Traditional Methods for Strengthening of reinforced Concrete Beams

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***Abstract*—With the passage of time, existing infrastructure which demands upgrading, retrofitting and/or repair is growing worldwide. Strengthening of structural elements such as beams, columns and slabs has become a mandatory step as on now, to reduce the amount of concrete waste generated by demolishing old construction in order to construct a new one. The strengthening of beams becomes difficult if it has to be strengthened to take revised loading due to many reasons. This paper aims at presenting both, traditional as well as advance strengthening techniques (specifically for beams) adopted actually on field. Concrete, steel and FRP composite are gaining importance as predominant materials for strengthening of existing RC beams on field [1]. Sometimes these materials are used in combination to achieve a good response and economy. Flexural, shear and axial strengthening can be done by the various techniques such as sprayed concrete, concrete jacketing, steel jacketing, near surface mounting technique, externally bonded FRP sheets or strips and many more. Researchers have been working extensively since years, adopting various techniques and materials for strengthening of existing reinforced concrete structures. The response of such strengthened structural elements is found to be quite satisfactory as compared to non-strengthened structural elements. This manuscript aims at presenting such mechanisms adopted for external strengthening of reinforced concrete structures.**

***Keywords*—Reinforced Concrete Beams, Strengthening, Mechanisms, Methods & Materials.**

I. INTRODUCTION

Repair and strengthening of reinforced concrete structures has become vital now a days due to number of situations where it may become necessary to increase the load-carrying capacity of a structure [2]. These include change of loading or occupancy, and structures which have been damaged owing to impact, ageing or material deterioration. Engineering fraternity has gained over hundred years of experience on experimentation knowledge, in reinforced concrete construction, and yet concrete deteriorates due to many natural and man-made factors. Strength assessment, design of strengthening mechanism and execution of strengthening of any existing structures is more complicated than any new construction [3].

Before strengthening of any structure, whole structure must undergo physical investigation and at the same time failure mode of structural element has to be evaluated. It may be happen sometimes that strengthening for flexure leads to shear failure instead of increasing load carrying capacity. It was observed from literature that only failure mode of structural element is not important because if a critical member of structure is strengthened, another member can become critical due to the stiffness changes in undetermined structural element. Hence, the whole structure must be investigated. The strengthening should be designed with consideration of maintenance and durability aspects.

Strengthening can be done for any structures such as bridges, buildings, dams, towers, chimneys, water tanks, electric polls, industrial sheds etc.

II. NEED FOR STRENGTHENING

Any structure is prone to deterioration during its service life and thereby the need for repair and strengthening arises. Need for strengthening arises as a result of design and construction error, revised loading condition, change of occupancy, updating of design code, lack of maintenance, increased traffic volume, blast & explosions, fire, earthquake, damage accumulated over time, overloading etc. Replacement of deteriorated structure or structural element requires enormous investment and may also be damaging for surrounding structures. So, strengthening becomes a suitable way for improving existing the load carrying capacity of existing structure and extends its service life. It is also an economical option rather than demolish and reconstruct a completely deteriorated structure. Hence, this aspect of civil engineering infrastructure restoration has received considerable recognition over past few years all over the world.

Specifically talking about the beam, than beam is considered to be the most common structural element. It is subjected to large forces such as gravity load and lateral load. As a result, a great attention has to be paid for good detailing of such components.

III. CONDITION EVALUATION OF EXISTING STRUCTURE

The most important aspect in any structural strengthening process is to evaluate the existing condition of whole structure, as well as condition of individual structural elements. To develop a suitable strengthening method, an evaluation of existing structure

should be conducted first. Condition assessment is necessary to determine the level of deterioration, condition of concrete, causes of deterioration, calculation of existing load carrying capacity and identification of appropriate strengthening mechanism to be adopted.

The procedure of condition assessment should include the following [4]:

- Assessment of available drawings, reports, maintenance records or any other document pertaining to the existing structure.
- Structural analysis for the deteriorated condition.
- Visual inspection of entire structure.
- Actual size of the structural element.
- Execute suitable testing program. The purpose of the testing program is to evaluate the extent of corrosion activity, the condition of concrete and collect all other data that might be useful to determine the cause for the deterioration.
- The location, size and cause of cracks in addition to concrete spalls.
- Appropriate evaluation of applied load and load transfer mechanism.
- One of the most critical characteristic to be considered when using any strengthening mechanism is the condition of concrete surface. Concrete in existing structure must be able to transfer the load safely, which is the base of any strengthening mechanism adopted. Sometimes surface concrete must be removed and replaced by new layer, prior to strengthening of any structural element.

