A Resilience Assessment of Structures Using Molecular Dynamics

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PROBLEM

Between 1993-2012, more than 75% of catastrophic losses in the United States were caused by windstorms (1). The Congressional Budget Office estimated an average annual damage amounting to $28 billion (0.16 percent of GDP), with a potential rise to $38 billion by 2075 – 55% of which is attributed to coastal development (2). This economic impact of wind related events calls for reevaluation of engineering approaches. Traditional structural mechanics approaches evaluate wind damage of structural elements (i.e. beams, plates, walls) in relation to a *design code*, while not accounting for the contribution of non-structural elements (i.e. sheathings, windows) which clearly reflect on building integrity (3). While more detailed frameworks accounting for all elements do exist, such as the Federal Emergency Management Agency's HAZUS-MH (FEMA 2016), they are only limited to *specific building types* and *qualitative damage description* (i.e. slight, moderate, extensive damage, and so on) (4). This motivates the development of an approach that can quantitatively address the complexity of buildings in element scale (i.e. structural/non-structural elements), and system scale (accounting for any building use and geometry).

APPROACH

In our approach, the structural/ non-structural elements of a building are modeled as a collection of mass points that carry information about the element weight and moving loads (figure 1b, 1c). The process of dividing elements into mass points is called *discretization*. Although modeling through discretization is at the core of existing finite element methods, the key difference in our model is that mass points interact through energy terms rather than connect through elements. In other words, a building can be seen as masses connected through "springs", where springs carry the energy information of stretching/ bending properties of real elements. The advantage of such modeling is the ease of introducing damage in these "springs", which would entail significant calculations in a finite element context. The approach is employed here for the assessment of fragility curves of buildings subject to wind loads.

FINDINGS

We demonstrated our approach using a typical office building, as defined by the Department of Energy Reference Building Library for Medium Offices. Elements were modeled using three different number of springs N per element (discretization), (N=3, 5 and 10, as shown in figure 1b, 1c).

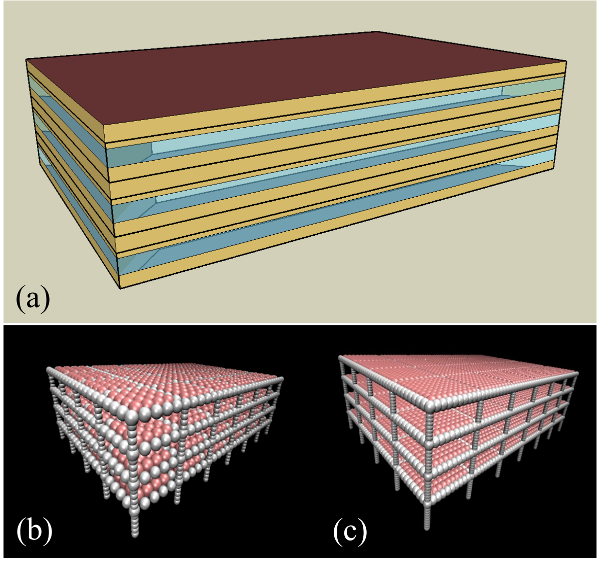

Figure 1: DOE-inspired office building (top) and different discretization levels (bottom), N=5 and N=10.

WHY DOES THIS RESEARCH MATTER?

- The need for accurate predictions of resilience of buildings requires a new generation of engineering tools that allow for damage assessment below the limit loads for which structures are classically designed.
- The approach presented in this brief has significant advantages over traditional methods such as Finite Elements, including absence of instabilities, ease of inelastic implementations, and speed of calculations.
- Fragility Curves can be used to evaluate the probability of failure of structures. These probabilities have become key to evaluate the resilience of structures and communities.
- We envision that such approaches can be used together with Computational Fluid Dynamics (CFD) simulations to evaluate the resilience of cities – an urgent task in view of perils of global warming

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At the core of our model is the description of the dynamics of buildings described through their vibrations: a description which allows direct comparison with existing models.

Figure 2 shows the comparison of vibrational periods of our model vs vibrational periods obtained through traditional Finite Element (FEM) simulations. As the discretization increases and our model becomes finer, the model periods approach the FEM periods, showing good match with existing methods. This is shown in the inlet on figure 2, with the error (difference between the two sets) decreasing with N.

Figure 3 shows the fragility curves for a reinforced concrete structure and a wood structure with timber-moment connections, using non-linear moment-curvature and moment-angle relationships, respectively. The curves represent the probability of damage (chosen as “collapse” in our simulations) vs wind speed.

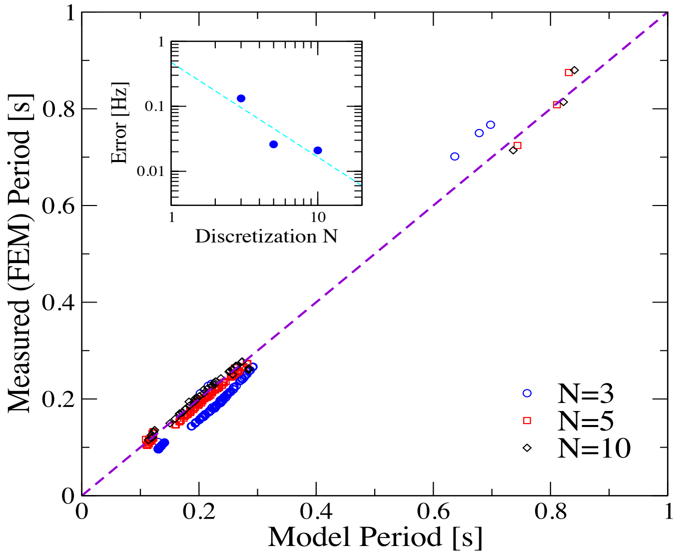

Figure 2: Model vs “measured” vibrational periods for different discretization levels, N=3, N=5 and N=10. The average quadratic error vs discretization level is displayed in the inlet.

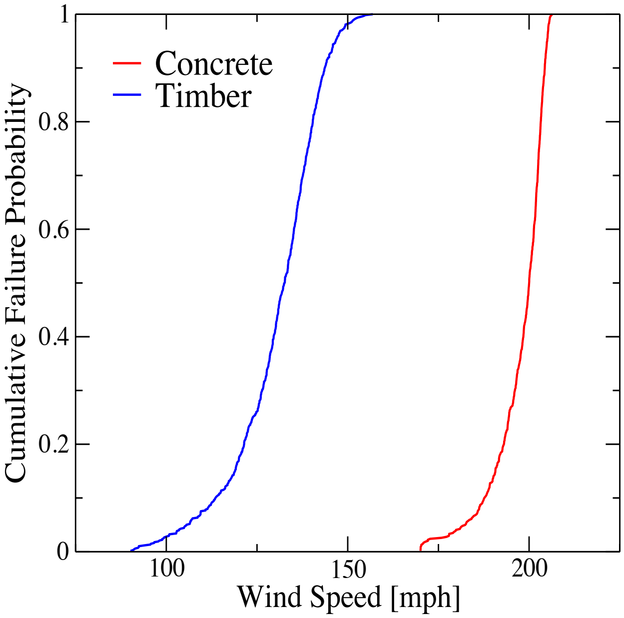

Figure 3: Example of fragility curves for a reinforced concrete and a wood structure.

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