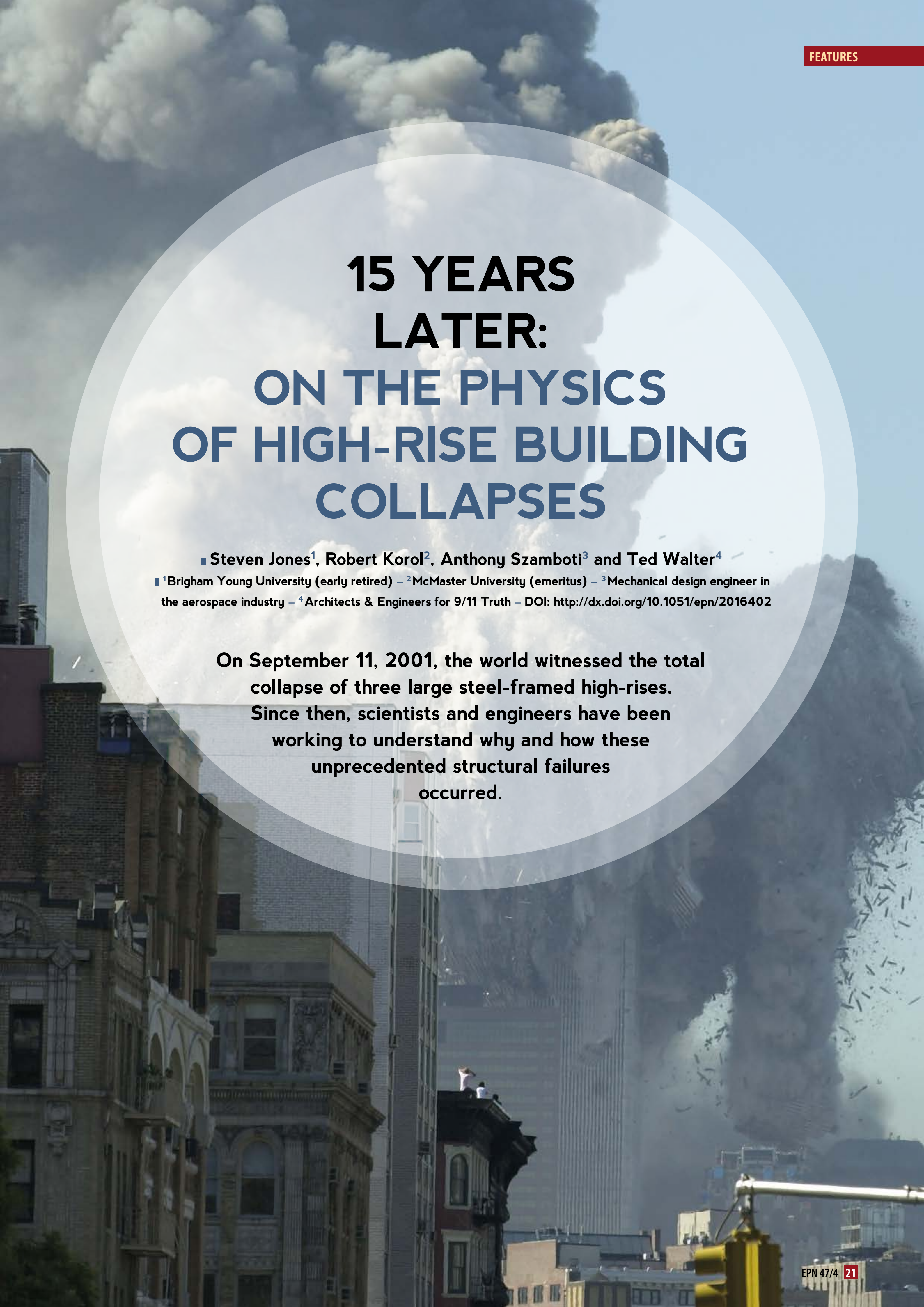

15 YEARS LATER: ON THE PHYSICS OF HIGH-RISE BUILDING COLLAPSES

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On September 11, 2001, the world witnessed the total collapse of three large steel-framed high-rises. Since then, scientists and engineers have been working to understand why and how these unprecedented structural failures occurred.

