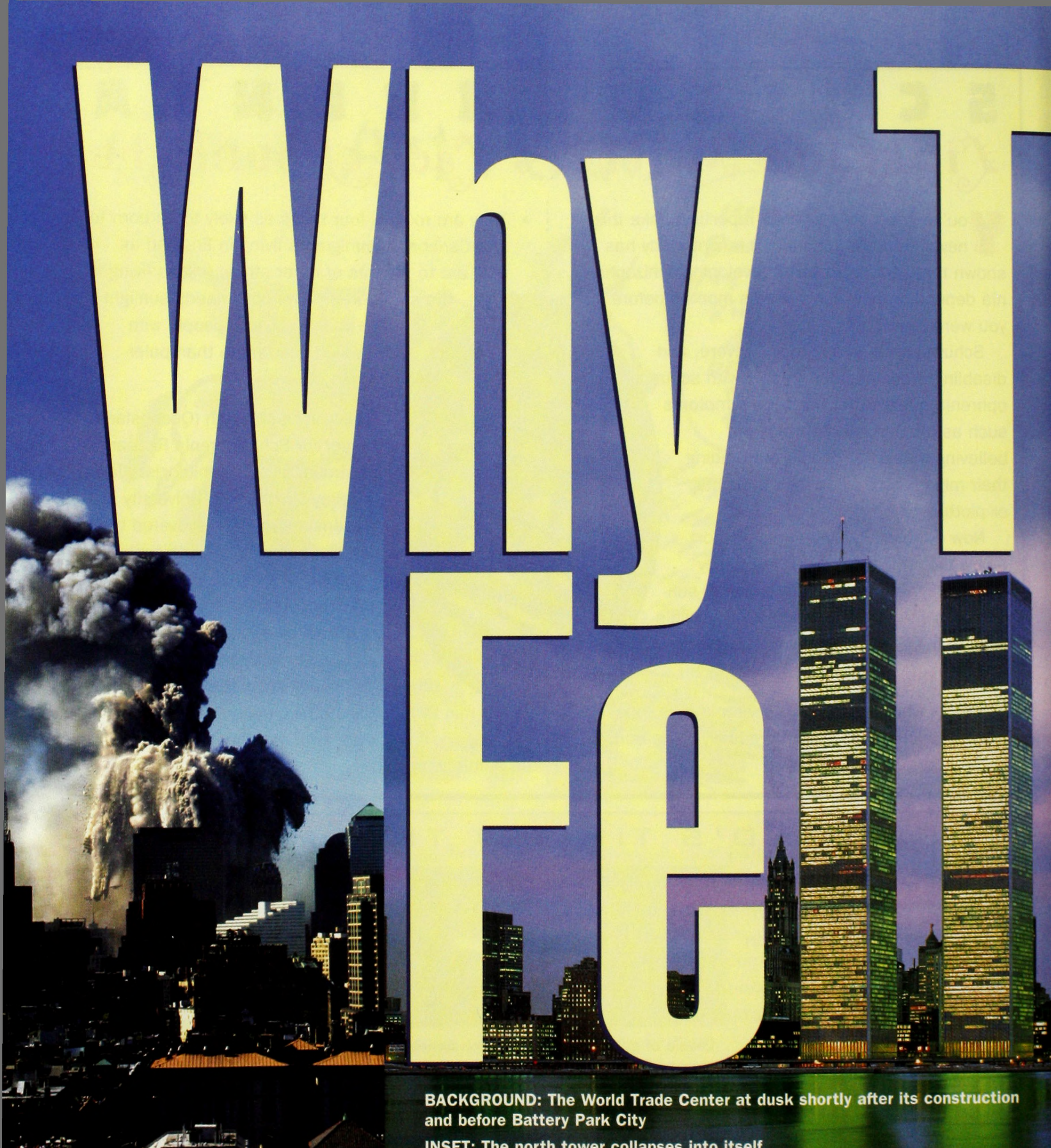
Why T Fell



BACKGROUND: The World Trade Center at dusk shortly after its construction and before Battery Park City

INSET: The north tower collapses into itself.

SCIENCE, ENGINEERING, & THE WORLD TRADE CENTER COLLAPSE

by MARY CARMICHAEL

hey

AFTER WATCHING the twin towers of the World Trade Center collapse last September, twice reducing 110 stories to five in less than a minute, it's hard to see how the buildings could have ever been considered safe. It's even harder to see how engineers can look at the events of September 11, 2001, as a relative success in terms of architectural strength. Consider this: The rubble at the site weighed a million tons. The site spanned a vast 16 acres (6 hectares). The nonstop cleanup, conducted day and night, still took the better part of a year. Even if the greatest loss — so many human lives — is excluded, there's no arguing: This was, in all senses, an enormous disaster.

