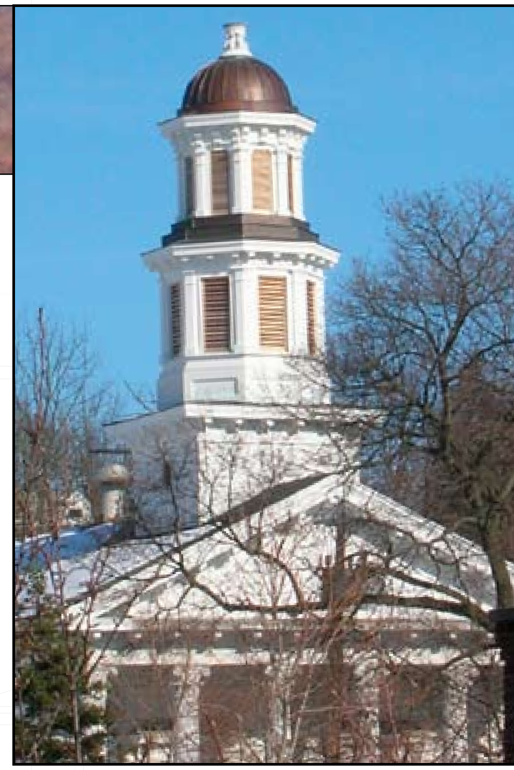
Repair of a Leaning Timber Steeple – Amen!

By Daniel Proper, P.E. and Melissa O'Leary, EIT



The Presbyterian Church of Catskill NY was constructed in the early 1840s. The building consists of a timber framed structure with a rubble foundation. In the early 1900s, the building was significantly modified with the addition of a 54-foot timber framed steeple and a Greek revival porch. Since that time, very little modifications have been performed on the church, beyond general maintenance (*Figure 1*).

As with a large number of similar small community churches, the combination of high cost of upkeep on the building and dwindling attendance resulted in the church selling the property and consolidating with adjacent congregations. In 2005, the church was purchased by private owners who took on the challenge of saving the historic structure for use as a residence and art studio.

Figure 1: Front façade of church, steeple surrounded with scaffolding.

The first task the new owner had to address was the failing timber steeple. The steeple was measured to be leaning out of plumb by approximately 12 inches over its 54 foot height, and was observed to swaying during storm events. In addition, the steeple had settled toward the east along its base by roughly 1¾ inches over its 12-foot span. The main concern facing the new owners was the possible failure of the steeple, and associated damage to the main structure and adjacent properties.

The new owner contracted with Crawford & Associates Engineering, PC, to assess the steeple's current condition and develop stabilization plans for immediate implementation.

Field Assessment and Analysis

The first engineering task involved documenting the structural configuration of the steeple and its supporting members, starting from the top and following the load path down to the foundation. Access to the steeple was obtained from exterior scaffolding, which was erected to aid in the inspection process as well as allow repair and replacement of the exterior decorative trim (*Figure 2*).

The steeple is supported at the attic level by transverse beams that direct the load to adjacent timber gable trusses. The trusses, in turn, carry the load to exterior and interior timber columns that are directly tied to the foundation system.

The base of the steeple, which rests on the transverse beams in the attic, consists of eight 10-inch square timber columns that stop near the gable roof line. At the roof line, the steeple is composed of eight 8-inch square timber columns that span to the under side of the domed roof, approximately 35 feet. The 8-inch columns are braced at 3 points along their height with compression rings consisting of 4x8 timber cross beams.

To assess the timber framing, each member was fully inspected using both destructive and nondestructive methods. The inspection started with a visual review of each member for signs of water infiltration, fungi decay, splitting, warping, and mechanical distress. Areas of concern were further assessed using sounding and probing test methods.

With the use of micro analysis, provided by the US Department of Agriculture – Forest Laboratory, the wood species of the column members was determined to be eastern hemlock. The wood species of the base transverse beams and supporting gable trusses were determined to be eastern white oak. With the wood species known, conservative values of the timber's physical properties were estimated based on past historical documents and current American Forest & Paper Association NDS stress tables.

Once the configuration and general material properties of the steeple were compiled, finite element models were generated to review stress development under general service and combined loading conditions. The software package employed was *Visual Analysis – Advanced*. The software allowed the timber members to be analyzed for full cross-sectional stresses and overall assemblage deflection. The finite element models were also used to analyze and size the various repair options investigated.

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Figure 2: View of steeple framing looking up from level 3, prior to reinforcement.

