Battenend composite columns

Autor(en): **Shakir-Khalil, Hassan / Hunaiti, Yasser M.**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **48 (1985)**

PDF erstellt am: **26.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-37475

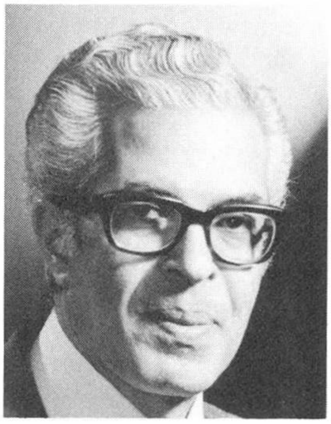
Battened Composite Columns

Colonnes diaphragmées mixtes

Verschalte Verbundstützen

Hassan SHAKIR-KHALIL
Lecturer
University of Manchester
Manchester, Great Britain

Yasser M. HUNAITI
On study leave
University of Jordan
Amman, Jordan



Hassan Shakir-Khalil graduated in Civil Engineering from Cairo University, Egypt, where he also obtained his Masters degree. He obtained his PhD degree from Cambridge University. During 1958–60 he worked in the Bridge Department with Krupp, Rheinhausen. He spent most of his working life in the academic field.

Yasser M. Hunaiti, born in Jordan in 1956, obtained his BSc (Eng.) in 1978 from Garyounis University, Libya. He was awarded a scholarship from University of Jordan, and obtained his MEng from McGill University, Canada, and has been reading for his PhD degree in Engineering at Manchester University, England since January 1983.

SUMMARY
The paper deals with a new type of composite column which consists of two steel channels facing each other and connected together with end and intermediate batten plates. The rectangular shaped core so formed is then filled with insitu plain concrete. Full scale tests have been carried out on this new type of column with a view to establishing that this form of composite column can be safely designed in accordance with both the new British Bridge Code and the European recommendations of the ECCS for Composite Structures.

RÉSUMÉ
Cet article décrit un nouveau type de colonnes mixtes composées de deux profilés en C réunis par des diaphragmes; l'espace intérieur ainsi créé est ensuite bétonné au chantier. Des essais ont été conduits pour montrer que ce type de colonnes peut être dimensionné en toute sécurité avec les Normes Britanniques et les Recommendations Européennes.

ZUSAMMENFASSUNG
Der Vortrag behandelt einen neuen Typ von Verbundstützen, welcher aus zwei sich gegenüberliegenden U-Stahlprofilen besteht, die an den Enden wie auch an Zwischenstellen mit Schalplatten verbunden sind. Der rechteckig geformte Kern wird mit Ortsbeton gefüllt. An diesem neuen Stützentyp wurden im Massstab 1:1 Versuche durchgeführt, mit dem Ziel zu beweisen, dass diese Art von Verbundstützen sowohl nach den Britischen Brückenbaunormen, wie nach den Europäischen Empfehlungen der EKS für Verbundkonstruktionen, sicher bemessen werden können.

1. INTRODUCTION

Composite columns of steel and concrete have been in use for several decades. Until recently, the methods of design for such columns have been of the empirical type, and were based on the experimental results of few full-scale tests and on very little research [1]. Two methods of design have now become available for the design of composite columns, namely the British Bridge Code [2] and the European recommendations for composite structures by the ECCS [3], referred to hereafter as the Bridge Code and the ECCS method. Both these methods of design are applicable to concrete-encased steel sections as well as to concrete-filled tubes. In the case of concrete-encased steel sections, sufficient longitudinal and transverse reinforcements are required to ensure full composite action up to failure between the structural steels and concrete elements, including the reinforcement. In the case of concrete-filled hollow steel sections, although no reinforcement is needed to ensure the composite action between the structural steel and concrete elements, reinforcement can be used for fire protection requirements.

2. WHY BATTENED COMPOSITE COLUMNS?

The concrete-encased type of composite column was a natural development of the traditional use of light concrete encasement as a means of fire protection for the structural steel section. This type of composite column suffers from the present situation in the construction industry in which the cost of the labour element has been rising steeply in the last few decades. The column requires a complete shuttering as well as a reinforcement cage which is further complicated by the presence of the steel core within. The concrete-filled hollow section requires neither shuttering nor real reinforcement since the tube is filled with plain in-situ concrete. However, the structural steel element of this type of composite column is exposed, being on the outside, and hence requires some form of fire protection. Furthermore, when using this type of column with standard flooring, it can be seen that the beam-column connections are neither of the simple type nor are they easily accessible as when the structural steel element of the column is of the rolled steel type.

