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Analysis of FRP in Strengthened RC Columns

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Abstract - *This research work focusses on the rehabilitation of corrosion-damaged concrete columns using Glass Fibre Reinforced Polymer (GFRP) wraps. An accelerated corrosion process was used to induce different levels of corrosion damage (15% and 30%) in the steel reinforcement. The columns were wrapped with different configurations of GFRP namely Chopped Strand Mat (CSM), Woven Rovings (WR) and Uni-Directional Cloth (UDC) of different thicknesses. The columns were tested under uni-axial compression till failure. The axial and lateral deflections were recorded at all load levels. The load carrying capacity, deformation capacity and ductility of the GFRP wrapped corrosion damaged concrete columns were evaluated. It has been found that the GFRP wraps enhanced the strength, deformation and ductility of the corrosion damaged concrete columns appreciably.*

Key Words: ANN, accelerated corrosion, deformation, ductility, GFRP wraps, regression, strength.

1. INTRODUCTION

Corrosion of reinforcing steel may occur due to carbonation, ingress of chloride ions, sulphate attack, inadequate cover and presence of cracks. Many techniques for combating rebar corrosion have been devised and adopted over the years. Fibre Reinforced Polymer (FRP) has been identified as a promising material in this direction. Its beneficial attributes such as high strength to weight ratio, durability and resistance to corrosion have led to their increased application.

1.1 HIGH STRENGTH CONCRETE

In recent years High Strength Concrete (HSC) having a compressive strength of 60 MPa and above is being used for high-rise buildings and long span bridges, HSC avoids the unacceptable oversized columns on the lower floors, allowing large column spacing's and usable floor space or increasing the number of possible stories without detracting from the lower floor. HSC reduces the dead load of bridge girders and lighter bridge piers and thus enable under pass clearance widths. Further HSC possesses uniform high density and very low impermeability, endowing itself with excellent resistance to aggressive environments and disintegrating agencies and benefiting the durability of concrete structures.

1.2 CLASSIFICATION OF CONCRETE

The advents of newer Concrete making technologies have given thrust for production of concrete with higher strength. Normal Strength Concrete (NSC), High Strength Concrete (HSC), Ultra High Strength Concrete (UHSC).

Table – 1: Classification of Concrete as per IS 456:2000

SI. No	Type	Grade Designation
1	Ordinary concrete	M10 to M20
2	Standard concrete	M25 to M55
3	High strength concrete	M60 to M80

Table – 2: Classification of Concrete as per ACI 363R-92

SI. No	Type of Concrete	Grade Designation
1	Normal strength concrete	21Mpa to 42Mpa
2	High strength concrete	60Mpa to 90Mpa
3	Ultra-high strength concrete	115Mpa to 160Mpa

1.3 PROPERTIES OF HIGH STRENGTH CONCRETE

Basic properties of HSC are different from those of NSC. The assessment of response of concrete structures depends on the accuracy of various basic properties of concrete. Most of the present codal provisions are based on the tests on NSC and their extension to HSC may prove to be dangerous. Finally, it is stressed that various codal provisions need a thorough revision for the effective and beneficial use of HSC in structures. However, concrete with a very low W/C (water-cement) ratio or W/B (water-binder) ratio had improved the flow ability (when used with Super plasticizers), higher flexural strength, low permeability, enhanced abrasion resistance, eminent elastic modulus and better durability. The Correlation between the modulus of elasticity and the compressive strength of concrete and the correlation between modulus of rupture and compressive strength of concrete.

Table -3: Correlation between the Modulus of Elasticity and the Compressive Strength of Concrete

Code of practice / Researchers	Expression for Modulus of Elasticity Ec, MPa	Range of Concrete Strength
ACI Code	$4730\sqrt{fc'}$	No specified maximum Strength
ACI committee 363	$3320\sqrt{fc'} + 6900$	21 MPa ≤ fc ' ≤ 83 MPa
Ahemad and Shah	$8800 (fc')^{0.325}$	fc ' ≤ 84 MPa
Norwegian code, NS 3473	$9500 (fc')^{0.3}$	25 MPa < fc ' < 85 MPa
Iravani	$4700 C_{ca} \sqrt{fc'}$	55 MPa < fc ' < 125 MPa

Table -4: Correlation between the Modulus of Rupture and the Compressive Strength of Concrete

Code of practice / Researchers	Flexural Strength f 'r MPa	Range of Concrete Strength
ACI Code	0.62 □ fc '	No specified maximum strength
ACI committee 363	0.94 □□fc '	21 MPa ≤ fc ' ≤ 83 MPa
Ahemad and Shah	0.44 (fc ')0.67	fc ' ≤ 84 MPa
Radin et. al	0.75 □□fc '	40 MPa ≤ fc ' ≤ 90 MPa
Imam et.al	1.44 (fc ')0.44	70 MPa ≤ fc ' ≤ 115 MPa
Burg and Ost	1.03 √ fc '	45 MPa ≤ fc ' ≤ 130 MPa

Factors Affecting Rate of Corrosion in Concrete

The factors which affect the rate of corrosion in concrete are:

(i)Quality of concrete

(ii)Cover thickness

(iii)Existing crack

(iv)Water content

(v)Oxygen content

1.4 FRP

The main constituents of FRP are fibre and resin. The mechanical properties of FRP are controlled by the fibre type whereas type of resin affects the durability. The most common types of FRP are as follows,

(i)Carbon Fibre Reinforced Polymer (CFRP)
(ii)Glass Fibre Reinforced Polymer (GFRP)
(iii)Aramid Fibre Reinforced Polymer (AFRP)



Fig-1 Full wrap Fig- 2 Discrete wrap Fig- 3 Spiral wrap

2.0 Objectives

1. To assess the effect of GFRP Wrapping as a rehabilitation technique for corrosion damaged concrete columns.

2. To study the axial and lateral stress-strain characteristics of GFRP confined corrosion-damaged concrete columns.

3. To evaluate the effect of GFRP wrapping on the strength and deformation of the corrosion damaged concrete columns.

4. To examine the ductility of GFRP confined corrosion-damaged concrete columns.

5. To understand the failure modes of corrosion-damaged concrete columns with and without GFRP confinement.

6. To compare the experimental results with predictions of theoretical models proposed by several researchers for FRP confined concrete.

7. To develop finite element-based model (using ANSYS) to predict the performance characteristics of GFRP confined corrosion-damaged columns.

8. To develop Artificial Neural Network (ANN) based model to predict the performance characteristics of GFRP confined corrosion-damaged concrete columns.

9. To propose regression equations for estimating the characteristics of GFRP wrapped corrosion -damaged concrete columns.

3.0 Experimental Work

An experimental work has been carried out to study the performance of GFRP wrapped corrosion-damaged concrete columns. A total of 21 specimens of 150mm diameter and 900mm height with varying levels of corrosion damage, wrap materials and wrap thickness were cast and tested for this investigation. Each of the seven specimens were subjected to 15% and 30% level of corrosion-damage and in that two-column specimen were used as corroded control. Glass fiber reinforced polymer wraps were used with different configurations such as CSM, UDC and WR. The wrapping was done with 3 mm and 5 mm thickness for each material. The columns were tested under monotonic loading in a loading frame of capacity 2000 kN.

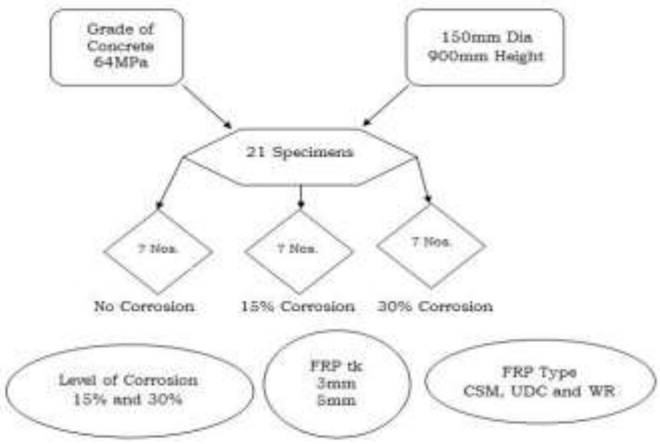

Fig-4: Experimental Investigation Flow Chart.

3.1- MATERIALS

The properties of concrete, steel reinforcements and GFRP sheets used in this study. The mix proportions of concrete are given in Table 3. The characteristic strength attained from the test was 64 MPa. All materials were weigh batched and mixed in a mixer machine.

Table-4 Mix Proportion of Concrete Material

Material	Quantity in kg/m³
Cement	450
River Sand	780
Coarse Aggregate 20mm	680
Coarse Aggregate 10mm	450
Hyper Plasticizer – Glenium B233	0.8% by weight of binder
Silica Fume	25
Water	160
Water to Cement Ratio	0.36

3.2-GLASS FIBRES

Glass fibres used for the study have various fibre configurations.

1. Chopped Strand Mat (CSM)
2. Uni-directional Cloth (UDC)
3. Woven Rovings (WR)

The Chopped Strand Mat (CSM) has randomly oriented E-glass fibres with an aspect ratio of 4800. The Uni-directional Cloth (UDC) has fibres oriented in single direction. The Woven Roving has interwoven fibres oriented at 90º to the longitudinal axis of the fabric. The fibre distributions of all the fibre materials were 450 gram per square metre.

