ZENITH

FRP Repair to a Reinforced Concrete Chimney

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David has over 19 years experience in the Industrial Chimney Industry giving David a specialist insight to the issues related in the rigging of tall structures. David has successfully managed numerous projects on oil refineries and power stations worldwide.

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Mo Ehsani is Professor Emeritus of Civil Engineering at the University of Arizona and President of QuakeWrap, Inc. He pioneered the field of repair and retrofit of structures with externally bonded FRP in the late 1980s and has applied this technique to numerous award-winning projects worldwide.

Introduction

This paper reviews the background, philosophy, repair scheme, scope and methodology used in the inspection and strengthening of a reinforced concrete chimney.

Background

The climate in the country where the chimney is located is continental. In the summer the temperatures can reach more than 53 Degrees Celsius and in winter the temperature can sink as low as minus 58 Degrees Celsius. The structures are exposed to some of the most extreme weather conditions this continent can experience.

This particular structure was constructed and commissioned in 1984 and has suffered from the absence of a proactive inspection and maintenance plan. (Figure 1)

FIG. 1 OVERALL VIEW OF THE CHIMNEY

In recent years the asset management and the local authorities have actively pursued a shift in attitude from reactive to proactive maintenance. Zenith was engaged to provide inspection criteria to determine a 'benchmark' condition in order to engage future inspection and maintenance.

Inspection Philosophy

The inspection criteria produced by Zenith was taken from the CICIND publication 'Manual for Inspection and Maintenance of Concrete and Brickwork Chimneys' and some additional information taken from various past experiences.

The inspection philosophy was to engage a partially destructive inspection of critical and less critical items including concrete windshield performance, capping detail, flue duct inlets and supports, steel lining performance, gas seals, expansion joints and surface coatings.

The detailed inspection impacted on the off-stream timeline. The asset management considered the off-stream duration and pursued a second option. The second option was based on a non-destructive visual examination of all accessible components. The reduced scope limited the conclusions that could be drawn from the inspection but suitable to allow a basic 'benchmark' result to be formulated.

The final scope required a visual examination only of the critical and less critical components.

Inspection Findings

The uppermost 5 meter section of the concrete windshield was found to be in a very poor condition. The reinforced concrete was found to be porous with large sections of spalling and decaying concrete noted throughout. Cavities through the windshield were found in three different elevations (Figure 2). Reinforcement steel was found in a serviceable condition but the concrete was now in a state of disrepair (Figure 3).

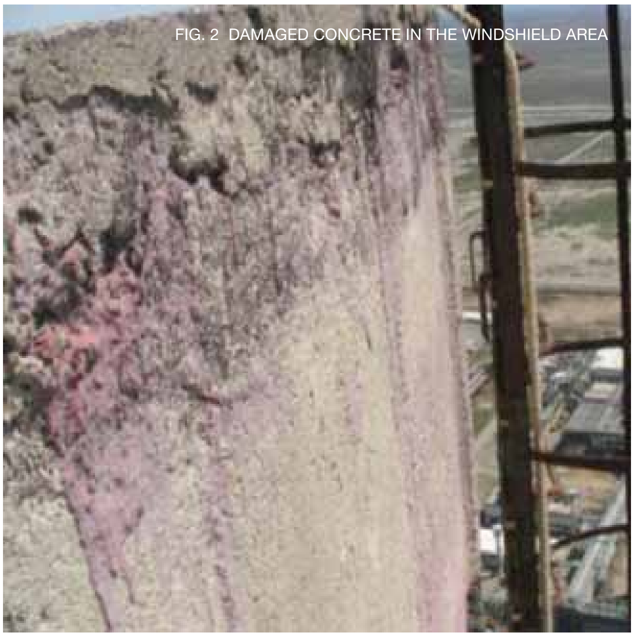


FIG. 2 DAMAGED CONCRETE IN THE WINDSHIELD AREA


FIG. 3 DAMAGED CONCRETE AND EXPOSED REINFORCING STEEL

The upper 30m of the in-situ caged access ladder and the uppermost full circumference steelwork platform were found to be in a very poor condition and required renewal.

The chimney lining comprised of two steel supported liners. The lining is not the subject matter of this paper but may well form the basis of a separate future technical paper.

Repair Scheme

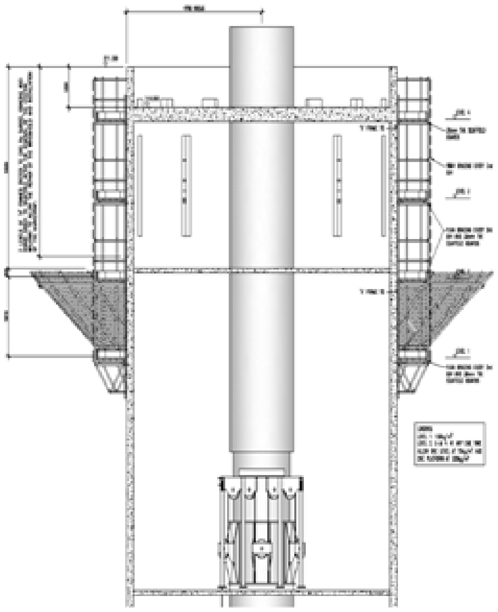
The strength and durability of the top of the chimney windshield was deemed to have weakened significantly and required re-strengthening. A number of options were available.