IV. FACTORS AFFECTING SELECTION OF STRENGTHENING METHOD

Whenever selecting the strengthening mechanism or material, limitations in strengthening must be considered [3]. Following are few of the listed limitations.

- Access to work area
- Operating schedules
- Budgetary limitations
- Required useful life of structure
- Environmental aspects and implications of weather
- Effect of strengthening on load transfer mechanism for other adjacent structural elements
- Aesthetical requirements

The most common issue for existing structure is poor and wrong documentation. Sometimes it is necessary to redesign the structure with the older design code based on which the structure was designed. Field investigation must be done to understand the existing structures. Design of the strengthening mechanism must be supported by today's codal provisions after strengthening of structures.

V. MECHANISMS FOR STRENGTHENING OF REINFORCED CONCRETE BEAMS

Beams are classified mainly as normal beams, T beams and deep beams. Now the beams are those structural elements on which the stability of entire structure depends on, so the beams should be capable of resisting loads acting on it. Often existing beams are not capable enough to take more loads, especially when occupancy conditions are changed or loads increase due to earthquake effects, corrosion of re-bars etc. In order to have an upper hand over time and process, external strengthening is better alternative as compared to any internal strengthening technique. External strengthening of structural element is done by many techniques, few are listed below:

1. Section enlargement technique by concrete jacketing
2. Strengthening by providing wire-mesh & Ferro-cement
3. Shot create with steel fibers
4. Using externally bonded steel plates
5. Strengthening using Fiber Reinforced Polymer (FRP) sheets
6. Strengthening using steel sections
7. Near Surface Mounting Technique (NSM)

1. Section enlargement by concrete jacketing [5]

Concrete jacketing of beams is suggested as it gives the connection to the columns and imparts required strength and stiffness to the structure. While jacketing a beam, its flexural resistance must be carefully computed to avoid the creation of a strong beam-weak column system. There are more chances of change of mode of failure and redistribution of forces in the strengthened structure. While adopting section enlargement by concrete jacketing for any beam, the location of critical section and contribution of the existing reinforcement should be taken into consideration. Jacketing of beam may be carried out in different ways, the most common one is, one-sided jackets or 3 and 4-sided jackets. At several occasions, the slab is made perforated to allow the ties to go through and to enable the casting of concrete. The beam should be jacketed through its entire length. The reinforcement is also to be added to increase flexural capacity of the beam. Top bars crossing the orthogonal beams are put through holes and the bottom bars have been placed under the soffit of the existing beams, at each side of the existing column. Beam transverse steel consists of sets of U-shaped ties fixed to the top jacket bars and of inverted U-shaped ties placed through perforations in the slab, closely spaced ties have been placed near the joint region where beam hinging is expected to occur. The main features of reinforcement details of beam jacketing are given in Table 1.

Table 1 Reinforcement of beam jacketing.

Minimum width for jacket Longitudinal reinforcement	- 8 cm if concrete cast in place or 4 cm for shotcreting - Percentage of steel on the jacket should be limited to 50 of the total area of the composite section.
Shear reinforcement	- Ignore the effect of existing shear reinforcement - New reinforcement should have 135 hooks and at each corner of the tie there must be at least one longitudinal bar. - The bar used for the tie should have at least 8 mm diameter
Depth of jacketed beam	- Span/depth ratio - Storey height - Ductile Behaviour

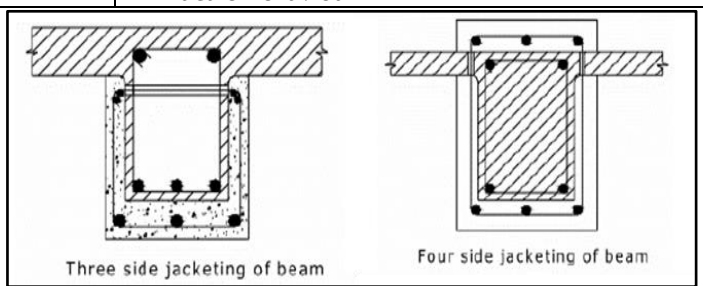

FIGURE 1 CONSTRUCTION TECHNIQUE FOR CONCRETE JACKETING OF BEAM

2. Section enlargement by concrete jacketing [5]

In housing construction, Ferro-Cement technology is rapidly gaining popularity. In this technology high grade mortar reinforced with layers of fine steel wire meshes is used. The use of precast Ferro-Cement elements in construction will reduce the cost and labor requirement substantially. With the industrialized building systems, the components can be mass-produced and hence, the method reduces the overall construction time. Principal advantages of Ferro-Cement over FRP sheets include fireproof without epoxy-bonded and flexibility in its use. Another significant advantage of this strengthening mechanism is in terms of low labor material and equipment cost. Different types of wire mesh can be used for strengthening purpose. For example hexagonal mesh, square mesh, expanded mesh, 3D mesh etc. Wire meshes are also available in galvanized form. Galvanizing, like welding, reduces the tensile strength. Strengthening by providing wire mesh is as shown in Figure 2.

