STRENGTHENING OF EXISTING REINFORCED CONCRETE BUILDINGS STRUCTURES FOR SEISMIC

USING CONCRETE JACKETING AND FIBER REINFORCED POLYMERS (FRP)MATERIALS

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1- INTRODUCTION

Reinforced concrete (RC) is a composite material made of concrete and steel reinforcement. Concrete is composed of cement,

filler, and water as well as corresponding additives for improving its characteristics.

The structure of concrete is quite complex, and its main components should be carefully selected using all available

Techniques to provide the corresponding necessary quality.

Despite the great advancement in the field of construction technology, control of built-in materials (quality of cement, filler,

and water), transport, and layering of concrete, it often happens that the built-in concrete does not reach the designed concrete

class. Sometimes, this deviation is of a larger scale. Therefore it is necessary to anticipate and take measures for repairing and

Strengthening that may be used for a smaller or a greater number of structural elements and the structure as a whole. The same

Problem may also occur during construction of additional storey's and enlargements. For this case, the existing structural system

can not satisfy the requirements for additional strength, stiffness, and deformation capacity.

It is a usual practice to repair and strengthen structures by using traditional methods (most frequently, jacketing of elements

). Recently, new innovative materials that use special construction technology are being applied to repair structures. The

Application of these materials is still the subject of a large number of investigations worldwide, especially regarding their utilization

in seismically active regions.

2-REPAIR AND STRENGTHENING OF BUILDINGS STRUCTURES

Strengthening of RC structural elements is an existing method to increase the earthquake resistance capacity of damaged or

Undamaged buildings. The strength of these structures can be moderately or significantly increased along with an improvement

in ductility. In other words, the concept of strengthening involves: a) increase in strength, b) increase in strength and ductility and

c) Increase in ductility, (Figure 1).

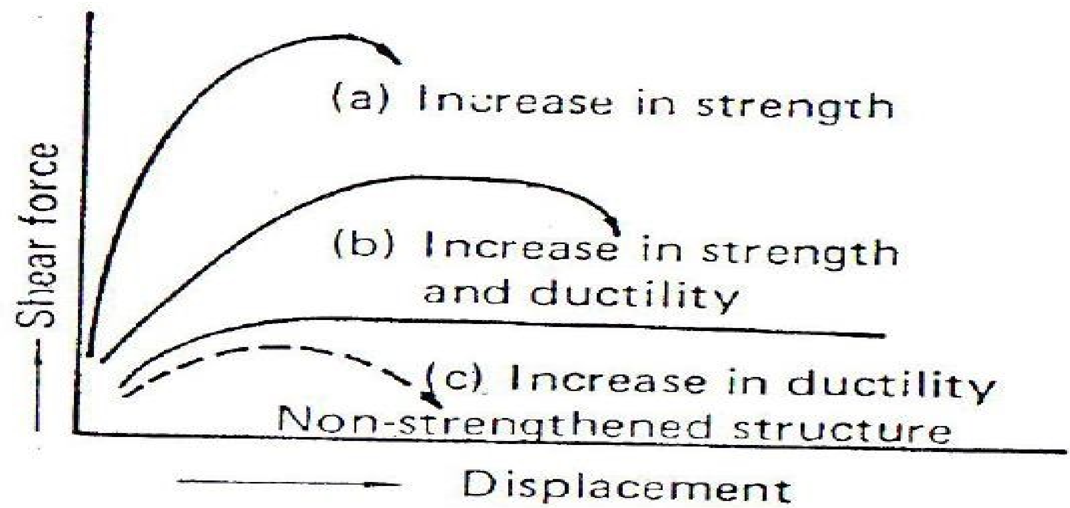


Figure 1 Concept of seismic strengthening

The methods for repair and strengthening of structures can be categorized into two main groups: sys tem

based repair and strengthening (global strengthening) and member based strengthening (local strengthening).

In system based strengthening methods, a structural system is modified by adding members such as RC

shear walls or additional steel bracing to improve the strength and stiffness characteristics of the building system.

A new frame can be introduced to increase the lateral strength and stiffness of a building. Similar to a new

wall, integrating a new frame building and providing foundations are critical design issues.