However, in this environment and taking into account the resources available the preferred option was to re-strengthen the top of the chimney with a 'Fiber Reinforced Polymer'. This technique has been used in a number of similar projects where there has been general degradation over the full circumference for a relatively short distance from the top.

Access Method

In order to facilitate access to the work area, Zenith's Structural Engineering Department designed a full circumference scaffold to envelop the entire area complete with a fan deck at a position 6m below the chimney termination point. (Figure 4)

FIG. 4 TEMPORARY WORKS DESIGN



Applicable Codes of Practice & Regulations

Management of Health & Safety at Work Regulations
Provision and Use of Work Equipment Regulations
Construction (Design and Management) Regulations
Construction (Health, Safety & Welfare) Regulations
Lifting Operations and Lifting Equipment Regulations
Work at Height Regulations

British Standards, European Norms and More:

BS 5974	Temporarily installed suspended scaffolds & access equipment.
BS EN 12811-1:2003	Temporary works equipment. Scaffolds. Performance requirements and general design
BS EN 12811-2:2004	Temporary works equipment. Information on materials
BS ISO 4308-1:2003	Cranes and lifting appliances. Selection of wire ropes.
IBC	International Building Code

ASTM	American Society for Testing and Materials
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ACI	American Concrete Institute
ACI 440.2R-08	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures."
ACI 440 R-96	State-of-the-Art Report on Fiber Reinforced Polymer (FRP) Reinforcement for Concrete Structures.
ACI 503 R	Pull-off test to determine FRP adhesion to concrete substrate.

Governing Factors

- **Environment**

The repair scheme proposed was to limit any off-stream time to a minimum. This repair scheme could be completed on-stream to a safe distance from the top of the chimney (6.00 meters). One of the flue liners was off-line whilst the other had a temporary heat shield extension thereby allowing safe access to the work area.

- **Resources**

The design of the FRP retrofit was completed by QuakeWrap engineers. The windshield area of the chimney presented signs of deterioration caused by constant exposure of corrosive vapors from the fumes. Repairing damaged areas with mortar alone was not sufficient to guarantee reoccurrence of spalling; therefore, alternative repair methods had to be considered. The repair materials not only had to guarantee full bonding with the substrate, but also confine the structure and protect it against corrosion for years to come.

Fiber Reinforced Polymer (FRP) materials are very versatile and offered unique advantages for repairing a structure of complex shape with multiple openings. For this project, a biaxial glass reinforcing fabric was selected. When properly installed, this fabric provides a tensile force equivalent to a 10 mm reinforcing steel at a spacing of 200 mm in both horizontal and vertical directions. Visual inspections of the damaged sections indicated that this level of reinforcement was more than the loss of strength that had occurred due to the corrosion of reinforcing steel. The biaxial glass fabric provides reinforcement in two orthogonal directions, allowing the interception of potential cracks.

- **Applicators Qualifications**

1. A minimum of two (2) years experience applying composite fibre-epoxy strengthening system to existing concrete elements.
2. Written certification from the manufacturer as an approved installer of the manufacturer's products.

Execution of the Works

The temporary scaffolding was erected on the external face of the windshield, leaving a clearance of about one foot between the scaffold and the concrete surface to facilitate the installation of the fabric. All damaged and defective concrete had to be repaired to be suitable to receive the FRP system. Special structural mortar and patching materials were used for this purpose, targeting areas where surface was not even or sunken. (Figures 5 and 6).


FIG. 5 REPAIR OF DAMAGED CONCRETE WITH MORTAR


FIG. 6 PATCHING OF DETERIORATED CONCRETE WITH MORTAR

Surface Preparation of Existing Concrete:

1. All surfaces shall be dry and free of surface moisture and frost.
2. All surfaces shall be sound. Remove deteriorated concrete, dust, laitance, grease, paint, curing compounds, waxes, impregnations, foreign particles, and other bond inhibiting materials from the surface by blast cleaning or equivalent mechanical means.
3. Surfaces shall be prepared for bonding by means of abrasive blasting or grinding to achieve maximum amplitude of 1/16". All contact surfaces shall then be cleaned by hand or compressed air to a dust free condition.
4. Surface irregularities less than one inch shall be filled with an approved repair mortar and smoothed. Surface irregularities greater than one inch shall be repaired using an approved cementitious repair mortar.

