A Thesis on

AN EXPRIMENTAL STUDY ON FLEXURAL BEHAVIOUR OF RETROFITTED RCC BEAM USING RC JACKETTING

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DECLARATION

I, **Syed Asjad Ashraf** (Enrolment No. 1800101559) student of **Master of Technology** (Structural Engineering), hereby declare that the work detailed in this Dissertation entitled **" An Experimental Study on Flexural Behaviour of Retrofitted RCC Beam Using RC Jacketing"** submitted to the Department of Civil Engineering, Integral University, Lucknow for the award of degree of **Master of Technology in "Structural Engineering"** is my original work. I have neither plagiarized nor submitted this work for the award of any other degree and not been submitted anywhere else.

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CERTIFICATE

Certified that the thesis entitled ***"An Experimental Study on Flexural Behaviour of Retrofitted RCC Beam Using RC Jacketing"*** *is being submitted by* **Mr. Syed Asjad Ashraf** *(Roll No. 1801431017) in partial fulfilment of the requirement for the award of degree of* ***Master of Technology in "Structural Engineering"*** *of Integral University, Lucknow, is a record of candidate's own work carried out by him under my supervision and guidance.*

The results presented in this thesis have not been submitted to any other university or institute for the award any other degree.

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ABSTRACT

Strengthening of existing reinforced concrete (RC) members is of great importance. Many techniques such as concrete jacketing, steel jacketing, steel skeleton and composite (FRP) are used. There are many experimental studies to strengthen the beam by RC jacketing, but there is still a need to improve the performance or rehabilitation of the retrofitted method. In the RC structure, the beam is subjected to uniform and continuous vertical loading with an increase in number of stories, which may lead to partial or total damage of the beam. The cost of reconstruction is much higher than that of retrofitting. Immediate attention is needed to overcome the total failure. Retrofitting is the process of addition of new features or modification to the old structures and bridges, i.e. it reduces the damage vulnerability of an existing structure due to seismic activities. The present study focuses on strengthening beams subjected to flexure load. By adding external reinforcement bars in tension side of the beam with 8mm and 10mm reinforcement bar along with variation in diameter of bar in the form of U shape jacket or three side (25 mm) is presented and examined. A total of twelve specimens having a beam cross section of (100x100) mm with overall length 700 mm with effective length 690 mm were tested. Specimens were classified into two groups. Group (I) contains four specimens (B1, B2, B3and B4) in which B1, B2 and B3, B4 were retrofitted by additional external reinforcement of 3-8ø, 3-10ø and 6-8ø, 6-10ø respectively, one-point load is applied on the beam. Group (II) contains eight specimens (B5, B6, B7, B8, B9, B10, B11 and B12) were strengthened by additional external reinforcement of 3-8ø (for B5, B6) , 3-10ø (for B7, B8) and 6-8ø (for B9, B10) , 6-10ø (for B11, B12) ,two point load is applied on the beam. These external bars are attached with U- Shape stirrups of dia. 8 mm and these stirrups are fixed by wielding to chipped beam (in three sides up to main reinforcement stirrups is shown). The size of retrofitted beams is 125 mm X 150 mm X 700 mm. These beams were cracked under one-point and two-point loading before and after retrofitting. The used strengthening technique can significantly enhance the flexural and shearing strength as well as the performance of the RC beams. For each case of beams, by variation in diameter and number of the additional external steel bars (from 3-Ø8, 3-Ø10 and 6-Ø8, 6-Ø10) increases the load carrying capacity from 45% to 55% respectively and decreases the beam deflection. The external rebar of 8 mm diameter shows less strength than 10 mm diameter. However, concrete shows good bonding as there is no spalling of concrete, when load is applied to the retrofitted beam.

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CHAPTER 1

INTRODUCTION

1.1. GENERAL OVERVIEW

Till to date, earthquakes are one of the most unpredictable and devastating natural disaster which cause extensive damage to the buildings/structures. This damage results in loss of lives and property. Thus, it is very important on the part of the civil engineers to build structures with high seismic performance. But here the question arises. "What to do with the present old/weak or earthquake structures?" It has been observed that majority of such structures/buildings may be safely reused if they are made seismically strong by using some methods/techniques (retrofitting techniques).

It is a better and economical choice as compared to demolition and reconstruction. Thus, there is need to restore or strengthen the old and weak or damaged buildings so that they can sustain future earthquake. It is one of the most important aspect of mitigation especially in earthquake prone areas which will reduce the earthquake hazards/damages. It is the most challenging task for a civil engineer in India as not much of experience and data is available in this field. Two types of building need to be retrofitted.

i. **Earthquake Damaged Building:** The buildings which are damaged or weakened by the earthquakes thus making them fit or safe for future.

ii. **Weak Buildings:** Building which have not experienced severe earthquakes but are seismically weak and are vulnerable.

Various codes and standards are published by Bureau of Indian Standards to help the structural engineers in this field.

1.2. Term Associated with Retrofitting

Retrofitting aims at increase in strength and ductility of the building/structure so that it can withstand the effects of earthquake safely. Various terms are associated with retrofitting which need to be understand carefully. These terms are explained below:

a) **Repair:** Making existing structures safer for future earthquake as per IS 13935:2007. It is defined as the process of reconstruction or renovation of any damaged part of a building in such a way that the building has the same strength and ductility as before the damaged lines. The term "Repair" refers to structural and non-structural elements. Repair work involves filling holes in masonry walls, fixing damaged beams and columns, removing or restoring damaged utility such as water to sewage pipes, fittings, gas and telephone lines.

b) **Retrofitting:** Resistance to earthquake can be upgraded to level of the present-day codes by adequate seismic retrofitting techniques as per IS 13935:2007. Enhancing the seismic resistance of a damaged building is called retrofitting (M Tomazevic). It has been found that the retrofitting costs are much lower than constructing a new building.

c) **Strengthening:** To enhance seismic resistance of a damaged building as per IS 13935:2007. In this method adding strength to any part of an existing building to provide higher strength and ductility than the original building. Strengthening can be done for both earthquake damaged buildings as well as seismically weak building.

d) **Restoration:** This term is commonly used with historically significant buildings, i.e. monuments. It is the process by which a weak or damaged structure is strengthened to replicate the structure as originally built. Damaged Building/Structure some parts or elements of it become weak due to weathering, ageing or any other reason. In restoration these parts are to be repaired and strengthened so that the structure become equally strong and look exactly like it was built originally.

1.3. Need of Retrofitting

As discussed above the need of retrofitting and strengthening is to increase the available seismic resistance of the weak/old or earthquake damaged building. In addition to this retrofitting/strengthening of a building is also required to be done in the following cases.

1) **Upgradation of a Code:** As the experience of the civil/structural engineers is increasing, codes/standards are also being upgraded from time to time. Thus, the buildings designed by the cod e, which has been revised/upgraded, need to be retrofitted to fulfil the latest codal provisions.
2) **Change in use of Buildings:** Whenever there are changes in the use/occupancy of a buildings, for example, public building converted to an industrial building or residential building to office building etc., there is a need to retrofit or strengthen the building to satisfy the codal provision as per the present class of the building.
3) **Important Buildings:** Important building such as hospitals, schools, historical monuments etc. need to be strengthened and restored from time to counter the effects of ageing and weathering.
4) **Retrofitting and Strengthening:** It is also needed in the case of extensions or expansion of the building, for example making more stories etc.

Replacement of damaged or unsafe buildings by reconstruction is not advisable due to following reasons:

i. The cost of reconstruction is much higher than retrofitting or strengthening.
ii. Historical architecture/monuments can be preserved by retrofitting.
iii. Retrofitting/strengthening takes much less time as compared to reconstruction.

The relative cost of retrofitting to construction determines what is to be done. If the cost of retrofitting is less than 50% of the reconstruction cost these retrofitting is done.

1.3.1. Retrofitting of Buildings

In traditional methods of retrofitting techniques may be categorized in two ways, depending upon the position and the extent of damage in structural member.

1) **Local Retrofitting or Member:** This approach is widely used to upgrade individual members or elements of a structure that are seismically weak. This method is cost-effective than the global retrofit alternative. The design or geometry of the building may not alter in this method. For example: beam or column jacketing, beam-column joints, strengthening individual footings.

2) **Global Retrofitting or Structural:** In the global method, the seismic resistance of the structure increases in terms of stiffness, ductility and strength. As a consequence, the geometry of the building can change. For example: adding new features or elements to the building, such as infill walls, columns, shear walls, bracing, buttresses, wall thickening, mass reduction, damping and base isolation.