The proposed battened composite column consists of two steel channel sections, battened together by means of end and intermediate batten plates, and the inside is then filled with plain in-situ concrete. This type of column compares favourably with the traditionally used composite columns given above. However, similar to the concrete-filled steel tubes, it has no concrete encasement, and therefore requires some form of fire protection. Compared to the traditional composite column sections, the battened composite column offers the following advantages:

- it requires shuttering of a simple and cheap form
- requires no reinforcement cage
- is more versatile since its load-carrying capacity can be altered simply by changing the depth of the column.
- makes very efficient use of the structural steel element since the steel is placed on the outside where it is most needed.
- provides easy access to the inside core, and hence, unlike concrete-filled tubes, makes for easy beam-column connections.

Tests have been carried out on full-scale battened composite columns and the results published elsewhere [4]. Further tests have been performed on another series of columns in which extensive strain measurements were taken, and which established the full composite action between the structural steel and concrete core up to failure [5]. Simple expressions have also been developed for the design of this type of column [6] and were based on an approach proposed by Johnson and Smith [7].

3. DESIGN OF COMPOSITE COLUMNS

The load carrying capacity of a short composite column is a function of its squash load N_u, the design ultimate moment of resistance M_u, and also the concrete contribution parameter α [8]. The squash load N_u is defined as the ultimate axial load for a short column and for short-term loading is given by:

$$N_u = A_s f_{sd} + A_c f_{cd} \qquad (1)\ a$$

$$= A_s f_{sk} + 0.83\, A_c f_{cu} \qquad (1)\ b$$

where the symbols are as given in the list of notation, and the material partial factors of safety are taken equal to unity. The design ultimate moment of resistance M_u of the section of a composite column can be calculated from the conditions of equilibrium across the section. The solution is based on the standard rectangular stress blocks used when analysing a composite steel - concrete section, and in which the concrete in tension is ignored. The concrete contribution parameter α , is given by the ratio of the portion of the squash load which is carried by the concrete core to the total value of the squash load of the composite section.

Under the combined effect of an axial load N and a bending moment M on a composite section, dimensionless interaction graphs of the type shown in Figure 1 could be developed by consideration of equilibrium conditions across the section. It can be seen that under a small axial load, the design ultimate moment of resistance of the section could be exceeded as a result of the stabilising effect the compressive force has on the equilibrium of the composite section.

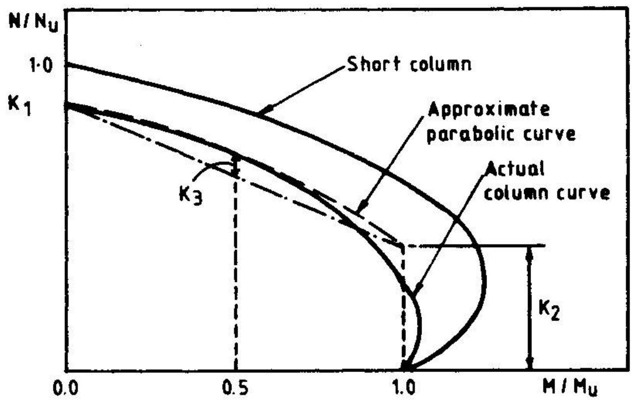


FIG. 1. TYPICAL INTRACTION GRAPHS FOR COMPOSITE COLUMNS.

The ultimate load-carrying capacity of an axially loaded composite column is given by:

$$N_k = K_1 N_u \qquad (2)$$

where K_1 is a reduction factor which depends on the slenderness of the column. Both the Bridge Code [2] and the ECCS method [3] take K_1 as a function of $\bar{\lambda}$, where $\bar{\lambda}$ is the equivalent slenderness ratio of the column, and which is given by:

$$\bar{\lambda} = (N_u/N_{cr})^{\frac{1}{2}} = L_e/L_c \qquad (3)$$

The ultimate load-carrying capacity of a composite column under axial compression and bending is given by:

$$N_k = K\, N_u \qquad (4)$$

where K is a reduction factor which depends on the reduction factor K_1 for axially loaded columns, the material and cross-section properties of the column section, and also on the shape and ratios of the bending moment distributions in the column. In this respect the design is simplified by the introduction of new factors K_2 and K_3 which are used to modify the actual interaction graphs as shown in Figure [1].

