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The performance of San Francisco's earthquake-resistant city halls: The old city hall in the earthquake of 1906 and the new city hall in the earthquake of 1989

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ABSTRACT: This paper examines the history and performance of two domed city halls, each built to resist seismic forces. In reaction to earthquake damage to a previous city hall in 1868, San Franciscans erected a new earthquake-proof building beginning in 1872. This building failed in the earthquake of 1906. Yet another city hall, begun in 1913, was built to be anti-seismic, in reaction to the failure of the previous one. The new city hall suffered serious fracturing in the 1989 Loma Prieta earthquake. The major weakness in both structures was in the dome supports, but the logic behind the decisions that contributed to their weakness forms an important chapter in anti-seismic engineering history.

INTRODUCTION

Twice in San Francisco's history, architects and engineers have attempted to design city halls to resist earthquakes, and twice the city halls have been damaged. The drum and supports of the first monumental city hall, begun in 1872, failed in the earthquake of 1906, and the drum and supports of the present city hall, begun in 1913, suffered fractures in the Loma Prieta earthquake of 1989. Today, protective scaffolding and shoring clutter passages and arches in the grand rotunda under the dome of the city hall, testifying to the damage it suffered. Yet the engineer of the present city hall, Christopher H. Snyder, had tried his best to design a building that would not duplicate the failure of the old one. Why was the location of some of the damage in these two structures similar? Do the fractures that can be seen in the present city hall illustrate Snyder's failure in understanding lessons of the past?

THE OLD CITY HALL

The City Hall that was built in 1872 replaced an earlier one that had been destroyed in the earthquake of 1868 (Baird, 1964, Huber, 1930). Citizens wanted a city hall which would symbolize the grandeur of San Francisco and which would incorporate new ideas of anti-seismic construction prevalent in the 1870s. The two major earthquakes which shook San Francisco in the 1865 and 1868 convinced many architects and engineers that anti-seismic design was important in major structures. Many attempted to build seismically resistant structures, which they naively called "earthquake proof." In the late 1860s and early 1870s such "earthquake proof" structures were commonplace (Tobriner, 1986). Advertisements appeared in the city directory claiming buildings were earthquake proof, and newspaper articles routinely mentioned earthquake-proofing techniques when describing new structures. The basic concept was that structures were to be tied together to act as units if an earthquake struck. One building, the Grand Hotel, was tied together by an internal wooden framework which, a newspaper article claims, had the solidity of a ship. Another great hotel, the Palace, built in 1870, was a brick structure tied together by iron bars or rods worked through its walls. These rods, combined with excellent mortar and frequent cross-walls, gave the Palace great solidity. It became a common practice to lay linked iron bars, called bond iron, in exterior walls all around a building (Tobriner, 1986).

Given the prevailing consciousness of earthquakes, it is no surprise that many of the decisions of the ill-fated San Francisco City Hall begun in 1872 concerned its potential to resist earthquakes (Tobriner, 1989, SFMR 1871-72, SFMR 1872-73, SFMR 1878-79). In the contract for the structure, earthquakes appear in several crucial passages. For example, under material and construction:

> "All the walls throughout, both the exterior and interior, to be thoroughly bonded with wrought iron, and every possible precaution used to prevent injury by earthquakes, and the quality of all the work throughout to be *first class*."

Again, in the controversy of whether to use brick or stone:

> "It is needless to repeat all the arguments, pro and con, leading to the determination. The chief ones in favor of brick were the lesser cost, the shorter time, and mainly the long-proved durability, and, when combined with the proper appliances adapted for that purpose, elasticity and tenacity—qualities first to be considered in resistance against earthquakes."

The brick structure was to be laced by iron bond to hold together its walls in earthquakes. Documents mention "fixing bond iron...," purchasing "...iron bonding...." Therefore, given the technology of the period, the construction of its walls would have been considered "earthquake proof." Further, the foundation of the building was secured with an anti-seismic iron bonding technique pioneered by the Pacific Submarine Earthquake-proof Wall Company.

Given these seismic concerns, it is a shock to see the scheme of the City Hall as it emerges from the design stage. The Canadian architect Augustus Laver (1834-1898), who designed in a High Victorian eclectic style, gave the city what it wanted, a civic building to rival in its size and ostentation any other in governmental building in the United States, whether federal, state, or civic. The building he first designed in a Victorian style had six small towers and one exceedingly high one, all culminating in mansard roofs. The commissioners decided to transform the mansard roof of the main tower into a dome, more expensive, more difficult to design, but more in keeping with the city's vision of itself.

