JOURNAL OF FLOOD ENGINEERING
Vol. 10 No. 2 (July-December, 2019)

Received: 14th July 2019 Revised: 17th August 2019 Accepted: 21st September 2019

ALTERNATIVE METHODS OF FLOOD MITIGATING EXISTING STRUCTURES

Paul Gugenheim
President and CEO,
Delta Structural Technology Inc.,

ABSTRACT: When Tropical Storm Allison, Hurricane Katrina, and Hurricane Rita blasted the Gulf Coast from Houston, Texas to Mobile, Alabama, tremendous damage was done to the existing structures due to inadequate flood protection standards. The United States Army Corps of Engineers (USCOE) and the Federal Emergency Management Agency (FEMA) have been upgrading the floodplain mapping along the Gulf of Mexico. It was determined that the 50 year flood level in some areas that had been the benchmark to be designed to was found to be inadequate and the benchmark was raised to the 100 year level. The base flood elevation, plus the mean flood level, plus one foot is used in the assessment and design of the flood mitigation of each building. Also, a study is required to determine the effect on adjacent buildings to the building that is mitigated and not taking on water. With this consideration, it is clear that substantial mitigation in an area must take place on multiple buildings.

1. TROPICAL STORM ALLISON

After the enormous amount of flooding that took place after Tropical Storm Allison in Houston as well as along the Gulf Coast into Louisiana with sustained substantial amounts of rainfall, the damage was astronomical. Downtown Houston has underground tunnels connecting many downtown buildings. The medical center also has many underground interconnected facilities along with extremely valuable research facilities. In two of the major research centers, the animal research was conducted in the basement of the facilities and the flood waters destroyed the research when the animals drowned causing almost incalculable losses.

The medical center in Houston embarked upon a process of upgrading the facilities, installing flood doors, strengthening walls, and determining weak areas above vaults and parking garages that would collapse under the weight of elevated water levels on the streets, sidewalks, landscaping, and berms.

In many of the areas when the fire proofing and sheet rock covering structural components was removed, a great deal of corrosion was discovered that over the years had also weakened the structures. The cost and long lead time associated with structural steel retrofitting created a problem for the reconstruction of the area. During this time, several structural engineers began exploring the possibility of repairing the concrete with high strength polymerized mortar and the applications of fiber reinforced polymer (frp) carbon fiber and e-glass fiber. FRP is not a new material. All Boeing aircraft use e-glass for the fuel tanks in the wings and the stealth fighter and bomber are made with carbon fiber. E-glass was invented in the 1950's for underground military fuel storage tanks. The Texas Department of Transportation began a test in 1999 to determine if composite fiber applied to concrete would prevent future corrosion and if corrosion 2 that was already present, increased, or stopped. If successful, the material could be used for retrofitting numerous bridges throughout the state at a fraction of the cost of replacement.

The Texas Department of Transportation began a test in 1999 to determine if 1.) Externally applied corrosion inhibitors were effective; 2.) If corrosion could be eliminated by wrapping the columns with frp, and; 3.) If high chloride levels were present in the existing concrete columns, would the frp enhance the existing corrosion and cause accelerated failure. Several manufacturers of spray on corrosion inhibitors were invited to participate in the test and were given ten concrete columns, three feet tall by ten inches wide in diameter, with four pieces of vertical steel reinforcement in a horizontal steel cage. Concrete was poured into the forms and allowed to cure. The cylinders were taken to several areas in the Ferguson Lab at the University of Texas in Austin and the corrosion inhibitor was externally applied and allowed to penetrate. Afterward, the cylinders were taken into the lab and frp e-glass wrap in several configurations was externally applied to the columns. Half of the columns were full height wrap and the other half was wrapped from the top to two thirds down, leaving the bottom third exposed.

