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EXPERIMENTAL STUDIES ON COLUMN STRENGTH OF EUROPEAN HEAVY SHAPES

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ABSTRACT

The European Convention for Constructional Steelwork (ECCS) has performed extensive column tests on specimens of small dimensions and light weights. The work reported herein is essentially an extension of the ECCS program to columns of heavy shape. The test program consists of full-size column tests (slenderness ratio of 50 and 95) and supplementary tests, namely, tension tests (full-size and ASTM standards), residual stress measurements, and stub column tests. The test specimens include shapes from four countries: Belgium, Britain, Germany and Italy. The tests have been conducted at Fritz Engineering Laboratory, Bethlehem, Pennsylvania.

This report presents the experimental results of the column tests as well as the supplementary tests. The column test results are compared with the latest proposed European Convention Column Curves (B3-24 and C3-24). A good correlation for $L/r = 95$ and slightly unconservative prediction for $L/r = 50$ are observed.

1. INTRODUCTION

Commission 8 of the European Convention for Constructional Steelwork (ECCS) instituted Subcommittee 8.1, chaired by D. Sfintesco, to conduct "experimental studies of buckling". The Subcommittee realized that column test data were essential for accurate determination of column strength curves. The Subcommittee proposed that the maximum strength of pinned-end steel columns of prismatic cross section should be studied based on the statistical and probabilistic concept of safety applied to buckling [1,2,3].

The basic idea in the statistical approach to the column strength problem is to collect a sufficiently large number of test data, and then to obtain mean maximum loads and standard deviations possessing statistical validity. The aim of this approach is to determine, for each group of shapes of a given steel grade, a column strength curve representing a constant probability of failure for all slenderness ratios. The ultimate goal is to obtain a consistent degree of safety of factor for all members of a structure, whatever may be their shape and level of stress [4].

The statistical test program has performed well over 1000 column tests [5]. The columns were taken at random from various stockyards of steelwork fabricators in several European countries in an effort to furnish representative samples of columns normally used in actual structures. Findings from earlier experimental investigations have served to form the basis for the column curve adopted by the European Convention in June 1964 [6]. However, this test program had been limited to light shapes only of mild steel. The extension of the application of the curve to columns of larger sizes and to other types of steels was left to be performed by theoretical means and eventually to be confirmed by experimental means.

This paper presents an experimental study on heavy columns fabricated in Europe to determine the conditions by which the results from the previous program on column strengths of small dimensions and light weights can be extended to such heavy columns. Prior to testing the European heavy columns, a preliminary experimental study on different column testing methods was conducted using seven heavy columns fabricated in the United States. The specimens were prepared from a single unstraightened rolled piece and had a size comparable to the shape considered in the European heavy column test program. As a result of this study, the testing method required by ECCS [3] has been clarified and a new procedure for testing of medium and heavy columns has been proposed [7].

To obtain conclusive experimental evidence on the strength of heavy columns with minimum cost, the test program included the specimens from four countries: Belgium, Britain, Germany and Italy. The tests have been conducted at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania. The test program consisted of pinned-end column tests (slenderness ratio of 50 and 95) and supplementary tests, namely, tension tests (full-size and ASTM standard), residual stress measurement, and stub column test. The results of the column tests are also compared with the recently proposed European Convention Column Curves [8].

2. THE TEST PROGRAM

Scope

The test program was limited to testing specimens from four European manufacturers found in Belgium, Britain, Germany and Italy. This choice was considered to be sufficient to furnish a good representation of population of "columns obtainable in Europe". From each manufacturer two specimens were selected as a typical representative of the production of the respective manufacturer. This results in a total of eight heavy column shapes. A typical schematic layout for the preparation of the test specimens is shown in Fig. 1. A summary of the test program is presented in Table 1.

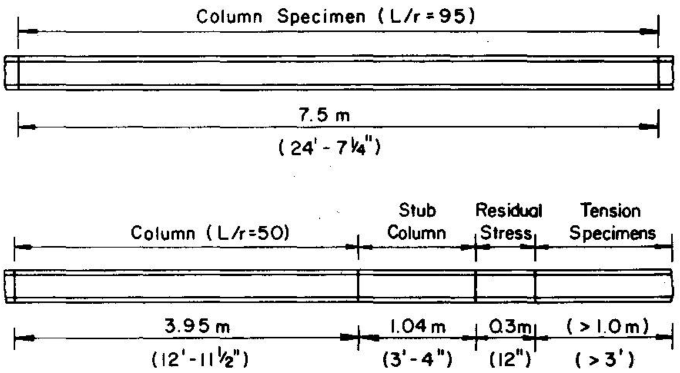


Fig. 1 Schematic Layout of Test Specimen from Each Rolling

TABLE 1: OUTLINE OF TEST PROGRAM

Source Country and Shape	Tension Tests ASTM	Tension Tests ECCS	Residual Stress Measurements	Stub Column Tests	Column Tests L/r=50	Column Tests L/r=95
BELGIUM (HEM 340)	8	8	2	2	2	2
BRITAIN (W12x161)	8	8	2	2	2	2
GERMANY (HEM 340)	8	-	2	2	2	2
ITALY (HEM 340)	8	8	2	2	2	2
Total Number of Tests	32	24	8	8	8	8

For the full-size column tests two slenderness ratios were chosen in the critical range; this was governed by practical and theoretical considerations. According to the ECCS [3] it was suggested to test columns of:
i) a slenderness ratio of 95 on the basis of theoretical considerations for which the variation of experimental results would be the greatest, and
ii) a slenderness ratio of 50 which would be of the same order of magnitude as the slenderness ratio normally used in multi-story building structures, yet, still in the critical range of slenderness ratio.

Through the applications of statistical analysis two experimental points may be established to represent the column buckling curve for heavy rolled shapes. These test points should enable a decision whether or not the experimental curve resulting from the basic program could be applied safely to heavy columns.

The Test Specimen

Two conditions governed the choice of the column size: i) the column must be a "heavy shape", and, ii) the specimen must be rolled by all of the four manufacturers.

According to ECCS definition a shape larger than HE 280 and having a thickness greater than 30 mm (1-1/8 in) is designated as a "heavy shape" [3]. To meet the above requirements, the shape HEM 340 was chosen for the specimens from the continental countries using the metric system, and the shape W12x161 from Britain (this shape is also rolled in the United States). (At the time, the HEM 340 was the heaviest shape then available in the continental countries.) The two shapes are very similar in cross sectional dimensions; the shapes are compared in Fig. 2.

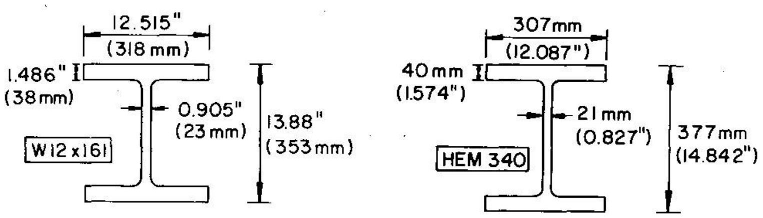


Fig. 2 Comparison of Cross Sectional Dimensions

3. SUPPLEMENTARY TESTS

The purpose of conducting supplementary tests is to determine the basic properties of specimens which are required to evaluate the theoretical column strengths. The following supplementary tests were performed:

Tension Tests

The tension tests were carried out in two ways: i) according to ASTM specifications [9] for standard 8-inch gage length specimen, and ii) following the ECCS recommendations [3] for full-size tension tests where the complete section is tested in tension using four plate specimens (the two flanges and two plates from the web). The gage length for the full-size tension tests is determined according to the formula $L = 5.65 \sqrt{A}$, where A is the cross sectional area of the tension specimen [3].

