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INTEGRITY OF STRUCTURE:
The Armature of our Architectural Heritage

by
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"In conducting business (especially for the office) never forget that the greatest danger arises from cocksure pride. Beware of over-confidence; especially in matters of structure."

From Cass Gilbert, Architect (1859-1934) *Maxims for My Office Organization* (*from Arttoday.com)*

September 11, 2001

The collapse of the World Trade Center towers has irrevocably changed our perceptions of buildings, at least for a generation. Even now, a year after the event, we struggle to make sense of an event that, until it occurred, was beyond our imagination. Bridges, radio towers, or other structures can fall down, but, absent an earthquake, major modern engineered buildings are simply not known to do so. They seem so solid, so permanent.

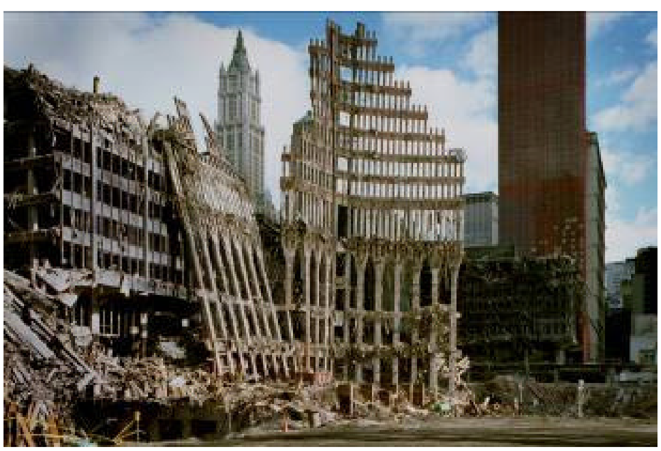

Figure 1: Ruins of World Trade Center North Tower façade with the Woolworth Building in the distance. Originally the tallest in the world, with the demise of the Twin Towers, the 1913 Woolworth Building has again resumed its status as the tallest building in Lower Manhattan.

Or course, intellectually, the collapse made sense. How could any building stand up to the fiery crash of a large fully loaded commercial airplane? In fact they withstood that force – only to suddenly collapse an hour later into an indefinable pile of debris – except for the evocative Gothic style ruin of the broken facade of each tower. (Figure 1)

Buildings have collapsed in history, but the Twin Tower collapses were broadcast on international television. Almost every camera in New York was trained on them when they happened, and millions watched in horror as they fell to the ground. The only thing missing from the experience of those who watched in on television was the earthquake-like thump when the pancaked floors – 110 of them – struck bottom. Who can now not think of structure when looking at a building – particularly when looking up at a tall building? How fragile they now seem.

After the disaster, one of the original principle engineers, Leslie Robertson, who still lives and works in New York City, was both excoriated and praised for the structural system of the buildings, a system unique in its time and unusual even today. On the one hand, he was praised for how they withstood the crash long enough for most occupants to escape. On the other hand, he was blamed for the pancake collapses that killed those who were unfortunate enough to be stuck in the buildings. In all of this, Robertson had to personally endure what few have ever had to endure – witnessing his life's masterwork collapse to the ground carrying more than 3,000 people to their deaths. It is an image that will remain forever engraved in his mind – as it is on all of ours.

After this catastrophe, who can now argue that structural design and building construction technology is of lesser importance than architecture on history and culture. Even the fleeting, but powerful, image of the collapsing towers, where their tops first tilted, then descended whole into the rising dust cloud, was shaped by the engineering design that was responsible for keeping them from collapsing immediately after the penetrating impacts of the passenger jets. They were constructed as hollow tubes, with only a central core and a perimeter walls of steel, rather than the more standard plan of an evenly spaced grid of columns. When the heat of the fires weakened the perimeter columns and the core, there was nothing to stop the progressive collapse of the pancaking floors between the core and the perimeter. Nothing other than the ground itself could arrest the fall of the multi-story upper part of each of the twin towers once the fires weakened the steel.