The local strengthening approach involves the modification of deficient elements to increase ductility so that

the deficient elements can reach their limit state in a ductile manner when subjected to design events.

The methods of strengthening RC columns in building structures using traditional methods (concreting and

steel jacketing) and strengthening of RC building structures using innovative FRP materials will be discussed further

in this study. In the end, two examples of application of FRP materials for repair and strengthening of RC structures

are presented. Additionally, the conclusions are presented in tables for emphasizing the advantages and drawbacks

of different techniques for global and local strengthening of RC building structures.

3 -REPAIR AND STRENGTHENING OF COLUMNS USING TRADITIONAL MATERIALS

3.1 Column strengthening

The purpose of column strengthening is to improve the strength and deformability capacity of damaged or

undamaged buildings. During the construction phase, when there is failure of concrete or any other substantial

material in reaching the required quality as per the design, strengthening of specific structural members will be

required. Increased resistance of columns means increase in flexural and shear strength of columns along with an

improvement in ductility by applying different techniques of strengthening.

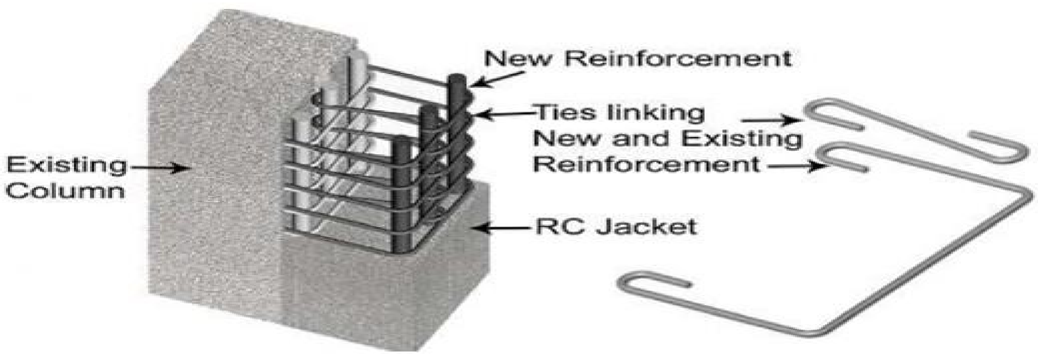
For damaged columns, depending on the degree and type of damage, different techniques, suchas resin

injection, removal and replacement, or jacketing may be applied. This depends on whether it is necessary to

increase or achieve the same strength and deformability capacity of the columns prior to the damage.

3.1.1 RC jacketing

- One of the most frequently applied methods used for strengthening reinforced concrete columns is the concrete



jacketing method (Figure 2 and Figure 3)

(Figure 2) Reinforced concrete jacketing of existing column.

RC jacketing can be defined as the confinement of an RC column with new reinforced concrete elements. It

may be implemented for various purposes based on the type of structural deficiency of the member. Columns

subjected to brittle failure can be jacketed to enhance resistance against shear, bending, and axial loads. Here,

although the purpose of RC jacketing is only to increase the axial load or shear strength, some changes will also

occur in the bending stiffness and moment capacity of the member after jacketing. By considering these changes

during the jacketing design, the jacketed section is ensured to achieve adequate shear and axial load strength.

Except for brittle damages, jacketing is applied for elements with inadequate bending capacity or ductility.

This way, the strength of the columns displaying a splice failure as a result of bending can also be improved.

Jacketing of the columns produces the best result if it is implemented at all 4 sides of the column. When necessary,

confinement at only 3 sides can also provide adequate performance. However, it is not generally recommended to

implement jacketing at 1 or 2 sides because no significant changes take place in the confinement characteristic of the member.

