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Discussion of "Why the Observed Motion History of World Trade Center Towers is Smooth," by JL Le and ZP Bazant (2011), *J. Mech. Eng.* 137(1), 82-84

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Le and Bazant are addressing a general argument about slowing down with collisions at each floor, assuming that their model of gravitational collapse from weakening by fires, initiated by the plane crashes, is correct. They start with an equation of velocity drop for the top mass only falling 1 story or less (3.7 m), then claim for the North Tower that the mass of the falling top segment is about 90 times as large as the mass of the 1st floor that it hits, slowing that velocity by 1.1%, and then go on to determine its result as it extends and breaks through that floor.

Four major issues's on Le and Bazant claims are addressed in this paper. First is their assertion about implications of their collapse model for the South Tower. Second is the very inadequate amount of energy expended in their gravitational collapse model, including the claimed ease of breaking through and demolishing each floor that they assert in explaining the smooth collapse, in contrast to independent calculations of the total energy expended in the observed collapses. Third is an underlying 1-dimensional (1D) assumption in the equations used to model the collapse in this paper and in previous papers it references. Shortcomings of this 1D model seriously challenge its validity, and thus that of the "crush-down, crush-up" model of gravitational collapse for the calculations they present. Fourth is a challenge to their broad claim that all objections have been shown invalid.

Looking first at the velocity of collapse used for their model, their discussion ignores the observed collapse of the South Tower's top segment that the model does not explain – it is obviously not being "crushed down", yet it is collapsing from the top down. When one views the photographic evidence of the collapse sequence of the South Tower, they see fall rates for the top segment of the Tower that vary with time, which in the initial second or more of its collapse are *much faster* than gravity could produce! This top segment collapses by itself (neither being "crushed-down" or "crushed-up"), and gravity certainly cannot have caused it, because it initially collapses at an an acceleration rate more than four times as large as that of gravity.

Le and Bazant first mention the South Tower in this paper by quoting a calculation from their gravitational model, similar to that they have done for the North Tower, for the maximum displacement (0.84 mm) of the first hit floor in their model (which is below the fire zone for the South Tower) caused by deceleration from the assumed moment of impact. This location is indeed where the collapse action started, as it began with white squibs shooting horizontally out the sides just below where the fires were (horizontal motion their 1D model neglects), and very shortly afterward the top segment (top 33 floors) of the tower starts leaning. Then the top 33-floor segment above where the white squibs came out suddenly began spurting gray dust out of its lower sides, *before* the bottom segment starts coming down. Le & Bazant discuss the collapse at the 77th floor (where the squibs come from) as the start of the South Tower coming down (the "crush-down" phase of their model) and ignore the very rapid collapse and disintegration of the top segment just as the 77th floor and floors just below it are coming apart.

The bottom 77 floor segment has at most just started disintegrating at its highest floors when that top segment begins rapidly collapsing and disintegrating, a process incompatible with their "crush-down, crush-up" model. A measurement of how fast the top of the top segment started coming down yields about 24 m (1 m) in the initial 1.0 s. This distance is substantially greater than could be covered in that short time from gravity alone by over a factor of four. That rapid collapse *cannot* be caused by gravity. Rather it appears to be an internal force, much like that producing the white squibs coming out the lower segment at the 77th floor and the gray dust that is coming out the lower sides of the Tower's upper segment. The initial very fast rate of the top segment collapse (when the the bottom segment has at best barely started falling) shows that gravity *is not* causing it. The energetic ejections of gray dust from the lower part of that top segment indicates that it is likely being pulled down by a force created by a large pressure gradients. An explosion inside that top segment, producing a high pressure that is quickly relieved at lower levels by the gray dust coming out lower down, could produce the rapid collapse observed.