Jacketing is the most commonly used methods for strengthening of structure/building. Types of jacketing are

I. Steel Jacketing
II. Reinforced Concrete Jacketing (RC Jacketing)
III. Wire Mortar Jacketing
IV. Fibre Reinforced Polymer Sheet Wrapping

1.4. Motivation

Retrofitting has gained significant attention due to its high strength, light weight, high corrosion resistance and ease of fabrication. RC Jacketing is cost-effective technique commonly use to retrofit damaged concrete structures even in earthquake-prone areas. RC Jacketing depends upon the good bond between the damaged member and the jacket, it can be achieved by increasing surface roughness by hammer and chisel, sand blasting, shear connectors, anchoring, epoxy.

1.4.1. Advantages of RC Retrofitting:

1. Enhance the Strength.
2. Increase the shear capacity of column.
3. Technique is easy and it does not need special design criteria.

1.4.2. Disadvantages of RC Retrofitting:

1. Cost effective
2. Requires intensive labour.
3. Increases dimension of structure.
4. Increases weight of structure.

1.5. OBJECTIVE OF THE STUDY

The main objectives of the work are

1. To study the flexural behaviour of Retrofitted RC beam.
2. To suggest a suitable diameter of rebar in RC jacketing for Retrofitted beam.
3. Compare experimental result.

CHAPTER 2

LITERATURE REVIEW

2.1. GENERAL OVERVIEW

The method of retrofitting principally depends on the horizontal and vertical load resisting system of the structure and the type of materials used for parent construction. It also relies on the technology that is feasible and economical. For understanding of mode of failure, structural Behaviour and weak and strong design aspects as derived from the earthquake damage surveys Exercise considerable influence on selection of retrofitting methods of buildings. Usually the retrofitting method is aimed at increasing the lateral resistance of the structure. The lateral resistance includes the lateral strength or stiffness and lateral displacement or ductility of the structure.

2.1.1. Source of Weakness in RC Frame Building

Earthquake engineering is not a pure science; rather it has been developed through the observation of failure of structure during earthquake (Otani, 2004). Damage survey reports of past earthquakes reveal the following main sources of weakness in reinforced concrete moment resistance concrete moment resisting frame building.

i. Discontinuous load path/ irregular load path.
ii. Lack of deformation compatibility of structural members.
iii. Quality of workmanship and poor quality of materials.

2.2. Beam

A beam is a structural element that is primarily subjected to flexural or bending. Beams support the slabs and transfer the load applied on slab to column. if the reinforcement is provided only in the tension zone, it is called a singly reinforced rectangular beam, whereas if the reinforcements are provided in both the compression and tension zones, it is called a doubly reinforced rectangular beam. Beams are classified as

i. Under-reinforced
ii. Over-reinforced
iii. Balanced

depending on their behaviour. Over-reinforced beams are to be avoided as they result in brittle failure of concrete under compression, which are sudden and do not give any warning before failure. Balanced sections are those in which both the concrete and steel fail at the same time. In under-reinforced beams, failure is initiated by the yielding of steel, even though the final failure may be due to concrete compression. This type of failure is ductile (due to inelastic deformation in steel reinforcement) and hence gives enough warning before failure.

2.3 Experimental and Analytical Program to Investigate the Behaviour of RC Beams using different type of Retrofitting Methods

Various researchers have conducted experiments to explore the behaviour of RC beam using different type of retrofitting methods under different types of load condition to the flexural strength of beam. This section deals with experiments conducted in different laboratories to understand the behaviour of RC beam.

Chalioris, Kytinou, Voutetaki, & Papadopoulos (2019) [1]: *Repair of Heavily Damaged RC Beams Failing in Shear Using U-Shaped Mortar Jackets*; experimentally investigated U-Shaped reinforcement jacketing (Fig. 1). The test is performed for two types of beam, i.e. the first cracked beam fails in the shear and the second heavily damaged beam. The majority of the research conducted on non-conventional jacket to strengthen the RC structural member. Use a U-shaped jackets in shear capacity. An experimental setup was made at the edge of the beam and supported on roller by the use of a rigid laboratory frame and hydraulic actuator placed at two points at the center of the beam. Based on experimental data, the overall performance substantially increased of jacketed beam in comparison to reference beam.

Fig. 1. Forming of U-Shaped Jackets with Gusting Cement Mortar Grout Matrix

Bahraq et al. (2019) [2]: *Experimental and Numerical Investigation of Shear Behavior of RC Beams Strengthened by Ultra-High Performance Concrete;* an experimental study is carried out on beams which are strengthened using three sides strengthening. In the RC beam, in which two rebars, i.e. 20 mm in the tension zone along with two rebars, i.e. 12 mm in compression zone. Shear reinforcement of stirrups with a diameter of 8 mm at 120 c/c along with a clear cover of 20 mm provided in 4-side, surface preparation is achieved by sand blasting up to 2 mm to attain a rough surface of retrofitting thickness 30 mm. The retrofitted beams with three-sided jacketing show a high resistance to failure and improved load carrying capacity. The retrofitted beam shows a stiffer, ductile behavior.

Hamed, El-kashif, & Salem (2018) [3]: *Flexural strengthening of preloaded reinforced concrete continuous beams;* performed an experimental study on the flexural behavior of RC continuous beam. Two types of retrofitting process are used here, i.e. RC jacket and strengthen with the Carbon Fiber Reinforced Polymer (CFRP) sheet (Fig. 2). By removing the outer clearance of the beam, RC layers reinforce the bond. U-shaped Stirrups installed by making a hole through a drilling machine (top and bottom sides). CFRP sheets laminated to the top and bottom of the continuous beam. Reducing the preload level increases the load carrying capacity and reduces the deflection of the reinforced beam. The RC layers resulted in a 108 per cent increase in load capacity plus a high conservation of deflection while a 51.5 per cent capacity improvement was achieved by strengthening CFRP.

Fig. 2. Steps of Strengthening using RC-Layers

Kathu Pradeep and Ajesh. K. Kottuppillil (2018) [4]: *Dynamic Behaviour of Reinforced Concrete Beam Column Joint Strengthened with Concrete Jacketing;* The retrofitting is done by introducing additional stirrups and longitudinal bars to the existing building along with layer of concrete, to enhance the flexure and shear capacity. In this study, model a T-beam-column joint, and to analyse these under cyclic loading conditions. The percentage variation of deformation in beam column joint with and without jacketing is found to be 7.31%.The percentage variation of stress in beam-column joint with and without jacketing is found to be 27.07%.From the obtained data it is clear that the provision of steel jacketing reduce the stress demands on the components. The larger and more closely spaced stirrups significantly increase the specimen’s ability to resist the larger number of cycles in the inelastic range leading to a greater energy dissipation capacity.

Neethu Mohan V.M, Lekshmi Priya R. and Shahas S. (2017) [5]: *A Study on the Flexural Strength of Ternary Blended Beam Without and With Retrofitting;* This paper summarizes the work on the properties of ternary blended cement concrete containing Rice Husk Ash (RHA) and Ground Granulated Blast Furnace Slag (GGBS). Beams were casted with optimum proportion of blend by replacing cement in concrete by 0%,10%.20%30%. Flexural tests were conducted after 28th day curing. Minimal loading is given and the beam that carries optimum load is taken for retrofitting. OPC-RHA-GGBS ternary cement concrete could be used as lightweight concrete in civil engineering and building works. The minimal optimum load carried for unretrofitted beams under flexural strength test is P10 i.e. 10% replacement of cement with pozzolana blend. The retrofitted beam carried more flexural strength compared to unretrofitted beam.

Al-Osta, Isa, Baluch, & Rahman (2017) [6]:*Flexural behavior of reinforced concrete beams strengthened with ultra-high performance fiber reinforced concrete;* analyzed two different techniques for reinforcing RC beams using ultra-high-performance reinforced fiber concrete (UHPFRC). In addition, finite element (FE) and analytical models have been developed to predict the behavior of beam samples. In UHPFRC, i.e. first by sand-blasting RC beam surfaces and casting UHPFRC in-situ around the beams inside the mold and second by attaching prefabricated UHPFRC strips to the RC beams using epoxy adhesive (Figs. 3 and 4). Experimental set-up in which beams were reinforced in three different sides under each technique; (i) bottom side reinforcement; (ii) two longitudinal sides reinforcing; (iii) three sides reinforcing and UHPFRC jacket thickness 30 mm. Reinforced beams on three sides showed the highest increase in capacity, while reinforced beams on the bottom side showed the least improvement. Bond strength testing shows the UHPFRC has good bonding properties, even without concrete substrate surface preparation. Nonetheless, it showed higher bond strength by concrete substrates, the surface of which is roughened by sandblasting. Specimens for which concrete and UHPFRC substrates are adhered to an epoxy adhesive have demonstrated a higher bond strength. The findings of the Finite Element Modelling (FEM) showed good agreement with the results of the experimental test. The FEM predicted peak load and the behavior of load-deflection were similar to the test values.