Three aspects of the design and placement of the building were seismically hazardous. First, the structure was built on unstable ground. The water table under the site was high, and according to later sources the concrete foundation, which in the 1870s was said to be laid over wet sand, was actually constructed over a filled lagoon. Second, the configuration of the building, in the form of a square courtyard with diagonal wings in the shape of a "w," was dangerous. Traditional rectangular buildings had been submitted to the jury, but they had lost in favor of the "w" shape because it best fit the triangular site chosen for the building. Today we know that the forces exerted on the joining walls of the "w" shape make it a hazardous configuration in earthquake country, but the San Franciscans of that time had no such understanding. Last, the top of the City Hall dome stood a full 335 feet. In other earthquake areas, like southern Italy, such tall structures had been forbidden by law (Tobriner, 1985). The commissioners knew the tower and dome were possibly dangerous and consulted several engineers, all of whom said the dome could withstand an earthquake.

Although the high dome was contested when first proposed, by 1888 the fabrication of its skeleton was underway at the Risdon Iron and Locomotive Works (SFMR 1888-89). They fabricated fifteen cast-iron columns which were to support the dome above the already erected entrance hall, two tiers of gallery joists, and large wrought iron girders for carrying the framework of the main tower. But because the height of the tower had been attacked by critics, the commissioners in power asked the local chapter of the American Institute of Architects, as well as six engineers, to discuss the merits and debits of the tower-dome project. Again engineers came forward to testify in favor of the structural durability of the dome tower.

For example, Calvin Brown, "civil engineer," said,

> "...at about the same time made an exhaustive report on the construction of the main tower, going into details, supported by figures, and holding that it was more than ample in strength to sustain the weight which could be placed upon it, as also to resist the force of winds and earthquakes; and was in addition correct in perspective in connection with a mansard roof."

No eyewitness reports of the collapse of the building in the earthquake of April 18, 1906 survive. But photographs of the ruins indicate that dome tower began to oscillate because of the ground motion of the earthquake. As the periods of the oscillation increased, the masonry which clad the sides of the dome tower was sloughed off of the iron structural framework and rained down on the rest of the building. About three quarters of the masonry from the dome tower fell on the main body of the building, bombarding the roof structure and exterior facades surrounding it. Pieces of the dome tower hitting the facade accentuated its inherent weakness, causing failures. In addition to ruining large portions of the interior and exterior, the failure of the dome, by destroying the exterior envelope of the building, compromised its defense against fires. The vulnerable interior with combustible office furniture and records was no longer protected by fire-proof walls and roofs.

The dome tower was not a complete failure. It did not entirely collapse. Careful examination of the rotunda after the earthquake by City Architect Newton J. Tharp showed that the center of the dome had shifted to the northeast a distance of eight and one-quarter inches out of plumb (SFMR 1907-1908). The roof of the dome, the lantern and the statue on top of the dome were all sound. But from the level of the bottom of the dome proper to the springing point of an interior glass dome above the rotunda entrance great damage occurred. Most of the masonry walls fell away from the eight steel columns supporting the dome at this level, and the remaining masonry was extremely hazardous. At a point about halfway up the steel columns nearly all the rivets in the splice plates between the columns were sheared off, leaving only the horizontal trusses to hold the columns in position. The eight steel columns holding the upper part of the tower rested on a set of four great girders, which in turn rested upon a complicated masonry, steel, and iron structure. The four girders were surrounded by bricks which according to Tharp were not reinforced (contrary to contracts and earlier descriptions). Aside from the surrounding masonry the girders were not tied together or braced. "Without reliance on the inertia of the rotunda walls the whole upper structure bearing upon the main interior columns would topple in a summer wind," according to Tharp.

We cannot be sure why the San Francisco City Hall dome tower failed in the earthquake of 1906. But it is probable that the steel work of the dome tower was badly designed and badly executed. According to Tharp, "on the whole...[the work] is well conceived and the workmanship of the best, but ...it was certainly a great oversight not to have introduced diagonal bracing." He continues:

> "For some reason the diagonal bracing in the vertical panels between the eight columns on four stages, thirty-two in all, was left out, although the pin-plates are in position on the columns. Directly above the four girders, the eight columns stand without effective bracing for a height of more than thirty feet."

