Case Study - The Fifty-Nine Story Crisis

Course Number: ET-02-201

PDH: 3

Approved for: AK, AL, AR, FL, GA, IA, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

State Board Approvals

Florida Provider # 0009553 License #868
Indiana Continuing Education Provider #CE21800088
Maryland Approved Provider of Continuing Professional Competency
New Jersey Professional Competency Approval #24GP00025600
North Carolina Approved Sponsor #S-0695
NYSED Sponsor #274

Course Author: Mathew Holstrom

How Our Written Courses Work

This document is the course text. You may review this material at your leisure before or after you purchase the course.
After the course has been purchased, review the technical material and then complete the quiz at your convenience.
A Certificate of Completion is available once you pass the exam (70% or greater). If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained).
If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH Pro.com.

Introduction

William LeMessurier, one of the nation's most distinguished structural engineers, served as design and construction consultant on the innovative Citicorp headquarters tower, which was completed in 1977 in New York. The next year, after a college student studying the tower design had called him to point out a possible deficiency, LeMessurier discovered that the building was indeed structurally deficient. LeMessurier faced a complex and difficult problem of professional responsibility in which he had to alert a broad group of people to the structural deficiency and enlist their cooperation in repairing the deficiency before a hurricane brought the building down.

His story was recounted in detail in "The Fifty-Nine-Story Crisis," which appeared in the May 29, 1995 issue of The New Yorker, and on November 17, 1995, LeMessurier himself came to MIT, from which he received his doctorate, to speak to prospective engineers about the decisions he had to make and the actions he took.

Part 1: Background and the History of Skyscrapers

By the early 1970s, when Citibank began plans for a huge new headquarters tower in midtown New York, the art of designing and building a strong, safe skyscraper seemed nearly perfected.

The skyscraper, like any other architectural form, had gone through a long period of evolution. After Elisha Otis's successful introduction of the first safety-brake-equipped elevator in the 1850s and the introduction of steel-frame construction, buildings began to grow upward. In 1910, the Metropolitan Life Building broke all records for height until that time: it was 50 stories high.

Figure 1: The Hancock Building in Chicago

By the 1930s, with the construction of the 102-story Empire State Building skyscrapers, thanks to their widespread success, had begun to sprout in many cities worldwide. Areas populated with these tall buildings found themselves growing, literally, ever upward. The skyscraper, coupled with the introduction of modern, efficient subway systems in cities like New York, made it possible for companies to employ workforces unprecedented in size. Consequently, city populations increased immensely.

By 1930, daring, creative architects and engineers had even begun to depart from what had been accepted as the "traditional" method of designing and constructing skyscrapers. Innovations in skyscraper design such as lighter materials, increased window area, and cantilevered supports, resulted in taller, lighter, and slimmer buildings. For instance, Chicago's record-breaking Hancock Building, incorporating an innovative system of diagonal bracing, shown in Figure 1, that allowed the building to be much leaner and lighter than it could be if it had been constructed in a traditional manner.

Part 2: LeMessurier's Innovative Citicorp Design

William LeMessurier was one of the country's most distinguished structural engineers when his Cambridge firm was called upon to act as a consultant to the planned Citibank corporate headquarters. LeMessurier had a vast array of experience with skyscrapers; the first building he designed, Boston's State Street Bank, incorporate an inventive cantilever girder system, and his famous Boston Federal Reserve Bank, was designed so that an airplane could, quite literally, fly directly through what appeared to be a large hole in the building.

Figure 2: Citicorp tower design

LeMessurier's experience with innovative designs was fortunate, since there was a criterion peculiar to the planned Citibank building. A church had partial ownership of the block where Citicorp planned tobuild. As a resolution, Citicorp agreed to build a new free-standing structure, located at one corner of the lot, to replace the current antiquated, dilapidated church. In return, the church granted "air rights" above its part of the block to Citicorp. Figure 2 depicts the bottom part of the first rendering of the Citicorp tower design, clearly showing the nine-story high, mid-wall-mounted stilts that would need to support the building.

In order to provide space for the new church, the Citicorp tower would therefore have to be situated on nine-story-high stilts, so the church could be constructed underneath. However, the church was to be located at a corner of the block, not in the middle of a block. This meant that the Citicorp tower's stilts would have to be in the middle of each of its walls, and not at the building's corners -- an unprecedented feat of engineering if it could be accomplished.

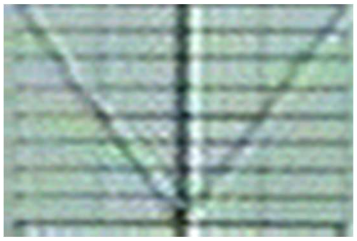

Figure 3: Citicorp tower's framework
and column support system

The innovative LeMessurier sketched an idea for the Citicorp tower's framework and column support system. Figure 3 depicts an eight-story section of his design. It called for large diagonal girders throughout the building. The girders would transfer the tower's great weight to the four huge columns that would anchor the structure to the ground. The new church could then be constructed as planned, underneath one of the tower's corners.

Part 3: The Discovery of the Change from Welds to Bolts

The Citicorp tower was constructed using LeMessurier's diagonal-bracing design, and work was finished in 1977. LeMessurier's innovation translated into a great weight savings; the tower was unusually light for its size. However, this meant that it would have a fair tendency to sway in the wind, so a tuned-mass damper was installed at the top of the building. The inertia of this 400-ton concrete block, which floated on pressurized oil bearings, worked to combat the tower's expected slight swaying. The Citicorp tower was the first structure ever to incorporate mechanical assistance to combat wind sway.