The test columns were placed in a heated salt water bath and electrodes attached to the four reinforcing bars. The test continued for seven years until the steel in the control columns with no protection failed. The remaining columns were opened for visual inspection, the columns that were wrapped did not experience corrosion under the frp wrap except along the line between the wrap and the unwrapped area in the partially wrapped columns. Salt was added to the mix to significantly raise the chloride content on some of the columns. The wrapped columns with the high chloride content had the same results as the columns with no elevated chloride content and showed no evidence of advanced corrosion. With this information, as well as the massive amount of testing at major universities around the world regarding strength, durability, and application technique, engineers began specifying frp for the repairs and strengthening of several buildings in the Texas Medical Center.

All of the buildings required the installation of flood doors and strengthening of the walls for the mounting of the doors and resisting the forces of the flood waters. Several types of doors were installed. The most common was the swing door with either air filled seals or foam

Figure 1: Various Swing Type Flood Doors

Figure 2: Passive Flood Door Before and After Activation

Figure 3: Simple Drop in Slat Door for Low Levels of Water

core seals. These doors require activation by the maintenance staff prior to the event. The other door was a passive door that the flood waters lift without any activation from the staff.

One of the most difficult strengthening jobs is to strengthen the beams holding the top slab in the underground power vaults beneath the sidewalks and streets. These vaults have enormous amounts of electricity in them and are very dangerous to work in. The power company, contractor, subcontractor, and structural engineer developed a plan to shield the transformers and allow the work to be done in just a few days.

2. HURRICANE KATRINA

Hurricane Katrina came roaring into the Gulf Coast region and devastated southeastern Louisiana and southwestern Mississippi. The Hurricane was a category three and brought with it extremely high storm surges, leading to devastating flooding. Much of southern Louisiana was inundated with storm surge, high flood waters, wind damage, and few firms left to do the architectural and engineering work as most had evacuated New Orleans prior to the arrival of the storm. An architect returned quickly and set up shop amidst the problems. They partnered with another architectural firm in Houston that was not affected by the storms but had extensive experience from the flood renovation caused by Tropical Storm Allison. The Houston firm had done a great deal of design in the aftermath of Allison and was familiar with the use of frp.

When the architects began digging through the damage, it became apparent that few if any blueprints of the buildings existed. One of the key buildings to bring back into operation was HCA Tulane Hospital in New Orleans. As many companies realized in the aftermath of a hurricane or storms that produce flooding, the basements tend to be the storage place for things such as operating manuals and building blueprints. The architect began contacting known engineering firms trying to find copies of existing structural drawings to determine how the hospital central plant was built. HCA Tulane Hospital is an old building and many changes were made to the structure over the years. When it was determined that very few prints were available, a ground penetrating radar firm was hired from Houston to run the equipment along the slabs and walls to determine the amount of and placement of the existing steel reinforcement and to identify copper pipe and imbedded electrical conduit in the concrete cmu walls.

With this information, the architect began producing drawings for the rebuilding of the central plant as well as the relocation of the emergency power generator and fuel tanks being added to an elevated parking garage area. What the survey revealed was that there were numerous cmu walls without any steel reinforcing, some that did have steel reinforcing but not a sufficient amount, and grade beams that were supposed to be in place but had never been installed. On the reinforcing plans of the foundation that were found, it became apparent that the internal grade beams shown were never poured and steel reinforcement was improperly placed. A hole was cut in the nine inch slab for visual verification of the ground penetrating radar results and although the slab was indeed nine inches thick, the wire mesh was not embedded in the concrete and actually sat on top of the sand fill.

The architects determined which walls would be the external walls to withstand the flood waters and which doors to either eliminate or replace with flood doors. The design team brought in a structural engineer from a Houston firm with a great deal of knowledge in frp carbon and e-glass fiber and how to provide a structural upgrade and waterproofing design with the material.

Included in the design were sump pumps to remove large amounts of water if a door was breached or left partially open. These were located in the floor area around the boilers and worked well when tested.

