THIN STEEL MANTLE AS LATERAL CONFINEMENT IN REINFORCED CONCRETE COLUMNS, TEST RESULTS

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ABSTRACT

This paper presents an experimental investigation on the effect of a steel mantle on strength and deformation behaviour of eccentrically loaded high strength concrete columns.

Circular concrete columns of 250 mm diameter with a thin steel mantle were studied with references in spirally reinforced columns. Concrete compressive strength in the main series was 85 MPa and in reference series 45 MPa. Test results are compared to load-moment interaction diagrams calculated using stress-strain relationships from the new Norwegian Code /1/.

The test results showed that a steel mantle improves moment-rotation characteristics and prevents a brittle type of failure.

Keywords: Construction, concrete, high-strength concrete, columns

1. INTRODUCTION

The research reported in this paper is concerned with investigations toward design of inner columns for building systems also using high-strength concrete. Such columns are subjected predominantly to axial loads and minor bending moments caused by imperfections, loading variation, end displacements and restraint conditions. Increase in load carrying capacity, for a given cross-section of a concrete column, is of great interest in design. However, increase in the bearing capacity by simple use of high-strength concrete is limited. This is due to the reduced effectiveness of the lateral confinement on the strength of such a concrete, when compared to lower strength concrete.

Furthermore, for a small cross-sectional area of the column, the relationship between the cross-section of the unconfined concrete cover and the column concrete core is unfavourable. An improvement is expected by using a thin steel mantle providing uniform confinement.

The programme /3/ consisted of testing a total of ten reinforced concrete circular columns under monotonic compression imposed with an initial eccentricity. Columns with a steel mantle were compared to those having typical spiral reinforcement without a steel mantle. Seven columns were cast using concrete quality C85 and three reference columns using C45 (characteristic compressive strength of 100 mm cubes at 28 days of 85 and 45 MPa respectively). The results of the eccentrically loaded columns are referred to load-moment interaction diagrams calculated using a stress-strain curve adopted by the new Norwegian Code /1/.

2. EXPERIMENTAL PROGRAMME

2.1. Test specimens

The test specimens were circular columns of 250 mm diameter and had a length of 2200 mm. Table 1 contains test parameters. Intended initial eccentricities are also listed in this table, where a=20 mm, b=40 mm and c=30 mm.

Table 1 Test series description

Column No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Concrete C45				x	x					x
C85	x	x	x			x	x	x	x	
Long.reinf. 6 ø 16mm	x	x		x		x	x	x	x	x
Steel mantle	x	x	x	x	x					
Spiral c 160						x	x			
Spiral c 33								x	x	x
Eccentricity	a	b	a	c	c	a	b	a	b	c

The columns were cast in vertical position. Columns without a steel mantle were cast in standard disposable tubular waxed cardboard molds.

The concrete mix proportions are given in Table 2. A series of control specimens were cast with each batch. Each series of control specimens consisted of 150/300 mm cylinders and three 100 mm cubes for assessment of 28-days concrete characteristics and additional 100/300 mm cylinders for registering of stress-strain concrete characteristics at the time of testing. The specimens were cured in the same humidity as the test columns.

Table 3 summarizes concrete characteristics of control specimens. Stress-strain concrete characteristics were registered in a servo-controlled closed loop machine in the strain control mode at a strain rate of 0.3 o/oo/min.

Table 2 Concrete mix proportions in kg/m^3 (l/m^3)

Batch No. Quality	1 C85	2 C85	3 C85	4 C45	5 C45	6 C45
Cement	520	560	560	420	420	420
Sand 0-8mm	900	900	900	1080	1080	1080
Gravel 8-12mm	400	400	400	760	760	760
Gravel 12-16mm	500	500	500	0	0	0
Silica fume	30	30	30	0	0	0
K.filler	60	0	0	0	0	0
P-admixt. (1)	8	7	7	3	3	3
HP-admixt.(1)	7	6	6	0	0	0
Water (1)	124	130	138	162	168	172
Column No.	S1,S3	S2,S6 S7	S8,S9	S5	S10	S4

Table 3 Concrete characteristics (average values)

