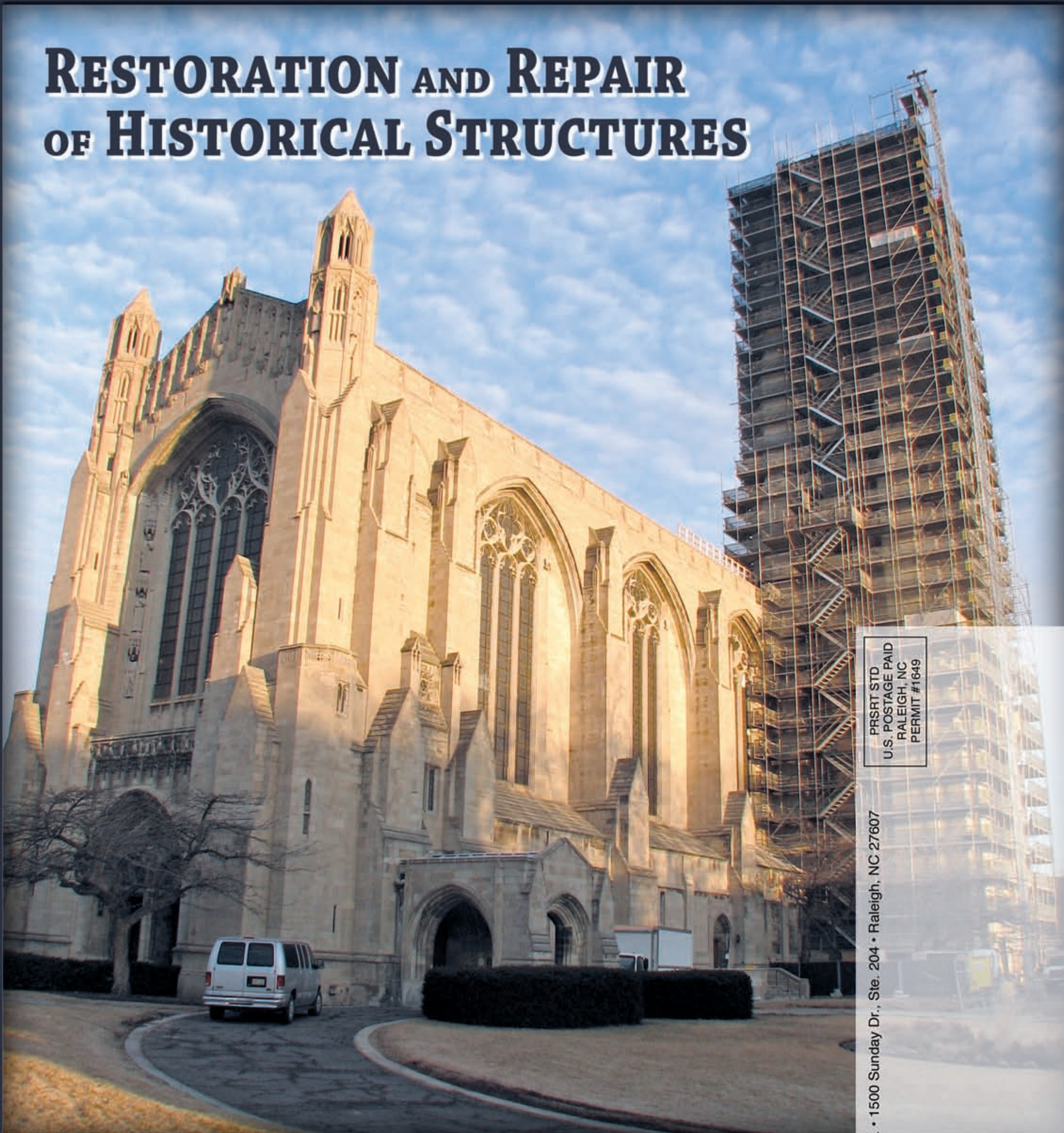
The Journal of RCI

interface

April 2009 • Vol. XXVII • No. 4 • $10.00

Restoration and Repair of Historical Structures



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Redintegration of Sanctorum:

Multidisciplinary Historic Rehabilitation of Rockefeller Memorial Chapel

By Donald Kilpatrick and Barry O'Quinn

Rockefeller Memorial Chapel, funded by John D. Rockefeller, remains as described at its dedication, "a building that would be central and dominant" on the University of Chicago campus. The building, adorned with numerous statuaries and ornate relief work of Indiana Bedford limestone and large expanses of stained glass interfaced with delicate carved stone traceries, is an excellent example of Gothic revival architecture as conceived by Bertram Grosvenor Goodhue. Transcending generations and the continued evolution of religion at the university, Rockefeller Memorial Chapel is an essential element of the campus and community.

Beginning in the spring of 2007, preliminary work scope commenced on a projected four-year construction term for the $14,000,000 restoration of varied building envelope features at the Rockefeller Memorial Chapel. The strategy for the repairs to the exterior walls was initially given consideration in 2001, after the completion of a critical façade ordinance inspection of the bell tower as mandated by city of Chicago code. Subsequent to that inspection, additional studies and inspections were performed on the remaining portions of the building.

HISTORY AND SIGNATURE FEATURES

The building cornerstone was laid on June 11, 1926, with the formal dedication occurring nearly two and a half years later, on October 28, 1928. Commissioned in 1918, architect Goodhue's signature Gothic themes are blended with Byzantine/Romanesque styles, resulting in an eclectic mix of architectural types, assuring that the structure's identity would not be lost in the heavy use of English Gothic on the surrounding campus. Goodhue passed away on April 23, 1924, and his associates were charged with completing the project.

In memoriam, a statue of Goodhue holding a model of another of his works (Cadet Chapel, West Point Military Academy) was placed on the interior south side of the east ambulatory door of the bell tower (*Photo 1*).

Photo 1 – A sculpture of architect Bertram Grosvenor Goodhue.

The Structure

Rockefeller Chapel measures approximately 260 ft in overall length and 102 ft wide as measured at the crossing, housing a balcony on the west side and bell tower on the east (*Photo 2*). The building, clad with Indiana Bedford limestone supported by high-mass, multiple wythes of brick backup, weighs in at approximately 32,000 tons. The construction is largely void of structural steel, with the noted exception of the nave roof trusses and beams establishing floor lines on the bell tower interior. The poured concrete foundation walls range in thickness from four to six feet. Access to the 206-ft-tall bell tower is accommodated by a series of suspended catwalks and a spiral staircase with 277 steps. In excess of 100 sculptures are found on the building exterior, providing further connections of the building to philosophy, academics, religion, and campus and community life.

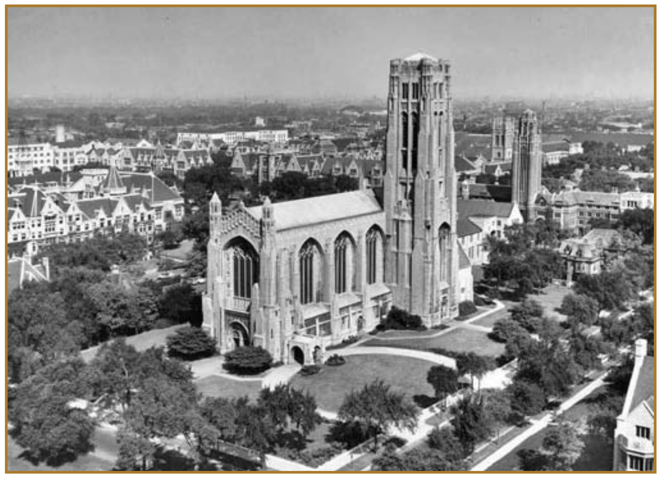


Photo 2 – Rockefeller Chapel.

Stained Glass Windows

Goodhue's design of the stained glass windows targeted the use of soft pastel colors, including mauve, amber, and pale blue. While the windows, reaching heights in excess of 40 ft, are recognized as some of the largest in the nation, they are not known for their artistic value when compared to other significant works. The architect's desired outcome, however, immediately becomes apparent when one enters the building, as the soft visual impact of the pastels and carefully repeated geometry of the panel frames for the lancets complements rather than overshadows other interior amenities (*Photo 3*).

Organ

In conjunction with the original construction, master builder E.M. Skinner was commissioned to install an organ capable of providing full orchestral sound (*Photo 4*). The instrument is generically identified as one of four "university organs," with others of similar grandeur found on campuses at Michigan, Yale, and Princeton. The inaugural recital of the Rockefeller Organ (Opus 634) was held on November 1, 1928. The original organ included 6,890 pipes subdivided into 108 ranks, with overall length of the varied pipes ranging from $\frac{3}{8}$ in to 32 ft. The majority of the works are housed in the organ loft area above the northeast chancel office, with a smaller gallery organ on the south end of the building installed as accompaniment for the choir.