The omission of the diagonal bracing is puzzling indeed, particularly since attachments for such bracing seem to have been provided. The discrepancies between Tharp's statements about lack of bond iron and court testimony concerning its insertion in the walls raises many questions about the correlation of what was specified and what was actually in the walls of the structure (Tobriner, 1986). But after the earthquake the discrepancies were never investigated. No legal inquiry into the unused attachments for diagonal bracing ever surfaced. And since no documents survive, we cannot assign blame as to whether engineers, contractors, or workmen omitted them. Even with the diagonal bracing in place, problems with the girder foundations still would have been extreme, perhaps because the bottom of the rotunda wasn't at first designed to support the circular drum support.

THE NEW CITY HALL

Of the many preparations for the Panama-Pacific International Exposition of 1915 that would celebrate the reconstruction of the city after the 1906 earthquake and fire, none seemed so symbolically important as the replacement of the ruins of the City Hall with a new structure—one more in keeping with San Francisco's image as a clean, new, politically incorruptible city rising from its ashes. The ruins that had been retrofitted to serve as a temporary city hall were finally condemned, and a blind competition opened for the design of a new building. The firm of John Bakewell, Jr. and Arthur Brown, Jr. won the competition.

Bakewell and Brown designed the new City Hall in a Beaux Arts French Baroque style with a rectangular ground plan topped by a heroic 301 foot dome (Cahill, 1916). The structural system of the building was to be steel frame with unreinforced brick and hollow clay tile infill. The exterior was clad in granite while the interior included granite, sandstone, marble and plaster finishes.

Once the citizens of San Francisco knew that the structure was going to be steel frame, questions about the building's structural integrity ceased. No one seems to have asked the architect or engineer about their plans for using this technology. It was the exterior facade of the building which received the most attention. Mayor Rolph and the Board of Supervisors supported the idea of an elegant new design for the Civic Center, based on the Beaux Arts concepts popularized by the City Beautiful movement. The City Hall was to be relocated from Market Street to Van Ness Avenue. One of the condemnations of the old site was "the fact that the ground on the old site is insecure, there having been a lagoon there at one time." However, Hayes Valley ground water percolates through the whole Civic Center area and flows through the old City Hall site to the edge of the former marsh, which reaches almost to Market near Eighth Street. The new site was perhaps only a little less saturated than the old one. There was water just six feet under the foundations, enough water for the foreman to sell it to the subcontractors working on the building for mixing mortar and cement and for watering their teams (Sebastian, 1978).

From the reports of the engineer, Christopher H. Snyder, and the foreman, George Wagner, interesting construction details emerge (Sebastian, 1978, and Snyder, 1916). Built on wet sand with an abundance of water underneath, the foundation for the structure, designed by Snyder, was the cheapest one Wagner had ever laid, costing only one-twentieth the cost of the total building, a very low ratio. It was made of concrete composed of brick aggregate, much of it from the previous City Hall foundation—itself of questionable quality—crushed and reused. The foundation was not on piles, but was a spread footing, designed to evenly bear on the wet sand.

Snyder's conception of the structure was that it would be "on the lines of a modern office building as far as the architecture would permit." Snyder states that "aside from the dome, which was a considerable problem, and the heavy stone work of the exterior walls and cornices, the steel work and foundations were similar to the ordinary Class A building" (Snyder, 1916). The dome was a special challenge, however. Consideration of the collapse of its predecessor can be seen in how it was "supported on four groups of five columns each, latticed together from the second floor to top...these carry girders nine feet deep, 60 feet long." The dome tower was divided into sixteen bays, with four circles of columns in the tower. "This tower was braced radially and circumferentially, like a gas holder frame, with five levels of horizontal bracing to maintain the circular shape against distortion." A wind load of 50 pounds per square foot, reduced for curvature and slope, was used in calculating the dome structure. To absorb and counteract shear pressure from the dome, diagonal horizontal bracing was placed in each of the floors near the dome, supporting towers to ensure the proper distribution.

The City Hall had a stiffly constructed dome and, hopefully, an appropriate foundation, but buried in Snyder's discussion of the main portion of the structure was a feature that San Franciscans and their engineers should have at least debated. He stated, "No wind was figured on the main structure, nor was any diagonal bracing used below the second floor, in order that the necessary flexibility against earthquakes should be retained"(Snyder, 1916). Snyder was putting into practice the idea of a flexible, shock-absorbing first story, which was extremely theoretical in 1912. The Structural Association of San Francisco had discussed this idea immediately after the earthquake of 1906, and it has been debated ever since, particularly vociferously in the San Francisco Bay Area in the late 1920s.

Snyder's idea was to dissipate the earthquake energy at the first floor rather than having it travel vertically through the structure. He depended upon the unreinforced brick masonry in the walls and the hollow clay tile infill to resist the lateral movement of the building as the steel frame flexed. He appears to have intentionally created discontinuities in the load path through the building in order to save it from complete collapse. His concept was tested in the Loma Prieta earthquake.

