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A SURVEY ON STRENGTHENING OF CONCRETE STRUCTURES

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Abstract - Concrete is one of the versatile material which is used in various types of construction. It is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure, buildings, industrial structures, bridges and highways etc. Concrete is usually the material of choice where strength, durability, impermeability, fire resistance and abrasion resistance are required. But in the concrete structures, most of the failures occur due to variety of reasons.AStructuralFailureissaidtooccurwhenthestructurelosesitsabilitytoperform its intended function. Most of these structures may become deteriorated with time due to corrosion, freezing, and thawing cycle, sulfate attack, and physical damage from impacts. Such deterioration may lead to inadequate flexural or shear strength of the concrete structure. Therefore proper strength of concrete is required to increase the capacity of structural members. In this study, the strengthening of concrete structures using various methods (Sprayed concrete, Ferrocement, Steel plates, FRP) and various techniques (Section Enlargement, External Plate Bonding, External Post Tensioning) are reviewed. These methods and techniques are highly used for improving the strength of structural elements. Analyzing the various methods and techniques, the most efficient method for strengthening of concrete structures can thus be obtained.

Keywords– Structural Failure, Shear strength, Compressive strength, Flexural strength.

I. Introduction

Defective construction that causes failure may be due to numerous reasons that may not easy to predict during the construction. Structural failures can be categorized based on many factors as detailedbelow.

Failure of structures may arise due to inadequate strength either due to faulty design or due to poor quality of material used in the construction. Catastrophic failures can take place when the structure is stressed beyond its critical stress level. The second type of failure is from fatigue considerations or excessive corrosion effects.

These failures usually begin when cracks form at critical stress points, such as squared corners and too close to the material's edge. These cracks grow as the material is repeatedly stressed and unloaded (cyclic loading), eventually reaching a critical length and causing the structure to suddenly fail under normal loading conditions. The third cause of failure can arise from a lack of consideration of unexpected problems. This type of failure can be caused by events such as vandalism, sabotage, or natural disasters such as earthquakes. It can also occur if those who use and maintain the construction are not properly trained and hence sometimes overstressing the structure. Analyzing the above types of failures in structures, it can be realized that the strength of structures is seriously damaged. Therefore it becomes essential to give adequate strength to structural components to prevent irreparable damages.

II. Methods Used For Strengthening of Concrete Structures

A. Ferrocement

It is also called a thin-shell concrete or ferro-concrete consisting of cement mortar reinforced by a number of closely spaced layers of steel wire mesh. The mesh may be made of metallic or suitable materials. It was developed by an Italian architect named P.L Nervi in 1940. Its own weight is less and there is no need of any form work in ferrocement. Time required for the construction is also low. Use of ferrocement is largely increased in the last decades. Maintenance cost is low.

Katsuki Takiguchi and Abdullah (2000) - The column specimens (circular ferrocement jacket and circular steel plate, carbon fibre) are tested and compared to enhanced the improvement percentage of strength, stiffness, ductility, energy dissipation etc. The results shows that ferrocement material give better strength for concrete structures.

AbodiJ. Talib, Abbas A.Ghanim and Mahmmod L. Mohammed Ridha (2017) - Using ferrocement mortar and U-layer steel plates, straight steel plates to improve the structural behavior on repair of reinforced concrete beams. By this experimental study ferrocement mortar used in the repair of reinforced concrete beams showed 18% increased the ultimate load capacity and straight layer of steel plates to repair the beams shows 24% increased the ultimate load capacity, while using U-layer of steel plates leads to the largest increase in the ultimate load

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capacity reaching 100% as a result of the increase in the flexural strength and shear resistance.

S. P. Shang, China L. O. Zeng and China H. Peng (2003) - An experimental research has been carried out to provide information on the flexural behavior of reinforced concrete beams strengthened with U-shape ferrocement. The results shows that ferrocement has increase the ultimate strength, crack-resisting capacity and bending stiffness of RC beams. And also used non-linear analysis method to obtain the whole load-deflection curves for RC beams.

