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Development of a specially designed high-strength transverse reinforcement for square concrete columns

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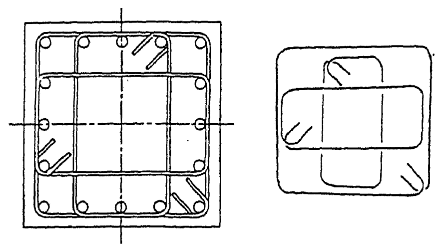
ABSTRACT; A new type of transverse reinforcement with a 1275 MPa(N/mm^2) yield strength was developed. This consists of a peripheral hoop and internal hoops, each of which is made from a one-piece steel bar without breaks or welding and is named the MULTI HOOP. Experimental studies were carried out on square concrete columns and in comparison with conventional reinforcement, this MULTI HOOP showed good ductility, and greater efficiency in fixing at the construction site. This reinforcement enables earthquake-resistant RC buildings to be constructed more economically.

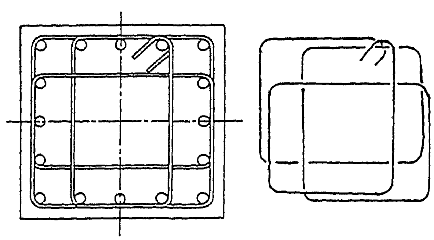
1 INTRODUCTION

A large number of very high-rise reinforced concrete (RC) buildings have recently been constracted. In these buildings, the columns and beams are subjected to very heavy axial loads, and it is important that the materials have high strength. The shape of the shear reinforcement is critical so that the building has sufficient resistance against earthquakes. Very many research studies have been carried out throughout the world on the materials and shape of the reinforcement (Yoshioka, Okada and Takeda, 1979.) (Sheikh and Uzumeri, 1980,1982.), and the combined use is now recommended of peripheral hoops and internal hoops because this configuration offers very good ductility. However this combination of different shapes takes a lot of time and it is difficult to assemble on site. In order to solve this problem, the new type of MULTI HOOP shear reinforcement was created, which consists of a peripheral hoop and internal hoops, each made from a one piece steel bar without breaks or welding.

The MULTI HOOP offers ease in assembling to reduce man power at the construction site, and provides high integrity for the structure. This report gives the results of experimental test on columns using MULTI HOOP with a 1275 MPa (N/mm^2) yield strength and of practical application. Experimental investigation was carried out to examine the strength and ductility of the reinforcement against shear force in a seismic design. In conjunction with the investigation of MULTI HOOP strength a computerized numerically controled machine was also developed to produce the shaped reinforcement in cooperation with a machine manufacture in Greece. This unique machine has enabled MULTI HOOP to be put into practical use.



a. conventional hoop



b. MULTI HOOP

Figure 1. Provided hoop configuration

2 PLAN OF THE TEST

The purpose of these tests was to confirm the shear resistance and ductile behavior of column using MULTI HOOP with a 1275 MPa(N/mm^2) yield strength as a transverse reinforcement under different conditions.

Table 1. Test Specimen Detail

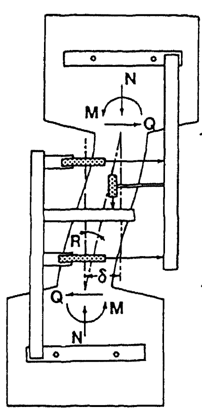
(No.) Specimen	Types of hoop	L (mm)	L/D	n (N/bDFc)	pw (%)	Fc (MPa)	Experimental value Qmax (KN)	Ru ($\times 10^{-3}$ rad.)	Theoritical value Qfu (KN)	Qsu (KN)
(1)S-C-70	Conventional hoop	750	2.5	0.3	0.381	348	545	15	575	360 (1.51)*
(2)S-M-70	MULTI HOOP	750	2.5	0.3	0.381	348	529	15	575	360 (1.47)*
(3)S-M-35	MULTI HOOP	750	2.5	0.3	0.762	348	595	25	575	460 (1.29)*
(4)F-C-35	Conventional hoop	1200	4.0	0.6	0.762	389	367	40	334	683 (1.10)*
(5)F-M-35	MULTI HOOP	1200	4.0	0.6	0.762	383	361	48	334	683 (1.08)*
(6)F-MS-35	MULTI spiral hoop	1200	4.0	0.6	0.762	389	380	50	334	683 (1.14)*

*: Qmax/Qu Qu=min(Qsu、Qfu)

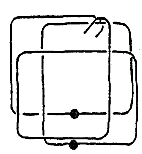
Table 2. Mechanical properties of reinforcing bars

Standard	Name	YS*1 (MPa)	TS*2 (MPa)	El*3 (%)
Transverse reinforcing	RB5.0	1407	1419	10.9
Longitudinal reinforcing	D13	418	595	23.4
	D16	428	647	21.0

*1:Yield stress or 0.2 % Proof stress
*2:Tensile stress *3:Elongation



a. Method of loading



b. Position of strain gages

Figure 2. Basic test method

2.1 Specimens

Two types of test specimens were used, one for shear failure and the other for yielding by column flexure.