These buildings have passed into history while they were still young –wiped completely from the face of the earth except for a few select pieces stacked behind the science labs of the National Institute of Science and Technology in Washington, DC and whatever still remains at the ironically named "Fresh Kills"[1] landfill site on Staten Island. In addition, in the penumbra cast

[1] The name "kill" came from the Dutch word for a small stream.

from their collapse, the other buildings of the World Trade Center complex were destroyed from the fires from the burning debris crashing through them. One of them, Seven World Trade Center, became the world's first steel-frame high-rise building to collapse solely because of fire, when it collapsed about six hours after the Twin Towers came down. At almost 50 stories, it would have been the tallest building in all but a few American cities. Even though the other buildings in the complex remained standing, except squashed by the cascade of debris, their steel structures were twisted and warped well beyond repair by the uncontrolled fires that raged in them for hours.

90 West Street

Figure 2: An enshrouded and burned out 90 West Street after the collapse of the World Trade Towers opposite.

On one side of the World Trade Center complex stood a much older building that was also almost completely burned out. It was not just older; it was more than half a century older. At the time it was constructed, at 28 stories, it was one of the tallest buildings in the world of its day. (Figure 2)

Located at 90 West Street, it was designed by Cass Gilbert and completed in 1907. Gilbert was also the architect of the more well known 792 foot high, 50 story Woolworth Building nearby, which, after the demise of the World Trade Center's Twin Towers, again holds the distinction of being the tallest building in lower Manhattan – remarkable for a building completed in 1913!

A year after the collapse of the towers, the interior of 90 West Street is a burned out ruin. Almost every floor suffered extensive fire damage, and some became sufficiently hot to soften the steel columns. This building stands as evidence of how far the burning debris was catapulted into the surrounding area. However, unlike all of the other burned out buildings, not only did it not collapse, as did Seven World Trade Center, *its structural system was only slightly damaged.* That system, which consists of hollow clay tile and riveted steel, proved to be more durable and capable of avoiding the destructive warping of the steel joists and columns that occurred in the massive group of 1960's seven-story buildings that surrounded the towers.

Figure 3: Buckled riveted steel column, 90 West Street

Only a few columns were slightly buckled, (Figure 3) a testament to the fact that even though the fires were hot, the onset of collapse was arrested (most probably by the rivets) just as it had been for many similarly constructed high-rise buildings which were thoroughly burned out in the San Francisco Earthquake and Fire of 1906 almost a century earlier.

This building stands as a testament to the resilience of the now archaic structural and fireproofing system of the building's structure. It also stands as a remarkable present-day chance to study what happened in San Francisco to the cluster of early high-rise buildings that existed in that city when the great 1906 earthquake and fire ravaged the entire downtown area, destroying all in its path except the high-rise buildings of similar construction as 90 West Street. It is even more remarkable to take note of the fact that almost all of the buildings in San Francisco in 1906 of this type were repaired after they were both damaged in the earthquake and completely burned out. Most of these repaired turn-of-the-century buildings are still extant today, almost a century later. Few people today are even aware that when they stay in the luxurious stately Fairmont Hotel or the equally impressive St. Francis Hotel that they are in the restored interiors of what had been burned out hulks in 1906. (Figure 4)

Figure 4: Burned hulk of the St. Francis Hotel in 1906. This steel frame in this building came through the fire in almost perfect condition. (FROM: A.L.A.Himmelwright, CE, The San Francisco Earthquake and Fire, The Roebling Construction Company, NY, 1906, p175.)

The detailed reports on the performance of the burned-out San Francisco buildings show that their performance in the extremely hot fires, although far from perfect, was in many cases good enough to allow the buildings to be restored. In fact, it was the 1906 earthquake and fire that demonstrated some of the problems with hollow clay tile fireproofing, as it was knocked off of the steel framing by expanding steel plumbing pipes, or cracked by the earthquake, but the earlier steel structural systems of riveted steel members, rather than welded rolled wide flange beams and columns of today, proved to be remarkably stable even where the tile had fallen away. As a result, these badly damaged buildings could be repaired.