Fig. 3. Strengthening process using Sandblasting and UHPFRC in-situ Reinforcement Techniques

Fig. 4. Strengthened Beams Prefabricate UHPFRC Strips using Epoxy Adhesive Bonding

Hamza Salim Mohammed Al Saadi, et al (2017) [7]: *An Experimental Study on Strengthening of Reinforced Concrete Flexural Members using Steel Wire Mesh;* In this method, wire mesh is used to increase the flexural capacity of the beam, but the installation of wire mesh is only on the flexible side, so that when a lot of testing is done shear crack occurs.

Jayasree, Ganesan, & Abraham (2016) [8]: *Effect of ferrocement jacketing on the flexural behaviour of beams with corroded reinforcement.* have studied that reinforcement corrosion is one of the main causes of degradation of Reinforced Cement Concrete (RCC) structures that affect the strength and durability of the load. A U-wrap ferrocement jacket was used in this work to retrofit the beams (Fig. 5). All beams were tested under two-point loading and the beam strength was retrofitted and the behavior was compared to the control specimens. The ferrocement retrofitting of the mesh reinforcement significantly enhanced the ultimate load carrying capacity of corroded beams more than that of the test samples. It also concluded that retrofitting with mesh reinforcement is insufficient for higher levels of corrosion and may therefore require an additional layer of mesh reinforcement to restore the ultimate load carrying capacity.

Fig. 5. Wrapping of Wire Mesh(U-Wrap)

Hazem M.F. Elbakry and Ahmed M. Tarabia (2016) [9]: *Factors affecting bond strength of RC column jackets;* studied the effects of surface preparation, the contributions of dowels and concrete jacket transverse reinforcement on the overall bond strength between new concrete jackets and old concrete. Thus, concluded that increasing the surface roughness of the substrate concrete by hand-chiselling is considerably more effective than grinding and the use of steel dowels to connect the new jacket concrete to the old concrete significantly improved the overall bond strength due to the developed shear friction.

Krainskyi, Khmil, & Blikharskiy, (2015) [10]: *The strength of reinforced concrete columns,strengthened by reinforced concrete jacketing under loading;* researched the impact of the load supported by the existing structure while improving the future performance of the strengthened structure. The main objective of this research was to assess the impact of that factor. In order to achieve this RC column specimens were strengthened to different levels after preliminary loading and tested for failure. In the experimental setup, several fasteners were welded to longitudinal reinforcement of the test specimens in the middle section. These fasteners were used to attach dial indicators to measure linear deformations of reinforcement. Same fasteners were welded to reinforcement jacket at midsection. The strengthened column limit decreases with the increase of previous loading level. No displacements, cracks or adherence losses between columns and jackets were observed.

Sayed H. Sayed (2015) [11]: "*Retrofitting of Concrete Short Columns after Subjecting to Elevated Temperature Using Different Types of Concrete Jackets***;** investigates the effect of repairing concrete columns after exposure to Elevated temperature using concrete jackets made of different types of concrete and the effect of using shear connectors on the bond between column surface and the jacket and concluded that there is a reduction of ultimate load of concrete columns exposed to elevated temperatures and there is a slight improvement from the use of shear connector. Further, it is said that for such columns exposed to elevated temperatures use of self-compacting concrete jacket is most suitable but the use of recycled concrete is not recommended for repairing RC columns.

Abo-Alanwar & Elbatal 2015 [12]: *A Smart Reinforced Steel Wire Mesh U-Shape Jacketing Technique in Strengthening and Retrofitting RC Beams;* proposed a method by which beam is reinforced by an external steel reinforcement and covered with a U-shaped wire mesh (Fig. 6). In the repair method, the different number of external reinforcement bars is used. The results show that the reinforcement method significantly increases the strength and performance of reinforced concrete beams with changes in the number of reinforcements from 2 No. of dia. 8 to 5 No. of dia. 8. It shows the results of load capacity increase from 108 per cent to 136 per cent.

Fig. 6. Expanded Galvanized Steel Wire Mesh U-Shaped Jacket with Two End Straps

Nguyen-Minh and Rovnak (2015) [13]: *Size effect in uncracked and pre-cracked reinforced concrete beams shear-strengthened with composite jackets examined;* the shear response of original (uncracked) or pre-cracked RC beams that have been strengthened or repaired, respectively, using U-shaped jackets made of epoxy-bonded glass or carbon FRP sheets. Test results indicated that the initial damage influenced the overall response of the jacketed beams. Although all beams, strengthened and repaired, failed in shear, the repaired ones exhibited reduced brittleness of the shear failure, tensile strains in stirrups and crack width with regard to the initially tested specimens.

Constantin E. Chalioris , Georgia E. Thermou (2014) [14]: *Behaviour of rehabilitated RC beams with self-compacting concrete jacketing – Analytical model and test results;*In this the use of thin reinforced self-compacting concrete jackets as a method to repair and strengthen underdesigned flexural concrete members is investigated by means of experimental and analytical studies. In the experimental tests in which beam were designed to fail mostly in shear. After initial loading to near failure, specimens were repaired with three-sided jackets having the minimum thickness required in order to provide adequate bar cover and were subsequently retested to demonstrate the strength and ductility enhancement that could be attained through the intervention. The experimental evidence illustrates that the thin reinforced concrete jackets combine a higher performance efficiency than conventional RC jackets with several of the advantages of other retrofit solutions such as synthetic composite jackets and it improved protection provided by mortar as compared with the resin matrices of conventional FRPs.

Bhavar, Dhake, & Ogale (2013) [15]: *Retrofitting of Existing RCC Buildings by Method of Jacketing;* studied the structural behavior of the RCC building and confirmed that classical reinforced concrete jackets are best implemented due to their flexibility and ease of use. In addition, the building reinforcement considered in this study is an attempt to increase life and withstand unnecessary disruptions, such as floods and earthquakes, etc. It is recommended that appropriate type of jacketing be retrofitted to the old RCC systems at the right time so that it can be cost-effective and safe for the future.

Badari Narayanan, Sengupta, & Satish Kumar (2012) [16]: *Seismic retrofit of beams in buildings for flexure using concrete jacket;* investigated the effect of jacketing on flexural strength and performance of beam. Firstly, slant shear tests were performed to evaluate the interface between old and new concrete. Secondly, beam samples were tested for the study the effect of jacketing on the positive bending of the span region. Third, samples were tested for beam-column-joint in order to study the effect of the jacketing on the positive bending of the beams adjacent to the joint. An experimental set-up was considered where simply supported beam specimens were tested under a two-point loading to study the effectiveness of concrete jacketing by increasing the mid-span positive flexural capacity. Results from the beam tested have been shown to increase ductility strength and ductility retention after concrete jacketing.

Constantin E. Chalioris, Constantin N. Pourzitidis (2012) [17]: *Rehabilitation of Shear-Damaged Reinforced Concrete Beams Using Self-Compacting Concrete Jacketing;*In this the application. of a reinforced self-compacting concrete jacket for the structural rehabilitation of shear damaged reinforced concrete beams is experimentally investigated. The damaged specimens were restored using relatively thin reinforced jackets (25 mm). The experimental program of this study includes monotonic four-point bending loading test RC beams damaged in shear and after their rehabilitation using reinforced U-formed SCC jackets, these retrofitted beams retested under the same loading. The examined SCC jacketing seems to be an easy-to apply and rather effective rehabilitation technique for damaged RC beams since the capacity of the jacketed beams was fully restored or ameliorated with respect to the initially tested specimens.

Achillopoulou and Karabinis (2012) [18]: *Force transfer between existing concrete columns with reinforced concrete jackets subjected to pseudo seismic axial loading;* investigated the repair of RC column specimens using SCC and traditional RC jackets, respectively. SCC jackets with welded wire mesh have been applied in damaged columns that have initially been loaded up to 80–85% of the theoretical load bearing capacity. RC jackets have been applied in damaged columns due to poor consolidation as constructional damages or due to axial compression preloading that caused severe concrete cracking and spalling. Test results of these studies highlighted the efficiency of the traditional RC and the advanced SCC jackets in terms of ultimate load bearing capacity.

Hamidreza Nasersaeed (2011) [19]: *Evaluation of Behaviour and Seismic Retrofitting of RC Structures by Concrete Jacket;* stated that using concrete jacket is effective method in increasing strength and stiffness in a structural frame and further concluded that RC jacketing technique is cheaper than other retrofitting techniques because of availability of materials and no requirement of highly trained labor. Also the congested arrangement of reinforcement limits the volume of extra concrete and buckling of longitudinal bars in the repaired concrete column.

