STRENGTHENING OF HISTORIC BRICK MASONRY FOUNDATIONS AT ST. PATRICK’S CHURCH: A CASE STUDY

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Abstract. Although structurally unaffected by Hurricane Katrina, long term settlement due to changes in soil moisture content, as well as deterioration of brick masonry foundations at St. Patrick’s Church in New Orleans, Louisiana led to movement, damage and distress of the church floors, walls, and bell tower. Located in the Central Business District and completed in 1840, St. Patrick’s is the second oldest parish in New Orleans, and is listed as a National Historic Landmark. Low clearance below the floor structure in which to access the masonry foundations, as well as the church’s desire to remain in operation provided unique challenges to implement the structural remediation. The effective use of compatible injected fill (CIF) to stabilize and strengthen existing masonry structures is well documented. Stabilizing and strengthening existing foundations in place allowed the church to remain in operation while minimizing disruption to the building. The strengthening process involved low-pressure injection of CIF into masonry voids, installation of stainless steel helical wall ties, and installation of diagonal stainless steel deformed bars into cored holes in foundation bases. Nondestructive evaluation (NDE) techniques such as surface penetrating radar were used to determine the magnitude of voids and deterioration prior to injection, and to verify complete filling afterward. The result of the structural remediation was the restoration of integrity to the original brick foundation walls without the need for disruptive excavation or interruption to church activities.
1 INTRODUCTION

Located in the Central Business District and completed in 1840, St. Patrick’s is the second oldest parish in New Orleans, Louisiana and is listed as a National Historic Landmark. The church was designed in the gothic style by James and Charles Dakin and built in what was then becoming to be known as the city’s “American Quarter.” An overall view of the church tower is shown in Figure 1.

The description of the building in the National Historic Register nomination mentions that problems were encountered during construction due to unstable soils. Soil instability was most likely caused by deep, poorly consolidated silt deposits with very low bearing capacity, which are present throughout New Orleans. Modifications were required to the original design of the tower and other portions of the church to address this issue. The church floor plan drawing by James and Charles Dakin is shown in Figure 2.

It is thought that a combination of compaction at the surface, settlement of underlying soils, and changes in moisture content are the primary causes of movement. In addition, de-watering and a lack of replacement sediment at the ground surface as a result of levees constructed to prevent flooding, has resulted in an estimated overall settlement of the entire city between 2 and 10 feet between 1895 and 1999 [1].

Figure 1. Overall view of St. Patrick’s church.
1.1 Building Structural System

The church and tower walls are constructed of multi-wythe unreinforced brick masonry walls. A series of intermediate foundation walls with regularly spaced pilasters and widened bases support the wood joist system under the church floor. These walls consist of 4 wythe thick brick masonry and extend along the entire length of the church, comprising the “crypt” area. Foundation walls are shown on plan drawings in Figure 3. The foundations themselves are relatively shallow, only extending 1 to 2 feet below the interior soil surface. A series of inverted masonry arches span between these foundation walls within the area below the bell tower (Figure 4). The inverted arch structures act to distribute large tower loads over a wide area, reducing foundation loads. Perimeter walls contain a series of regularly spaced buttresses along the exterior. The mortar used throughout the building is a soft, lime-based formulation.
Figure 3. Plan view of church foundations, depicting interior crypt walls running east-west. Drawings by Morphy Makofsky, Inc.

Figure 4. Typical crypt foundation walls (left). Inverted masonry arch (right).

1.2 Distress conditions

Over time, the mortar in collar joints between brick wythes had deteriorated, resulting in extensive voids, and multi-wythe walls which were no longer well connected. Mortar that had been reduced to powder and fallen out of mortar joints was collecting at the base of many of the walls and pilasters.

Distress conditions such as cracks and spalling were visible throughout the building. Floor movement and settling was reported by church staff, who had installed shims below floor members throughout the building in response to this movement. The tops of several foundation walls were visibly uneven due to differential settlement.
Figure 5. Foundation distress conditions: deteriorated mortar (left) and cracking (right).

The most evident indication of building movement was a visible outward lean of the church’s south wall. Measurements indicated approximately 2 ½ inches of overall lateral displacement of the wall had occurred relative to one of the upper floors, resulting in reduced bearing area for joists (Figure 6) as the wall pulled away from floor framing.

Figure 6. Loss of floor joist bearing due to lateral wall movement.

2 STABILIZATION AND REPAIR SCHEME

As part of a broader scope of structural repairs, the project structural engineer specified the installation of compatible injected fill (CIF) into masonry voids, installation of stainless steel helical wall ties, and installation of diagonal stainless steel deformed bars into cored holes in foundation bases. The CIF injection process included pre-installation evaluation of the existing foundations, CIF mix testing, installation, and post-installation verification.
2.1 Pre-installation observations

Prior to repair and strengthening work, visual and nondestructive observations were conducted to evaluate existing conditions and develop a protocol for injection and reinforcing installation to satisfy design requirements. The primary investigative techniques used in this project were microwave radar scanning and borescope examination. Microwave radar scanning was used to evaluate internal wall condition by locating anomalies such as voids within the wall thickness. Borescope examination is conducted by inserting a fiber optic probe into small diameter holes drilled into mortar joints. This technique provides direct visual observation of internal void structures, the degree of mortar joint filling, and condition of embedded objects.