Batch No. Quality	1 C85	2 C85	3 C85	4 C45	5 C45	6 C45
Standard test on 100 mm cubes and 150/300 mm cylinders						
Con. age days	28	27	27	27	29	29
Weight kg/m^3	2.41	2.41	2.34	2.34	2.28	2.35
Compr.strength						
Cubes MPa	78.9	83.9	81.2	46.3	40.4	48.9
Cylinders MPa	72.6	71.1	69.9	40.7	35.7	46.4
E-modulus MPa	32678	31394	32043	28705	27115	29642
Stress-strain characteristics on 100/300 mm cylinders						
Con. age days	49	50	55	55	53	53
Compr.str. MPa	71.0	74.9	67.0	38.7	34.6	42.0
Strain ϵ_{co} o/oo	2.65	3.10	2.73	2.34	2.24	2.45
E-modulus MPa	32182	30632	29307	26062	25359	25218

Eight columns were longitudinally reinforced with 6 reinforcing bars diameter 16 mm of quality K500TS. The concrete cover to the longitudinal reinforcement was 25 mm. Two columns with steel mantles were unreinforced in order to study the behaviour of a plain concrete filled mantle. The longitudinally reinforced columns with a steel mantle were without other lateral reinforcement.

All columns without steel mantle were spirally reinforced using 8 mm K400TS reinforcing steel. The spiral pitch c/c 33 mm and 160 mm was used. As a steel mantle a thin 2 mm steel plate was used, with yield stress 240 MPa, bent into shape and longitudinally welded in tubular form.

Both ends of the columns were additionally reinforced on a length of 300 mm with 8 mm diameter spirals c/c 33 mm to prevent premature damage at the end zones. The columns were equipped with 50 mm bottom steel plates where the ends of the longitudinal reinforcing bars were screwed in, which allowed precise levelling of the bar ends at the top of column. The top surfaces were prepared using a thin layer of steel-plastic which hardened under slight pressure prior to test loading.

2.2. Experimental set-up and instrumentation

Columns were tested in a load controlled 5 MN testing machine. Load was imposed through a roller-hinge end loading system assuring that the columns were loaded eccentrically. The roller-hinge system had a device protecting against rotation of the hinge in unloaded state, which was released at approximately 200 kN to allow free rotation of column ends in the bending plane during further loading.

The columns with the steel mantle were equipped with electrical strain gauges glued to the outer surface of the mantle at the middle height of the columns. The gauges were placed at opposite faces in the bending plane and at both sides of the section. The gauge type used allowed registering of longitudinal and transverse strain at the same point. The other columns had electrical strain gauges for longitudinal strain registering only, glued to the concrete surface at the same position as previous and additional gauges of the same type placed in the bending plane 300 mm over and under the middle height of the column.

Inductive displacement transducers with measured length of 100 mm were attached to the column to measure horizontal displacement of the column at middle height, at both ends and additionally in one point 400 mm above the middle height.

The readings automatically registered during loading were axial load, displacements in bending plane and strain at the measuring points.

The columns were loaded monotonically to the maximum load carrying capacity. If the capacity did not drop dramatically, loading was continued until horizontal displacement exceeded the value limited by the loading system.

2.3. Test results

The columns after testing are shown in Figure 1. All the columns behaved in the same manner prior to reaching the maximum load. The columns without the steel mantle failed in a brittle manner with a sudden drop of load, except S10 (C45) to some extent. The columns with a steel mantle had a significant post-peak moment capacity at slightly lower axial loads. However, at increasing curvature, local buckling of the mantle was observed. Except for columns S3, S5, S7 and S9 the failure occurred in a zone at the middle height section. In further analysis all moment values are referred to the middle height of the columns.