The Bridge Code as well as the ECCS for Composite Structures are only applicable to concrete-encased steel sections and concrete-filled steel tubes. Neither method is applicable to the proposed battened composite column since the structural steel part of the column is not included in either table C16.1, Figure 16.1 or Figure C16.1 of the European recommendations [3]. It was therefore necessary to provide experimental evidence that both the Bridge Code and the ECCS could be safely applied in the design of the proposed column.

4. TESTS ON BATTENED COMPOSITE COLUMNS

4.1 Test rig

Full scale tests on battened composite columns were carried out in a 10 000 kN capacity test rig which has been described elsewhere [10]. The load was applied to the columns by way of a pair of crossed knife-edges acting through a pair of 75mm thick plates at each end. The loading system consisted of 38mm round bars positioned in either 15mm deep V-shaped notches or in 5mm deep, 40mm diameter circular grooves in the loading plates. A system of holes in the set of loading plates nearer the column ends, and to which the column end plates were bolted, enabled the columns to be accurately fixed to the thick loading plates giving a high degree of accuracy in applying the load at the required eccentricities.

4.2 Test specimens

Figure 2 and Table 1 give details of the tested columns. End plates 15mm thick were welded to the column ends using 6mm fillet welds. The cross-sectional areas of the channels given in Table 1 were estimated by their weight; this was in preference to the use of the tables which gave only the nominal dimensions. The sizes of the batten plates used are given in Table 1, and are seen to be substantially smaller than required in accordance with the design specifications of bare structural steel battened columns [1]. The maximum size of aggregate used for the concrete was 10mm, and the properties of the concrete mix were 1: 1.9 : 2.4 /0.55. All columns were cast and tested horizontally, which of course would not be the case in practice.

Figure 3 shows the details of the column ends when tested with end eccentricities larger than half the column depth or breadth measured along the minor and major axes respectively. In such cases, the end plates were taken large enough to accomodate the applied compressive force within their dimensions. Triangular stiffening plates were welded to both the end plates and column ends to ensure that premature failure of the columns would not occur as a result of local failure at the column ends.

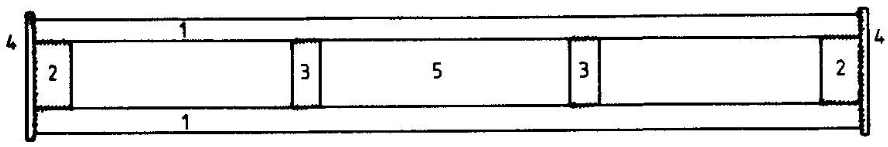
4.3 Instrumentation

The columns were instrumented to measure the longitudinal strains in the steel channels using electrical strain gauges, and in the concrete using a Demec strain gauge. The Demec gauge was also used to detect and measure the transverse separation between the flanges of the steel channels and the concrete at positions midway between the battens. Only one half of each column length was instrumented for strain measurements, and typical positions of the various gauges are shown in Figure 4. The electrical strain gauges on the batten plates, which were only used in a few of the tested columns, showed that the batten plates acted only as ties between the steel channel flanges, and that the battens were not subjected to bending moments as in the case of battened bare steel columns. Dial gauges were used to measure the column defflections at mid-span both in the minor and major axes directions. Resin was also applied to parts of the columns which were not instrumented in order to observe the progress and extent of the yielding of the structural steel elements.

