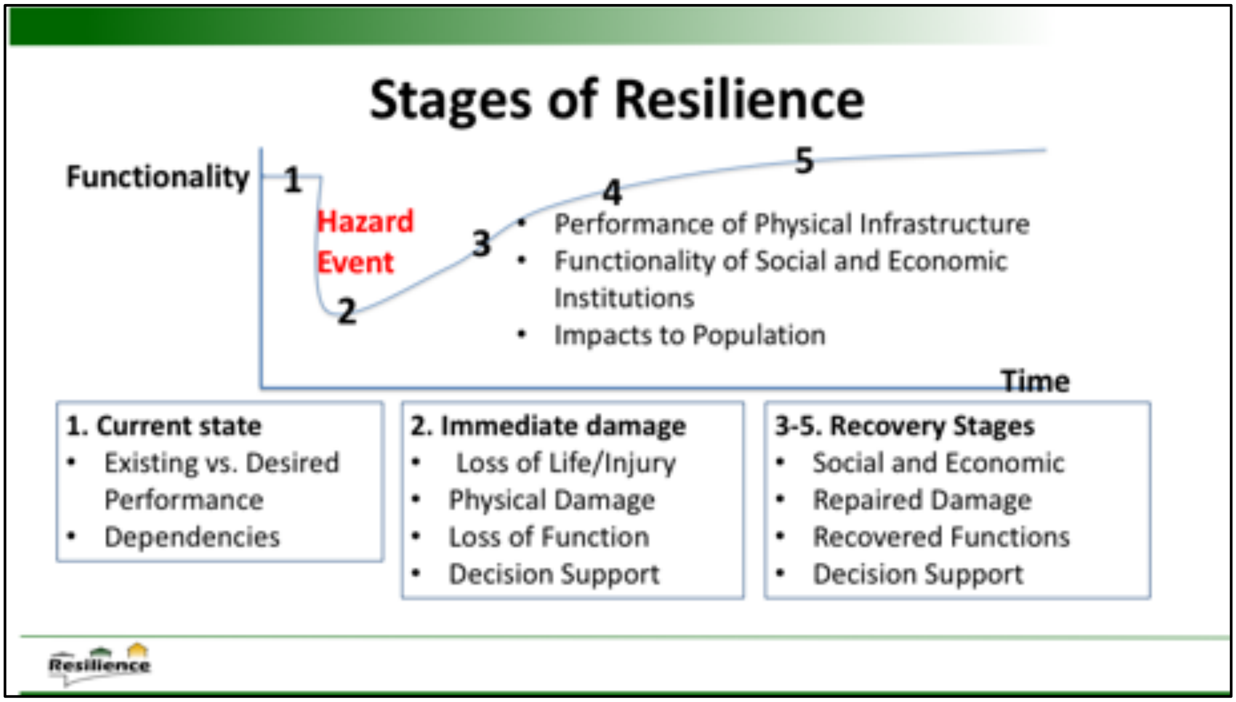
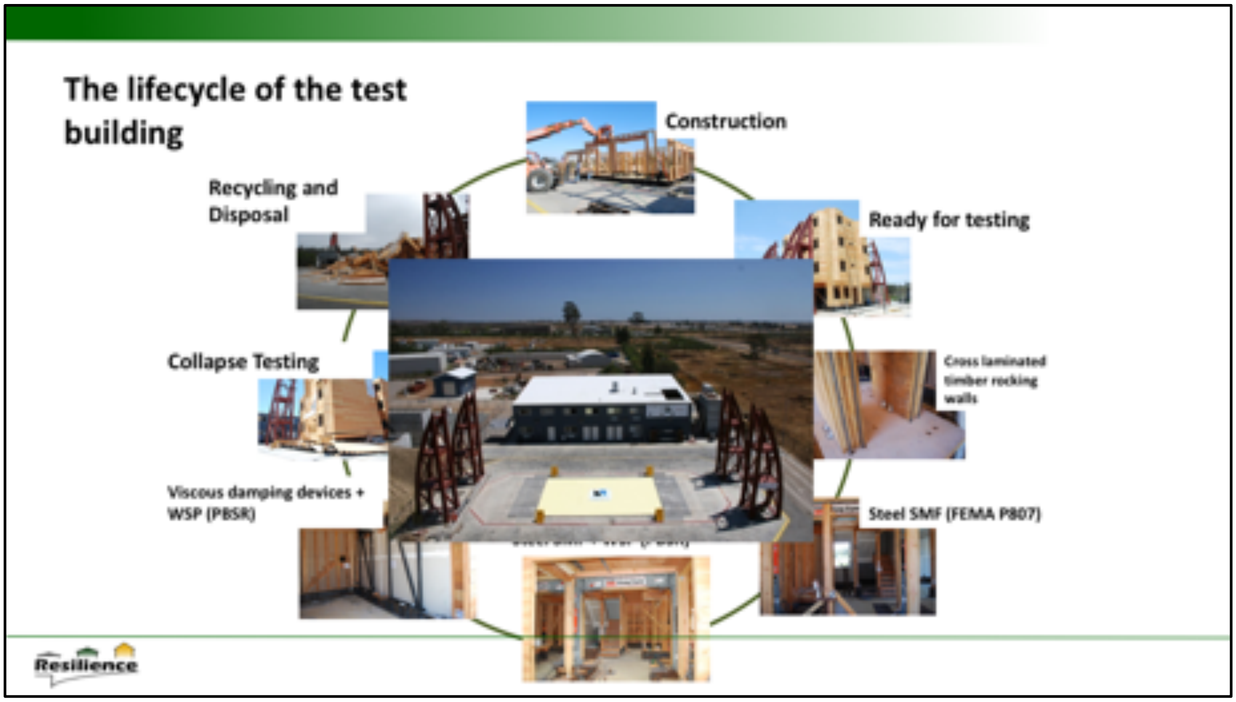


Good morning. Urban resilience to earthquakes requires that buildings perform well in strong ground shaking, but for true resilience this is a necessary condition – but it is not a sufficient condition. As you've heard about already this morning – lifelines play a major role for physical infrastructure, but all physical infrastructure supports social and economic institutions.



Resilience can be explained, or at least simplified, into five major stages of functionality – the current state, followed by damage from the event where emergency response is taking place – followed by recovery. Most engineering has focused on improving performance in earthquakes to reduce the effect of the hazard and less attention has been paid to stages 3 through 5. For a true urban resilience, planning at all stages must take place and remain active throughout the recovery.