A total of thirty-two 8-inch gage length (ASTM A570) specimens were tested in tension. From each column, two coupons were prepared from the flanges and two from the web as shown in Fig. 3. The static yield strength was defined by the stress at 0.005 in/in strain. The recorded static yield strength varies between 28.7 ksi (198 N/mm^2) and 36.2 ksi (250 N/mm^2) for the flanges, and between 29.0 ksi (200 N/mm^2) and 36.7 ksi (253 N/mm^2) for the webs. Table 2 gives the test results. For most of the specimens tested, it was observed that the flange specimens had a lower yield strength and a gradual transition from the elastic to the strain hardening range, while the web specimens exhibited a higher yield strength, a "flat" yield plateau and a marked onset of strain hardening. Figure 4 shows a typical stress-strain relationship of tension specimens taken from the flange and the web.

A total of twenty-four full-size tension tests were conducted following ECCS recommendations. The static yield strength was also defined by

TABLE 2: TENSION COUPON TEST RESULTS (ASTM)

Specimen	Location	Upper Yield Stress σ_{yu} ksi (N/mm²)	Dynamic Yield Stress σ_{yd} ksi (N/mm²)	Static Yield Stress σ_{ys} ksi (N/mm²)	Ultimate Stress σ_u ksi (N/mm²)	Fracture Stress σ_f ksi (N/mm²)	Percent Elongation %	Reduction of Area %
B-1-B-1-5	1	-- --	33.4 (230)	30.8 (212)	55.2 (381)	40.7 (281)	36.9	59.5
	2	35.6 (245)	33.4 (230)	31.4 (216)	57.9 (399)	44.1 (304)	36.0	41.6
	3	-- --	34.4 (237)	33.0 (228)	58.0 (340)	45.0 (310)	34.1	59.2
	4	32.3 (223)	32.3 (223)	30.1 (208)	55.7 (384)	43.0 (296)	36.4	58.9
B-1-B-2-4	1	32.2 (222)	30.8 (212)	29.4 (203)	54.0 (572)	41.3 (285)	38.1	62.2
	2	31.1 (214)	33.9 (234)	31.7 (219)	57.0 (393)	43.4 (299)	32.3	60.0
	3	34.4 (237)	34.4 (237)	32.4 (223)	57.7 (398)	43.5 (300)	32.8	60.1
	4	32.2 (222)	32.2 (222)	30.7 (212)	52.1 (359)	41.4 (285)	36.5	59.8
B-1-GB-1-5	1	-- --	32.7 (225)	31.3 (216)	65.6 (452)	44.8 (309)	50.1	67.6
	2	36.1 (249)	35.8 (247)	34.2 (236)	66.9 (461)	47.5 (328)	31.3	61.7
	3	34.9 (246)	34.5 (238)	33.1 (228)	61.7 (425)	45.6 (314)	30.0	64.8
	4	34.0 (234)	34.9 (241)	33.5 (231)	65.3 (450)	42.9 (296)	50.4	68.7
B-1-GB-2-4	1	29.5 (203)	29.9 (206)	28.8 (199)	60.5 (417)	40.6 (280)	53.3	70.1
	2	-- --	35.1 (242)	33.2 (229)	65.4 (451)	45.5 (314)	34.0	66.3
	3	33.4 (230)	32.4 (223)	31.0 (214)	61.8 (426)	42.4 (292)	33.8	65.6
	4	31.6 (218)	31.8 (219)	30.8 (212)	60.5 (417)	39.9 (275)	62.6	69.5
B-1-D-3-5	1	34.8 (240)	33.7 (232)	32.7 (225)	58.0 (340)	44.0 (303)	38.1	62.0
	2	36.6 (252)	36.3 (250)	35.2 (243)	60.9 (420)	47.9 (330)	33.5	57.3
	3	36.9 (254)	36.9 (254)	35.0 (241)	60.9 (420)	47.0 (324)	33.1	54.6
	4	37.2 (256)	34.5 (238)	31.9 (220)	57.4 (396)	43.8 (302)	38.6	63.2
B-1-D-4-4	1	40.0 (276)	37.1 (256)	36.2 (250)	61.0 (421)	46.9 (323)	40.6	59.6
	2	40.5 (279)	39.3 (271)	36.7 (253)	65.1 (449)	53.6 (370)	35.3	54.8
	3	37.3 (257)	36.7 (253)	34.1 (235)	60.2 (415)	63.8 (440)	36.0	54.5
	4	36.6 (252)	35.6 (245)	33.4 (230)	61.0 (421)	46.9 (323)	38.5	59.2
B-1-I-1-5	1	30.4 (210)	30.4 (210)	29.3 (202)	60.4 (416)	43.0 (296)	37.5	64.2
	2	-- --	31.3 (216)	29.6 (204)	58.8 (405)	41.4 (285)	31.8	63.4
	3	35.1 (242)	33.5 (231)	31.1 (214)	59.4 (410)	43.4 (299)	34.3	61.6
	4	31.9 (220)	31.9 (220)	29.8 (205)	60.7 (419)	43.5 (300)	36.3	62.7
B-1-I-2-4	1	30.2 (208)	30.7 (212)	28.7 (198)	60.5 (417)	43.1 (297)	37.5	64.0
	2	-- --	32.7 (225)	30.8 (212)	60.7 (419)	43.6 (301)	33.8	64.8
	3	33.5 (231)	30.9 (213)	29.0 (200)	54.5 (376)	41.4 (285)	32.6	66.6
	4	-- --	30.2 (208)	29.3 (202)	59.4 (410)	43.5 (300)	37.5	66.5

Fig. 3 Location of Tension Test Specimens

the stress at 0.005 in/in strain. The test results are given in Table 3. The full-size tension test results were seen to correspond very closely to those obtained from the ASTM tests. Since the full-size tension tests did not seem to yield any additional or different information on material properties than those given by ASTM tests the full-size tension tests were not carried out for all columns.

Residual Stress Measurements

The procedure used for the residual stress measurements was the sectioning method, involving longitudinal saw cuts across the thickness of width of the component plates. A detailed discription of the sectioning method is given in Ref. 10.

Residual stress measurements were made on a total of eight specimens. To obtain a more accurate and smoother variation of the measured values, each specimen was cut into seventy longitudinal strips. Figure 5 shows the measured residual stress distributions for all specimens. A close agreement was observed for the magnitude and distribution of residual stresses in the flanges of all the specimens. The edges have compressive residual stresses with an average value of 9.5 ksi (65 N/mm^2) or 0.28 σ_y.

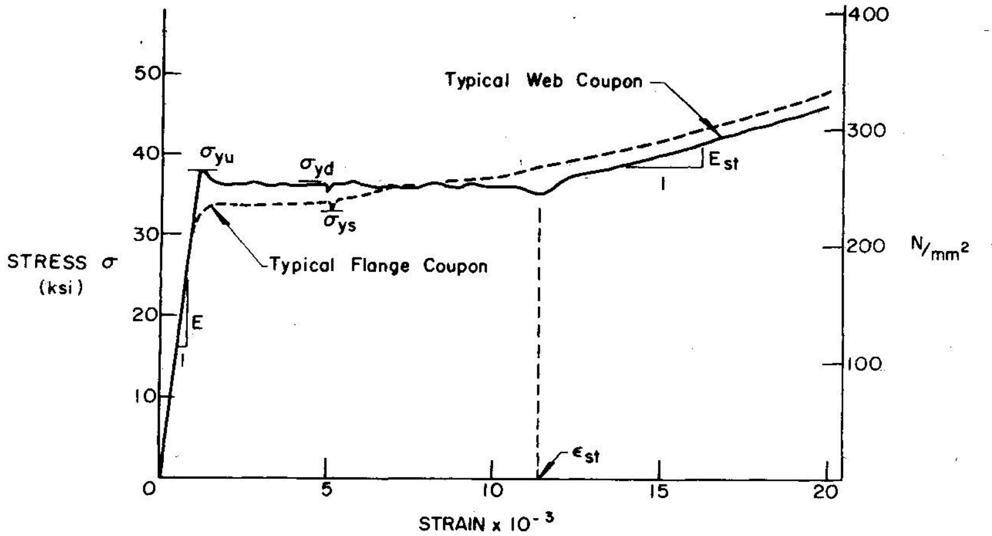


Fig. 4 Stress-Strain Curves

Stub Column Test

Prior to the testing of any column, a stub column test was prepared on a section from the same piece from which the actual column was prepared. The purpose of stub column test is to determine the average stress-strain relationship for the entire cross section which takes into account the effects of residual stress and yield strength variation over the cross section. The proportional limit, the yield strength, the elastic modulus, and the tangent modulus are the most important data furnished by the curve.

