INTERNAL STRENGTHENING OF HISTORIC CLAY BRICK MASONRY PUMP HOUSES IN NEW ORLEANS

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ABSTRACT

Following the devastating flooding caused by Hurricane Katrina in 2005, the United States Army Corps of Engineers evaluated the performance failures associated with the pumping stations used to move storm water out of the city. These pump stations were typically housed in unreinforced clay brick masonry buildings constructed between 1890 and 1940. The Corps of Engineers embarked on improvements to the stations that included elevated control platforms, more reliable backup power sources, and structural improvements to the buildings themselves. Due to very tight clearances at the building interior and the need to keep pump stations operational at all times, surface mounted interior framing was not a strengthening option, and the historic exterior appearance was to be maintained after completion of the work.

The strengthening methodology selected for the structural retrofits included low-pressure injection of compatible injected fill into the masonry wall voids and installation of vertical and horizontal stainless steel deformed reinforcing bars within the wall thickness. The stainless steel reinforcing bars were installed into precision-cored holes that typically extended over the full wall height, and they were grouted in place using the compatible injected fill material.

The result of the structural retrofit was an invisible enhancement that dramatically improved wind and flood load resistance of the brick walls without compromising the appearance or interior space of the pump stations. The entire project was completed while the stations remained in operation. Ground penetrating radar and other quality control methods have been used to confirm that the installation was successful.

KEYWORDS: injection, masonry, repair, strengthening, grout, retrofit

HURRICANE KATRINA

On Monday, August 29, 2005 Hurricane Katrina made landfall near the border between Louisiana and Mississippi on the United States Gulf Coast (Figure 1). At the time of landfall, the hurricane was a Category 3 storm with sustained winds of over 200 km/h (125 mph). The storm surge created by the storm flooded the New Orleans metropolitan area, which includes large areas that are up to 3 meters (9 feet) below mean sea level, and the area is generally bowl-shaped. The storm resulted in over 1800 deaths and over 81 billion US Dollars in damage.

The storm also revealed susceptibilities in the levee and storm water pumping system used to remove floodwater from low-lying areas.

Figure 1: Satellite image of Hurricane Katrina prior to landfall near New Orleans, Louisiana. Image from www.NASA.com.

PUMP STATIONS

As part of the rebuilding and recovery process the United States Army Corps of Engineers (USACE) determined that the pump stations used to remove rain and flood water from the New Orleans area required significant power supply, control, and structural upgrades. Many of the active pump stations were originally constructed between about 1890 and 1940 using multi-wythe, load-bearing clay brick masonry walls and riveted steel truss roof structures (Figure 2).

Figure 2: Overall view of typical Drainage Pump Station. Pump Station 7 is shown here.

DESIGN REQUIREMENTS

Since these buildings are critical to the life safety of residents in the area, the USACE determined that the structures should be designed to resist wind loads associated with a full Category 4 hurricane of 251 km/hr (156 mph). Since New Orleans is not located directly on the Gulf Coast, this is a fairly conservative assumption. The buildings were assigned an Importance Category of IV (the highest), resulting in design wind load increases of 15% over typical structures. Additionally, the pump stations were required to resist flood loads of up to approximately 1.5 meters (5 feet) above grade. This resulted in tremendous lateral load requirements for out-of-plane bending of the exterior walls, diaphragm loads, and shear wall loads. Since the existing exterior walls at many pump stations were constructed using unreinforced masonry, generally with fairly soft clay brick units and lime mortars, significant structural enhancement was required. This structural enhancement was further complicated by variable and frequently voided construction of the inner masonry wythes and poor connectivity between masonry wythes.

OPERATIONAL CHALLENGES

In addition to the structural challenges associated with this project, there were significant logistical obstacles associated with working on the pump stations. The pump stations contain extremely large water pumps, generators, and other mechanical equipment that is tightly spaced and requires access on all sides for maintenance. This equipment and the associated plumbing and overhead cranes provide minimal opportunities for supplemental interior framing and strengthening members (Figure 3). The building exteriors are considered to be historically significant and were not to be altered by the strengthening measures. Additionally, these pump stations are used on a regular basis to remove rain water and runoff from the storm sewer system of New Orleans. Therefore, the pump stations were required to remain fully and completely operational during the entire structural enhancement process. This placed severe restrictions on the amount and type of work that could be performed at the building interior.

Figure 3: View of pipes adjacent to exterior walls at left and large pumps housed by the pump stations at right.