5. External corners shall be rounded to at least a 1/2" radius when perpendicular to fiber orientation and internal corners shall be smoothed by trowelling epoxy mortar into the corners.

6. The adhesive strength of the surface shall be verified after preparation by random pull off testing (ACI 503R) at the direction of the Engineer. Minimum tensile strength is 200 psi with concrete substrate failure, or as approved by the Engineer.

A special saturating table was constructed at the bottom of the chimney (Figure 7). Pieces of fabric about 1.2 m wide x 6 m long were saturated with a two component epoxy resin. The option of performing this task at the top of the chimney was considered at first; however, due to space limitation and high winds, this option was ruled out. The saturated rolls of fabric were wrapped around a PVC tube for ease of transportation and handling.


FIG. 7 SATURATING TABLE

Once the resin was mixed (Figure 8) and poured onto the fabric, the crew was against the clock since they only had close to twenty minutes from the resin mixing to the final installation of the fabric on its final destination. Usually, when resin starts to set while the fabric is being installed, it becomes difficult to handle and is not recommended to use it. Being on a remote location, wasting of materials due to temperature was not an option, therefore, special care was taken on the timing and handling of materials. Saturation of dry fabric and the application of the bonding agent (epoxy paste) were done simultaneously and by the time that the saturated fabric arrived on top, the coated surface was ready to receive the fabric, which created a nonstop routine.

As the first step of installation, a high-viscosity epoxy (Tack Coat) was mixed and applied with a trowel to the concrete surface (Figure 9). The thickness of this coating was approximately 1 mm. Installation process began at the interior-top part of the chimney (Figure 10), applying the fabric vertically and unrolling it all the way down (Figure 11), ensuring that any entrapped air between the fabric and the concrete surface was removed. A crew of four men performed this task on top of the chimney, where the high wind gusts often added to the challenge of the installation.


FIG. 8 MIXING OF RESIN


FIG. 9 APPLICATION OF TACK COAT


FIG. 10 INSTALLATION OF THE FABRIC

FIG. 11 INSTALLATION OF FABRIC

The FRP fabric was cut and trimmed around the openings (Figure 12). This added a little extra time to the installation and on hot days care had to be taken to ensure that these activities could be completed before the epoxy would begin to set. Installation of the fabric was facilitated through a clearance of approximately one foot between the scaffold and concrete substrate (Figure 13) that allowed the fabric to go all the way down to the limits of the repair area, and then trimmed at the bottom (Figure 14).

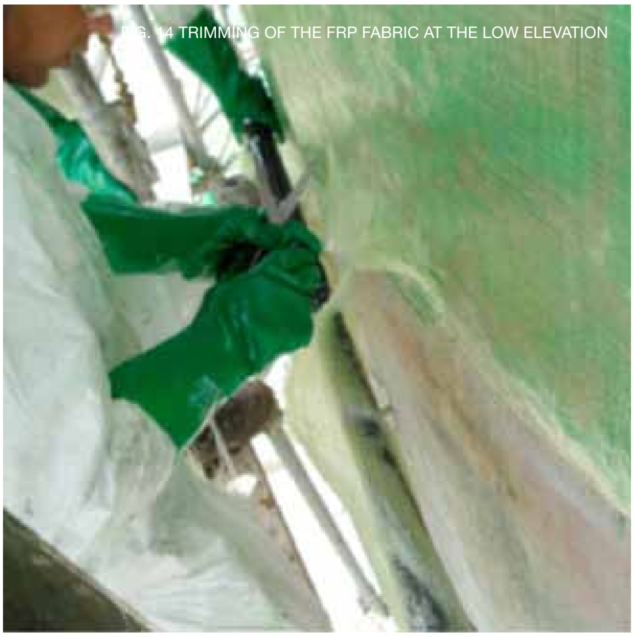


FIG. 14 TRIMMING OF THE FRP FABRIC AT THE LOW ELEVATION

FIG. 12 CUTTING OF FABRIC AROUND OPENINGS

The FRP application process continued non-stop for four days at a height of 690 ft from the ground, checking and inspecting the quality of the application and repairing any imperfection that might have occurred due to the wind or other factors. After the FRP installation was completed, a special coating of chemical liquid plastic heat tolerant acid resistant paint was applied to the windshield area, restoring the original colour of the chimney (Figure 15).

FIG. 13 GAP BETWEEN SCAFFOLDING AND CHIMNEY

FIG. 15 REPAIRED CHIMNEY AFTER APPLICATION OF PAINT

On completion of the FRP application, the top 30m of the caged access ladder and in addition the top full circumference access platform were replaced.

Future Maintenance

The future inspection criteria have been developed to include inspection of the modified region of the chimney and development of a proactive maintenance scheme to ensure the longevity and performance of the structure. The FRP system is not expected to require any maintenance during its service life.

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