Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 60 (1990)

Artikel: Composite shell columns

Autor: Shakir-Khalil, Hassan

DOI: https://doi.org/10.5169/seals-46558

Composite Shell Columns

Colonnes à coque mixte

Verbund-Hohlstützen

Hassan SHAKIR-KHALIL
Dr. Eng.
Univ. of Manchester
England, UK

Hassan Shakir-Khalil obtained his BSc. and MSc. degrees from the University of Cairo, Egypt, and his PhD. degree from the University of Cambridge, England, UK. He spent two years in the Bridge Department of Krupp, Rheinhausen, FRG and has been in the academic field for most of his life.

SUMMARY

Columns of circular section have been tested to investigate their use as legs of off-shore platforms and similar structures. The section of these composite shell columns is made of outer and inner cylindrical steel shells which are 2 mm and 1 mm thick respectively, and the 12 mm annular cavity between the shells is filled with micro-concrete. Tests and numerical work carried out confirm that columns of such sections are of practical use, and that additional work is required to further investigate their behaviour and utilize their full potential.

RÉSUMÉ

Des colonnes de section circulaire ont été testées pour analyser la possibilité de les utiliser dans les plates-formes en mer ou dans des structures similaires. La section de ces colonnes est composée de deux coques cylindriques en acier disposées concentriquement; l'épaisseur de la coque extérieure est de 2 mm et celle intérieure de 1 mm. La cavité annulaire réservée entre elles est remplie de microbéton. Les essais et les calculs numériques effectués jusqu'ici ont montré que des colonnes ayant de telles sections s'avèrent d'un emploi pratique; toutefois une étude supplémentaire est nécessaire en vue d'analyser leur comportement et de pouvoir utiliser leurs possibilités globales.

ZUSAMMENFASSUNG

Stützen mit Kreisquerschnitt wurden hinsichtlich ihrer Eignung für Bohrinseln und ähnliche Bauwerke geprüft. Sie bestehen aus zwei konzentrischen Stahlrohren, deren Zwischenraum von 12 mm Breite mit Mikrobeton gefüllt ist. Versuche und Berechnungen bestätigen die Eignung derartiger Querschnitte für praktische Anwendungen.

1. Introduction

Steel-concrete-steel composite shells have been developed in the Civil Engineering Department, University of Manchester, England [2, 3]. The section of these composite shells is made of two relatively thin concentric, cylindrical steel shells, and the annular cavity is then filled with a filler material. Resin and grout were first used as the filler material for small scale specimens, and micro-concrete was later used for larger specimens in order to simulate full-scale structures. These shells had originally been developed for use as compression chambers for use in deep-sea structures.

Using this type of composite shell construction, a preliminary series of tests on 4m long columns was conducted with a view to studying the behaviour of such columns and also to establishing their carrying capacity [5, 6]. The composite cylindrical shell of the columns had outer and inner diameters of 200mm and 172mm respectively, and the annular cavity was 12m wide. Both the outer and inner steel shells were 1mm thick, and grout was used as the filler material. The test results of these columns were rather disappointing due to the relatively large shrinkage of the grout, and also as a result of premature failure of the columns due to local buckling of the 1mm thick outer steel shell.

2. Column specimens

The composite shells of the column specimens whose test results are reported here, had outer and inner diameters of 202mm and 172mm, and the outer and inner steel shells were 2mm and 1mm thick respectively, Fig.1. The steel shells of each column were assembled from three outer and three inner steel cylinders. The steel cylinders were rolled from 1220mm long steel plates, and the longitudinal edges of each rolled cylinder were butt welded together.