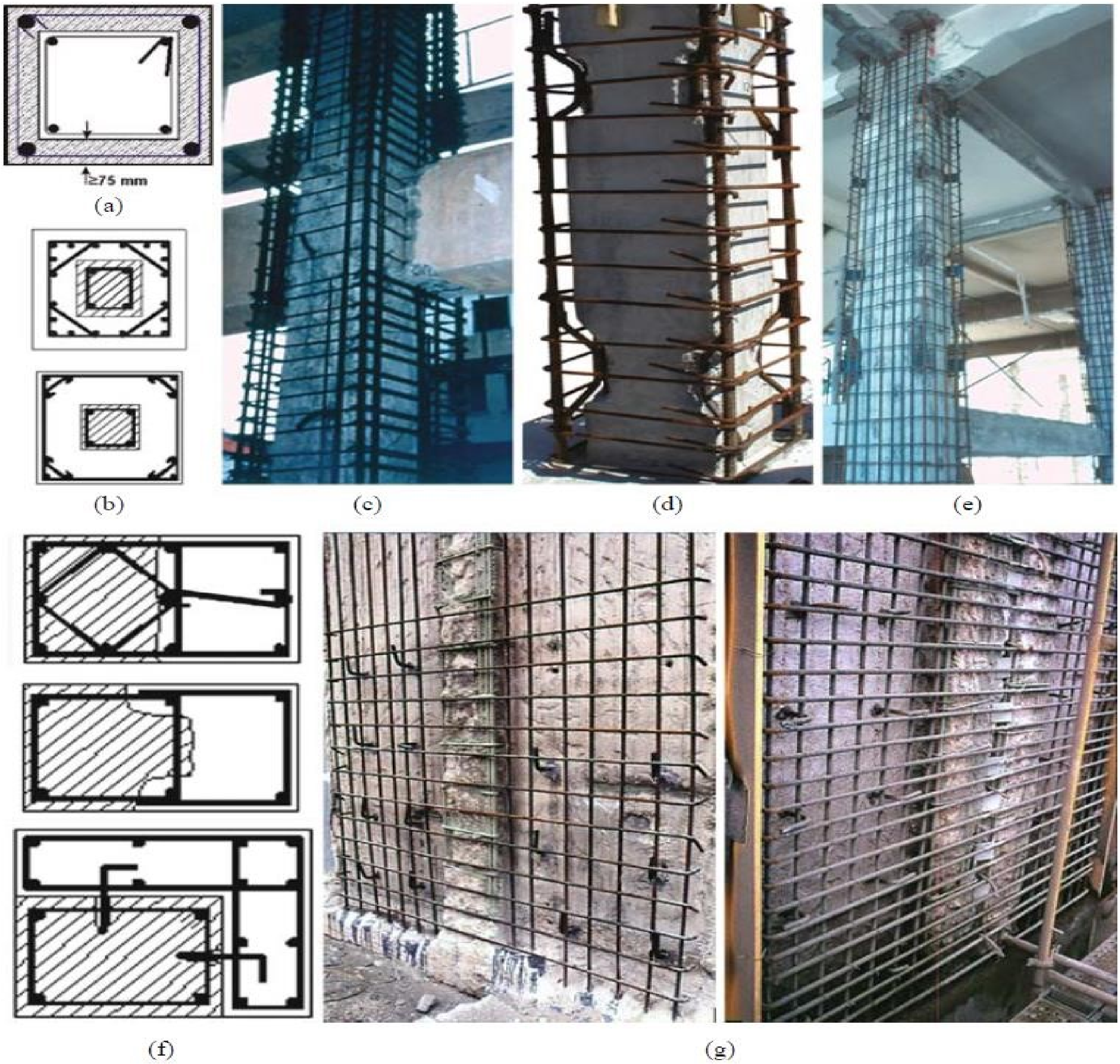


Figure 3 Concrete jackets in columns: a) simplest case b) jacket bars bundled near corners, engaged by

cross-ties or orthogonal tie c) jacket bars bundled at corners, dowels at interface with old column d) U -

bars welded to corner bars e) steel plates welded to corner bars f) one-or two-sided jackets g) one-sided

concrete overlay with single curtain of two way reinforcement at exterior f ace of perimeter walls.

3.1.2 Steel jackets

Jacketing with steel elements is a practical method used frequently for various applications. A typical steel jacketing

application is presented in Figure 4.