NOTE FROM THE EDITORS

This feature is somewhat different from our usual purely scientific articles, in that it contains some speculation. However, given the timing and the importance of the issue, we consider that this feature is sufficiently technical and interesting to merit publication for our readers. Obviously, the content of this article is the responsibility of the authors.

In August 2002, the U.S. National Institute of Standards and Technology (NIST) launched what would become a six-year investigation of the three building failures that occurred on September 11, 2001 (9/11): the well-known collapses of the World Trade Center (WTC) Twin Towers that morning and the lesser-known collapse late that afternoon of the 47-story World Trade Center Building 7, which was not struck by an airplane. NIST conducted its investigation based on the stated premise that the "WTC Towers and WTC 7 [were] the only known cases of total structural collapse in high-rise buildings where fires played a significant role."

Indeed, neither before nor since 9/11 have fires caused the total collapse of a steel-framed high-rise—nor has any other natural event, with the exception of the 1985 Mexico City earthquake, which toppled a 21-story office building. Otherwise, the only phenomenon capable of collapsing such buildings completely has been by way of a procedure known as controlled demolition, whereby explosives or other devices are used to bring down a structure intentionally. Although NIST finally concluded after several years of investigation that all three collapses on 9/11 were due primarily to fires, fifteen years after the event a growing number of architects, engineers, and scientists are unconvinced by that explanation.

Preventing high-rise failures

Steel-framed high-rises have endured large fires without suffering total collapse for four main reasons:
1) Fires typically are not hot enough and do not last long enough in any single area to generate enough energy to heat the large structural members to the point where they fail (the temperature at which structural steel loses enough strength to fail is dependent on the factor of safety used in the design. In the case of WTC 7, for example, the factor of safety was generally 3 or higher. Here, 67% of the strength would need to be lost for failure to ensue, which would require the steel to be heated to about 660°C); **2)** Most high-rises have fire suppression systems (water sprinklers), which further prevent a fire from releasing sufficient energy to heat the steel to a critical failure state; **3)** Structural members are protected by fireproofing materials, which are designed to prevent them from reaching failure temperatures within specified time periods; and **4)** Steel-framed high-rises are designed to be highly redundant structural systems. Thus, if a localized failure occurs, it does not result in a disproportionate collapse of the entire structure.

Throughout history, three steel-framed high-rises are known to have suffered partial collapses due to fires; none of those led to a total collapse. Countless other steel-framed high-rises have experienced large, long-lasting fires without suffering either partial or total collapse (see, for example, Fig. 1a and 1b) [1].

In addition to resisting ever-present gravity loads and occasional fires, high-rises must be designed to resist loads generated during other extreme events—in particular, high winds and earthquakes. Designing for high-wind and seismic events mainly requires the ability of the structure to resist lateral loads, which generate both tensile and compressive stresses in the columns due to bending, the latter stresses then being combined with gravity-induced compressive stresses due to vertical loads. It was not until steel became widely manufactured that the ability to resist large lateral loads was achieved and the construction of high-rises became possible. Steel is both very strong and ductile, which allows it to withstand the tensile stresses generated by lateral loads, unlike brittle materials, such as concrete, that are weak in tension. Although concrete is used in some high-rises today, steel reinforcement is needed in virtually all cases.

To allow for the resistance of lateral loads, high-rises are often designed such that the percentage of their columns' load capacity used for gravity loads is relatively

▾ **FIG. 1:** WTC 5 is an example of how steel-framed high-rises typically perform in large fires. It burned for over eight hours on September 11, 2001, and did not suffer a total collapse (Source: FEMA).

▲ **FIG. 2:** WTC 7 fell symmetrically and at free-fall acceleration for a period of 2.25 seconds of its collapse (Source: NIST).

low. The exterior columns of the Twin Towers, for example, used only about 20% of their capacity to withstand gravity loads, leaving a large margin for the additional lateral loads that occur during high-wind and seismic events [2].

