RETROFITTING OF REINFORCED CONCRETE WITH FERROCEMENT JACKETING

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1. INTRODUCTION

The devastations caused by the earthquakes in the recent past clearly attests the need for effective seismic strengthening techniques to prevent such failures in the future. The primary aim of design practice for bridges located in regions of high seismicity shall be such that the columns develop ductile flexural plastic hinges at predetermined locations. An increase in the confinement in the potential plastic regions of columns will increase the compressive strength of the core concrete and ultimate compression strain and ductility[1]. Strengthening techniques typically involve methods for increasing the confining forces either in the potential plastic hinge regions or over the entire column[2]. In this paper, the results of an experimental investigation conducted to strengthen the shear deficient reinforced concrete bridge piers using ferrocement jacketing as a retrofitting material is presented. A finite element model is developed and the results obtained from the numerical analysis were compared with the experimental results.

2. EXPERIMENTAL PROGRAM

In this research three scale model bridge pier specimens of dimensions 360 x360mm pier portion with a footing dimensions of 600x600mm were designed as shear deficient specimens. The specimens were reinforced with 6 D-16, 4 D-13 and 4 D-19, 4 D-13 and 4 D-16, 4 D-13 respectively distributed around the perimeter of the pier cross section. 10mm diameter ties at 300mm spacing were used as transverse reinforcement in the pier portion. Of the three, first specimen was considered as control specimen while the second and third specimens were strengthened with four layers (V_f = 2.56%) and six layers(V_f =3.46%). The mortar used for the ferrocement was High Performance Shrinkage Compensating Mortar[3]. The woven wire mesh of 2.76mm square opening and 0.45mm diameter with a tensile strength of 700Mpa was used. The required length as per the number of layers was cut and wrapped around the pier with an overlap of 100mm. The spacing between the layers and the cover to the inner and outer surface was provided with temporary spacer rods to infill the mortar. **Fig 1(a)** and **(b)** shows some details of the preparation of the ferrocement specimen. A small gap is left between the pier and the foundation for the ferrocement to prevent excessive increase in flexural strength[4,5]. The flexural strength of the columns is increased in a controlled manner through anchor bolts.

3. LOADING PROCEDURE

Cyclic loading was applied on the specimens along with a constant axial stress of 1.47Mpa. **Fig 2** shows the schematic diagram of the loading pattern. The lateral load applied was controlled by displacement increment. The lateral load was applied by a 200mm stroke electrically operated accelerometer. All the specimens were instrumented with strain gauges mounted on the longitudinal and lateral reinforcement where appropriate, while the displacement transducers and laser devices were used to measure the lateral displacement. DAQ System connected to a 16-channel card scope and signal conditioner system was used for monitoring the specimens during testing.

Fig 1(a) Ferrocement Jacketing

The time displacement input is shown in **Fig 3**.

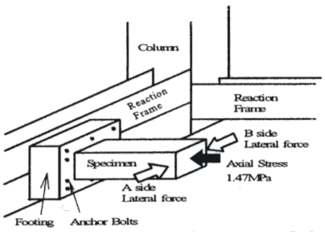

Fig.2 Schematic Diagram of the Loading

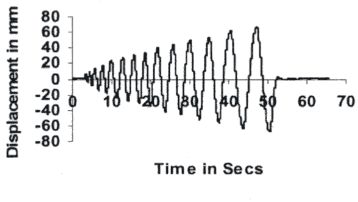

Fig.3 Time Vs Displacement

Fig 1(b) Spacer rods between Mesh Layers

4. DISCUSSION OF RESULTS

The control specimen exhibited shear failure and failed by disintegration of micro concrete due to lack of proper confinement and may be yielding and rupture of the transverse reinforcement. The control specimens as expected could not develop the flexural capacity and there was a continuous decrease in the load with increasing displacement in both the push and pull directions. The maximum measured moments were approximately 70% of the theoretical strength calculated. The lateral displacement response of the control specimen at 100mm from the free end of the pier is shown in **Fig.4**.