Giovanni Martinola, Alberto Meda (2010) [20]:*Strengthening and repair of RC beams with fiber reinforced concrete;* In this use of a jacket made of fiber reinforced concrete with tensile hardening behavior for strengthening RC beams is investigated. A 40 mm jacket of this material was directly applied to the beam surface. In experimental investigation the application of the HPFRC jecketing technique used for strengthening existing RC beam. The proposed technique provides a significant structural enhancement; due to the remarkably increase of the beam stiffness under service load, the mid-span displacement can be remarkably reduced. As a matter of fact, the jacked acts like a sort of external prestressing, by keeping the initial uncracked stiffness of the element.

Kothandaraman, S. and Vasudevan, G. (2010) [21]: *Flexural retrofitting of RC beams using external bars at soffit level*; conducted an experimental study on the flexural behaviour of retrofitted reinforced concrete (RC) beams using external bars inserted in anchoring holes at soffit (bottom) level by two methods: (i) external reinforcements were connected to the beam soffit as straight bars and checked in single-point loading; (ii) by splitting the bars into two pieces, the external bars were fixed, anchoring them in the beams separately and tied (lapped) by welding all other requirements kept in the same manner (Figs. 7 and 8). Experimental research has shown that this method has led to an increased moment carrying capacity, a decrease in deflection, a boost in crack width and ductility.

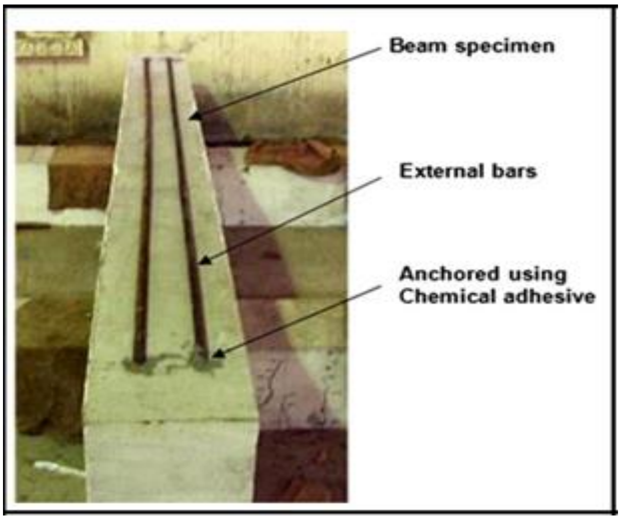


Fig. 7. External Bar Represented at Underside of Beam

Fig. 8. External Bars at Beam Soffit Prior to Welding and Anchoring

Gnanasekaran Kaliyaperumal and Amlan Kumar Sengupta (2009) [22]: *Seismic retrofit of columns in buildings for flexure using concrete jacket;* investigates the effect of concrete jacketing on the flexural strength and performance of columns and it was concluded that the self-compacting concrete was found to be suitable for use in the concrete jacket and the retrofitted specimens did not show any visible delamination between the existing concrete and the concrete in the jacket. Moreover, the roughening of the surface of the existing concrete by motorized wire brush was found to be satisfactory for the type of tests conducted. Further, this study can be extended to the exterior or corner columns by testing the corresponding sub assemblage specimens.

Tsonos (2007) [23]: *Effectiveness of CFRP jackets in post-earthquake and pre-earthquake retrofitting of beam-column sub assemblages;* also experimentally investigated the effectiveness of RC and FRP jacketing in external beam-column joint specimens as post-earthquake and pre-earthquake retrofitting. Undamaged or shear-damaged joint specimens under initial lateral cyclic loading have successfully been strengthened or rehabilitated, respectively, using high-strength mortar jackets reinforced with meticulous reinforcement arrangements or by FRP jackets with various configurations in the joint area. Results have demonstrated the merits and the shortcomings of both jacketing techniques as strengthening or repair methods.

E S Ju´lio, F Branco and V D Silva (2003) [24]: *Structural rehabilitation of columns with reinforced concrete jacketing studied;* the structural rehabilitation of columns with reinforced concrete jacketing and concluded that the RC jacketing strengthening method, unlike other techniques, leads to a uniformly distributed increase in strength and stiffness of columns. Further, the durability of the original column is also improved, in contrast to the corrosion and fire protection needs of other techniques where steel is exposed or where epoxy resins are used. Moreover, removing the concrete from the deteriorated zone by hand chipping, jackhammering, electric hammering or any other method that causes micro-cracking of the substrate, should be followed by sand-blasting or water demolition techniques.

Rodriguez and Park (1994) [25]: *Seismic load test on reinforced concrete columns;* Conducted further testing on rectangular columns repaired and strengthened by concrete jackets under compressive axial loading as well as lateral loading. Rebar hoops are provided as the retrofit reinforcement for the concrete jackets. Concrete jackets increase the strength and stiffness of the as-built (unretrofitted or base) columns by up to three times. It is also shown that damage before the retrofit has no significant influence on the performance of the jacketed columns. Overall, concrete jackets with rebar reinforcement significantly improve stiffness, strength and ductility of typical reinforced concrete columns, but construction is very labour-intensive.

Liew and Cheong (1991) [26]: *Flexural Behaviour of Jacketed RC Beams;* tested the simply supported beams retrofitted with jackets by using prepacked aggregate concrete. The additional reinforcement cage was attached by fixing the stirrups in the pre-located recesses. They concluded that the flexural strength can be predicted by assuming full bond between the existing and new concrete.

2.4. Inference/Conclusion of Literature Review:

A lot of research work on RC Retrofitting has been done by researchers. However, scope on retrofitting of structure still exist and work may carried out by modification in the existing techniques.

Based on the literature studies it can be concluded that RC jacketing can withstand flexural load and imparts high stiffness and ductility. However, weight of structure increased. It requires less skilled labour and cheaper than other retrofitting methods. Analytical data was close to experimental test values.

CHAPTER 3

METHODOLOGY

Following steps are involved in carrying out the experimental study presented in this thesis:

3.1. Collection of Material.
3.2. Nominal Mix for M20 Grade of with Nominal Maximum size of aggregate as 10mm.
   a. Mixing of material for M20 grade (1:1.5:3).
   b. Cube preparation of size 150mm X 150mm X 150mm.
   c. Testing of cube at 7 day and 28 day.
   d. Result
3.3. Design of beam i.e. 700 X 100 X 100 mm.
3.4. Preparation of reinforced concrete beam.
   a. Description of Samples.
   b. Reinforcement Detailing.
   c. Formwork for Beams.
   d. Reinforcement Placing.
   e. Casting and Curing.
3.5. Testing on Reference Beam.
3.6. Retrofit of dismantle or cracked beam.
3.7. Testing on Retrofitted Beam.
3.8. Comparison of retrofitted beam with reference beam.

3.1 Collection of Material

The details of all materials used in the experimental work as follows.

3.1.1. Cement

The use of naturally occurring limestone will result in natural cement (hydraulic lime), whereas carefully computerized mixing of components can be used to make manufactured cements (Portland Cement). A cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete.
Portland Pozzolana Cement (PPC)
The name pozzolan is now frequently used to describe a range of materials both natural and artificial. The PPC was classified into three grades, 33 grades, 43 grades, 53 grades. These grades depending upon the strength of cement at 28 days. It means not less than 33 N/mm2 or 43 N/mm2 or 53 N/mm2.

3.1.2. Aggregates

The fine and coarse aggregates occupy about 60–75 per cent of the concrete volume (70–85% by mass) and hence strongly influence the properties of fresh as well as hardened concrete, its

mixture proportions, and the economy. Aggregates used in concrete should comply with the requirement of IS 383:1970. Aggregates are commonly classified into fine and coarse aggregates.
Fine aggregates generally consist of natural sand or crushed stone with particle size smaller than about 5 mm (materials passing through 4.75 mm IS sieve).
Coarse aggregates consist of one or a combination of gravels or crushed stone with particle size larger than 5 mm (usually between 10 mm and 40 mm).
The factors of aggregates that may directly or indirectly influence the properties of concrete. The coarse aggregates form the main matrix of the concrete and hence provide strength to the concrete, whereas the fine aggregates form the filler matrix and hence reduce the porosity of concrete.

3.1.3. Water

Water plays an important role in the workability, strength, and durability of concrete. Too much water reduces the concrete strength, whereas too little will make the concrete unworkable. The water used for mixing and curing should be clean and free from injurious amounts of oils, acids, alkalis, salts, sugars, or organic materials, which may affect the concrete or steel. As per Clause 5.4 of IS 456, potable water is considered satisfactory for mixing as well as curing concrete; otherwise, the water to be used should be tested as per IS 3025-Parts 1 to 32 (1984to 1988). In general, sea water should not be used for mixing or curing concrete. The permissible limits for impurities as per Clause 5.4 of IS 456 are given in Table 1.10. The pH value of water used for mixing should be greater than six.