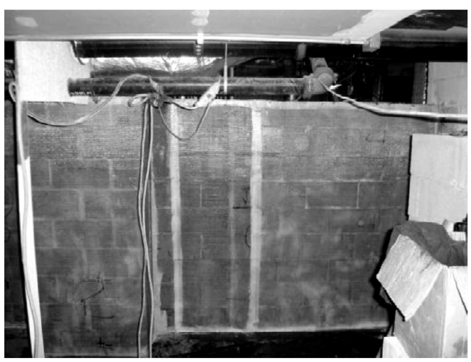
The FEMA-provided flood hazard data for this site indicated that the Base Flood Elevation mapped for this site was elevation was approximately 5 feet above existing grade. Using this flood depth, and also considering one foot of freeboard, the wall was analyzed for a flood condition that placed 6 feet of water above grade and against the structure. With this information, the unreinforced cmu external walls would not resist the flood water pressure and needed to be reinforced. Many of the walls required drilling holes in each vertical line of cmu cells, vacuuming out the existing vermiculite insulation, and filling the walls to a height of six feet with grout. Prior to the infill, eight foot long reinforcing steel bars were inserted on 24" centers with two feet epoxied into the grade beams.

Drilling and Pouring Concrete Grout for Wall Strengthening

New 6 ft. tall CMU Walls with Grout Infill

Figure 4

One of the greatest challenges was that the hospital emergency room was not to be disturbed for any reason. HCA Tulane Hospital is the teaching hospital where much of the downtown care took place and with the enormous disaster of the Hurricane, many people became seriously



FRP Wrapped Wall Under Construction

Completed Wall Strengthened and Waterproofed

Figure 5

ill and needed care. The decision was made to temporarily sacrifice the emergency rooms in case of another flood, but keep the power operating. The emergency rooms could be cleaned out quickly and begin running again if all the power was in place. The internal common walls between the equipment room and the emergency rooms then required strengthening and in some cases, six foot tall hidden walls were constructed in other areas and wallboard installed to the next floor covering the false walls. After examining the existing walls, it was determined that numerous intersecting walls could be strengthened to form buttresses by filling them with grout and applying frp wrap.

After the infilling was complete, the walls were covered with e-glass frp to a height of six feet and eighteen inches along the floor to insure a good seal at the joint of the slab and wall. The frp was then painted with a polyurethane paint for UV protection and finish.

The final step was to install the flood doors. There are two kinds of seals on swing doors, an air filled seal and a foam seal with no air infill. The foam seal doors were selected and installed in various locations. Included in the door selection were the single swing door, double door assembly, and two special vertical guillotine type doors for the boilers.

The boilers and the power units presented challenging design problems. First, the power units required specific air inflow to cool the radiators and in turn cool the power units. The intakes were large louvers that were below the six foot flood level.

Figure 6: Louvers That Extended Below the Flood Level

It was decided in the final design was to change out the cooling jackets for water coolers, raise the louvers above the FEMA-provided flood hazard data for this site indicated that the Base Flood Elevation mapped for this site was elevation of 5 feet above existing grade plus the one foot of freeboard for a total of six foot and turn them horizontal to get the correct amount of air flow needed. With the boilers, the area needed to remain open for servicing and the boilers could not be moved. The flood door company designed a customized vertical lift door that was not a roll up, but rather on an external vertical track with the door stored vertically

Figure 7: Vertical Guillotine Doors Prior to Flood Test

above the opening and closed only for inclement weather. It should be noted that no flood door should be used daily in place of a walk through door as the seals will wear out and lose the watertight fit.

Next to the overhead doors were the pipe inlets through inserted the wall for the fire department. The annulus around the pipe was infilled and sealed behind the surface brick where it penetrated the cmu.

One question that continues to arise is the issue of ground water from flood surge below the slab. This occurred in Galveston at a hospital and the frp e-glass was run across the floor and sufficiently strengthened the structure to stop water penetration.