Muhammed Salih D.S, and C. Arunkumar (2016) - To evaluate the ultimate load carrying capacity using ferrocement jackets. And also study the comparison results of strengthened using ferrocement with 0.1% of polypropylene fibre and strengthened using ferrocement without polypropylene. By comparing this ferrocement jacketing with 0% polypropylene is effective and practical technique for strengthening damaged columns but ferrocement with 0.1% polypropylene is highly effective and perform the highest strength for concrete columns.

Mitali Patel, Aadil Mansuri, Chintan Patel and Dr. S. A. Vasanwala (2017) - Strengthening of RC beams using welded and wire-mesh along with ferrocement and microconcrete. In this paper, the strain in steel, strain in concrete, load, deflection etc values are measured. Result shows an excellent improvement in the performance of externally strengthened beams as compared to other beams.

Gurbir Singh Benipal and Kamaldeep Singh (2015) - In this research, ferrocement with wire mesh are used to increase the percentage of load carrying capacity for beams and determine the mechanical properties (ductility, stiffness, strength etc.) of concrete beams.

Ezz-Eldeen H. A (2015) - Strengthening of concrete beams using steel wire mesh and steel angles. Depending upon the number of steel wire mesh and angle size the load carrying capacity has beam increased. The result shows that the number of steel wire mesh plies fixed with 2, 4 and 6 vertical clamps increase the beam carrying capacity from 26.59% to 49.55% and also the angle size at the bottom corners of beams inside the wire mesh decreases the beams deformation.

S.U. Khan, S.F.A. Rafeeqi and T. Ayub (2013) - Different ferrocement strengthening techniques are used in this experimental study. Based on the number of ferro-mesh layers and development length to identify the parameters such as stiffness, strength, ductility and also to enhancing the load carrying capacity of RC beams.

K. Eswaran, Dr.J Sridhar, N. Karunya and R.T AnithaRanee (2016) - The important objective is to study the flexural behavior of predamaged beams with ferrocement laminates under two point loading. By the analytical results, fibrous ferrocement laminates are increased the flexural strength upto 70% compared to other various materials and also multiple layers of ferro-mesh layers are increased maximum stiffness of beams.

P. Paramasivam, C. T. E. Lim & K. C. G. Ong (1997) - Mid span deflection, load capacities, maximum shear stress are estimated using ferrocement laminate.

B. Steel Plates

Steelplate is a method of constructing heavy reinforced concrete item. The method has excellent strength because the steel is on the outside, where tensile forces are often greatest. The parallel plate assemblies can be constructed quickly in off-site fabrication facilities.

By Eray Ozbek, Meryem Bocek and Sabahattin Aykac (2016) - By adding epoxy bonding of the external plate on the beam to investigated the behavior of flexure and load capacity of beams. The external plates with end connection leads to increased the yielding loads of the plated beams in the range of 150-170 % and the ultimate loads in the range of 130-160 %.

Dr. Ashraf A. Alfeehan (2014) - Replacing the internal reinforcement with external steel plates to increasing the ultimate moment capacity of RC beams. The ratio of steel replacement with 33%, 67% and 100% leads to deflection 12.5%, 7.7% and 4.6% respectively.

Augusto Gomes and Julio appeleton - Using external reinforcement to strengthening of reinforced columns and beams. This external steel plate resisting the forces and to prevent the failures of concrete structures.

Julio Appeleton and Vitor Silva (1995) - The Strengthening was evaluated by applying the coefficient technique such as external steel plate. Load test analysis were conducted on before and after strengthening of concrete beams. By this experimental test yield values are determined and compared.

D.A. Van Gemert - Repair and strengthening of reinforced concrete plates by epoxy bonded steel stirrups. From the laboratory test shear values are obtained. This method is may be used for wide range of retrofitting and restoration of damaged structures.

