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A State-of-the-Art Review on Strengthening Technique used for Existing Column with Steel Jacketing

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Abstract: ***This paper review a technique used for strengthening of existing columns with steel jacketing. Generally, steel jacketing is consisting of steel angle profile, steel plates/strips with different configurations. After Gorkha earthquake - 2015, thousands of people were killed and the buildings, infrastructures were damaged. After that earthquake, lots of building needed to be strengthening its capacities to meet the present code provision and to make them earthquake resistant building. In this paper, a non-destructive test of an existing reinforced concrete column will be first presented and after that both experimental and analytical investigations conducted by various researchers have been reviewed.***

Keywords: NDT Test, Strength, RC Column, Steel Jacketing, Strengthening

1. Introduction

Seismic retrofit or Strengthening is done to enhance the structural capacities (strength, stiffness, ductility, stability and integrity) of structure, so that the performance level of the building can be raised to withstand the design earthquake consideration [1].According to Khushnood et.al [2], it is necessary because in most of the case major problems involved with the damaged columns are due to the poor transverse reinforcement detailing, which resulted in inadequate shear strength and flexural ductility of columns. Steel Jacketing is one of the effective methods in order to improve the earthquake resistant capacity. According to SAKINO et. al [3], steel jacketing has two more remarkable merits; 1) to easily provide a large amount of transverse steel, hence strong confinement to the compressed concrete and 2) to prevent spalling off of the shell concrete. According to Abhishek Jodawat et al. [4], retrofit by steel jacketing means providing additional jacket layer which may supply the required transverse reinforcement and enhance the seismic performance by providing additional ductility, and reducing the seismic force demand.

The performance level of building reduces along with its life time. The design consideration also effects on its structural capacity, safety level due to varieties of causes or situations such as deterioration of concrete, alternation of building units, larger loads due to extension of structure etc. This structure behaves normally during its life time but after meeting with design period, it cannot capable to take the existing loads and obviously it will not be possible to take the extra loads on it. Enhancement of structural behaviour or performance level of such a deficient building can be done by increasing strength of structure element through the process of retrofitting [5].

2. Techniques used for RC Column by Steel Jacketing

The use of steel jacketing technique is proved to be valid to upgrade the columns carrying capacity for column subjected to eccentric loading [6]. According to Choi et al. [7], Steel jacketing method enhanced the strength and the ductility of the concrete cylinders and the jacket system was able to make full use of the capacity for plastic deformation afforded by the jackets. Generally, steel jacketing consists of four longitudinal angle profiles placed on each corner of the existing reinforced concrete column after chiseling and they are connected with each other by horizontal steel strips at certain spacing throughout bottom to top of the column [1]. They are welded to the angle profiles and can be either round bars or steel straps.

The angle profile size should be no less than L 50X50X5.Gaps and voids between the angle profiles and the surface of the existing column must be filled with non-shrinking cement grout or resin grout. In general, an improvement of the ductile behavior and an increase of the axial load capacity of the strengthened column is achieved [8].

3. Analytical calculation methods in order to determine the capacity of steel jacketing of RC columns

In the past, many analytical models are invented in order to determine the capacity of steel jacketing of RC column by steel jacketing. Islam et. al [9] explained about the different types of proposed models and two of them are mentioned here.

a) Euro Code No: 4 (1994)

According to Euro code [10], the ultimate load carrying capacity of strengthened RC column with steel angle and strips are given below;

$$P_{EC4} = 0.85A_c f_c + A_s f_{ys} + 8.(L_1.t).f_{yL}$$

Where,
A_c = Area of RC column (BXD)
f_c = Compressive strength of concrete
A_s = Area of Longitudinal steel
f_{ys} = Yield strength of longitudinal steel
L_1 = Leg length of angle
t= Thickness of angle section
f_{yL} = Yield stress of steel angle