While it remains to be seen if the restoration of 90 West Street will be undertaken, the mere fact that it is possible provides an opportunity to study the technical attributes of the first phase of skyscraper design known as the Chicago Frame. It is this phase of building structural design that laid the groundwork for the evolution of building construction to what is now the almost universal use of frame construction for large buildings in all parts of the globe – a revolutionary transition in construction technology away from the masonry bearing wall that had dated back almost to the beginning of historic time.

Hagia Sophia

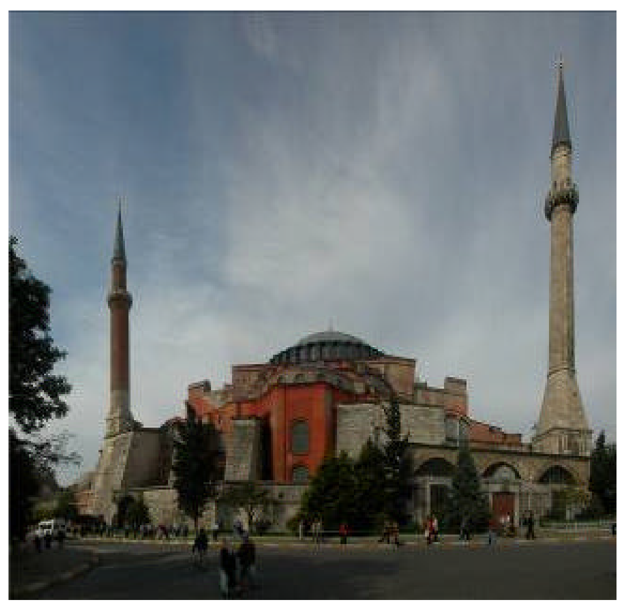

Figure 5: Exterior of the eastern side of Hagia Sophia. This view shows the many large buttresses added over the centuries to support the original church. (To be able to illustrate this view in a single image, two wide-angle photographs have been joined together.)

Historically, it was much more rare for buildings to be completely removed than it is today. This is true even for heavily damaged buildings. Hagia Sophia, constructed in the 6th Century, has lasted 40 times the life span of the World Trade Center towers, yet an earthquake collapsed part of the dome in 557. In the rebuilding process, the shape of the dome was changed, making it more stable, and the great buttresses were built, wiping out the original Justinian period exterior design with its late classical portico. (Figure 5)

After centuries of earthquakes and differential settlement, the former church has now taken on an almost organic character. What we see today as the historical monument is radically different than what was designed and first constructed back in the 6th Century, yet few would propose that it be reconstructed to that original appearance. To do so would mean that the building would no longer be old, and thus no longer a genuine relic of history. It is not just the patina from the effects of time that settles onto the materials that contributes to the organic, ever changing, yet timeless quality of this landmark, it is also the massive added buttresses and the shape of the reconstructed dome that are now just as important in the building's history as they are responsible for its continued survival. Structural analysis and rehabilitation is a continuous process. Work is being carried out today to restore the interior, but, thankfully, any urge to augment or replace the bearing masonry structure of this building with reinforced concrete, as has been done in many other historic buildings, has been overcome by the overwhelming scale and weight of the building itself.

Examining such histories is also a way of understanding the field of historic preservation. The field has gone through many changes over the past two centuries. While in Great Britain and Europe, the 19th Century was characterized by the restoration of ruins into artistic, but sometimes fanciful, recreations of what had been thought to have once existed, the 20th Century has been marked by the growth of a separate professional discipline of conservation practice that has placed an emphasis on the protection of the surviving parts of historic structures, rather than their reconstruction to an earlier date. This shift is straightforward in those familiar cases involving ancient masonry monuments and ruins, where the structural system is one and the same as the architectural finish. Where philosophical conflicts tend to arise is with those buildings, particularly of the 19th and the 20th centuries, where the elements of the structural system are largely hidden underneath the architectural finishes and do not in themselves determine the shape of the architectural detailing.