C. Sprayed Concrete

Sprayed concrete is referred as gunite or shotcrete. It is a method of applying concrete that is generally self supporting without the need for formwork. Some advantages are as follows:

1. Access high strength.
2. The holding time is unlimited.

3. There is no concrete waste generation.

4. Spraying with less air demand.

5. There is less dust generation. Hence the working environment is improved.

Y.G. Diab (1998) - Evaluated the effectiveness of repairing reinforced concrete beams with a layer of sprayed concrete. In this paper the ultimate load, deflection, longitudinal strains, and cracking shapes of RC beams are discussed.

D. FRP (Fibre Reinforced Polymer)

Fibre-reinforced plastic (FRP), also called fibre-reinforced polymer, is a composite material made up of a polymer matrix reinforced with fibres. FRP composites are advanced composite materials that are very attractive for use in civil engineering applications due to their high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, lightweight and potentially high durability. Their application is of great importance in constructed infrastructure facilities, such as buildings, bridges, pipelines, etc. Recently, their use has increased in the rehabilitation ofconcrete structures. FRP products are plastic prior to curing, allowing them to be easily applied to surfaces of varying shapes and sizes. Types ofFibres-There are many different types of fibers that can be used to reinforce polymer matrix composites. The most common are carbon fibers (AS4, IM7, etc.) and glass fibers (S-glass, E-glass, etc.).

Carbon Fiber Reinforced Polymer - Carbon fibers are conductive, have an excellent combination of high modulus and high tensile strength, have a very low (slightly negative) CTE and offer good resistance to high temperatures. Carbon fibers are frequently categorized using tensile modulus. There are fivecategories of carbon fibers generally used in composites: low modulus, standard modulus, intermediate modulus, high modulus and ultra-high modulus. The exact cut- off for these categories will vary depending on the reference consulted, but in general, low modulus fibers have a tensile modulus of less than 30Msi and ultra-high modulus fibers have tensile modulus greater than 75Msi. As a point of comparison, steel has a tensile modulus of 29Msi. As the modulus increases, the fibrestend to get more brittle, more expensive and harder to handle. Further, the tensile strength of the fibers generally increases as the modulus increases from low to intermediate, but then tends to fall off in the high and ultra-high modulus fibers, i.e. the tensile strength of carbon fibers tends to be the greatest for the intermediate modulus fibers. For these reasons, standard and intermediate modulus fibers tend to give the best overall performance, unless the application is verystiffness-oriented.

Glass Fibre Reinforced Polymer - Glass fibres are basically made by mixing silica, sand, limestone, folic acid and other minor ingredients. The mix is heated until it melts at about 1260°C. The molten glass is then allowed to flow through fine holes in a platinum plate. Glass is generally a good impact resistant fibre but weighs more than carbon oraramid. A glass fibre is not as strong or stiff as carbon fiber, but it has characteristics that make it desirable in many applications. Glass fibre is non-conductive (i.e. an insulator) and it is generally in visible to most types of transmissions. This makes it a good choice when dealing with electrical or broad cast applications. There are five major types of glass fibers. A-glass (alkali glass) has good chemical resistance, but lower electrical properties. C-glass (chemical glass) has very high chemical resistance. E-glass (electrical glass) is an excellent insulator and resists attacks from water. S-Glass (structural glass) is optimized for mechanical properties. D-glass (dielectric glass) has the best electrical properties but lacks in mechanical properties when compared to E and S glass.

Other Fibres- While carbon fibres and glass fibres are the most common reinforcements in thermoplastic composites, there are other options. Aramid fibers (such as Kevlar® and Twaron) and boron fibers have been used in composites and offer some beneficial properties (excellent toughness and compressive strength, respectively). However they have characteristics that have limited their use (susceptibility to light/difficulty machining and brittleness, respectively). Still others include ceramic fibers like SiC or aluminum oxide. These may be attractive for their compression, insulating, or high-temperature properties. Advantages of Fibre Reinforced Polymers.

There are several advantages in using FRP for strengthening structural elements. Some of them are:

1) FRP can provide a maximum material stiffness to density ratio of 3.5 to 5 times that of aluminum orsteel.
2) It has high fatigue endurancelimits.
3) It can absorb impactenergies.
4) The material properties can be strengthened whererequired.
5) The corrosion potential isreduced.
6) Joints and fasteners are eliminated orsimplified.