Table 1. 2. show the detail of specimens and reinforcing bars. The main variables were the configuration of transverse reinforcement, the ratio of reinforcement and the degree of axial load. The deformation capacity (R_u) is defined as the point that shear force falls to 80 % of the maximum shear force.

The hoop reinforcement provided is shown in Figure 1. The conventional arrangement has one square peripheral hoop and two overlapping rectangular internal hoops, each with a 135 ° hook anchor. MULTI HOOP has one square peripheral hoop and two overlapping rectangular internal hoops, while MULTI SPIRAL HOOP is a spiral form of MULTI HOOP to create many layers. These MULTI HOOP components are made in one piece from bar so they need only one 135 ° hook anchor, MULTI SPIRAL HOOP needings only one hook anchor for many layers.

Figure 2 (b) shows the positions where electrical-resistance strain gages were attached to the transverse hoops.

The test specimens had the same cross-sectional dimensions of 300 mm × 300 mm, with height L=750 mm for the shear failure type, and L=1200 mm for the flexure type.

2.2 Procedure of test

Figure 2 (a) shows the method of loading. The column was loaded axially in compression, and a lateral load was applied to top side stub. The axial load and lateral load were measured by 2940 KN and 1960 KN load cells on the respective hydraulic jacks. The lateral load was applied in both the forward and reverse directions, consisting of two cycles each to the point of deflection angle R=55 × 10^{-3} for shear failure type and R=65 × 10^{-3} for flexure type. The horizontal deflections (δ) of each specimens was measured by an

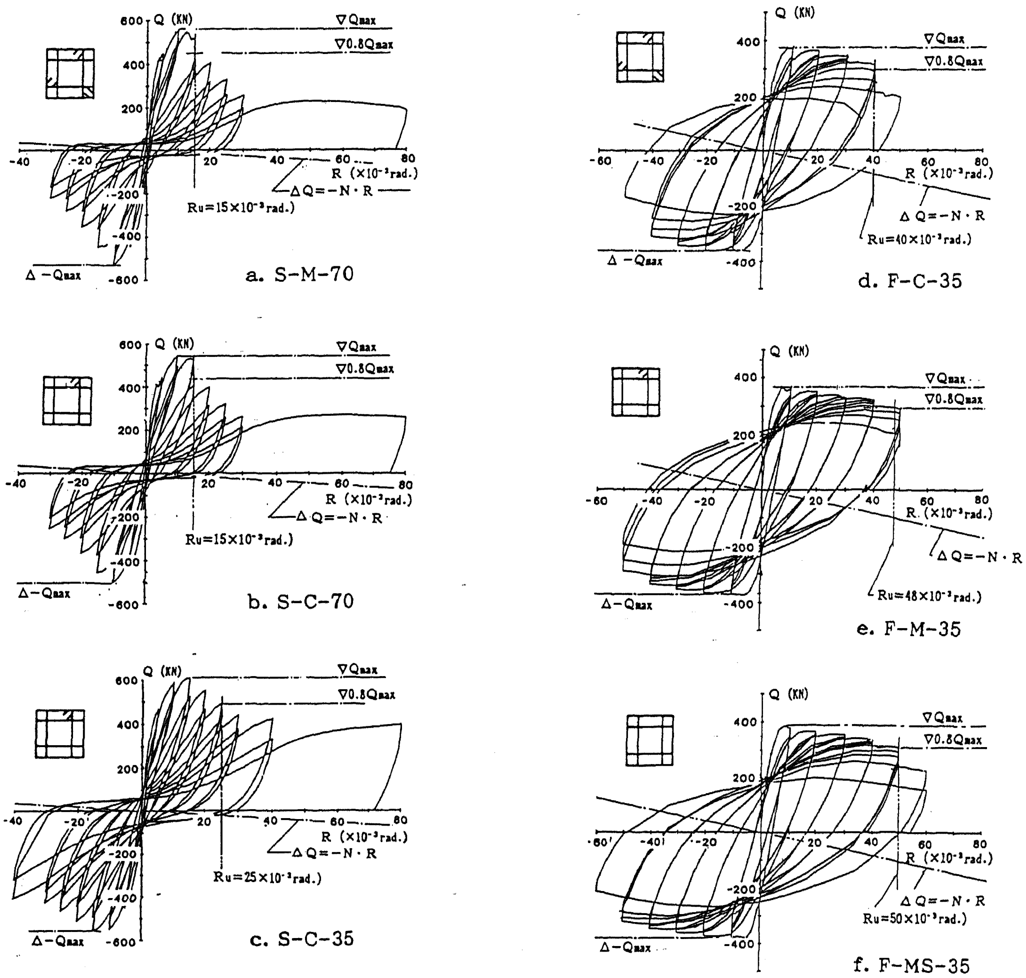
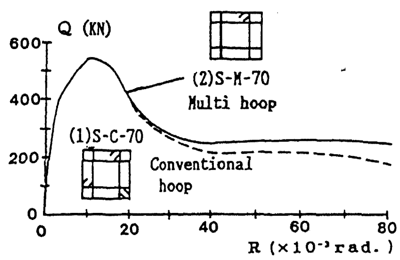
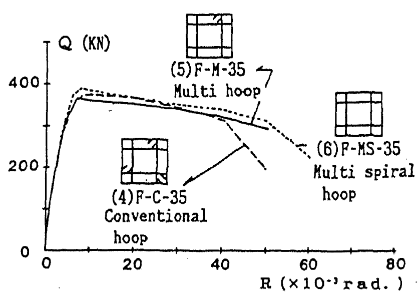