TABLE 1 : DETAILS AND PROPERTIES OF COLUMNS

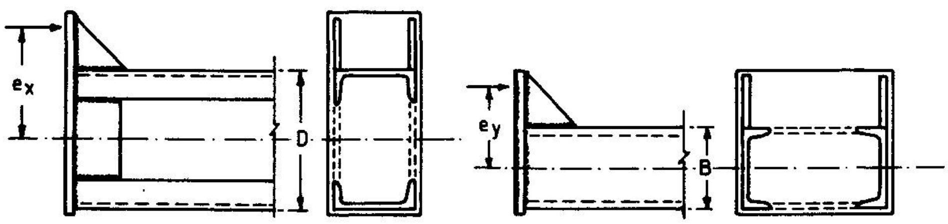
Column No.	Size of channel (mm x mm)	Depth of column (mm)	Batten plates: Thickness (mm)	Batten plates: Length of end battens (mm)	Batten plates: Length of intermediate battens (mm)	Steel channels: Area $A_{s/2}$ (mm^2)	Steel channels: Characteristic strength f_{sk} (N/mm^2)	Steel channels: Yield strain ϵ_y (%)	Steel channels: Elastic modulus E_s (kN/mm^2)	Concrete core: Area A_c (mm^2)	Concrete core: Cube strength f_{cu} (N/mm^2)	Concrete core: Elastic modulus, Bridge Code (kN/mm^2)	Concrete core: Elastic modulus, ECCS (kN/mm^2)	Effective length L_{ex} (mm)	Effective length L_{ey} (mm)
1	152x76	' 352	10	150	100	2242	267	NR*	205.0#	48860	45.0	32.0	22.4	3174	2904
2	152x76	352	8	180	120	2273	270	"	"	48790	37.0	29.7	18.4	3180	2910
3	152x76	352	8	180	120	2274	268	"	"	48790	35.0	29.2	17.4	3180	2910
4	203x89	428	10	200	140	3579	274	"	"	80220	41.0	30.8	20.4	3180	2910
5	203x89	428	10	200	140	3579	279	"	"	80220	38.0	29.9	18.9	3180	2910
6	254x76	402	10	220	150	3621	337	"	"	94360	41.0	30.8	20.4	3180	2910
7	254x76	402	10	220	150	3621	333	"	"	94360	47.0	32.5	23.4	3180	2910
8	152x76	352	8	150	120	2342	330	"	"	48860	39.0	30.3	19.4	3180	2910
9	152x76	352	8	150	120	2342	330	"	"	48860	46.0	32.2	22.9	3180	2910
10	152x76	350	6	120	90	2269	312	"	207.0#	48800	38.3	30.0	19.1	3180	2910
11	152x76	350	6	120	90	2268	314	"	"	48800	40.6	30.7	20.3	3180	2910
12	152x76	350	6	120	90	2386	298	0.24	203.4	48570	38.9	30.3	19.3	3180	2910
13	152x76	350	6	120	90	2388	295	0.22	203.4	48560	36.6	29.5	18.3	3180	2910
14	152x76	350	6	120	90	2335	267	0.25	211.7	48670	42.4	31.3	21.1	3180	2910
15	152x76	350	6	120	90	2277	274	0.30	221.3	48790	41.6	31.0	20.8	3180	2910
16	152x76	350	6	120	90	2292	278	0.30	221.6	48760	38.8	30.3	19.3	3180	2910
17	152x76	350	6	120	90	2272	277	0.30	225.5	48800	34.3	29.0	17.1	3180	2910
18	152x76	350	6	120	90	2285	323	NR*	207.0#	48770	42.0	31.0	20.9	2910	3180
19	152x76	350	6	120	90	2268	310	"	"	48800	48.2	33.0	24.0	2910	3180
20	152x76	350	6	120	90	2365	296	0.22	233.7	48610	36.6	29.5	18.3	2910	3180
21	152x76	350	6	120	90	2380	272	0.21	230.0	48580	39.5	30.5	19.7	2910	3180
22	152x76	350	6	120	90	2300	278	0.29	205.4	48740	35.2	29.3	17.5	2910	3180
23	152x76	350	6	120	90	2300	288	0.28	204.1	48740	33.7	28.9	16.8	2910	3180
24	152x76	350	6	120	90	2300	272	0.29	207.4	48740	33.4	28.8	16.6	2910	3180
25	152x76	350	6	120	90	2300	291	0.30	204.8	48740	42.6	31.3	21.2	2910	3180
26	152x76	350	6	120	90	2300	273	0.30	208.3	48740	38.6	30.2	19.3	2910	3180

* Values were not recorded   # Average values   Material partial safety factors are ignored.



1. Steel channels (2·7m long) 2. End batten plates
3. Intermediate batten plates 4. End plates 5. Plain concrete core.

FIG. 2. DETAILS OF COLUMN SPECIMENS.



a) Bending about major axis   b) Bending about minor axis

FIG : 3. DETAILS OF COLUMN ENDS SUBJECTED TO LARGE ECCENTRICITIES

4.4 Test results

Some of the test results of columns 1-9 have been published elsewhere [4]. Moreover, the results of the extensive strain measurements on columns 10-26 have also been published, and showed clearly the presence of full composite action between the structural steel and concrete elements of the battened composite column up to failure [5].

