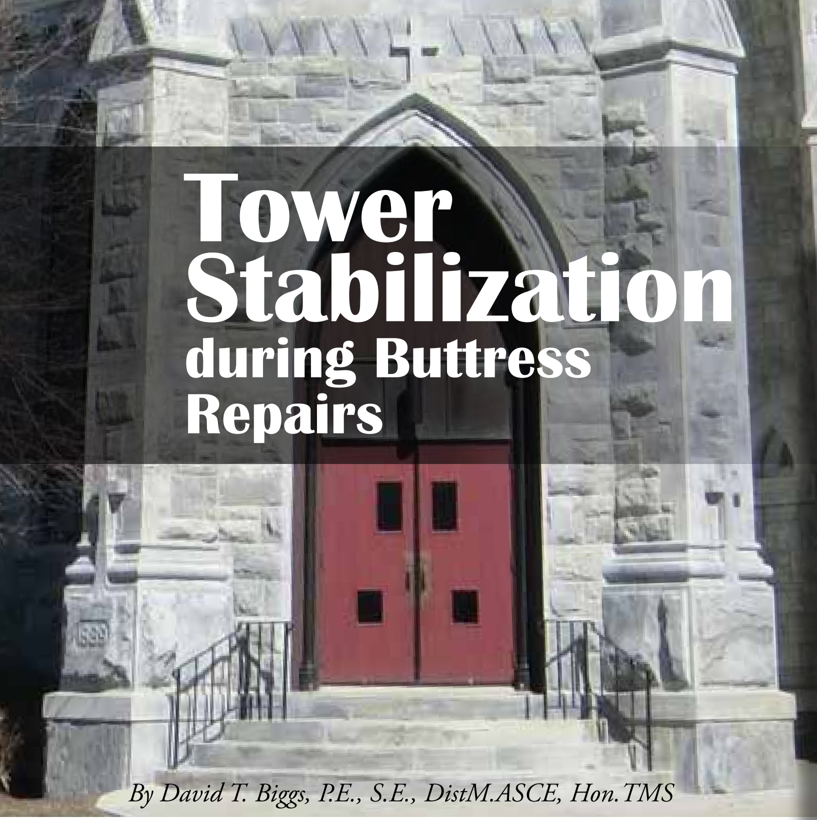

Tower Stabilization during Buttress Repairs

By David T. Biggs, P.E., S.E., DistM.ASCE, Hon.TMS

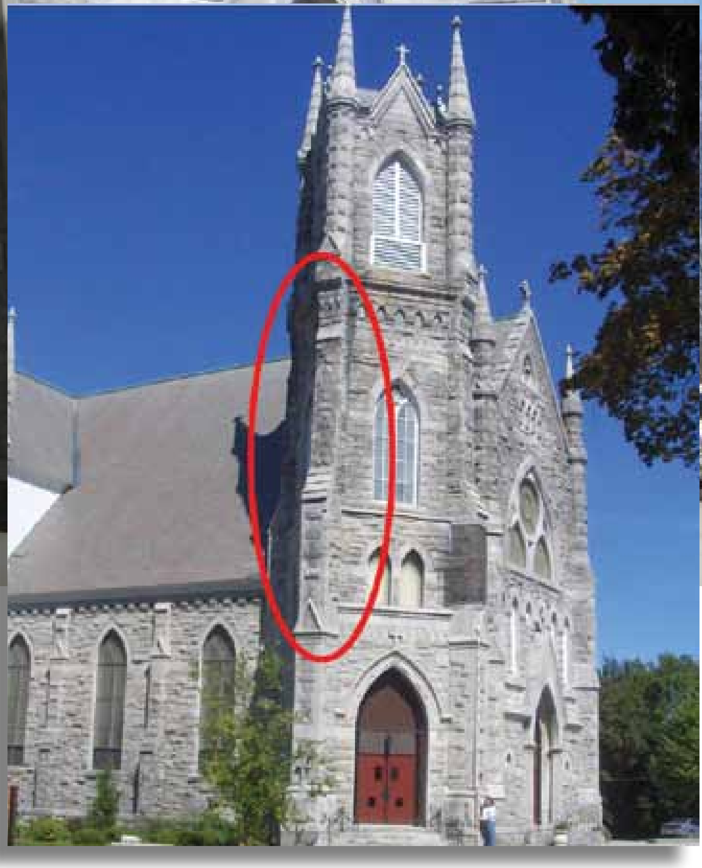

Figure 1: 1892 Church – Vermont, USA.

Masonry towers are the focal point of numerous historic buildings and monuments. They grace most religious structures and many significant civil works. These towers present numerous difficulties for engineers and architects to define the nature of their problems and develop necessary repair interventions. Among the most challenging concerns is structural deterioration of the buttresses and walls. Depending upon where it occurs over the height of the tower, such deterioration produces a weakness that can cause local or global instability of the tower, requiring strengthening as a possible intervention. This can vary, from repointing with supplemental reinforcement to in-situ injection with transversal pinning to partial removal and reconstruction.

Structural problems with towers can affect either the local or global stability of the tower during restoration and strengthening. Caution must be taken on any invasive intervention to avoid further instability of the tower during implementation of the repairs.

Problems