3.2 Nominal Mix for M20 Grade

For M20, the Cement: Sand: Aggregate ratio should be in 1:1.5:3 i.e. 1 part of cement, 1.5 part of sand and 3 part of aggragate.IS:456-2000 has recommended that minimum grade of concrete shall be not less than M20 in reinforced concrete work. Design mix concrete is preferred to nominal mix. If design concrete cannot be used for any reason on work for grade M20 or lower, nominal mixes may be used with the permission of engineer-in charge, which however is likely to involve a higher is likely to involve a higher cement content.

3.2.1 Mixing of material for M20 grade

Fig.9 Mixing of Material

3.2.2 Cube preparation of size 150mm X 150mm X 150mm.

Fig.10 Cube Preparation

3.2.3 Casting of Cube:

Fig.11 Casting of Cube

3.2.4 Curing of Cube:

Fig.12 Cubes in Curing Tank

3.2.5.1 Testing of Cube at 7 day

Fig.13 (a) Cube Tests on CTM (7 Days)

3.2.5.2 Testing of cube at 28 day:

Fig.13 (b) Cube Tests on CTM (28 Days)

3.2.6 Results

Total 8 concrete cubes were casted using nominal M20 mix. These cubes were properly cured and testing was done after 7 days and 28 days using Automatic Compression Testing machine of capacity of 3000 KN to determine the characteristics strength of the concrete.

7 Days Cube Tests
Table 1: 7 days Cube Report

SAMPLE NO.	STENGHT (MPa)
1	14.9
2	19.5
3	16.5

28 Days Cube Tests
Table 2: 28 days Cube Report

SAMPLE NO.	STENGHT (MPa)
1	26.6
2	21.6
3	24.8

3.3 Design of beam

Size of Beam: 700mm X 100mm X 100 mm

f_{ck}= 20 N/mm^2

f_y = 415 N/mm^2

b = 100 mm

Cover =20 mm

D = 100 mm

d= 80 mm

$M_u = 0.36 f_{ck} b x_{umax}(d-.42x_m)$

$x_{umax} / d = .48$

$x_{umax} = .48 \text{ x } 80$

$= 38.4$ mm

$M_u = .36 \text{ x } 20 \text{ x } 100 \text{ x } 38.4 \ (80 - .42 \text{ x } 38.4)$

=1765933.056 N-mm

$M_u = 0.87 f_y A_{st} (d-0.42x_m)$

$= 0.87 \text{ x } 415 \text{ x } A_{st} (80-0.42 \text{ x } 38.4)$

$= 23060.9856 \, A_{st}$

$A_{st} = 1765933.056/23060.9856$

=76.57665143 mm^2

No of bars = $\frac{A_{st}}{\frac{\pi}{4} \, 8^2}$

=1.52 (take 2 No. of bar)

M_u = 1765933.050 N-mm

=1.76 KN-m

Check for Depth of Neutral Axis

$x_m = \frac{0.87fy \, Ast}{0.36fck.b}$

$= \frac{0.87 \text{ X } 415 \text{ X } 4 \text{ X} \frac{\pi}{4} \, 8^2}{0.36 \text{ X } 20 \text{ X } 100}$

x_m = 100.8

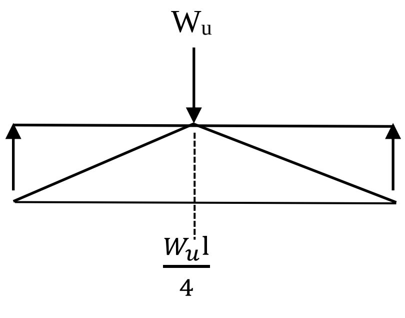
$M_u = 0.87 f_y A_{st} (d-0.42x_m)$

$= 0.87 \text{ X } 0.87 \text{ X } 415 \text{ X } 4 \text{ X } \frac{\pi}{4} \, 8^2 \text{ X } (80 – 0.42 \text{ X } 100.8)$

= 2734158.185 N-mm

= 2.734 KN-m

For One Point Load

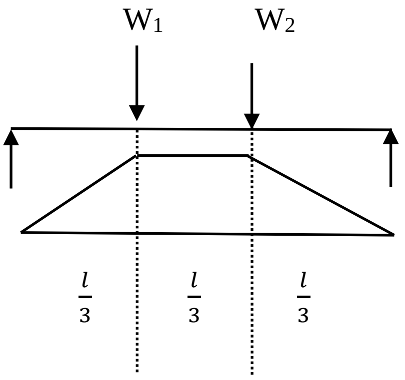


$M_u = \frac{W_u l}{4}$

$2.734 = \frac{W_u \times .7}{4}$

W_u = 15.622 KN

For Two Pont Load



$\frac{W_1 \times l}{3}$ = 2.734 (since, $M_u = \frac{W_1 l}{3}$)

$\frac{W_1 \times .7}{2}$ = 2.734

W_1= 11.71 KN

Similarly, for W_2 =11.71 KN

Total= W_1+W_2

= 11.71 +11.71

= 23.42 KN

3.4. Preparation of Reinforced Concrete Beam

The preparation of reinforced concrete beams was involved following the steps.

3.4.1. Description of Samples

There are 12 beams casted and the curing is performed for 28 days. It will be cracked by one-point and two-point loading in flexural testing machine to lose its strength and then retrofitted by external re-bars and stirrups.

Beam of Size: 700 mm X 100 mm X100 mm

a. Total No. of Beam Casted = 12
b. Length = 700 mm
c. Cross Sectional Area = 100 mm X 100 mm

Fig.14 Different Stages of Beam Preparation

3.4.2 Reinforcement Detailing

Following are the details of reinforcement.

a. Cage Size = 60 mm X 60 mm X 660 mm
b. Clear Cover = 20 mm
c. Main Steel of 8 mm dia. and length 660 mm
d. Stirrups = 8 mm dia. of size 60 mm X 60 mm

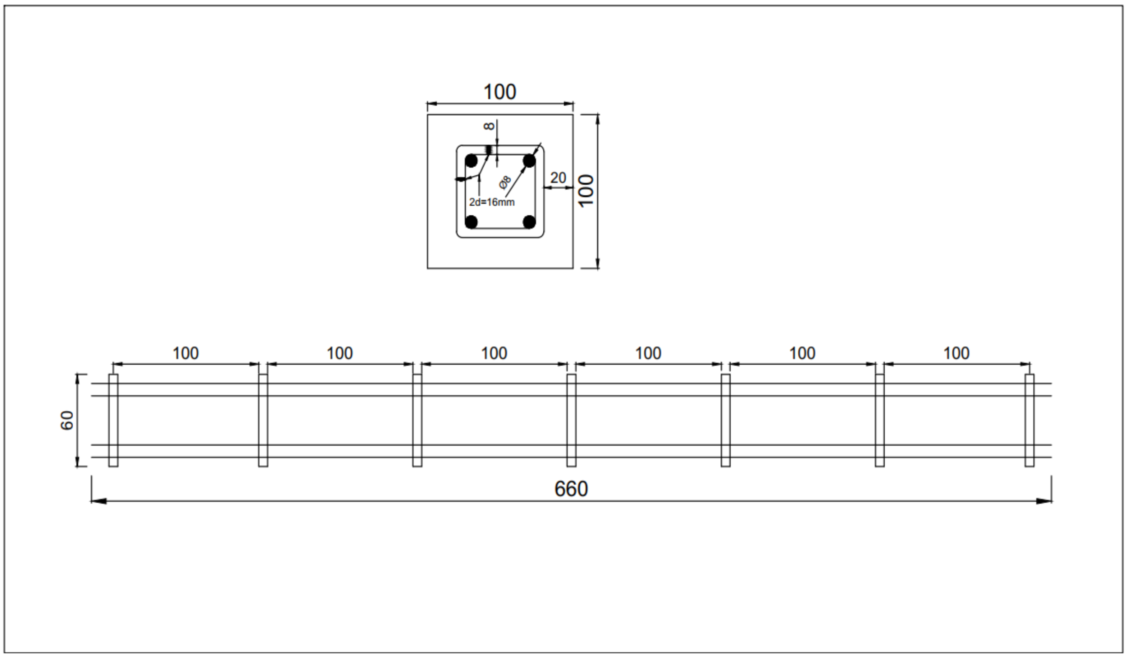


Fig.15 Reinforcement Detailing of Beam

3.4.3. Cracking of Beam in One Point Load And Two Point Load

Fig.16 Testing on FTM (At One Point Load and Two Point Load)

28 Days Beam Tests

Table 3: 28 days Beam Test Report at One Point Load

SAMPLE NO.	INITIAL CRACK STENGHT (KN)
B1	7.4
B2	9.3
B3	6.2
B4	7.9

Table 4: 28 days Beam Test Report at Two Point Load

SAMPLE NO.	INITIAL CRACK STENGHT (KN)
B5	19.3
B6	20.7
B7	21.8
B8	19.8
B9	23
B10	22.9
B11	22.5
B12	21.9

3.5. Preparation of Retrofitted Reinforced Beam by RC Jacketing Method

3.5.1 Reinforcement Detailing of RC Jacketing

Following are the details of reinforcement.

a. Size of Formwork = 150 mm X 150 mm X 700 mm
b. Clear Cover = 21 mm
c. Longitudinal Steel used in three side of 8 mm dia. and 10 mm dia. of length 690 mm
d. U-Stirrups = 8 mm dia. of size 100 mm X 86.5mm.

