Restoration Of Brick Chimney By CFRP Method

Dr. Gopal Rai(1), Chandan M(2).

(1) Ph.D. (IIT Bombay), CEO:Dhirendra Group of Companies.

(2) ME. (UVCE Bangalore), Earthquake Engineering.

Team members:

1. Client: ITC Infotech Bangalore (FMS&CPO)
2. Design and execution: Dhirendra group of companya specialised construction company
3. Consultant: Dr. Chethan K. Assistant professor, Department of Civil engineering, UVCE, Bangalore.

Abstract:

Brick chimneys in the path of industrial revolution have always been important structure in the landscape. The advancement in technology brought high end machines which runs by electric power. Hence the functional significance of the structure is lost over years. Butthey have taken another direction in their importance as a historic or heritage structure. Most of the chimneys throughout the world are extinct because of poor/no maintenance.Here it describes restoration of one such chimney located at ITC limited Bangalore with the advanced method of retrofitting using carbon fibre reinforced polymer. The chimney which is given new lease of life concentrated to enhance its resistance towards hoop stresses. The chimney is strengthened and restored usingcarbon fibre reinforced polymer composites. Regardless of their limitations which are absolutely taken care of, it has proved its effectiveness during and after the execution over conventional methods. The assessment of deterioration, the better possible solution based on the probable causes for the deterioration, methodology followed to fix various types of deterioration are also discussed.

Keywords: *heritage structure, Polymer composites, hoop stresses effectiveness.*

1. Introduction:

Chimney is basically designed to facilitate exit of the smoke produced from the fire place or furnace. It also jobs as a draft that provides air to the fire. In the late 18th century Sir Benjamin Thompson established the definitive forms and proper relationships of the chimney's essential parts. The conventional brick chimney, forming the first industrial installations is nowadays replaced with construction of engineering design and dimensions. A brick chimney is composed of three main elements,

Base: Main purpose is to transmit the loads on the stack to the foundation

Stack: Most important part of the chimney that carries away the smoke and increasing the draught needed to burnthe coal efficiently. Shape is usually round or polygon.

Crown: Decorative part protects the structure against rainwater seepage.

The height of the chimney can range from 20 to 50m, however there are chimneys higher than 100m and even as high as 178m.

Dhirendra Group of Company (DGC)

2. Defects in the chimney

The possible defects in the chimneyare listed and are may be due to poor quality of material, workmanship, construction methods and weather conditions.

- Flacking of bricks over time can cause complete disintegration.
- Degradationof mortar weakens the joints
- Predominant winds may cause permanent displacement of not designed properly.
- In the lower section of stack when the combustion stops the temperature quickly falls. This variation can cause tensile forces strong enough to produce crack of diverse magnitude.
- Moisture in the chimney can cause degradation.
- Lightning strikes are responsible for some serious structural cracks or collapse
- An earthquake forces usually cause damage near the base or in the upper third of the chimney
- Damage may also be caused by living organisms.
- In recent years another type of damage has been found in the form of a deficient restoration operation or repairs, which may not only affect the chimney's aesthetics but also its structural behaviour.

Figure 1: ***Important parts of chimney***

Figure 2: ***Erection of scaffolding around the chimney.***

3. Fibre Reinforced Polymer Sheet Wrapping

The selection of a proper strengthening and repair technique is closely related to the state of the structure to be strengthened, the targeted effects, the environmental conditions, etc. Between alternatives, the final evaluation is mainly driven by the cost effectiveness, where it is not only of interest to minimize initial costs, but also the future maintenance costs. FRP material consists of a large number of advanced features of small, continuous, oriented, non-metallic fibre composition, implanted in the polymer matrix. Utilized as structural reinforcement. Carbon fibre wrapping uses structural carbon fibre for strengthening technique causes minimum disturbance to the structural members as compared to conventional methods.The carbon fibrewhich has properties such as high and low temperature properties, long working time, high elongation of about 1.2%, ambient cure and 100% solvent free. The density of the fibre is 1.8g/cm2 elasticity modulus of such fibre ranges from 220-240 GPa, dry fibre tensile strength 4000-4500 MPa.

