Performance of RC Columns Confined with Welded Wire Mesh Around External and Internal Concrete Cores

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Abstract-Effectiveness of locally available welded wire mesh (WWM) as an additional confinement in reinforced concrete square columns was evaluated under axial loads. For this purpose three groups of 200×200×975mm square column specimens were cast with different arrangement of locally available WWM and conventional stirrups. In group-1, specimens were confined with ties and WWM wrapped around inner core of specimen. In group-2 specimens, WWM was wrapped around outer core and in group-3, specimens were prepared with conventional ties only. Three specimens were also cast without any reinforcement. The investigation concluded that the axial capacity of columns in group-1 and 2 was 8.5% and 15.7% higher than group-3 specimens. Core concrete strength was improved by 14.6 % and 23 % for specimens of group 1 and 2 respectively as compared with group 3. Strength enhancement factor was also improved by 10.25% and 18% respectively. The study concluded that WWM as an additional confinement improves the performance of RC columns in terms of overall strength, core concrete strength and strength enhancement factor. However the efficiency of specimen with WWM wrapped around the external core is superior to the specimen confined with mesh wrapped around the internal core.

Keywords-Columns, Confinement, Wire Mesh, Strength Enhancement Factor, Stirrups, Stress-Strain Curves, Axial Load

I. INTRODUCTION

In the event of earthquake high compression stresses are induced in RC members that result in the development of transverse strains in RC columns. Reinforcement if present applies reactive pressure on core concrete and limits the cracking. This adds to the ability of concrete to sustain high stresses and strains [i]. Richart et al. [ii] concluded from his research that the strength of concrete with active lateral fluid pressure is approximately the same as for the concrete confined with spirals. Later Sheikh S. A. [iii] studied the effectiveness of ties as confinement steel in concrete. Further Mander et al. [iv-v] based on his own work and others works[vi-viii] concluded that there are many other factors that improve confinement and resulting ductility of concrete. These factors include spacing and volumetric ratio of transverse reinforcement, number and arrangement of longitudinal bars, additional overlapping hoops and cross ties and spiral and circular hoops. WWF apart from use as temperature reinforcement may be used for various purposes. For example, these may be used to avoid the congestion caused by the hooks in the stirrups and crossties. Welded wire fabric (WWF) as confining transverse reinforcement in columns is an alternative to conventional steel ties. The WWF may be placed transversely in the core of the concrete column in parallel stack with a uniform longitudinal spacing or it may be wrapped around the column in addition to conventional ties [ix].

WWF as confinement reinforcement for concrete columns can be used to improve the earthquake resistance of structures [i]. Another research concluded that WWF shows improvement if used in combination with conventional reinforced specimens [x].

In high strength concrete the ductility demand increases, which necessitates the increased volume and number of transverse reinforcement with complex arrangements. To overcome resulting reinforcement congestion problems in columns, another study proposed the use of welded wire reinforcement (WWR) in the form of bundles [xi]. The authors concluded that WWF can be ideally replaced with conventional ties when the volumetric ratio was equal to or larger than 4.0%. It was also determined that for the same volumetric ratio of transverse steel, the use of WWR provided higher strength in axial compression as compared to conventional ties. WWF reinforcement eliminates few structural detailing problems, results better economy and quality control [xii]. Another experimental investigation on the behavior of square concrete columns confined by WWF concluded that the confinement provided by WWF also enhanced strength and ductility of square columns. In a previous study

[xiii] Expanded Metal Mesh (EMM) layer was wrapped in addition to regular tie reinforcement. The results indicated that the columns, confined with proposed lateral reinforcement, revealed significant improvement in the strength and ductility. Also, high reduction in the ties volumetric ratio with no loss in ultimate load could be achieved by installing the EMM layer. Welded wire mesh/Fabric with wire spacing less than 20 times of wire diameter, the crack spacing is independent of the type of reinforcements and bond performance [xiv]. Research also concluded that tension stiffening of welded wire mesh with small wire spacing is higher than the RC elements reinforced with deformed bars. Welded wire mesh, shows smaller crack spacing and crack width compared to conventional reinforcing bars, however it has smaller structure ductility.