Figure 3: New transverse steel channels bearing on bottom chord of gable trusses, and sandwiching the bottom support columns of the steeple, final bolting not installed.

Findings from Assessment

The inspection revealed that the sway and settlement of the steeple was due to a variety of factors. The interior foundation support posts were observed to consist of cedar logs resting on inadequate rubble footing. The transverse beams at the attic level had begun to sag due to long term creep loading and cross-sectional reduction at the mortise and tendon joints.

At the time of the inspection, the lateral force resistance system for the steeple had been severely weakened. The lateral bracing for the lower third of the steeple consisted of 3-inch x 6-inch timber cross members. The lateral resistance for the upper two-thirds involved the cantilever action of the 8-inch square columns, in combination with the rotation rigidity of the mortise and tendon connections.

The lower cross-bracing members were attached to the vertical columns with metal spikes. The majority of the cross-bracing members were observed to have splits and/or fungi decay at or near the spike locations. The majority of the mortise and tendon connections of the upper columns had weakened due to shrinkage and extensive cyclic loading, and were not providing real resistance against lateral movement of the steeple.

Structural analysis determined that the adjacent gable trusses and underlying support structure had sufficient strength to handle the lateral and gravity loads imposed by the steeple. Hence, the general goal was to establish a defined lateral force resistance system within the steeple that would carry the load to the adjacent trusses. In addition, reinforcing would be needed to repair the deficient vertical support elements in the basement and attic level.

Repair Methods Utilized

The existing cedar posts in the basement were replaced with steel HSS columns. The rubble footings were removed and new cast-in-place concrete footings installed. The new columns and footings were installed with the use of temporary jacking to create an active load path.

The sagging transverse beams at the attic level were abandoned in place and circumvented with steel channels, C8x18.75. The channels ran perpendicular to the main gable trusses in sets of two and bore on the bottom chord of the trusses. The channels, in turn, sandwiched the timber base columns of the steeple and were connected using thru bolts. To allow for adequate clearance, HSS stub columns were used to properly position the channels on top of the bottom chord (*Figure 3*).

Lateral reinforcement options investigated for the steeple consisted of improving the deteriorated connection points with steel plates and installing new lateral resistant support elements. Specific methods reviewed included shear paneling, cable cross-bracing, tension rod cross-bracing, and installation of knee bends/rigid connections.

Per the analysis, the wood shear paneling could not develop sufficient strength necessary to handle the wind and seismic loading conditions. The knee bracing option induced disproportionate flexure stress on the existing timber members, requiring excessive strengthening. The cable and tension rod cross bracing options were very similar in layout, and took advantage of the good condition of main timber columns. In the end, tension rod cross bracing was selected over cables due to cost, flexibility of installation, and the ability to easily adjust in the future with the use of turnbuckles. Furthermore, the cross bracing option allowed the louvers to be operable, which was an important requirement for the owner.

The cross bracing extended from the roof level down to attic level. At the attic level, the tension rods were attached to the new transverse