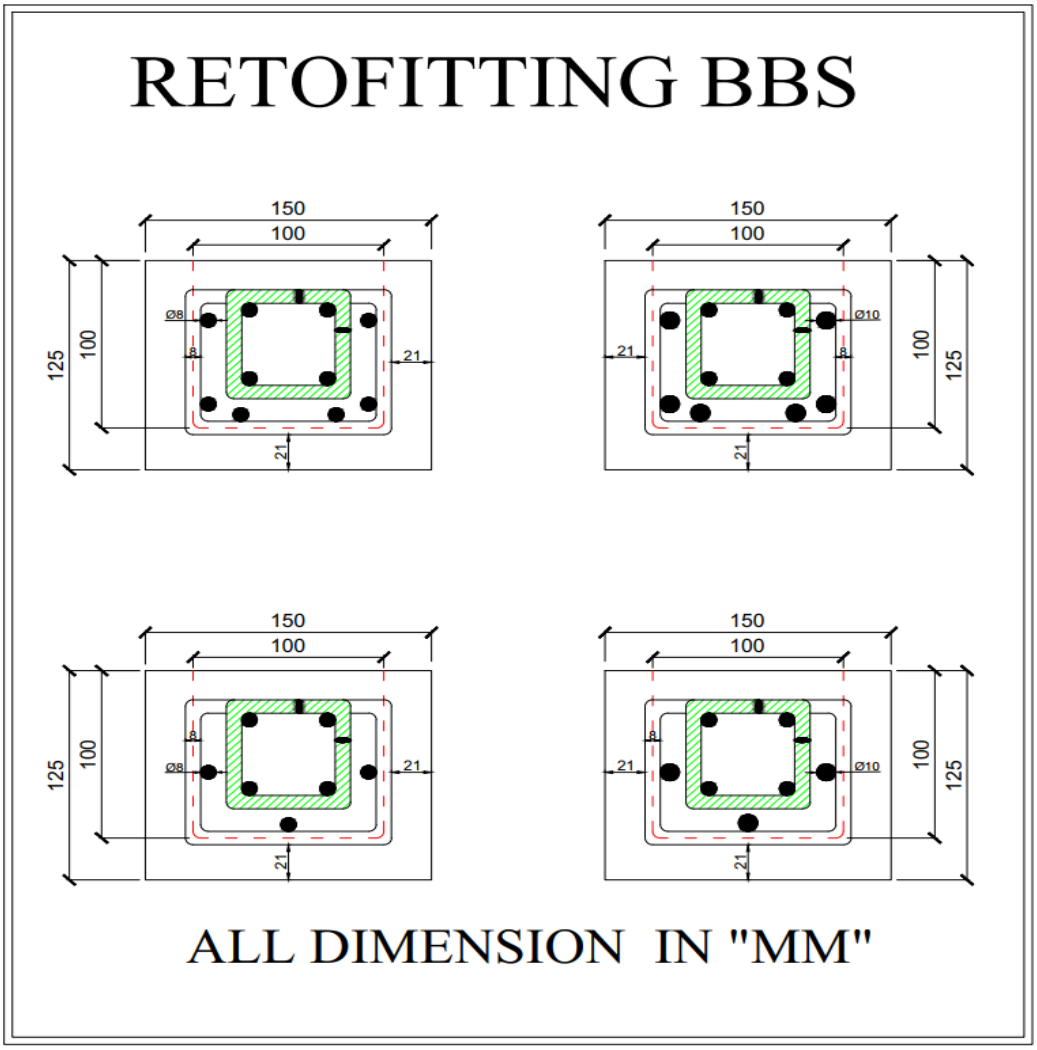


Fig.17 Reinforcement Detailing

3.5.2. Preparation of Retrofitted beam

Fig.18 Different Stages of Retrofitted Beam

3.5.3. Testing of Retrofitted Beam

Fig.19 Testing of Retrofitted Beam

CHAPTER 4
RESULTS AND DISCUSSION

4. Results

4.1. Analysis of Test Results

In this experimental study, the load carrying capacity of reference beams and retrofitted beams were tested until the beams getting crack. A total of 12 beams were casted of core dimension (100mm X 100mm X 700mm). 4 of these were tested for One Point Load and rest 8 were tested for Two Point Load on FTM until the crack was developed. 3-Beams each from both groups were taken and retrofitted on three sides with 3-External Bars of 8mm each, and rest were retrofitted on three sides with 3-External Bars of 10mm each. Similarly, 3-Beams each from both groups were taken and retrofitted on three sides with 6-External Bars of 8mm each, and rest were retrofitted on three sides with 6-External Bars of 10mm. Then after 28-days of curing, these 12 retrofitted beams were tested on FTM, which produced below result:

Table No.5(a): Strength of Retrofitted Beam - One Point Load

Specimen No.	Dimension of Beams	External Bar Dia. Used to Retrofit	Dimension of Retrofitted Beam	Initial Crack of Beam (KN)	Strength of Retrofitted beam (KN)	
					Initial Crack	Failure
B1	100mm X100mm X 700mm	3-8ø	150mm X 125mm X 700mm	7.4	16	34
B2		3-10ø		9.3	18.8	38.5

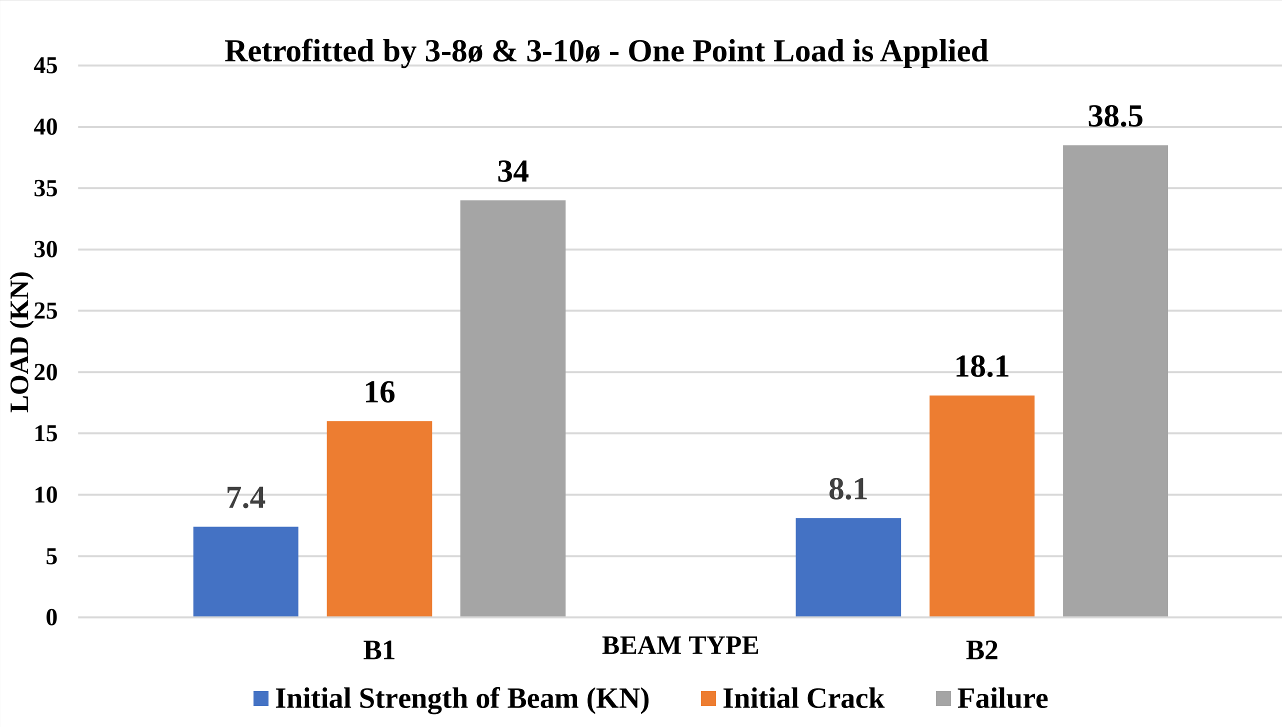


Fig.20: Retrofitted by 3-8ø & 3-10ø & Tested by One Point Load

Table No.5(b): Strength of Retrofitted Beam - One Point Load						
Specimen No.	**Dimension of Beams**	**External Bar Dia. Used to Retrofit**	**Dimension of Retrofitted Beam**	**Initial Crack of Beam (KN)**	**Strength Regain after Retrofitting (KN)**	
					Initial Crack	**Failure**
B3	100mm X100mm X 700mm	6-8ø	150mm X 125mm X 700mm	6.2	17.3	35.6
B4		6-10ø		7.9	19.4	37.2