Figure 3. Horizontal load-horizontal deflection hysteresis loops



a. Shear failure type



b. Flexure type

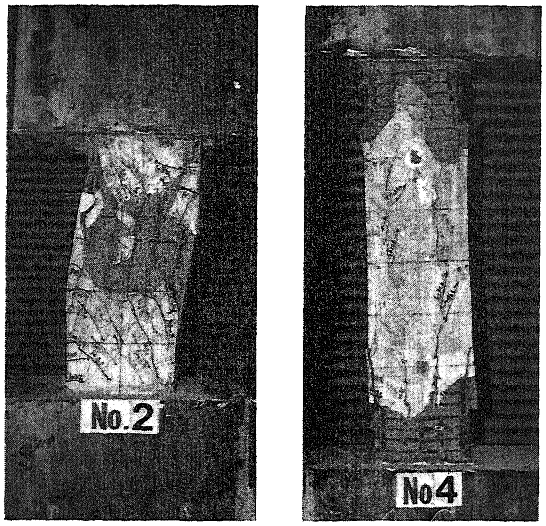
Figure 4. Comparison of ductility curves

electro-displacement trans-ducer, the deflection angle (R) being calculated as R= δ /L.

3 TEST RESULTS

3-1 Deflection behavior

Figure 3 show horizontal load (Q)-horizontal deflection (R) hysteresis loops.