PRE-CONSTRUCTION TESTING

In order to properly analyze the existing masonry structures and select appropriate repair materials, the mechanical properties of the existing masonry were evaluated using in-situ testing. Compressive strength and stiffness of the masonry (both the face brick and the common brick backup) was evaluated using flatjack testing in accordance with ASTM C1197 *Standard Test Method for In Situ Measurement of Masonry Deformability Properties Using the Flatjack Method* (Figure 4). The masonry generally was found to have a compressive strength of approximately 2.6 MPa (375 psi) and a stiffness of approximately 2800 MPa (400,000 psi). Flexural strength of the masonry (for out-of-plane loads) was evaluated using a field adaptation of the bond wrench test described in ASTM *C1072 Standard Test Methods for Measurement of Masonry Flexural Bond Strength*.

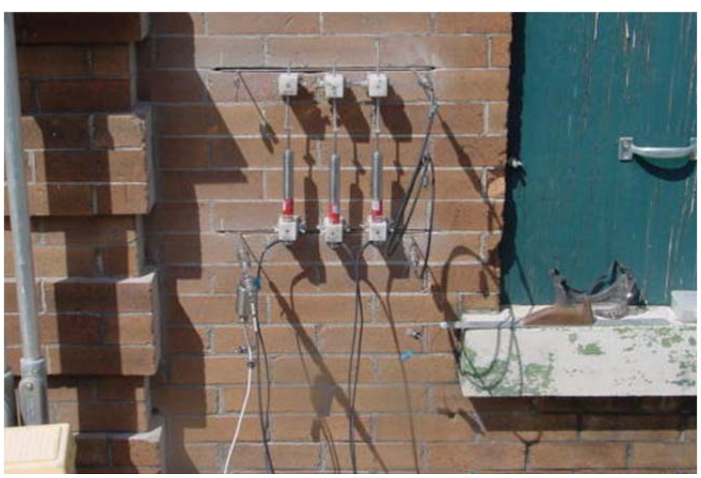

Figure 4: Flatjack testing at Pump Station 7 to determine existing masonry compressive strength and stiffness.

MATERIAL COMPATIBILITY

The material evaluation of the existing historic masonry was critical not only to structural retrofit analysis and design assumptions but also to repair material development. In order to ensure composite behavior between masonry wythes, helical ties were to be installed and the masonry assembly was to be grouted solid using a compatible injected fill (CIF), essentially a fine self-consolidating grout. In order to ensure compatibility of the CIF material with the surrounding masonry, the mix design for each pump station was custom developed to have similar strength and stiffness to the masonry assembly at that structure. The mix generally had a compressive strength of approximately 6.9 MPa (1000 psi) and a stiffness of approximately 2800 MPa (500,000 psi). By striving for compatibility of the repair material with the surrounding structure, stress concentrations and other potential hazards to the historic fabric of the buildings were minimized. Additionally, the mix designs were to provide similar vapor permeability to the surrounding masonry structure in order to avoid potentially detrimental vapor barriers in the hot, humid New Orleans climate. The specific mix components and proportions are propriety information.

RETROFIT COMPONENTS

The final retrofit strengthening design included several components. As mentioned previously, the existing masonry wythes were tied together using stainless steel helical rods and injected solid with CIF. The masonry walls were also strengthened internally using vertical and horizontal stainless steel reinforcing bars (Figure 5). Vertical bars were installed into holes that were cored from the top of the wall into the foundation using specialty coring equipment. Since development of the vertical reinforcing at the base of the wall was sometimes critical to the strengthening design, a special end detail was used to engage the reinforcing into the foundations. The bottoms of core holes were reverse tapered, and the bars were installed with a washer and sock at the base (Figure 6). This connection provided a positive, mechanical attachment to the foundations that can be significantly more effective than adhesive bonding of the reinforcing alone. The stainless steel reinforcing was comprised of bars with a hollow core that permitted relatively simple filling of the taper with CIF material.

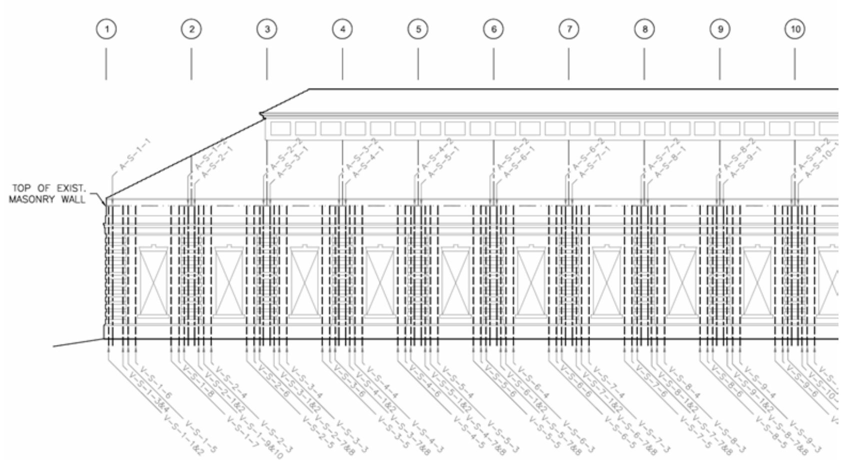

Figure 5: Portion of reinforcing bar shop drawings showing typical vertical reinforcing location and spacing.