4. Case Study

A brick chimney built using country burnt bricks during the year 1912-1919 is now the historic/ monumental structure located at ITC Limited Bangalore.It is in the late months of 2018, strengthening of this structure got commenced.
After the research made by the expertise in the company R&M International Pvt. Ltd. they came up with procedure to strengthen such brick chimney. The work was continuously monitored and advised by the expertise throughout the execution period and was finally completed in the month of March 2019.

4.1 Description of the structure:

The structure is 23m high chimney containing two stepped square pedestal at the base having dimension 3.2mX1.65m (side X height) and 3.0mX2.35m. The stack is circular in shape which is 18m high with bottom diameter 2.6m and top diameter 1.8m. The crown has circular band which adds to the beauty of the structure.

4.2 Assessment

- The chimney is 100 year old industrial structure built with alternate header and stretcher course.
- The thickness of the wall at the top is 230mm and at the bottom predicted to be 630mm.
- Base of the chimney is found to be plastered with cement mortar whereas the stack is just painted multiple times in the opinion of maintenance.
- Earthing cable was found to be tarred at the ground level.
- A 4m length crack is found at the location 2m from the top and it is identified to be structural one. It may be due to following reasons,
  1. Excessive axial or hoop stresses.
  2. Failure of lightning arrestor.
  3. Earthquake forces or by predominant winds.
  4. Closeness of masonry joints.

4.3 Problem statement:

Improvement in the resistance to axial and hoop stresses are focused to encounter,and thus to preserve the structure over longer period. Hoop stress is the one which is set up in resisting the bursting effect of the applied pressure and can be most conveniently treated by considering the equilibrium of the cylinder. $\sigma H = (p \cdot d) / 2t$, where p is the pressure d is the diameter and t is the thickness of the cylindrical section.
A stress that tends to compress or elongate are termed to be axial stresses. Although there was no exact prediction of the stresses the design has been made in the direction of durability and longevity of the structure.

Figure 3: Assessment of crack on the stack.