A church in Vermont with an 80-foot-tall tower (*Figure 1*) was completed in 1892. The walls are multi-leaf brick and the exterior is faced with limestone that is 6 to 8 inches thick. The corner buttresses have a core of rubble stone. Based upon visual observations, water was saturating the buttresses and deteriorating the exterior mortar. Random cracks were noted in the mortar joints and several stones were displaced outward from the buttresses.

Investigations indicated that the face stones of the buttresses were not well connected to the core. While the walls had header stones, there was an inadequate number of header stones to interlock the rubble core with the face stones of the buttresses. This was primarily evident over the mid-height of the buttresses. Both the upper and lower portions of the buttresses were in good condition; only the middle sections were deteriorated. See the oval on *Figure 1* that highlights the distressed area. All four buttresses were affected.

The lack of interlock of the face stones in combination with freeze-thaw action caused the exterior leaf stone to shift and crack the mortar joints. Removal of several stones further indicated that water infiltration

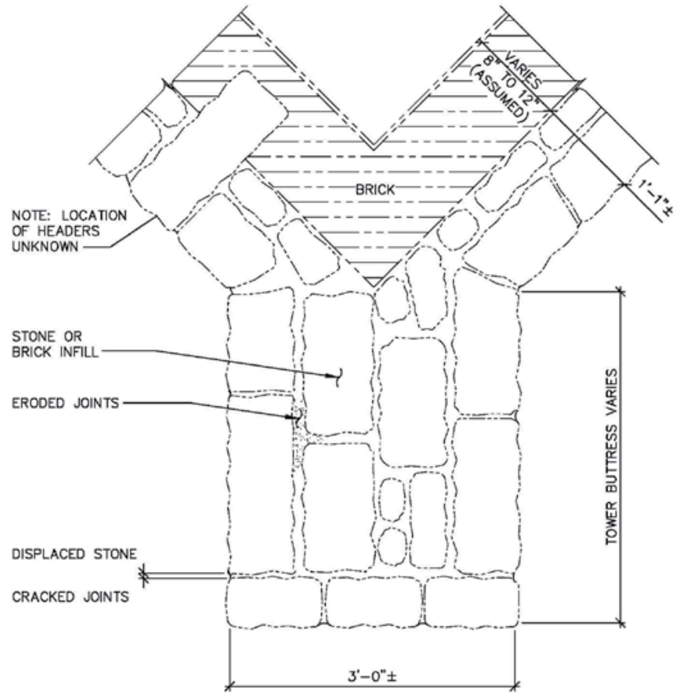

Figure 2: Existing buttress.