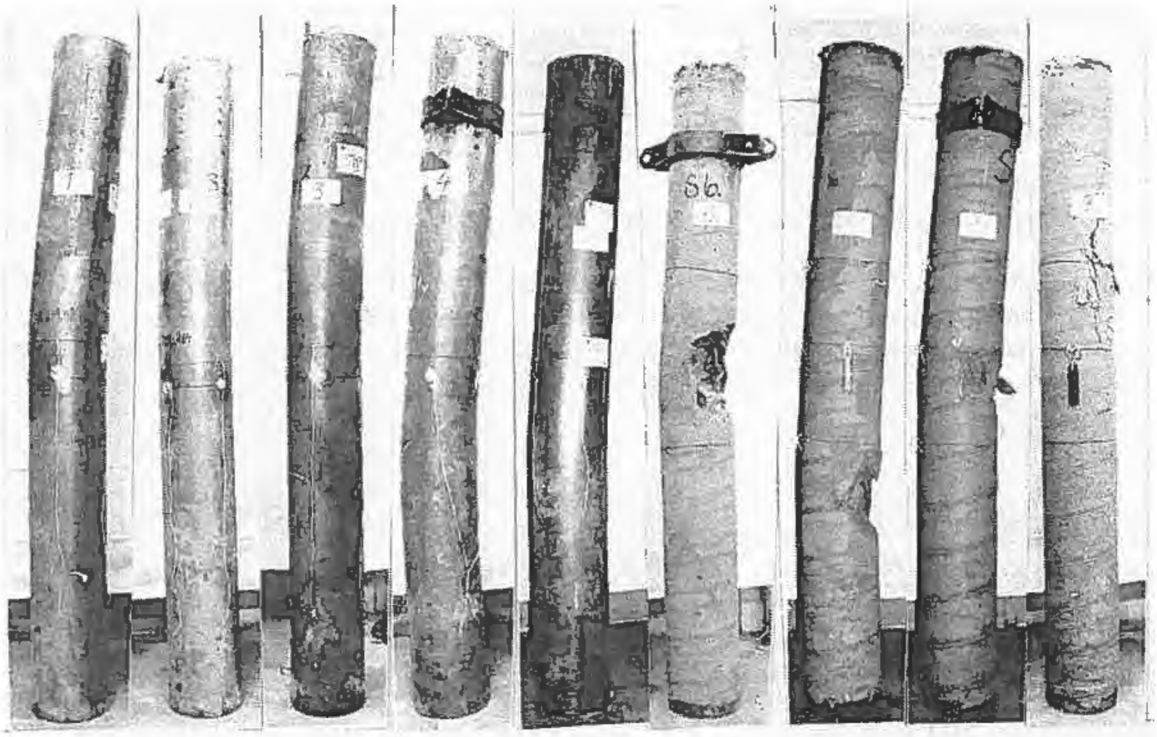


Fig 1. Columns after completed testing

The columns were placed in the machine with a geometrical control of the intended initial eccentricity. However, the final assessment of the initial eccentricity is based on strain readings at the middle height of the column at an early stage of the loading test.

Table 5 gives maximum loads, initial eccentricity and horizontal displacement at the column's middle height. The moments calculated as maximum load multiplied by the sum of initial eccentricity and horizontal displacement are also given in the table.

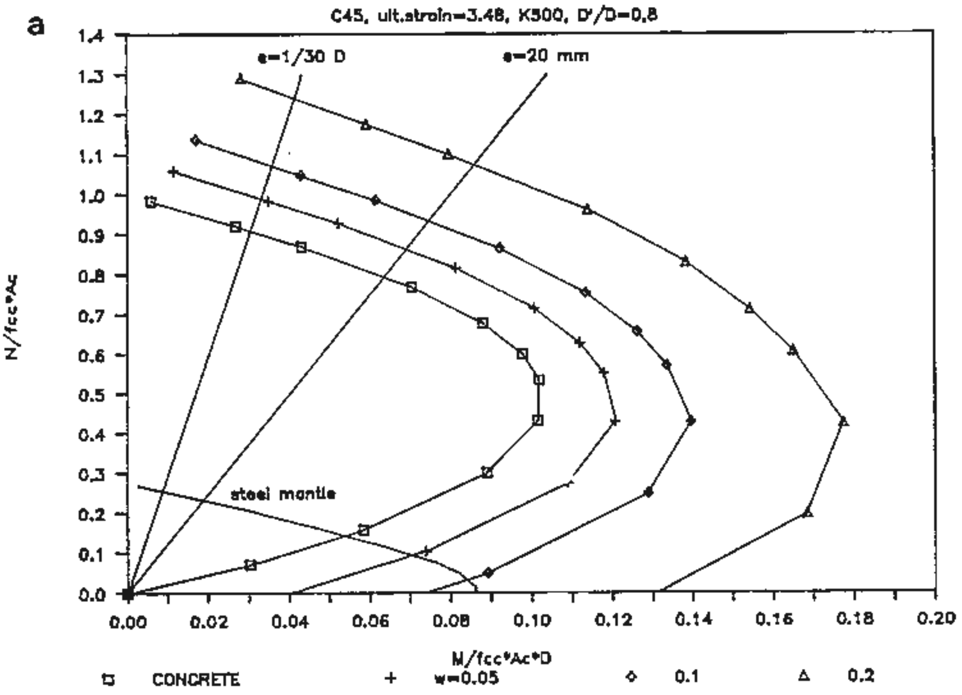
Table 5 Maximum load, initial eccentricity and horizontal displacement