The length of the stub column was selected such that it is sufficiently long to retain the original residual stress in the column but short enough to prevent any premature failure occurring before the yield of the section is obtained. The stub column length used in this test program was 40 inches (1.02 m). The procedure used in testing the stub column is described in detail in Ref. 11

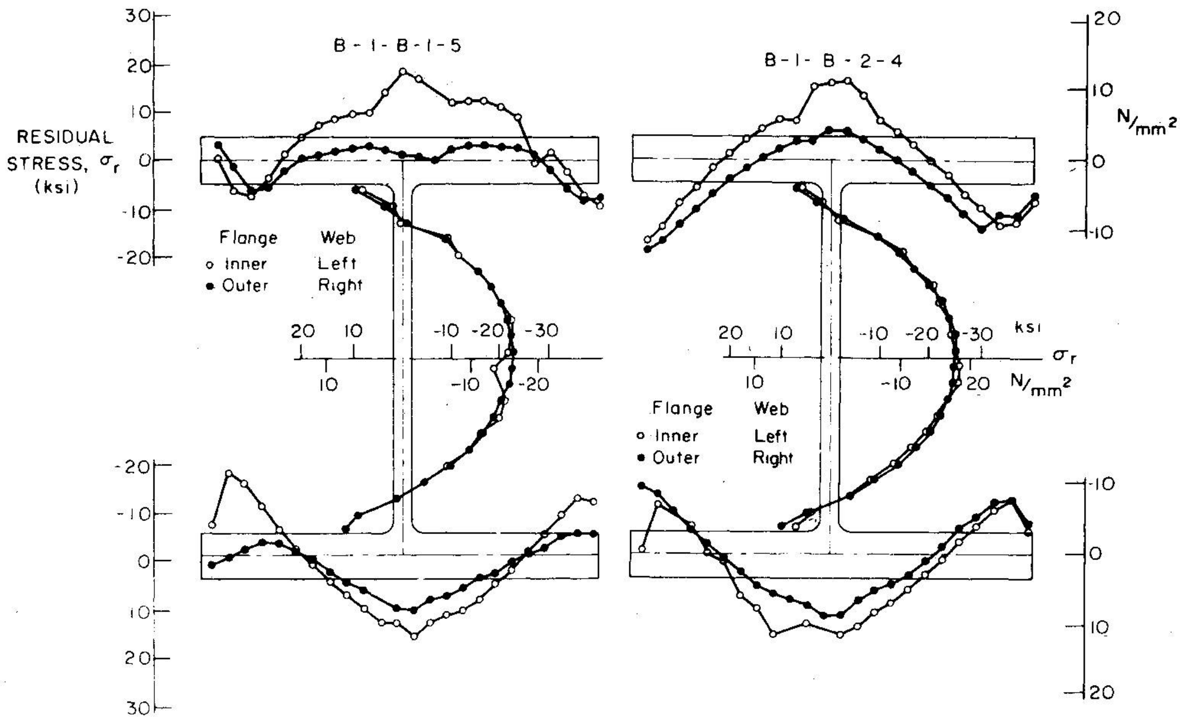


Fig. 5a Residual Stresses in HEM (Belgium)

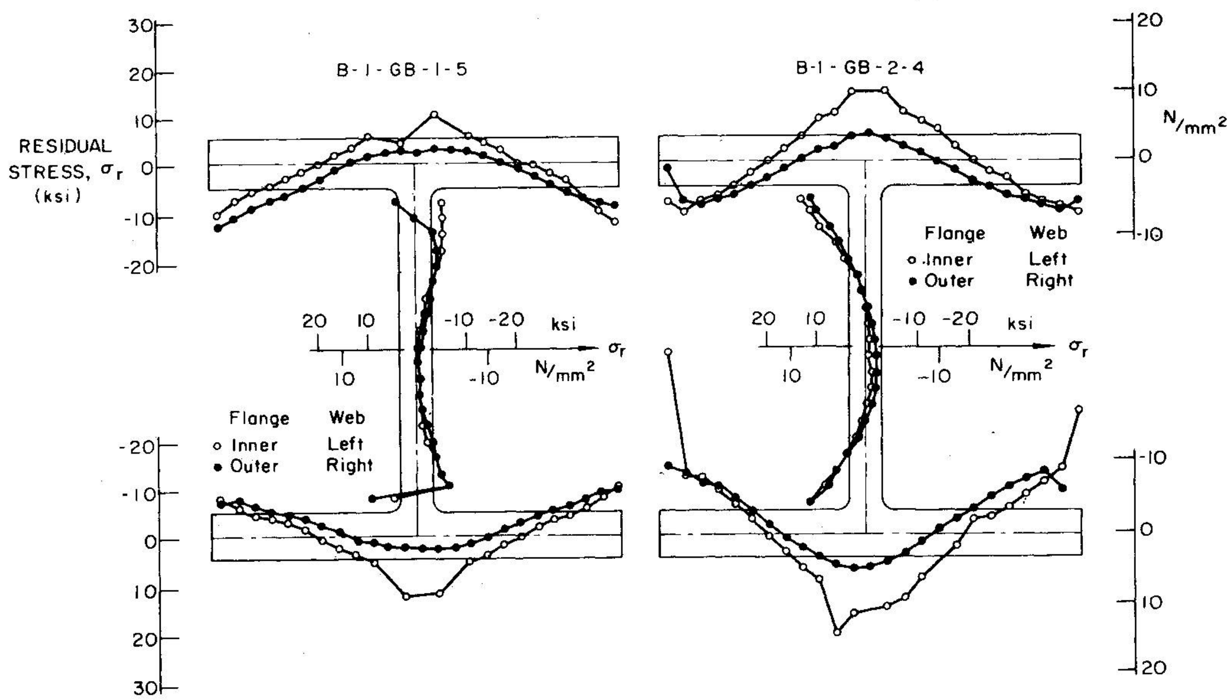


Fig. 5b Residual Stresses in W12x161 (Britain)