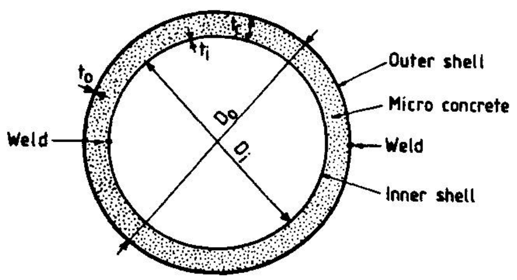

Fig.1 Column cross-section

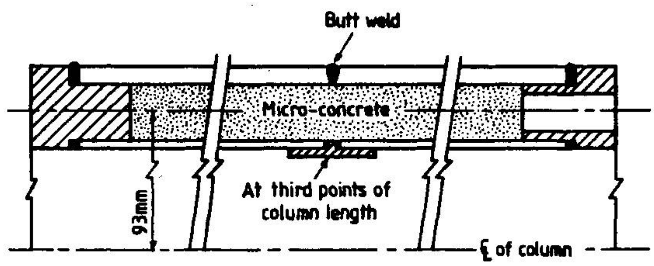

Fig.2 Details of columns

The inner shell was first assembled by fillet welding the 1220mm long and 1mm thick inner steel cylinders to backing steel strips. Four spacers 12mm wide were then welded to the inner shell, and the outer shell was assembled by butt welding the 2mm outer cylinders together. The steel shells of the composite column were finally completed by being welded to two end rings. One of the end rings was solid, and the other was provided with slots to enable the casting of the micro-concrete to be carried out, Fig.2. The completely assembled column was 3680mm long. When the column was ready for the casting of concrete, it was strapped to an I-section column which was bolted at the base to the laboratory strong floor. The 12mm annulus between the outer and inner steel shells was filled with micro-concrete of 3mm maximum aggregate size and the columns were vibrated during the concrete casting process.

In addition to the tests on the columns, tests were carried out on steel tension coupons, 100mm concrete cubes and 150x300mm concrete cylinders to establish the material properties of the steel and micro-concrete used. Tests were also carried out on 200mm high stub columns in order to compare the experimental squash loads with the predictions of the British Standard BS5400 [1]. The section of the stub columns was identical to that of the tested columns, and the experimental failure loads were compared to the BS5400 predictions as given by the following expression in which the material partial safety factors are taken equal to unity:

$$N_u = f_{sd} A_s + 0.67 f_{cu} A_s \qquad (1)$$

where the terms are as defined in the notation.

3. Instrumentation

The columns were tested in the horizontal position in a 3,000kN capacity test rig capable of accommodating columns up to 5m long. Fig.3 shows a general view of the test rig together with the data logging equipment used in these tests. The test set up, test procedure and the instumentation have been fully described elsewhere [4]. When bolted to the 50mm thick end loading plates of the rig, the columns had effective buckling lengths of 3990mm and 3860mm in the horizontal and vertical planes respectively. When being tested, the columns were subjected to eccentric end compressive forces. The first four columns were subjected to equal end eccentricities of 10, 25, 75 and 150mm, whereas the last two columns were subjected to unequal end eccentricities of 75 and 25mm for one column, and 150 and 75mm for the other.

Fig.3 View of 3,000kN test rig

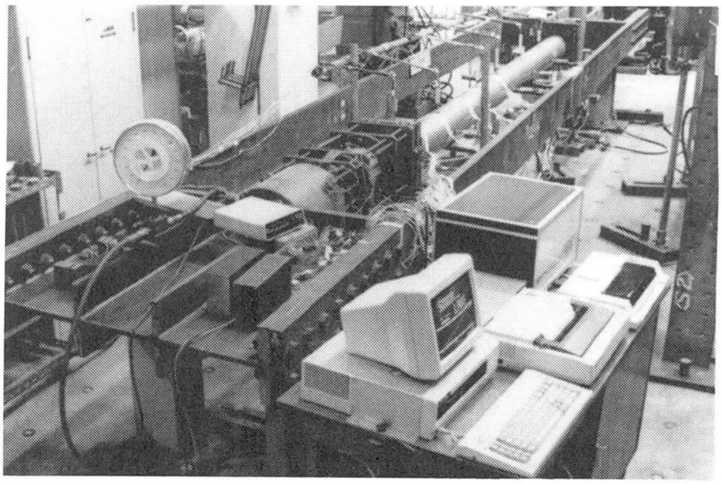

Fig.4 shows locations I - V at which the column sections were instrumented with strain gauges, and also the positions 'T' where vertical and horizontal displacement transducers were located. The first four columns which were symetrically loaded were provided with strain gauges at sections I, II and III only, whereas the last two columns were instrumented at all five sections. Fig.5 gives the details of the strain gauges at the different sections along the column length, and shows that strain gauges were fixed to the inner surface of the inner steel shell at section II of all columns. Sections IV and V were only instrumented at the top and bottom extreme fibres of the outer shell.