Figure 3: Tower with personnel-access scaffolding. Courtesy of Micahel Gnazzo.

Figure 4: Tower with proposed cable locations.

and freeze-thaw had deteriorated the binding mortar inside the buttresses. Voids had developed due to the erosion of the interior mortar in both the buttresses and random areas of the walls of the tower. The walls were approximately 22 inches thick; the buttresses were approximately 3 feet thick. *Figure 2* shows the section through one of the buttresses.

Restoration Repair

The intervention selected for the buttresses was to remove and rebuild them in the damaged areas, inject the voids in the adjacent walls and other buttresses, and pin the face stones of the walls at the injected areas. The buttress reconstruction included stainless steel anchors to bond the stones with the rebuilt masonry core. The reconstruction reused the existing stones.

Proportionate to the wall thickness of the tower, the buttresses occupy the majority of the wall corner. If the buttresses were all to be removed simultaneously, the reduced section area of the masonry would cause the stresses in the remaining stones to be excessive. In addition, the tower would be become unbalanced because the buttresses against the building would not be removed to the same degree as the outer buttresses. Since a stability analysis indicated that removing and rebuilding all four corners simultaneously would be detrimental, the work was sequenced to avoid excessive stresses and to maintain stability of the tower.

One option was to build a massive scaffolding structure to shore and underpin the removal area. The cost was deemed excessive and alternate methods were considered. After several analyses, the work was planned so that it could be performed on two buttresses at a time by removing opposing corners to balance the load on the tower. The scaffolding that was used was only needed for personnel access and to stage materials. It was not used for tower support (*Figure 3*).

Tower Stabilization during Buttress Reconstruction

The tower stabilization scheme was subdivided into both global and local actions. The global action was to wrap the upper portion of the tower with cables to resist overturning of the corners. In addition, the buttresses were removed two at a time, leaving the opposing corners intact. The local stabilization required that the stones immediately above the removal area be held in place to prevent movement.

Global Tower Stabilization

The goal of the stabilization procedure was to hold the top of the tower in place so that the buttress removal and reconstruction could occur without heavy shoring. The scheme utilized steel cables wrapped around the top of the tower. Figure 4 shows the tower before reconstruction, with the proposed cables located. The buttresses below the lower cable were to be removed and reconstructed down to above the main door entrance.

Figure 5 shows a graphic with the buttress removed below leaving the upper portion overhanging. *Figure 6* shows that the removals below would produce an eccentric load on the remaining

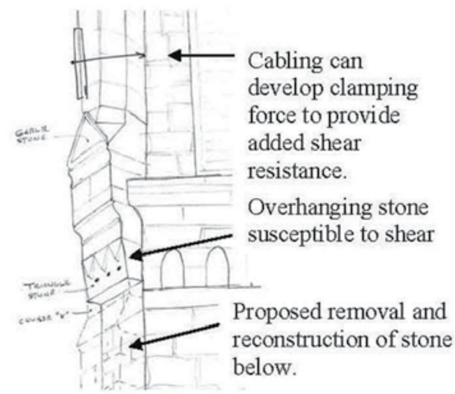

Figure 5: Overhang created by removals.

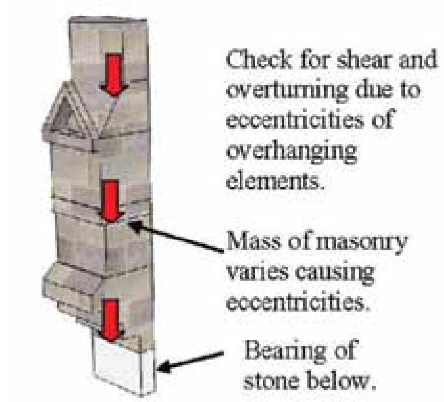

Figure 6: Upper stones produce eccentricity at overhang.