And yet, for all the destruction — and for all the disbelief Americans felt as they watched the towers collapse — engineers unanimously say that the buildings performed "magnificently" after terrorists crashed a plane into the side of each. Because the towers stayed standing for about an hour each, they gave rescue workers enough time to get tens of thousands of people out. The towers owed their resilience largely to their architect, Minoru Yamasaki, and structural engineer Leslie Robertson. The men's original design enabled the buildings to withstand the impact of the planes, crumpling only after jet-fuel fires weakened their steel beams.

AN EXTRAORDINARY DESIGN

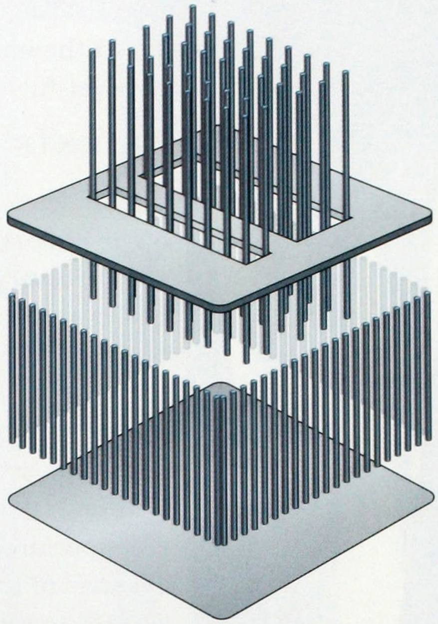
Constructed with cheaper methods, many other buildings would have collapsed immediately. Today's most common skyscraper design places vertical support beams throughout a building. Others have diagonal beams as their main means of support. But the World Trade Center was built *before* those were the standards. Raised in the 1960s, the glass-and-steel towers were designed and built with innovation and special attention to safety and stability because of their extreme height. Engineers wanted to make sure the towers could withstand hurricane-force winds of up to 200 mph (320 kph) — on an especially windy day, the towers could sway up to several feet in either direction. With memories of a 1945 plane crash into the Empire State Building lurking in their minds, engineers and architects also designed the towers to withstand the force of a Boeing 707 (at the time, planes were much smaller than they are today and carried less fuel).

The engineers agreed that the secret to ensuring the buildings would stand tall under extreme circumstances rested in their supporting steel columns, which were set up differently from most skyscrapers'. The majority of the beams framed the outside walls of the towers: 61 beams (placed only 18 inches [46 centimeters] apart) per 211-foot (64-meter) side provided maximum reinforcement. Engineers often refer to this as a solid "steel tube" design, and rightly so compared to most buildings, which may have vertical support columns spaced as far as 20 feet (6 meters) apart. The outer columns helped the buildings withstand a huge wind load, but another, smaller group of steel beams shot through the centers of the buildings and bore the main load of supporting the towers. This "core," which housed elevator shafts and stairwells, was connected to the outer steel columns by still more steel running through each concrete floor. The "double support" may have been what ultimately kept the buildings standing for so long.

GRAVITY AND TOO MUCH HEAT

All the same, no amount of reinforcement could have prevented the towers' eventual collapse. Immediately after September 11, most engineers thought the fires, and not the planes' impacts, were to blame. That theory has generally held up, with a little tweaking. A federal investigation was inconclusive, but it did conform with engineers' suspicions. The steel columns didn't actually melt. But as the fires inside the buildings consumed more and more jet fuel — about 24,000 gallons (90,000 liters) of it — they overwhelmed the buildings' sprinkler systems, started to weaken the concrete insulation around the steel, and then debilitated the steel itself. Most of the fluffy fireproofing material on the tow-

Adapted from http://wtcnyc1.com/collapse.html



A hollow tube of closely spaced perimeter columns formed the main structural component of each tower. A central core was designed to carry only part of the vertical load.

ers' steel columns was blasted off by the plane crashes. With flames reaching temperatures of 1,500 degrees Fahrenheit (800 degrees Celsius) and higher, the steel columns started to warp, and the top floors buckled. (It takes temperatures of 2,700 degrees F. [1,500 degrees C.] to *melt* steel.) From then on, the towers had no more chance of standing than a building targeted for demolition. Their collapse was the first known instance of steel buildings collapsing because of fire alone.

In fact, the collapse played out just like a controlled demolition would. To destroy a building, experts usually place explosives not just on the lowest three floors, but also on higher floors. (Damaging just the lower floors usually won't make a building collapse — a lesson terrorists must have learned in 1993, when a bomb exploded in the underground garage of the Trade Center but the buildings were left standing.) With the top floors exploding, demolition experts can

continued on page 10

The tangle of steel and stone at Ground Zero took the better part of a year to clean up.