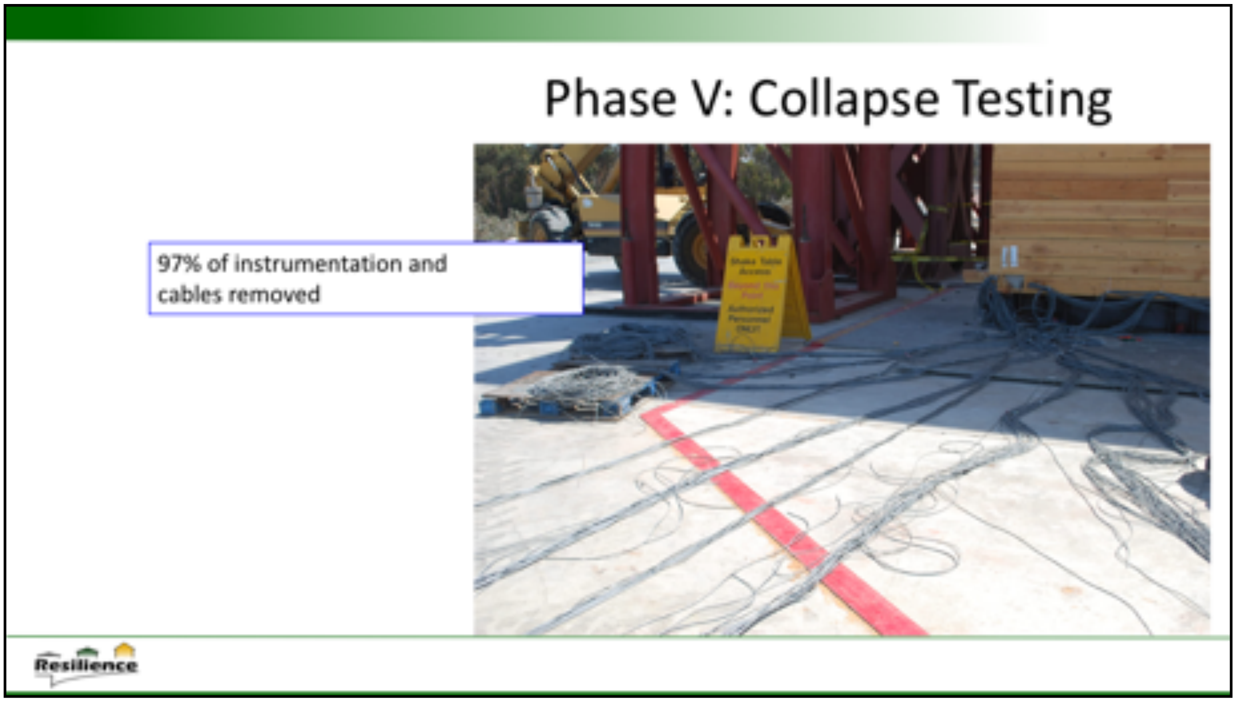


Let me begin todays technical presentation with a past test program I led at the University of California San Diego's outdoor shake table in 2013. This represents thousands of wood buildings in and around San Francisco that we're built in the 1940's and are considered dangerous in a major earthquake. We conducted a number of retrofits to help inform policy and develop a technical understanding of the behavior of these buildings.

Resilience

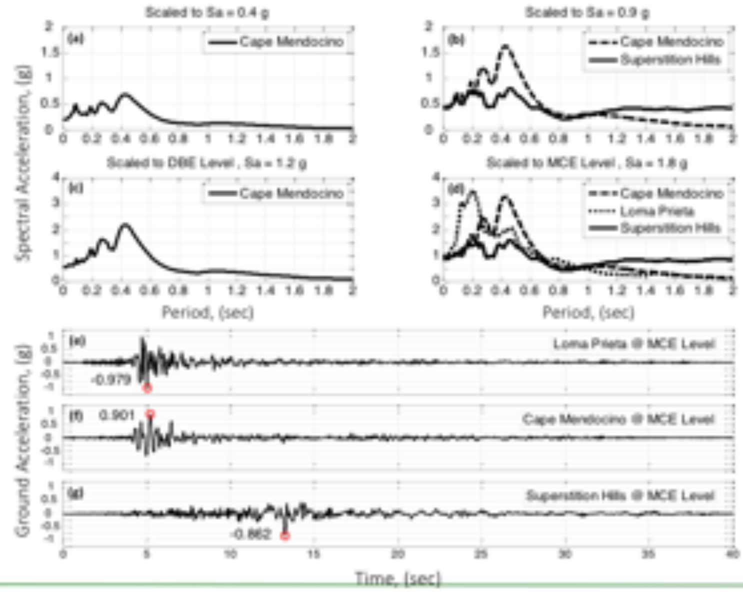
Some photos of construction.

The finished building on the right and some real buildings on the left. The shape and similarity is obvious, but the footprint of the test building was limited by the size of the shake table.

