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Experimental investigation of stress–strain behavior of CFRP confined Low Strength Concrete (LSC) cylinders

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HIGHLIGHTS

- A parametric experimental study on Low Strength Concrete (LSC) cylinders.
- Investigating the effects of varying the number of CFRP layers and unconfined concrete strength of cylinders on the performance and mechanics of confined concrete.
- The aim is to predict the behavior of LSC cylinders and evaluate the enhancement in strength and ductility as a result of external confinement with high strength CFRP wraps.
- A significant up gradation in compressive strength and ductility of CFRP wrapped LSC confined cylinders was observed.
- A large increase in compressive strength can be attained even for low strength concrete, with the application of high strength CFRP composites. Therefore, existing deficient structures could be effectively strengthened which will recover their original state and enable them to survive even larger potential earthquakes.

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ABSTRACT

The research presents a parametric experimental study on Low Strength Concrete (LSC) cylinders. The variables include the number of Carbon Fiber Reinforced Polymer (CFRP) layers and unconfined compressive strength of concrete. The aim is to predict the behavior of confined LSC cylinders and evaluate the enhancement in strength and ductility due to this external confinement with high strength CFRP wraps. The experimental results revealed a significant up gradation in compressive strength and ductility of CFRP wrapped LSC cylinders and showed a substantial contribution of this external confinement to the overall stability and stiffness of this composite system. The research concluded that various existing but seismic deficient concrete structures could be effectively strengthened with CFRP technique; which will not only recover their original state but also enable them to survive even larger potential earthquakes due to improved strength and ductility.

1. Introduction

Inadequate seismic design of columns and use of Low Strength Concrete (LSC) are among the major causes of structure failure. Fiber Reinforced Polymers (FRP) materials are also getting popularity in the field of civil engineering, finding applications involving the strengthening and rehabilitation of existing but deficient reinforced concrete structures. The technique is being used worldwide externally for enhancing the axial and flexural load carrying capacities of columns when the internal confining reinforcement is inadequate.

Concrete structures deteriorate with the passage of time as a result of interaction with the surrounding environment. Repairing and strengthening of such existing but deficient concrete structures with FRP materials provides a viable and widely accepted engineering solution for extending the service life of structures. The strengthening techniques results in enhancing the load carrying and deformation capacities of such structures [1]. These

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materials offer various benefits including high strength and stiffness, great durability, and ease of installation. The geometry and shape of the structural member influences the confining effect produced by FRP wrapping and performance of circular columns is paramount as it allows the fibers to be effective on entire cross section [2]. In addition to strengthening, the technique also improves the ductility of structures [3]. Among the various FRP materials, Carbon Fiber Reinforced Polymer (CFRP) replaced the conventional techniques of steel and concrete jacketing because of having various advantages such as easy handling, least disturbance and time consumption to implement [4].

Earthquakes reveal the susceptibility of existing reinforced concrete structures. To resist comparatively larger seismic event, the structures require enhanced ductility for better dissipation of earthquake energy. Structures designed without considering the seismic effects, experience extensive damages during an earthquake. The disastrous earthquake of 8th Oct 2005 in Northern areas of Pakistan resulted in great loss; about 0.1 million people lost their lives in addition to huge loss of infrastructure [5]. After this earthquake extensive survey was conducted [6] that revealed the major reasons behind the failure of structures during this catastrophic event. The use of LSC and lack of spiral/confining reinforcement were among the major causes of damages and eventual failure in majority of the structures during this earthquake [7]. Usually the devastating events often result in revision of code specifications. In Pakistan, after the historic earthquake of 2005, a new building code was formulated i.e. Building Code of Pakistan BCP-2007 [8]. The revision in seismic code put almost every city to a higher category of seismic prone zone. This upgradation of seismic zones made hundreds of thousands of existing structures to be deficient in resisting the future earthquake forces and thus require rehabilitation and strengthening techniques to be employed for enhancing their lateral load carrying and deformation capacities [9].