Observations show that the bottom segment is falling from gravity at a slightly slower rate than that produced by gravitational acceleration. The Le and Bazant claim that falling matter hitting the floors cause an imperceptibly small slowdown would imply that the amount of the energy expended in the fall to overcome friction can only be a small fraction of the gravitational potential (MgH, where M is that total mass, and H the mass-weighted average height) of the Towers. That expenditure in their model is at most about 0.206 MgH from the minimum value of the alpha parameter Le and Bazant claim in their Eq. (1), assuming their maximum value of energy is the same for each floor broken through. However, independent calculations of the energy expended in the collapses of the Towers have produced estimates of that expenditure to be at least 25MgH or more.[Hoffman, 1983] This implies that the "crush-up, crush-down" model cannot begin to account for the energy expended in the WTC collapses – indeed, from the maximum energy expenditure claimed in Le and Bazant's paper, over a factor of 100. Hoffman identified energy being expended for crushing the concrete. heating the concrete and the suspended gases, and vaporization of the water. Any rough validity to these energy expenditure calculations would imply that these collapses cannot be caused by fire-induced gravitational collapse as Le and Bazant presume in this paper.

Another question is raised by Le and Bazant's computed ease of breaking through the first floor. Were the Towers so poorly built as to cause such little resistance after part of the upper floors were burnt by fires from the planes – despite being constructed with specifications for tolerating a plane crash? Not according to the tests carried out by NIST metallurgy experts (at the behest of the NIST Committee) (Banovic et al, 2007), who concluded that whole Tower met *all* the specs given for the soundness of the Tower. Those specs maintained structural integrity against a direct plane crash, so that Towers were well-designed for a plane crash. It is not believable that a plane crash could possibly left them so vulnerable to collapsing, much less collapsing as quickly as they did with the fires it started.

The third issue is the underlying assumption in the computer model that Le and Bazant use for their numerical calculation in the second section in their paper, with the computer model discussed in more depth in Bazant and Verdure (2007) and in Bazant et al (2008a). Crucial limits of the 1D assumption used in these equations seriously challenge their validity for the complex 3D structure of the Towers, and thus of the "crush-down, crush-up" model of gravitational collapse that they represent. Bazant et al introduced equations they say are generalized in Appendix 2 of their 2008a paper that includes a more detailed model that considers crushing in both directions. They later solve those equations in their reply to Gourley's criticism for not including "crushing up" at the same time as they did "crushing down".(Gourley, 2008; Bazant et al, 2008b) However, their generalized equations are still 1D.

Their equations encompass an implicit 1D structure of the Towers, and Le and Bazant make all their calculations in this paper using 1D in their "crush-down, crush-up" model. The motivation for 1D equations appears to be expressed in Bazant (1980) in which, after pointing out in his section 5 that "long thin-walled beams" can be approximately treated so that their differential equation for the equation of motion is 1D, he says "for open cross-sections the most important deformation mode is the warping of the cross-section, with the bimoment being the associated force variable." He apparently assumes that warping the cross section in the gravitational force direction is the *only* important process for the Towers. Is that vertical dimension, the direction of gravitational force, the only important dimension in those collapses?

Bazant et al defended these equations as being necessary against the comment by Bjorkman, despite his efforts to demonstrate that just basic principles of physics show the gravitational collapse of their model is not possible.(Bjorkman, 2010; Bazant et al, 2010). But in fact this 1D equation cannot model the Towers collapses correctly, because the horizontal dimension is very important in the physics of those collapses. This includes the squibs repeatedly shooting out in this horizontal dimension, the South Tower's top segment making a sudden shift in the horizontal direction in its collapse, very large pieces hurled out from of both Towers having considerable momentum and kinetic energy in this horizontal dimension. There are large streams shooting out in the horizontal dimension with large debris coming out from the Towers – not only with a downward component, but also an upward component in the case of the North Tower. These effects are all neglected in a 1D model, yet they are very important processes in the Towers collapses.

The Towers are definitely not 417 m telephone poles (as 1D models would imply). Such tall telephone-like poles would be far more unstable to a gravitational collapse than the Towers, but even they also would not collapse by the "crush-down, crush-up" model. A pole-type structure would collapse by breaking into pieces on the way down, a process requiring at least 2D to describe.

The fact is that the Towers have 287 or so columns spread over the horizontal dimension, and these columns were designed to take a load of up to 2,000% of their weight, such as the load created by other buckled columns, all producing a shift of the position of weight-bearing in that horizontal dimension. These critical effects are all improperly treated in the 1D model, since it ignores the horizontal extensions of the Towers, and completely neglects the interlocking internal structure that would be a major resistance to such instabilities – indeed, also a major resistance to anything close to near free-fall conditions that Le & Bazant are asserting in their model. The Towers were well-constructed over 44,000 ft2 horizontally with interlocking structures to provide for very high stability, and all of that is ignored in the simple 1D model that is the primary focus in the Le and Bazant paper and several papers referenced. The "crush down/crush up" equations are totally inadequate for describing the observed Tower collapses, giving very misleading solutions.