K.L Muthuramu, A. Chandran, S. Govindarajan and S. Karunanidhi (2010) - To determine the performance of GFRP sheet in strengthening of concrete elements. By the experimental test GFRP sheet is increased the flexural strength. The result shows in this experimental study is 2 number of GFRP sheet is gives a good strength and

ultimate load capacity if it increasing the number of GFRP sheet the brittle failure is caused. Depending upon the number of layers of GFRP sheet percentage of strength should be obtained.

Abdeldjelil Belarbia and Bora acun (2013) - Extensive investigation has been conducted on structural members to identify the flexural and axial capacity due to strengthening of FRP systems. Based on the analytical results shear strength has increased with the strengthening of concrete structures using FRP.

Manish Kumar Tiwari, Rajiv Chandak and R.K. Yadav - From the study, column can be confined with GFRP sheets to increase their strength. GFRP material is also used in seismic retrofitting. The result shows that the specimen is wrapped with 8 layers of GFRP sheets 47% increases the strength.

R. Sudhakar and Dr. P. Partheeban (2017) - Using GFRP material used in strengthening and retrofitting of reinforced concrete columns. On comparing the experimental results, the compressive strength of RCC column is increased 15.31% by wrapped with single layered GFRP and 31.35% increased by wrapped with double layered GFRP more than the control column. The percentage decrease of deflection in single layered GFRP wrapped column is 53.5% and double layered GFRP wrapped column is 64.68% compared to control column.

Deepak Kumar, Govind Ravish (2015) - Applications of FRP are studied in this paper. By this study literature FRP is considered as a very excellent technique, high corrosion resistance, and also it increased the high tensile strength of a concrete structures. From this analysis both advantages and disadvantages are studied.

Ranganath T.V.L and Raghu Yadav .G (2015) - Investigated the flexural and compressive strength of concrete members with strengthening of FRP (CFRP & GFRP). In this paper, single wrap (74%) , double wrap (138%) and partially single wrap (46%), partially double wrapped (77%) with E- glass fibers and partially wrapped single layered (63%) , double (91%) layered with CFRP. From the result carbon fibers are better than glass fibers in improving the compressive strength and flexural strength of plain concrete members.

Yung-Chih Wang and Ming-Gin Lee (2007) - In this experimental study, beam-column joint is strengthened with Ultra high strength steel fibre, normal concrete, and high strength mortar. On comparing these experimental results ultra high strength steel fibre reinforced concrete exposed an excellent potential in terms of abrasion resistance, compressive strength, flexural strength, rebar bonding, shear resisting etc.

K. P. Jaya (2012) - RC column are wrapping with multiple layers of GFRP and single layer of CFRP. The load carrying capacity of CFRP wrapped specimen with one layer of jacketing is 98.3% and 70% for GFRP with 6 layers of wrapping, the ductility of CFRP wrapped specimen is increased only 2.7% and 70% increased for GFRP with 6 layers of wrapping. From this analysis increase in cost of construction for CFRP wrapping is 43% compared to specimen with 6 layers of GFRP wrapping.

Ratan Kharatmol, Pankaj Sananse, Rohit Tambe, Ms.Raksha J. Khare (2014) - Examined the strengthening of beams using carbon fibre reinforced polymer sheets. In this paper it has aimed to change the structural behavior of R.C.C Beams wrapped with Carbon Fibre Reinforced Polymer Laminates to enhance the flexural and shear capacity of beams. The Beams B1 B2B3curedfor7daysand28daysweretestedontheFlexuralTes tingmachine. We can conclude that the CFRP wrapped at tension side gives better strength as compared to CFRP wrapped at two parallel sides but gives less strength as compared to CFRP wrapped at three sides. CFRP wrapped at three sides gives higher strength but as the CFRP composites is costly it increasing the cost of construction so from economic point of consideration CFRP wrapped at tension side to the beam is advisable.

