# Use of FRP Composites for Rehabilitation of Heritage Structures

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All heritage buildings have their unique historical significance. Their character defining elements that account for its heritage values vary from structure to structure. The master builders of the Middle Ages were able to use geometrical rules, developed through centuries of trial and error, to build structural elements at times when there was no knowledge of material properties or allowable stresses.

The preservation and strengthening of heritage structures is tricky, the intended change in the use of such building will invariably create difficulties to tackle, which in turn would make compliance with the statutory building safety and health requirements a challenge. Another balance to be considered is the need for preservation of character-defining elements of the heritage buildings and the need to comply with the minimum building safety and health standards.

Repair and strengthening by grouting of brick and stone masonry walls has been largely applied throughout Europe on historic buildings, nevertheless no great effort was done in advance and during the time to test the effectiveness of this technique.

The seismic resistance of historic masonry buildings is a special scenario to consider. The seismic analysis of unreinforced masonry structures is a field in its infancy, with most earthquake engineers insisting that historic buildings do not have sufficient ductility to resist a major seismic event. Many engineers would propose that a structure need to be strengthened to improve its seismic resistance, but as a profession, we should caution that our understanding of the seismic response of masonry buildings is limited at present.

Many reasons are present for proper attention to be given to these heritage/ Masonry structures. The following are the major reasons for them to undergo rehabilitation, strengthening:

1. Temperature changes and exposure to moisture and other environmental factors result in deterioration, weakening, fatigue effects, chemical attacks, weathering and inadequate maintenance and distress of masonry elements.

2. Old masonry construction as unreinforced structures is especially vulnerable due to many environmental calamities like:

♦ Earthquakes ♦ Tsunamis ♦ Excessive rain ♦ Soil pressure ♦ Settlements due to underground construction ♦ Problems due to construction of newer structures around and below. ♦ Vibrations induced due to various factors. ♦ Fire also weakens the structure and calls for rehabilitation.

3. These structures are often overloaded over the period of time as the requirement of floor space and strength has become high with the today's world.

4. The use of many structures has also changed many times during the time. As the structure were not designed and made for all kinds of future loads, it is very evident that these structures need attention and strengthening.

**There are numerous ways of doing the strengthening.**

- **Confinement:** It literally means to impede the deformation.
- **Reinforcement:** Taking use of new materials and technology to build sections around to impart extra strength.
- **Enlargement:** Widening of the resisting section with the addition of new material.
- **Material substitution:** Removal and replacement of damaged parts of a structure. The materials used in the reconstruction may be similar to the original ones or possess better mechanical properties.
- **Structural substitution:** Creation of new load bearing structure with modern materials, without the dismantling of the old one.
- **Tying:** Binding together different elements or different parts of a single element.
- **Propping:** Supporting a part of a structure with additional elements made of steel or other new materials. The main distinction has to be made between lateral propping (strutting) and vertical propping.
- **Anchoring:** Fastening an element or a part of a structure to a firmer solid. The most diffuse form is an-choring to rock and soil. This intervention is used to improve the stability of a structure and to avoid its collapse in case of a seismic event.
- **Prestressing:** Changing the stress field in a structure or in an element using external loads or induced compression before loading.
- **Isolation:** Absorbing the seismic forces and vibrations in external devices usually placed between the proper foundation and the masonry structure.
- **Soil stabilization:** Intervention focused on the soil beneath the structure, aiming at an improvement of its bearing capacity.

**Most of the above techniques and materials involve the following**

- Use of heavy materials inducing dead load
- Changing the original floor space and creating more space constraints

by increasing size and inducing new structural members
- Semi-destructive practices involved, which are very harmful and undesirable for old structures as they need to be conserved and some of them are of high cultural values
- Changing the look and aesthetics of the existing structure as it involves erecting new members, enlargement of size, use of different and new materials etc.

Finally, it is the responsibility to understand the proper requirement of these structures as they are not from the modern world and have to be taken care with proper expertise and guidance i.e. errors in any kind of restoration are highly un desirable.

FRP composites when used properly on these structures, they are best suited for tackling these problems of masonry structures, which can be used to make them durable, ductile and stronger for the times ahead.

This paper further presents some use of FRP strengthening techniques in masonry structures.

## FRP Use in Structural Repair and rehabilitation

FRP composites have been lately very popular in the field of structural rehabilitation. The use of materials, like carbon or glass fiber composites, has considerably increased in the field of rehabilitation. RCC structures that have been successfully rehabilitated and strengthened have considerably increased.

The FRPs present several well-known advantages, including negligible specific weight, corrosion immunity, and high-tensile strength. Flexibility and easy application also allow a wide range of application areas that is strengthening and restoration in several damaging conditions.