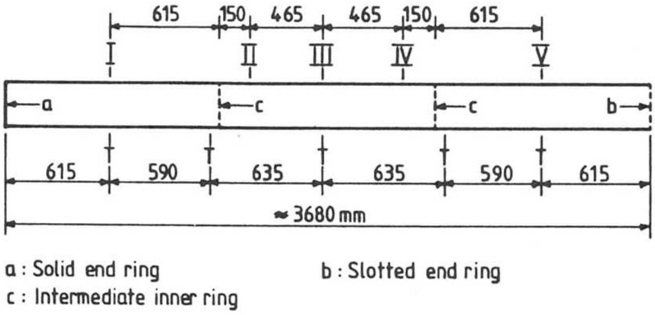

Fig.4 Column details and instrumentation

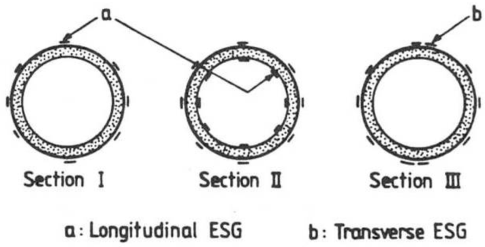

Fig.5 Position of strain gauges

4. Test results

Table 1 gives the material properties as well as the test results of the 200mm high stub tubes. The table shows the actual thicknesses of the steel shells used and also the design strengths f_{sdi} and f_{sdo} of the inner and outer shells. The table shows that the squash loads of the tested stub columns were always in excess of the BS5400 predictions, and that the margin of safety ranged between 2% and 25%.

The properties of the tested columns are given in Table 2, and include the values of the squash load, N_u , and ultimate moment of resistance, M_u , as calculated in accordance with BS5400 when the partial safety factors of the materials are taken equal to unity.

Table 1 Results of tests on short composite tubes

Sp. No.	Height (mm)	t_i (mm)	t_o (mm)	A_{si} (mm²)	A_{so} (mm²)	f_{sdi} (N/mm²)	f_{sdo} (N/mm²)	f_{cu} (N/mm²)	N_u (kN) Exp.	N_u (kN) BS	Exp/BS
1	200	1.02	1.93	554	1213	223	219	46.3	758	607	1.25
2	"	"	"	"	"	"	"	45.1	710	601	1.18
3	"	"	"	"	"	"	"	46.2	660	606	1.09
4	"	1.04	1.97	565	1238	234	186	48.2	590	578	1.02
5	"	1.05	1.98	571	1244	218	193	43.0	620	567	1.09
6	"	1.03	"	560	1244	236	178	43.4	640	579	1.11
7	"	1.04	1.97	565	1238	255	178	44.0	610	600	1.02

Table 2 Properties of tested columns

Col. No.	e_1 mm	e_2 mm	t_i mm	t_o mm	A_s mm²	f_{sd} N/mm²	f_{cu} N/mm²	E_s kN/mm²	(BS5400) N_u(kN)	(BS5400) M_u(kNm)
1	10	10	1.02	1.97	1792	196	44.1	197	555	25.5
2	25	25	"	1.96	1786	216	44.0	195	592	28.0
3	75	75	1.04	1.97	1803	210	48.2	190	578	25.9
4	150	150	1.05	1.98	1815	205	43.0	194	567	26.2
5	75	25	1.03	"	1804	207	43.4	194	579	27.1
6	150	75	1.04	1.97	1803	217	44.0	194	600	28.1

Fig.6 shows the strains in the extreme fibres at the mid-length section of the tested columns. It can be seen that, with the exception of columns 1 and 2, very high strains were recorded both in tension and in compression. These strains were in excess of the yield strains as obtained from the tension coupon specimens. Columns 1 and 2 were subjected to relatively small end eccentricities, and failure occurred before yield was reached in the tension fibres.

The in-plane displacements at mid-span of the columns are shown in Fig.7. With the exception of column 2, the load-diplacement relationships are seen to exhibit large plateau at failure, and the descending branch of the column behaviour was followed whenever possible in the post failure stage.