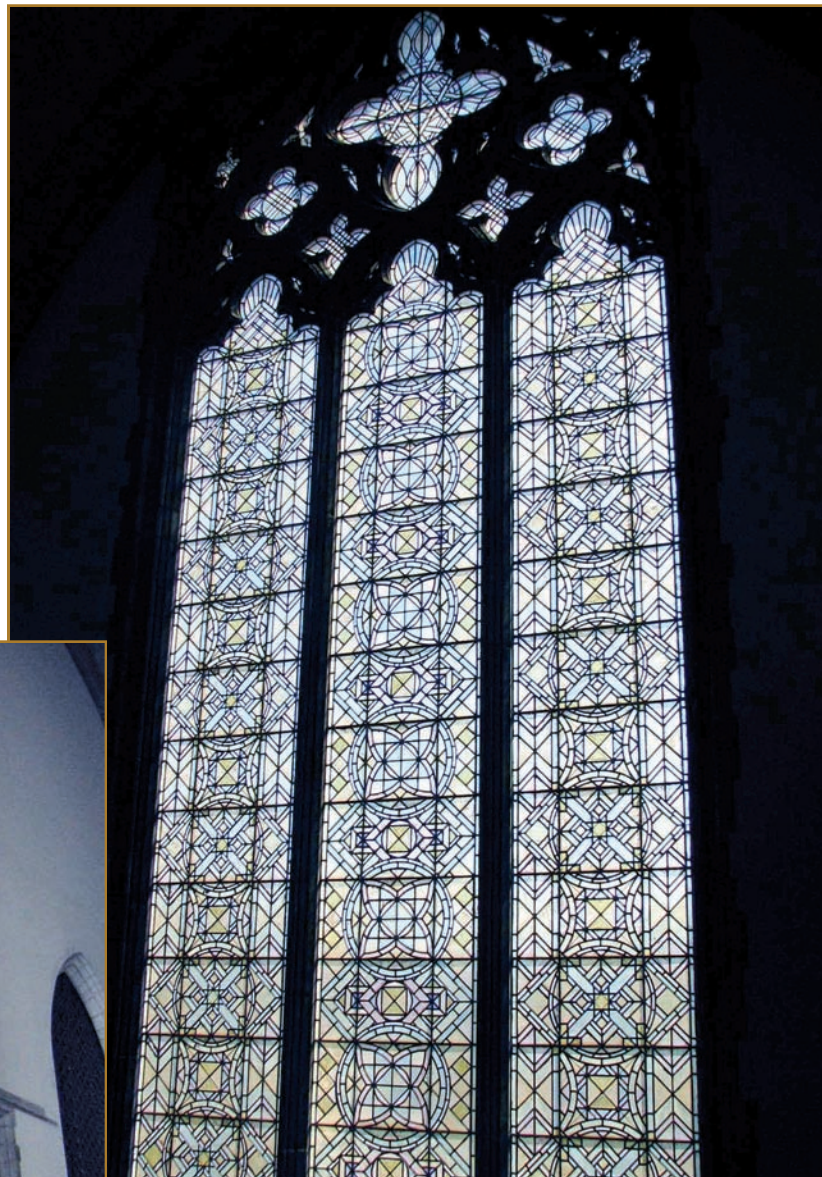


Photo 3 – Typical lancet window as seen from nave interior.

Photo 4 – Restored façade pipes of the E.M. Skinner organ.

Photo 5 – Circa 1934 loading of the tower with carillon bells.

Carillon

The Laura Spelman Rockefeller Memorial Carillon (*Photo 5*) is recognized as the second largest such installation in the world, rivaled only by another Rockefeller-funded carillon housed within the tower of the Riverside Church in New York City. The Rockefeller Memorial Chapel installation is the largest in the world when giving consideration to all castings having been sourced by one foundry (Gillett and Johnston, Croydon, England). The total weight of the combined 72 bells approaches 200,000 lbs, composed of approximately 156,000 lbs of copper and 44,000 lbs of tin. The largest bell weighs approximately 18 tons, with a base width of nearly 10 ft, with smaller counterparts chiming in at a weight of 10.5 lbs and a base width of 5.25 in.

EVOLUTION OF THE MASTER PLAN

In 2002, subsequent to acceptance and review of the façade ordinance inspection specific to the bell tower, university facilities staff endorsed continued investigations that revealed significant distress on the remaining portions of the building. Basement flooding had become an all-too-common occurrence, and the stained glass windows were allowing the passage of water to the building interior. Damage to interior finishes and exterior cladding was occurring at random locations as a result of failed drain leaders.

A variety of distress conditions were given consideration early in development of the restoration strategy, with the building and site drainage features of the package thought to be the only significant departure from "building envelope" repairs. In late 2005, university staff facilitators were exploring options centered on the restoration of the Laura Spelman Rockefeller carillon (bells housed in the tower) and the E.M. Skinner organ.

Through careful coordination and forward planning, the respective teams joined together in mid-2006, sharing needs for their specific areas of discipline. Through the collaborative effort, they developed a master plan targeting readily discernable economies of volume, most notably in the shared use of work platforms. Preliminary estimated savings are projected to be in the range of $500,000 to $600,000. The introduction of work scopes, removed from exterior cladding and roof repairs, including upgrades and repairs to the building instrumentation (bells and organ) and stained glass, increased the projected total cost from $14,000,000 to $20,000,000. The initial bid package was presented to prospective bidders in June 2007, including the following work scope items:

- Replacement and repair of cut/carved limestone cladding, approximately 4,000 stones.
- Complete reconfiguration of existing roof drainage.
- Complete replacement of all subsurface drainage components to city of Chicago storm sewer.
- Reroofing of bell tower (batten-seam red copper replacing existing lead-coated copper).
- Reroofing of chancel office with new Vermont green graduated slate.
- Reroofing ancillary roof areas, tower exterior pulpits, gallery roofs of the nave.
- Rebuilding of parapet walls' tower and nave to accommodate revisions.
- Complete conservation/restoration of all stained glass, with all scaffolding and special needs relative to access by the general contractor.
- Sandblasting and painting of all mild steel-stained glass accessory support mechanisms/frames (operable hopper windowframes, exterior *ferramenta*).
- Coordination of trades by general contractor to maximize economies through shared use of work platforms.
- Through addendum dated June 2008, complete demolition and reconstruction of playing cabin for the carillon at the 160-ft level of the tower interior.
- Coordination of bell restorative effort with Royal Eijsbouts, a bell foundry from the Netherlands.
- Steel erection for previously mentioned playing cabin array of bells.
- General bell tower interior cleaning and painting of bell tower steel framing.
- Asbestos abatement in nave attic interior (performed under separate contract in advance of the July 2007 release of bid documents to general contractors).
- Repair of concrete cover (fireproofing) at varied floor lines of the tower interior.
- Lightning protection.

INITIAL CHALLENGES

The standard practice promoted by university staff facilitators on both vintage structures and modern-era buildings is to look beyond the initial, readily discernable distress conditions to understand the mechanics of failures. In very broad terms, the current condition indices of vintage structures can be attributed to time-weighted compromises in performance rather than the distress conditions typical of newer construction, which can be written off to a missing bead of sealant or an improperly installed flashing. While this approach will predictably result in a higher probable cost of construction, the benefits realized are found in the development of whole-building repair/restoration strategies that address the interdisciplinary relationships of one component of the assembly to another. Final work scopes are invariably reduced to levels based on order of magnitude, with an emphasis on those items that are critical to the repair of identified areas of localized distress.

A significant number of owner-mandated issues required discussion in the early planning stages of the project, most notably the key parameter of cost. Lessons learned from other projects involving the restoration of the building envelope on vintage structures were given consideration in the development of broad-stroke, work-scope items further identified in 2003. Based on previous experience, it has been determined that the inclusion of one or more site-specific work-scope items often has impact on other parts of the building sometimes far removed from the work itself. The addition of multiple disciplines, some of which are clearly removed from the building envelope, further complicated the process. The introduction of a few project milestone tasks (in some instances, firm deadlines established by others around which major celebrations have been scheduled) brought additional layers of difficulty to the planning process. The seemingly straightforward work-scope items centered on the repair of the building envelope evolved to include a myriad of disjointed tasks.

The most challenging aspect of this master plan was to maximize the opportunities presented through early recognition of economies in volume, scheduling, and the removal of real or imagined barriers at the face of the work in advance of the bidding process. Foremost in the development of the plan was equal consideration of all components identified during the open review period initiated by the façade ordinance inspection of 2002. This included, but was not limited to, building site, drainage, and stained glass windows.

Stained Glass Windows

University facilities services chose to enter into a separate contract with a stained glass studio removed from the bid package that was to be released to the prequalified pool of general contractors for the remaining portions of the building envelope restoration. This approach alone resulted in a cost reduction of nearly $125,000, avoiding the traditional 5% markups for the general contractor on subcontracted services. In addition, this approach required exhaustive forward planning, as the successful bidder for the masonry repair package would also be responsible for all needs relative to access and temporary closures of window openings subsequent to the removal of the glass. A similar separate contract was issued for the restoration of the carillon, with the general contractor again responsible for all crane time, scaffolding, temporary storage of bells, and allowances for manpower assistance. These conditions were communicated early and often to all bidders.

The selection process for the studio of choice was based on a series of interviews with reputable service providers, including mock-ups of varied repair strategies. The means and methods for the repair strategies were developed by the contractors. Final studio selection was based in part on the respective studios' level of professionalism and overall fit with the project team, based on their interpretive response to baseline inquiries specific to best value as measured by long-term performance. Understanding that access to the windows would require a significant investment in scaffolding on both the interior and exterior for extended durations, it was decided that complete removal and in-studio restoration were the most practical in the presence of the owner's interest in a long-term repair.

Landmarks

The building is on the local registry of historic places, as designated by the City of Chicago Landmarks Commission. Early in the planning stages, during discussions of initial work scope limits, the commission was recognized as part of the design team and found to be a willing participant in a number of meetings where areas of common interest were discussed (i.e., stained glass window restoration, changes to portal openings in the parapet wall, louver modifications). The benefits of having the Landmarks Commission as a participant in the planning process was realized through its working knowledge of the project in advance of the general contractor's submitting plans for permits. Common ground was established for all design considerations that, in the absence of everyone's participation, may have been cause for delay in issuing the building permit.

Building and Site Drainage

The sweeping revisions to the building and site drainage provided justification for a schematic-level design meeting with City of Chicago water and sewer district personnel. A schematic-level rendering of the design intent (most notably, the connections to existing city of Chicago storm and sanitary lines) was sent to district offices for review in advance of the meeting. A ten-minute meeting resulted in their verbal endorsement of the schematic drawings and triggered the development of final plumbing drawings for inclusion in the bid set documents that would be issued to the general contractors.