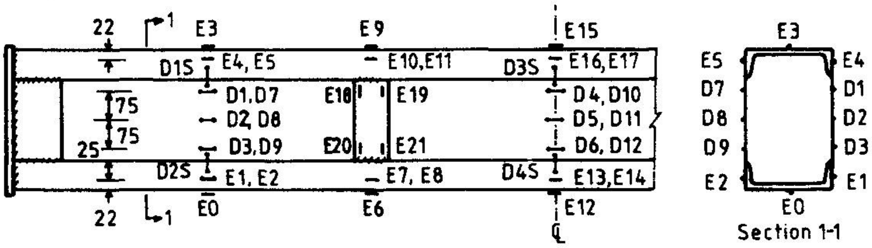


FIG : 4. TYPICAL POSITION OF STRAIN GAUGES
(Distances given in mm for channel size 152 × 76)

Figure 5 shows some typical load-deflection curves of the tested columns. Columns subjected to minor axis bending showed negligible deformations in the minor axis direction, and such deflections were therefore omitted from the figure. On the other hand, columns subjected to major axis bending suffered a small minor axis bending due to their self weight. The minor axis moments were further magnified by the effect of the compression force, and consequently the columns deflected in both the major and minor axis direction. The last two columns in the series were subjected to biaxial bending and therefore exhibited deformations in both directions as seen in Figure 5. The deflections measured in the major axis direction were always measured using dial gauges resting against the flanges of both steel channels, and hence the angle of twist of the mid-span section could also be evaluated. Under large eccentricities, columns tested under major axis bending showed very little twist. The largest recorded angle of twist at failure was 2×10^{-2} radian for column 12 (e_x = 120mm). The other major axis columns suffered angles of twist of less than 3.5×10^{-3} radian at failure.

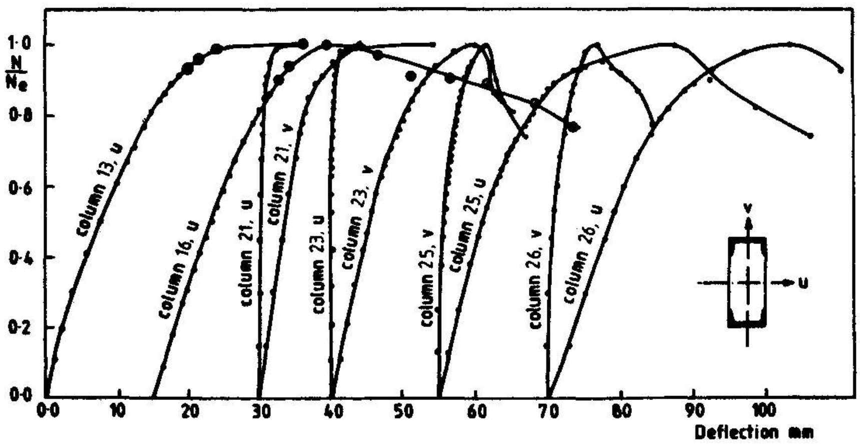


FIG 5. LOAD-DEFLECTION CURVES

Tables 1 and 2 show the details and results of all tests carried out on full scale battened composite columns. With the exception of column 9, which was tested in double curvature, all columns were tested in single curvature. Each column was made by using a 6.0m long steel channel section, from which a 5.4m length was used for the column, and the remaining 0.6m was used to determine the material properties of the steel channel. The characteristic strength of steel was determined from tests on tension specimens machined from the 0.6m long channel section, usually one or two specimens from the web and one from each flange. The characteristic strength of concrete was determined for each column from an average value of tests on at least four 100mm cubes.