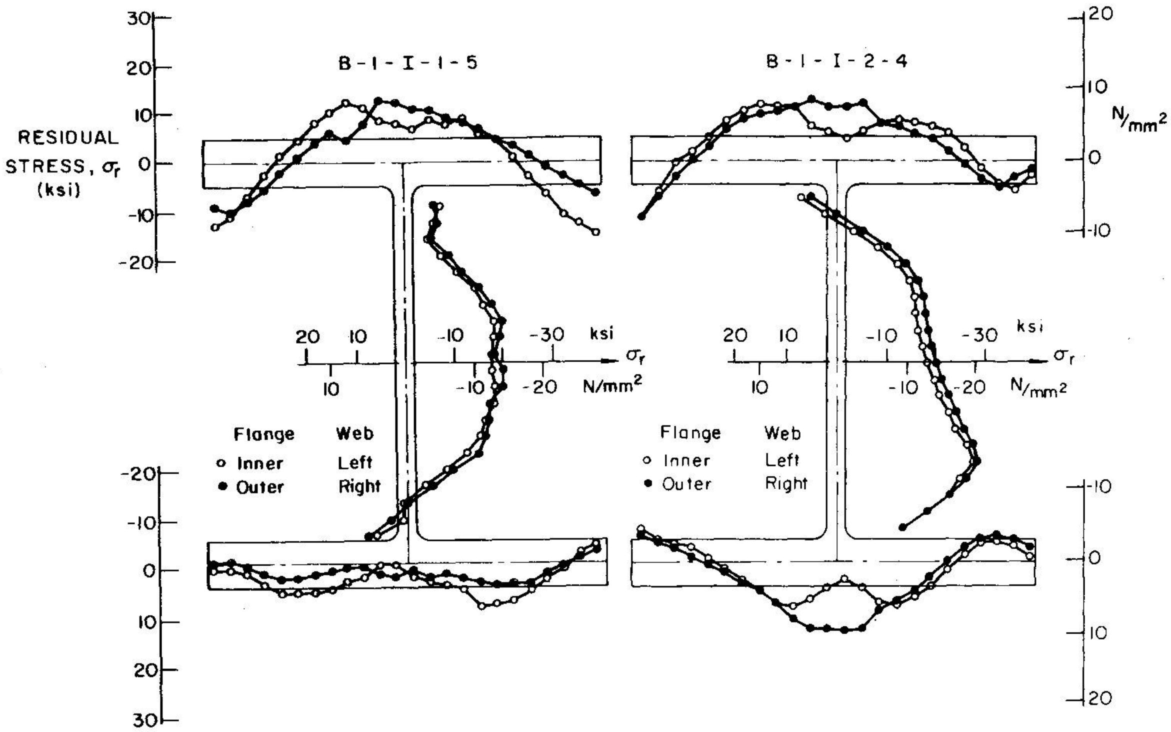


Fig. 5c Residual Stresses in HEM 340 (Italy)

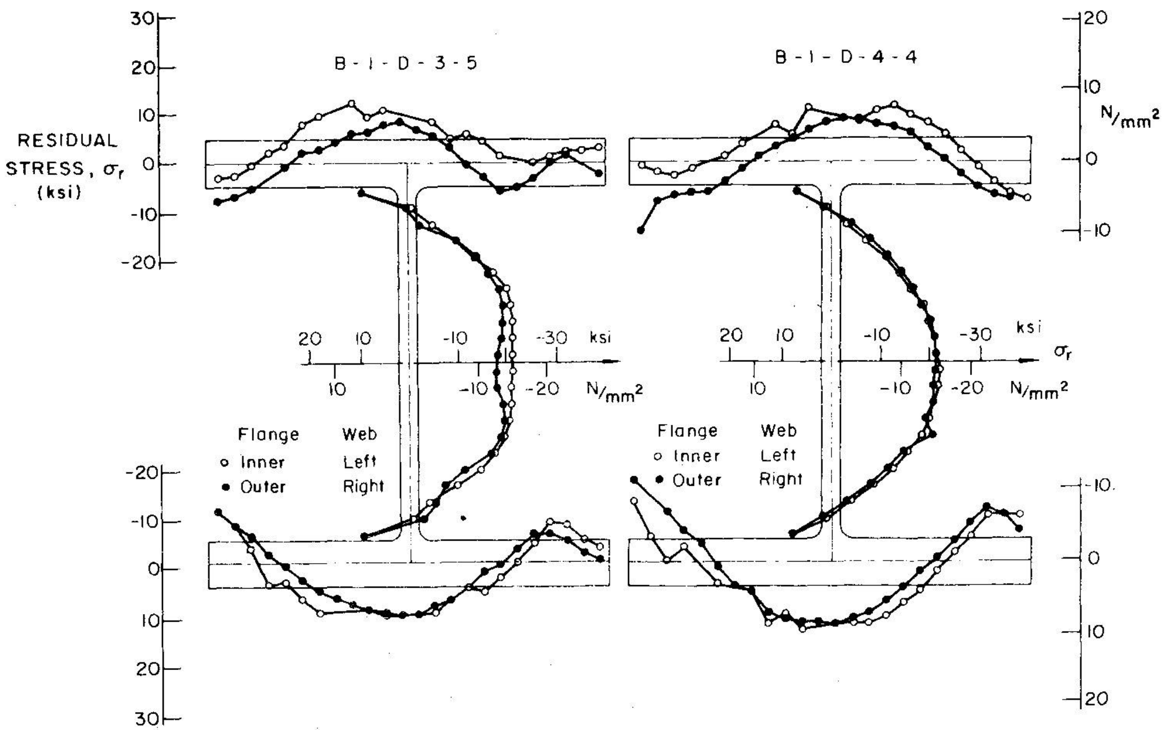


Fig. 5d Residual Stresses in HEM 340 (Germany)

TABLE 3: FULL-SIZE TENSION TEST RESULTS (ECCS)

Specimen	Location	Upper Yield Stress σ_{yu} ksi (N/mm²)	Dynamic Yield Stress σ_{ud} ksi (N/mm²)	Static Yield Stress σ_{ys} ksi (N/mm²)	Ultimate Stress σ_u ksi (N/mm²)	Fracture Stress σ_t ksi (N/mm²)	Percent Elongation %	Reduction of Area %
B-1-B-1-5	1	33.2 (229)	32.5 (224)	30.1 (208)	56.9 (392)	49.8 (336)	41.6	42.0
	2	34.7 (239)	34.2 (236)	32.5 (224)	57.4 (396)	50.1 (345)	28.8	40.1
	3	34.8 (240)	33.5 (231)	31.7 (219)	57.3 (395)	49.1 (339)	31.9	45.0
	4	32.8 (226)	31.8 (219)	29.6 (204)	56.2 (387)	50.5 (348)	41.3	41.5
B-1-B-2-4	1	32.6 (225)	32.1 (221)	30.2 (208)	57.2 (394)	50.6 (349)	44.4	43.7
	2	35.1 (242)	34.4 (237)	32.7 (225)	57.8 (399)	49.4 (341)	29.4	38.5
	3	35.2 (243)	34.2 (236)	32.4 (223)	57.3 (395)	49.1 (339)	28.8	41.4
	4	32.6 (225)	32.3 (223)	29.4 (203)	56.2 (387)	50.4 (348)	43.1	43.5
B-1-GB-1-5	1	-- --	31.0 (214)	29.3 (202)	61.0 (421)	51.0 (352)	42.5	43.1
	2	35.2 (243)	34.5 (238)	32.2 (222)	62.8 (433)	51.7 (356)	28.1	41.9
	3	33.9 (234)	33.3 (230)	32.0 (229)	61.4 (423)	48.5 (334)	28.1	48.7
	4	-- --	31.4 (217)	29.5 (203)	60.9 (420)	40.9 (282)	40.6	41.4
B-1-GB-2-4	1	34.5 (238)	34.3 (236)	32.5 (224)	66.1 (456)	55.8 (385)	41.8	58.8
	2	37.0 (255)	35.7 (246)	33.8 (233)	64.5 (445)	53.5 (369)	24.7	59.4
	3	36.7 (253)	36.0 (248)	34.5 (238)	64.2 (443)	35.7 (246)	28.1	46.6
	4	35.0 (241)	34.9 (241)	32.9 (227)	66.7 (460)	56.0 (386)	40.6	59.6
B-1-I-1-5	1	-- --	30.7 (212)	28.2 (194)	58.9 (406)	50.5 (348)	37.5	52.3
	2	-- --	32.2 (222)	30.5 (210)	58.7 (405)	46.5 (321)	27.5	42.4
	3	32.1 (221)	31.5 (217)	30.2 (208)	59.3 (409)	49.9 (344)	28.75	40.8
	4	-- --	31.1 (214)	28.9 (199)	60.0 (414)	51.4 (354)	40.0	47.0
B-1-I-2-4	1	-- --	30.0 (207)	28.2 (194)	59.0 (407)	50.6 (349)	41.6	44.2
	2	-- --	31.9 (220)	30.2 (208)	60.3 (416)	48.3 (333)	28.8	42.3
	3	32.3 (223)	32.0 (221)	30.4 (210)	59.9 (413)	47.9 (330)	29.4	44.2
	4	-- --	31.2 (215)	29.8 (205)	61.4 (423)	52.4 (361)	42.2	42.9

