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Why the Towers Fell

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Abstract

It's been 25 years since the world watched the collapse of the Twin Towers in New York City. In the aftermath of 9/11, there were those who looked upon the failure of the towers with suspicion. All that steel and concrete, yet both towers fell. In an eerily and nearly identical vertical motion, the tops of the towers fell straight down, taking the rest of each building with them as they collapsed to the streets below.

Introduction

The absence of comprehensive forensic study at the time [1], and the lack of reconstruction of the debris as occurred after the loss of TWA 800 [2], has let suspicion evolve into conspiracy theories, many of which still linger today. For example, some have speculated that there must have been explosives, or other ordnance, inside the planes or towers that were responsible for the collapse. People want to believe the structural design would have prevented the towers from falling or offered more time to evacuate.

The truth, rather, is an unforgiving piece of physics and engineering that is understood better now than it was then. This physics, that allows objects to withstand changes in strength and stability, is fundamental to the engineering design calculations used to create any physical structure: Too much energy added and the system is overloaded, too little inherent energy when built and the structure is fragile.

Strength comes from material: the steel and concrete used to construct the towers. Stability comes from structure: the bolts, riv ets, welds, and connectors fastening the material into shape. These two concepts are not as synonymous as one might believe. The resilience of any structure is the ability of the system to deal with changes in energy, whether applied naturally (think earthquake or hurricane) or through manmade means (explosions or fires). A system fails when the applied energy either (a) overwhelms the strength of the material, (b) reduces the energy storage capacity of the system, or (c) yields a combination of both (a) and (b). As recent research has shown, option (c) does not need to exceed the individual capacities of either (a) or (b) to create catastrophic failure.

To understand this principle and its influence on the Twin Tower collapse, let us imagine we build a stack of any set of identical objects. Maybe it's a stacking of beer cans, produce in a supermarket, or children's building blocks. The stack is described by two factors: the strength of the material and the stability of the structure.

Anyone who has stacked anything knows that you cannot make the structure taller without limit: eventually the structure tips over due to a lack of stability. Even at a modest height, the structure has a strength that can be quantified by adding weight to the top until it collapses. Such a test, however, mixes the ideas of how strong the materials are with failure (lack of stability) when some load or weight is exceeded.

Conversely, in Jenga™ the game ends when the stack becomes unstable and the structure collapses. The block tower falls due to a lack of stability, not because the wooden blocks are suddenly weak-

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er. The removal of the blocks reduces the energy storage capacity within the system. To illustrate the complexities of this energy balance in structures, engineers and scientists at ECS Government Solutions, U.S. Army Corps of Engineers (USACE), and Baylor University have studied sandcastles, like those children build at a beach, to better distinguish the difference between strength and stability in packed sand [3,4]. As anyone who has made sandcastles can tell you, packing sand with no water leaves a sandcastle dry and easily blown away by the wind, while adding too much water leads to an unstable mush that falls under its own weight. However, there's a sweet spot, or region, between the two extremes: just enough water to enhance adhesion between the grains, but not so much that excess water turns the sandcastle from a solid into something more like wet oatmeal. This sweet spot is like the inherent energy balance that is desired and achieved through engineering designs used in daily life: towers, bridges, dams, homes, cars, planes, etc. But until recently, what happens when the system's implicit energy balance is interrupted as in option (c) has not been well understood.

That research has led to a diagram that allows strength and stability of such structures to be described independently, demonstrating enhancement of stability by the fluid and the eventual failure of the structure by either exceeding the strength or losing stability. The limits of those characteristics provide an envelope within which the structure is both strong and stable. Along one axis of the graph, the object fails due to a lack of strength; along the other axis, the object fails due to a lack of stability. In some experiments, significant amounts of material were removed, yet the structure remains stable, akin to the plane impact on the Towers. In other experiments, adding water moved the structure from stability to instability, without changing the strength of the material within the structure, akin to the fires caused by the jet fuel. However, strength failures and instability failures are visually different. Why then did both Towers collapse so similarly, and why did the second Tower struck, fall first?