Household fiber glass fly mesh and 12.7 ×12.7mm galvanized steel wire meshes installed in the formwork of cylindrical columns also improved column behavior [xv]. The columns were tested under concentric, eccentric, and pure bending loading. The testing results have shown that wire mesh significantly improved the load carrying capacity under both concentric and eccentric loading, but it did not significantly increase the ductility of columns for each load case.

WWM can also be used for repair of damaged columns, properties like initial stiffness of the specimens with concrete jackets reinforced with rebar and WWM were very similar before concrete cracking [xvi]. At high temperatures compressive strength of a galvanized iron (GI) welded mesh specimen is higher compared to conventional specimen in before and after a fire at a temperature of about 500°C[xvii].

Previous research work favors the use of WWM as an additional confinement in RC columns. However, WWM can be used externally around stirrups and internally around core. There is no experimental evidence on how its location inside RC columns effects the behavior in terms of strength, ductility and crack development. Therefore this investigation discusses an interesting aspect of WWM related to its placement inside concrete core. In this experimental investigation merits and demerits of using WWM externally or internally as confinement in RC square is evaluated in terms column axial capacity, core concrete strength and strength enhancement factor.

II. Experimental Program

This section discusses the material properties, formwork and test setup developed for conducting the present investigation. In this research, nine specimens were cast with different arrangement of confining steel and two specimens were cast with plain concrete only. Compressive strength of concrete at the time of the testing was 31 MPa. In order to investigate the effect of location of WWM in RC columns, locally available galvanized iron welded wire mesh (GW mesh) was used as an additional confinement. The specimens were divided into three main groups. In group-1, GW mesh was wrapped around external cores (outer side of column ties) and in group-2, mesh was wrapped around internal cores (inner side of core) of column specimens. For comparison purposes, group-3 specimens were cast with no mesh at all. The specimens were tested under axial load.

III. Description of Tested Columns

In this investigation eleven 200×200×975mm square column specimens were cast in four groups. Specimens were provided with four 12.5mm diameter bars as longitudinal reinforcement. In group-1, three specimens were confined with conventional stirrups at 180mm spacing and an additional confinement in the form of galvanized wire mesh was wrapped around the inner core. Specimens in group-2 were confined with conventional stirrup spaced at 180mm and GW mesh was wrapped around the outer core. In group-3, specimens were confined with conventional stirrups at 100mm spacing with no wire mesh confinement at all. For comparison purposes, in group-4 only two specimens were cast with plain concrete. Structural details of all the specimens are shown in Fig. 1.

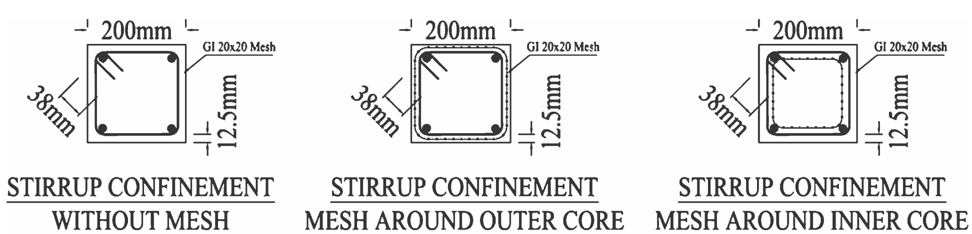

Fig. 1. Structural detailing of specimens

In order to simplify the understanding of the test results suitable specimen nomenclature was selected. In the nomenclature the suffixes i, o, s and p was used with numbers. Suffixes "i" and "o" are used for core confined internally and externally respectively. The suffix "s" stands for stirrup confinement and "p" stands for plain concrete. Details of nomenclature is shown in Table I.