Contract Delivery

Based on demonstrated success on other restorative projects at the campus, facilities services selected a guaranteed maximum price (GMP) based on time and materials agreement for this project. Award of the project was based on price matched with an interview process at which all bidders had an opportunity to promote their firm, their understanding of the documents, and their ability to meet milestone tasks and complete the work in accordance with the plans and specifications. A scoring system, reflecting a total maximum score of 100 points as published in the project specifications, was used in the evaluation process.

Negotiations with the selected firm followed, with revisions to varied work scopes, reducing the overall project cost from a low bid of nearly $20,000,000 to approximately $14,000,000, while maintaining the baseline depth and quality of the original design intent. The majority of these savings was realized by changing the work scope specific to the stone tracery in-fill of the major window openings. The original design intent was to completely remove all tracery in-fill and reset it with stainless steel pins at the stone cusps. Based on current condition indices, designers determined that this work was not required.

Beyond the actual work-scope items are the soft issues encountered on all projects in which heavy pedestrian traffic can be anticipated. The chapel is used on a regular basis for convocations, weddings, visiting artists, state funerals, Sunday services, and tour groups. On preestablished dates, work would either have to stop or occur at diminished levels to accommodate the above described. The safety of the general public and those who have office space in the building is critical to the project. Overhead canopies and fences direct pedestrian traffic to open building egress in areas removed from active construction. Established trees from saplings in Jerusalem are present in close proximity to the building, prompting an evaluation of health and pruning by an arborist in advance of the work. Explicit terms related to grounds restoration clearly identify limits for which the general contractor assumes responsibility.

Acknowledging the standard of care prescribed by facilities services has resulted in a bid package and work performed to date that has met expectations relative to schedule and cost. The active participation of key

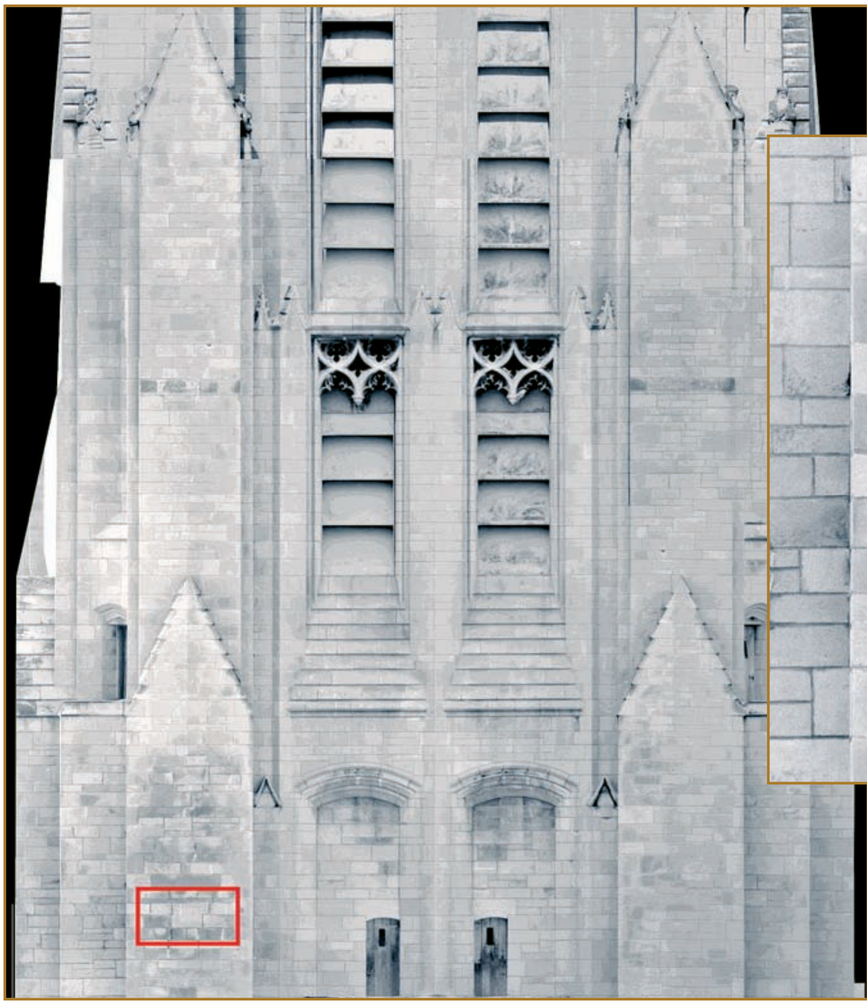


Photo 6 – Digital photogrammetry of partial east tower elevation.

Photo 7 – Enlarged area of localized distress below tower balcony roof with failed drain leader.

university facilities staff throughout extended study and design development, coordinating and dovetailing the input from varied interests removed from tasks central to the restoration of the building envelope, has culminated in a restoration strategy consistent with the owners' expectations.

THE BID PACKAGE

The original bid solicitation was released May 15, 2007, to a group of five prequalified general contractors who expressed interest in the project. In June of 2007, a formal prebid meeting was held with the prospective bidders, followed by individual site visits and prebid meetings. These were staggered to accommodate individual site tours by each of the bidders and their selected pool of subcontract service providers. This approach was due to limited access, prohibiting large groups from site-specific areas of interest. Additional site inspection dates and times were available to the contractors during the open bid period, with advance arrangements made through chapel staff. One individual led the tours, and questions posed by any one or more of the bidders were answered in writing with equal distribution to all prospective bidders.

Releases of "additional information" were distributed to all bidders as a supplement to the original bid solicitation, consisting of 179 sheets. This information included copies of available original building drawings, Subsurface Utility Engineering (SUE) survey drawings, and preliminary renderings of the above-playing-cabin steel framing for the bells as provided by Royal Eijsbouts. On June 8, 2007, an addendum for complete demolition and reconstruction of the existing playing cabin at the 160-ft level of the bell tower interior was issued.

Critical to the success of the project were project milestones as submitted in the original release of the bid-set documents. Both the restoration of the carillon and E.M. Skinner organ were funded in part by gifts to the university by past presidents and alumni. In the presence of the increased work scope – most notably, complete reconstruction of the playing cabin, addition of the extrados, tonal opening for the organ, and reinstallation of the stained glass window above the organ loft – explicit deadlines for milestone tasks were established. All bidders were informed that if there were any questions specific to their ability to meet the published deadlines for the project milestones, then they should reconsider their interest in pursuing the work.

The bid form presented a total of 40 identified GMP line items with an additional 17 unit price costs, including additions and deductions based on final counts, with provisions for five alternate items. In addition, the general contractor would be responsible for all provisions of access and hoisting for the trades, removed from limestone cladding repair and partial reroofing; but he would be only participatory in the restorative process specific to the carillon and stained glass windows. This included all temporary closures of major window openings, both interior and exterior; crane time; and special rigging for maneuvering the bells in and out of the upper tower limits. This forward-planning strategy was built around the published milestone tasks, and default in any one or more of the critical path items would invariably jeopardize the gala scheduled for the first week of June 2008.

Photo 8 – Typical stone distress resulting from corroded steel strap and/or the open cell (receiver) in the stone subjected to freeze/thaw damages.

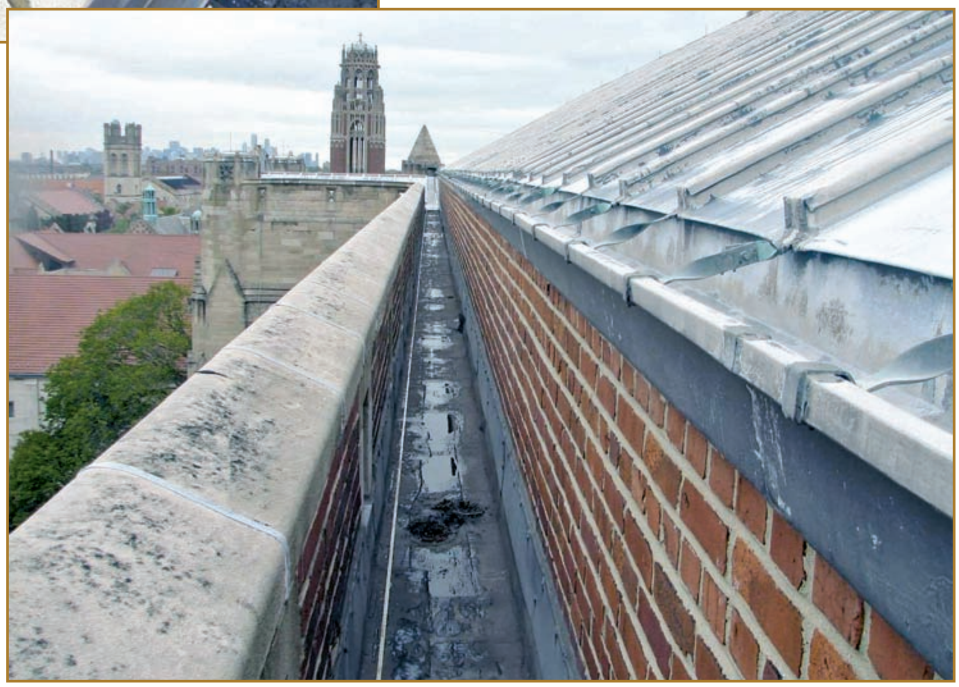


Photo 9 – Typical integral gallery at the east and west sides of the nave (below).

