Common Threads

Structural Issues in Historic Buildings

By Craig M. Bennett, Jr., P.E.

Charleston, South Carolina is blessed with historic structures. Eighteenth and nineteenth century houses, churches and civic buildings adorn every block. The city has interesting challenges for the structural engineer… the east coast's largest earthquake, hurricanes, city-wide fires and poor soils have put buildings and their designers to the test.

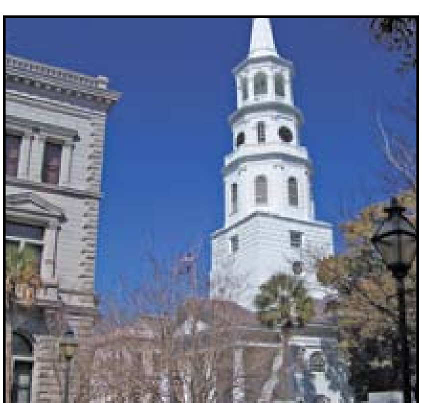
Because the primary structural materials found here, soil, masonry, timber and iron, are the same as those used everywhere over the last three centuries, structural issues common to buildings in Charleston are found in historic buildings all over the nation. Buildings move due to consolidation of soils; masonry cracks; lime leaches out of mortar; timber creeps under stress and rots when faced with water intrusion and iron corrodes. The only threat not severe here is a regular freeze-thaw cycle.

A look at a few of these historic structures and a comparison of their behavior with that of other buildings found around the southeast will show the similarities in the issues the preservation engineer faces.

1751 - St. Michael's Episcopal Church, Charleston, South Carolina

Construction on the brick masonry for St. Michael's was started in 1751. The spire was topped out at about 175 feet in 1764 and a ring of eight bells, cast by a predecessor of the Whitechapel Bell Foundry in London, was installed for full-circle English change ringing. Time took its toll on the running gear for the bells, and there are no records that they were rung full circle after about 1813. After the Civil War, they were recast, again in the same foundry, but were not properly installed locally. Finally, in 1992, we, with architect Dan Beaman, sent the bells back to Whitechapel yet again for maintenance and reinstalled them in 1993 for full circle change ringing.

The lateral loads caused by swinging bells were more critical in 1993 than they had been in the 1764 installation. In the earthquake of 1886, the steeple had settled several inches and had been severely fractured. After 1989's Hurricane Hugo, we had had to straighten the top 50 feet, the timber spire. We were also aware that we had potential lateral loads of up to 20,000 lbs imposed on the tower with every swing of the bells. Although concerned about mixing old and new materials, we took a lesson from the English preservation engineers and tied the tower together with an internal reinforced concrete ring beam at the level of the bell frame. Today the eight bells, the largest of which weighs almost a ton, and their eight human ringers, announce services on Sunday morning, and ring for weddings, Independence Day and June 28, Carolina Day, commemorating the first decisive victory of the American Revolution. Most gratifying is that the local ringers are regularly joined in the celebration with ringers from the United Kingdom.



St. Michael's Church, Charleston, SC - 1751.

1763 - Pompion Hill Chapel, Huger, South Carolina

Between 1998 and 2002, a drought left the expansive clays under Pompion Hill Chapel unusually dry. Differential settlement, perhaps exacerbated by several campaigns of foundation repairs, caused severe cracking of the plaster and some masonry damage in this stunning structure. To make matters worse, several roof trusses, supported on severely overstressed extended top chords over a coved ceiling, had failed, transferring their loads into the roof sheathing, then into the end walls, by diaphragm action.

Pompion Hill Chapel, Huger, SC - 1763

Replacement of the failed trusses in kind would have been appropriate from a preservation standpoint, but exact replacement timber members would have, in time, failed under load like the original. Fortunately, there was room between the roof framing and the structure of the coved ceiling for contractor Tommy Graham to install deep timber sister members on each side of each truss, carrying the bending moment at the top chord extensions and preserving the original construction for future generations.