TABLE 2 : TEST RESULTS OF COLUMNS

Column No.	Eccentricity: About major axis e_x (mm)	Eccentricity: About minor axis e_y (mm)	Eccentricity ratio: About major axis e_x/D	Eccentricity ratio: About minor axis e_y/B	Squash load N_u (kN)	Conc. contribution factor α	Ult. moment of resistance: M_{ux} (kNm)	Ult. moment of resistance: M_{uy} (kNm)	Exp. Failure load N_e (kN)	Mid-span deflection at failure: v (mm)	Mid-span deflection at failure: u (mm)	Mid-span moment at failure: M_{ex}(*) (kNm)	Mid-span moment at failure: M_{ey}(#) (kNm)	Bridge Code: Reduction factor K_B	Bridge Code: Ult. load N_{kB} (kN)	Bridge Code: N_e/N_{kB}	ECCS: Reduction factor KE	ECCS: Ult. load N_{kE} (kN)	ECCS: N_e/N_{kE}
1	0	0	0	0	3022	0.604	-	80.4	2610	-	4.5	-	11.8	0.755	2283	1.14	0.851	2571	1.01
2	0	8	0	0.05	2726	0.550	-	81.4	2290	-	11.2	-	44.0	0.657	1790	1.28	0.701	1911	1.20
3	0	40	0	0.26	2636	0.538	-	80.6	1338	-	18.8	-	78.7	0.406	1070	1.25	0.411	1082	1.24
4	0	10	0	0.05	4691	0.582	-	174.0	4250	-	7.2	-	73.1	0.747	3502	1.21	0.776	3639	1.17
5	0	30	0	0.15	4527	0.559	-	176.3	3093	-	14.8	-	138.6	0.589	2665	1.16	0.594	2687	1.15
6	0	12	0	0.05	5652	0.568	-	261.3	5063	-	4.0	-	81.0	0.792	4479	1.13	0.803	4538	1.12
7	0	25	0	0.10	6092	0.604	-	261.3	4432	-	9.6	-	153.4	0.673	4097	1.08	0.675	4110	1.08
8	0	0	0	0	3121	0.505	-	101.5	2539	-	4.5	-	11.4	0.761	2375	1.07	0.838	2615	0.97
9	0	50	0	0.33	3403	0.546	-	102.4	1776	-	N.R.	-	-	0.554	1884	0.94	0.547	1861	0.95
10	0	40	0	0.26	2967	0.523	-	93.4	1357	-	N.R.	-	68.0*	0.402	1192	1.14	0.407	1208	1.12
11	0	40	0	0.26	3069	0.536	-	94.2	1494	-	10.1	-	74.9	0.394	1209	1.24	0.400	1228	1.22
12	0	60	0	0.39	2990	0.524	-	93.8	1185	-	31.5	-	108.4	0.319	955	1.24	0.321	961	1.23
13	0	80	0	0.52	2884	0.512	-	92.6	986	-	35.1	-	113.5	0.272	784	1.26	0.272	784	1.26
14	0	100	0	0.66	2960	0.579	-	83.2	777	-	28.8	-	100.1	0.211	626	1.24	0.213	630	1.23
15	0	120	0	0.79	2932	0.574	-	83.2	643	-	29.0	-	95.8	0.186	546	1.18	0.187	549	1.17
16	0	140	0	0.92	2844	0.552	-	84.6	553	-	24.8	-	91.1	0.172	488	1.13	0.172	489	1.13
17	0	160	0	1.05	2648	0.525	-	83.0	491	-	26.4	-	91.5	0.162	429	1.14	0.162	429	1.14
18	40	0	0.11	0	3176	0.535	225.7	-	2252	14.7	4.3	123.2	-	0.566	1797	1.25	0.615	1952	1.15
19	80	0	0.23	0	3359	0.581	215.0	-	1825	18.4	3.5	179.6	-	0.455	1528	1.19	0.487	1635	1.12
20	120	0	0.34	0	2877	0.513	214.1	-	1521	21.0	9.1	214.5	-	0.408	1175	1.29	0.432	1244	1.22
21	160	0	0.46	0	2887	0.552	198.0	-	1346	24.5	5.4	248.3	-	0.350	1011	1.33	0.368	1061	1.27
22	200	0	0.57	0	2703	0.527	195.5	-	1212	17.4	4.0	263.4	-	0.313	845	1.43	0.322	870	1.39
23	280	0	0.80	0	2688	0.507	202.6	-	950	20.3	4.4	285.2	-	0.247	665	1.43	0.257	690	1.38
24	360	0	1.03	0	2602	0.519	191.3	-	728	19.6	7.4	276.4	-	0.191	498	1.46	0.198	513	1.42
25	80	40	0.23	0.26	3062	0.563	204.7	89.1	1205	6.8	32.5	104.5	87.4	0.281	861	1.40	0.285	873	1.38
26	160	80	0.46	0.52	2817	0.554	192.0	83.4	664	7.0	33.8	110.9	75.6	0.180	508	1.31	0.180	506	1.31