CONDITION INDICES AND WORK SCOPES

Building Envelope – Limestone Cladding

In the absence of a full complement of original building drawings, digital photogrammetry was selected as a means to record present-day condition indices and was subsequently utilized as the primary method to graphically impart site-specific work scope locations and limits to the bidders (*Photo 6*). The high-resolution photography delivers a permanent record of building and can be integrated with AutoCAD, accommodating manipulation of the images in full and partial elevations. The graphic representation derived from the photogrammetry yielded a significant reduction in cost over traditional methods of delivery (line drawings) while achieving unsurpassed interpretive quality of the building's varied features. Using the images, the engineering staff was able to view the building stone-by-stone, locating and cataloging over 4,000 individual units requiring varied repairs ranging from wholesale replacement to injection and patching (*Photo 7*). [Editor's note: See "Digital Close-Range Stereophotogrammetry for Heritage Recording: The Impact of Responsible Measurement," by Peter Belden Trieb and Don Kilpatrick, *Interface*, November/December 2004.]

Primary work scope items specific to the limestone cladding range from the above-described replacement and *in-situ* repair for individual stones to areas of select wholesale removal and rebuilding, including allowances for the reconstruction of brick backup. The majority of the individual stone distress conditions are driven by corrosion of the mild steel straps used as part of the original construction as a means to mechanically anchor the four-in ashlar stones to the brick backup. Typically, the straps extending from their set positions in the backup wall are engaged into pockets of the ashlars.

With corrodible metal within two inches of the outer wall, cyclical exposure to moisture had resulted in rusting, volumetric expansion of the steel, and cracking of the stone (*Photo 8*). At the stone mullions of the major window openings, similar conditions exist, with the corrosion causing cracking that radiates from the centrally located steel pins. All replacement anchors, pins, and straps required for setting and repairing stone are stainless steel. The tower turrets and pinnacle features above the nave roof on the north and south ends of the building will be completely torn down and rebuilt using stainless steel pins with provisions for new, galvanized tension rings.

Integral gutters or long, narrow gallery roofs are present between the lead-coated, copper batten-seam roof of the nave and visible from grade parapet wall condition (*Photo 9*). These roof areas are served by wall-mounted exterior/interior drain heads that are routed to the attic, where they are combined with attached downspouts from the nave roof above. Revisions to the building drainage will require select demolition and reconstruction of the parapet wall features to accommodate new drain-head elevations at a level that will ensure the required 1/8-in-per-ft slope on new laterals on the attic interior from the south end of the building to the north end.

In addition, the revised finished height and slope of the new integral gutter sections will invariably result in less-than-desirable flashing conditions at the portal openings in the parapet wall. To address these conditions, the original design included replacement of the three-stone set establishing the portal opening with a new single stone of matching ornamentation, less the opening through the wall-in section. Early dialogue with City of Chicago Landmarks, including mock-ups using limestone blanks to in-fill the openings from the building side of the parapet wall, was critical to approval of this minor change in building aesthetics that, when completed, will not be readily discernable from grade.

In an effort to maximize the reuse of existing stone cladding at the parapet wall, options are currently being explored that will salvage the majority of the three-stone set establishing the portal openings. The center stone will be removed and saw cut, salvaging the stone surrounding the opening, and new pieces of similar ornamentation (less the opening through the wall) will be carved and set as infill. This will accommodate the final revised height of the finished integral gutter assembly, assuring positive slope to drain (*Photos 10* and *11*).

Stained Glass Windows

Conrad Schmitt Studios of New Berlin, Wisconsin, was commissioned to provide restorative services for the stained glass windows of the chapel. The window assemblies are among the largest in the nation, with each of the primary lancets on the varied exposures reaching an overall height in excess of 30 ft to the bottom of the spring line, with an overall height of approximately 45 ft to the top of the arch. Above the spring line, the openings of ornate carved tracery are in-filled, decorative, smaller pieces of kite glass and quatrefoils carefully following the contours established by the stone surround and tracery (*Photo 12*). All stained glass in the lancets, quatrefoil, and cinquefoil windows is being removed for complete in-studio restoration. It is estimated that in excess of 20,000 pounds of new lead came will be required for the restoration of the stained glass, with a total surface area of approximately 5,000 sq ft, involving the complete resetting of nearly 50,000 individual pieces of art glass. It is anticipated that nearly 20,000 hours of studio time will be required to complete the project.

Rectangular panels (typically 16 per lancet, measuring 4 ft 6½ in x 2 ft 7/8 in) are wire-tied to an exterior steel frame or *ferramenta*, a system of window support popular in medieval times. Ends of the horizontal components of the *ferramenta* are set in pockets of the stone surround, and window mullions are held in place with lead inserts. At vertical and horizontal intersections, the 1-in x 5/8-in steel bar stock is half-lapped with tapped set screws centered in the lap area. Additional machined splices are present in the long vertical sections, two per lancet. Spacing of the exterior support bars is structured to carefully match the individual interior support bars for each panel of rectangular glass from the lancet in-fill. The resulting panel support bar assembly, closely mirrored by the exterior ferramenta, achieves an assembly of robust structural integrity rarely seen in stained glass window installations in the United States.

For restoration, all rectangular panel in-fills of the lancets and the exterior support bar framing were completely removed. Templates of all windows were taken in advance of removal, supplemented by a dig-

Photo 10 – Carved stone central to the three-stone set establishing the portal openings.

Photo 11 – Area of stone infill on roof side of parapet wall required to accommodate revised height of finished gallery roof.

ital photo record/documentation of current glass condition indices. In areas where stone surround (primarily tracery elements) was subject to change by virtue of necessary replacement or *in-situ* repairs, a second series of templates was required. Each panel and assembly of decorative tracery infill was transported to the studio for complete restoration. All panels are disassembled in a water tank for the express intent of containing residual lead. The individual pieces of glass are carefully labeled relative to location specific to original setting and are cleaned. All cracked glass is replaced with restoration glass of matching color and finish. High-fire glass stains, consisting of pigment and powdered glass, are applied to the restoration glass utilizing techniques consistent with the original random pattern of handwork. The glass is then fired in a kiln at a temperature of 1,150°F. The kiln treatment essentially fuses the glazing to the host piece of glass. Subsequent to firing, the glass is allowed to cool with the kiln so as to avoid concerns relative to the glass's becoming brittle due to rapid cooling.

Photo 12 – At some locations, the stained glass and exterior support framing provided supplemental support to damaged stone tracery.

Widespread corrosion was noted on the exterior support bar framing, with section loss noted at the pockets where the steel engaged the stone surround and mullions. Comparative analysis using the Munsell scale indicated that the earliest detected paint layers were black in color. The restorative effort included surface preparation to a white blast and rebuild of the areas of loss

Photo 13 – Wood forms set in advance of pouring molten lead to fill the pocket in the stone surround.

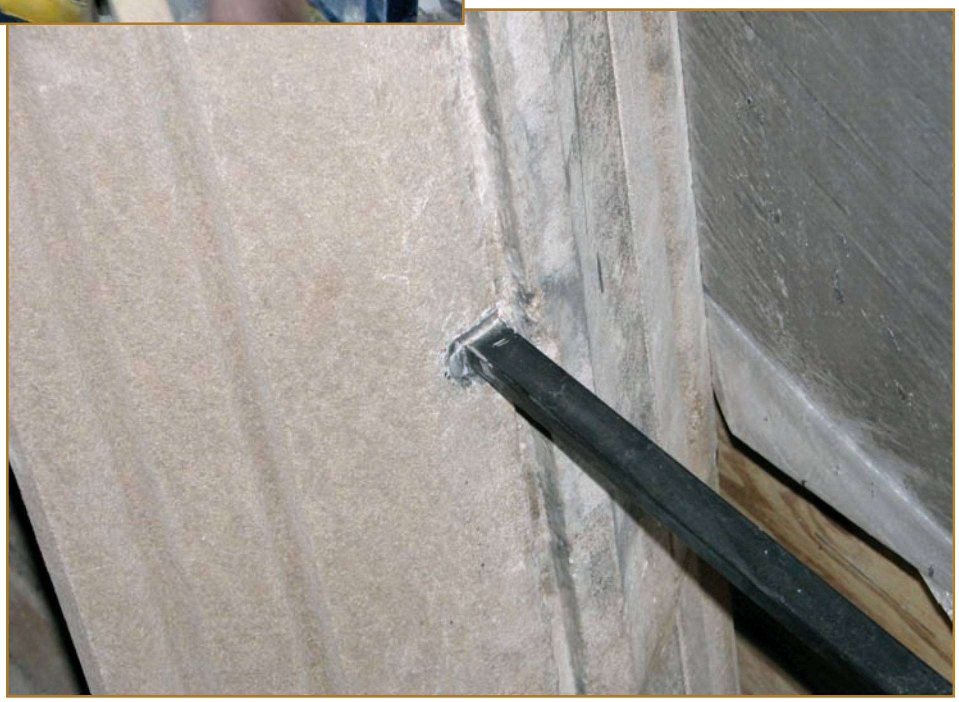


Photo 14 – Finished interface of exterior support bar framing and stone surround.

with "buildup" welding. The buildup welding was executed to an extent slightly greater than that of the original stock dimensions and then machined to match. Individual pieces of the assembly are painted with a two-coat primer, with the initial base coat a zinc-rich epoxy, followed by a high-build epoxy primer and a topcoat of flat-black urethane.

Reinstallation of the exterior support bar framing, more specifically replicating the lead packing around the horizontal bars set into pockets of the stone surround and mullions, required the development of new means and methods. The steel was initially dry set in the openings to assure that applicable tolerances had been achieved, and then molten lead was installed into the pockets. Crucibles were used to heat the lead, which was poured around each of the bars interfaced with the stone. Wood forms were used to contain the molten lead in the pockets (*Photos 13* and *14*).

BUILDING AND SITE DRAINAGE

Damage to interior finishes and sinkholes at grade are representative of the water-borne distress that can be attributed to the overall marginal condition of original building and site drainage features. The resulting damage and all-too-regular occurrence of an undercroft occupancy exposed to flooding during periods of heavy rain provided justification for sweeping revisions to original drainage assemblies. This aspect of the project will include the complete replacement of all below-grade storm and sanitary sewers, abandonment of all original cast-iron hub and spigot risers built into exterior walls and buttresses, and retrofit of the tower drainage features.