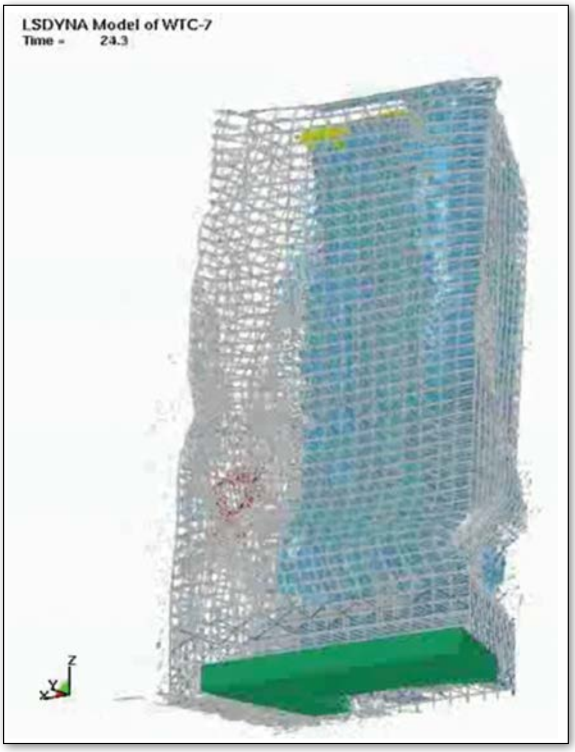
Because the only loads present on 9/11 after the impact of the airplanes were gravity and fire (there were no high winds that day), many engineers were surprised that the Twin Towers completely collapsed. The towers, in fact, had been designed specifically to withstand the impact of a jetliner, as the head structural engineer, John Skilling, explained in an interview with the *Seattle Times* following the 1993 World Trade Center bombing: "Our analysis indicated the biggest problem would be the fact that all the fuel (from the airplane) would dump into the building. There would be a horrendous fire. A lot of people would be killed," he said. "The building structure would still be there." Skilling went on to say he didn't think a single 200-pound [90-kg] car bomb would topple or do major structural damage to either of the Twin Towers. "However," he added, "I'm not saying that properly applied explosives—shaped explosives—of that magnitude could not do a tremendous amount of damage.… I would imagine that if you took the top expert in that type of work and gave him the assignment of bringing these buildings down with explosives, I would bet that he could do it."

In other words, Skilling believed the only mechanism that could bring down the Twin Towers was controlled demolition.

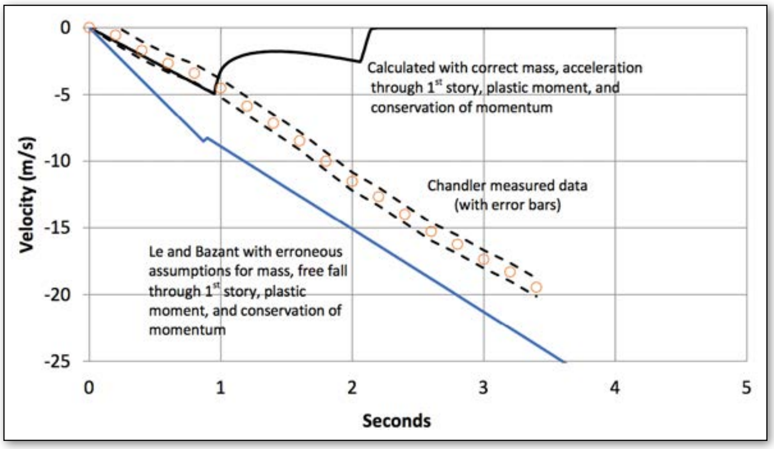
Techniques of controlled demolition

Controlled demolition is not a new practice. For years it was predominantly done with cranes swinging heavy iron balls to simply break buildings into small pieces. Occasionally, there were structures that could not be brought down this way. In 1935, the two 191-m-tall Sky Ride towers of the 1933 World's Fair in Chicago were demolished with 680 kg of thermite and 58 kg of dynamite. Thermite is an incendiary containing a metal powder fuel (most commonly aluminum) and a metal oxide (most commonly iron(III) oxide or "rust"). Eventually, when there were enough large steel-framed buildings that needed to be brought down more efficiently and inexpensively, the use of shaped cutter charges became the norm. Because shaped charges have the ability to focus explosive energy, they can be placed so as to diagonally cut through steel columns quickly and reliably.