TABLE 4: STUB COLUMN TEST RESULTS

Specimen	P_{yd} kips (MN)	P_{ys} kips (MN)	σ_{yd} ksi (N/mm²)	σ_{ys} ksi (N/mm²)
B-1-B-1-5	1550 (6895)	1450 (6450)	32.78 (226)	30.37 (209)
B-1-B-2-4	1524 (6779)	1436 (6388)	32.41 (223)	30.84 (213)
B-1-GB-1-5	1450 (6450)	1374 (6112)	31.17 (215)	29.54 (204)
B-1-GB-2-4	1552 (6904)	1470 (6539)	33.87 (234)	32.08 (221)
B-1-D-3-5	1746 (7767)	1676 (7455)	35.44 (244)	34.02 (235)
B-1-D-4-4	1744 (7758)	1670 (7428)	32.25 (222)	33.75 (233)
B-1-I-1-5	1438 (6397)	1356 (6032)	29.61 (204)	27.79 (192)
	1498 (6663)	1390 (6183)	31.56 (218)	29.29 (202)

The stub column specimens were tested in the 5-million pound capacity capacity universal hydraulic testing machine in Fritz Engineering Laboratory. Figure 6 shows the column set-up and instrumentations. Each specimen was aligned such that the deviation in strain field did not exceed 5 percent of the average value, the specimen was loaded continuously with only one stop made at the yield plateau to determine the static yield strength level. The static yield strength was found using a yield stress level criterion defined by the stress at 0.005 in/in strain [11]. A strain rate corresponding to a stress rate of $1/kp/mm^2/min$ was used throughout the test after it was established in the elastic range. The results from these tests are given in Fig. 7. The elastic modulus, the proportional limit, the tangent modulus, and the average yield strength are the important data furnished by these curves. A summary of the stub column test results is given in Table 4.

4. COLUMN TESTS

A total of sixteen full-size column tests were conducted: four from each of the four source countries at the slenderness ratios of 50 and 95. These slenderness ratios were chosen on the basis that thet cover the critical range according to theoretical and practical considerations. All column tests were conducted in the same 5 million pound capacity universal hydraulic testing machine. Pinned-end support conditions were used in the minor axis direction and fixed in the direction of the major axis.

The end fixtures used in this test program were developed at Fritz Engineering Laboratory [12] and have been used extensively and with success in previous tests. A detailed description of the instrumentation and the procedure followed in testing the columns may be found in Ref. 13.

Initial Measurements

Initial measurements of the geometric characteristics of the columns were taken since variations in cross-sectional area and shape and the initial out-of-straightness will affect the column strength. Cross-sectional measurements were taken at five locations: at the ends and at the two quarter points of the column length. The initial out-of-straightness of each specimen was measured at nine levels, each spaced at one-eighth of the column length. Measurements were taken in the direction of the two principal axes. A summary of the measured geometric characteristics of the column specimens is given in Table 5.

Testing Procedure

The testing of heavy columns requires a well-developed testing procedure, more complete in instrumentation and supplementary tests, than is the case for light columns.

The alignment of the columns, which is regarded as the most important step in column testing, was performed in accordance with the ECCS recommendations: geometrical alignment with reference to the center of the web. The end plates were first matched to the web centers at each support and were finally centered with respect to the centerline of the testing machine.

The instrumentation for each column test consisted of potentiometers attached at quarter points to measure lateral displacements in the two principal axes and the angles of twist, electric resistant strain gages at the ends and at midheight, electrical rotation gages at the supports, and dial gage to measure the overall shortening. A typical column test set-up is shown in Fig. 8.

In each test the column was loaded continuously at a constant axial strain rate corresponding to a stress rate of 1 kp/mm^2/min (1.42 ksi/min) established during the elastic stage. All measurements were instantly recorded at fixed time intervals until the maximum load was almost reached immediately after which the loading was stopped to determine the maximum "static" load. This load is determined by maintaining the cross-head movement until the applied load was stabilized. The maximum "dynamic" load, the load recognized as the "maximum" load by ECCS, was obtained as the reading indicated by the stopping of the follower of the dial in the testing machine. After the static load was recorded the loading was resumed, using the originally established rate of cross head movement, until the end of test.

The measured load versus midheight deflection curves for all column tests are shown in Fig. 9. The values shown at the zero-load level correspond to the midheight initial out-of-straightness of the columns. Table 6 summarizes the results of the column tests.

Evaluation of Column Test Results

The ECCS has proposed three column strength curves for various types of shapes [8]. The appropriate curve to a particular shape is selected on the basis of: i) steel grade, ii) thickness of component plate, and iii) the depth-width ratio of the cross section.

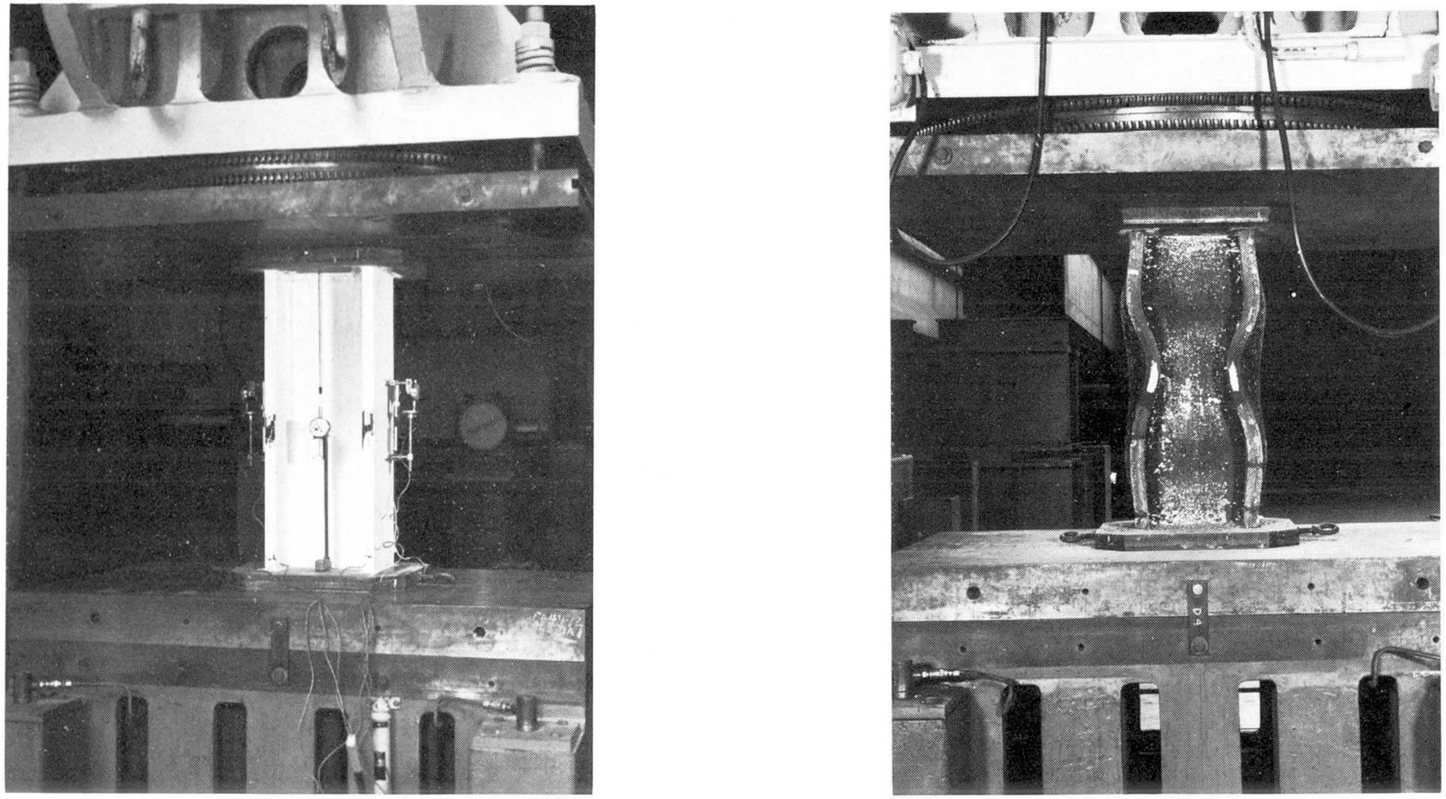
From conditions i) and ii) all specimens used in the test program belong in one group--all specimens have steel grades that relate closely to E 24 (St 37) and the thicknesses are greater than 30 mm (1-1/8 in.). Item iii), however, divides the specimens into two groups and requires use of different curves. According to the selection table given in Ref. 8, Curve B3-24 (the middle curve of the three) corresponds to the specimens from the continental countries (HEM 340) since h/b (= 1.23) > 1.20; for the British shapes (W12x161) Curve C3-24 (the lowest curve of the three) must be used since h/b (= 1.11) < 1.20. However, the assignment of different curves for these specimens does not seem justified since the shapes are essentially identical in cross-sectional properties, yield strength and residual stresses. Moreover, as shown in Fig. 10 and Table 6, comparison of the results of the British column tests discloses the same evidence. It is, therefore, recommended that a critical review be made of the depth-width ratio as a criterion for selecting the proper column strength curves.