As evidenced by a review of available record photographs, the cast-iron hub and spigot drain risers were installed concurrently with the multiple-wythe brick backup and limestone cladding. This construction practice placed the risers within the confines of the high mass walls in areas where replacement-in-kind, relative to location, would result in significant disruption of interior finishes and, by some measure, would have been cost prohibitive. Using infrared equipment, the locations of several risers on the interior side of the limestone-clad buttresses were confirmed.

The typical risers in the buttresses service separate drain heads; one each servicing the gutter and leader of the lead-coated, batten-seam roof of the nave, with the other connected to the large integral gutter serving the narrow band of roofing behind the high parapet walls (*Figure 1, Condition A*). Both drain heads are routed to the nave attic interior, where accessory lead-coated copper piping is interfaced with the cast-iron risers, continuing into the masonry walls at the base of the vaulted ceilings. The risers continue down the interior side of the buttress and turn toward the building exterior, where the piping follows the contours established by the steel-reinforced, poured concrete deck for the stone weathering. The stone weathering roof areas are served by lead-coated copper gutters with one drain per segment on each side of the buttress as presented on the building exterior (*Figure 1, Condition B*). These drains are combined with the single riser dedicated to the nave drains, and again are presented, with cleanouts, at regular intervals in the basement (*Figure 1, Condition C*).

There are nine tower roof drains, with four each at the promenade roof level, four at the small triangular roofs, and a single floor drain in the ceiling of the switch gear room. Connected to the primary riser on the south tower interior is a leader that originally passed through confines of the carillon playing cabin that was originally installed to accommodate drainage from the playing cabin roof. Drain heads at the promenade roof were not properly installed as part of the 1987 restorative effort, with an APP membrane merely draped over an insert.

This condition left the assembly susceptible to moisture damage, most notably in the form of corrosion of the steel beams, resulting in volumetric expansion and loss of concrete cover (fire protection). (See *Photo 15*.) Additional distress specific to this condition was noted in the outside face of the limestone cladding at and below the roofline. The drains, as small triangular roofs, are completely restricted to the extent that water builds to level, exceeding the height of the membrane and accessory flashings. As a result, a significant volume of water has essentially been pumped into the high-mass walls, driving accelerated corrosion of mild steel straps anchoring the 4-in ashlar stones to the multiple-wythe masonry backup.

Understanding that the combined nave riser and stone weathering drainage layout could not be replaced in kind, the new design focused on provisions that would accommodate the installation of a new system without requiring disruption of interior finishes. Design parameters must also acknowledge ease of installation and end use with respect to future maintenance and servicing. The resultant design maximizes the opportunity presented in the attic of the nave combined with available chase locations for risers on the north end of the building interior (*Figure 2, Revised Building Drainage*). An initial survey of the attic interior indicated the available tolerances between the base of the ceiling vaults and upper limits of the interior masonry backup wall were adequate to establish new lateral runs at

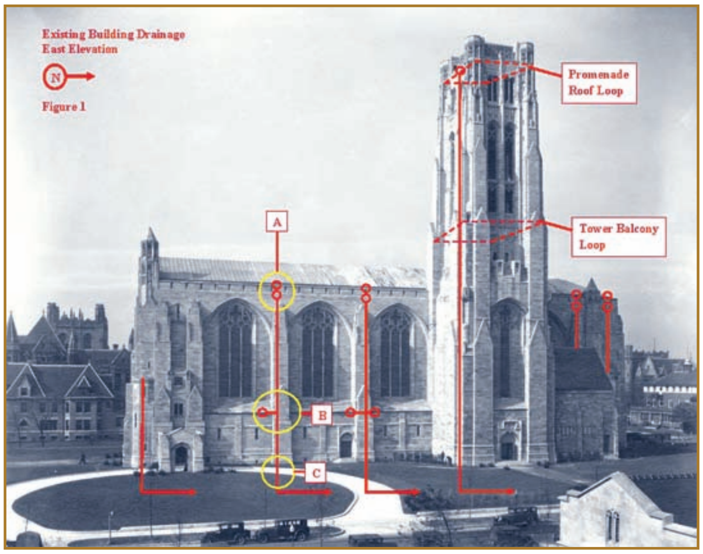
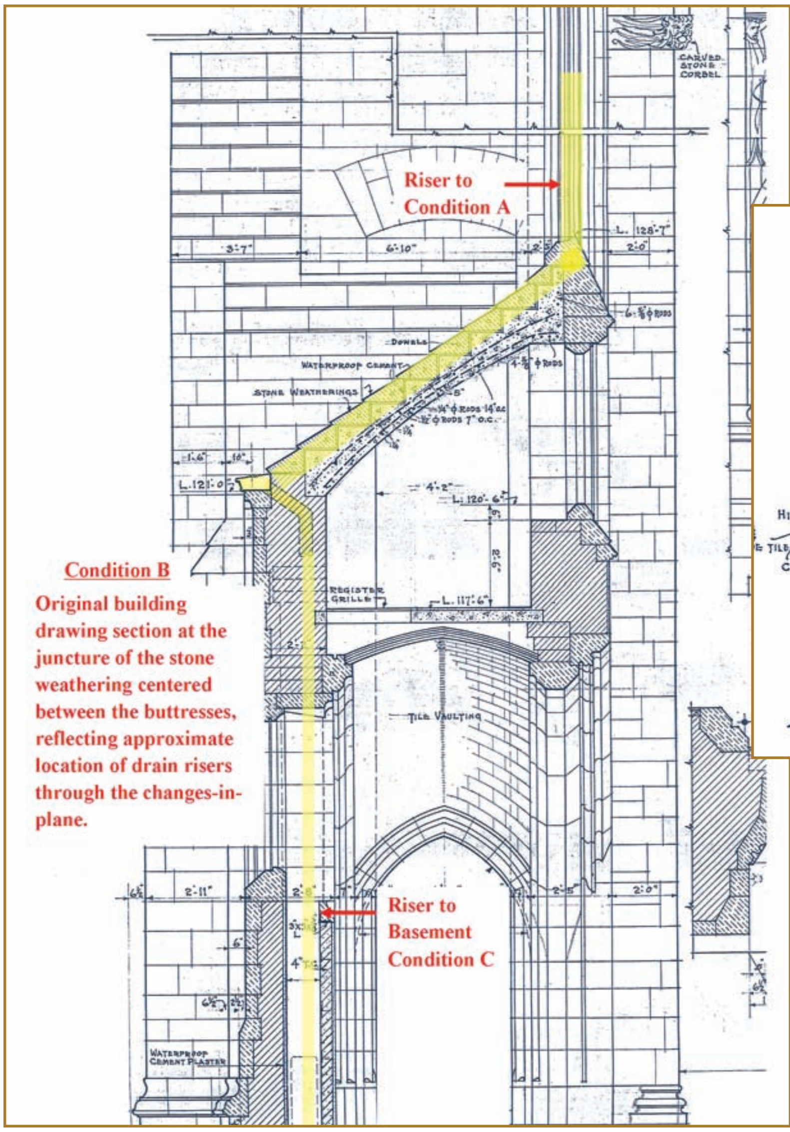


Figure 1 – Existing building drainage, east elevation.



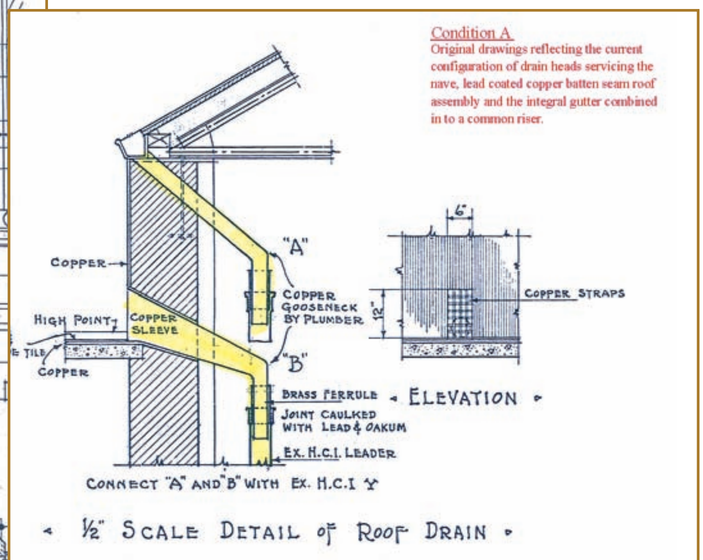


Figure 1, Condition A – Original drawings reflecting the current configuration of drain heads serving the nave, lead-coated copper batten-seam roof assembly, and the integral gutter combined into a common riser.

Figure 1, Condition B – Original building drawing section at the juncture of the stone weathering centered between the buttresses, reflecting approximate location of drain risers through the changes in plane.

