Citicorp Center Tower: failure

Based on an article originally published in *The New Yorker*, Sean Brady reflects on the Citicorp tower crisis.

One day in June 1978, William LeMessurier, then fifty two years old and one of North America's most respected high rise engineers, received a call from a New Jersey engineering student. The student was writing a paper on the Citicorp tower, which was designed by LeMessurier and completed the previous year in Manhattan. At the time, this 280m high, 59 story building, the seventh tallest in the world, was supported by a 23,000t steel structure, and was clad in glass and reflective aluminium.

The student asked about the structure's four columns, because according to his professor they were placed at the wrong locations. These columns were nine storeys high, and rather than being located at the building's corners, they were located at the centre of each of the building's faces (Figure 1). LeMessurier politely pointed out that there was a very good reason for their unusual location. Indeed, far from being an error, LeMessurier told the student that they were ideally located to resist quartering winds – winds blowing towards the corner of the building. LeMessurier provided the student with further information, referred him to a technical article on the building, and the call ended.

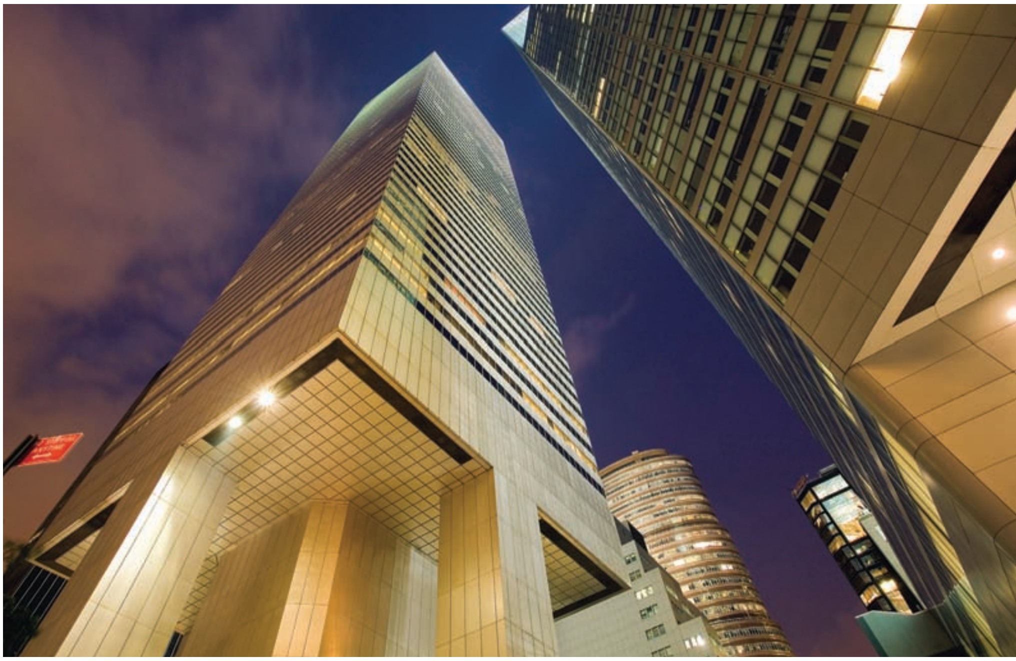

Figure 1
Centred columns of Citicorp Center Tower

Design

The reason LeMessurier had originally designed the building with its columns located at the centre of each face was the presence of St. Peter's Lutheran Church. This small, dilapidated structure was built in 1905 and was located on the proposed Citicorp Center site. It was agreed that the church would be demolished and rebuilt, and would be located at one of the corners of the proposed Citibank tower. To accommodate this design requirement, LeMessurier conceived a structural design with columns located mid face, with six, eight-story-high V shaped bracing systems (in the form of inverted chevrons) to accommodate wind loads and to support the 22m cantilevered overhangs at the building's corners – one of which would overhang St. Peter's Church. In true engineering style, LeMessurier had conceived this structural solution (literally) on the back of a napkin in a Greek restaurant in Cambridge, Massachusetts.

Prompted by the phone call, LeMessurier, also an adjunct professor at Harvard and MIT, decided that a discussion of the building's unusual bracing system would form an interesting lecture for his engineering students. He set about calculating forces in the bracing due to perpendicular wind loading on each building face, which he had, of course, long since established. Then he calculated the forces in the structure due to a quarterly wind blowing from a 45 degree angle - a purely intellectual exercise: if a building can resist winds from perpendicular directions, it can typically resist quartering winds.

But LeMessurier suddenly discovered this was not the case for the Citicorp tower: due to the innovative bracing system, the calculations indicated that the quartering winds increased the forces in four of the eight chevrons by 40%.

Unfortunately, things were about to get worse. In the initial design, it was conceived that each chevron would consist of three separate sections that were welded together. But the steel supplier for the project, Bethlehem Steel, proposed that cheaper bolted connections, instead of welded connections, could be used. This design change had been approved by LeMessurier's New York office, but LeMessurier himself only became aware of it one month prior to receiving the student's call and long after construction was complete.

LeMessurier wondered if the design office had considered quartering winds (and the larger forces in the chevrons) when designing these bolted connections?

He checked and they hadn't. At this point LeMessurier describes himself as feeling "pretty shaky" because his calculations indicated that the forces in the bolted connections increased by 160% due to these winds. Further investigation indicated that the design had not considered the appropriate factor of safety, making the situation worse.