(*) $M_{ex} = N_e (e_x + v)$ (#) $M_{ey} = N_e (e_y + u)$ *Deflection assumed to be the same as column 11

The elastic modulus of steel was either determined for each column from the test results on the tension specimens, or was taken 205 kN/mm^2 or 207 kN/mm^2; these being very close to the average experimental values obtained for a group of columns. The elastic modulus of concrete given in Table 1 was obtained in accordance with the Bridge Code and the ECCS recommendations. As seen from Table 2, the actual failure loads of the columns are all in excess of the predicted values as obtained by the Bridge Code and the ECCS recommendations. It should be noted that in using these methods of design, it was decided to use curve "a" of the European buckling curves for bare steel columns. It was originally thought that curve "c" was more appropriate for use for the bare steel section of the battened composite column, but further considerations indicated that curve "a" should be used. The choice of curve "a" for the design of battened composite columns was supported by the test results which showed that the use of curve "c" gave predicted failure loads which were very conservative.

The ratios of the failure loads to the predicted values are shown graphically in Figure 6 both for minor and major axis bending. The two recommended methods of design seem to be in fairly good agreement, with the Bridge Code giving ultimate loads which are marginally lower than those predicted by the ECCS method. As seen from Figure 6, the failure to predicted load ratio reaches a peak at eccentricity ratios of 0.5 and 0.6, after which it levels off at values of 1.15 and 1.45 for minor and major axis bending respectively. The closest agreement between the experimental and predicted values is for the case of axial compression where the eccentricity is equal to zero.

Figure 7 shows the failure loads of the columns in which steel channels of size 152 x 76 were used. The failure loads are shown against the interaction graph of a short column of the same dimensions and for which a concrete contribution parameter of α = 0.55 was taken; this being an average value for the tested columns as seen from Table 2. The interaction curves obtained on the basis of the Bridge Code and the ECCS recommendations are shown also in Figure 7, and are plotted using the factors K_1 K_2 and K_3 as obtained by the design recommendations. It can be seen from the figure that all the experimental failure loads are higher than predicted by both methods of design.