Observations during this investigation found collar joints between brick wythes to be nearly empty, with an estimate of only 30% mortar fill. Radar scanning confirmed by visual borescope observation conducted at several locations established that this condition was prevalent throughout the building foundations. The results of these observations were used in development of an injection protocol and installation sequence.

2.2 CIF injection

The extensive, interconnected internal void structure of the masonry foundations, the distress conditions observed on site, and the need to engage and mobilize new reinforcing rods constituted the rationale behind the CIF injection protocol.

The effective use of CIF to stabilize and strengthen existing masonry structures is documented [2]-[4] but is a technique that is somewhat unfamiliar and underutilized in the United States. CIF is similar to a fine, self-consolidating masonry grout, but the proprietary mix formula used on this project was designed specifically to have similar strength, stiffness, and vapor permeability properties to those of historic masonry. The CIF formulation has been used by the authors in several buildings in the New Orleans area of similar age and condition with successful results.

The CIF development and quality assurance program consisted of a series of tests performed to evaluate the plastic properties of the fluid mix, and the mechanical properties of cured material specimens. Tests of fluid mix properties included ASTM C939-10, Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method) [5], ASTM C940-10a, Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory [6], wet density by use of a mud balance, and a more severe variation of ACI 423.9M-10, Test Method for Bleed Stability of Cementitious Post-Tensioning Tendon Grout [7] was used to measure water separation after 10 minutes under 10 psi pressure in a Gelman pressure cell. Stability is an important property of the CIF as segregation of the constituents during the injection process can result in incomplete filling of voids or inconsistent bonding and strength properties. The criteria for the fluid CIF mix were as follows: flow time between 18 and 28 seconds, greater than 1% expansion, less than 0.5% bleeding, and less than 5 ml water loss in the bleed stability test. Specimens were cast in prism molds of historic brick and tested for compressive strength following the method of ASTM C1019-13, Standard Test Method for Sampling and Testing Grout [8]. The average compressive strength of CIF specimens was measured between 800 and 1,200 psi.

2.3 Remedial repairs and strengthening

Stainless steel helical wall ties, installation of diagonal stainless steel deformed bars, extensive repointing and rebuilding were performed in conjunction as part of the repair and strengthening work. Helical wall ties were used to enhance the connection between wythes while also resisting the internal pressure of the fluid CIF material during injection. Diagonal stainless steel
hollow bars were installed in core holes drilled in the base of the foundations to provide reinforcement as well as to facilitate injection of portions of the foundations below grade, while the portions of walls above grade were injected through ports drilled in wall faces. Diagonal bars and helical wall ties are shown in Figure 7 and Figure 8. Due to cracks and the condition of existing mortar, repointing was required over significant portions of wall surfaces to close gaps, prevent leaks during injection, and replace heavily eroded, deteriorated, or absent mortar.

![Figure 7. Section view of anchor and wall tie installation.](image)

![Figure 8. Examples of helical wall tie installation (left), and diagonal hollow bars (right).](image)

2.4 Unique site challenges

Low clearance below the floor structure in which to access the masonry foundations, as well as the church’s desire to remain in operation provided unique challenges to implement the structural remediation. Access to the foundations was only possible by way of a small hatch in one of the exterior walls through which all personnel, equipment, and materials needed to pass through to perform the work. Material preparation and mixing was therefore performed at the building exterior, and pumped through tubes to the application point under the church. A view of typical operations at the building exterior is shown in Figure 9. In addition, the church’s regular schedule of activities including twice daily services was to be kept uninterrupted. Therefore, the repair work was performed so as to minimize disruption to church activities. The work area was accessed from the exterior, the installation work took place under the church floor, and only “quiet work” such as repointing was performed during church services.
3 POST-INSTALLATION TESTING

After injection and other repairs had been completed, post-installation testing was performed to verify filling of voids with CIF. Areas that were examined during pre-installation observations were rechecked using radar and borescope techniques, and additional locations were examined as well to confirm wall solidity. Approximately 50 feet of total wall length at locations spread throughout all foundation walls was scanned during the verification process. One example of radar observations compared before and after injection is shown in Figure 10. Borescope examinations were also conducted before and after injection, and at several locations to confirm radar findings. An example comparison between borescope observations of voided cavities before injection and solidly filled after injection is shown in Figure 11.
4 CONCLUSIONS

Stabilizing and strengthening existing foundations in place allowed the church to remain in operation while minimizing disruption to the building. Since the work on the foundation walls has concluded, the church maintenance supervisor reported that floor movement and settling had ceased.

A total of 1,240 stainless steel ¾ inch diameter hollow injection anchors were installed into the foundation footings. An estimated total of 69,200 lb of CIF material was injected into the foundations, representing approximately 10% of foundation volume.

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