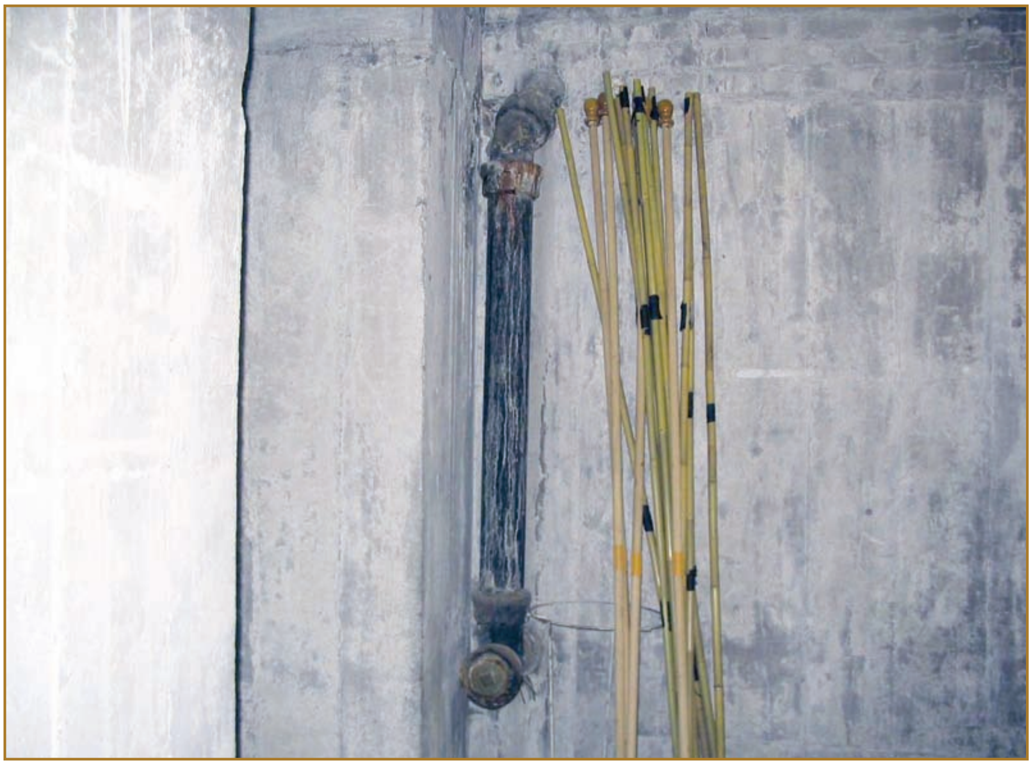


Figure 1, Condition C – Typical drain leader exiting the buttress as presented in the basement.

1/8-in-per-ft slope from the south end of the building to the north end. New laterals, one each on the east and west sides, will pick up each of the primary roof drains servicing the nave, lead-coated, copper-batten-seam roof assembly. The entire length of the new above-ceiling (attic laterals) drain lines will be chased by a drip pan equipped with alarms. This redundancy in design will provide reasonable assurance that leaks, should they occur as the new system is placed in service, will be contained. The drip pans will be connected to primary risers on the east and west sides of the north end of the building. The new tower drainage will largely be replaced in kind with respect to drain head and riser locations, with the noted exception found in its connection to the new east lateral above the vaulted ceiling as described previously. The apparent lack of positive slope and relatively small pipe size as originally installed are believed to have been contributing factors to the slow demise of the tower drainage systems. The new pipe size will be increased from 1½ to 2 inches at the drain head and 4 inches in the closed loop, serving the four tower-promenade roof drains in conjunction with increased slope to the primary riser on all drain leader laterals.

In the presence of recurring sinkholes at grade, it was determined that it would be prudent to videotape the varied stormwater drains exiting the building that connect to city of Chicago sewer system. Through this exercise, it was determined that a number of the laterals leaving the building had collapsed and were completely restricted. These findings provided justification for a complete SUE survey for the express intent of locating all subsurface utilities, including water mains, telephone, gas, electrical service, storm and sanitary sewers, and steam tunnels. This information was critical to the development of design documents for complete reconstruction of the site's civil work and, perhaps more notably, provided the bidders with precise location and depths of subsurface features. The location work was accomplished by placing an electrical current in the below-grade utilities that was subsequently traced above grade with tracking sensors. Precise depth of the subsurface utilities was established using vacuum excavations, avoiding the inherent hazards of mechanized removal of overburden and minimizing disruption of the grounds.

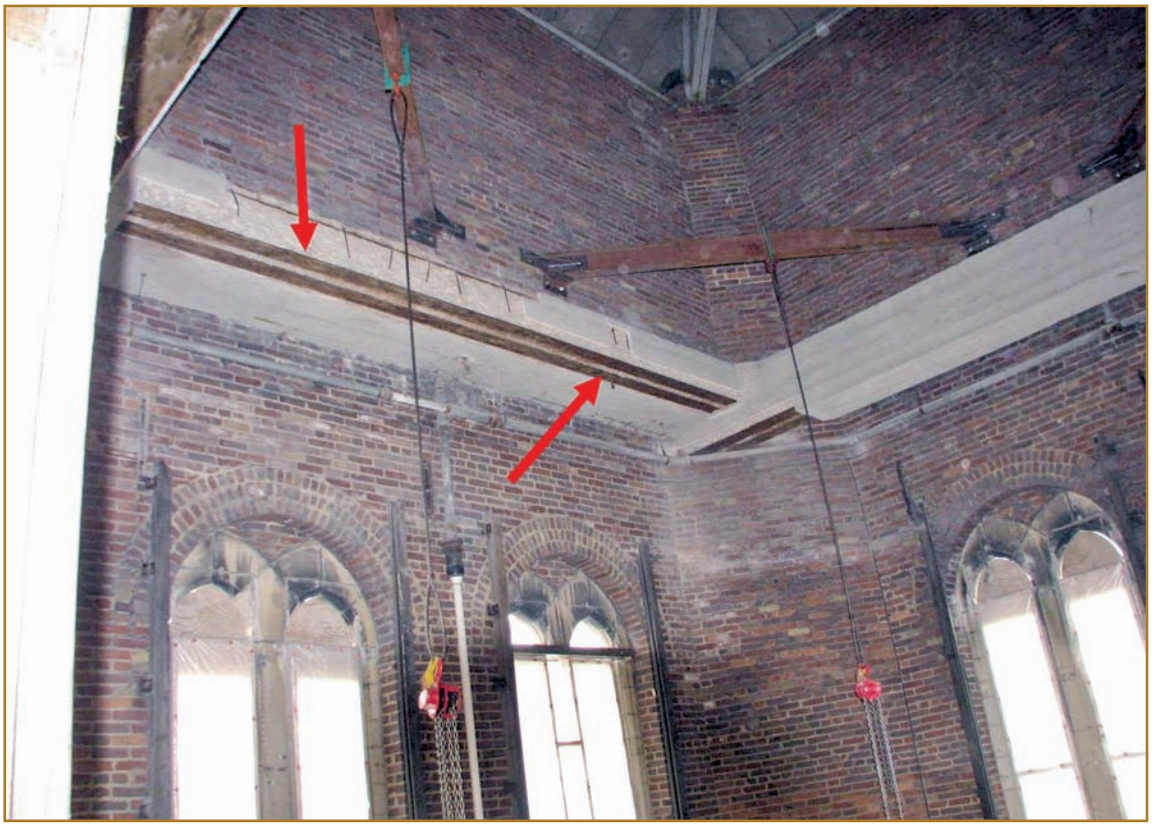


Photo 15 – Loss of concrete cover (fireproofing) at upper tower limits resulting from recurring water entry.

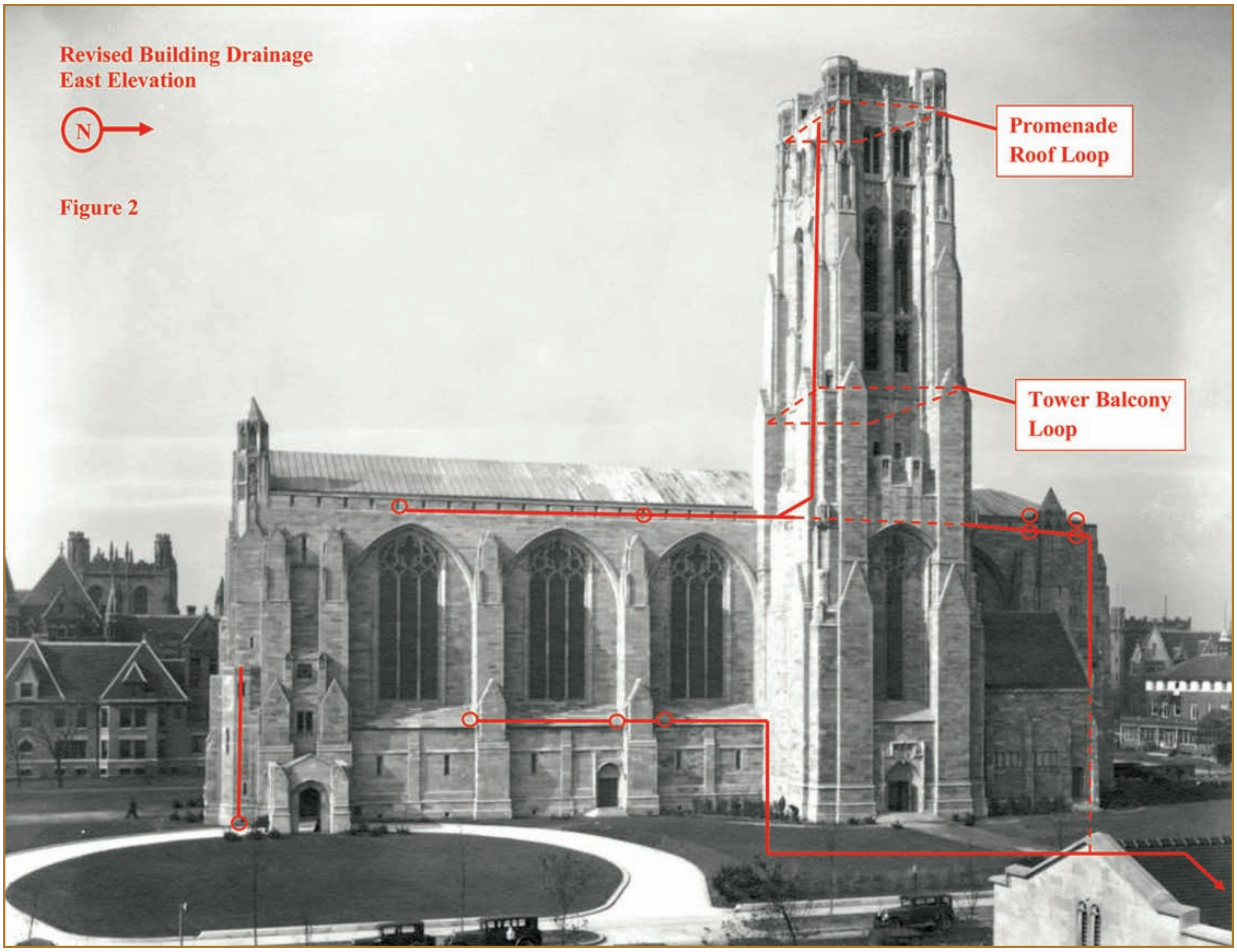
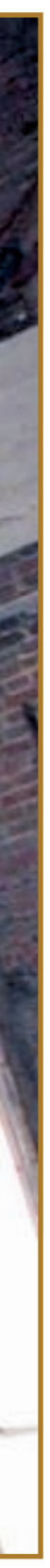


Figure 2 – Revised building drainage.