In general, the technique used to demolish large buildings involves cutting the columns in a large enough area of the building to cause the intact portion above that area to fall and crush itself as well as crush whatever remains below it. This technique can be done in an even more sophisticated way, by timing the charges to go off in a sequence so that the columns closest to the center are destroyed first. The failure of the interior columns creates an inward pull on the exterior and causes the majority of the building to be pulled inward and downward while materials are being crushed, thus keeping the crushed materials in a somewhat confined area—often within the building's "footprint." This method is often referred to as "implosion."



◀ **FIG. 3:** The final frame of NIST's WTC 7 computer model shows large deformations to the exterior not observed in the videos (Source: NIST).



▲ **FIG. 4:** The above graph [10] compares David Chandler's measurement [9] of the velocity of the roofline of WTC 1 with Bažant's erroneous calculation [11] and with Szamboti and Johns' calculation using corrected input values for mass, acceleration through the first story, conservation of momentum, and plastic moment (the maximum bending moment a structural section can withstand). The calculations show that—in the absence of explosives—the upper section of WTC 1 would have arrested after falling for two stories (Source: Ref. [10]).

The case of WTC 7

The total collapse of WTC 7 at 5:20 PM on 9/11, shown in Fig. 2, is remarkable because it exemplified all the signature features of an implosion: The building dropped in absolute free fall for the first 2.25 seconds of its descent over a distance of 32 meters or eight stories [3]. Its transition from stasis to free fall was sudden, occurring in approximately one-half second. It fell symmetrically straight down. Its steel frame was almost entirely dismembered and deposited mostly inside the building's footprint, while most of its concrete was pulverized into tiny particles. Finally, the collapse was rapid, occurring in less than seven seconds.

Given the nature of the collapse, any investigation adhering to the scientific method should have seriously considered the controlled demolition hypothesis, if not started with it. Instead, NIST (as well as the Federal Emergency Management Agency (FEMA), which conducted a preliminary study prior to the NIST investigation) began with the predetermined conclusion that the collapse was caused by fires.

Trying to prove this predetermined conclusion was apparently difficult. FEMA's nine-month study concluded by saying, "The specifics of the fires in WTC 7 and how they caused the building to collapse remain unknown at this time. Although the total diesel fuel on the premises contained massive potential energy, the best hypothesis has only a low probability of occurrence." NIST, meanwhile, had to postpone the release of its WTC 7 report from mid-2005 to November 2008. As late as March 2006, NIST's lead investigator, Dr. Shyam Sunder, was quoted as saying, "Truthfully, I don't really know. We've had trouble getting a handle on building No. 7."

All the while, NIST was steadfast in ignoring evidence that conflicted with its predetermined conclusion. The most notable example was its attempt to deny that WTC 7 underwent free fall. When pressed about that matter during a technical briefing, Dr. Sunder dismissed it by saying, "[A] free-fall time would be an object that has no structural components below it." But in the case of WTC 7, he claimed, "there was structural resistance that was provided." Only after being challenged by high school physics teacher David Chandler and by physics professor Steven Jones (one of the authors of this article), who had measured the fall on video, did NIST acknowledge a 2.25-second period of free fall in its final report. Yet NIST's computer model shows no such period of free fall, nor did NIST attempt to explain how WTC 7 could have had "no structural components below it" for eight stories.

Instead, NIST's final report provides an elaborate scenario involving an unprecedented failure mechanism: the thermal expansion of floor beams pushing an adjoining girder off its seat. The alleged walk-off of this girder then supposedly caused an eight-floor cascade of floor failures, which, combined with the failure of two other girder connections—also due to thermal expansion—left a key column unsupported over nine stories, causing it to buckle. This single column failure allegedly precipitated the collapse of the entire interior structure, leaving the exterior unsupported as a hollow shell. The exterior columns then allegedly buckled over a two-second period and the entire exterior fell simultaneously as a unit [3].