Figure 4 Steel jacketing applied to RC columns

Steel jacketing can be readily used to enhance the shear strength and ductility of reinforced concrete elements

with minimum increase in size. Located at the corners of an element, L-profiles are coupled by means of steel

plates and confined. With the maintenance of continuity between storey's, steel jacketing can be used to increase

the bending strength. The maintenance of adequate strength between the steel element and the reinforced concrete element is inevitable for the improvement of bending capacity. The setbacks of this method are: 1) it requires

protection against corrosion and fire. 2) It is costlier than concrete jacketing and needs skilled workers

4 REPAIR AND STRENGTHENING OF BUILDINGS USING INNOVATIVE MATERIALS

4.1 Fiber Reinforced Polymers (FRP)

FRP composites comprise high tensile strength fibers within a polymer matrix. Generally, carbon or glass fibers are

present in a matrix, such as vinyl ester or epoxy. These materials are manufactured to form plates under factor y

conditions, generally by a pultrusion process.

The primary materials in a composite are the reinforcement fibers and polymer matrix. Other materials are

incorporated in the composite, but are less significant in terms of cost and effect on properties. The term polymer

composites include both thermosetting and thermoplastic resins. The most commonly used thermosetting resins in

composites are polyester, urethane methacrylate, vinyl ester, epoxy, and phenolic. These materials are isotropic

materials and allow load transfer between fibers. The matrix protects the notch-sensitive fibers from abrasion, and

forms a protective barrier between the fibers and the environment, thus preventing an attack from moisture,

chemicals, and oxidation. It also plays an important role in providing shear, transverse tensile, and compression

properties. The thermo mechanical performance of the composite is also governed by the matrix performance.

Reinforcement fibers are classified in three main families: glass, aramid, and carbon. There are other fiber s,

which are relatively insignificant. The most important property of the fibers is their elastic modulus. The fibers must

be significantly stiffer than the matrix which allows them to carry most of the stress. Consequently, they must also

have high strength. Reinforcements are available in a variety of configurations. However, there are three main

categories:

- Unidirectional, where all the fibers lie in one direction.

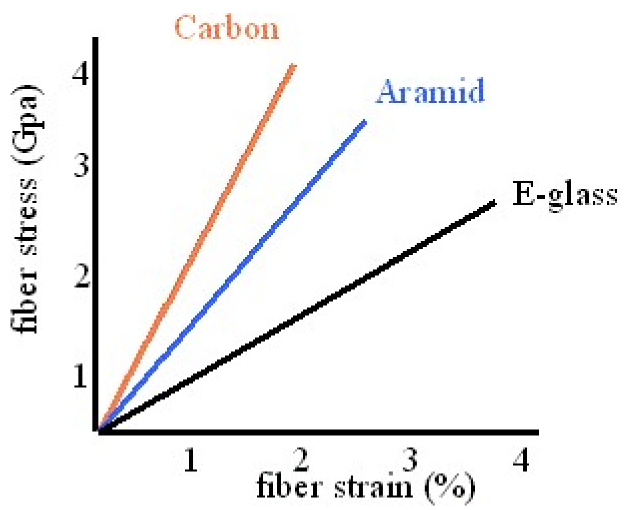
- Bidirectional, where the fibers lie at 90° to one another. This is achieved either by use of w oven fabric,

non-woven fabric or by using separate layers of fibers that are unidirectional, but successively laid at 90°.

- Random, where the fibers are randomly distributed in-plane.

Stress-strain fiber behavior is different for every type of fiber. (Figure 5). Different FRP shapes (Figure 6)

and Different material properties are given in Table 1.



(Figure 5) Stress- strain fiber behavior.