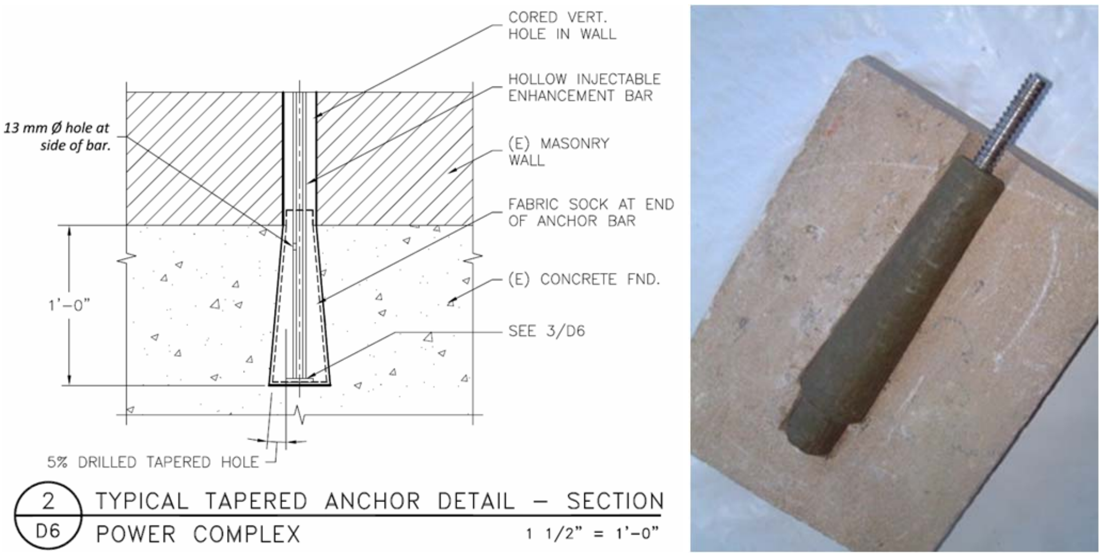

Figure 6: Left, design detail showing the reverse tapered vertical reinforcing termination. Right, installed taper.

Portions of the installation of helical ties between wythes and vertical reinforcing is shown in Figure 7. Generally, holes were cored for vertical reinforcing placement prior to injection grouting, although coring both before and after injection has been performed. Each approach has a unique set of challenges.

Figure 7: At left, installation of helical wall ties into existing clay brick masonry walls. At right, coring at the top of the exterior walls in order to insert vertical reinforcing.

LATERAL LOAD SYSTEMS

In addition to masonry wall strengthening, other lateral load resisting system elements often required significant strengthening. In some cases, large steel trusses were constructed at the top of the walls to supplement or replace the diaphragm provided by the existing roof structure. At pump stations with poor aspect ratios (i.e. extremely long and narrow), the use of a diaphragm and shear wall system was not practical for the design loads. Since construction of intermediate interior frames or shear walls was not possible given the constraints of the operating stations, the exterior walls at these buildings were analyzed assuming that they would have to cantilever off of the existing foundations, making base of wall connections critical to performance (and resulting in large vertical reinforcing requirements).

EXISTING MASONRY CONDITION

Like most construction projects and virtually all remediation projects, there were several challenges with implementing the structural retrofit design concepts. In some areas, the existing masonry wall mortar joints were in poor condition, occasionally even resulting in loose or dislodged units (Figure 8). Therefore, prior to coring and CIF injection, significant repointing of the mortar joints was required in some areas. This initial repair work allowed for the coring to take place with less risk of localized damage due to loose units and CIF injection to proceed without excessive leakage at the interior and exterior wall surfaces.