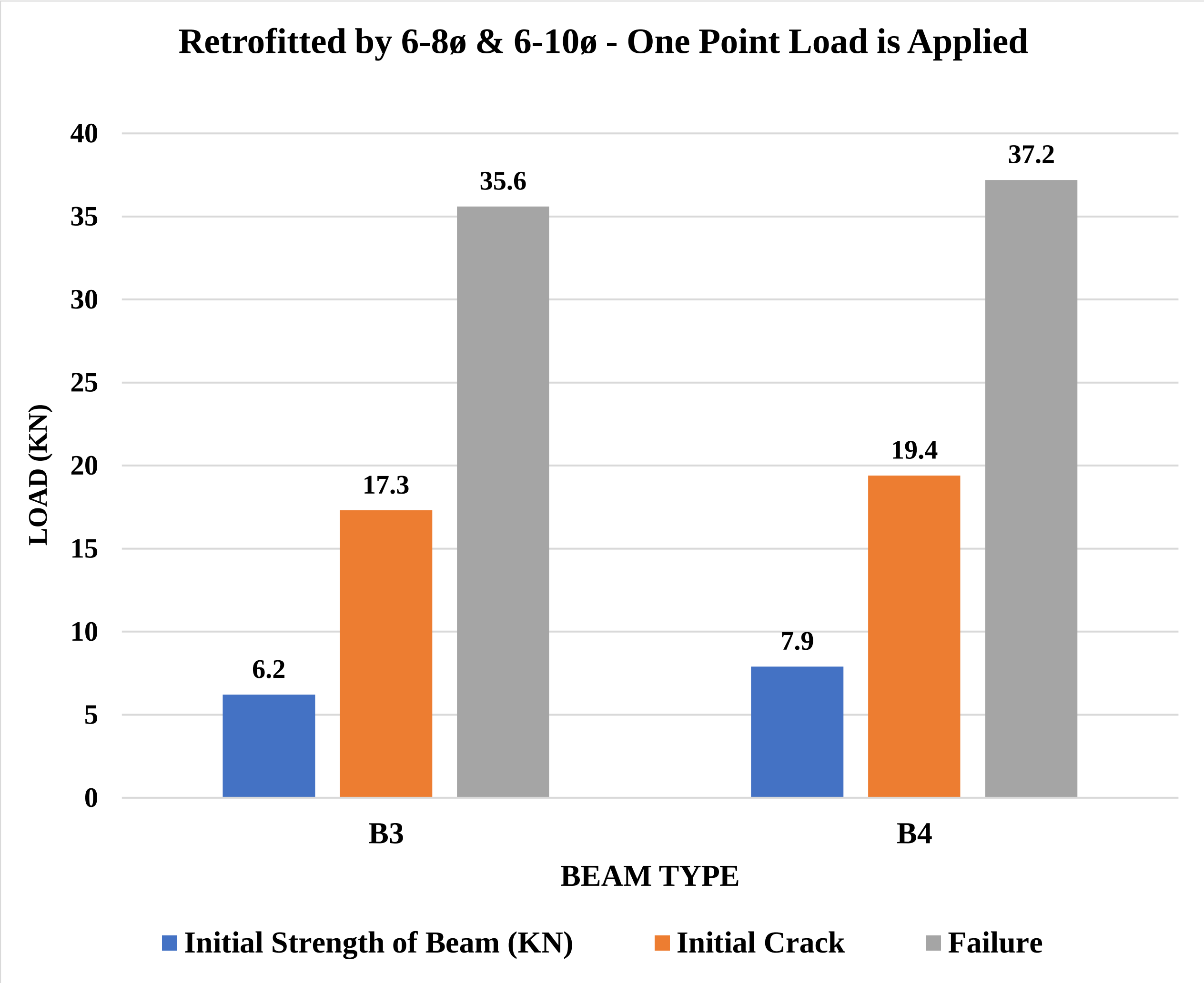


Fig.21 Retrofitted by 6-8ø & 6-10ø & Tested by One Point Load

Table No.6(a): Strength Regain after Retrofit - Two Point Load						
Specimen No.	**Dimension of Beams**	**External Bar Dia. Used to Retrofit**	**Dimension of Retrofitted Beam**	**Initial Crack of Beam (KN)**	**Strength regain after Retrofitting (KN)**	
					Initial Crack	**Failure**
B5	100mm X100mm X 700mm	3-8ø	150mm X 125mm X 700mm	19.3	30.2	41.7
B6				20.7	41.8	50.3
B7		3-8ø		21.8	42.7	53.9
B8				19.8	44.1	55