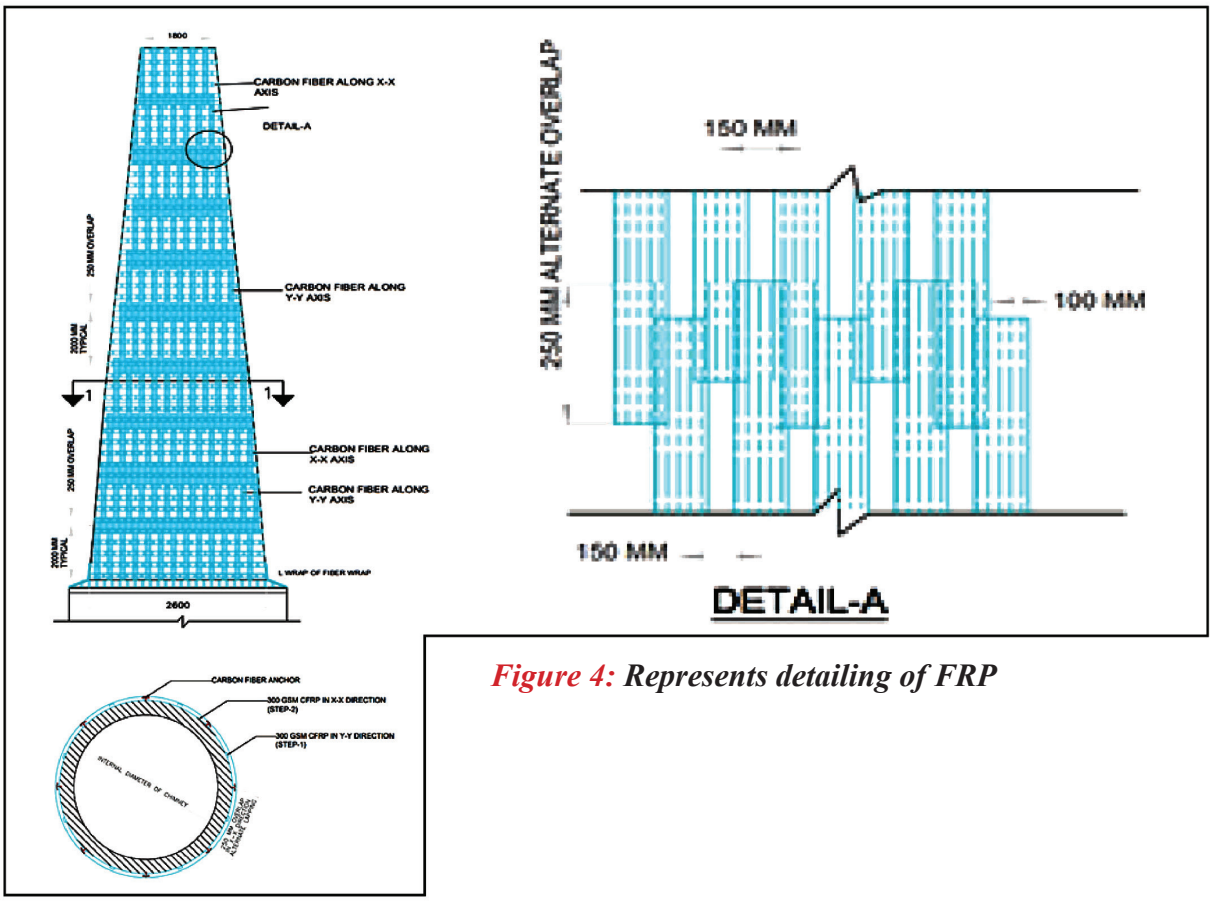


Figure 4: Represents detailing of FRP

4.4 Detailing adopted: On the base of the chimney,

- 100mm wide 300GSM CFRP at 300mm c/c both in X and Y direction.
- Carbon anchors at 300mm c/c in both the direction.
- Carbon fibre at the corner with an inclination of 45o, 100mm wide.

As there is offset in the pedestal in vertical direction there will be concentration of stresses at the corners, these stresses which in future may results in diagonal cracks, to mitigate such effect, inclined strips are provided.

On the stack,

- 300 GSM CFRP of 100 mm wide @ 150 mm c/c in x& y directions with carbon fibre anchors at 1000 mm c/c.
- Length of the strip shall be 2000 to 2300 in vertical direction as the stack is tapered.
- 250mm overlapping is taken both in vertical and horizontal strips for the effectiveness of fibre wrap.
- Carbon anchors are provided 500mm diagonal spacing between two adjacent strips.

The three major stresses to be addressed in the design of chimney are developed due to,

a) Self-weight of chimney: Self weight of the chimney corresponds to the dead weight of the brick masonry and lining at the crown

b) Wind pressure: The design wind load on chimney depends on cross-sectional shape of the chimneyand hence for circular shape factor of 0.7 can be considered.(7)

Table 1: Testing results

Trial no.	Sample Description	Failure Load (kN)	Failure Plane	Interpretation
1	Bare Brick surface (without any CFRP system) – Right face top pedestal	0.70	Brick Surface	As the failure occurred in the brick, the epoxy overlay at the interface is sound and intact.
2	Single strip CFRP system on brick – left face bottom pedestal	0.90	Brick Surface	There is 28% (0.2 KN) increase in the failure load as well. Weaker plane still being in the brick.
3	Triple strip CFRP system on brick– left face bottom pedestal	Exceeds permitted range	Failure did not occur	No failure was observed in either brick or FRP system.

c) Temperature stresses: Due to temperature gradient between inside and outside faces of the chimney stresses gets developed both in horizontal and vertical direction. Inner surface being at higher temperature will have the tendency to expand but the outer fibres will try to restrain this effect. Hence the retrained expansion results in compression of the inner fibres and tension of the outer fibre in this consequence the stack is subjected to bending moment in vertical direction.