Masonry structures have always been used since the dawn of construction, and nowadays, due to aging, material degradation, settlements, and structural alterations, usually some members need strengthening to re-establish their performance. In this aspect, FRP composites in the form of bonded laminates applied to the external surface of masonry have become a viable solution. The most important reason is that they comply with the cultural value of the building.

There are numerous possibilities in terms of material properties and application methodology of FRP materials in old heritage structure as it is important to conserve the cultural significance and aestheticity of the structure. The following is the major applications of FRP composites in masonry structures.

There are two techniques, which are normally adopted for strengthening of masonry systems.

- **Single layers of composites and FRP wrap:** In this method, separate matrix and fiber are used, and they form the composite at the place of application after wet Lay-up. It is also known as wet Layup system.
- **Carbon Composite Laminates:** In this method pre-cured carbon fiber laminates/Plates are used, which are bonded adhesively with the structural member.

The guidelines are very important for any technology/ method to be commonly accepted and used. Lack of guidelines for strengthening of masonry structures with FRP have for been resisting the use of these materials on masonry structures. The technical committee of ACI 440 is working on bringing the code for use of these materials. Until then the use of FRP composites have to be made aware by publications and journals.

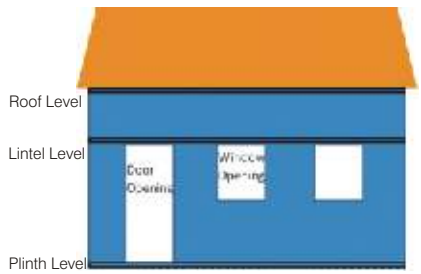
FRP can be effectively used in strengthening on the walls in flexure by applying procured laminates or rods made of FRP in the vertical direction (Fig 1).

Fig 1. Flexure and shear strengthening of the walls using FRP Composites

Shear Strengthening can be done by using FRP Composites and applying in horizontal directions as shown in Fig 1.

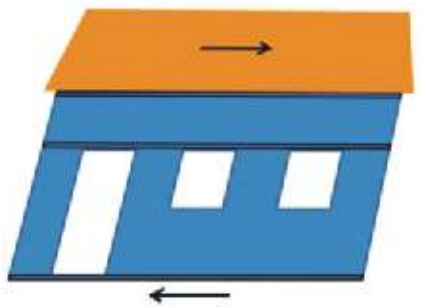
Seismic strengthening: As shown in fig the behavior of Masonry structures in the effect of seismic forces.

The actual cracks developed after an earthquake is shown in Fig 3.

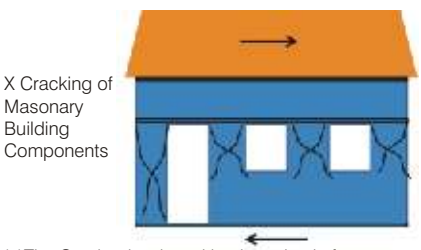



Masonary Building Components

(a)Basic Masonary Components



(b) Rocking and seismic forces acting on the structure.




(a)The Cracks developed by the seismic forces

Fig 2: The seismic behavior of the structure

The strengthening of these components is done by applying cross laminates so that they can resist the move-

Santa Monica, Northridge Earthquake, 1994

Fig 3: Cracks developed in the earthquake.

ment and development of these cracks in the direction perpendicular to their application. Examples are shown in Fig 4.

Fig 4: Diagonal Bracing of wall for strengthening

### Case Study 1: Retrofitting of a Old Bungalow in Alibag

In Alibag, an old bungalow was in bad condition as per structural point of view. It belonged to a known business man in south Mumbai. Bungalow is a load-bearing structure and number of floor is G+1. It was found that some horizontal crack near first floor beam.

To protect the structure from any further cracking and harm a structural consultant was appointed, and he collaborated with R&M International to execute the work. It was decided to be done with the help of glass and carbon fiber from both the face of the wall. The Bungalow and cracks are shown in Fig 5, 6 and 7.

R&M International was appointed for the execution of the work. It was successfully completed in 2012. The following was used to strengthen the wall.

Fig 5: Front View of the Structure.

Fig 6: Horizontal Crack on the Structure.

Fig 7: Horizontal Crack in the wall

a. **Carbon FRP:** First Carbon fiber is applied over the structure. The orientation of the carbon fiber sheet was vertical as shown in Fig 8a.
b. **Glass Fiber:** After curing period of carbon fiber sheet, horizontal sheet is applied as per the drawing as shown in Fig. 8b.

The same procedure was used to retrofit the structure from inside.

Fig 8: a) Vertical Application of C- FRP wrap and horizontal application of G-FRP.

Fig 8(b): The Back side view of the structure.

### Case Study 2: Repair and Strengthening of Settlement affected old structure in Delhi.

The US India Foundation is located in Caunaght place, New Delhi. The Building under consideration was built in 1928. The structure is a load bearing brick masonry G+1 structure.