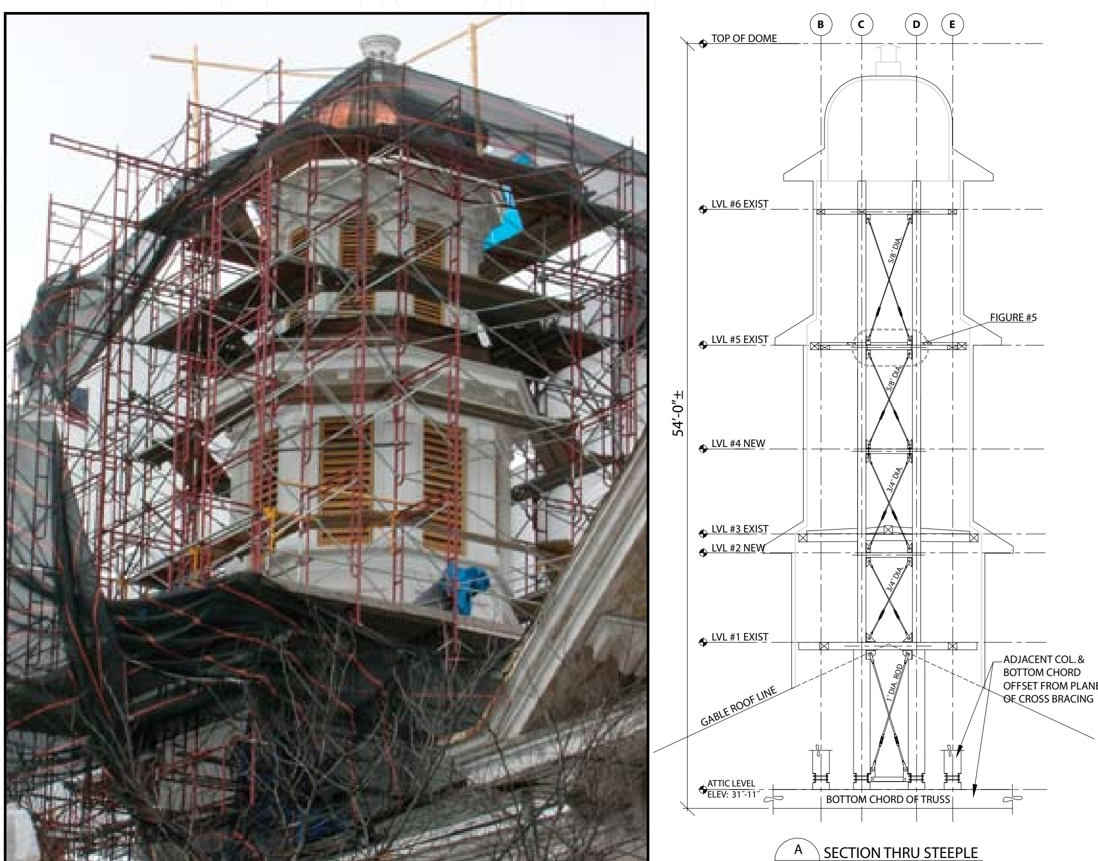

Figure 4: Section view thru centerline of steeple showing tension rod cross bracing, which was installed on four sides of steeple.

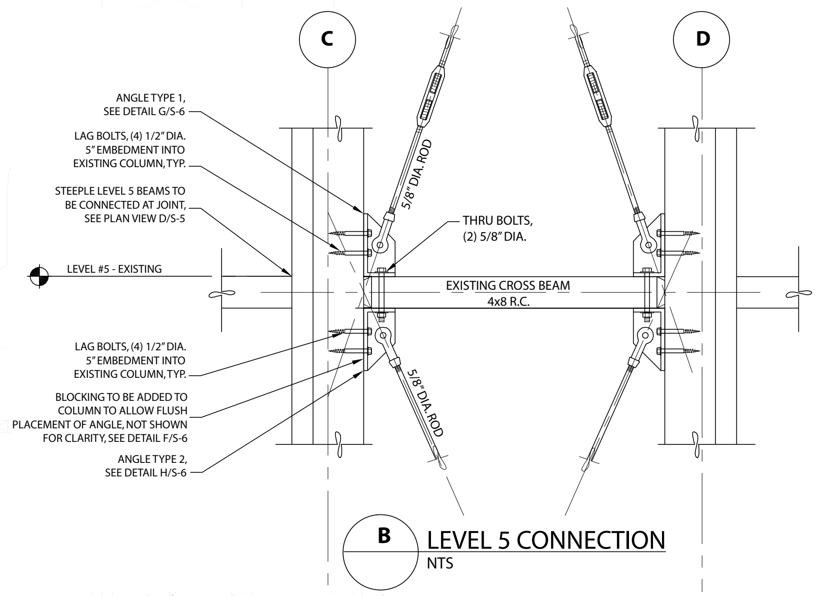

Figure 5: Detail of typical connection reinforcement at compression ring.

steel channels. The load, in turn, was then directed to the existing main timber roof trusses and interior support columns.

The bracing pattern was broken up into 5 panels of varying height (*Figure 4*). The nodal points coincided with the existing timber compression rings, consisting of 4-inch x 8-inch cross beams. However, two additional rings were added to reduce the slenderness ratio of the support columns. In addition, the added rings reduced the height to width ratio of the tension rods and aided in overcoming construction clearance concerns. The timber rings were reinforced with $^3/_{16}$-inch strapping anchored to the cross beams with ¼-inch lag bolts.

The timber connections were reinforced with ⅜-inch thick angle brackets with a center gusset plate to accept the clevis of the tension rods. The brackets were connected vertically with thru bolts and anchored to the timber columns with lag bolts. The tension rod axis was designed to be eccentric to the axis of the columns. This allowed the reduction in the height of the gusset plates and maintained uniformity with the bracket configuration. The additional flexure stress induced by the eccentricity was accounted for in the finite models, and the timber columns were found to be acceptable.