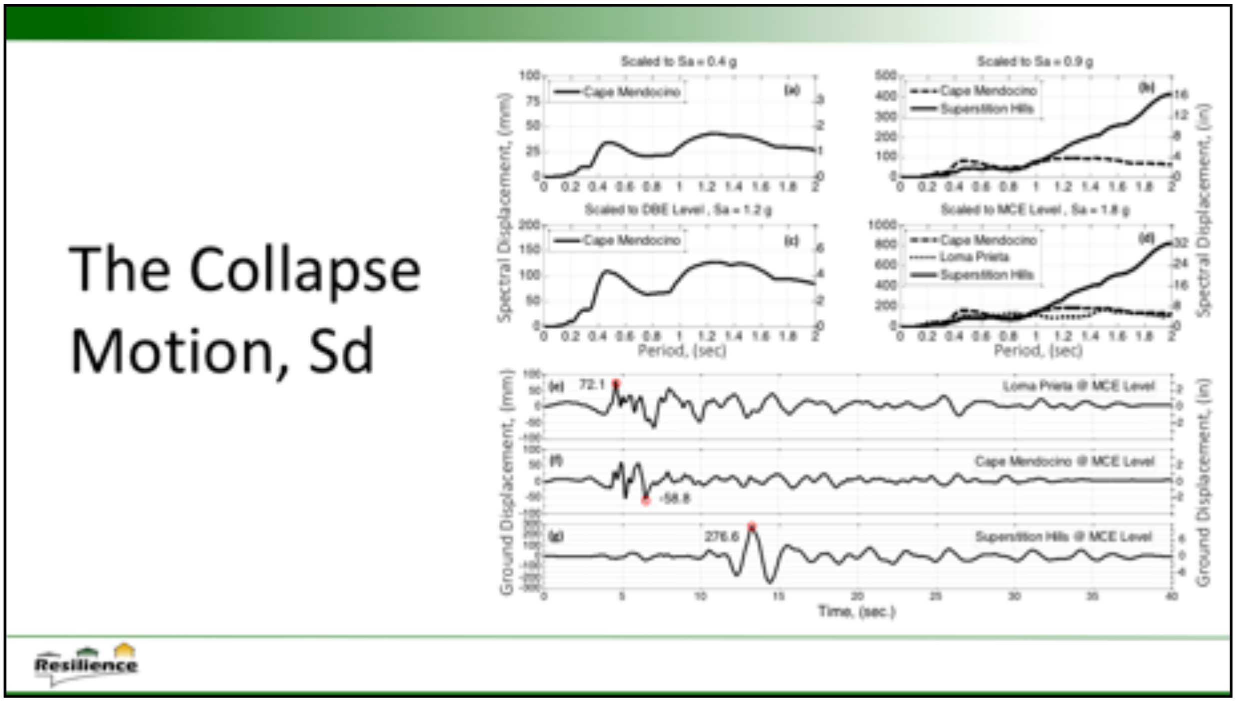


All retrofit tests were successful, even at Maximum Credible Earthquake scaling. However, to better understand and model the collapse behavior of this type of soft-story building, almost all the instrumentation was removed and the building and then it was tested without retrofits in place.

The Collapse Motion, Sa

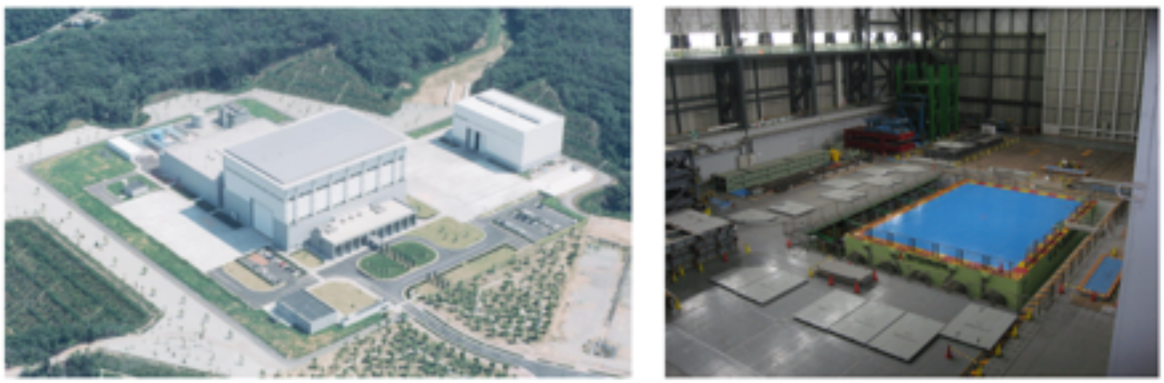


In order to select a collapse motion - several different earthquakes were considered. Looking at the windows in the top right one can see that scaling to MCE level - the Loma Prieta earthquake looks quite significant as does the Cape Mendocino record.



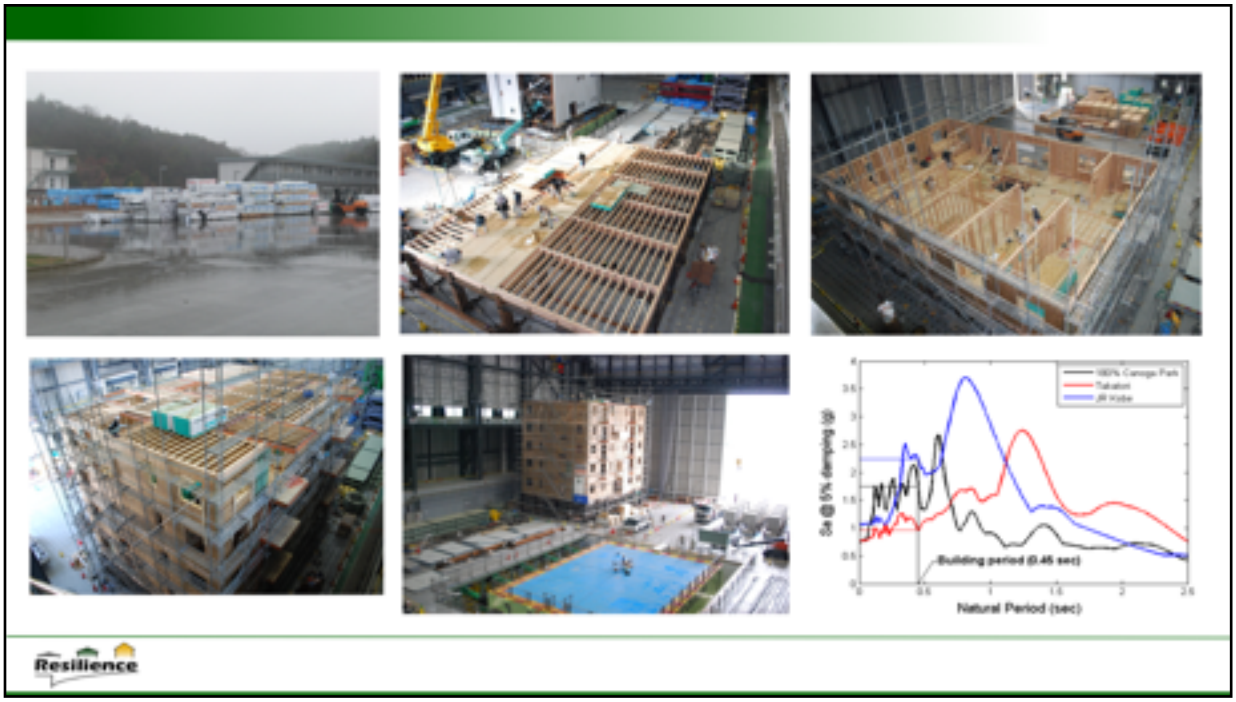
However, when one considers the spectral displacement, clearly the Superstition Hills earthquake appears to be a more significant event. The period of the un-retrofitted building being tested is approximately one second. One can see that as the period elongates during shaking likely in excess of two seconds the spectral displacement increases significantly.

Here are some images of the collapsed building.