a. S-M-70 b. F-M-35

Figure 5. Appearance of specimen

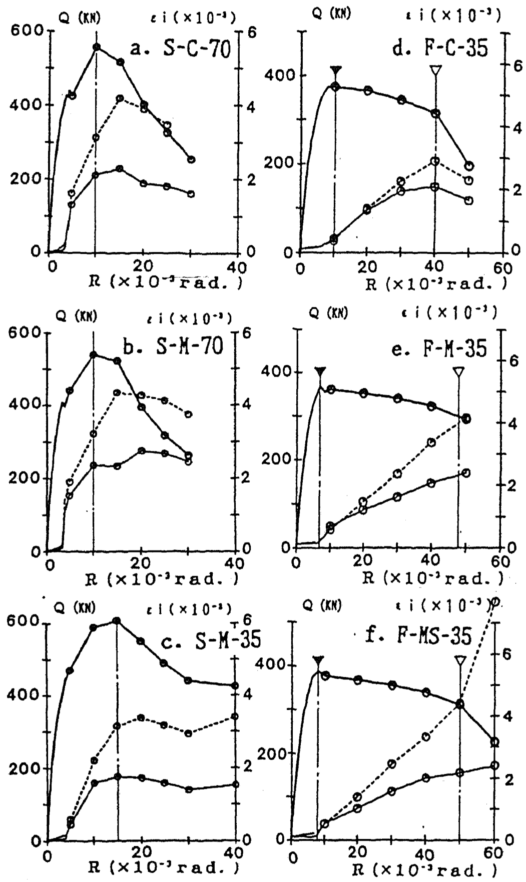


Figure 6. Behavior of strains on the trans verse reinforcement

Figures 3 (a),(b) and (c) show the loops of shear failure type. The loops of specimen S-C-70 (conventional hoop) (a) and specimen S-M-70 (MULTI HOOP) (b) with same hoop ratio (p_w) show same ultimate shear strength and being greater than the theoretical value (Q_{su}) caluculated by the formula of AIJ. Unit S-M-35 (c) having 2 times hoop ratio show better curvature than the other two.

Figure 4 (a) shows a comparison between the ductility curves for shear failure type of specimen S-C-70 and S-M-70. The hook anchor of specimen S-C-70 at the corner of the cross section slipped out from concrete at a difle-ction of $R=65 \times 10^{-3}$ rad. This failure did not occur on specimen S-M-70 with MULTI HOOP because the hook anchor was located near the middle of the peripheral hoop, thus avoiding the corner.

The loops of flexure type are shown in Figure 3 (d), (e) and (f). The ultimate shear strength of every specimen show good coincidence with theoretical ultimate flexural strength (Q_{fu}).

Figure 4 (b) shows a comparison between the ductility curves for the flexure type of specimen F-C-35 (conventional hoop), F-M-35 (MULTI HOOP) and F-MS-35 (MULTI SPIRAL HOOP). In this case, a high level axial load n=0.6 was applied, each of them having the same four hoop leg areas. Specimen F-MS-35 had the best ductility characteristics, followed by F-M-35, F-C-35. Each specimen fail by yielding of the longitudinal steel bar with spalling away of the covering concrete, except for the core concrete surrounded by the internal hoop. From this results, it is suggested that the ductility characteristics were influenced by the degree of confinement of the core concrete in the plastic hinge region, the MULTI SPIRAL HOOP type having only one or two 135 ° hooks per column so that each layer was very strong. On the other hand, the conventional type had 78 weak points (hooks) per column.

Figures 5 (a) and (b) show the appearrance of specimens S-M-70 and F-M-35 at end of test.

3.2 Hoop strain behavior

Figure 6 shows the average strain behavior in the transverse reinforcement between the leg and middle of column.

Specimen S-C-70, S-M-70 and S-MS-35, shear failure type shown in (a) (b) (c). The strain of S-C-70 and S-M-70 show same behavior until the peak strain like as deflection hysteresis loops show. The strain of every specimens come to peak near the maximum shear force and then leveled or slightly reduced. In the comparison of peripheral hoops and internal hoops, the maximum strain on the internal hoops are 2 times of the peripheral hoops.

(d) (e) (f) shows the strain behavior of specimen F-C-35 and specimen F-MS-35 when the

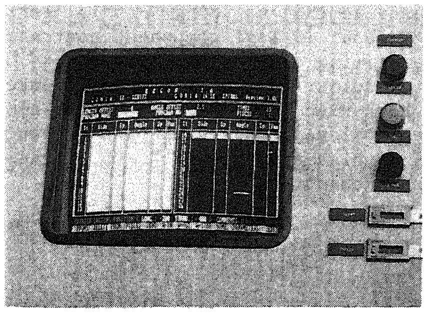


Figure 7. Operation panel

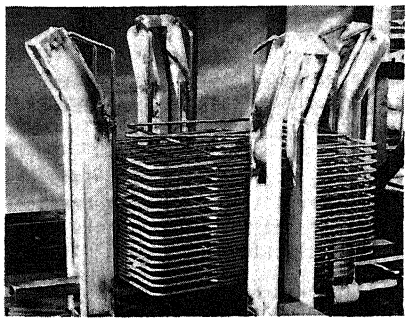


Figure 8. Production of MULTI spiral hoop

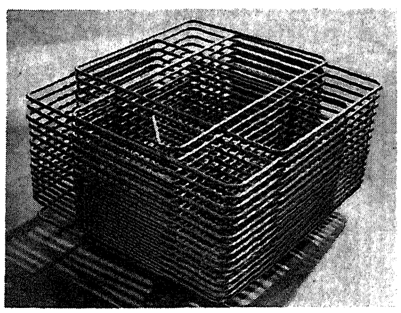


Figure 9. Tipical products

applied axial load level was n=0.6. The average strain in the plastic hinge region of the specimen F-C-35 reached ε i=3 × 10^{-3} at the defrection R=40 × 10^{-3} and then it began to reduce. However, the strain in F-MS-35 reached ε i=3.5 × 10^{-3} at the same deflection (R) and continued to increase up to yielding, so that the hoops continued to confine the concrete most effectively. From these results, it is assumed that, in the case of the conventional hoop, the hook anchor began to loosen when the deformation became large (approx. R=4 × 10^{-3}), while this didn't happen with the MULTI SPIRAL HOOP because of its good constraining characteristics.