Fig-5: Chopped Strand mat Fabric

Fig-6: Uni Directional Cloth Fabric

Fig-6 Woven Rovings Fabric

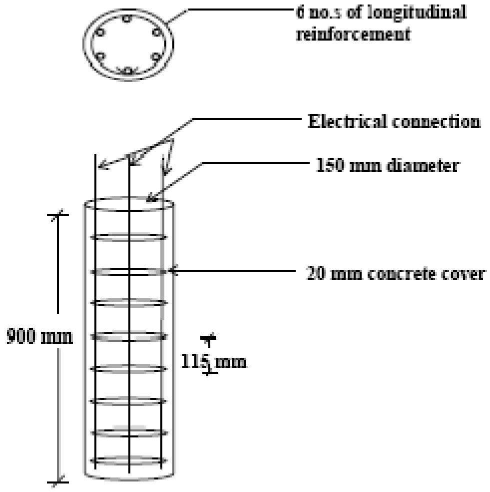

Fig-7 Details of Specimens

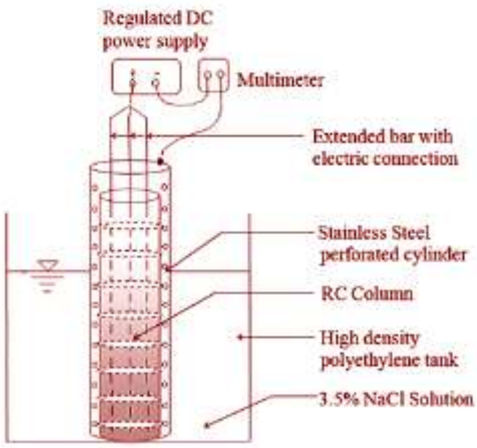

Fig-8 Schematic View of Accelerated Corrosion Set-up

3.3 TEST SET-UP AND INSTRUMENTATION

All the specimens were tested in a loading frame of capacity 2000 kN. To measure the axial compression of the column specimen, two deflectometers with a least count of 0.01mm were fitted at top and bottom of the specimen. A lateral extensometer was provided at mid-height of the column to measure the lateral strain. Fig. 9 shows the test set up and instrumentation provided for the test specimens.

Fig-9 Test Set-up and Instrumentation

3.4 TEST PROCEDURE

1. The column specimen was placed in a loading frame of capacity 2000kN. The specimen was capped at both ends.
2. The verticality of the column was checked with a plumb bob.
3. The load application was achieved through a hydraulic loading jack placed at the bottom of the specimen.
4. The deflectometers and extensometer were mounted at their respective positions and they were then adjusted to zero.
5. An initial load was applied slowly so that the column specimen was set properly to take further loads.
6. Successive uniform load increments were applied to the column. The axial deformation at top and bottom was noted from the deflectometers. The lateral deformation was recorded from the lateral extensometer.
7. The column specimen was tested to failure.
8. The failure mode of the column specimen was observed and recorded.

4.0 RESULTS AND DISCUSSIONS

A total number of twenty-one RC columns were cast and tested under axial compression. The investigation is mainly focused on load carrying capacity, deformation and ductility of the rehabilitated columns. The performance of unwrapped and wrapped corrosion-damaged columns was evaluated by considering the non-corroded unwrapped specimen as reference. The influence of wrap material corresponding to their thickness was calculated by considering CSMGFRP wrapped specimen as reference. The stress-strain characteristics of the columns for various levels of corrosion damage, GFRP wrap material and thickness of GFRP wrapping were presented and discussed. The ductility performance for various levels of corrosion damage, GFRP wrap material and thickness of GFRP wrapping of the columns were also presented and discussed. Typical failure modes of tested column specimens were observed and presented.

Table-5 Summary of Test Results

Specimen Designation	Ultimate Load kN	Ultimate Stress (Mpa)	Deformation (mm)
NC CON	750	42.44	3.14
NC CSM 3	800	45.27	3.24
NC CSM 5	850	48.10	3.56
NC UDC 3	1200	67.91	4.57
NC UDC 5	1275	72.15	4.96
NC WR 3	1075	60.83	4.34
NC WR 5	1125	63.66	4.52
CD 15 CON	725	41.03	3.09
CD 15 CSM 3	775	43.86	3.19
CD 15 CSM 5	825	46.69	3.28
CD 15 UDC 3	1175	66.49	4.35
CD 15 UDC 5	1225	69.32	4.66
CD 15 WR 3	1025	58.00	3.59
CD 15 WR 5	1075	60.83	4.13
CD 30 CON	700	39.61	3.06
CD 30 CSM 3	750	42.44	3.32
CD 30 CSM 5	800	45.27	3.36
CD 30 UDC 3	1125	63.66	4.29
CD 30 UDC 5	1200	67.91	4.75
CD 30 WR 3	975	55.17	3.24
CD 30 WR 5	1025	58.00	3.82

4.1 EFFECTS OF GFRP WRAPPING

The level of corrosion-damaged columns was compared with the non-corroded unwrapped control specimen. The ultimate load capacity for a corroded unwrapped column dropped to 3.33% and 6.67% for 15% and 30% level of corrosion damage respectively. The axial compression capacity was significantly decreased due to the corrosion damages such as cracking and cross-sectional loss of steel reinforcement.

5.0 CONCLUSION

GFRP wrapped corrosion-damaged concrete columns show a considerable enhancement in the load carrying capacity, deflection and ductility than the control concrete columns. UDCGFRP wrapped corrosion-damaged concrete column exhibit a better performance when compared to CSMGFRP and WRGFRP. The GFRP wrapped corrosion-damaged column showed an increase in ultimate load by 30% when compared to the corroded - unwrapped column. The GFRP confined corrosion-damaged columns exhibit a maximum increase in ultimate axial deformation by 38% when compared with the corroded- unwrapped column. The GFRP wrapped corrosion-damaged concrete columns exhibit a maximum increase of 125% in ductility.

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