NIST was able to arrive at this scenario only by omitting or misrepresenting critical structural features in its computer modelling.[4] Correcting just one of these errors renders NIST's collapse initiation indisputably impossible. Yet even with errors that were favorable to its predetermined conclusion, NIST's computer model (see Fig. 3) fails to replicate the observed collapse, instead showing large deformations to the exterior that are not observed in the videos and showing no period of free fall. Also, the model terminates, without explanation, less than two seconds into the seven-second collapse. Unfortunately, NIST's computer modelling cannot be independently verified because NIST has refused to release a large portion of its modelling data on the basis that doing so "might jeopardize public safety."

The case of the Twin Towers

Whereas NIST did attempt to analyze and model the collapse of WTC 7, it did not do so in the case of the Twin Towers. In NIST's own words, "The focus of the investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower....this sequence is referred to as the 'probable collapse sequence,' although it includes little analysis of the structural behaviour of the tower after the conditions for collapse initiation were reached and collapse became inevitable."[5]

Thus, the definitive report on the collapse of the Twin Towers contains no analysis of why the lower sections failed to arrest or even slow the descent of the upper sections—which NIST acknowledges "came down essentially in free fall" [5-6]—nor does it explain the various other phenomena observed during the collapses. When a group of petitioners filed a formal Request for Correction asking NIST to perform such analysis, NIST replied that it was "unable to provide a full explanation of the total collapse" because "the computer models [were] not able to converge on a solution."

However, NIST did do one thing in an attempt to substantiate its assertion that the lower floors would not be able to arrest or slow the descent of the upper sections in a gravity-driven collapse. On page 323 of NCSTAR 1-6, NIST cited a paper by civil engineering professor Zdeněk Bažant and his graduate student, Yong Zhou, that was published in January 2002 [7] which, according to NIST, "addressed the question of why a total collapse occurred" (as if that question were naturally outside the scope of its own investigation). In their paper, Bažant and Zhou claimed there would have been a powerful jolt when the falling upper section impacted the lower section, causing an amplified load sufficient to initiate buckling in the columns. They also claimed that the gravitational energy would have been 8.4 times the energy dissipation capacity of the columns during buckling.

In the years since, researchers have measured the descent of WTC 1's upper section and found that it never decelerated—*i.e.*, there was no powerful jolt [8-9]. Researchers have also criticized Bažant's use of free-fall acceleration through the first story of the collapse, when measurements show it was actually roughly half of gravitational acceleration [2]. After falling for one story, the measurements show a 6.1 m/s velocity instead of the 8.5 m/s velocity that would be the result of free fall. This difference in velocity effectively doubles the kinetic energy, because it is a function of the square of the velocity. In addition, researchers have demonstrated that the 58×10^6 kg mass Bažant used for the upper section's mass was the maximum design load—not the actual 33×10^6 kg service load [10]. Together, these two errors embellished the kinetic energy of the falling mass by 3.4 times. In addition, it has been shown that the column energy dissipation capacity used by Bažant was at least 3 times too low [2].

In January 2011 [11] Bažant and another graduate student of his, Jia-Liang Le, attempted to dismiss the lack-of-deceleration criticism by claiming there would be a velocity loss of only about 3%, which would be too small to be observed by the camera resolution. Le and Bažant also claimed conservation-of-momentum velocity loss would be only 1.1%. However, it appears that Le and Bažant erroneously used an upper section mass of 54.18×10^6 kg and an impacted floor mass of just 0.627×10^6 kg, which contradicted the floor mass of 3.87×10^6 kg Bažant had used in earlier papers. The former floor mass is representative of the concrete floor slab only, whereas the latter floor mass includes all the other materials on the floor. Correcting this alone increases the conservation-of-momentum velocity loss by more than 6 times, to a value of 7.1%. Additionally, the column energy dissipation has been shown to be far more significant than Bažant claimed. Researchers have since provided calculations showing that a natural collapse over one story would not only decelerate, but would actually arrest after one or two stories of fall (see Fig. 4) [2, 10].