E-Defense in Miki, JAPAN

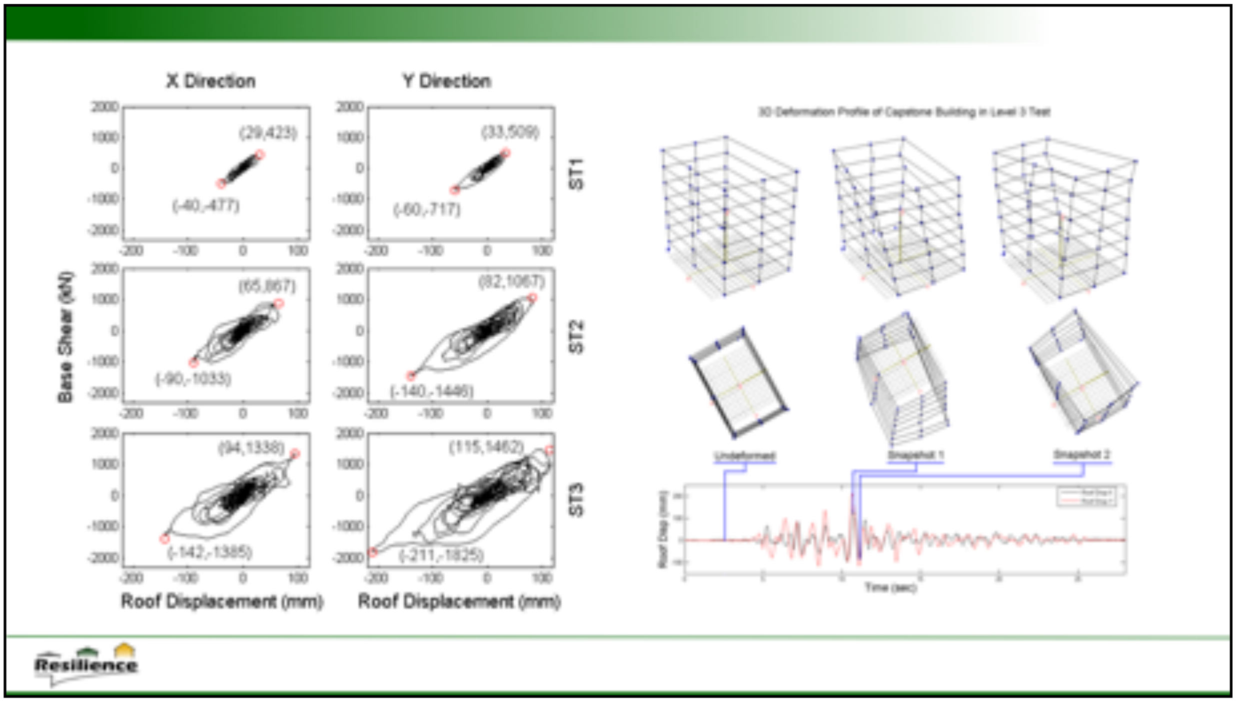
We now move on to a familiar shake table where I led a test program in 2009. This was the first US collaboration at E-Defense and was funded by the network for earthquake engineering simulation or NEES.



Here are some photos of materials shipped from the US, as well as construction photos. On the bottom right the spectral acceleration, or response spectra, for the 180% Canoga Park record that was used in the MCE level shake is shown in black.

This is the maximum credible earthquake test on July 14, 2009 at E-defense. The six story wood frame building that was constructed using the performance-based design approach. The performance objective was to limit damage to non-structural damage at MCE level approximately using about a 50 percent non-exceedance probability for 2.2% inter-story drift.

This is the sixth floor during the same shake which experienced close to 2G acceleration.



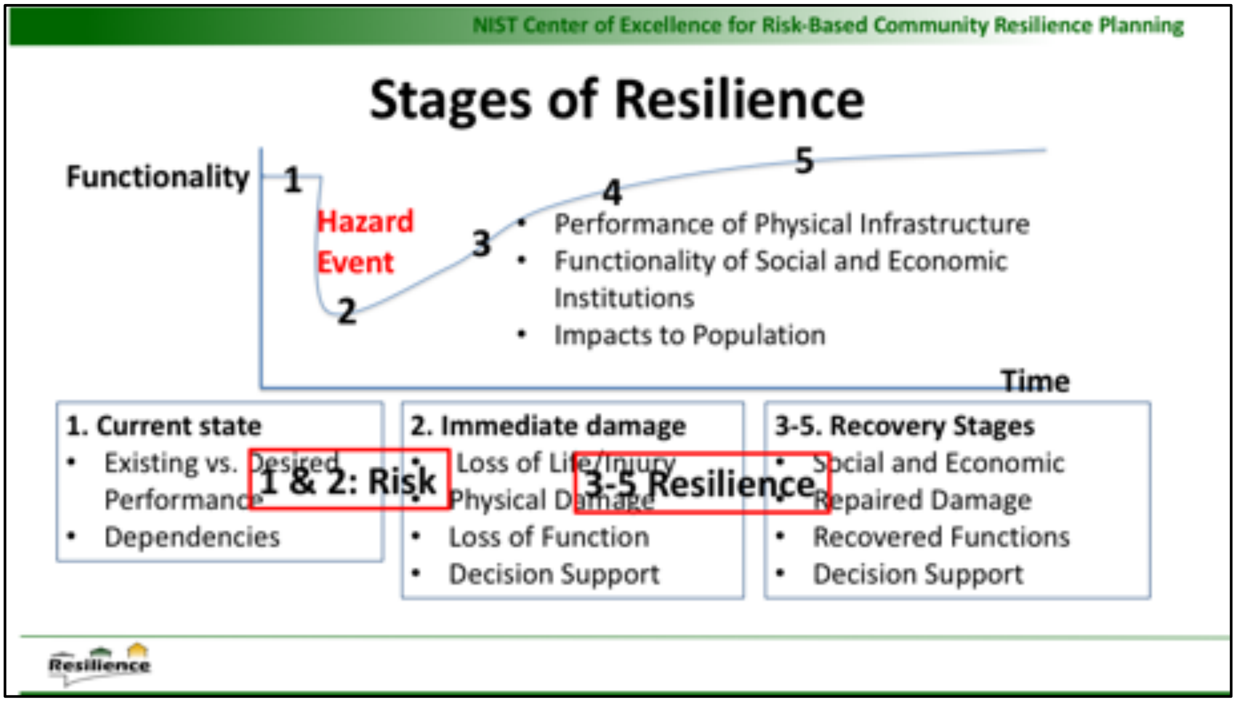
Here we see the hysteresis plots, and on the bottom right can see approximately 211 mm of total displacement at roof level and about 1800 kN base shear.

