Generating Component-level Building-specific Fragility Curves

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What are Fragility Curves?

One of the most essential tools for representing the vulnerability of a structure is the fragility curve. By capturing the probability of damage at a given load level, fragility curves provide a way to express how a structure may respond to wind, fire, or seismic hazards.

Methods for generating building fragility curves can be grouped into two different approaches: top-down or bottom-up. The bottom-up approach is the least costly and time-consuming. It involves generating fragility curves for an arbitrary set of components in a structure to create one master building fragility curve.

Top-down approaches, on the other hand, treat a building as a single unit, incorporating its many components together rather than treating them separately. This latter approach has proven difficult due to a lack of robust theoretical knowledge

Key Takeaways:

- Unlike conventional approaches, this model generates a complete building curve without having to explicitly calculate curves for each component.
- Using this method, stakeholders will be able to more readily test the efficacy of different building designs prior to construction.
- Researchers applied this model to a case study of several building designs subjected to wind loads. They found that concrete structures were the least likely to fail.

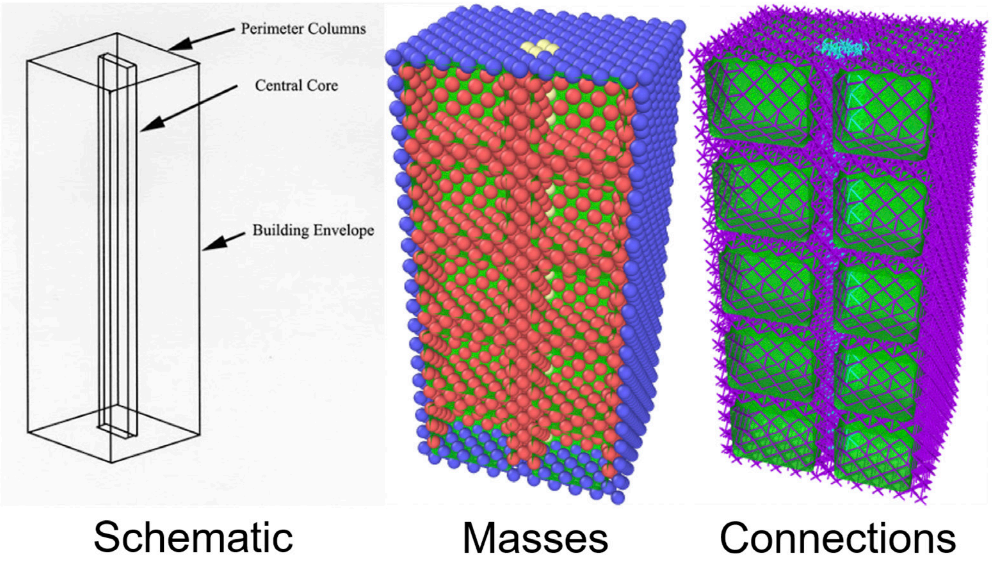

Figure 1. A comparison between a schematic and a simulation model. Masses in blue are for the building envelope, red masses are walls, and the yellow masses represent the central column.

and the absence of sufficient simulation methods.

In response, CSHub researchers have developed a method that combines both top-down and bottom-up approaches to integrate the structural and non-structural members into a single materials-specific fragility curve for any given building type.

Simulating Damage

Our method is grounded in statistical physics and realized through Monte Carlo simulations, which are inherently probabilistic, meaning that it explores a wide array of scenarios to find the most likely outcome. The benefit of simulations is that they can reconcile the divide between overly simplified analytical models and prohibitively expensive at-scale experiments.

The method begins by creating a simulation model of mass points and the connections that hold them together (**See Figure 1**). We can add specificity to the model by invoking different types of mass points and connections. For example, a wall (non-structural member) is modeled with different mass points than a column (structural); the same applies to the connections in the wall and the column.

A simulation is used in the model to consider the energy changes caused by a specific loading scenario, such as wind-loading. That simulation progresses until we reach failure, at which point, the damage probabilities are recorded and reported in the form of a fragility curve.

Concrete Mitigates Failure

We model a 5-story building with a central core and differentiate walls from the building envelope. The schematic and simulation model showing the mass points and connections are shown in **Figure 1**.

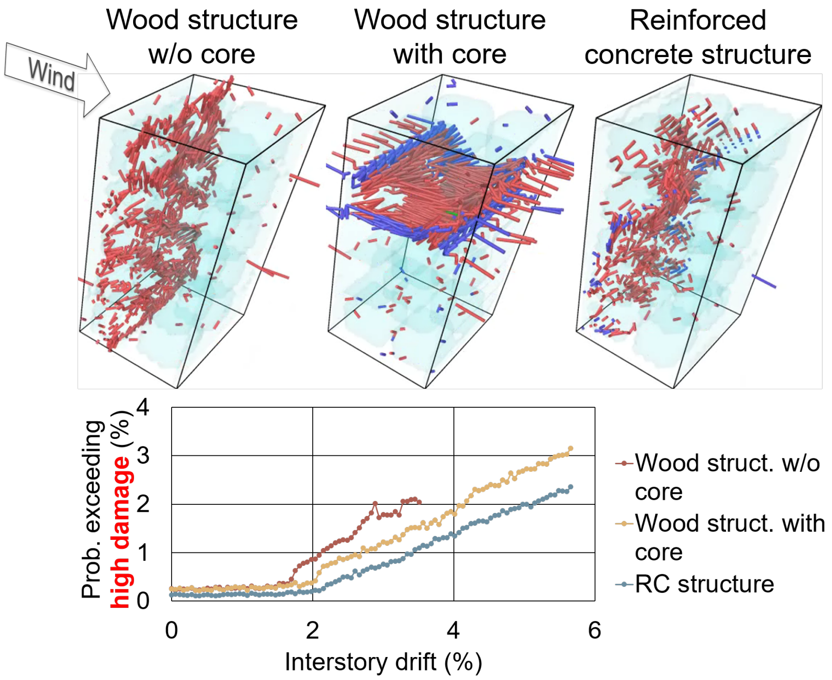

Figure 2. Damage maps and fragility curves for three different 5-story building models subjected to the same wind loading. From least to most damage tolerant, they are a wood structure without a central core, a wood structure with a central core, and a reinforced concrete structure.

Damage maps show broken connections in the building core (green), building envelope (blue), and walls (red). Broken connections outside the envelope are debris.

Interstory drift refers to the percentage by which the floors shift from their original position relative to their height.

Keeping the geometry of the building the same, we consider three different building materials and designs: i) a wood building without a central core, ii) a wood building with a central core, and iii) a reinforced concrete building. All buildings have a building envelope.

When subjected to wind loading, the entire side of the wood structure without a central core shears off, marking the worst level of damage among the three considered cases. At the same loading, a wood building with a central core loses an entire floor. A reinforced concrete structure under the same conditions stays intact, albeit with extensive damage throughout the building. The fragility curves in **Figure 2** quantify the probabilities of damage for all three cases: Reinforced concrete has the minimum probability of exceedance of damage, while the wood structure without a central core is the most likely to fail.

These results demonstrate that this quantitative resilience assessment Monte Carlo simulation tool is applicable at both the component and building levels. The ultimate goal is to include this resilience tool in early design to generate more extensive simulation models and create project-specific component-level and building-level fragility curves.

Related Links:

- CSHub Buildings Research
- CSHub Buildings Resilience Research
- CSHub Buildings LCCA Research

Citation:

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