In Fig. 10 the European Convention Curves are compared with the experimental points located at two Standard Deviations below the mean values. A good correlation for the columns with L/r = 95, but an unconservative prediction for L/r = 50, are observed.

5. SUMMARY AND CONCLUSIONS

This report presents the results of an experimental investigation into the behavior and strength of heavy European columns. The study is essentially an extension to heavy columns of the ECCS program, which has completed extensive tests of columns of small dimensions and light weights. The program was restricted to test specimens from four countries: Belgium, Britain, Germany and Italy. The experiments consisted of: i) tension tests (standard and full-size tests), ii) residual stress measurements, iii) stub column tests, and iv) full-size column tests (slenderness ratio of 50 and 95). The shapes used were HEM 340 from the continental countries and W12x161 from Britain.

Based on this investigation, the following conclusions may be made:



a) Instrumentation

b) End of Test

Fig. 6 Stub Column Test Set-Up

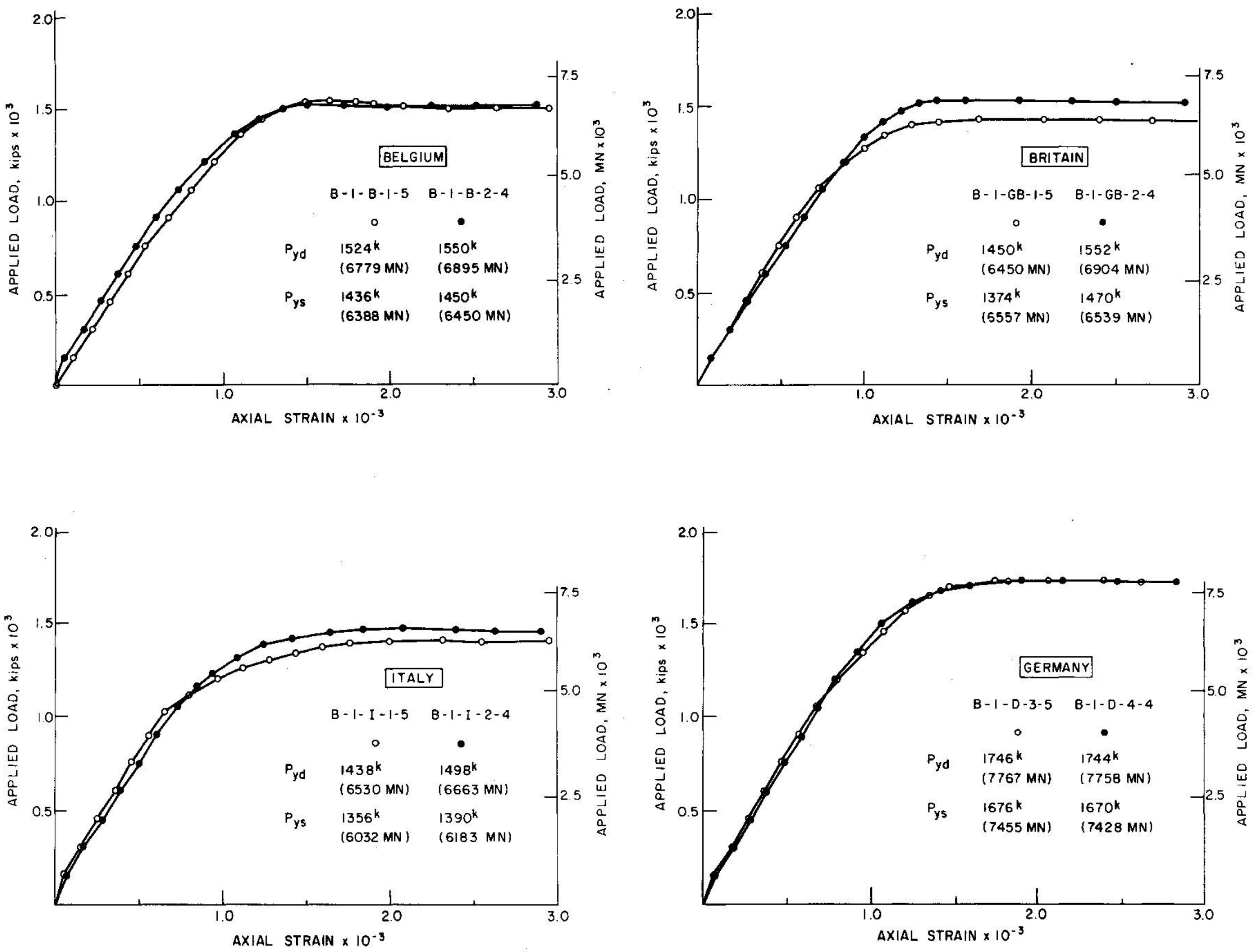
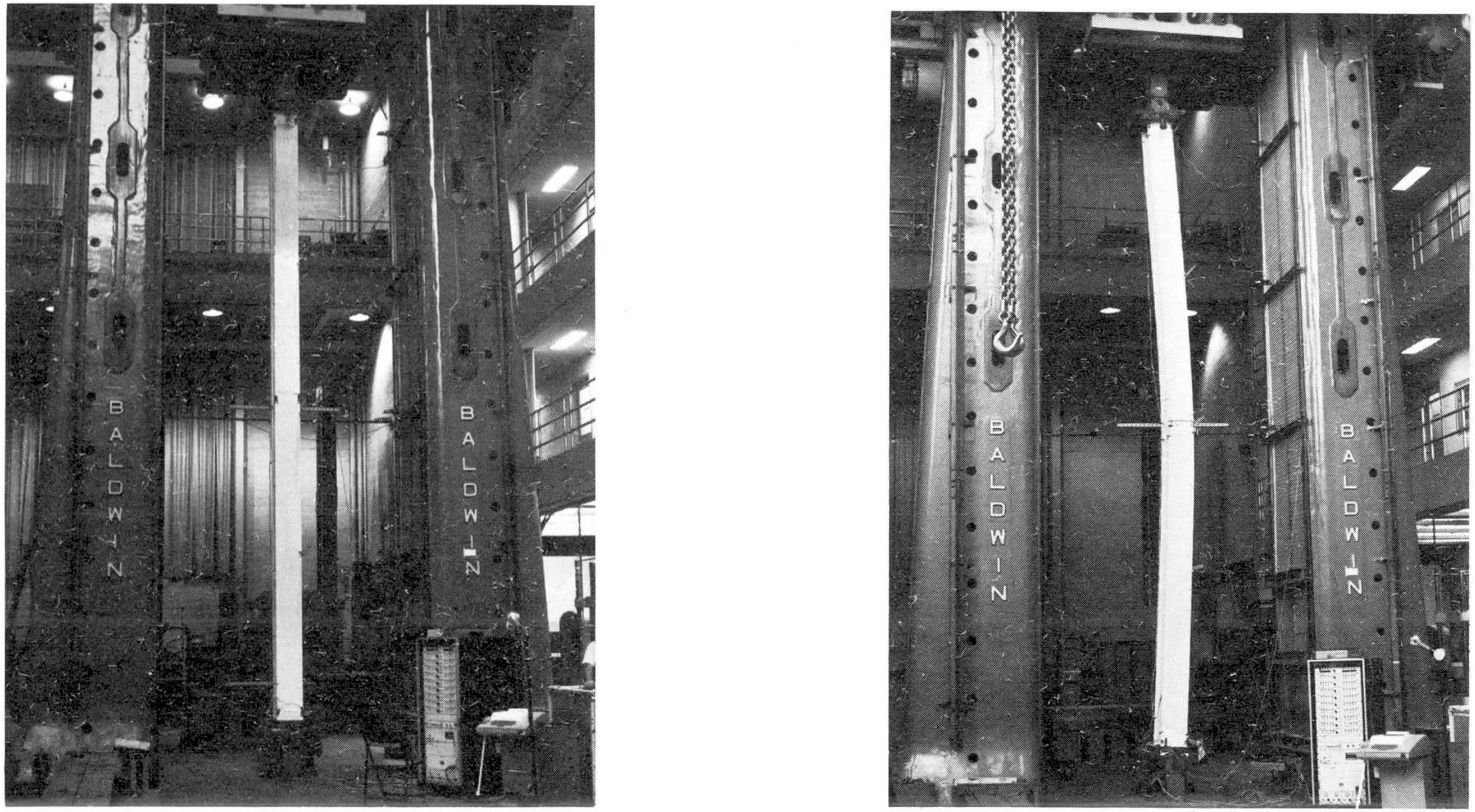