Expectations

Performance Expectations	Corresponding Peak Inter-story Drift (%)	Wood Framing and OSB/Plywood Sheathing	Gypsum Wall Board (GWB)
Level A	0.1 – 1.0%	Minor Splitting and cracking of sill plates (some propagation) Slight sheathing nail withdraw	Slight cracking of GWB Diagonal propagation from door/window openings Partial screw withdraw Cracking at ceiling-to-wall interface
Level B	1.0 - 2.0%	Permanent differential movement of adjacent panels Corner sheathing nail pullout Cracking/splitting of sill/top plates	Crushing at corners of GWB Cracking of GWB taped/mud joints
Level C	2.0 - 4.0%	Splitting of sill plates equal to anchor bolt diameter Cracking of studs above anchor bolts Possible failure of anchor bolts	Separation of GWB corners in ceiling Buckling of GWB at openings
Level D	4.0 - 7.0%	Severe damage across edge nail lines, separation of sheathing Vertical posts uplifted Failure of anchor bolts	Large pieces separated from framing Entire joints separated and dislodged

Resilience

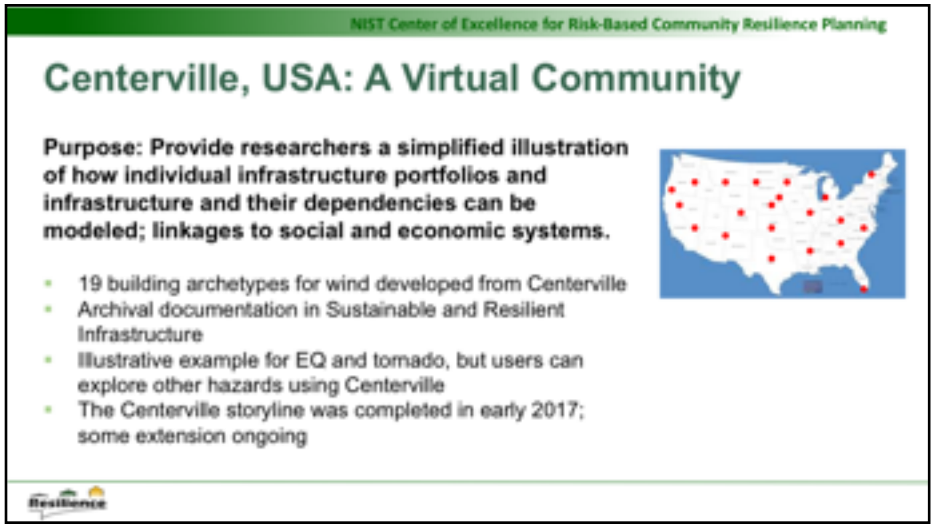
Of particular interest is the damage description that occurred. Level C, which was derived from low-rise wood construction during testing in the United States, wound up reducing to level A damage for mid-rise wood buildings. This was a significant result and is well documented in journal papers.



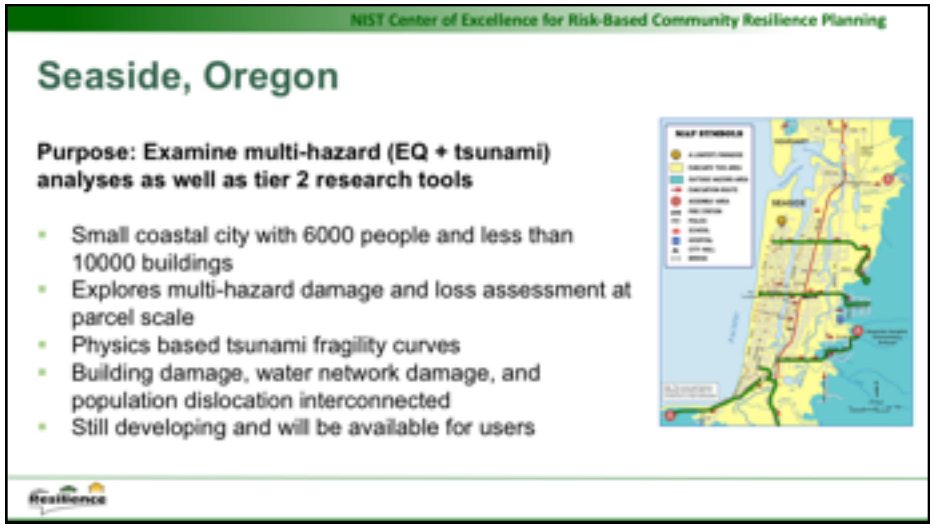
Having now seen a building that is not resilient and a building that is resilient I return to the stages of resilience - stages one and two can be considered part of risk whereas stages three through five have a significant effect on the modeling or the complexities of understanding resilience. They are the most difficult to model.

So, before I go further I would like to introduce the Center for Risk-based Community Resilience Planning funded by the National Institute of Standards and Technology. I Co-direct the Center which is a 12 University partnership with NIST and involves the National Center for Supercomputing Applications. The overall objective of the center is to understand and quantify factors that make communities resilient to hazards.

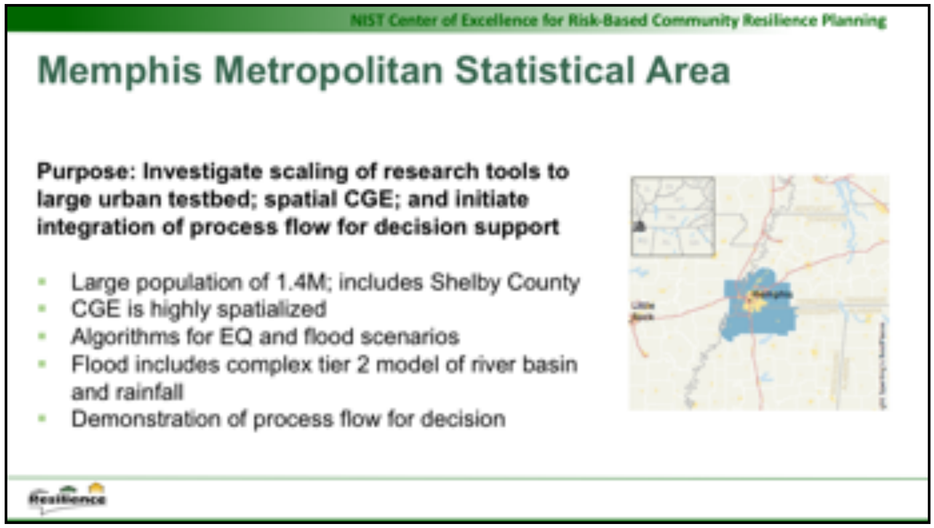
It is critical to study individual and multiple and competing hazards, all physical infrastructure including networks or lifelines and buildings, and social systems economic systems as well as optimization strategies to find near optimal solutions for enhancing community resilience. A number of test beds have been developed with three of the four testbeds involving earthquake.