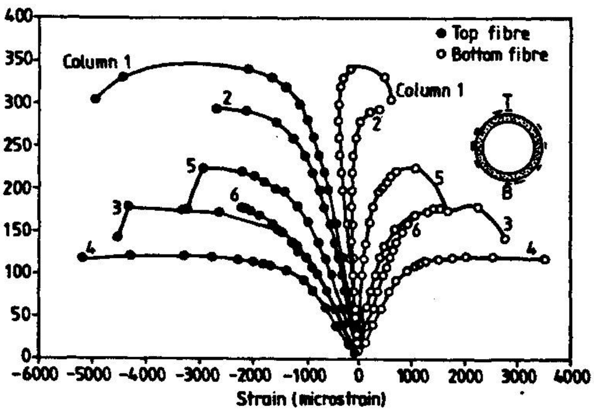

Fig.6 Mid-length strains

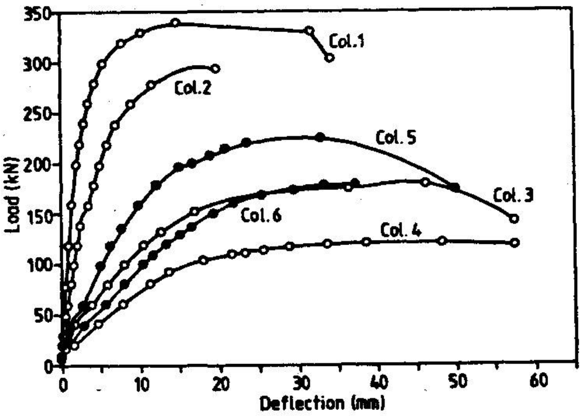

Fig.7 Mid-length displacements

When failure took place, a local buckle was observed to have formed in the outer shell of the columns. The buckle was quite pronounced in the post failure stage, and was accompanied by the crushing of the micro-concrete and the formation of a series of buckles in the inner shell. This can be seen from Figs.8 and 9 of column 2 after the completion of the test.

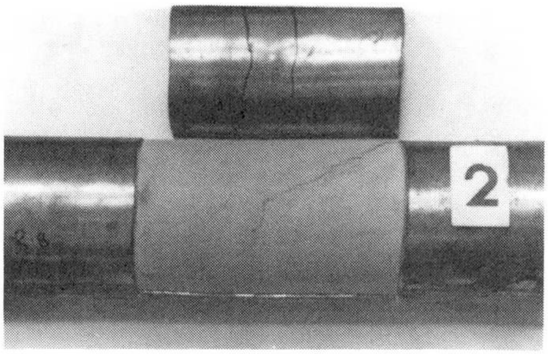

Fig.8 View of outer shell and concrete

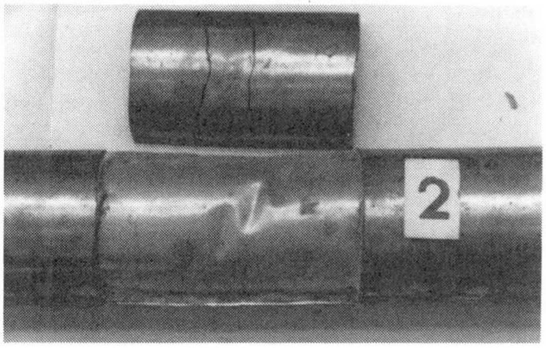

Fig.9 Buckles in inner shell

Table 3 Results of tests on columns

Col. No.	N_e (kN)	N_p (kN)	N_{fe} (kN)	N_e/N_p	N_e/N_{fe}	N_e/N_u
1	340	423	330	0.80	1.03	0.58
2	294	360	303	0.82	0.97	0.49
3	179	207	181	0.86	0.99	0.30
4	119	130	118	0.91	1.01	0.19
5	225	249	N/A	0.90	N/A	0.35
6	161	179	"	1.11	"	0.29

Table 3 gives the results of the column tests. It shows the experimental failure loads, N_e , the predicted failure loads in accordance with BS5400, N_p , and the theoretical failure loads as calculated by the finite element method, N_{fe} [4, 7]. The latter is applicable only to columns 1-4 which were symetrically loaded. The table shows that, for the symetrically loaded columns, the test results are in good agreement with the finite element predictions, but are between 9% and 20% less than the British Standard predictions.

It is noteworthy that when tests were carried on bond slip specimens in which grout was used as the filler material [5, 6], failure always took place between the filler material and the outer steel shell. This was as a result of the relatively large shrinkage of the grout due the high moisture content required to ensure the easy workability into the 12mm annulus. This caused the grout to cling to the inner shell, and perhaps caused partial separation between the filler and the outer shell. In the column tests of that series, this lead to premature failure due to the local buckling of the outer shell in which the half wave lengths of the buckles were about 20mm long [5, 6]. This was overcome in the current series of tests both by using micro-concrete as the filler material, as it does not shrink as much as grout, and also by increasing the thickness of the outer shell from 1mm to 2mm.