Restoration of E.M. Skinner Organ

In January 2007, additional funding was approved for the construction of an extrados wall opening in the north wall of the tower ambulatory. Schantz Organ Company, the firm retained to restore the 7,000-plus pipe E.M. Skinner organ, promoted the addition of a tonal opening to achieve improved balance and sound distribution for the restored instrument. Interestingly, the geometry of the wall section above the floor line of the organ loft suggested that similar considerations for a tonal opening may have been included in the original construction (*Photo 16*). Inspection openings through plaster interior finishes were made on the organ-loft side of the wall to confirm the presence of a rowlock arch above the spring line. Infrared equipment was used to visualize the relative location of the arch from the tower side of the wall and to confirm the homogeneous nature of the construction (i.e., concealed beams, open pockets, etc.).

Plans and specifications were developed for construction of the new extrados opening. It was required that the tonal opening be completed by early September 2007, as the restored workings for the organ were scheduled to return in the middle of the month. A new structural steel arch was introduced to the rough opening after demolition of the 10-in-thick in-fill of brick and plaster finishes, followed by a cut limestone surround patterned after that found on the clerestory windows of the nave (*Photo 17*).

The return of the restored instrument to the confines of the organ loft resulted in work scope revisions, perhaps viewed more as a change in construction sequencing than an increase in the overall volume of the work. Pipe shades (a hand-carved ornate lattice of Appalachian oak intended to soften the symmetry of the varied lengths of the façade pipes) are centered below a three-lancet window with a history of minor leaks. With the university investing nearly $2 million in restoration of the organ, the restoration team decided that the organ loft window should be repaired before reinstallation of the restored instrument. It was also determined that all mullions and stone tracery in the opening would also be removed to facilitate visual inspections of the steel pins at the stone-to-stone joinery.

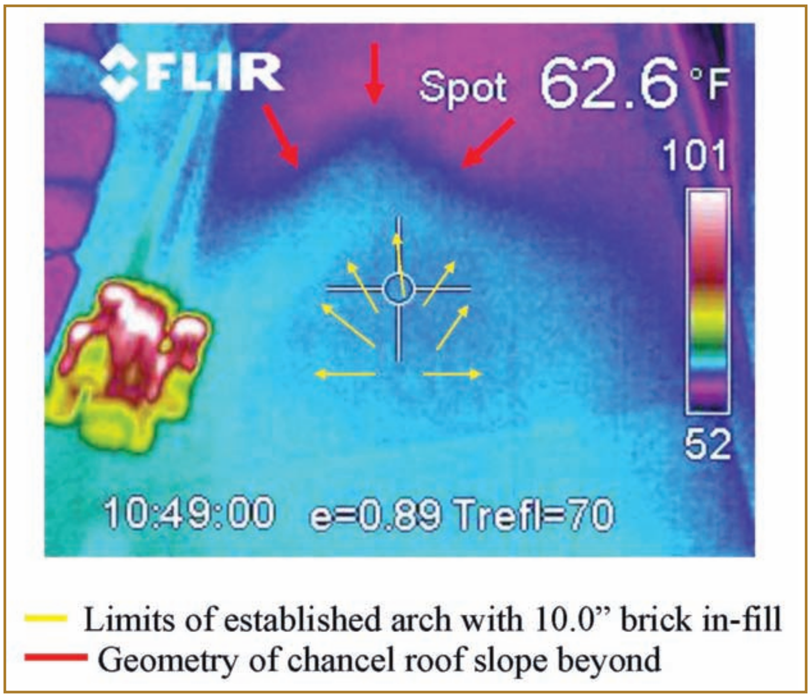


Photo 16 – Photogrammetry shows considerations for a tonal opening may have been included in the original construction.

The findings were very instructional, and the integrity of steel pins at the stone joinery was determined to be satisfactory, which was useful in establishing work scopes for the balance of the major window openings (*Photo 18*). The single pin, centered in the 18-in-deep tracery stones, was exhibiting mild surface rusting, with no evidence to suggest that corrosion was contributing to stone distress. This work was in part considered a large-scale inspection opening, while at the same time it provided assurance that the restored Skinner organ would not be subjected to damage from leaking windows.

Asbestos Abatement

With exterior work platforms and scaffolding to grade, concurrent work scopes were under way for asbestos abatement. Using hoists originally intended to transport removed stone tracery and mullions to grade, abatement workers were busy in the attic area and bell tower removing ACBM (primarily pipe lagging) from drain leaders and abandoned steam lines. To facilitate bulk removal of the hazardous materials, a temporary hatch was installed in the batten-seam roof assembly of the nave. This feature was left in place to be utilized by plumbing trades for the pending revisions to the building drainage systems.

Photo 17 – Final setting of cut limestone surround in tonal opening.

The Laura Spelman Rockefeller Carillon

Interestingly, the carillon was not built during the original construction completed in 1928, but rather was built in 1932. Installation of the instrument required selective removal of concrete-covered (fireproofing) structural steel beams

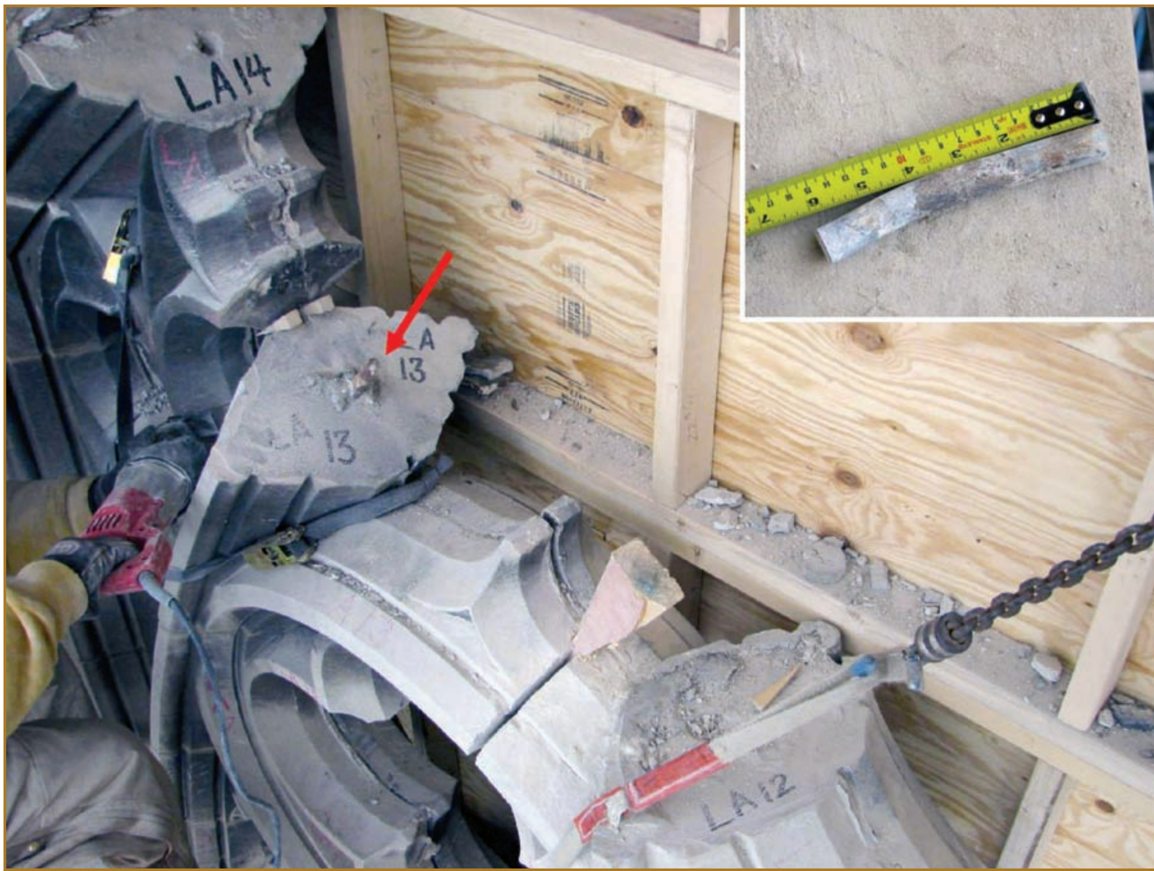


Photo 18 – Overall condition of steel pins at stone cusps from the organ loft window location.

Photo 19 – Restored bell array above the playing cabin on the tower interior.

and floor slabs established at regular intervals on the tower interior. Residual pitch-based waterproofing and quarry tile is present on the tower interior walls at the former floor lines and floor slab of the playing cabin. As originally constructed, louvers were not present in the rough openings at the former floor lines as currently provided. At the inside corners, pocket openings were established through the floor lines to accept the primary vertical steel columns of the carillon framing assembly. Steel framing for bells below the playing cabin is completely independent of the surrounding tower exterior walls.