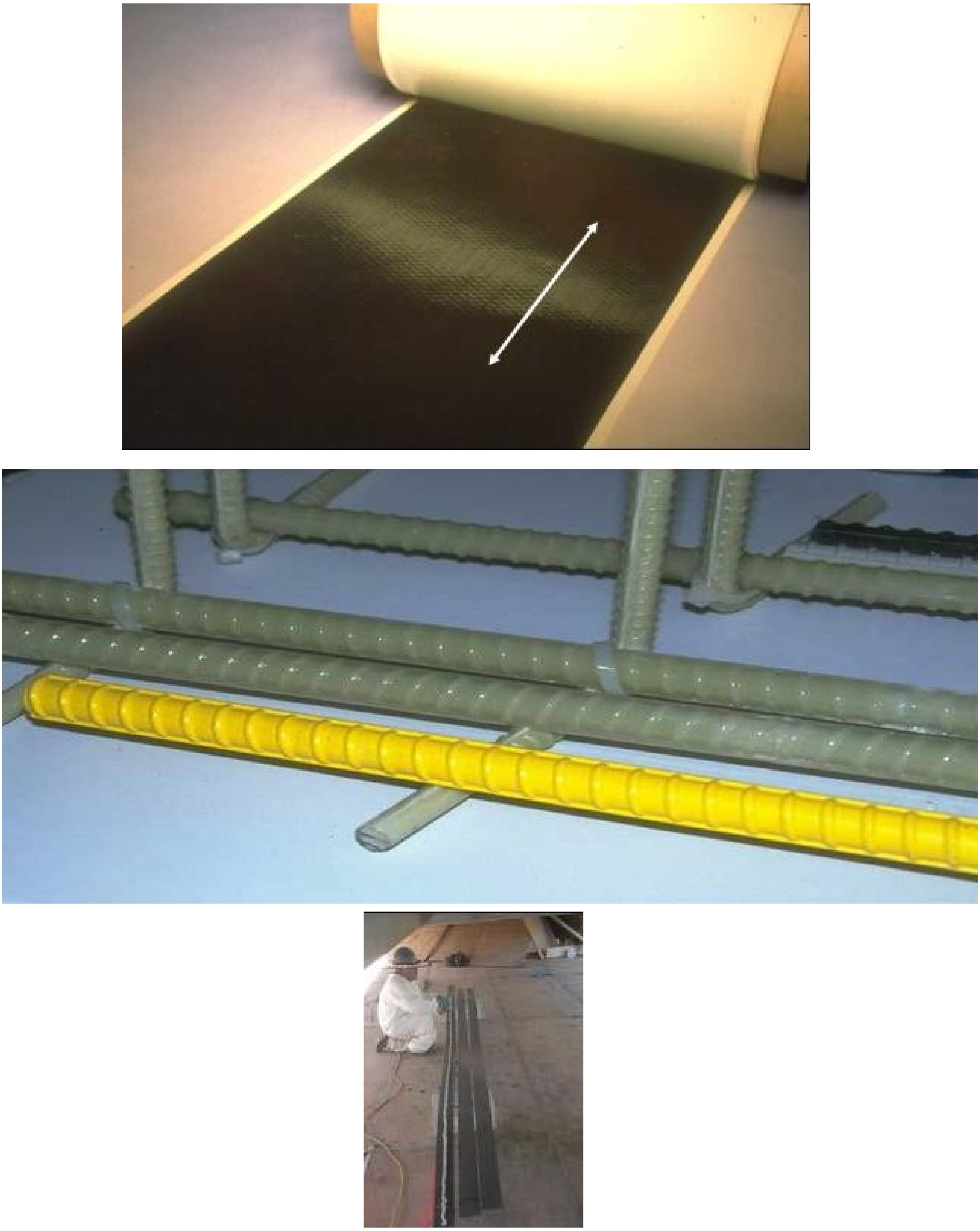


Figure 6 Different FRP shapes a) sheet b) bars c) pre cured laminate.

Table 1 FRP materials - Fiber comparison

Strength Modulus Moisture and chemical resistance Cost

	Strength	Modulus	Moisture &Chemical Resistance	Cost
CARBON	**High**	**High**	**Excellent**	**High**
ARAMID	**High**	**Intermediate**	**Good**	**High**
E-GLASS	**High**	**Low**	**Low**	**Low**

4.2 Repair and strengthening of an existing building using FRP

The application of FRP materials for strengthening RC building structures enables the achievement of a greater

deformability capacity (ductility) of the structures. This way, the seismic resistance, shear, and flexural strength of

the building structures can be increased by minimal increase in the cross-sectional dimension.

In the strengthening procedure, the following is assumed:

The choice and design of the adopted strengthening system is made by an appropriately

qualified and experienced engineer.

The installation process is carried out by personnel having appropriate skills and experience.

Proper supervision and quality control is provided during installation.

Construction materials are used as specified in the following.

The FRP strengthening system should be designed to have appropriate strength, and satisfy serviceability

and durability requirements. In case of fire, the strength of the selected FRP strengthening system has to be adequate for the required period of time.