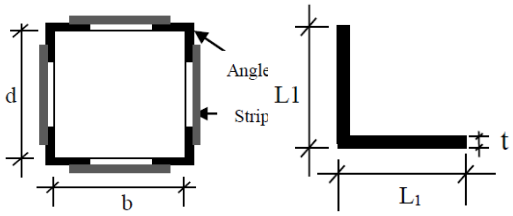

Figure 1: Components of Steel Jacketing

b) Regalado (1999)

According to Regalado's design equation [11], allowable load carrying capacity of strengthened RC column can be calculated according to Eq. (II);

$$P_{Reg} = 0.6 * \left(0.85A_c f_c + A_s f_{ys} + 8.(L_1.t).f_{yL}\right)$$

4. Details for Steel Jacketing

Local strengthening of columns has been frequently accomplished by jacketing with steel plates and according to Shri. Pravin B. Waghmare [12], a general feature of steel jacketing is mentioned in a table.

Steel Plate Thickness	-At least 6 mm.
Height of jacket	• 1.2 to 1.5 times splice length in case of flexural columns. • Full height of column in case of shear columns.
Free ends of jackets bottom clearance.	• Welded throughout the height of jacket, size of weld1". • 38 mm (1.5 inch), steel jacket may be terminated above the top of footing to avoid any possible bearing of the steel jacket against the footing, to avoid local damage to the jacket and/or an undesirable or unintended increase in flexural capacity.
Gap between steel jacket and concrete column Size of anchor Number of anchor bolts	• 25 mm fill with cementations grout. • 25 mm in diameter and 300 mm long embedded in 200 mm into concrete column. • Bolts were installed through pre-drilled holes on the steel jacket using an epoxy adhesive. • Two anchor bolts are intended to stiffen the steel jacket and improve confinement of the splice.

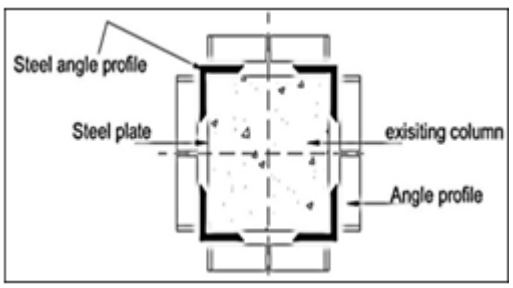

Figure 2: Steel Jacketing of column

5. Construction Methodology

5.1 Assessment of physical condition of existing Columns

Non-destructive test (NDT) can be used to determine the physical condition of an object without affecting that objects ability [1]. NDT method is considered as an effective method for evaluation of existing concrete structures with regard to their strength, durability and quality [13].

Various NDT methods can be used for testing concrete:
1) Ultrasonic pulse velocity test
2) Schmidt Rebound hammer test
3) Surface hardness tests
4) Penetration and pull out tests
5) Dynamic or vibration tests
6) Combined methods
7) Radioactive and nuclear methods
8) Magnetic and electrical methods
9) Acoustic emission techniques

The commonly used NDTs are the Rebound hammer tests and Ultrasonic pulse velocity test.

5.1.1 Ultrasonic pulse velocity test

UPV method is one of the important methods of NDT for determination of quality of concrete. UPV method involves a measurement of travel time over the known path distance (Length) pulse of ultrasonic compressional waves. Generally, the pulse velocity is determined by using following equation.
Pulse Velocity=Path Length/Transmit time

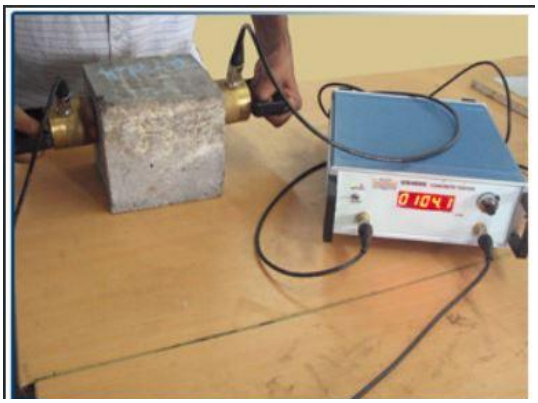

Figure 3: Ultrasonic pulse velocity instrument

Generally, the higher value of pulse velocity reflects higher the quality and durability of concrete and lower value of pulse velocity stands for lower quality of concrete.