The shear and flexural strengths of existing deficient bridge pier columns can be significantly improved with CFRP wrapping [10–15]. In past, experimental research had been focused on investigating the confining effects of FRP materials with different parameters [16,17]. However, the present research deals with the results of an experimental program carried out for studying the effectiveness of CFRP confinement and the upgradation of strength and stress–strain response of low strength unconfined concrete cylinders, wrapped with multiple layers of high strength CFRP jackets. The confining action as a result of wrapping CFRP jackets not only prevents the occurrence of buckling in longitudinal reinforcement but also delays the spalling phenomenon in reinforced concrete at higher load levels. The aims of the present research include:

- Quantifying the effectiveness of externally bonded CFRP wraps for enhancing the strength and ductility of concrete cylinders having low unconfined concrete strengths i.e. 12.41 MPa (1800 psi) and 16.55 MPa (2400 psi).
- Investigating the effects of varying the number of CFRP layers on the performance and mechanics of confined concrete.
- After upgradation of seismic zones due to a catastrophic event, the existing LSC structures cannot be ignored even if they are not yet damaged. The comparison of experimental results would give insight to enhancement in strength and ductility of such existing but deficient Reinforced Concrete (RC) structures. The research would help in evaluation of such surviving RC structures especially LSC circular bridge piers which are susceptible to a comparatively larger earthquakes in future. Therefore, such deficient structures can be strengthened by CFRP application to achieve desire level of strength and ductility to resist next larger seismic events.

2. Behavior of steel vs FRP composites

Concrete has ability to expand in lateral direction before it undergoes failure. If this lateral expansion is controlled, a considerable increase in concrete strength and deformation may be achieved. In past, the enhancement in strength and ductility of structures was achieved by confinement using steel jacketing. Presently, the application of fiber material in construction industry has evolved many more strengthening schemes which are preferred over normal steel application. Steel and FRP composites material behave differently due to their different stress–strain response. Researchers [18,19] had compared various materials used for retrofitting purpose and the comparison stress–strain behavior for them is shown in Fig. 1. FRP shows a linear elastic behavior up to failure and fails in a brittle mode whereas; steel has an elastic–plastic behavior. Also the FRP materials lack in ductility which steel possess.

3. Material properties

3.1. Concrete mix design

Concrete mix design was prepared after a number of trial mixes to achieve the desired low compressive strength of 12.41 and 16.55 MPa (1800 psi and 2400 psi). Mixtures were prepared and mixed in the lab by means of a mechanical mixer. The details of concrete mix design used in experimental work are tabulated in Table 1.

3.2. FRP material

In order to obtain the properties of Carbon Fiber Reinforced Polymer (CFRP) C-230, Ultimate Tensile Strength Test (UTS) has been performed using UTS–SHIMADZU, state of the art machine having a capacity of 20 kN and furnished with a built in software i.e. Trapezium which enables automatic plotting of stress–strain curves. The testing equipment in the laboratory is shown in Fig. 2. Three samples of CFRP were prepared with different gauge lengths of 131, 129 and 128 mm and having widths of 12, 21 and 20.5 mm respectively, as shown in Fig. 3. The prepared samples were fixed in the jaws of the machine and strain at the rate 2 mm/min was applied and maintained in all the tested specimens. The results of the experiments are shown in Table 2 and the stress–strain curve is shown in Fig. 14.

The results of test performed on CFRP are as follow:–

- Average ultimate stress = 486.6 N/mm^2
- Average ultimate strain = 1.7883% = 0.01788 mm/mm
- The modulus of elasticity = 486.6/0.01788 = 27215 N/mm^2 = 27.215 kN/mm^2

The value of modulus of elasticity of CFRP laminate as per the manufacturer is 28 kN/mm^2. From the results of test performed on CFRP laminates, the value obtained is 27.22 kN/mm^2 which is close enough to the value of "*E*" i.e. 28 kN/mm^2, provided by the manufacturer of CFRP. The properties of epoxy (bonding material: Sikadur-300) and CFRP laminate as per the manufacturer are tabulated in Table 3.

4. Experimental work

In order to investigate the confinement effect of CFRP wrapping on LSC, the experimental work involves the casting and testing of eighteen test cylinders (standard size of 150 mm diameter and 300 mm height) having a characteristic low strength concrete.