This presents a conservation dilemma, particularly in earthquake areas, where structural issues are involved in the rehabilitation. *Is the historical integrity of the building dependent on the integrity of a given building's structural system? Is it the duty of a conservator to consider the structural systems of a building when a conservation plan is developed?* Even more basic is this question: *what is the cultural value of the structural system of an historic structure – and what is its contribution to the cultural value of the building as a whole?* These questions could also apply to other technological aspects of a building such as heating, and ventilation, but the issue of the structural system should be considered to be in a special category, as it provides the armature on which the visual identity of the building as an artifact is dependent.

Apart from the relationship between the structure and the architecture, the history of structures has its own trajectory, sometimes independent of architectural history per-se. Sometimes a building of only modest note in terms of architectural history may hold a pivotal position in structural history or the evolution of building construction technology.

It has often been particularly challenging to focus conservation efforts on the technology of structures and construction when, as is often the case, the surviving artifacts of this history are hidden, only to be revealed, and thus discovered, when work is undertaken. In addition, building technology has gone through such a radical change over the course of the last 150 years that, when confronted with conservation questions, there are few people available either to recognize cultural and historical value in archaic systems, much less be able to properly assess them and come up with methodologies for preservation and interpretation. In addition, there are often stringent codes requirements that stipulate radical restructuring work in older buildings when major remodeling or rehabilitation is carried out. Usually, these codes have been written without any recognition of the kinds of archaic building systems that are being affected by the rehabilitation work, and thus they are blind to any recognition of inherent historical or cultural qualities that may exist in such systems.

The collision between integrity of original fabric and current engineering and construction methods has become most apparent around the issue of earthquake safety. Earthquakes affect both historic and modern buildings. In seismically active parts of the world, the demand to reduce the potential for catastrophic damage from earthquakes has advanced the cause of mitigation through both the strengthening of existing buildings and the improvement of the codes for new construction. The need is overwhelming, and it is unlikely that the vulnerable areas of the world will ever be able to address all of the risks before future earthquakes. An important building conservation question thus is: *do we strengthen historic structures at risk of earthquake damage, and, if so, how is the destruction of the structural integrity of the given historic building to be avoided? Is it better to preserve a building untouched when it may be heavily damaged or destroyed in an earthquake, or strengthen it even at* *the cost of a loss of its integrity? If strengthened, then how is its integrity to be preserved when current codes often preclude the use of archaic practices in new work on existing buildings?* Under such circumstances, it may be best to leave the structure alone to take its chances, because at least then it will be preserved for as long as possible – *or is this position irresponsible, because of the risk to its inhabitants?*

Many projects in the United States and Europe involving the seismic strengthening of an historic structure have suffered from a separation of the architectural conservation from the structural strengthening. While the highest grade of ancient monuments have usually benefited from an integrated consideration of all of these issues, the buildings of lesser symbolic importance, which are nonetheless of great value in defining the architecture and culture of cities and regions, have frequently suffered from major structural upgrading carried out without regard for the heritage value of the original structural systems. Sometimes this has even consisted of the complete internal demolition or "gutting" of a given structure, and its reconstruction in an entirely different system. Indeed, it has not just been wartime damage that has lead to the reconstruction of historic masonry and timber structures into reinforced concrete, preserving only the exterior masonry. This practice has been widespread throughout Europe even for the remodeling of structures that are still sound. It has been done most frequently in both Europe and North America when buildings have gone through a change of use that triggers an upgrade to current codes. In the United States, notable examples of this practice include even such well known historic structures as the White House in Washington DC in the 1950's and the California State Capital in Sacramento in the 1980's.