4 PRODUCTION AND APPLICATION

4.1 Production facilities

It was necessary to develop a new bending machine to produce these complex shaped reinforcement components efficiently. This machine has to have high durability, power and accuracy to bend and cut high-strength steel bar. Also needed is high accuracy in production length and bending angle to correctly form the peripheral and internal hoops. This new machine was developed in cooperation with ERGON S.A. in Greece having advanced technology in this field.

This machine has a CNC AC servo-motor system for both rolling and bending and a hydraulic system for cutting and counter torsion, with easy operation through a visual display unit, the machine achieves high productivity.

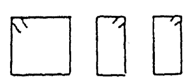
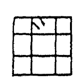
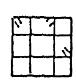
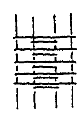
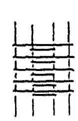
One of the characteristics of this machine is the manipulation of products in the X-Y and Z directions, with rotation following the movement of the workpiece.

Figures 7,8,9. show the machine and tipical products.

4.2 Working efficiency on site

During 1991, MULTI HOOP concrete reinforcement was used in four high-rise RC buildings having 20-25 floors and showed very good working efficiency. Table 3 shows a comparison of operation flow of the procedure for fixing transverse reinforcement. Figure 10 shows the

Table 3. Comparison of the assembly procedure for a column

Operation	Conventional hoop	MULTI HOOP
Procurment and storage	3 packages 	1 package 
Pre-assembling the internal hoops	30 min/column 	Not necessary
Assembling to longitudinal bars	30 min/column 	30 min/colmn 
sum	1 hour/column	30 min/colmn

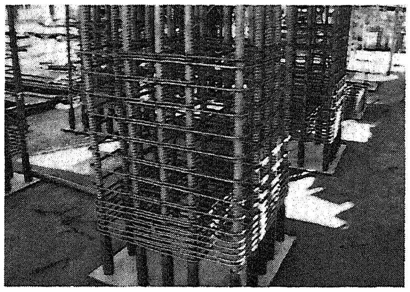


Figure 10. Assembling to longitudinal bars

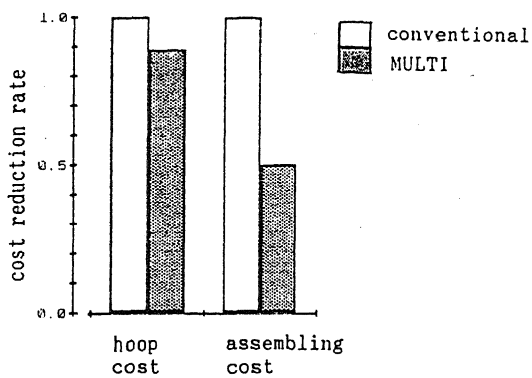


Figure 11. Comparison of cost

assembling of MULTI HOOP to longitudinal bar of actual building.

An example of calculation of merit is shown in Figure 11. By applying MULTI HOOP to a high-rise reinforced concrete (RC) building, it is estimated that about 10 % of component cost and 50% of hoop fixing cost can be saved.

Additional benefits are;

The reduced stock volume and easy parts control.

Reducing the size of columns by using high-strength reinforcement saves concrete and floor space.

The less hook anchor of MULTI HOOP enables easy concrete operation.

5 CONCLUSIONS

MULTI HOOP and conventional hoop reinforcement showed almost the same ultimate shear strength, while MULTI HOOP had better ductility than a conventional hoop.

The strain on an internal hoop was greater than on a peripheral hoop, reaching yield strain level at $R=6 \times 10^{-3}$ deformation, and it had great relations with the behavior of columns.

By applying MULTI HOOP to a high-rise reinforced concrete (RC) building, it is estimated that about 10 % of component cost and 50% of hoop fixing cost can be saved.

The test results indicate that earthquake resistant high-rise RC buildings can be constructed economically and with high reliablity by using high-strength MULTI HOOP transverse reinforcement.

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