Fig. 7 Stub Column Test Results



a) Beginning of Test

b) End of Test

Fig. 8 Set-Up for Column Testing

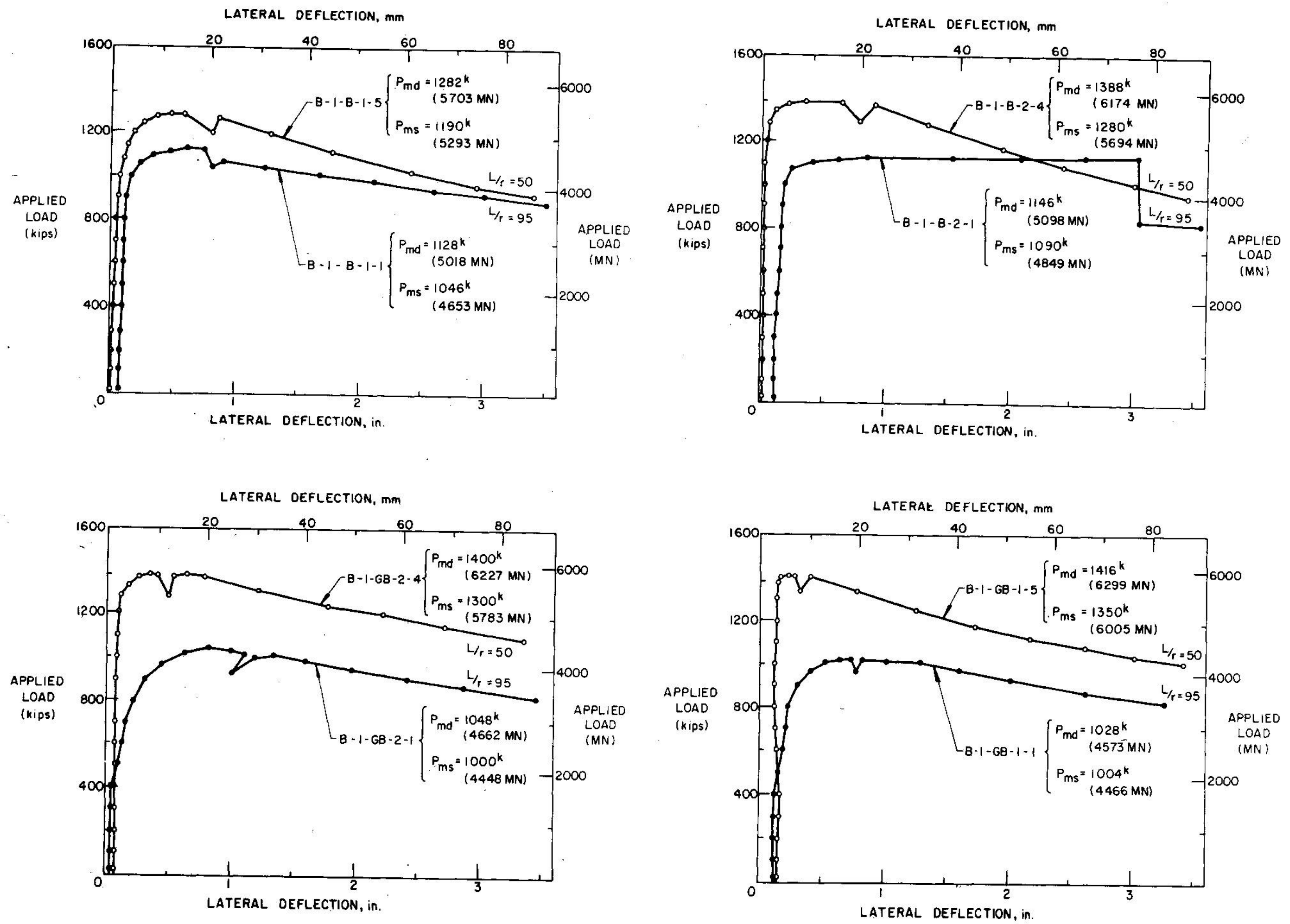


Fig. 9a Pinned-End Column Test Results

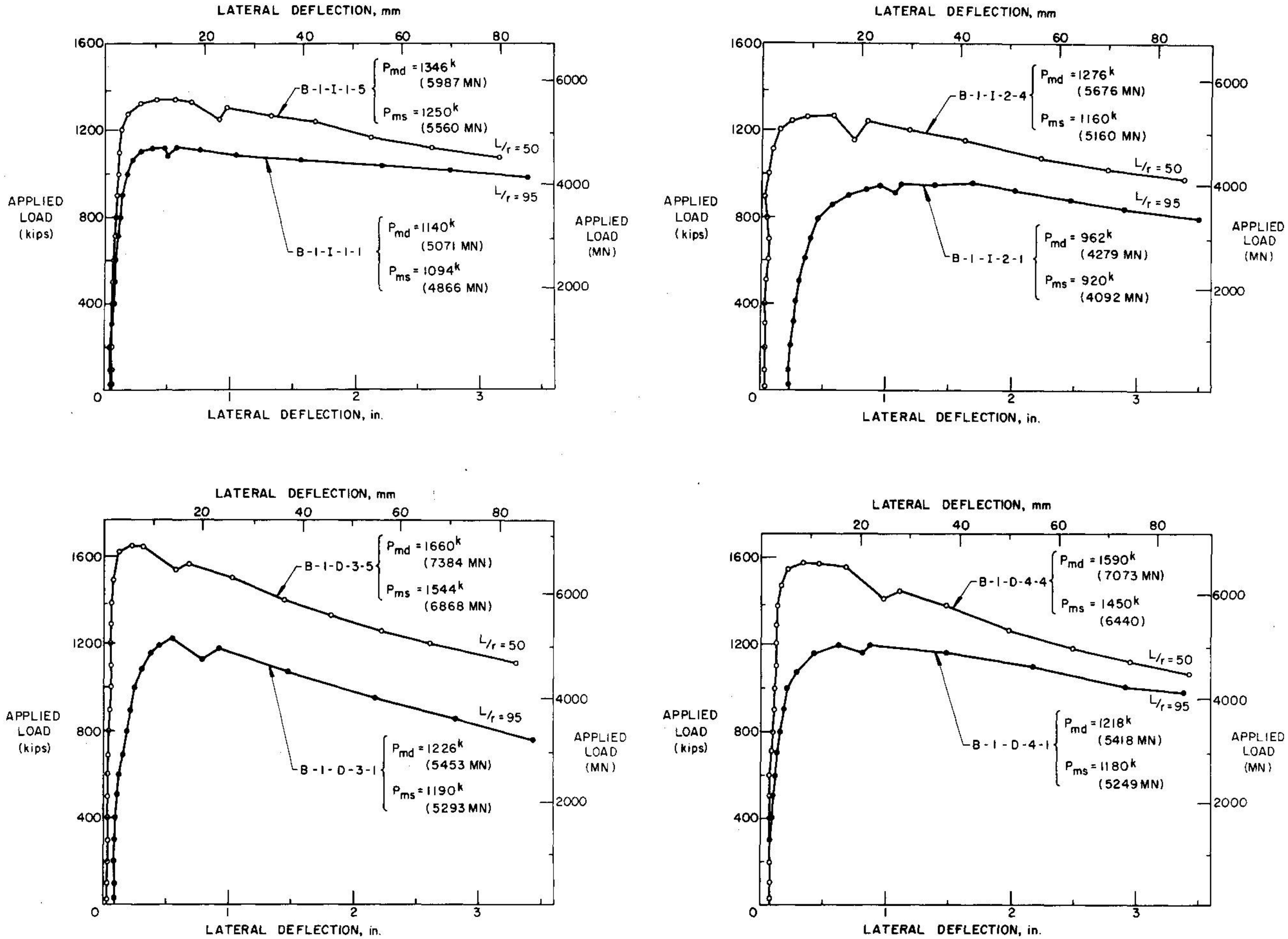


Fig. 9b Pinned-End Column Test Results

TABLE 5: MEASUREMENTS OF GEOMETRIC CHARACTERISTICS OF THE TEST SPECIMENS

Specimen	CROSS SECTION MEASUREMENTS B in. (mm)	D in. (mm)	T in. (mm)	W in. (mm)	Area in. (mm)	Initial Out-of-Straightness Minor e_x in. (mm)	Major e_y in. (mm)	Length in. (M)
B-1-B-1-5	12.17 (309)	14.90 (378)	1.54 (39)	0.82 (21)	47.28 (30503)	0.01 (0.3)	0.01 (0.3)	155.5 (3.94)
B-1-B-2-4	12.15 (309)	14.89 (378)	1.53 (39)	0.82 (21)	47.02 (30335)	0.02 (0.5)	0.01 (0.3)	155.5 (3.94)
B-1-B-1-1	12.19 (310)	14.93 (379)	1.55 (39)	0.82 (21)	47.45 (30612)	0.08 (2.0)	0.07 (1.8)	295.25 (7.50)
B-1-B-2-1	12.14 (308)	14.91 (379)	1.54 (39)	0.80 (20)	46.94 (30284)	0.11 (2.8)	0.09 (2.3)	295.25 (7.50)
B-1-GB-1-5	12.51 (318)	13.87 (352)	1.48 (38)	0.89 (23)	46.53 (30019)	0.15 (3.8)	0.02 (0.5)	160.0 (4.06)
B-1-GB-2-4	12.43 (316)	12.82 (351)	1.47 (38)	0.87 (22)	45.82 (29561)	0.08 (2.0)	0.01 (0.3)	160.0 (4.06)
B-1-GB-1-1	12.42 (315)	12.87 (352)	1.48 (38)	0.92 (23)	46.90 (30270)	0.13 (3.3)	0.04 (1.0)	304.0 (7.72)
B-1-GB-2-1	12.43 (316)	12.86 (352)	1.46 (37)	0.86 (22)	45.84 (29580)	0.04 (1.0)	0.08 (2.0)	304.0 (7.72)
B-1-D-3-5	12.26 (311)	14.89 (378)	1.59 (40)	0.89 (23)	49.27 (31787)	0.02 (0.5)	0.02 (0.5)	155.5 (3.94)
B-1-D-4-4	12.21 (310)	14.87 (378)	1.59 (40)	0.92 (23)	49.48 (31923)	0.06 (1.5)	0.92 (23.4)	155.5 (3.94)
B-1-D-3-1	12.25 (311)	14.87 (378)	1.58 (40)	0.88 (22)	49.07 (31658)	0.08 (2.0)	0.04 (1.0)	295.25 (7.50)