TABLE I
CONFINEMENT DETAILS OF TEST SPECIMENS

Serial No (1)	**Column No (2)**	**Group No (3)**	**Description (4)**	**Spacing of Stirrup confinement (mm) (5)**
1	1i	Group-1	wire mesh wrapped around inner concrete core	10mm Dia at 180mm spacing
2	2i			
3	3i			
4	4o	Group-2	wire mesh wrapped around outer concrete core	10mm Dia at 180mm spacing
5	5o			
6	6o			
7	7s	Group-3	No Mesh	10mm Dia at 100mm spacing
8	8s			
9	9s			
10	10p	Group-4	Plain Concrete	
11	11p			

In all specimens four Grade 60 deformed bars having 12.5mm diameter were used as longitudinal bars. All ties used were 10 mm diameter having Grade 60 steel. Spacing of ties without GW mesh was 100mm. However, in specimens when GW mesh was used, 50% less stirrups were used thus stirrup spacing was increased to 180 mm.

In the present research locally available GW mesh was used as an addition confinement. The mesh was fabricated by using a 1.25 x 0.7mm Grade 40 square wire and it was welded at 16mm grid. The pictorial view of the GW mesh used in this investigation is shown in Fig. 2.

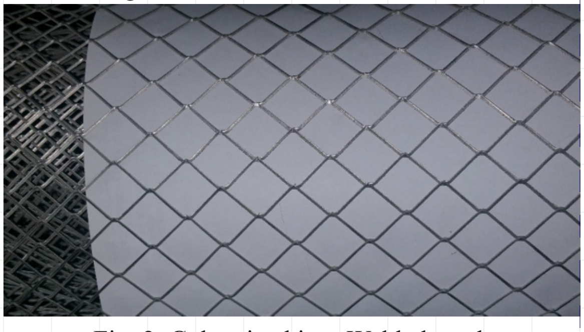

Fig. 2. Galvanized iron Welded mesh

IV. SPECIMEN CONSTRUCTION AND TEST SET UP

Concrete in the specimens was poured with formwork standing vertically to simulate the field condition as shown in Fig. 3. Concrete for the test specimen was mixed in the tilting mixer while its compaction in specimens was done with the help of internal vibrator.

Fig. 3. Specimens placed in form work, ready for pouring

Before starting test, top and bottom end of the specimen were strengthened using 50 mm thick mild steel collar. The specimens were tested on 5000kN capacity compression testing machine. During the test, loading rate and strains were recorded manually. In order to avoid dynamic effect, loading rate was kept within the range 0.14 to 0.34 MPa/Sec, recommended by ASTM standards. The axial load was recorded using MCC Multitest servo-hydraulic command system attached to the machine. At each load level, axial deformation in specimens was manually recorded using dial gauges attached on both faces of the specimen. Strain corresponding to each load level was calculated by dividing the gauging reading by gauge length which was 600mm. Fig. 4 shows the test on specimen in progress.

Fig. 4. Test setup

A displacement control based testing arrangement has been devised wherein dial gauges were used to find the axial deformation between two specific points as shown in Figure 4. During loading axial deformation was directly read from the dial gauge at suitable intervals. In order to prevent extensive damage to core the tests were stopped near peak load. This limitation was set to evaluate the hidden capabilities of RC column with additional mesh confinement to restore their strength after repair.

V. Test Results and Observations

Each specimen was tested under axial loading. Load and corresponding axial deformations were recorded and analyzed. The test data was used to analyze the efficiency of GW mesh in terms of the axial capacity of columns, core concrete strength and strength enhancement factor. Stress strain graphs were also plotted for each specimen.

Fig. 5, 6 and 7 show the condition of specimens in each group at the end of the test. The visual observation of group 1 specimen indicated that the inner core remained intact and the cracks did not penetrate within the core. After spalling of clear cover main bars depicted outwards buckling.