Column No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Max.load MN	2.6	2.0	2.4	1.7	1.3	2.5	2.0	2.8	2.0	1.5
Eccentr. mm	23.0	46.0	18.0	30.0	30.0	20.0	35.0	18.0	40.0	30.0
Displac. mm	9.4	10.8	9.9	16.3	19.8	10.0	11.4	8.9	10.5	12.9
Moment kNm	84	114	67	80	67	75	93	76	101	66

Since the load carrying capacities of columns with different initial eccentricity and stiffness can not be compared directly, the results are related to simplified load-moment interaction diagrams where registered loads can be plotted against the load multiplied by the sum of the initial eccentricity and the actual displacement. Such obtained load-moment curves are shown in Figure 3.

3. APPROXIMATE LOAD-MOMENT INTERACTION CURVES

Interaction curves for combination of axial force and moment are computed numerically. Assuming that plane sections remain plane, the corresponding stresses are computed using stress-strain relations given by the Norwegian Code /1/.



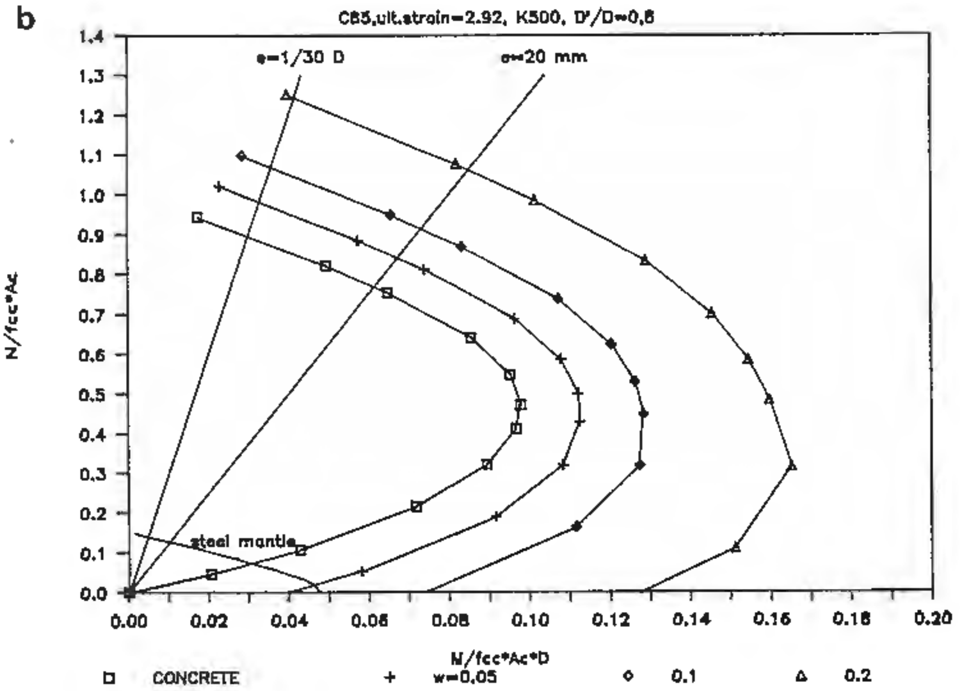
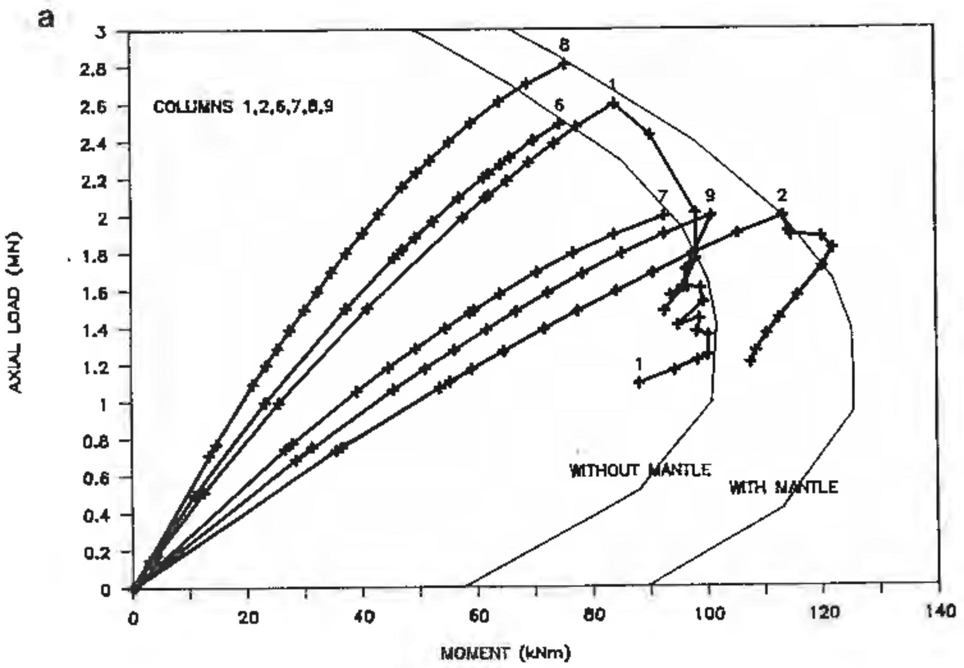
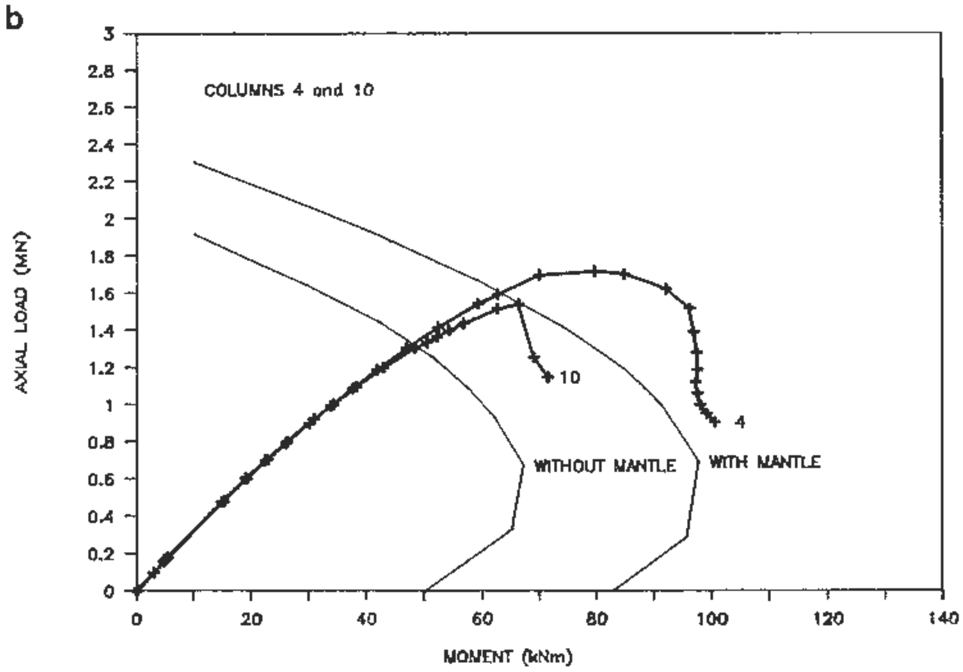


Fig 2. Dimensionless interaction curves for circular columns: a - columns with C45 concrete and, b - C85 concrete, where: D'/D - diameter of concrete core to diameter of column ratio, $w = (f_s A_s)/(f_{cc} A_c)$