Figure 4: Citicorp tower under construction

In May 1978, LeMessurier, acting as structural consultant to a new building being planned in Pittsburgh, again thought of using a sort of diagonal brace as part of his design. As in the Citicorp tower, the braces were intended to be joined with full-penetration welds, but the process of welding, though it resulted in extremely strong joints, was expensive and time-consuming. A potential contractor for the Pittsburgh construction job pointed this out to LeMessurier, who immediately thought to counteract the contractor's fears with the success story of his Citicorp tower and its welded joints.

Unknown to LeMessurier, however, was that during the Citicorp tower's construction. Figure 4 shows the tower under construction. The Citicorp contractors had decided, based on the cost of welding, to put the braces together using less expensive bolted joints. Though bolted joints were weaker than welded joints, the New York contractors had agreed that welds would be unnecessarily strong and that bolts would be sufficient for the job.

When LeMessurier referred the Pittsburgh contractor, concerned over the cost of welding, to the successful Citicorp job, he was told of the substitution of bolts for welds in the Citicorp project. LeMessurier did not consider the change to pose a safety hazard, however, since the substitution was rather reasonable from an engineering standpoint, and there wasn't any reason for LeMessurier, a distant consultant, to have been previously informed. This assessment would change over the next month, however, as LeMessurier would soon encounter new data indicating that the switch from welds to bolts compounded another danger with potentially catastrophic consequences.

Part 4: Exploring the Effects of Quartering Winds

In June 1978, a month after LeMessurier was told of the switch from welds to bolts in the Citicorp building, he received a telephone call from a student. This student's professor had been studying LeMessurier's Citicorp design and had concluded that LeMessurier had put the building's nine-story supports in the wrong place. The supports belonged on the tower's corners, according to this professor, not at the tower's midpoints.

The professor had not understood the design problem that had been faced, so LeMessurier explained his entire line of reasoning for putting the tower's supports at the building's midpoints. He added that his unique design, including the supports and the diagonal-brace system, made the building particularly resistant to quartering, or diagonal, winds -- that is, winds coming on the diagonal and so hitting two sides of the building simultaneously. Figure 5 presents a diagram of why perpendicular winds cause sway in a building.

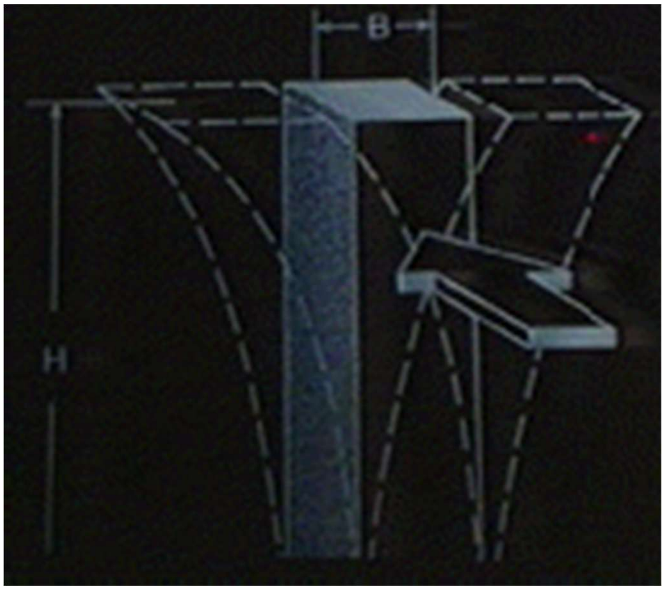

Figure 5: Perpendicular winds causing sway in building

Shortly thereafter, LeMessurier decided that the subject of the Citicorp tower and quartering winds would make an interesting topic for the structural engineering class he taught at Harvard. Since at the time the requirements of the New York building code, like all other building codes, had covered only perpendicular winds, LeMessurier did not know how his design would fare in quartering winds.

Interested to see if the building's diagonal braces would be as strong in quartering winds as they had been calculated to be in perpendicular winds, LeMessurier did some computations. He found that for a given quartering wind, stresses in half of a certain number of structural members increased by 40 percent.

Then he became concerned about the substitution of bolts for welds. Had the New York contractors taken quartering winds into account when they replaced the welds with bolts? Had they used the right number of bolts? The second question was particularly important -- a 40 percent increase in stress on certain structural members resulted in a 160 percent increase of stress on the building's joints, so it was vital that the correct number of bolts be used to ensure that each joint was the proper strength.

What he found out was disturbing. The New York firm had disregarded quartering winds when they substituted bolted joints for welded ones. Furthermore, the contractors had interpreted the New York building code in such a way as to exempt many of the tower's diagonal braces from loadbearing calculations, so they had used far too few bolts.

Shaken, LeMessurier reviewed old wind-tunnel tests of the building's design against his new quartering-wind calculations (these tests had modeled a large part of midtown Manhattan), and found that under adverse weather conditions, the tower's bracing system would be put under even further stress. The innovative tuned-mass damper, designed to reduce the building's normal slight swaying, was not designed to keep the building from being blown down in a major storm; this further worried LeMessurier.

Purchase this course to see the remainder of the technical materials.