Group-2 specimens resisted the cover spalling. This behavior was due to presence of mesh within the cover. The double action of cover resisted development of micro cracks on one hand and prevented large cover spalls on the other hand. The buckling of main bars was also prevented by the combined effect of stirrups and mesh. Even at peak loads no such signs of main bar buckling were noticed.

Specimens in group-3 showed usual behavior during application of load. Clear cover spalled off just before reaching the peak load. Extensive cracking in specimens was observed that was penetrated deep into the core. Main bars also buckled outward at few locations.

Fig. 5. Pictorial View of specimen “3i” of Group 1

Fig. 6. Pictorial View of specimen “6o”

Fig. 7. Pictorial View of specimen “7s” and “8s”

The condition of the specimen at the end of the test confirm that the group-2 exhibited superior behavior in terms of cracking and concrete crushing. At the same load levels minor cracks appeared on the surface. Also the cover had to chisel off to view the condition of GW mesh concealed in concrete cover. Fig. 5 shows the condition of specimen at the end of the test. Specimens with inner core confined with GW mesh showed the tendency of main bars to buckle out as shown in Fig. 6. Group three specimens showed maximum damage. Cover of specimen of group-3 spalled off at many locations. The inner core of these specimens also showed visible crushing.

VI. STRESS STRAIN GRAPHS

Stress strain curves were plotted by recording the deformation at suitable load intervals. The stresses were plotted on ordinate and strain on the abscissa. The Fig. 8-10 shows the stress versus strain curves for all columns in group 1, 2 and 3 respectively.

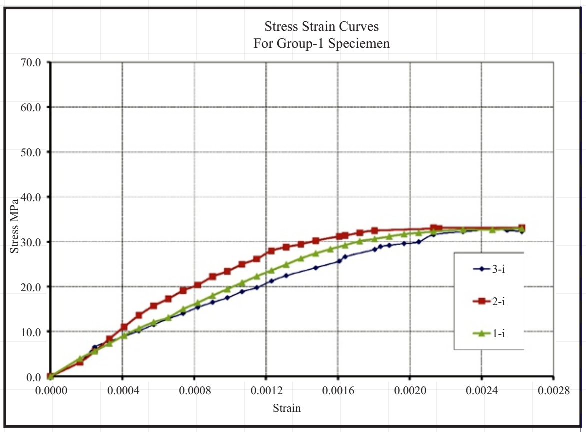

Fig. 8. Stress strain curves for group-1 specimen (Inner core confined by GW Mesh)

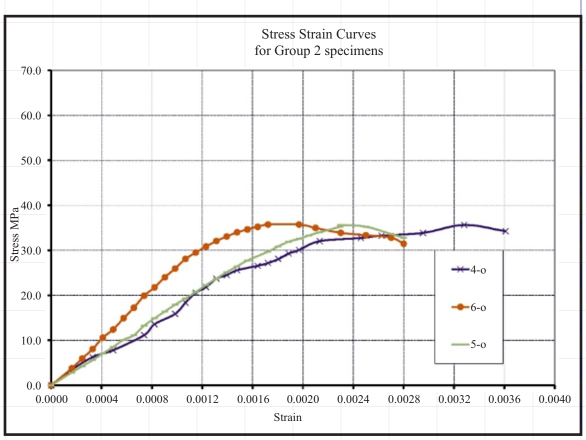

Fig. 9. Stress strain curves for group-2 specimen (Outer core confined by GW Mesh)

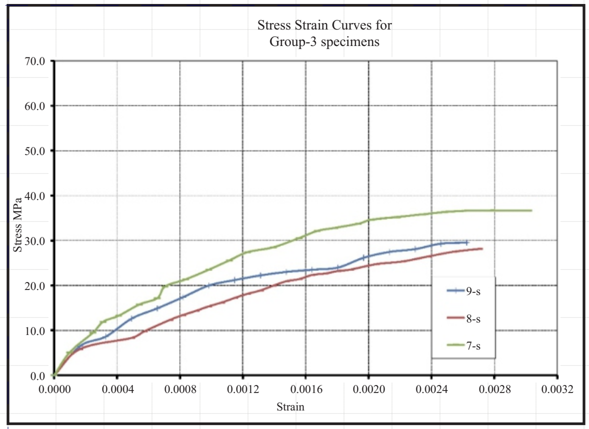

Fig. 10. Stress strain curves for group-3 specimen (No GW Mesh)