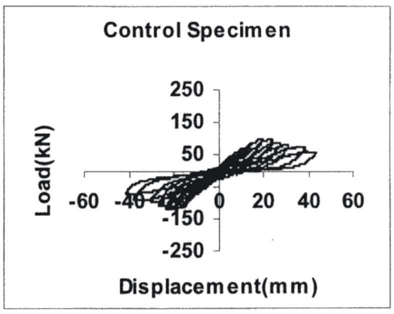

Fig 4. Load Vs Lateral Displacement

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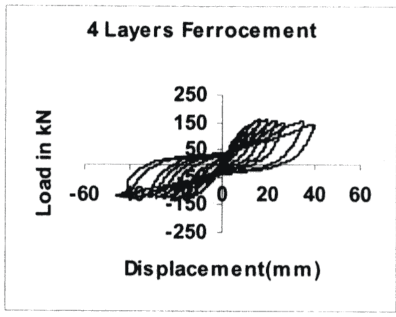
For the ferrocement jacketed specimens though the first crack was noted at almost the same load as that of the control specimen, fine vertical cracks formed with the increase in the load on the surface of the jackets with in the tension zone. As compared to the control specimen the shear strength of strengthened columns was enhanced by about 50%. Increase in the ductility was noticed with ferrocement jacketing. The ferrocement-jacketed specimens also did not show increase in the flexural strength, which was important to prevent over loading of the footing. For ferrocement-strengthened specimens except for a few fine cracks almost parallel to the pier axis, no physical damage was observed on the strengthening jacket through out the tests and they remained in good condition even after the completion of the test.
It was noted that for four layered ferrocement specimen at a drift ratio of about 10% the concrete within the gaps started to crush and this crushing slowly extended into the foundation. It was also observed that no single longitudinal bar suffered fracture despite large lateral displacement at an imposed drift ratio of 10% for four layered and 14% for six layered specimens. In both the specimens it may be noted from **Figs 5** and **6** that there is a stable hysteretic behaviour. In general it may be stated that the piers with ferrocement jacketing were effective in improving the seismic performance with inadequate shear strength. The Lateral load-Displacement peak envelopes of the control specimens and the strengthened piers are presented in **Fig.7**. It can be noted that the four layered and six layered specimens exhibited identical lateral-load displacement response. But there was a significant increase in the strength, stiffness and ductility in six-layered specimen.

Concrete is a restraint sensitive material and its response depends on the lateral confinement. The enhancement of the deformation capacity is very important in shear deficient structures in seismic regions and can be achieved through the confinement of concrete using ferrocement. **Figs. 8, 9** and **10** shows the Lateral Load Vs Strain response of control and Ferrocement jacketed specimens. The increase in the deformation capacity is evident and indicates an improvement in ductility.



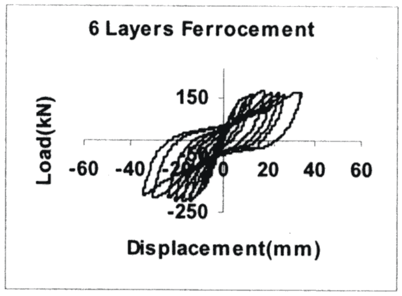


Fig 5, 6 Load Vs Lateral Displacement

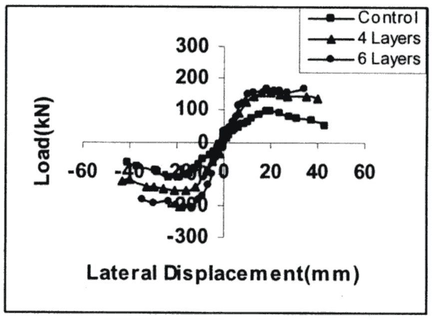
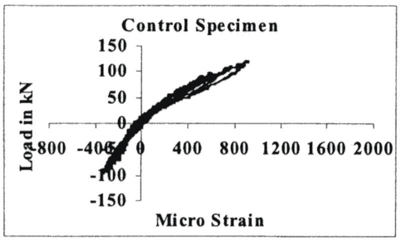
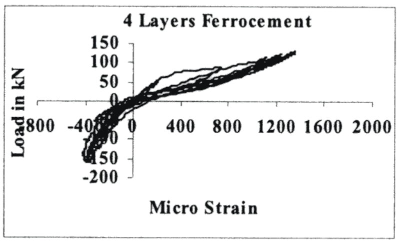


Fig 7 Lateral Load Vs Displacement





Figs 8 and 9 Load Vs Strain

5.0 NUMERICAL MODEL

A finite element model of the pier with foundation is created using SAP 2000. The model is simulated with the same material properties and boundary conditions as the actual specimen. The displacements and stresses in the elastic portion are obtained as shown in the **Table-1.**

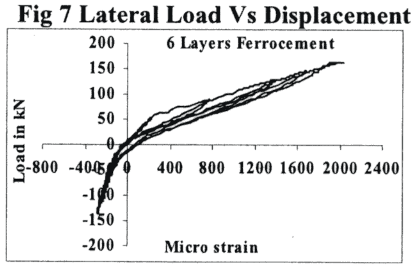


Fig 10 Load Vs Strain

6.0CONCLUSIONS

The study summarizes that by providing external confinement using ferrocement the stiffness, strength and ductility could be improved significantly. The mode of failure could be changed from brittle shear failure to ductile flexural failure. Ferrocement jacketing specimens have resulted in small diameter cracks and were intact even after testing. The numerical and experimental values compared well.

Table-1 Experimental and Numerical Values

Specimen	Displacement (mm)		Stress (N/mm^2)		Result
	0	H/2	H/2	H	
Control Specimen	4.60	3.00	4.2	7.1	Expt.
	4.53	2.88	3.6	6.0	Num.
4-Layered Ferrocement	1.72	1.19	2.7	5.0	Expt.
	1.69	1.08	2.4	4.5	Num.
6 Layered Ferrocement	1.39	0.84	1.9	2.4	Expt.
	1.37	0.81	1.4	2.1	Num.

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