IS 13311-1992 code of practice for Ultra sonic pulse Velocity describes the details of pulse velocity and condition of concrete.

Quality of concrete as per IS 13311 (part 1) 1992 [14]

	Ultrasonic pulse velocity(km/sec)	Quality of concrete
1	Above 4.5 km/sec	Excellent
2	3.5-4.5 km/sec	Good
3	3-3.5 km/sec	Medium
4	Below 3 km/sec	Doubtful

5.1.2 Schmidt Rebound hammer test

Schmidt rebound hammer test is one of the non-destructive test in order to determine the compressive strength of concrete. It is developed in 1948 by a Emst Schmidt a Swiss engineer for testing concrete, based upon rebound principle when strikes concrete [1].

As per Indian code IS: 13311(2)-1992 [15], the rebound hammer test has the following objectives:

1) To determine the compressive strength of the concrete by relating the rebound index and the compressive strength
2) To assess the uniformity of the concrete.
3) To assess the quality of the concrete based on the standard specifications.
4) To relate one concrete element with other in terms of quality.

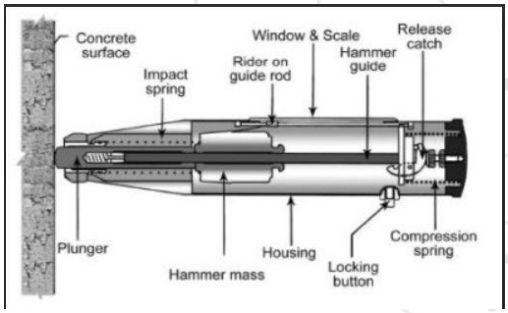

Figure 4: Schmidt rebound hammer instrument

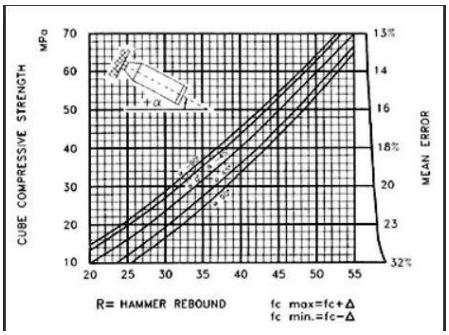

Figure 5: Calibration Chart

5.2 Construction Procedure

- Size of angle section as well as number and size of horizontal steel strips depend on the structure analysis of existing column.
- Existing column should be chiselled before the placement of angle section on four corners of the column.
- At the base and top of the column, angle section should be connected with bolt connection with steel plates. And to fill up the void, a strong bonding epoxy material should be used.
- After having a steel caging on existing column surface to make strong bond between old and new concrete appropriate epoxy material should be coated before pouring the concrete.
- Before the epoxy material dries, new micro silica or micro concreting should have poured in to the jacket. Concrete used should be rich concrete having low shrinkage, consisting of small aggregates, sand, cement and additional materials to prevent shrinkage.

6. Failure modes of steel jacketing

According to different literature, generally two types of failures modes occurred in the column strengthened by steel jacketing. The first one is the yielding of longitudinal angles and the second one is the yielding of horizontal strips Cirtek, [16] Calderon et al., [17] Tarabia and Albakry [18]

1) Yielding of Angles

One of the failure occurred in the strengthen column is due to the yielding of angles in which angles are buckled at the middle portion of two strips. After that angle section are no longer able to confine the concrete. According to Badalamenti et al. [19], when column is subjected to bending and axial force, the concrete starts to expand laterally that results angle yielding.