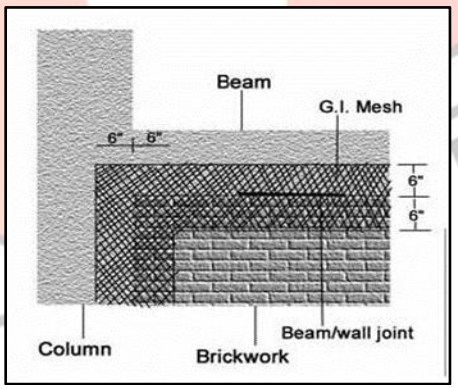

FIGURE 2 STRENGTHENING BY WIRE – MESH TECHNIQUE

3. Shotcreting with steel fibers [7]

Shotcreting is a method of applying a combination of sand and Portland cement which are mixed pneumatically and conveyed in dry state to the nozzle of a pressure gun, where water is mixed and hydration takes place just prior to expulsion. The material bonds perfectly to prepared surface of masonry and steel. In versatility of application to curved or irregular surfaces, its high strength after application and good physical characteristics, make for an ideal means to achieve added structural capability in walls and other elements. There are some minor restrictions of clearance, thickness, direction of application, etc. In short creating technique, different types of fibers are used such as steel, glass, synthetic fibers etc. Typical applications for fiber-reinforced shotcreting are in tunnel linings, surface coatings on rock and soil, slopes, structures, embankments, or other structures that may be subject to high deformations or where crack control is needed.

FIGURE 3 FIBER REINFORCED SHOTCRETING ON A TUNNEL WALL

4. Using externally bonded steel plates [8]

Structural retrofit work has come to the forefront of industrial practice in response to the problems of an ageing infrastructure. These problems, coupled with revisions in structural codes to better accommodate natural phenomena, create the need for the development of successful structural retrofit technologies. The important characteristics of repair-type work are: a predominance of labour and shut-down costs as opposed to material costs, time and site constraints, long-term durability, and selection of methodology and design. An established method for upgrading reinforced concrete (RC) members, including prestressed members, is steel plate bonding. This method originated from the strengthening of steel beams with epoxy-adhered steel plates. The idea was proposed for the repair of concrete members, and was followed by several years of research until it became accepted for field practice. Experimental projects that have been conducted to investigate the influence of several factors, such as plate thickness, type of adhesive and anchoring conditions.

In general, bonding steel plates to the tension flange of concrete beams increases both strength and stiffness of the beam and reduces cracks. However, corrosion of the steel can be a problem as corrosion can damage the bond and eventually lead to the failure of the repair technique and structure. Also, shear and flexure peeling could develop after the formation of shear diagonal cracks, or when the curvature in the beam is increased. Reinforced concrete beams can be strengthened and stiffened by bonding mild steel plates to the tension face of the beam. The technique of bonding mild steel plates to the soffit of reinforced concrete beams is often used to improve the flexural performance of existing structures, as it increases the strength and stiffness of the beams and also reduces the crack widths in the concrete. This bonding technique has further advantages, as it has been found in practice to be simple and rapid in application, does not significantly reduce the height of the structure, and can be applied while the structure is in use. This technique has been adopted to repair buildings, strengthen bridges and it has been used all over the world. However, experimental tests show that these externally bonded plates have a tendency to peel away after the formation of the diagonal shear cracks or when the curvature in the beam is increased.

5. Strengthening using Fiber Reinforced Polymer (FRP) sheets [8]

In response to the increasing need for repair or retrofit of existing reinforced concrete structures in the world, a new structural strengthening technology had emerged. Ongoing development of cost-effective production techniques for Fiber Reinforced polymers (FRP) has progressed to the level that these once-referred to as the "space-age" materials are ready for the construction industry. Reduced material cost, coupled with labor savings inherent with its low weight and high strength make FRP an attractive alternative to steel plates for external strengthening. Steel-plate bonding has been a tool of the concrete-repair industry for the past twenty years. However, the high cost of labor in setting heavy plates, the difficulties in handling splicing of plates, and concerns about corrosion of the steel plates have limited the use of this technique. Because of its excellent weight-to-strength properties, recently reduced material costs, relatively unlimited material length availability, comparably simpler installation, and immunity to corrosion, the use of FRP presents an attractive alternative for externally bonded strengthening technique.