The FRP strengthening system will be located in certain areas where tensile stresses will be carried out. FRP

composites cannot be relied upon for carrying compressive stresses.

Design of FRP strengthening system should be performed in compliance with the following principles:

The risks to which the structure can be subjected to shall be accurately identified, removed, or attenuate d

before the process.

The strengthening configuration should not be very sensitive to the above risks.

Strengthening systems should survive the occurrence of acceptable localized damages.

Strengthening systems that collapses without previous warning shall be avoided.

The above defined basic requirements can be fulfilled if the following conditions are satisfied:

Suitable materials are chosen.

Design is properly executed with an adequate choice of construction details.

Quality control procedures are defined for design and construction adequate to the particular project.

4.3 Strengthening design principles

Design with FRP composites should be carried out in terms of serviceability limit state (SLS) and ultimate limit state

(ULS) defined by the current building codes. Structures and structural members strengthened with FRP should be

designed to have the design strength, Rd, at all sections at least equal to the required strength, Ed, calculated for the factored load and forces in combinations as per the current building codes. The following expression represents

the foregoing:

$Ed \le Rd$

The design values are obtained from the characteristic values through appropriate partial factors that are

different for each limit state as indicated in the current building code. Specific partial factors for FRP materials are

indicated in a specific document. For structural applications using FRP to be carried out on single structural

members, when the conditions for upgrading are not met, it shall be proven that the adopted strengthening method

provides the structure with a significant level of safety with respect to the applied loads.

(Figure 7) Flexural strengthening

Flexural design of FRP strengthened members (Figure 7) requires that both flexural capacity, MRd, and

factored ultimate moment, MSd, satisfy the following expression:

$MSd \quad \leq \ MRd$
(2)

Design at ULS of FRP confined members requires factored design axial load, NSd, and factored axial capacity,

NRcc,d to satisfy the following expression:

$NSd \leq NR\ CC\ ,d$ (3)

4.3.1 Confinement strengthening

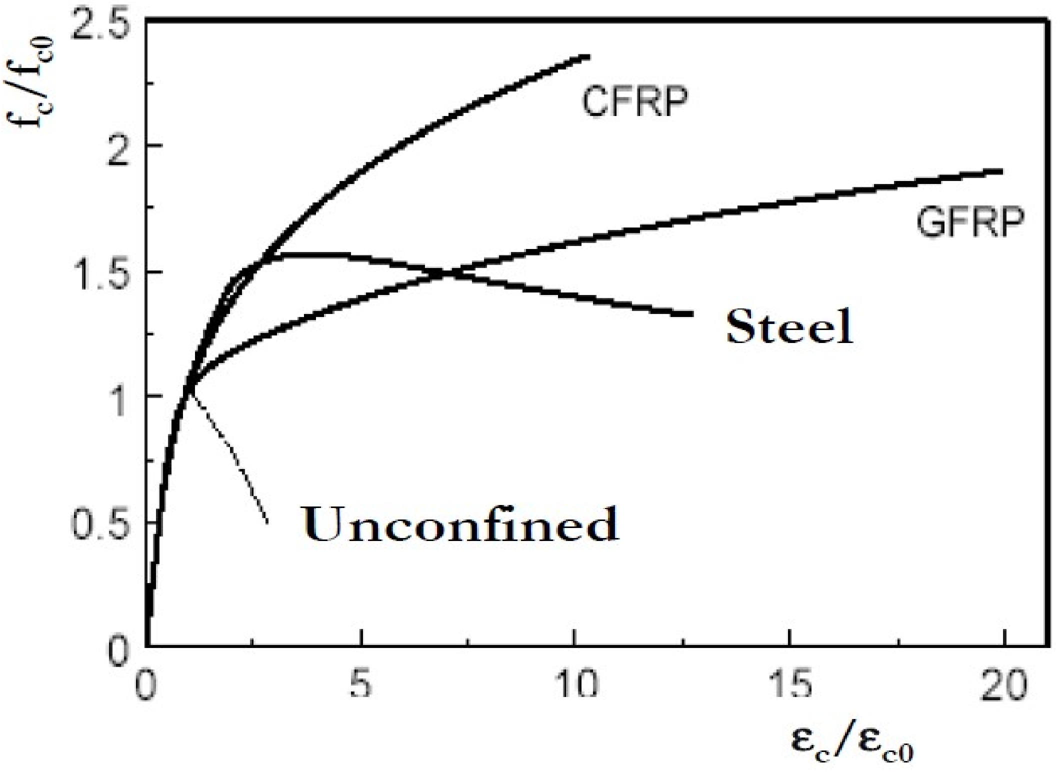
Confinement strengthening (Figure 8) consists of:

- Cleaning and repair
- Primer
- Adhesive
- FRP strips
- Last adhesive layer

(Figure8) Confinement strengthening

The difference between concrete jacketing and FRP wrapping is that FRP jacketing increases member

ductility while concrete jacketing increases ductility and strength (Figure 9).



(Figure9) Effect of confining for different device material

4.3.2. Seismic strengthening with FRP

The most strictly connected aspect of the hazard in southern European countries is represented by a number of

existing RC structures that are under-designed or designed using old codes and construction practices. Casualties

and losses occur mainly due to deficient RC buildings that are not adequately designed for earthquake resistance.

One way to increase seismic resistance of the structures is strengthening with FRP materials.

Regarding the type and size of selected FRP systems and urgency of FRP installation, the following shall be

taken into account:

(1) Common errors shall be eliminated

(2) Major building irregularities cannot be eliminated using FRP as a strengthening technique

(3) A better resistance regularity can be obtained by strengthening local ductility

(4) Localized strengthening shall not reduce the overall ductility of the structure

The FRP seismic strengthening strategy is based on the following principles:

1) Avoiding brittle failure mechanisms

- Shear failure
- Lap splice failure
- Instability of longitudinal reinforcement in compression

2) Avoiding soft-storey mechanisms

3) Increasing the global deformation capacity by:

- Enhancing the ductility of plastic hinges
- Re localizing plastic hinges

To perform local strengthening, external joints of a structure should be strengthened by satisfying the

previously stated principles, (Figure 10).

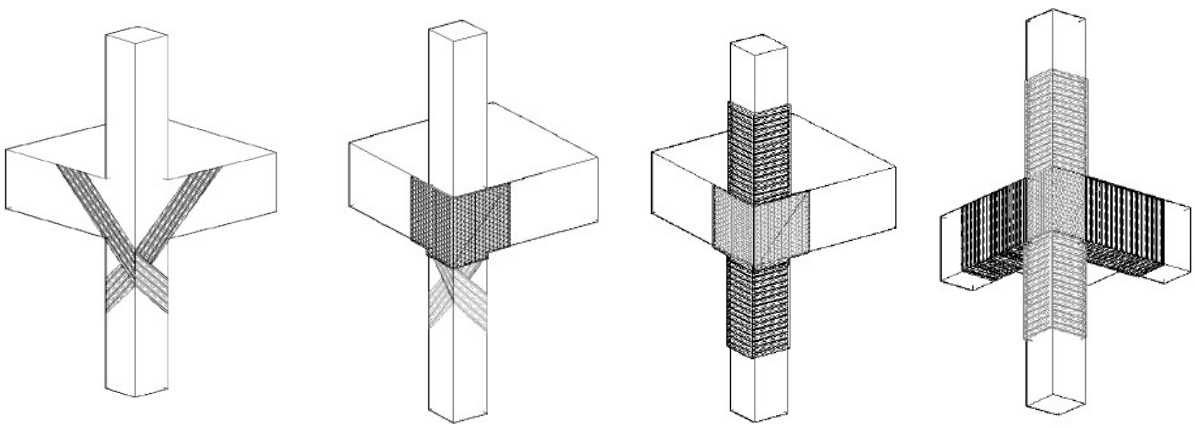
(1) Diagonal uni axial steel sheets are designed

(2) Quadriaxial CFRP sheet increases shear strength

(3) Column end confinement using CFRP uni axial sheets (Concrete ultimate strain increases and thus

the curvature and rotational capacity increases)

(4) U-shaped sheets on beams.



(Figure10) Seismic strengthening of external joints using CFRP sheets.