The cumulative weight of the 72 bells cast by Gillett and Johnson in Croydon, England, totals approximately 199,907 lbs. Fourteen of the largest bells (ranging in weight from 3,227 to 36,920 lbs) are fixed to a rigid steel frame below the carillon playing cabin, between the 108- and 150-ft level of the tower interior. Above the lower 14 largest bells and playing cabin are the remaining 58 bells (weighing from 10 to 2,689 lbs) affixed to steel framing that is interfaced with the floor slab, projecting through and above the roof line of the cabin (*Photo 19*). Removed from past alterations to the once-operable louvers, occasional upgrades and repairs to the workings of the instrument, the carillon, and playing cabin remain largely as installed in 1932.

In 2005, the university entered into an agreement with Royal Eijsbouts (RE), a bell foundry from Amsterdam with a restoration division, engaging their services for much-needed repairs. Initially, the work scope was limited to removal, tuning, and reinstallation of the bell array above the roof of the playing cabin; repairs/replacement of hammers on the larger, below-cabin bells; and equipping the clavier (console) with upgrades.

In early 2007, based on the availability of additional funding, the work scope was revised to include consideration for the complete removal and reconstruction of a new playing cabin at the 160-ft level of the tower interior. The playing cabin houses the clavier or playing console for the carillon, which is linked by a series of rods and cables to each individual bell. The purely mechanical action of the operator's feet applied to pedals at the floor of the console or striking of the batons at the keyboard with closed fists peals the bells above and below the cabin. Obsolete cabin interior amenities included a large drum that enabled play of the carillon similar to that of a player piano. Small brass studs could be placed in one of thousands of positions in the drum that, when rotated, struck a pick-up mechanism, completing an electrical circuit that would peal a bell. Portions of this dated equipment were salvaged for historical value, with the balance of the workings being disposed of in favor of increased open floor space to accommodate visitors during performances.

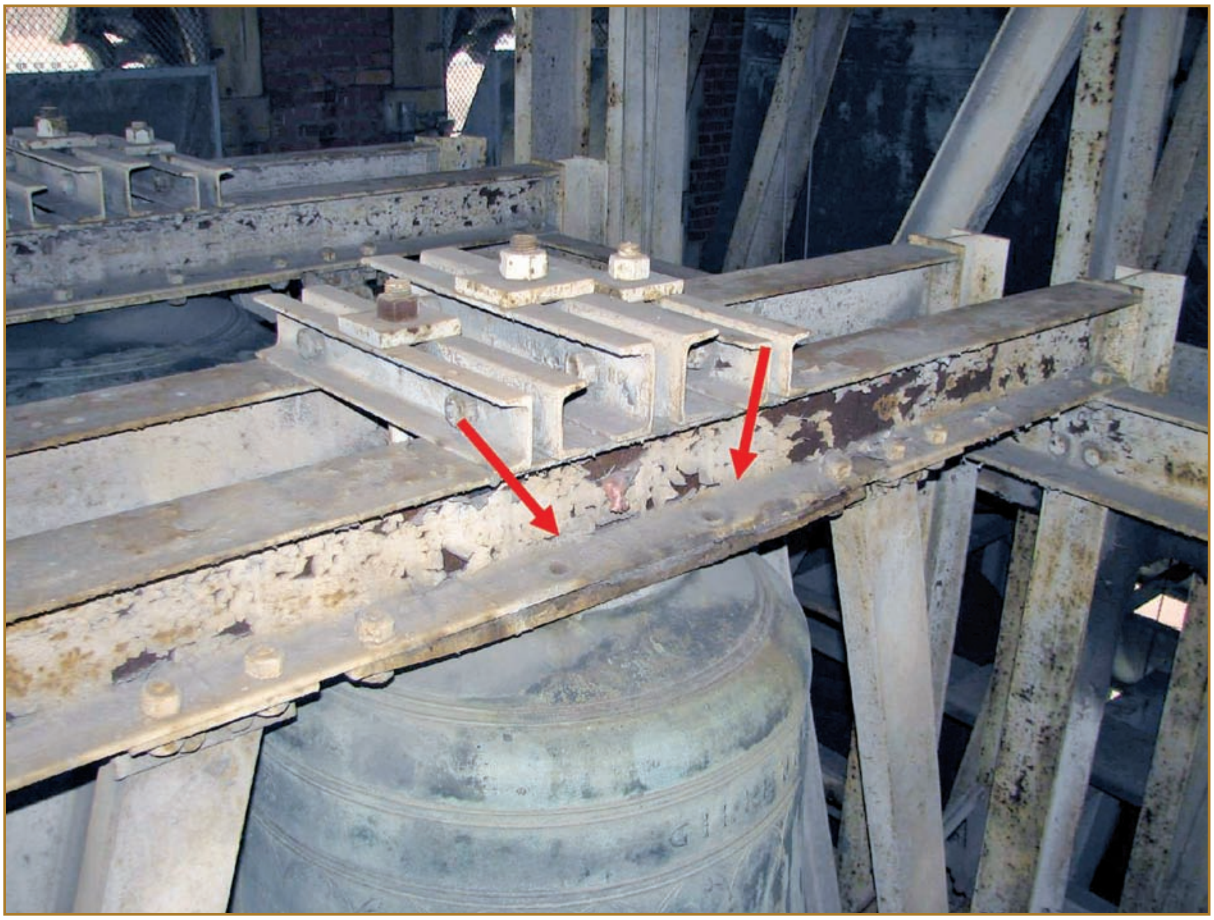


Photo 20 – Wind-driven rains entered the tower interior, resulting in heavy corrosion of steel plates and failure of bolted connections.

This increased work scope was deemed appropriate and necessary, based on present-day conditions affecting the structural steel framing, which was exhibiting severe areas of localized corrosion and measurable deflection, most notably in the floor slab of the playing cabin. It was also noted that mounting plates of the upper bells below the cabin had been subjected to damage from corrosion, with significant deflection. In some instances, three or four bolts of an eight-bolt pattern had sheared due to the volumetric expansion of the plate steel (*Photo 20*). The cause of the corrosion was determined to be stone tracery at the upper limits of the large louver openings, admitting water during heavy, wind-driven rains. The revised louver design includes provisions for a custom louver assembly of minimal depth that will be installed behind the tracery to minimize the volume of wind-driven rain that enters the tower interior.

Careful coordination of disciplines was required to achieve the owner-mandated soft issues specific to the new playing cabin, equipped amenities, and, most notably, the established deadline for a gala celebrating the restored instrument scheduled for the first weekend of June 2008 (*Photos 21* and *22*). A matrix of cabin as-built conditions was established and distributed to all involved parties for review and comment. Comments were consolidated, and the design criteria for the new cabin was begun based on the joint efforts of engineers from both Inspec and RE.

Subsequently, it was determined that the above-cabin array of bells would be supported by columns mounted outboard of the cabin interior to accommodate more open-end use, hosting guest carilloneurs and visitors for recitals. Somewhat removed from the structural engineering aspect of building the new playing cabin, it was determined that RE would design all above-cabin portions of the bell support system with clear separation of responsibilities occurring at four of the outboard columns. RE provided the loads, moments, and column reactions that were used by Inspec engineers as the design criteria for primary floor-slab structural framing of the new cabin floor.

The resultant bid package placed the responsibility for special needs relative to scaffolding, hoisting, and shoring, on the general contractor. In addition, it was the responsibility of the successful bidder to submit the RE-generated drawings for the above-cabin steel framing to a licensed

Photo 22 – New wall framing and truss assembly for the playing cabin.

Photo 21 – Ironworkers set new steel framing and decking for the playing cabin at the 160-ft level of the tower interior.

structural engineer for review and comment prior to final acceptance and for the generation of shop drawings. Using applicable AISC criteria and local standard practice, the review comments were communicated to and endorsed by RE engineers. Interdisciplinary aspects for the construction of the new playing cabin included concrete work, electrical, mechanical, roofing, light-gauge metal framing and trusses, EIFS, and steel erection, all of which were the responsibility of the general contractor.

CLOSING REMARKS

In summary, few charged with stewardship of such an outstanding facility, or those in the building restoration field, are presented with work of this sophistication in terms of architectural significance, tempered by a rich history and self-evident connection to the community and the rest of the University of Chicago.

Through a forward-planning process in excess of four years, all were provided with reasonable assurance that the initial work scopes defined (stone-cladding repair, partial reroofing, stained glass restoration, and plumbing) could be dovetailed with disciplines far removed from the building envelope (carillon and organ restoration), resulting in significant reductions in overall cost to the owner. Measurable economies in volume will yield cumulative savings in the range of $750,000 to $1,000,000 over the projected three-year construction window. Upon completion, the building will again impart the visions of grandeur in scale and harmony of tone established by those dedicated to the form and function of spirituality as central and dominant to life on the University of Chicago campus.

Special thanks goes to project team members, including University of Chicago Facility Services, Conrad Schmitt Studios, Royal Eijsbouts, and Berglund/Jones Joint Venture, the general contractor on the project, and its roster of service providers for subcontracted services, for their participation in this challenging project.

Vintage photographs courtesy of Special Collections Research Center, University of Chicago Library, ***www.photofiles.lib.uchicago.edu****.*

AUTHOR'S NOTE: *This paper was originally presented as a session at the RCI Building Envelope Technology Symposium in Atlanta, GA, in October 2008 and published in the* Proceedings *of that event.*

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Barry O'Quinn has been with the University of Chicago for 20 years. He has been responsible for all building envelope issues and projects for the last 15 years. O'Quinn has implemented a long-term master plan for the restoration of the campus's approximately 156 building envelopes. He has been and is active in the design issues that best suit the restoration of the buildings' roofing systems and masonry façades. O'Quinn is a member of NRCA and RCI.