On October 17, 1989, the San Francisco City Hall was shaken by the magnitude 7.1 Loma Prieta earthquake which caused damage throughout a 8,000 square kilometer area. The single greatest loss of life occurred in Oakland, 90 kilometers from the epicenter, when 42 people were killed in the collapse of the Cypress Street Viaduct, a one-mile elevated segment of Interstate Highway 880. In addition to damaging the San Francisco Bay bridge, the earthquake destroyed scores of unreinforced masonry buildings and damaged engineered structures in Santa Cruz, Watsonville, Oakland, and San Francisco.

While the City Hall's exterior appears undamaged by the earthquake, its interior was damaged in several locations, most notably in the rotunda underneath the dome. Although the comprehensive report of the performance and proposed retrofit of the structure is still confidential, some general observations can be made. The areas of damage included the cracking of unreinforced masonry at the ground floor and the main floor levels, cracked hollow clay tile throughout the building, the cracking of reinforced concrete slabs around the dome, the cracking of hollow clay tiles and marble on stairwells adjacent to rotunda, and the cracking of hollow clay tiles in the stairwells adjacent to light wells, the displacement and cracking of interior stone cladding of rotunda, the cracking of cladding in the rotunda arches, and the cracking of concrete walls in some rotunda towers and some slabs of the dome. (Elsesser, E., 1992.)

Why was the fracturing in the City Hall so extensive? Until the final damage report is published and debated, the cause of the numerous cracks can only be conjectured. It is possible that the dome moved more than Snyder anticipated because the forces to which it was subjected were far greater than he imagined. Perhaps the dome supports did not function as independently from the rest of the structure as he thought they would, and his soft story concept compromised the dome support. It is also likely that the fractures in the hollow clay tile and the brickwork suggest that Snyder's energy-dissipating soft story was tested by the shaking in the Loma Prieta earthquake. The cracking of the infill was a necessary sacrifice as the shaking was transmitted from the foundations to the structure. If this hypothesis is correct, the building performed as Snyder had planned it to.

CONCLUSION

The magnitude of damage the 1913 City Hall suffered in earthquake of 1989 is small in comparison to the damage the 1872 City Hall suffered in 1906. Both structures were specifically designed to resist earthquakes although no anti-seismic codes had been promulgated—in fact, seismic codes would only appear in California in 1933. In the earlier building, a combination of design alterations and construction negligence contributed to its failure. If Augustus Laver had lived to see his building fail in the earthquake of 1906 he would have been humiliated by its poor performance. Yet it is important to recognize that the dome's failure was far from unique. An exactly comparable failure occurred in the library of Stanford University to the south of San Francisco in the earthquake of 1906. Here, too, the lantern, dome, and covering survived, held aloft by steel columns that in their oscillation destroyed the dome tower walls and the masonry structure around the base of the dome tower. Similarly, the high tower of the Ferry Building, with a heavily diagonally braced steel interior, almost failed. Although rivets were sprung throughout the height of the tower, it did not dislodge its exterior masonry and remained standing, but the basic problem was the same as that of San Francisco's City Hall. High towers, like the extraordinarily high San Francisco City Hall dome tower, act like inverted pendulums in earthquakes and that is the problem that many San Francisco architects failed to address.

Snyder, in designing the structure for Bakewell and Brown's city hall, tried to come to grips with the problem of a high domed building. His city hall survived the Loma Prieta earthquake with comparatively little damage compared to the collapse of the previous city hall. But if the soft story dissipated energy as Snyder had planned, it also lost much of its potential strength. Once fractured it can no longer be expected to save the building again. The dome and drum, having cracked restraints around them in the comparatively short (15 second) Loma Prieta earthquake, may be far weaker than Snyder supposed. Now the structure stands with its interior marble and stone cracked and its rotunda under protective scaffolding, recalling the ruined portions of the old city hall which were temporarily shored and used after the earthquake of 1906. A retrofit of the old city hall was voted down in 1906 but a retrofit of the new city hall is mandatory if it is to survive as the symbol of San Francisco. A retrofit, not merely repair of the damage, is necessary to compensate for the now-used soft-story infill protection.

How can the usefulness of the soft-story solution be assessed? Would Snyder feel the structural integrity justified destruction of the decorated interior walls? Would the architects have asked for another solution if they had realized the ramifications of Snyder's idea? What is our opinion today as construction decisions are again being made?

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