Due to ongoing tunneling below the structure cracks were developed in the brick walls and the cracks were seen in the right hand side block of the structure. As the client wanted the structure to be safe and strengthening measures to be undertaken.

The following observations were done for the cracks developed.

- The cracks were present in the right hand side of the structure and in the middle portion.
- The cracks were uniformly present in all walls and columns of the structure.
- Two major cracks were present, which could be seen to have a clear presence throughout the wall.
- The cracks were present at the first floor as well as the ground floor.

As the cracks were present all over the walls in the right hand side of the structure, it becomes important to take

care of the cracks and to give extra strength so as to remove any concern, which might arise in future and makes the structure stable.

Fig 9: Major crack developed on the 1st floor as seen from outside

Fig 10: Cracks present as seen inside on the columns and on the top.

## Repair Methodology

The following were the steps involved in repairing and strengthening of the structure.

- All the area where cracks have appeared had to be cleaned and all the plaster and other superficial and protective materials such as the gypsum, etc had to be removed where the cracks had been noticed.
- The area where crack had propagated needed to be cleaned and exposed properly with the help of sand papers and less impact tools.
- The crack propagation can be of two types. They can either be on the joint which is the more likely one, and it can also be through the bricks.
- The cracked mortar has to be removed by means of a toothing chisel or a special pointer's grinder, to a uniform depth that is twice the joint width or until sound mortar is reached. Care must be taken not to damage the brick edges. Remove all dust and debris from the joint by brushing, blowing with air or rinsing with water.
- Refilling or repointing mortar should be carefully selected and formulated. It is always advised to produce best results to fill them with the original mortar itself. Otherwise, a mix of 1 part Portland cement, 4 parts hydrated lime and 11¼ to 15 parts fine sand is used to fill the removed mortar space.
- The repointing mortar should be prehydrated to reduce excessive shrinkage. The proper prehydration process is as follows: All dry ingredients should be thoroughly mixed. Only enough clean water should be added to the dry mix to produce a damp consistency which will retain its shape when formed into a ball. The mortar should be mixed to this dampened condition 1 to 1½ before adding water for placement. The joints to be repointed should be dampened, but to ensure a good bond, the brickwork must absorb all surface water before repointing mortar is placed. Water should be added to the pre-hydrated mortar to bring it to a workable consistency (somewhat drier than conventional mortar). The mortar should be packed tightly into the joints in thin layers (6.4 mm maximum), as shown in Figure 5c. The joints should be tooled to match the original profile after the last layer of mortar is "thumbprint" hard, as in Figure 5d. As it may be difficult to determine which joints allow moisture to penetrate, it is advisable to repoint all mortar joints in the affected wall area.
- For cracks hairline in the bricks. If the bricks are very much damaged it can be removed and replaced one at a time. A small part of the brick could also be used and replaced by using the repointing mix as described above.
- The whole repaired surface will be then applied with carbon fiber wrap as per the Fig 6. The full drawing is enclosed with the report.

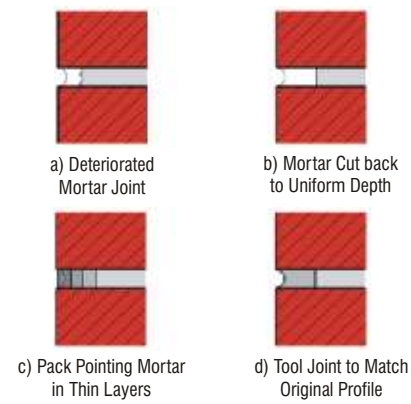
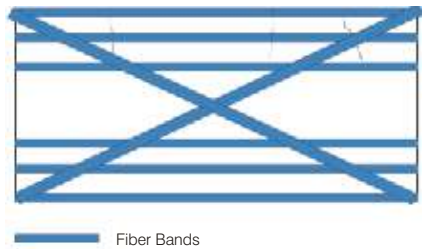



Fig 11: Repointing Methodology in the joints.




Scheme of Fiber Treatment for Strengthening walls

Fig 12: Wrapping details along the Walls which were affected by cracks.

- The columns have to be installed with fiber wrap with laminates where the plane is changing as shown in figure 7.

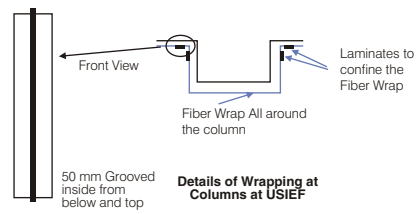



Fig 13: The details of confinement of columns with FRP and Laminates

Fig 14: (a) Column Wrapping done for confinement and strengthening (b) Wraps done over the cracks for arresting them.

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