Because ground modification would have been far more expensive than the church could have afforded, on the recommendation of geotechnical engineer Jim Hussin of Hayward Baker, it was elected to try an underground irrigation system as a means of keeping the soils beneath the walls moist. Time will tell whether or not this approach will work long term, but initial monitoring of 46 survey bolts hidden around the perimeter of the building shows a slow movement upward of the portions of the structure which had settled the most.

1814 – The Cathedral Church of St. Luke and St. Paul, Charleston, South Carolina

In the late summer of 2001, a church member at the Cathedral Church of St. Luke and St. Paul noticed that one of the timber columns in the balcony appeared to have pushed its way into a hollow millwork box supporting it, damaging the plinth block and torus at the column base. Investigation revealed that, over time, there had been a total of 12 inches of differential settlement under the tower, and that there was a five inch differential settlement between the exterior walls of the church and the balcony columns only 12 feet away. The roof trusses had transferred their loads from the outside walls to the interior columns, pushing them through the hollow boxes. Only the lateral support of the balcony rail had kept the columns from falling and dropping a 38,000 lb plaster vault 44 feet into the nave of the church.

Cathedral Church of St. Luke and St. Paul, Charleston, SC - 1814.

While there is little doubt that the six timber roof trusses originally spanned the 61 feet from exterior wall to exterior wall, analysis showed that they did it with stresses of around 3000 psi, much higher than the 1200 psi which we might use in design today. High stresses and load redistribution had taken their toll on the trusses, and strengthening was necessary before putting the truss loads back on the outside walls. Unfortunately, the cost of improving the foundations or the soils under the church was prohibitive. But dealing with the secondary effects was not entirely unreasonable. Work now underway with Palmetto Craftsmen has, like Pompion Hill, sistered the trusses to preserve original historic fabric and taken the loads off of the balcony columns. But just in case the walls move several more inches and drop the trusses onto the balcony columns again, the balcony column load path has been strengthened to provide the appropriate redundant load path.

1826 – The Fireproof Building, Charleston, South Carolina

Robert Mills' Fireproof Building was built as a government record storage building and continues to be used for archival storage, now for the South Carolina Historical Society. Mills had designed the building with masonry walls and floors, supported on masonry vaults. Unfortunately, installation of modern tall storage shelves and the removal of a wall in the basement had caused extraordinary thrusts in several masonry vaults, resulting in a small bulge in an exterior wall on the west side and some exterior wall cracking.

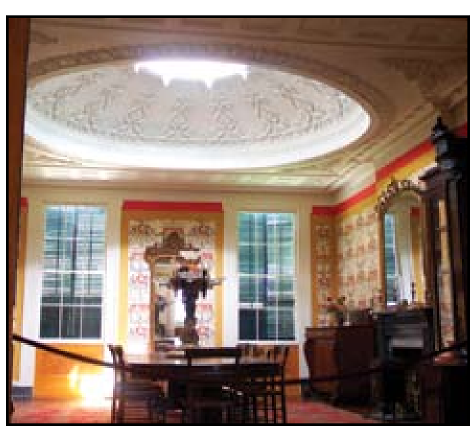
The Fireproof Building, Charleston, SC - 1826.

Any sort of structural intervention in a building of this age must be undertaken very carefully, and only after considerable study. Rather than undertake any remedial construction work, we recommended relocating the heaviest loads to rooms whose walls could handle the thrusts and recommended keeping offices in the rooms with less masonry to resist the thrust of the vaults. Sometimes the best structural intervention involves no construction at all!

1843 - Gaineswood, Demopolis, Alabama

Lest one think that all old buildings are masonry, we should mention one of the more unusual historic structures. Gaineswood is an absolutely beautiful Greek Revival plantation house, built between 1843 and 1861 in Demopolis, Alabama. Carefully designed to give the appearance of being a masonry building, it is actually a wood framed structure, finished in stucco on the outside and plaster on the inside.

Creep in the very highly stressed pine ceiling joists which support two 13-foot diameter plaster domes had allowed one dome to drop about three inches, and the other to drop five. Two previous efforts to reinforce the joists had been largely unsuccessful. By installing small timber and steel rod trusses over the domes and lifting them very slightly (about an inch, each) with threaded rods placed around the dome perimeters, it was possible to take the load off of the existing structure to arrest further creep and allow repair of the fractured plaster. Fortunately, it did not require removing either the original structural system or the two attempted repairs.