The decision for selecting the type of FRP material for the repair and/or strengthening process of the structural

elements of the RC building structure can be made after a detailed analysis of the bearing capacity and deformability

of the damaged and non-damaged elements of the RC structures is performed. In doing so, a detailed diagnosis

should be performed regarding the reasons necessary for repair and strengthening of the structural elements. It

should be defined whether a structure is damaged by an external phenomenon (for example, earthquake) or due

to sub-standard quality of built-in materials lower than the designed specifications (for instance, lower class

concrete or insufficient reinforcement). Based on the above conclusions, the type of FRP material will be selected.

For instance, carbon FRP is characterized by high strength, high modulus of elasticity, and excellent chemical

resistance. However, its deformability capacity is much lower than that of aramid and e-glass. On the other hand,

e-glass has a lower strength capacity, but a much greater deformability capacity. The price may certainly have a

greater role in the selection of the material to be used. After defining the scope of work, (it can be a combination of

FRP and concrete), additional analysis should be performed again to check whether the new strengthened

structural system satisfies all the requirement prescribed by the existing regulations. FRP materials are still the

subject of a lot of investigations, especially regarding their use in seismically active regions.

5 -CONCLUSION

The conclusions are listed in tables 2 and 3, providing insight into the advantages and disadvantages of differ en t

types of repair and strengthening.

The global retrofit strategies are presented in Table 2 with their advantages and drawbacks. For example, the

addition of infill walls can result in increased lateral stiffness. Infill walls are easy to implement and can experience

premature failure due to dislodging and crushing. It increases the weight of the structure without increasing ductility.

Other strategies require integration with the existing system with the exception of those including braces. They

require adequate foundation, which makes them more expensive. Nevertheless, it increases the overall ductility of

the system.

Table 3 shows the comparison between local retrofit strategies of concrete jacketing, steel jacketing of

columns, bonding steel plates to beams, and fiber reinforced polymer wrapping. For example, when using concrete

and FRP jacketing, both methods can increase the ductility of the cross section as well as the flexural and shear

strength. In geometry, FRP wrapping results in a minimal increase in size of the cross section compared to concrete

jacketing. However, FRP requires proper fire protection, skilled labor force, and can be more expensive.

More details on the above strategies are listed in the tables below.

Strengthening strategy	Merits	Demerits	Comments
Addition of infill walls	Increases lateral stiffness of a storey. Can support vertical load if adjacent column fails.	May have premature failure due to crushing of corners or dislodging. Does not increase ductility. Increases weight.	Low cost. Low disruption. Easy to implement.
Addition of shear walls, wing walls and buttress walls	Increases lateral strength and stiffness of the building substantially. May increase ductility.	May increase design base shear. Increase in lateral resistance is concentrated near the walls. Needs adequate foundation.	Needs integration of the walls to the building. High disruption based on location involves drilling of holes in the existing buildings.
Addition of braces	Increases lateral strength and stiffness of a storey substantially. Increases ductility.	Connection of braces to an existing frame can be difficult	Passive energy dissipation devices can be incorporated to increase damping/stiffness or both
Addition of frames	Increases lateral strength and stiffness of the building. May increase ductility.	Needs adequate foundation.	Needs integration of the frames to the building

Table 3 Comparative evaluation of the local retrofit strategies

Strengthening strategy	Merits	Demerits	Comments
Concrete jacketing	Increases flexural and shear strength and ductility of the member. Easy to analyze. Compatible with original substrate.	Size of the member increases. Anchoring of bars for flexural strength; Involves drilling of holes in the existing concrete. Needs surface preparation of the existing member.	Low cost. High disruption. Experience of traditional RC construction is adequate.
Steel jacketing of columns	Increases shear strength and ductility. Minimal increase in size.	Cannot be used for increasing the flexural strength. Needs protection against corrosion and fire.	Can be used as a temporary measure after an earthquake. Cost can be high. Low description. Needs skilled labor.
Bonding steel plates to beams	Increases either flexural or shear strengths. Minimal increase in size.	Use of bolts involves drilling in the existing concrete. Needs protection against corrosion and fire.	More suitable for strengthening against gravity loads. Cost can be high. Low disruption. Needs skilled labor.
Fiber Reinforced Polymer wrapping	Increases ductility. May increase flexural or shear strength. Minimal increase in size. Rapid installation.	Needs protection against fire.	Cost can be high. Low description. Needs skilled labor.