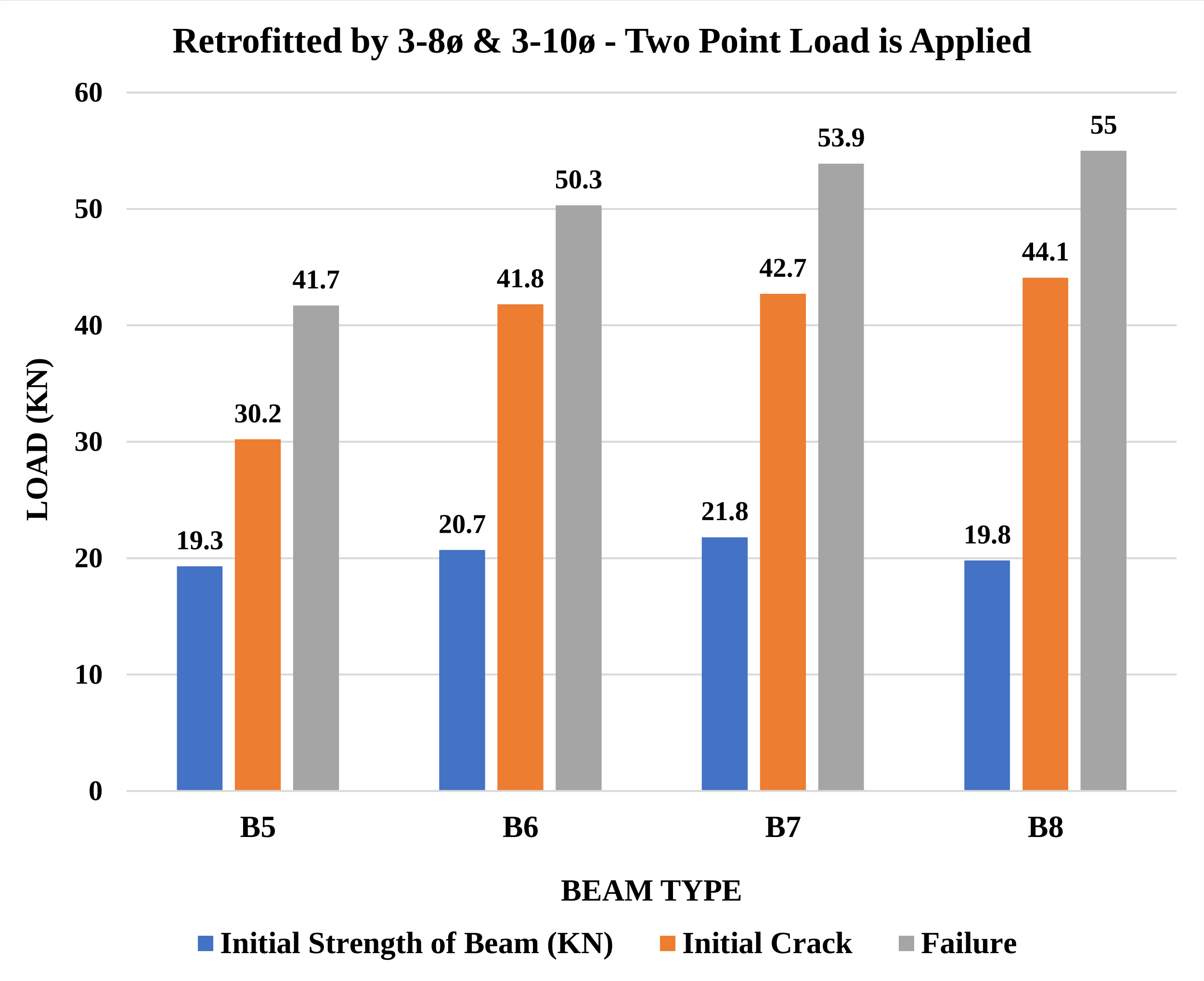


Fig.22 Retrofitted by 3-8ø & 3-10ø & Tested by Two Point Load

Table No.8 Strength regain after Retrofit - Two Point Load						
Specimen No.	**Dimension of Beams**	**External Bar Dia. Used to Retrofit**	**Dimension of Retrofitted Beam**	**Initial Strength of Beam (KN)**	**Strength regain after Retrofitting (KN)**	
					Initial Crack	**Failure**
B9	100mm X100mm X 700mm	6-8ø	150mm X 125mm X 700mm	23	42	69.7
B10				22.9	45.3	65
B11		6-10ø		22.5	44.9	72.3
B12				21.9	46.6	77.6

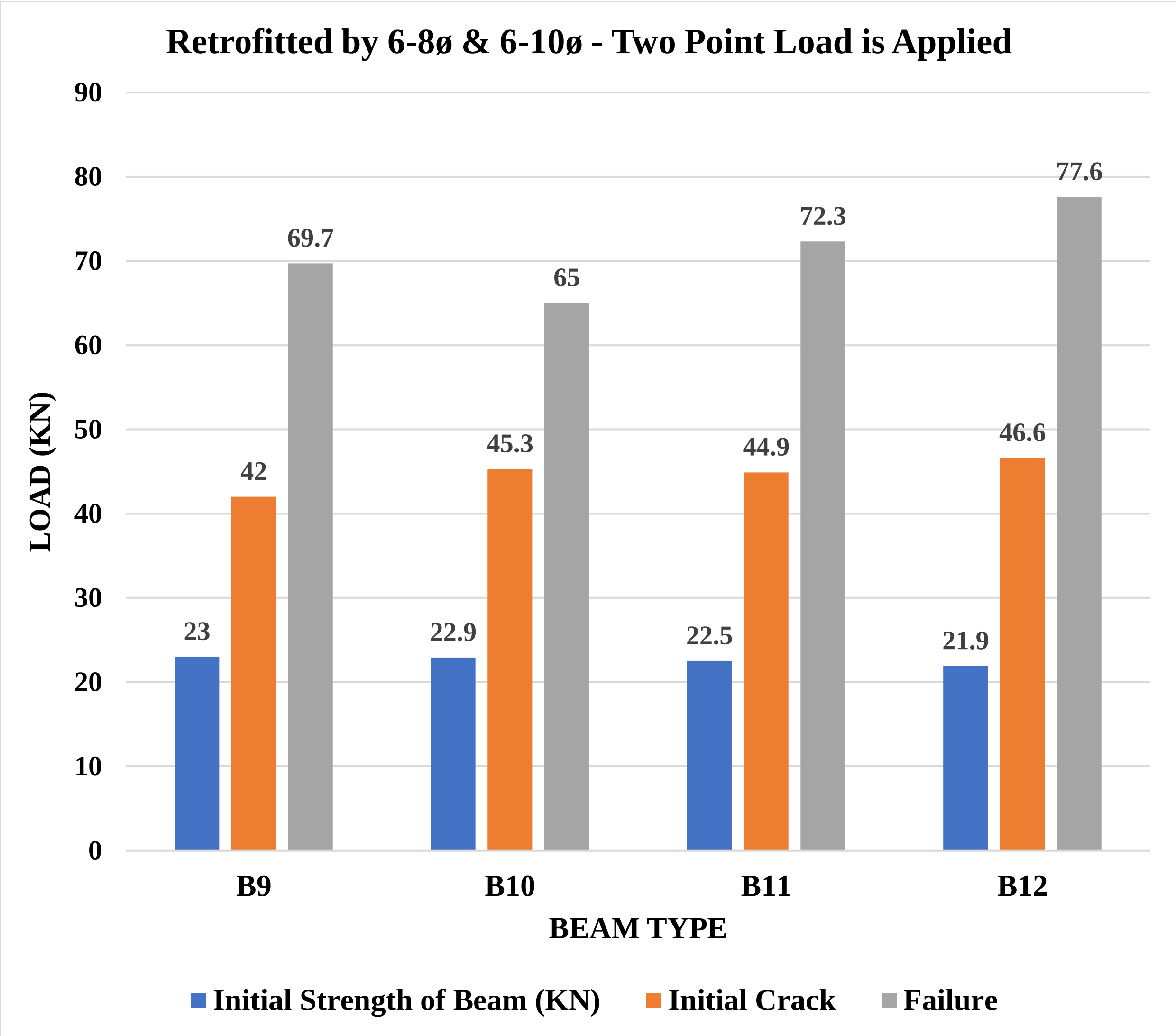


Fig.23 Retrofitted by 6-8ø & 6-10ø & Tested by Two Point Load

4.2. Discussion

A total of twelve specimens having a beam cross section of (100x100) mm with overall length 700 mm with effective length 690 mm were tested. Specimens were classified into two groups.

1. Group (I) contains four specimens (B1, B2, B3and B4) in which B1, B2 and B3, B4 were retrofitted by additional external reinforcement of 3-8ø, 3-10ø and 6-8ø, 6-10ø respectively, one-point load is applied on the beam.
2. Group (II) contains eight specimens (B5, B6, B7, B8, B9, B10, B11 and B12) were strengthened by additional external reinforcement of 3-8ø (for B5, B6) , 3-10ø (for B7, B8) and 6-8ø (for B9, B10) , 6-10ø (for B11, B12) ,two point load is applied on the beam.

These external bars are attached with U- Shape stirrups of dia. 8 mm and these stirrups are fixed by wielding to chipped beam (in three sides up to main reinforcement stirrups is shown). The size of retrofitted beams is 125 mm X 150 mm X 700 mm. These beams were cracked under one-point and two-point loading before and after retrofitting. The used strengthening technique can significantly enhance the flexural and shearing strength as well as the performance of the RC beams. For each case of beams, by variation in diameter and number of the additional external steel bars (from 3-Ø8, 3-Ø10 and 6-Ø8, 6-Ø10) increases the load carrying capacity from 45% to 55% respectively and decreases the beam deflection. The external rebar of 8 mm diameter shows less strength than 10 mm diameter. However, concrete shows good bonding as there is no spoiling of concrete, when load is applied to the retrofitted beam.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Traditional RC jacketing will continue to grow as an economical and long-lasting retrofitting technique. Following conclusions and recommendation are draw:

1. The presented strengthening technique can significantly increase the load carrying capacity, enhance the flexural and shearing strength as well as the performance of the RC beams.
2. By variation in diameter and number of the additional external steel bars (from 3-Ø8,3-Ø10 and 6-Ø8, 6-Ø10) increases the load carrying capacity from 45% to 55% respectively and decreases the beam deflection. Hence, the external rebar of 8 mm diameter shows less strength than 10 mm diameter.
3. Overall increase in strength of beam up to 65 to 75 %.
4. It is also observed that presence of voids in the concrete due to lack of compaction. Hence self-compacting concrete recommended.
5. Old and new concrete shows good bonding in which chipping of beam are done by chisel.
6. Overall size of beam increase.
7. Use of re-cycled concrete in the RC jacketing is not recommended for repairing beams.
8. It was also concluded that there is a need to perform an additional experimental work on the retrofit of beam by composite jacketing and even using different types of concrete and making proper bond, such that classical RC jacketing can be compared with other types of jacketing

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LIST OF PUBLICATION

1. Syed Asjad Ashraf, Dr. Sabih Ahmad, Abdullah Anwar, Juned Ahmad. (2020). An Exprimental Study on Flexural Behaviour of Retrofitted RCC Beam Using RC Jacketing, Compliance Engineering Journal, Volume 11, Issue 11, 2020.
2. Sabih Ahmad, Abdullah Anwar, Avaneesh Kumar Yadav and Syed Asjad Ashraf (2020). Flexural Behaviour of Retrofitted RCC Beam Using RC Jacketing: A Review, IJARET, Volume 11, Issue 10, October 2020