IT'S A DESIGN CONTEST!

For as long as it stood, the World Trade Center drew attention because of its towers' height. But it wasn't just tall. It was wide, too, with a tremendous plaza in the middle the size of a tiny city. So when the towers came down, many people thought that the best way to memorialize them would be to leave that tremendous plaza just as it was — a huge space that once symbolized vast promise, now symbolizing vast emptiness. Life moved on, though, and after just a few weeks, it became clear that something had to be built on the site. Space was too precious (and too expensive) in New York City to let it go to waste. But what could fill this particular space?

The most obvious response was to rebuild the towers, maybe even taller than they were before. But if the towers did get rebuilt, who would want to work in them? And how could we know they wouldn't be targeted again? Others countered with preliminary plans for an arts center or an antiterrorism institute. Some wanted new, scaled-down office space. Some envisioned soaring skyscraper monuments that would recall — but not copy — the original design. But all those ideas had the same major flaws. They were hugely expensive. (One architect put the cost of rebuilding the original towers at $4.5 billion.) They might seem disrespectful. And most of them would take years to build.

There was at least one idea that got around those problems, but it had problems of its own. Fred Bernstein, an architecture writer who lives in New York City, had never designed a building before he planned his monument — two glass and steel piers, exactly the same size as the towers, jutting into New York Harbor and bearing all the victims' names. One "tower" would point to the Statue of Liberty, the other to Ellis Island, the former first stop for millions of immigrants to the U.S. The design, which you can see at **www.fredbernstein.com**, is handicapped-accessible, keeps the original WTC site free for building (or rebuilding), and could itself be constructed in just a year. The problem? It might slow down boat traffic in the harbor.

With no perfect plan — at least as of press time — maybe the architects could use a little help. What would you plan for the site? New towers? A pair of piers? Something completely different? Put your idea on paper (a pencil sketch or computer drawing), with an explanation of why you think it would be appropriate, and send it to Design for New York Contest, *ODYSSEY,* 30 Grove St., Suite C, Peterborough, NH 03458. Be sure to include a statement, signed by a parent or teacher, indicating that the idea and work is your own. Make sure that your entry is postmarked no later than October 31, 2002. *You* might be selected as our design winner. We'll publish the three best proposals, and the winner will receive the Great Buildings Collection CD-ROM, which provides a whole library of architecture on compact disc. He or she will also receive *911: The Book of Help* (Cricket Books: 2002), a collection of essays and poems written in the weeks following the disaster by some of the best-known authors for young adults.

M.C.

GRAVITY TAKES AN ASTONISHING TOLL

As the old saying goes, the bigger they are, the harder they fall. That lesson never became so painfully clear as in the aftermath of the collapse of the World Trade Center.

"The airplanes destroyed 20 stories of the building, and gravity did the rest," says Swarthmore College physics professor Frank Moscatelli, a native New Yorker. "Their splendor was their undoing."

The towers stood 1,353 feet (411 meters) tall and together weighed more than a million tons. As a result, they struck the ground at a furious 120 mph (192 kph) and released an enormous amount of potential energy — estimated by Moscatelli at 680 billion joules.

How much is that?

Well, one *joule* (the basic unit of energy) is equal to the work done when a force of one ***newton*** acts over a distance of one meter. An estimated 680 billion of them is equal to just one percent of the energy packed into an atomic bomb, and a severe earthquake might unleash 147,600 times as much power. But 680 billion is still a lot — seismic recordings registered the towers' collapse as equal to a minor earthquake, such as the one that jostled New York City in January 2001. (A monitoring station near the city kept picking up smaller signals after the towers came down because debris was still falling around the ruins.)

When the towers fell, people in New York didn't feel like they had been in an earthquake, possibly because the collapses gave off more low-frequency energy, and less high-frequency, than a quake would. Why? An earthquake is caused by a quick, intense rupture in a ***fault,*** while the collapses took a longer time and released energy in stages as each floor caved in.

create what they call a "pancake effect," which you might realize is the same as a downward domino effect. Unlike dominos, of course, the towers fell straight down rather than sideways (although some pictures do appear to show one of the towers leaning slightly to one side as it collapsed). But their downfall was caused by the same forces that knock a line of dominos on their faces: Floors on the top gave in, crashing through the floors below them. As each concrete floor fell, it added force to the collapse — making it harder for each floor to hold up against the increasing pressure. Once the top floors gave way, the rest of the catastrophe was inevitable (see sidebar, left).