Ciaran McSwiggan, Amir Fam (2017) - Studied the flexural strengthening of reinforced concrete beams with fibre reinforced polymer sheets. This experimental investigation included two types of bio-based resins such as an epoxidized pine oil resin blend and a fur-fural alcohol resin used in flexural strengthen in go freinforced concrete be amsusing CFRP and GFRP Sheets. Nine full scale rectangular steel reinforced concrete beams were tested and eight of the beams were strengthened using externally bonded CFRP & GFRP sheets. Result showed that the full scale beams increased by 18-54% Peak load and 9- 46% increased yielding load. For the CFRP strengthened full scale beams 46% increased in yielding load and 49% & 54% increase in ultimate load and for GFRP strengthened full scale beams 23% increased in yielding load and 43%& 32% increase in ultimate load. Depending upon the number of FRP layers and types of fibres the result has been increased or decreased.

III. Techniques Used For Strengthening of Concrete Structures

A. Section Enlargement

The section enlargement method is relatively easy to c onstruct and economically effective. This method of strengthening involves placing additional "bonded" reinforced concrete to an existing structural member in the form of an overlay or a jacket. With section enlargement, columns, beams, slabs, and walls can be enlarged to increase their load-carrying capacity or stiffness.

The disadvantages of this method are a high risk of corrosion of embedded reinforcing steel and concrete

deterioration. These problems are associated with relative dimensional incompatibility between existing and new concrete.

Yuandong Wang, Shen Yang, Miao Han and Xun Yang (2013) - to enhance the shear ability using method of section enlargement with RC beam. And also bearing capacity is increased in this technique. By this experimental study the results improved 150% shear capacity of beam and ultimate bearing capacity increased upto 70-80%.

B. External post tensioning

External post tensioning is an effective and simple technique to restore the load-carrying capacity of many type of bridge superstructures. External tendons are used for strengthening steel-concrete composite structures. This technique is economical, easy monitoring and maintenance cost is low.

A F Daly and R J Woodward - Efficient and economic solution for a wide range of structures. It is used to increasing the strength, stiffness of concrete structures and improve the serviceability behavior of existing damaged structures and to prevent the cracking by using this external post tensioning technique.

Elisabeth Staehli, Jean-Claude Peslier and Philippe Funck (1995) - External post tensioning tendons are adding to damaged structures. This is a cost effective technique to strengthening the existing damaged structures and this technique is mostly preferred in highway bridges.

C. External Plate Bonding

External plate bonding is a method of strengthening which involves adhering additional reinforcement to the external faces of a structural member. This technique relies heavily on the physical properties of the material used to attach the new reinforcement and the long-term durability of the reinforcement material. The adhesive is needed to transfer stresses from the structural element to additional reinforcement. By this technique it is used to reduce deflection, increase flexural strength, and improve resistance in shear in certain instances.

Mark Shaw - Aim of this research is to collect the exact details of external plate bonding (steel plates and composite plates are used). From this study, external plate bonding technique is highly effective for strengthening of concrete structures.

Kris Brosens, Omar Ahmed and Dionys Van Gemert - This paper study the various applications of externally bonded technique for the strengthening of Concrete structures. In this technique plates or laminates used for externally bonding to strengthening of concrete structures. It is highly effective in tensile strength, stiffness, ductility, anchorage length and improve the mechanical properties of structures.

Hamid Rahimi and Allan Hutchinson (2001) - By using externally bonded plates to strengthening of concrete beams. It increased stiffness and strength of the beams with composite plates and also increased 230% of ultimate load carrying capacity of beams.

Thiru Aravinthan - This paper investigated the effective solution for shear strengthening of bridge structures. By the investigation of various techniques, external post tensioning is only effective to repair the shear cracks or to increase the shear strength of concrete members.

IV. Conclusion

In this survey various methods and techniques on strengthening of concrete structures are analyzed.

From the analysis, FRP Sheet is most commonly used method which is not economical in some cases andferrocement method is also used in strengthening of concrete structures.

Each methods and techniques has its own advantages and disadvantages.

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