The axial capacity of the column "P_o" can be computed using relation given below [xviii]:-

$$P_o = \alpha f'_c \left(A_g - A_s - A_{sm} \right) + A_s f_y + A_{sm} f_{ym} \quad (1)$$

Where,

Ag = Gross area of column

A_s = Area of longitudinal steel

A_m = Area of longitudinal steel

f_y = Yield strength of steel

f'_c = concrete strength in this case it is the strength of cylinder at the time of testing

A_{sm} = Area of mesh steel

f_{ym} = Yield strength of mesh steel

The value of α varies between 0.85 and 0.9 for large size samples [xix] and in this investigation, value of α was taken equal to 0.85.

Computed concrete contribution to the column strength under pure concentric loading P_{oconc} is given as [xviii] :-

$$P_{oconc} = \alpha f'_c \left(A_g - A_s - A_{sm} \right) \quad (2)$$

Core concrete contribution towards specimen behavior depends on the properties of confinement and core dimensions. As in this research core was confined internally as well as externally. Computed core concrete contribution under concentric loading for different cases of confinement was obtained using this basic relation:-.

$$P_{ocore} = \alpha f'_c \left(A_{core} - A_s - A_{sm} \right) \quad (3)$$

Maximum column load $P_{o\,max}$ was calculated using this basic relation.

$$P_{o\max} = P_{test} - A_s f_y - A_{sm} f_y \quad (4)$$

Where,

A_{core} = Area of core; internal for group-1 specimen and external for group-2 specimen

P_{test} = Maximum column load applied in the test.

Theoretical axial capacity of columns, concrete contribution and core concrete contribution towards column strength were calculated for all columns, using equations 1, 2 and 3 respectively.

The results of all the calculations discussed above have been summarized in Table II.

TABLE II
SUMMARY OF TEST RESULTS

Column Specimen (1)	Type of Confinement (2)	P_o (kN) (3)	P_{oconc} (kN) (4)	P_{ocore} (kN) (5)	P_{test} (kN) (6)	P_{cmax} (kN) (7)	P_{test}/P_o (8)	P_{omax}/P_{ocore} (9)	f_{cc} (Mpa) (10)	$Ks=f_{cc}/0.85/f_c'$ (11)
1i	wire mesh at Inner core	1259	1029	785	1359	1170	1.08	1.49	33.98	1.29
2i	wire mesh at Inner core	1259	1029	785	1367	1178	1.09	1.50	34.18	1.30
3i	wire mesh at Inner core	1259	1029	785	1351	1162	1.07	1.48	33.78	1.28
4o	wire mesh at Outer core	1264	1029	786	1415	1226	1.12	1.56	35.38	1.34
5o	wire mesh at Outer core	1264	1029	786	1471	1282	1.16	1.63	36.78	1.39
6o	wire mesh at Outer core	1264	1029	786	1475	1286	1.17	1.64	36.88	1.40
7s	stirrups	1240	1031	786	1314	1105	1.06	1.41	32.85	1.25
8s	stirrups	1240	1031	786	1164	955	0.94	1.21	29.10	1.10
9s	stirrups	1240	1031	786	1220	1011	0.98	1.29	30.50	1.16
10p	plain	1044	1044	1044	1044	1044	1.00	1.00	-	-
11p	plain	1044	1044	1044	1120	1044	1.07	1.00	-	-

VII. AXIAL CAPACITY OF COLUMNS

The ratio P_{test}/P_o compares the tested capacity of columns with the computed one. For group-1 and 2 columns the average values of above parameter were 8.5 and 15.7 % higher than group-3 specimens. This indicates that during axial load GW/WWM has been more effective. Test results show that Average Axial load carrying capacity of group-2 specimens was 6.9% higher than that of group-1 specimen. These results confirm that wrapping mesh around outer core is more beneficial than wrapping around the inner core.