The principles behind externally bonding FRP plates or wraps to concrete structures are very similar to the principles used in application of bonded steel plates. In general, the member's flexural, shear, or axial strength is increased or better mobilized by the external application of high-tensile-strength material. External reinforcement with FRP is fit for many structural applications, such as:

- Capacity up gradation due to a change in use.
- Passive confinement to improve seismic resistance.
- Crack control and crack stitching.
- Strengthening around new openings in slabs.

Notwithstanding its promise, the use of FRP for structural strengthening has a fairly short history, and there is a need for additional laboratory tests and analytical data substantiation to broaden its use. Consequently, the use of FRP in structural strengthening and retrofit application should be approached with caution and with sound engineering judgment. FRP should not be used in the following situations [9] (Kelly et al., 1997).

- The condition of the substrate is unknown or largely deteriorated
- There is ongoing substantial corrosion of the mild-steel reinforcement
- There is no mild-steel reinforcement to provide ductile behavior, etc.

Engineers attempting to use FRP in external reinforcement applications today, are facing the adaptability challenges of this

innovation. No clear technical norms for concrete design with FRP reinforcement exist at present, although few countries have laid down guidelines in recent years.

6. Strengthening using steel sections

In this technique different section of steel are used for strengthening of existing beams. For strengthening of beam in flexure, I-section of steel was bonded at the bottom of the beam. Similarly for strengthening if beam in shear channel section of steel is bolted at the sides of beam as shown in Figure 4. By this technique load carrying capacity of the beam will increase.

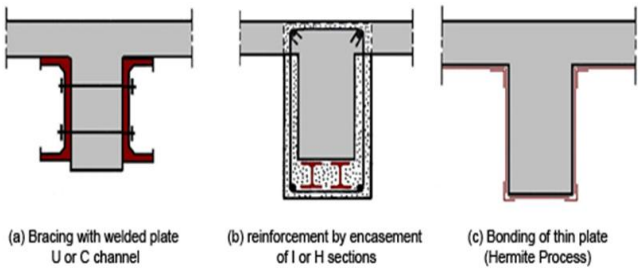

FIGURE 4 STRENGTHENING USING STEEL SECTION [9]

7. Near Surface Mounting Technique (NSM) [10]

FRP has been used in different configurations and techniques to make use of the material effectively and to ensure long service life of the selected system. One of these innovative strengthening techniques is the near-surface mounting (NSM) technique which consists of placing FRP reinforcing bars or strips into grooves precut into the concrete cover in the tension zone of the strengthened concrete member and bonded to the three sides of the groove using high-strength epoxy adhesive or cementitious grout. This method is relatively simple and here, the grid considerably enhances the bond of the mounted FRP reinforcements, thereby using the material more effectively. Configuration of the FRP reinforcements used for the NSM technique is controlled by the depth of the concrete cover. After installation, the NSM-FRP reinforcements are protected against mechanical damage, wear, impact, and vandalism from vehicles [12]. The technique could also provide better fire resistance in the event of a fire and therefore, it could reduce the cost of fire protection measures.

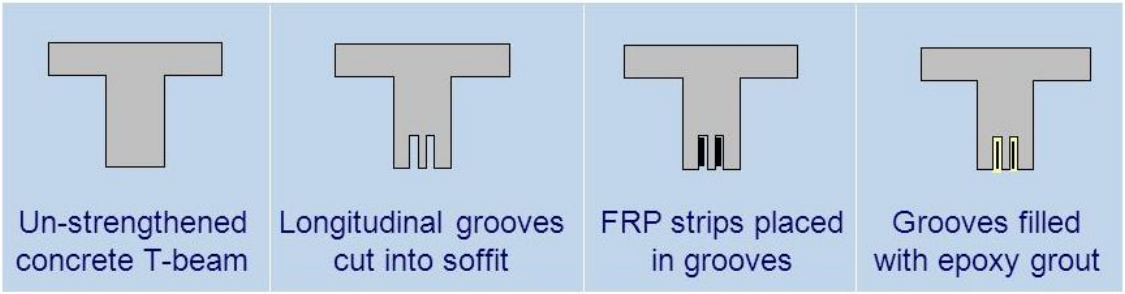

FIGURE 5 STRENGTHENING USING NSM

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