Construction Phase

Quotes were obtained from a few hand selected contractors with the skill set necessary to perform the work. Dimensions North, of Catskill, NY, was hired with an aggressive schedule and a construction budget of $105,000. Dimensions North specializes in historic buildings and has extensive experience dealing with timber structures, which made them an ideal choice for this project.

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Cross bracing installed at level 2, upper rods not installed.

Daniel B Proper, P.E. has worked in the upper Hudson Valley Region for the past 15 years performing a wide variety of structural engineering services involving both new and historic structures. He is a current member of ASCE and SEI Institute, and specializes in the design of conventional wood, timber and masonry structures.

Over the past three years, Melissa O'Leary has focused on the structural design of custom residences and the renovation of timber structures.

Construction started with the foundation and worked upwards to ensure a positive load transfer. To reduce confusion during the construction process, the angle connection brackets were designed and fabricated to fit at multiple locations. In addition, thru bolts were specified only at square or straight sawn connection points due to the difficultly of obtaining proper alignments when dealing with hand hewn timber. When connecting into the hand hewn columns, lag bolts were the preferred method.

The main problem encountered was ensuring proper alignment of the tension rods thru the center point of the primary timber members. To aid in this process, temporary plywood brackets were created to lay out the placement of the reinforcement prior to fabrication. This coordination helped significantly in keeping the project on schedule and within budget.

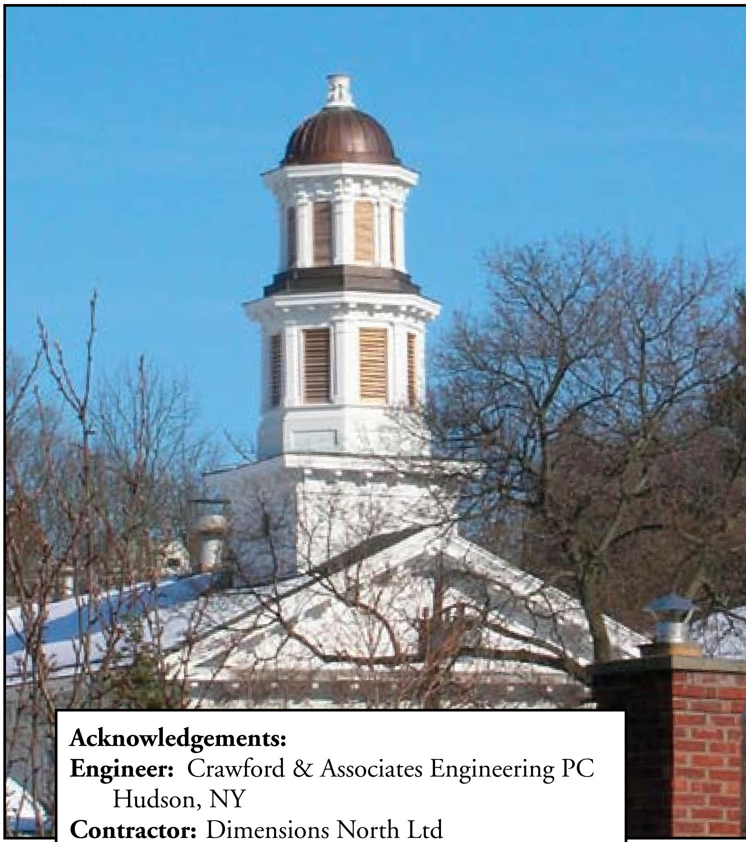
Due to the unevenness of the column members and the acute angle to the cross bracing plane, the majority of the connections required the addition of wood blocking to obtain proper positioning of the brackets (*Figure 5, page 35*). The blocking was constructed from parallam stock since it was of large dimension and had a low moisture content, similar to that of the existing timbers. The blocking was attached to the main columns via the lag bolts of the connection and construction adhesive meeting ASTM standard 2559.

Some connections required chipping away of the column cross-sections to allow proper placement of the angle brackets. Per our analysis, the contractor was provided with maximum removal tolerance to ensure allowable stress would not be exceeded.

Conclusion

The addition of steel reinforcements and cross bracing provided an economic solution to repair the steeple's lateral support system. However, the method utilized for this project would not work in all cases. The fact that the main columns were in good condition, and the timber trusses had a significant residual capacity, pointed to the process selected.

The use of the finite element modeling aided significantly in reviewing multiple options and determining the best fit to rectify the steeple. Nonetheless, transferring the analytical results into practical construction methods/details was not a simple task. This was overcome by having an open teamwork approach between the contractor, structural engineer and owners. The other key component was the skill of the contractor to follow through with the finalized details, and surmount the problems inherent to old timber structures.▪



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