University of California, Berkeley's South Hall

One example that particularly brought this issue to light was the seismic upgrading of the oldest building on the University of California, Berkeley campus, South Hall, in the 1980s. South Hall was constructed of brick and iron in 1873, having been designed by Architect David Farquharson.[2] In the mid 1980's, the University of California, Berkeley, embarked on a seismic retrofit program. South Hall, a handsome High Victorian unreinforced brick building with a Mansard roof was first on the list because it had been deemed to be of a high hazard. The engineers who undertook the study were unaware that the building had been constructed with its own original system of reinforcement of the masonry specifically designed to resist earthquake damage. At the time it was constructed in 1873, it was already known that the Bay Area was subject to frequent tremors, and large earthquakes had caused extensive damage in 1865 and in 1868.

After examining this building when it was torn apart for a modern-day seismic retrofit, it was impressive to see what measures that the stewards of the fledgling university went to in order to protect the first building on the campus in what was yet still a part of the "Wild West." Unfortunately, this unique chance for research was only briefly available for a small number of people, as this remarkable structural system was largely destroyed and sealed behind an impermeable wall of concrete without being documented.

Figure 6A: Bond iron inside the brick exterior wall of South Hall exposed during construction work.

When the walls were opened up to install reinforced concrete pilasters before the new reinforced shotcrete wall was sprayed over the surface of the historic masonry, it was discovered "bond iron" – a system of wrought iron bars that tied the building together above and below the windows on every level – was imbedded in the brick masonry. (Figure 6A) In addition, the beams and joists were anchored to the walls with iron ties that were imbedded into the walls so that they would be hidden on the exterior. (Figure 6B)

Figure 6B: Dog anchors in South Hall walls exposed by construction work.

[2] Stephen Tobriner, *South Hall and Seismic Safety at the University of California in 1870*, Chronicle of the University of California, Spring 1998.

Huge story-high ornamental cast iron plates that were attached to the corners of the building should have provided a clue to what was inside. (Figure 6C) The large bosses on these plates proved to be the nuts that held the ends of the bond iron straps that ran from corner to corner through the length of every wall. Ironically, there was historical evidence in the University's own records of the existence of this reinforcing, but historical research was not included as part of the design phase of the project and thus this remarkable historic anti-seismic structural system was revealed only so that it could be destroyed in order to construct a modern-day version of the same thing.

Figure 6C: Exterior of South Hall showing large ornamental cast iron corner bracket. The bond iron in the brick walls terminates at the large bosses.

The tragedy of this project is that, once discovered, nothing was done either to (1) adapt the modern retrofit project to either preserve or to take advantage of the original system, or (2) accurately document it for the historical record of a nineteenth century earthquake resistant building technology. In the process of installing the new system, the iron rods were all cut and destroyed. The brick structure was encased in a tomb of concrete shotcrete, a material that is impossible to remove or replace. The destruction of this record of historic technology is thus a loss of an important historical engineering artifact. (Figure 7)

Figure 7: Interior walls of South Hall being covered by steel and shotcrete.

Would the original system have performed well in an earthquake? While it is impossible to say for sure, we do know that the building survived the 1906 earthquake. However, Berkeley was not so severely affected as San Francisco and the University's concern has to do with the nearby Hayward Fault. It is known from the performance of other buildings that joist anchors significantly improve the performance of unreinforced masonry buildings compared to those without them, and, in addition to joist anchors, South Hall has bond-iron laid directly into each wall. The best local example of the performance of bond iron subjected to the full brunt of a great earthquake is San Francisco's original Palace Hotel. When constructed in 1873, the 6 story block-sized building was reported to be the largest hotel in the country. In 1906, reports of its condition before the fire consumed it were that the earthquake itself did not damage it. In fact, even after the fire, which raged out of control in the city that lacked the means to fight it, consumed all of the wooden parts of the building, the brick walls remained standing to their entire eight story height, topped even by the chimneys, still in place despite both the great earthquake and raging blaze.