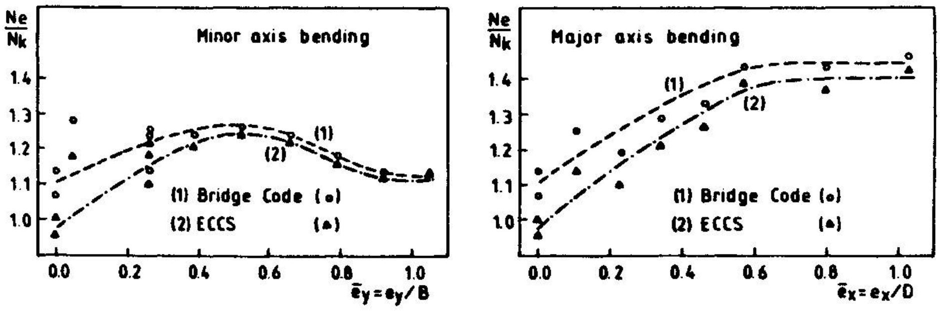


FIG. 6 FAILURE LOAD V. ECCENTRICITY FOR COLUMNS

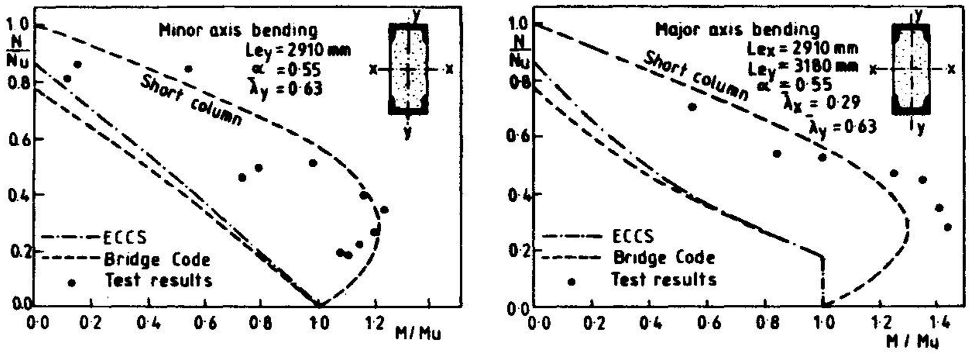


FIG. 7. INTRACTION CURVES UNDER UNIAXIAL BENDING FOR COLUMNS USING 152 x 76 STEEL CHANNELS

5. CONCLUSIONS

Results of tests on battened composite columns reported both here and elsewhere, confirm that full composite action up to failure is present between the structural elements of the column, namely the concrete core and the structural steel channels. The results also show that both the Bridge Code and the ECCS recommendations could be safely used for the design of the column since the experimental failure loads were always in excess of the predicted values. The experimental investigation thus confirms that the battened composite column is a practical way of combining concrete and structural steel in such a way that the best use is made of their material properties.

6. NOTATION

A_c, A_s	:	Area of concrete core and structural steel section respectively.
B, D	:	Breadth and depth of section respectively.
E_c, E_s	:	Elastic modulus of concrete and structural steel respectively.
e_x, e_y	:	Eccentricity about the major and minor axes respectively.
$\bar{e}_x$, $\bar{e}_y$	:	Eccentricity ratios e_x/D and e_y/B respectively.
f_{cu}	:	Cube strength of concrete
f_{cd}, f_{sd}	:	Design strength of concrete and steel respectively
f_{ck}, f_{sk}	:	Characteristic strength of concrete and steel respectively.
K_1	:	Reduction factor for an axially loaded composite column.
K_{1B}, K_{1E}	:	K_1 as obtained from Bridge Code and ECCS respectively.

K	:	Reduction factor for a composite column subjected to compression and bending.
K_B, K_E	:	Reduction factor K as obtained from Bridge Code and ECCS respectively.
L_e	:	Effective column length about appropriate axis
L_c	:	Critical length of column for which its squash load equals its Euler critical load.
M	:	Factored moment on composite column
M_u	:	Design ultimate moment of resistance of composite section.
M_{ux}, M_{uy}	:	M_u value about major and minor axis of section respectively.
N_e, M_e	:	Experimental failure load and moment respectively.
N	:	Factored normal force on composite column
N_{cr}	:	Euler critical load of composite column
N_u	:	Squash load of composite column
N_k	:	Ultimate load-carrying capacity of composite column
N_{kB}, N_{kE}	:	N_k value as obtained from the Bridge Code and ECCS recommendations respectively.
u, v	:	Deflections at column mid-span in the direction of the X and Y axes respectively.
α	:	Concrete contribution parameter
λ	:	Slenderness ratio of column.
$\bar{\lambda}$	:	Equivalent slenderness ratio of column.

7.REFERENCES

1. BS 449: Part 2, "The use of structural steel in buildings", British Standard Institution, 1969.
2. BS 5400: "Steel, concrete and composite bridges, Part 5: Code of Practice for design of composite bridges", British Standard Institution, 1979.
3. European Convention of Constructional Steelwork (ECCS): "Composite Structures",1981.
4. TAYLOR, T., SHAKIR-KHALIL, H., YEE, Y.M., "Some Tests on a new type of composite column", Proc. Instn. Civ.Engnrs, Part 2, vol. 75, June 1983.
5. SHAKIR-KHALIL, H. and HUNAITI, Y.M., "Behaviour of battened composite columns", Conference, Applied solid mechanics, University of Strathclyde, Glasgow, U.K., March 1985.
6. YEE, Y. M., SHAKIR-KHALIL, H., TAYLOR R., "Design expressions for a new type of composite column", Journal of Constructional steel research, vol.2, No.2, June 1982.
7. JOHNSON, R.P. and SMITH, D.G.E., "A simple design method for composite columns", The Structural Engineer, vol. 58A, No. 3, March 1980.
8. BASU, A.K. and SUMMERVILLE, W., "Derivation of formulae for the design of rectangular composite columns", Proc. Instn. Civ.Engnrs, Supp. vol., 1969.
9. VIRDI, K.S. and DOWLING, P.J., "A unified design method for composite columns", Publications, IABSE, vol. 36 II, 1976.
10. HORNE, M.R., and NARAYANAN, R., "Ultimate capacity of longitudinally stiffened plates used in box girders", Proc. Instn. Civ.Engnrs, Part 2, vol. 61, June 1976.

Leere Seite
Blank page
Page vide