VIII. CORE CONCRETE STRENGTH

Performance of core concrete affects the behavior of columns after cover spalling and especially at post peak stage. In this investigation special care was taken to prevent core concrete from excessive damage so that the specimens could be effectively retrofitted later on. Therefore axial loads were not applied beyond the peak loads. The effect of presence of mesh around inner and outer core was studied from the Ratio of maximum applied load to the core concrete contributions at peak load. The ratios $P_{c\,max}/P_{ocore}$ for all the specimens are presented in columns 9, Table 2. These values for group-1 and 2 specimens were found to be 1.5 and 1.6 respectively. These values were 14.5% and 23.6 % higher than group-3 specimens. Therefore, both groups exhibited improvement in the core concrete strength. However, 63 % higher values of group-2 specimens endorse that mesh wrapped around the outer core is more effective than the mesh wrapped around inner core.

IX. STRENGTH ENHANCEMENT FACTOR

Strength enhancement factor “Ks” is the numerical expression that describes the contribution of confinement towards overall column axial load carrying capacity [xix]. It is the ratio of maximum confined concrete strength to the cylindrical strength of concrete and is given as:-

$$K_s = f_{cc} / 0.85 f'_c \quad (5)$$

Where

f_{cc} = confined concrete strength calculated by relation $P_{c\,max}/A_g$

It was also found that that wire mesh can be effectively used to enhance confinement of RC columns even if the stirrup spacing is more. In this investigation stirrup spacing was increased by 80% when GW mesh was used as an additional confinement.

Average of Strength enhancement factors for all three groups were calculated and values are shown in Column 11, Table II. The results of other groups were compared with the values obtained from group 3 specimens (stirrup confinement). The results show that average strength enhancement factors of group-1 (inner core confined with WWM) and 2 (Outer core confined with WWM) are 10.2% and 18% higher than average value of group-3 respectively. These results also confirm that mesh wrapped around the outer core enhances the column efficiency in terms of strength enhancement factor by 76% as compared to the mesh wrapped around the inner core.

X. Conclusions

In this research performance of RC specimen confined with different arrangements of GW Mesh and conventional stirrups was evaluated. The study revealed that confinement of RC specimen with wire mesh on external core is more effective than inner core. Main conclusions of this investigation are as under:-

1. Axial capacity of columns in group-1 and 2 was 8.5% and 15.7% higher than group-3 specimens.
2. Core concrete strength was improved by 14.6 % and 23 % for specimens of group-1 and 2 respectively as compared with group-3.
3. Strength enhancement factor "Ks" was also improved by 10.25% and 18% respectively as compared group-3 specimens.
4. Axial capacity of specimen confined with stirrups and GW mesh wrapped around externally was 85% higher, core concrete strength was 57% higher and Strength Enhancement Factor was 75.5 % higher.
5. External core confinement also delays cracks development and propagation.
6. The study also concluded that wire mesh can be effectively used to enhance confinement of RC columns by decreasing the number of stirrups.
7. The study concluded that mesh confinement improves the performance of RC columns in terms of overall strength, core concrete strength and strength enhancement factor. However the efficiency of specimen with mesh wrapped around the external core is superior to the specimen confined with mesh wrapping the internal core.

Acknowledgment

The research was funded by University of Engineering and Technology Taxila. The corresponding author also appreciates the MS Scientific Corporation, Pakistan, MS CONTROLS, and their staff at CONTROLS Head Quarter, Milano Italy for supporting, and funding the training Program of their equipment used in this research.

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