The South Hall retrofit project presents an existential problem. *Has the cultural value of the building been* *forever compromised by the destruction of its interior and imbedded structural elements? What about the large cast iron ornamental plates on the corners that remain in place? Now that they have been reduced to only an ornamental purpose, are they diminished in significance?*

These cultural heritage questions are not the only critical questions. *What about the life safety issues that spawned the project in the first place? Has the real or perceived risk that had been identified by the structural engineers for what was thought to be an unreinforced masonry building justified the destruction? Or, by contrast, has the destruction of the older system actually made the building riskier now than before, or at least little better for the effort?*

The conflict between earthquake safety and historic preservation is a difficult one to mediate, as both issues are relative. There is neither an absolutely correct level of earthquake safety, nor a single immutable definition of cultural significance. Both concepts shift over time. While earthquake safety may seem to the public to be related to how closely a building meets code, this is not always the case. As can be seen from South Hall and the buildings in San Francisco that survived the 1906 earthquake and fire, as well as 90 West Street, earlier technologies of construction were sometimes at least as good – and sometimes better – than modern construction, regardless of the prevailing codes. Thus buildings constructed to an earlier pre-code technology may suffer more from the perception of risk than from the particular risk itself.

This is an important problem, and it must be understood on a number of levels if conservation is to be achieved for examples of early structural design and construction. The problem is not the codes themselves, as most codes provide for alternative means of meeting the intent of the code provisions. The problem is that any alternative to the letter of the code requires more analytical work, and more work justifying and defending the existing structure, all of which requires specialized training and experience. With all of the ambiguities that exist, few people are willing to take on this endeavor, even if they have some knowledge of the archaic technologies. Thus the historic structures suffer radical and costly changes as a result of the effort to make them more easily confirm to the present day's structural design and construction technology conventions. The tragedy is that this can often reveal a level of arrogance that blocks out any possibility of learning from what was done in the past – and of gaining insights into contemporary design that may actually improve the way buildings are constructed now and in the future. The issue thus goes beyond that of losing examples of what was competently created in the past. Part of the knowledge-base on which creative design in the future depends is destroyed.

To illustrate this point, one only has to turn to the continuing debate surrounding the constituents in masonry mortar. Today building codes require extremely strong, cement-rich mortars in new construction. This common practice now sits alongside the now well-accepted conservation practice that weaker, more lime rich mortars perform better than the use of cement. Yet this acquired knowledge stands in contrast to standard modern building practice, despite the often-rapid deterioration and prevalence of leaks found in modern masonry cladding. In addition, modern designs have had to incorporate frequent short-lived and disfiguring putty joints into masonry walls – reducing what is meant to look like solid masonry to the appearance of tile or wallpaper. Putty joints did not exist in masonry in the nineteenth century or earlier.

In the end, a study of the structure and construction of older buildings can teach us the importance of what Cass Gilbert posted on his office wall – humility. Just when one is convinced that what we do now must be better than anything that preceded us, we often discover that our predecessors have been there before – and we discover that, with fewer materials at their disposal, they sometimes were able to build structures of remarkable durability. The thousands of pancake-collapsed buildings in recent earthquakes lying next to ancient monuments and older vernacular buildings – all still standing – should provide reason enough to look more carefully and respectfully at the archaic structural systems that underlies their architectural finishes. It should also motivate us to insist on conserving these structural systems as an integral part of the historic buildings that we try so hard to save for our children.

Randolph Langenbach, Disaster Recovery Analyst for the Federal Emergency Management Agency (FEMA), is a recipient of a 2002-2003 Rome Prize in Historic Preservation. He began his research on the structural issues in the preservation of historic masonry buildings in earthquake areas when he migrated to California to teach at the University of California, Berkeley after many years documenting mill towns in New England, Great Britain and India. His work for FEMA has included work on the recovery effort in New York City after the World Trade Center tragedy. He received a Master of Architecture degree from the Harvard Graduate School of Design, and a Diploma in Britain at the Conservation from the Institute of Advanced Architectural Studies in York. His dissertation for the IAAS degree lead in 1978 to the creation of SAVE Britain's Heritage exhibition and catalogue *Satanic Mills, the Industrial Architecture of the Pennines*, for which he was co-author and photographer. This article, *The Integrity of* Structure, was first presented at the ICOMOS General Assembly in Madrid in December, 2002. More information can be found on the web at www.conservationtech.com.