Despite the use of micro-concrete and a thicker outer shell, the test results show that the columns failed to reach the failure loads predicted by BS5400. However, as the failure loads of the columns are in good agreement with the finite element predictions, it seems likely that the BS5400 in its current form is not strictly applicable to the type of section investigated here. It should be mentioned that the BS5400 is only applicable to normal density concrete, with no reference to the use of micro-concrete, and that the 2mm thickness of the steel shell violates the minimum wall thickness requirement of BS5400.

5. Conclusions

It should be reiterated here that the columns tested in this series satisfy neither of the BS5400 requirements regarding the type of concrete used nor the minimum wall thickness of the steel section. With the exception of column 6, the experimental failure loads of the columns are seen to be below the predictions of BS5400. However, the results of columns 1-4, which failed to reach the predictions of BS5400, are seen to be within ±3% of the finite element analysis predictions. This seems to indicate that the BS5400 predictions for this type of composite column are on the unconservative side, and that perhaps a lower column buckling curve should be selected for the design of these columns.

The test results clearly indicate that such composite columns have potential for use in practice. The carrying capacity of such columns would be improved for larger column sections which would allow the use of normal density concrete in the relatively wider annular cavity. This would perhaps improve the concrete-steel bond strength as a result of the reduction in the shrinkage of concrete, and thus enhance the local bucling resistance of the outer steel shell. The structural steel sections used would also be relatively free from the built-in residual stresses due to welding which must have had an adverse effect on the tested columns. Failure of the columns was always accompanied by buckling of the outer shell in the vicinity of the weld at the third points of the column length where the steel cylinders were welded together to form the outer shell. This weld caused circumferential compressive stresses in the heat affected zone, which in turn resulted perhaps in premature buckling of the outer steel shell.

The test results reported here confirm that full scale experimental work is required before the application of BS5400 to the design of columns of unusual dimensions and cross-sections. They also illustrate the practical potential of such columns. However, more tests are required to fully investigate the behaviour of this type of column, and predict its safe carrying capacity.

NOTATION

A_c , A_s	Areas of concrete and steel respectively.
A_{si} , A_{s0}	Areas of the inner and outer steel shells.
D_i , D_o	Inner and outer diameters of composite shell.
E_c , E_s	Elastic moduli of concrete and steel respectively.
e	Eccentricity at which the end compressive load is applied.
$\bar{e}$	Eccentricity ratio, given by e/D_0
f_{cd} , f_{sd}	Design strengths of concrete and steel respectively, taken as the respective characteristic strength divided by the material partial safety factor γ_m .
f_{cu}	Characteristic 28 day cube strength of concrete.
f_{sdi}, f_{sdo}	Design strengths of the steel of the inner and outer shells.
M_u	Ultimate moment of resistance of composite section.
N_e	Experimental failure load of column.
N_{fe}	Failure load as predicted by finite element analysis
N_p	Predicted failure load of column in accordance with BS5400.
N_u	Squash load of column.
t_c, t_i, t_0	Thicknesses of concrete, inner and outer steel shells, respectively.
γ_{mc}, γ_{ms}	Material partial safety factors of concrete and steel respectively, taken equal to unity when comparing predicted with experimental failure loads.

REFERENCES

1. British Standards Institution: "Steel, concrete and composite bridges, Part 5: Code of practice for design of composite bridges". BS5400, 1979.
2. Montague, P. (1975): "A simple composite construction for cylindrical shells subjected to external pressure". Journal of Mechanical Engineering Science, vol. 17, No. 2, Feb. 1975, pp. 105-113.
3. Montague, P. (1978): "The experimental behaviour of double-skinned composite, circular, cylindrical shells under external pressure". Journal of Mechanical Engineering Science, vol. 20, No. 1(b), Feb. 1978, pp. 21-34.
4. Shakir-Khalil, H. and Boufennara, K.: "Columns of concrete-filled concentric steel shells". Accepted for publication, Structural Engineering Review.
5. Shakir-Khalil, H. and Illouli, S. (1987): "Composite columns of concentric steel tubes". Proceedings, "Non-conventional structures", Conference, London, Dec. 1987, vol. 1, pp. 73-82.
6. Shakir-Khalil, H. and Illouli, S. (1988): "Columns of composite cylindrical shells". Structural Engineering Review, vol. 1, 1988, pp. 113-118.
7. Shakir-Khalil, H. and Zeghiche, J. (19898): "Experimental behaviour of concrete-filled rolled rectangular hollow section columns". The Structural Engineer, vol. 67, No. 19, Oct. 89, pp. 346-353.