2) Yielding of Strips

Another type of failure is yielding of horizontal strips. Generally, this type of failure is observed when angles are remained indirectly loaded (length of angles are less than the length of column) [9]. When axial load is introduced to column the expansion of concrete exerts pressure on horizontal strips [18], [19].

7. Factors affecting on load carrying capacity

Load carrying capacity of strengthened column varied depending on the configuration of steel jacket as well as its arrangements. Many factors are available in the literature which influences the load carrying capacity of RC column strengthened by steel jacketing and most important parameters are: size and thickness steel angles and strips, spacing of strips, confining pressure and concrete strength [9].

a) Effect of Strip Spacing

Load carrying capacity of strengthened RC column is influenced by the strip spacing. If the spacing of strips is closed to each other than it will confine concrete significantly by which it resists the concrete to expand laterally when subjected to compressive load. By increasing spacing between the strips will decrease the load carrying capacity of column which was mentioned by [16] after his experimental results.

b) Effect of Strip Area

According to experimental investigation of Cirtek L. et al. [16], load carrying capacity is increased with increasing the area of strip. Larger width of the strip provides larger area of confined concrete.

c) Effect of Angle Area

Steel angle section is one of the vital structural elements to carry out the load of strengthened columns. It is clear that the increased in the area of angle will definitely increase the load carrying capacity of the strengthened column as it is the main structural elements of strengthening section.

d) Effect of confining pressure

According to Islam et. al [9], confining pressure has a great effect on load carrying capacity of strengthened column with steel jacket and the confinement is mostly depending on arrangement of strips and angles.

8. Design Section Example

In this section, consider an arbitrary RC column of 230 X 230 mm section having 3000 mm height. The area of longitudinal rebar used in the column 1206 mm2 (6-16 mm) with yield strength of 415 MPa. The compressive strength of concrete is 15 MPa and existing 230 X230 column is strengthened by steel jacking.

Firstly, it is necessary to define steel angle section and horizontal steel strips in order to calculate load carrying capacity of strengthened column section.

Let us consider the 75 X75 X6 mm angle section and calculation are based on paper from Islam et. al [9] design example.

Thickness of angle section $t_{ang} \geq 0.1XL_1 = 0.1X75 = 7.5\ mm > 6mm$, In order to satisfy above relation, it is necessary to increase thickness of angle section, i.e. >7.5 mm.

Leg length $L_1 \geq 0.2\beta\ where\ \beta = 0.5(a+b) = 0.5 * (230+230) = 230\ mm$

$L_1 \geq 0.2\beta = 0.2 * 230 = 46\ mm < 75\ mm\ ..OK$

Horizontal steel strip thickness, $t_{str} \leq t_{ang}$; $t_{str} = 6mm < 8mm\ (ok)$

Area of strip should satisfy the condition; $A_{str} \geq 0.004\beta^2 = 0.004(230^2) = 211.6\ mm$

So, minimum width of strip= $\frac{211.6}{6} = 35.27\ mm$

New Angle Section: 75 X 75 X8 mm

Horizontal Steel Strip width: 90 mm > 35.27 mm

9. Conclusion

Many guidelines are used regarding seismic retrofitting and strengthening columns of existing school, office, hospital and apartment building. Unlike other techniques, Steel Jacketing method leads to increase load carrying capacity of existing columns. The durability of the existing column is also improved. Based on various literatures and experimental and analytical results from different researchers, the following conclusions may be made:

- Steel jacketing is one of the techniques used to upgrade the load carrying capacity of existing column.
- Load carrying capacity of existing column will be increased with increase in the cover area of steel angle section, steel horizontal strips. And decreased with increasing the horizontal strips spacing.
- Retrofitted column shows the higher ductility in comparison with normal reinforced cement concrete column as it shows enhanced behaviour after yielding displacement or yielding.
- Generally, failure mode of RC column was brittle while strengthening with steel jacket, it changed failure mode to be more ductile.

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