8. QAFCO Prill Tower – CFRP CFRP plates bonded to concrete

Introduction
The Prill tower is located within a large chemical manufacturing plant in Qatar, Middle East, and produces 400,000 tonnes of urea prills each year. The tower operates 365 days per year and a day of 'down time' costs the structure owner £600,000.

Step 1.
Type of structure

The Qafco Prill tower is a 65m tall tower, approximately 12m in diameter (36m circumference), with a 3m diameter stair tower adjacent. The structure was originally constructed using the slip form technique over 30 years ago. The tower is not totally circular (as a result of the original construction process).

There are many locations of spalling of within the tower causing loss of section and further horizontal cracking.

The analysis of the tower showed that it had insufficient strength to carry the horizontal (hoop) bending for the daily thermal loading.

Figure 1. The Prill tower, shrouded with sheeting to control the bonding environment

Step 2.
Design conditions

The loadings considered within the assessment and detailed finite element analysis are: dead load, live load (e.g. during operation), wind loading and thermal loading. As previously stated, the tower was found to be understrength in the hoop direction (the steel reinforcement in the hoop direction was only 10mm diameter), with a capacity of approximately 35kNm and a required capacity of 112kNm. The vertical bending capacity was deemed sufficient.

The thermal gradient across the reinforced concrete walls of the structure was approximately $31^{\circ}C$ (internal temp>$70^{\circ}C$), which was assumed to be the main loading case that was either excluded or underestimated in the original structure design, causing the structure to be understrength.

Step 3.
Initial testing and investigation

The tower was inspected prior to the finite element analysis and measurements were taken of:

- The loss of section and location,
- Cube samples to establish concrete grade,
- Concrete test samples to establish levels of carbonation and chlorination,
- Temperatures at key locations of the tower, both internal and external.

Step 4.
Material selection

A number of options were proposed for strengthening the tower and these included:

1. CFRP laminate bonding in the hoop direction
2. Steel plate bonding (jacketing) in the hoop direction
3. Addition of 10 concrete rings equally spaced along the height of the tower

Mouchel Parkman recommended the CFRP option based on the following:

- It would have the least disruption to the operations of the tower as the CFRP option was estimated at 25 days installation period
- The steel or concrete options would require at least 90 days installation period
- The concrete or steel options needed extensive strengthening of the foundations
- The CFRP option required the least amount of scaffolding and lifting plant to carry out the works.

The laminates and adhesive had to have the ability to maintain their properties at relatively high temperature environments and thus had to be of high quality.

Pultruded laminates were chosen as the manufacturing method, as it was also critical to minimise the installation period. The materials chosen were manufactured by Degussa Feb MBT; laminates were 1.8mm thick, 160mm wide on 250m long rolls. A special modified adhesive was selected based on liaison with the material manufacturer, to ensure adequate working time and performance of the adhesive at the high installation temperatures. The laminates had a peel ply to minimise working time and to ensure a good quality bond.

Figure 2. CFRP Material Roll

Step 5.
Partial factors

The partial factors for the structural design were in accordance with TR55 as the design was for strengthening concrete. These partial safety factors are detailed within the case studies for Brockley Slip Road, St. Michael's Road and New Moss Road Bridges.

Step 6.
Design calculations

The design was performed in accordance with TR55 and BS8110. This resulted in the design requiring 2 No. 160mm wide x 1.8mm thick hoops of laminates per metre rise of tower. This totalled approximately 3.5km of laminates for the whole tower.

Step 7.
Design conformance check

The level of strengthening required for the structure to continue operating was achieved.

Step 8.
Prepare specification

The specification was prepared by the Employer's Representative to ensure that the works performed by the contractor on site matched the assumptions made in the design process. The specification was similar to that shown in the case study for St. Michael's Road Bridge.

Step 9.
Specific materials selection

No requirements in addition to those outlined in Step 4.

Step 10.
Method Statement for application of reinforcement

The Method Statement for installation of the CFRP laminates was prepared by the specialist laminate bonding contractor, Balvac, who were employed as sub contractors to the main contractor Apollo. The Method Statement was carefully checked by the Employer's Representative so that all efforts were made to ensure that the works had a minimum risk of overrunning.

The Method Statement detailed how the bonding environment was to be maintained, the lengths of laminate to be cut, techniques for performing this, how the laminates and surface were to be prepared and how to support the laminates during the curing of the adhesive. Additional points within the method statement detailed remedial works that can be performed if adhesive voids are discovered.

Figure 3. The proposed method of securing the laminates to the tower whilst the adhesive cured

The shutdown period for the tower was limited to 25 days. Any delays to this period would have incurred significant liquidated damages. This required a rate of installing 15 laminates per day.

Step 11.
Site activities prior to installation

Extensive scaffolding was erected to ensure that the works could be carried out at various lifts on the tower during the shutdown period, and that all the mixing and application of the adhesive, etc could be carried out on the tower to facilitate the installation process. The scaffolding was also completely shrouded (Figure 1) to provide protection from the direct sunlight and to maintain a suitable temperature and humidity regime for effective bonding. The outside temperature was between 38 – 45°C during the works, and the temperature inside the scaffolding was 5 – 6°C below the ambient.

Step 12.
Surface preparation

The concrete surface was prepared by grit blasting and then vacuum cleaned to be free from dust.

Step 13.
Application of composite materials system

The bonding works were performed by 2 crews of 12 men working 12 hour shifts. Once the surface preparation was deemed sufficient, the first CFRP laminates were cut to length, the peel ply removed and adhesive applied to both the substrate and the plate. The laminates were installed in 11m lengths (3 laminates per hoop) with lap laminates installed for continuity. The curing supports for the CFRP laminates were steel flats with timber backing laminates, attached to the tower using 70mm long screws drilled into the concrete at 300mm – 500mm centres. The laminates were tap tested 24 hours after bonding to check for voids. Laminates with voids greater than a 35mm x 35mm area were to be drilled with two small 3mm holes and filled with a low viscosity resin; the area was then lapped with a composite plate.

On day one, only 3 laminates were installed, on day 2, 6 laminates were installed and on day 3, 8 laminates were installed. At this point the client began having serious concerns about the progress. However, on day 4, 12 laminates were installed, on day 5, 18 laminates were installed and following this 22 laminates were installed per day, meeting the programmed finish in 20 days rather than 25.

Step 14.
Final QA checks, inspection and approval

Tests were performed on the adhesive T_g, tensile modulus and strength in addition to requesting the manufacturer to supply characteristic values of tensile modulus and strength of the laminates. The laminates were tap tested and any voids exceeding the limits set within the specification were repaired.

The QA checks were selected for detailed study in Technical Report No. 5d, Section 3. This is because of the volume of data collected and analysed by the Independent Test House, Oxford Brookes University. Detailed consideration of the data was of great assistance in defining the acceptance criteria proposed by the MMS6 project for on-site QC testing.

Figure 4. Checking and repairing voids

Inspection/Maintenance/Monitoring Regime

Further works were carried out on the concrete in the tower in the following year to ensure that the structure could continue operating. The tower was then painted to protect the laminates from direct UV and to ensure that the finished product was well presented.

Figure 5. Strengthened and painted Prill tower