Wind loading

Before deciding what to do, LeMessurier wanted to understand, in more detail, how the structure responded to wind loading, so he travelled to Canada on the 26th July to meet with Alan Davenport, the director of the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario. Davenport had undertaken wind tunnel tests during the structure's design, and he was asked to retrieve the files. What he found brought more troubling news. While the theoretical 160%

averted

increase in loading was correct, in practice the loading could be much higher because of the potential for the quarterly winds to dynamically excite the flexible structure. In risk terms, this information suggested that the structure would fail in a wind storm with a return period of 1 in 16 years. As LeMessurier reported years after the event, “that was very low, awesomely low.”

But there was one positive consideration. The building was fitted with a 370t concrete tuned mass damper on the top floor to reduce building sway under normal wind loading conditions. It was the first of its kind installed in a tall building, and it would help minimise vibrations and theoretically reduce the risk of failure to a 1 in 55 year storm. But again there was a problem, it couldn’t be relied upon during a storm event due to the likely loss of electrical power - the mass damper would be ineffective when needed most. Even more distressing, it was now the end of July and hurricane season would commence in November.

Faced with this information, LeMessurier essentially blew the whistle on himself on the 2nd August and alerted Citicorp. There followed a complex round of hushed meetings with insurers, lawyers, and Citicorp on how to manage the risk and strengthen the structure. If the US$175 million tower were to collapse, up to 200 000 members of the public were at risk[1]. The Department of Buildings were alerted, they commended LeMessurier on his courage and candour, and asked to be kept informed.

Retrofit

The following morning, at a meeting in the Citicorp tower, LeMessurier proposed a solution to strengthen two hundred of the bolted joints. The solution consisted of welding 50mm thick plates across each bolted joint - essentially providing a permanent ‘band aid’ solution in the truest sense. During the meeting, workman removed sheetrock to expose an actual bolted joint on a vacant level in the tower, and it was concluded that LeMessurier’s solution was practically feasible. Interestingly, during the initial design, LeMessurier had wanted the steel structure on the outside of the building, thus making it an architectural feature, but the architect, Hugh Stubbins, had overruled him. Now, as a fortuitous consequence, the bolted joints were readily accessible for welding from inside the building.

But the clock was now ticking to ensure that the retrofit was completed before November. LeMessurier’s office completed the plate design, and Karl Koch Erecting, the same firm that had erected the World Trade Center, were engaged to complete the retrofit.

It would be undertaken at night. Teams of drywall crews and carpenters would put up plywood screens around each bolted joint and remove the drywall from 5pm onwards each day. At 8pm, welding of the plates would commence and continue to 4am, when labourers would clean up the mess before the first office workers arrived. Work would continue seven days a week, the Department of Buildings would fast track the certification of welders to meet the shortfall of trained personnel, and LeMessurier would determine the order of the joints to be retrofitted to progressively strengthen the structure. Evacuation plans for the area were drawn up in the event of an actual storm event. Backup power was provided for the tuned mass damper to keep it operating in the event of power loss, and its manufacturer, MTS Systems, provided round the clock technical support to ensure it remained operational. A special advisory group of weather experts was set up to provide wind predictions four times a day, and strain gauges were installed to monitor the structure’s behaviour. There was a problem however: their wires were mysteriously cut because they had been installed by non-union electricians.

With the large number of individuals now involved in the management of the crisis, Citicorp released a media statement indicating that strengthening work was being undertaken, but the integrity of the structure was not in question. Discussions continue with respect to the ethical nature of this statement and the role LeMessurier played in its release[1]. However, although the media were generally uninterested, the New York Times attempted to contact LeMessurier personally[2]. Advised that he had little choice but to talk to the media, but not looking forward to being interrogated, he called the New York Times to find that all journalists, along with the journalists from all the major papers, had just gone on strike. By incredible coincidence, this strike would continue until several weeks after the retrofit was completed, with the true story of the crisis remaining hidden until it was first broken by Joe Morgenstern, in an article titled ‘The Fifty-Nine Story Crisis’ in *The New Yorker* magazine in 1995[3].

Work continued in earnest, but on the 1st of September, the weather service reported that a storm, Hurricane Ella, lay off Cape Hatteras and was heading for New York. LeMessurier recalls the feeling that they were probably going to have to hit the panic button, but a few hours later the hurricane changed direction and began moving out to sea.

Finally, welding was completed in October, and it had taken the combined resources of LeMessurier’s engineers, Citicorp, city officials, a team of welders and labourers, and US$4.3 million to increase the structure’s wind resistance from a 1 in 16 year event, to a 1 in 700 year event – a building now considered to have one of the highest wind ratings in the world.

Aftermath

During the crisis, all focus had remained on completing the retrofit, but once complete, the inevitable legal wrangling began, with Citicorp commencing legal action against LeMessurier (and the architect, Stubbins) seeking indemnification for all costs. Morgenstern’s article reports that Citicorp’s approach was remarkably free from the usual vitriol that accompanies such proceedings, and when LeMessurier offered Citicorp US$2 million, which was the value of his insurance policy, it was accepted. No litigation ensued, and Stubbins was held harmless.

Since the story became public in 1995, LeMessurier has been hailed for his ethical conduct: he found an error, he owned up, and he fixed it. While there are, of course, dissenting opinions[1], the predominant view in the literature is that his professional reputation, rather than being damaged, was enhanced by his conduct. Over the years, LeMessurier would discuss this crisis in his Harvard course and he reminds his students that ‘You have a social obligation. In return for getting a license and being regarded with respect, you’re supposed to be self-sacrificing and look beyond the interest of yourself and your client to society as a whole. And the most wonderful part of my story is that when I did it nothing bad happened’.

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