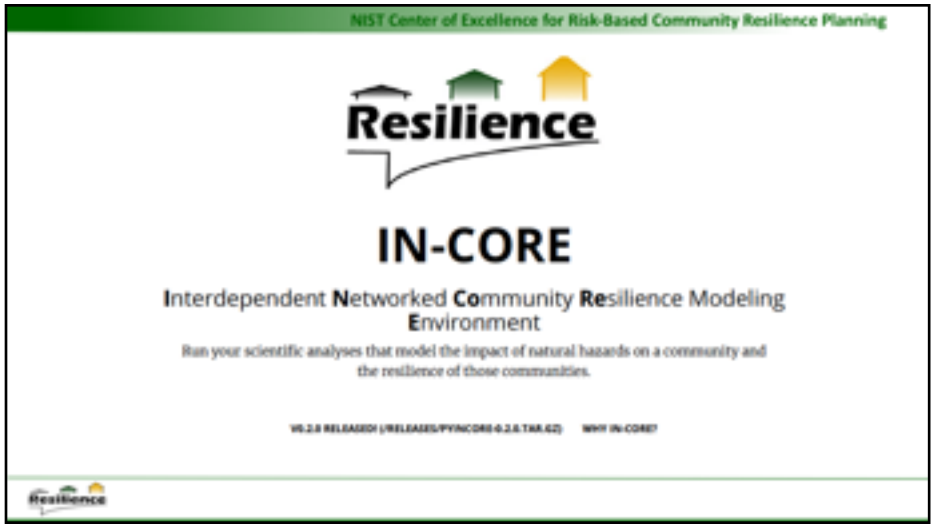
Without going into too much detail, Centerville is a virtual community that was designed to accelerate interdisciplinary collaboration as well as stress many of the models to better understand how to connect economics, social science, and the physical structure.



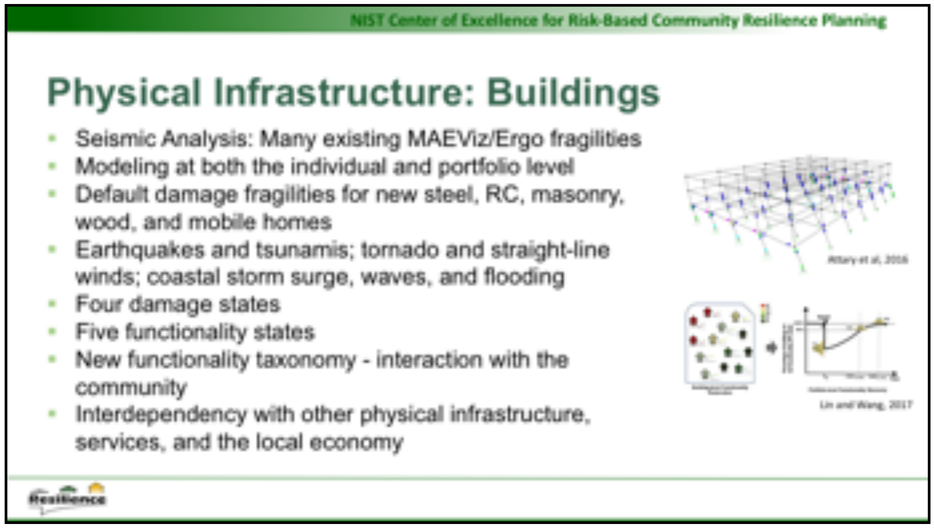
Seaside Oregon looks at the Cascadia subduction zone event which includes a major magnitude nine earthquake plus a tsunami in succession.



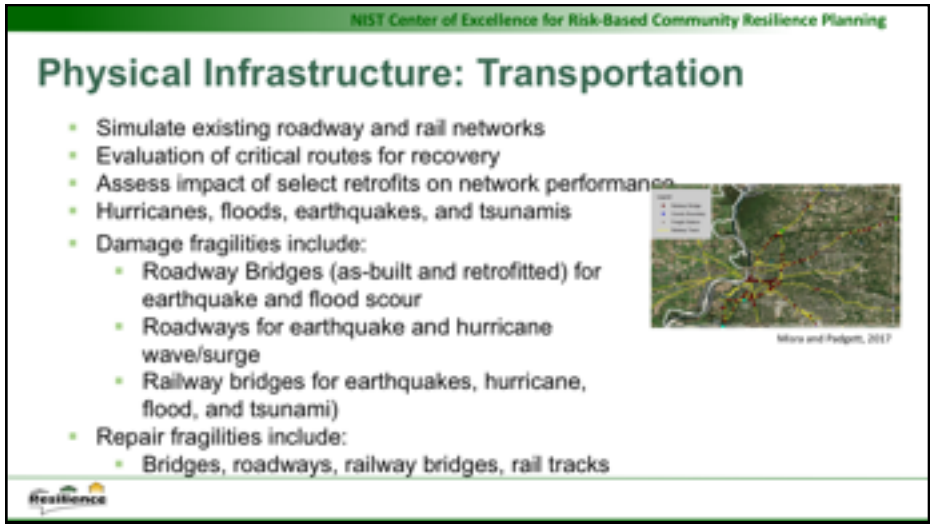
The Memphis metropolitan statistical area includes population of 1.4 million and represents the largest testbed. This allows center researchers to look at issues of scaling as well as the consideration of a spatial computer computable general equilibrium model for economics modeling.