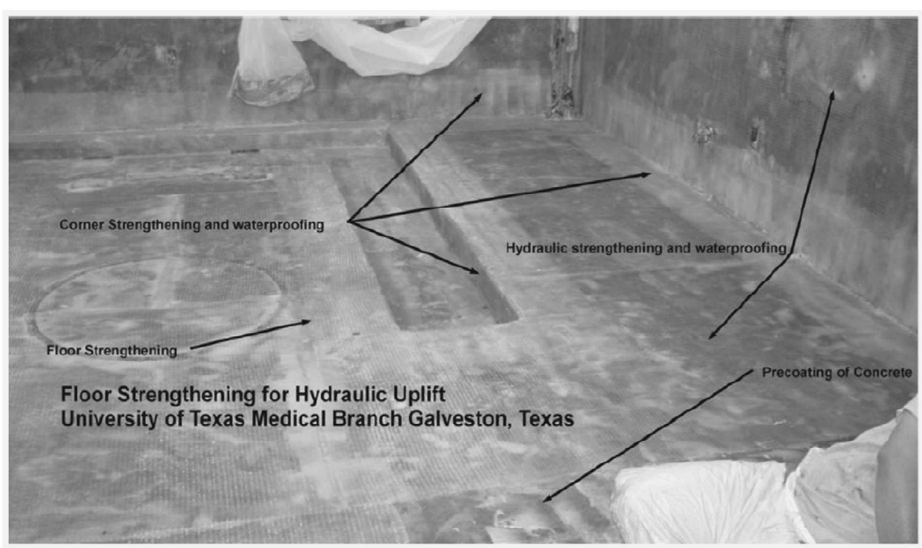
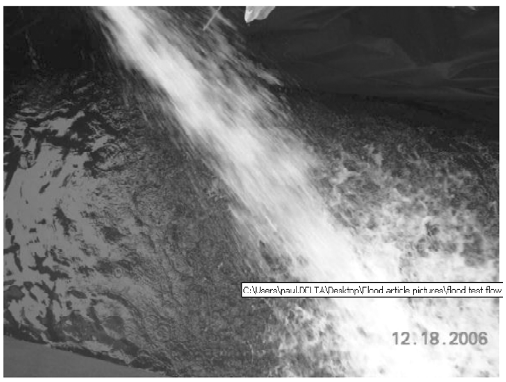


Figure 8: Floor Strengthening for Uplift From Tides or Ground Water

After completion of the project, water was pumped into the sumps and the flow capability substantiated. Following the sump test, the hospital built a sandbag dam around the central plant and flooded it to full design height of five feet to check for seepage and leaks. The system worked as designed.



Actual Flood Test at HCA Tulane Hospital

Flood Door with Six Ft of Water and No Leaks at the Door or Walls

Figure 9

During this time, an adjacent building was being retrofitted to become a cancer center. With the heavy loads from the power equipment above the planned space, structural steel was designed to reinforce the structure. When the plans were finished and reviewed, it was revealed that many of the steel posts would need to be located in the middle of the new examination rooms, which was unacceptable. The hospital asked for an alternative method and the frp solution implemented because it was one third the price of the steel, was installed in three days, and left the examination rooms clear of obstructions.

PARTICIPANTS

Tropical Storm Allison: Page Southerland Page Architects, Houston, Texas, Walter P. Moore Structural Engineers, Houston, Texas, Haynes Whaley Structural Engineers Houston, Texas, Delta Structural Technology Inc., Structural and FRP Contractor, Houston, Texas.

Hurricane Katrina: Verges Rome Architects, New Orleans, Louisiana; Page Southerland Page Architects, Houston, Texas; Garner Structural Engineers, Austin, Texas; Delta Structural Technology Inc., Structural and FRP Contractor Paul Gugenheim is the president and CEO of Delta Structural Technology Inc. now located in the Houston suburb of Conroe, Texas and has owned the company for 28 years. Mr. Gugenheim holds an engineering degree from Texas A and M University and is active in the Structural Engineers of Texas, New Mexico Structural Engineers, American Concrete Institute, American Society of Civil Engineers, Oklahoma Structural Engineers, and is a member of the national expert materials panel for FEMA to rewrite the TB 2 bulletin for nonresidential construction materials. Paul can be reached at 281-821-3006 or paul@fiberwrap.com.