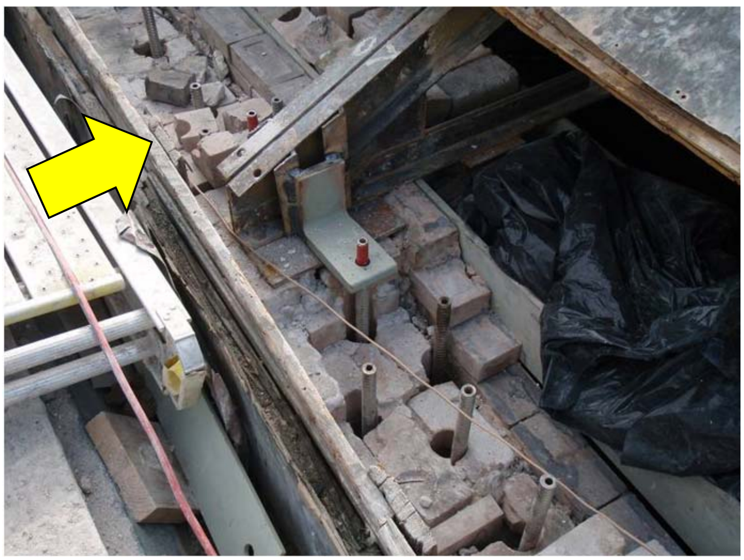

Figure 8: Top of masonry wall condition during vertical reinforcing installation. Dislodged bricks are indicated with an arrow.

DISTRESS CONDITIONS

Other challenges in the repair process included unique distress conditions. For example, some buildings contained significant cracks associated with differential foundation movement between the original structure and an addition. Often repairs in these areas included additional crack stitching or reinforcing and localized masonry repairs. At one pump station, there were several abandoned clay brick masonry pits that constantly leaked water and appeared to be contributing to erosion and other structural distress. The injection of the masonry in these pits required multiple stages and occasionally CIF mix modifications in order to both stop the water leaks and inject the below-grade masonry solid.

CONSTRUCTION PERIOD TESTING

In order to help ensure the quality of the CIF materials and installation during construction, numerous site and laboratory tests were conducted. The CIF material was sampled both from the batch plant and from the site and tested for compressive strength and vapor transmission properties. Wet material property tests such as bleeding and expansion testing were performed on the batch plant samples. Twice daily field tests were conducted to ensure proper flow of the CIF material (Figure 9), and wet material density was also tested twice daily.

Figure 9: Left, flow cone testing to verify viscosity of CIF material. Center, compression testing of a hardened CIF sample. Right, brick forms used to cast CIF compression samples.

During installation, a utility location device was used to verify proper location of vertical reinforcing. Pachometers and ground penetrating radar (GPR) were regularly used to find the extents of steel lintels and other embedded metals. The use of fiber optic borescopes was also common when subsurface conditions required verification.

RESULTS AND CONCLUSIONS

Although retrofit work is on-going at several structures, the work at three pump stations has been completed, including Pump Station 7 (Figure 10). Pump Station 7 includes approximately 1050 sq. m (11,000 sq. ft.) of wall area, typically approximately 460 mm (18 inches) thick. Into these walls, approximately 32 cu m (42 cu. yd.) of CIF grout was injected (approximately 7% of the wall volume) to fill voids. A total of approximately 2700 m (9000 linear feet) of vertical stainless steel reinforcing bars were installed.

After completion at Pump Station 7, the structural enhancement appears to be successful. The walls have been grouted solid, and this has been confirmed using ground penetrating radar (GPR), borescope observations, and even (unintentionally) by subsequent coring through walls by electricians (Figure 11). The vertical reinforcing was installed successfully using the reverse tapered end connections, and helical wall ties were installed throughout the masonry exterior.

Perhaps as importantly, the entire retrofit project was completed without interrupting the continuous operation of the pump station. The enhancement was also completed without significant alteration to the appearance of the historic façade, and the materials used should remain compatible with the historic fabric throughout the life of the structure. Although not the primary objective in most areas, the injection of the exterior walls should also provide improved moisture resistance for the exterior walls.

Figure 10: Overall view of southwest corner of Drainage Pump Station Number 7 showing the clay brick masonry exterior walls after completion of the strengthening project.

In our opinion, the design and construction methods used for this structural retrofit were successful and could be adapted for use in numerous applications. The principles implemented in this project could be useful for other types of wind, seismic, and blast retrofits, especially of historic and aesthetically sensitive structures. Even retrofits for the purposes of adaptive reuse or redevelopment could benefit from the unobtrusive and aesthetically pleasing aspects of this approach. This method of strengthening works within the structure to enhance the originally intended structural performance, rather than imposing outside restraint in ways that the original design never contemplated. When executed well, it is capable of providing elegant and invisible structural enhancement solutions.

Figure 11: Left, view of voids in brick masonry prior to injection at window jamb. Middle, view looking into a core hole made after completion of CIF injection showing the lighter colored CIF material has filled the voids in the wall. Right, core extracted from the exterior wall by the electrician after completion of CIF injection showing a helical wall tie and filled voids.

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