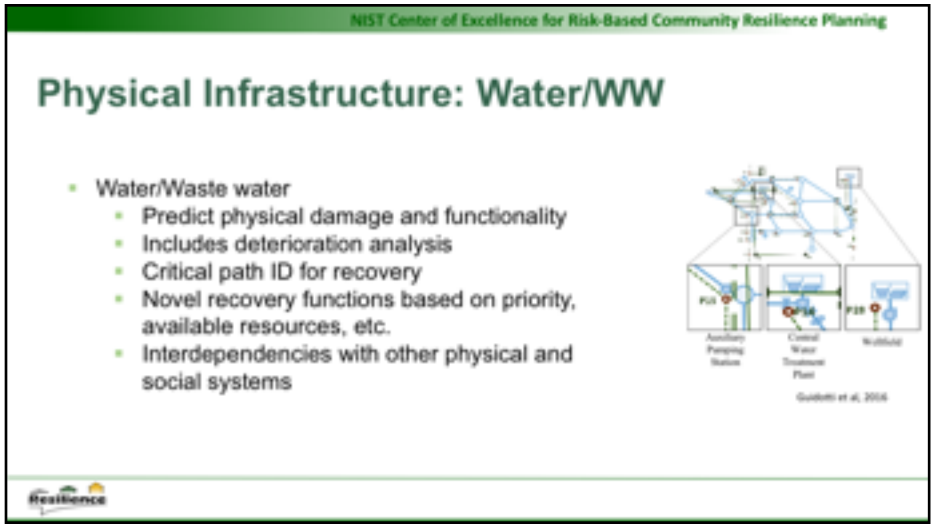
IN-CORE is a computational environment that will be released in December. It will be open source and available to research communities worldwide and it is hoped that it will accelerate the ability of engineers and scientists to study resilience.



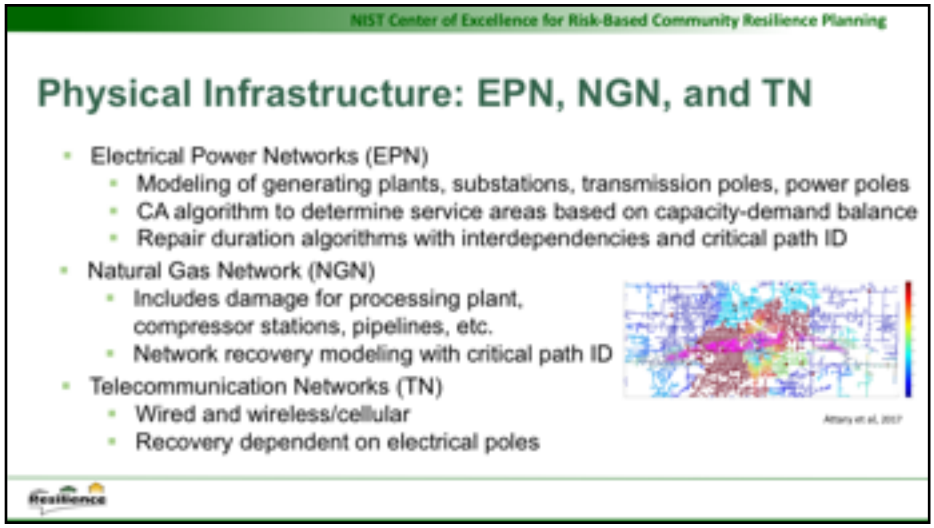
As the title of my presentation indicates clearly resilient buildings are a necessary condition to enable a resilient urban region.



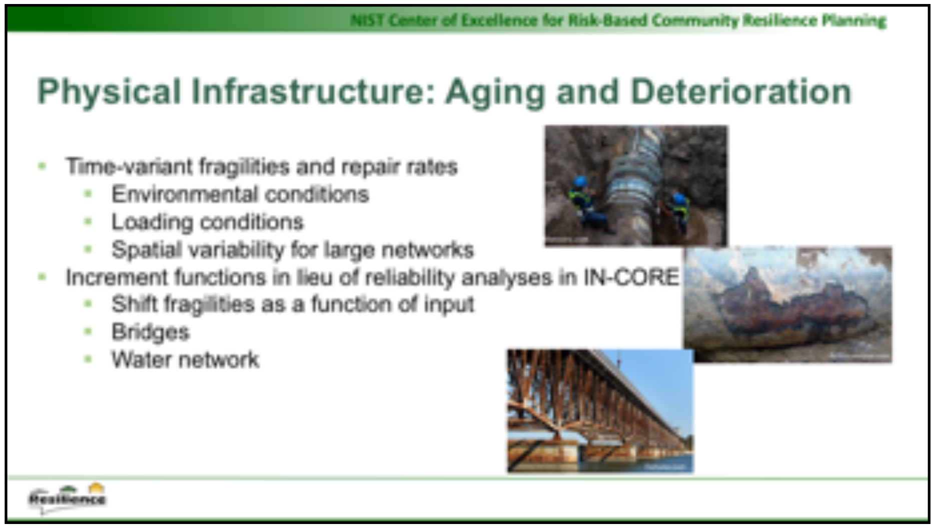
Transportation is also key to connectivity of the physical urban environment and enables social institutions to serve the people within the community.



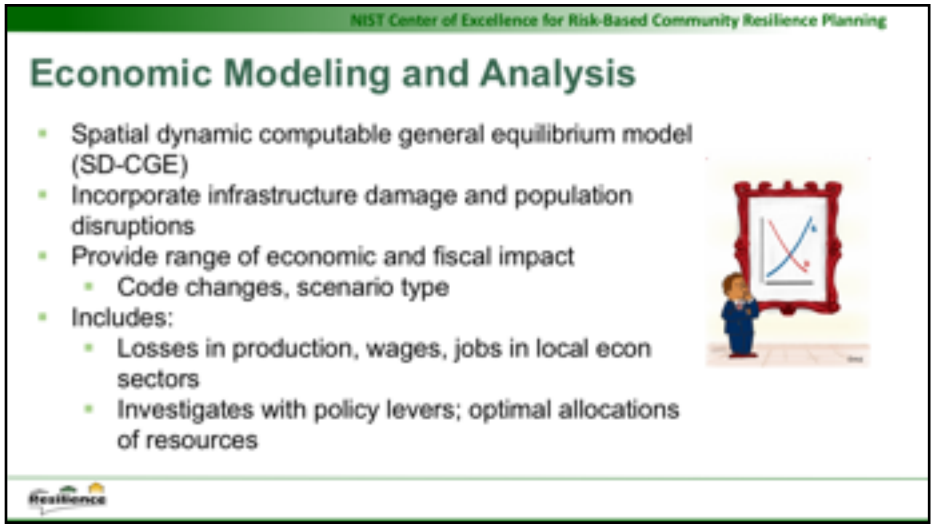
Clearly water and wastewater is critical to having a resilient infrastructure and is interlinked with virtually all buildings and much of the other physical infrastructure.