Other evidence unexplained

The collapse mechanics discussed above are only a fraction of the available evidence indicating that the airplane impacts and ensuing fires did not cause the collapse of the Twin Towers. Videos show that the upper section of each tower disintegrated within the first four seconds of collapse. After that point, not a single video shows the upper sections that purportedly descended all the way to the ground before being crushed. Videos and photographs also show numerous high-velocity bursts of debris being ejected from point-like sources (see Fig. 5). NIST refers to these as "puffs of smoke" but fails to properly analyze them [6]. NIST also provides no explanation for the midair pulverization of most of the towers' concrete, the near-total dismemberment of their steel frames, or the ejection of those materials up to 150 meters in all directions.

NIST sidesteps the well-documented presence of molten metal throughout the debris field and asserts that the orange molten metal seen pouring out of WTC 2 for the seven minutes before its collapse was aluminum from the aircraft combined with organic materials (see Fig. 6) [6]. Yet experiments have shown that molten aluminum, even when mixed with organic materials, has a silvery appearance—thus suggesting that the orange molten metal was instead emanating from a thermite reaction being used to weaken the structure [12]. Meanwhile, unreacted nano-thermitic material has since been discovered in multiple independent WTC dust samples [13].

◂ **FIG. 5:** High-velocity bursts of debris, or "squibs," were ejected from point-like sources in WTC 1 and WTC 2, as many as 20 to 30 stories below the collapse front (Source: Noah K. Murray).

▸ **FIG. 6:** Molten metal was seen pouring out of WTC 2 continuously for the seven minutes leading up to its collapse (Sources: WABC-TV, NIST).

As for eyewitness accounts, some 156 witnesses, including 135 first responders, have been documented as saying that they saw, heard, and/or felt explosions prior to and/or during the collapses [14]. That the Twin Towers were brought down with explosives appears to have been the initial prevailing view among most first responders. "I thought it was exploding, actually," said John Coyle, a fire marshal. "Everyone I think at that point still thought these things were blown up" [15].

Conclusion

It bears repeating that fires have never caused the total collapse of a steel-framed high-rise before or since 9/11. Did we witness an unprecedented event three separate times on September 11, 2001? The NIST reports, which attempted to support that unlikely conclusion, fail to persuade a growing number of architects, engineers, and scientists. Instead, the evidence points overwhelmingly to the conclusion that all three buildings were destroyed by controlled demolition. Given the far-reaching implications, it is morally imperative that this hypothesis be the subject of a truly scientific and impartial investigation by responsible authorities. ■

About the Authors

Steven Jones is a former full professor of physics at Brigham Young University. His major research interests have been in the areas of fusion, solar energy, and archaeometry. He has authored or co-authored a number of papers documenting evidence of extremely high temperatures during the WTC destruction and evidence of unreacted nano-thermitic material in the WTC dust.

Robert Korol is a professor emeritus of civil engineering at McMaster University in Ontario, Canada, as well as a fellow of the Canadian Society for Civil Engineering and the Engineering Institute of Canada. His major research interests have been in the areas of structural mechanics and steel structures. More recently, he has undertaken experimental research into the post-buckling resistance of H-shaped steel columns and into the energy absorption associated with pulverization of concrete floors.

Anthony Szamboti is a mechanical design engineer with over 25 years of structural design experience in the aerospace and communications industries. Since 2006, he has authored or co-authored a number of technical papers on the WTC high-rise failures that are published in the *Journal of 9/11 Studies* and in the *International Journal of Protective Structures*.

Ted Walter is the director of strategy and development for Architects & Engineers for 9/11 Truth (AE911Truth), a nonprofit organization that today represents more than 2,500 architects and engineers. In 2015, he authored AE911Truth's *Beyond Misinformation: What Science Says About the Destruction of World Trade Center Buildings 1, 2, and 7*. He holds a Master of Public Policy degree from the University of California, Berkeley.

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