Finally, I challenge Le and Bazant's statement at the beginning of their paper where they say ”All the objections of the proponents of the controlled-demolition hypothesis have been shown invalid.” In particular, that is not correct in their response to the recent comment by Bjorkman (Bjorkman, 2010; Bazant et al, 2010). Commentor Bjorkman challenges the validity of the 1D model based on observations, as well as on an earlier critique by MacQueen and Szamboti (2009). Bjorkman states that equations are not needed to see from observations that Le and Bazant's model is wrong. Le and Bazant disagree with that, responding that equations are vital. However, questions of the collapse of the Towers are at least 2D because of important features observed in the horizontal direction. Le and Bazant's 1D gravitational equations for that analysis are not adequate, and they cannot counter Bjorkman's objection unless they present a quantative model of the Tower that is at least 2D in their equations of motion.

One point in Bjorkman's conclusion is correct, but needs backing up. That is that in Le and Bazants collapse model ”the destruction should have been stopped up top due to all local failures developing, when part C contacts part A and friction develops between all partly damaged parts at floor 98,” pointing out Le and Bazant's neglect the friction of those failures. The accuracy of this statement can be understood from principles of energy and momentum conservation. The momentum and energy conservation principles are ironclad, and I pointed out their implication for the collapses in (Grabbe, 2008). The Twin Towers were, as are all tall buildings of course, architecturally built so that the mass decreases with height, and the conservation principle imply that the top segments (14 floors for the North Tower, 33 floors for the South Tower) do not have enough energy and momentum to completely gravitationally crush down the much-more massive bulk of the floors below that, so any initiated collapse would soon be arrested. The calculations of Le and Bazant in this and previous papers apparently violate energy and momentum conservation, and Bjorkman says they are untenable.

Regarding these questions of gravitational collapse and the 2D nature of the collapse that is challenged in Le and Bazant's paper, I invite for comparison a conference presentation on probably the world's worst fire in a skyscaper, and the *only* one that ever caused partial collapse of a building: that of the Windsor Building in Madrid, Spain in 2005.(Ikeda and Sekizawa, 2005) Unlike the WTC Tower fires, which collapsed in times of 1:41 (North Tower) and 0:56 (South Tower), the Windsor building continued for 22 hours, and its flames on the top of the building were much more widespread and intense than those atop the North Tower. The very top of the Windsor building partially collapsed at the top, but *none* of the rest of the building collapsed. Indeed, the collapse was arrested after part of the top collapsed, as one would expect because of the inhomogeneous nature of fire destruction. Clearly, looking at the details of that paper, that collapse was 2D in nature, and none of the floors as a whole collapsed. It was the perimeter columns of the top floors that collapsed, but not the central top floor columns or any other part of the building. There is no means by which anyone could even begin to describe this fire-induced collapse with 1D equations.

The Windsor building was steel-reinforced (whereas the WTC buildings were full steel buildings), but even after burning for 22 hours the fires did *not* appear to take out that steel-reinforcement – only the nonmetallic parts of the floors. It is not reasonable to claim that fires could seriously degrade the metallic structure throughout the Towers in the under-2-hour time interval for the North Tower and under-1-hour for the South Tower. Yet hundreds of pieces were flying out in *all* different directions in the WTC collapses, a highly-dynamic condition very different from the Windsor Building with very limited partial collapse.

This example indicates how quite unbelievable it is that the interlocked steel structure and steel-floors completely collapsed all the way down only from fires in the WTC Towers. Conclusions are that: (1) the collapses are filled with significant motion in the horizontal direction, (2) the energy/momentum conservation and energy inadequacy problems with the gravitational model contradict the observed collapses, and (3) the fundamental problems with their 1D model indicate it is inadquate to correctly model the collapses. All of these demonstrate that the claims made by Le and Bazant on why the collapses were ”smooth” are not correct.

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