MANY LIVES LOST, BUT MANY SAVED

So if the towers were never going to stay standing, why all the extra support? Was it futile after all? Suppose for a minute that the towers hadn't been built with all that reinforcement — that they'd collapsed a few minutes after being struck. The rubble at the site still would weigh a million tons. The site still would span a vast 16 acres. The cleanup still would have taken as long. But how many more people would have died? It's a figure no one wants to calculate.

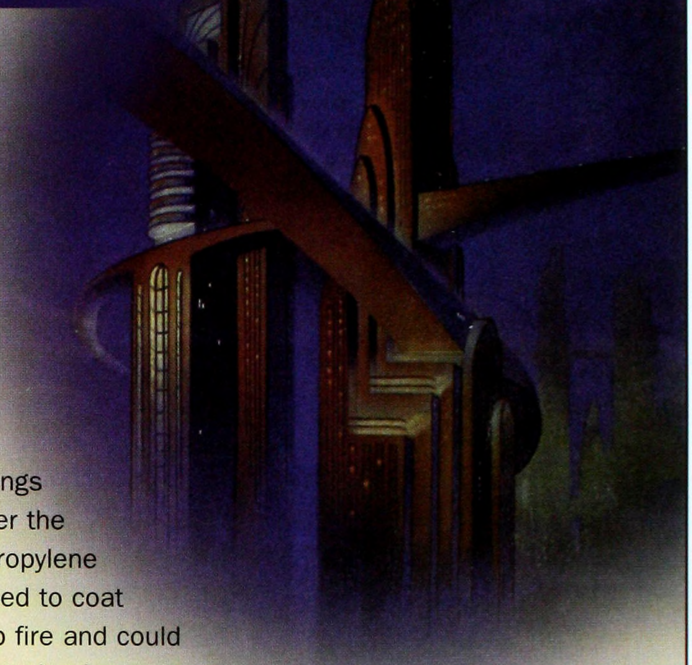
Thankfully, because a team of engineers and architects made the Trade Center as safe as it could possibly be, no one has to.

Mary Carmichael lives in New York and is a science reporter for *Newsweek* magazine.

Newton — The unit of force required to accelerate a mass of one kilogram one meter per second per second

Fault — A fracture in a rock formation caused by the shifting of the Earth's crust

THE FUTURE OF SKYSCRAPERS



Skyscrapers have always had their enemies among architects. Not all of the structures are elegant like the Chrysler Building or the Empire State Building. Even the World Trade Center, with its astounding height and subtle neo-Gothic flourishes, was panned by architects as a "milk carton" — boring, boxy, and plain.

But with the Trade Center in ruins, beauty is no longer the only concern about skyscrapers. They no longer appear safe, either. That is the challenge to the new generation of architects and engineers: How do you make a skyscraper secure?

For one, you don't build it so tall, even if that means it's not as beautiful. The World Trade Center towers had 110 stories each. Most buildings today have only 80 or so. More stories are inefficient because the necessary elevators and structural support take up a huge amount of space. A smaller building would be safer from similar terrorist attacks using planes, and wouldn't wreak so much damage if it did collapse. And there's a psychological benefit to building smaller: About 55 percent of New Yorkers now say they don't feel safe working in tall buildings.

Once architects and engineers agree on the size of a building, technology can be used to keep the smaller and safer skyscraper standing. Since most of the fluffy fireproofing material on the towers' steel columns was blasted off by the plane crashes, engineers now are taking another look at alternative ways to protect columns and ward off warping. The materials used in offshore oil-drilling platforms may provide one way to keep buildings from bending under the heat of fire. Polypropylene fibers currently used to coat the platforms stop fire and could be adapted easily to land use. Columns that hold up a building could have a similar coating.

Of course, even protective coatings last only so long under extreme conditions. So designers also are looking for new ways to evacuate buildings before a collapse. They might construct separate, wider stairwells and elevators for rescue personnel who rush up into buildings while tenants are rushing down and out. New skyscrapers may also be built with networks of fiber-optic cables buried in their concrete walls. The cables would warn police and firefighters of impending collapse when beams in a building warped or melted. As fire or gravity weakened parts of a building, sensors in the cables would notice changes in temperature or pressure and alert a main control system by changing the color of the light flowing through the nearby cables. The color change would tell security exactly where the problem exists. Best of all, this photonic technology isn't far off (*photonics* simply means technology that uses *photons*, the basic unit of light, to do its work). Railroads are now using it to make sure that their tracks are strong, and a few test buildings are already up and running.

In any case, with technology and planning, skyscrapers will continue to dominate city skylines. Towers weren't too popular with builders even before September 11; they usually rise in good economic times instead of bad ones. But the skyscraper was invented in America, and most architects and engineers say it will always be an icon of our ingenuity, no matter what the condition of the economy. Good economic times and the towers will both come back, and we can hope they'll both be stronger, if not bigger, than ever before.

M.C.