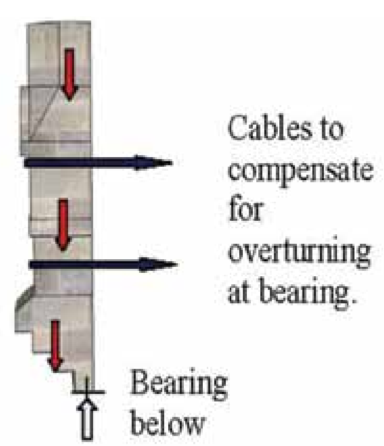

Figure 7: Overturning restraint with cables.

Figure 8: Corner protection for cable on stone.

Figure 9a: Pinning upper stones before lower buttress removal.

Figure 9b: Partial buttress removal below the the pinned stones in Figure 9a.

masonry. *Figure 7 (page 31)* shows that, with very little bearing area remaining below the corners due to the removals, cables were needed to overcome overturning and provide a clamping force that would increase the shear capacity of the upper masonry at the corners.

The two cables in *Figure 7* were wrapped around the tower and tightened. The corner stones that were clamped by the cables were protected from damage by crush plates made up of a piece of steel pipe with a wooden filler that is formed to the edge of the stones (*Figure 8*). Alignment tabs were welded to the pipe for the cables. The extra cable shown in the lower portion of the photograph is not stressed.

Local Stone Stabilization

Prior to actual buttress removal, the stone just above the area was reanchored using drilled-in pin anchors to provide localized support and stability. *Figure 9a* shows the stainless steel pins being installed. These 1-inch-diameter steel pins were drilled and adhesive anchored into the backing material. After the restoration was completed, the pins were subsequently cut below the face stone and a patching material was used to cover the hole.

Figure 9b shows the area below *Figue 9a* after the stones of the buttress below were removed. The pins from *Figure 9a* are shown by the arrow.

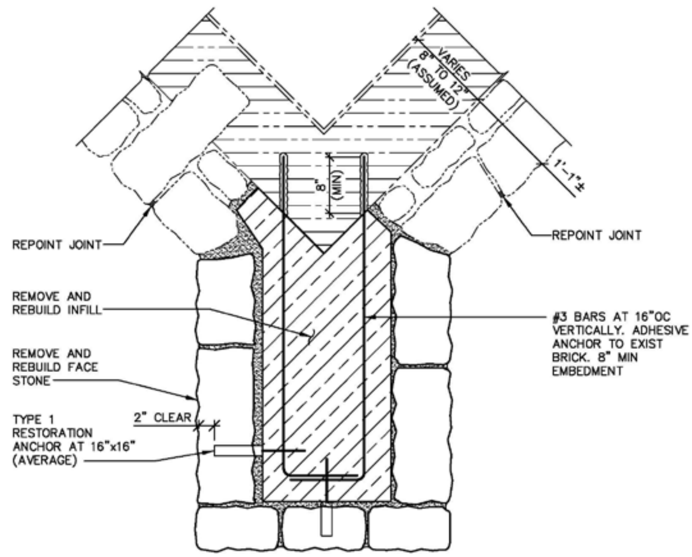

Figure 10: Detail of buttress reconstruction.

Buttress Reconstruction

Figure 10 shows graphically the reconstruction of the buttress. The core of the buttress was reconstructed and anchored to the brick backing wall using #3 reinforcing bars drilled and adhesive grouted 8 inches into the brick. The reinforcement was installed at 16 inches on center over the height of the buttress. Stainless steel ties were used to provide additional bonding of the face stones to the core of the buttresses by attaching them to the #3 bars (*Figure 11*).

Figure 11: Stainless steel anchors to bond face stones.

Conclusion

Restoration interventions take many forms. However, the contractor must implement the intervention while maintaining the structure in a stable condition. This article provides some problems observed and methods used to stabilize a church tower during the construction phase. The methods were developed in cooperation with the masonry contractor.▪

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