One of the twin domes at Gaineswood, this one over the dining room.

1846 - Grace Episcopal Church, Charleston, South Carolina

Grace Church was only 40 years old when the earthquake of 1886 nearly destroyed it. The two legs of the tower closest to the nave sank about eight inches, severely damaging the attached clerestory walls and breaking the tie rod which spanned the grand arch between those legs. Courageous repairs undertaken immediately afterward included rebuilding the grand arch, installation of inverted arches under two of the tower legs and extensive repairs to the clerestory walls.

The tower arch at Grace continues to spread and the members bracing the clerestory walls are moving.

The iron rods installed after the earthquake are now corroded; the fractures in the masonry open and close with temperature and humidity, but trend towards opening; and the tower continues to settle, with an easily noticed lean toward the nave. Work now starting will tie the walls of the tower together with embedded stainless steel rods. Once the tower is stabilized, the options are to either improve the soils under the tower or underpin it with micropiles. The process will be guided with a non-linear structural model that accounts for the largest of the existing cracks and, most importantly, for the inability of the masonry to carry any significant tension stress.

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1906 - St. Luke's Episcopal Church, Atlanta, Georgia

It seems that many 20th century designers had lost track of the need for stiff buttressing to resist the thrust of large arches. The chancel arch of St. Luke's is a good example. Even a simple linear elastic finite element analysis shows the problems with the behavior of the arch, a reality made more apparent by a large crack found during the 1998-2000 renovation. Deep flat plates on each face of the wall over the arch successfully tied the buttresses together. Interestingly enough, the church warden chose to have us leave the interior plate slightly exposed. The plate was left flush with the plaster, with exposed bolt heads, "so that the members of the church could see where at least a little of their money went."

The chancel arch at St. Luke's Church, Atlanta, GA - 1906.

1907 - Washington National Cathedral, Washington, District of Columbia

Robert Mark, Joe Alonso and John Runkle (engineer, stone mason and conservator, respectively) of The Cathedral Church of St. Peter and St. Paul have been kind enough to share some of their expertise, and permit the author the pleasure of comparing some of the structural problems seen in several Gothic churches around the southeast with those seen in the Cathedral. Unfortunately, not even this most well known of American cathedrals is immune to structural issues.

The Cathedral was designed just after the turn of the century by architects George Frederick Bodley and Henry Vaughan. According to Robert Mark, in the 1920s, Philip Frohman enlarged the design for the two towers on the west face considerably, but did not do the same with the tower foundations. So one finds today in the Cathedral the same issues that one finds in many other Gothic churches… settlement of both west towers and of the crossing tower. This movement of the tall portions of the building relative to the lighter clerestory walls of the nave has caused cracking in the walls and vaults. Structural distress, like that in many masonry buildings with tall elements, shows up invariably in the last bays of the nave walls, adjoining the towers.

Looking back, we see that some structural issues are common to several of these buildings. Support settlement seems to take a heavier toll than almost any other cause of distress. Creep in overstressed timber and masonry, tension cracks in masonry, and damage to all materials due to water intrusion follow closely behind.

Back at National Cathedral, Mark, Alonso and Runkle continue to monitor movement, and, when appropriate, deal with any structural distress. These stewards of the great Cathedral confront the same issues we do in other churches, and, like we, are entrusted with making sure that our grandchildren's grandchildren can enjoy these historic structures the same way we do today.▪

Washington National Cathedral, Washington, DC - 1907.

Craig M. Bennett Jr., P. E., is a structural engineer and a founding principal of 4SE, Inc. in Charleston, South Carolina. His own work focuses exclusively on existing buildings. Bennett considers it a tremendous privilege to work on historic structures. Four of the first five buildings mentioned in this article are National Historic Landmarks. Future articles will explore some of these projects in more depth. Bennett can be reached via e-mail at ***CBennett@4SEinc.com****.*