4.5 Methodology:

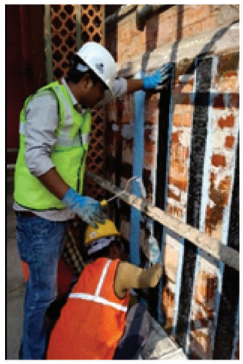
- Surface preparation includesremoval deteriorated brickwork, dust, foreign particles, and other bond inhibiting materials from the surface by equivalent mechanical means.
- Application of bonding coat, after the surface has been made free from all the loose particles and the bricks are exposed, one layer of bond coat (chemical for proper bonding between existing and new surface) has to be applied on the exposed brick surface.
- Application of surkhi mortar and polymer modified mortar:Applied to treat deteriorated brick surface matching material composition and also to make a plain surface for real bonding with CFRP.
- Application of primer:Primer is applied over the surface in a given proportion and allowed to cure for at least 12-24hrs.This helps in providing compatible surface for the saturant and also fills very minuet voids on the surface.
- Application of carbon fibre:includes application of first coat satuant followed by carbon fibre wrap, anchoring, second coat saturant and finally sand sprinkling
- Plastering, giving brick texture and then painting, the plastered surface is cured for around 10 to 15 days. Brick texture is given before the plaster is dried.
- Fixing lightning arrester and top cap of GI material with anticorrosive coat on it is placed at the top.

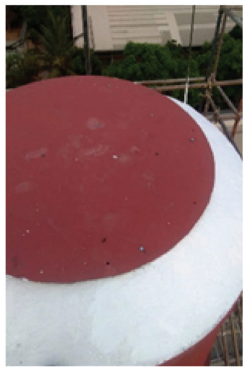
Dhirendra Group of Company (DGC)

4.6 Testing:

To assure the effectiveness of the CFRP system with brick work against its bonding, Pull Off tests were performed at three different points on the surface of a repair or an overlay material. The method may also be used to evaluate the bonding strength. Reference: ASTM C-1583-04.

The test was successfully performed at the three test locations, the results of which are given in table below.





5. Conclusion

- Chimneys are affected by different types of damage and suffered from poor maintance. Hence proper repair and rehabilitation is required to enhance its aesthetics and structural behaviour.
- The technology of fibre wrapping as a rehabilitation method not only increases stratural significance will also contribute to low maintanance charges in the future perception as it has various advantages in the direction of durability.
- From the qualitative analysis carried out by testing, we can conclude that, fibre along with saturant will have better bonding property with brick work as well.
- FRP not only served for its conservation but also the strength of the structure as a whole has been significantly increased.

6. References

1. P. Spratt & J.W. Jordan (2005) The conservation of masonry chimney stacks, Australian Journal of Multi-disciplinary Engineering, 3:1, 27-34, DOI: 10.1080/14488388.2005.11464730

2. Peter Spratt. Preservation of Old Buildings, Salt Attack and its Control, Paper to 1981 IEAust. Conference, Canberra.

3. A. Ghobara, T. Baumber,Seismic response and retrofit of industrial brick masonry chimneys. Concordia university on 02/15/19.

4. Arya, A.S., and Paul, D.K. 1977. Earthquake response of tall chimneys. Proceedings of the Sixth World Conference on Earth- quake Engineering, New Delhi, India, Vol. 2, pp. 1247-1257

5. Atkinson, R.H., Amadei, B., Sture, S., and Saeb, S. 1987. Deformation and failure characteristics of masonry bed joints under shear loading. Proceedings, Fourth North American Masonry 128 CAN. J. CIV. EN (3. VOL. 19, 1992 Conference, the University of California, Los Angeles, Calif. Vol. 2, pp. 61-1 to 14.

6. Shiau, L.-C., and Yang, H.T.Y. 1980. Elasto-plastic seismic response of chimney. ASCE Journal of the Structural Division, 106(ST4): 791-807.

7. Dr. R. N. Krishnaraju Advanced reinforced concrete design (IS 456-2000). Second edition