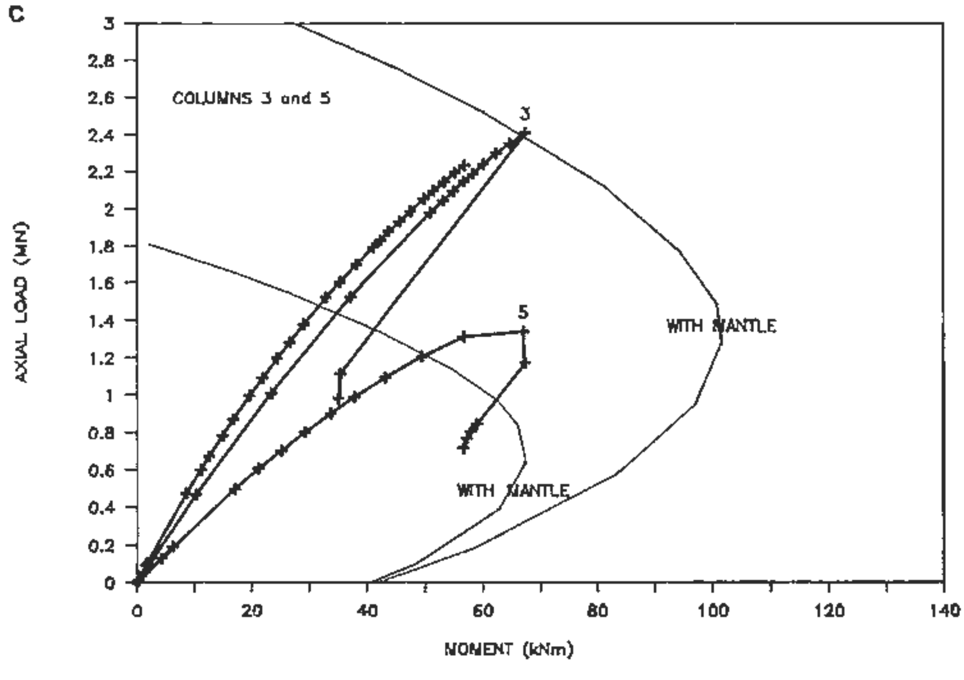


Fig 3. Experimental load-moment curves and interaction curves: a- Columns S1, S2, S6, S7, S8, S9, b- Columns S4, S10, c- Columns S3, S5 (without longitudinal reinforcement)

For the particular case, in which the interaction curves are plotted together with experimental load-moment curves in Figure 3, the characteristic concrete strength given by the Norwegian Code /1/ is replaced by the average concrete cylinder compressive strength with a factor 0.82. (This somewhat arbitrary choice of stress values is justified by earlier recognized /2/ validity of a relation $f_{col} = 0.82\ f_{cyl}$ for axial loaded concrete columns.) The columns of corresponding type are grouped in the same graphs.

The contribution of the steel mantle is taken into account by superposition of load and moment obtained for the reinforced concrete column and those for the mantle at the same curvature. The interaction curves in Figure 2 are plotted in dimensionless form. The curves represent plain concrete behaviour, reinforced concrete column with different amounts of reinforcement and the contribution of a steel mantle.

Figure 3 indicates that the effect of the increase of the lateral deflection with increasing load is similar for both concretes tested. According to the formula in Appendix A of the Norwegian Code /1/ an approximate value of lateral displacement for ultimate loads above balance point is in linear proportionality to concrete strength.

4. SUMMARY AND CONCLUSIONS

On the basis of tests on eccentrically loaded circular columns, the following main conclusions are drawn:

- The presented simplified analysis gives a reasonable prediction of the behaviour of eccentrically loaded columns with C85 concrete but underestimates columns with C45 concrete. (The effect of the triaxial state of stress in confined concrete and a bi-axial state of stress in the steel mantle is not included in the analysis.)

- The general behaviour of columns does not appear to be affected by the presence of the thin steel mantle prior to reaching the peak load.

- The confinement by the steel mantle prevents a brittle type of failure at the peak load.

In the small size spiral reinforced circular columns such as those tested, the loss of strength from spalling of the cover is not compensated by the potential increase in strength resulting from confinement of the core by the spiral. In the case of uniform confinement by a steel mantle the increase in ultimate strength above the longitudinal contribution of the mantle is negligible. Nevertheless, tests show a significant improvement in the load carrying capacity of the columns beyond the peak load. In the absence of other limiting requirements, this makes it possible to include an all concrete cross-section into the active section in design.

As an illustration, for columns of the geometry and reinforcement ratio of those tested, the use of concrete quality C85 and steel mantle increases the design capacity in the range of 1.60 to 2.20 of capacity of C45 concrete columns without concrete cover included. It should be noted that increasing eccentricity results in a higher ratio, since at increasing eccentricity the effect of the triaxial state of stress in confined C45 concrete decreases. In the Norwegian Code /1/ the increase in strength due to the confinement is not assumed for concrete qualities over C55.

Employing the concept presented, with a steel mantle utilized as confinement, the increase in design capacity of small size columns is significant. Furthermore, this concept is beneficial where ductility is a major design consideration. The main concern in the further studies is to extend the experimental programme to examine other aspects of the use of uniform confinement.

5. ACKNOWLEDGMENTS

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