On 9/11, the towers, structures of concrete, steel and rivets, stood in their constructed state, jammed in their stable configuration, until each was struck by a plane: the first tower at 9:59 a.m. and the second tower at 10:28 a.m. The planes damaged the structures locally, applying energy but not enough to cause immediate failure. The orientation of the second plane's collision caused more damage vertically. Then, the fires, steel, concrete and rivets were no less strong, but like adding water to the sandcastles, the fires destabilized the structures. By this two-step process, the buildings were moved from inside, to a point outside, their strength/stability envelope.

No extra ordnance or conspiracy-breeding subterfuge was necessary. The towers fell because of two physical processes working in tandem. The initial damage by the collisions alone may not have toppled the towers. And a fire alone might have consumed the towers from the inside and left the structures hollowed out but still standing. However, the fires that spread in the structure after the impact of the planes reduced the energy storage capacity supporting the tops of the towers, causing an instability. Once set in motion, the avalanche of material was unstoppable, barreling down over lower floors, consuming each structure and the lives still inside. That is why the towers fell.

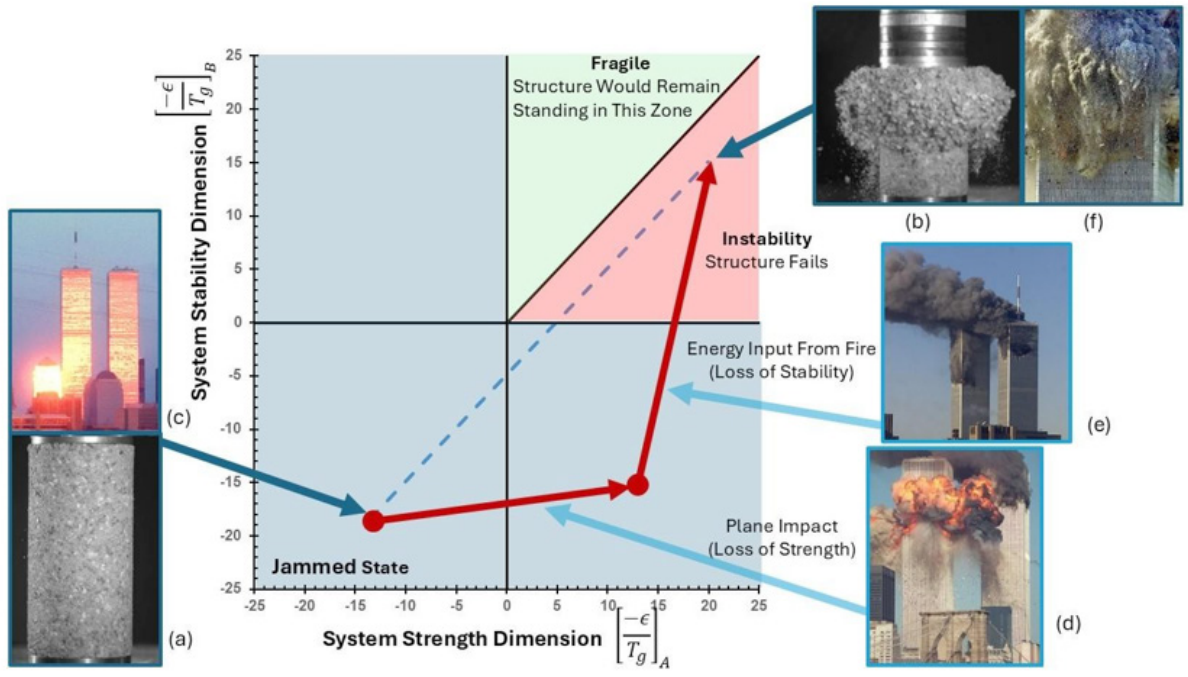


Figure: Jammed sand columns (a) demonstrate transitions due to loss of strength and/or loss of stability leading to (b) collapse. When the Twin Towers (c) were attacked on 9/11, the collision of the planes led to a loss of (d) strength while the fires resulted in a loss of (e) stability that led to (f) collapse. The graph in the figure is from research by the authors [3,4]. The photos of the Twin Towers are from the New York Times Photo Archive.

Acknowledgment

None.

Conflict of interest

None.

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