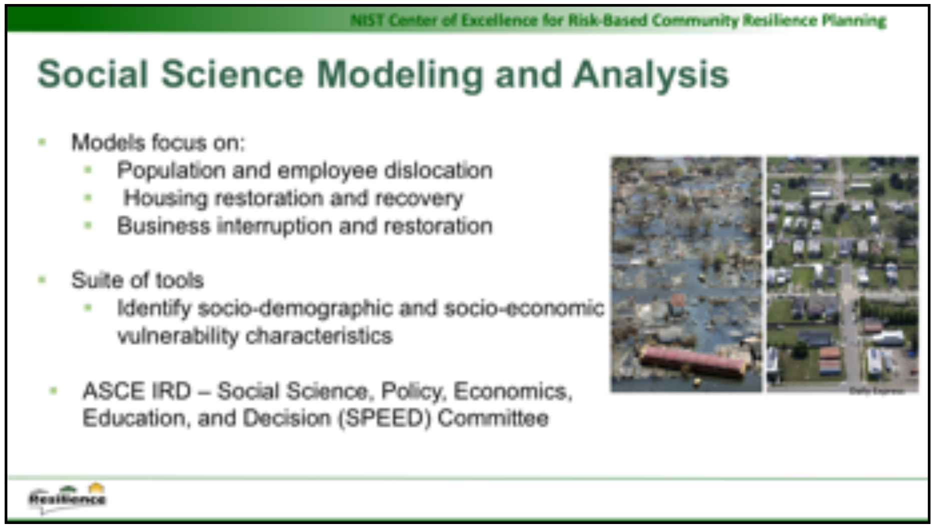
The electrical power network the natural gas networks telecommunications or communications in general must all remain operational or be restored quickly in order for a community to be considered resilient.



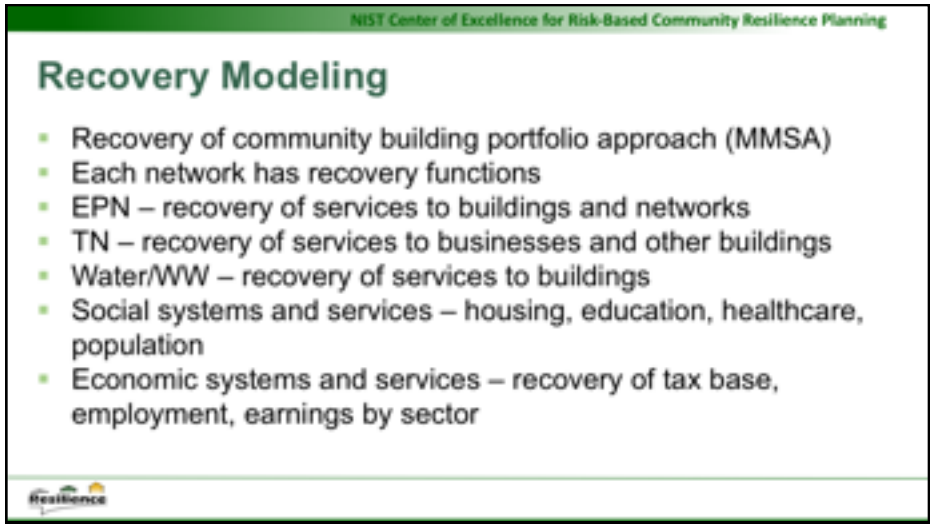
Another situation that occurs and is quite evident in the US is the aging in deterioration of infrastructure. Such conditions must be taken into account when setting up the model of an urban area.



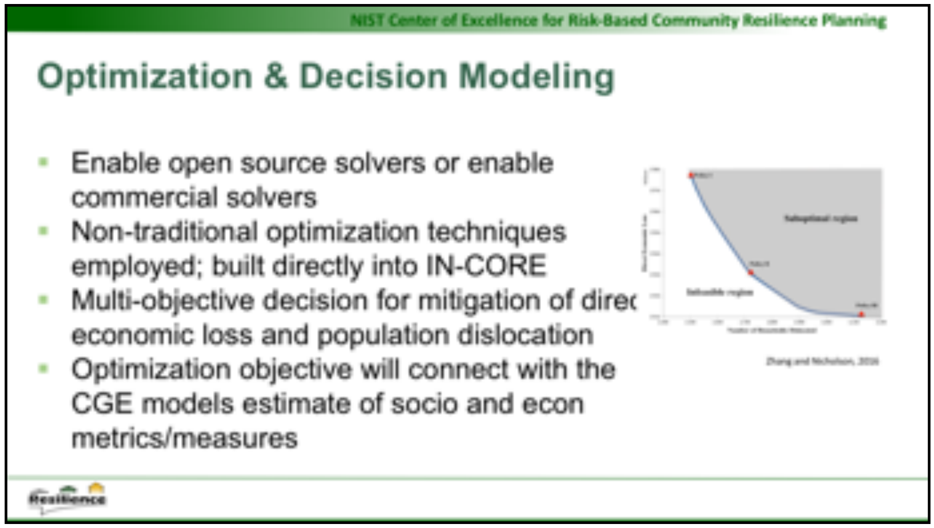
Economic models are also critical. The physical infrastructure, including buildings, as well as social systems directly affects economic recovery or resilience. Spatial dynamic computable general equilibrium models are one of the most advanced techniques available to economists and is being included in urban resilience modeling.



If we consider all physical infrastructure the purpose of such infrastructure is to serve the population or the needs of the population, social science modeling and analysis is critical to understanding and being able to model a resilient urban area. This includes models such as population and employee dislocation, housing restoration and recovery, and of course business interruption and restoration. The ASCE Infrastructure Resilience Division has five committees as you've heard about. I service co-chair of the social science, policy, economics, education, and decision committee known as SPEED. Such modeling and enabling consideration of these areas within civil infrastructure projects is the objective of the SPEED committee.



Finally, recovery remodeling is critical. Earlier, I mentioned the stages of resilience - stage one and stage two have been modeled by engineers and scientists worldwide for many decades. Stages three through five are new to most engineering and thus are more difficult to model. However, during recovery we work in the space that defines resilience stages three through five.



In order to provide risk informed decision support there are usually competing objectives subjected to a variety of constraints. In engineering, we often work with to find a Pareto front upon which decision and/or policy-makers can selected from a group of laterantives based on needs and opinions that cannot be modeled. This can be performed in many dimensions however it’s more typical for decision-makers to make these decisions in up to 4 to 5 dimensions or simply parameters. This can be accomplished with the help of a dashboard approach rather than weighting factors to ensure it is risk-informed.

And so with that I would like to conclude and thank you for your time and attention. I'd also like to acknowledge the NIST for their funding of the Center of Excellence, a number of people that supported both the NEES-Soft and the NEESWood projects including the National Science Foundation. Finally, thank you to the Japan Society of Civil Engineers and ASCE.