B-1-D-4-1	12.20 (310)	14.89 (378)	1.59 (40)	0.89 (23)	50.51 (32587)	0.06 (1.5)	0.06 (1.5)	295.25 (7.50)
B-1-I-1-5	12.11 (308)	14.93 (379)	1.60 (41)	0.84 (21)	48.57 (31335)	0.06 (1.5)	0.04 (1.0)	155.5 (3.94)
B-1-I-2-4	12.06 (306)	14.88 (378)	1.58 (30)	0.81 (21)	47.46 (30619)	0.03 (0.8)	0.02 (0.5)	155.5 (3.94)
B-1-I-1-1	12.09 (307)	14.93 (379)	1.60 (41)	0.85 (22)	48.57 (31335)	0.05 (1.3)	0.10 (2.5)	295.25 (7.50)
B-1-I-2-1	12.06 (306)	14.87 (378)	1.57 (40)	0.85 (22)	48.18 (31084)	0.22 (5.6)	0.01 (0.3)	295.25 (7.50)

TABLE 6: RESULTS OF COLUMN TESTS

Specimen	Slenderness Ratio L/r	Initial Out-of-Straightness $(\delta_o/L)x10^3$	Maximum Dynamic Load P_{md}	Maximum Static Load P_{sd}	P_{md}/P_{sd}
B-1-B-1-5	50	0.06	1282 (5703)	1190 (5293)	0.83
B-1-B-2-4	50	0.13	1388 (6174)	1280 (5694)	0.91
B-1-B-1-1	95	0.26	1128 (5018)	1046 (4653)	0.73
B-1-B-2-1	95	0.36	1146 (5098)	1090 (4849)	0.75
B-1-GB-1-5	50	0.97	1416 (6299)	1350 (6005)	0.97
B-1-GB-2-4	50	0.52	1400 (6227)	1330 (5783)	0.90
B-1-GB-1-1	95	0.43	1028 (4573)	1004 (4466)	0.71
B-1-GB-2-1	95	0.13	1048 (4662)	1000 (4448)	0.68
B-1-D-3-5	50	0.13	1660 (7384)	1544 (6868)	0.95
B-1-D-4-4	50	0.39	1590 (7073)	1450 (6440)	0.90
B-1-D-3-1	95	0.26	1226 (5453)	1190 (5292)	0.70
B-1-D-4-1	95	0.20	1218 (5418)	1180 (5249)	0.70
B-1-I-1-5	50	0.39	1346 (5987)	1250 (5560)	0.94
B-1-I-2-4	50	0.19	1276 (5676)	1160 (5160)	0.85
B-1-I-1-1	95	0.16	1140 (5071)	1094 (4806)	0.79
B-1-I-2-1	95	0.73	962 (4279)	920 (4092)	0.65

1. The testing of heavy columns requires a well-developed testing procedure, more complete in instrumentation and supplementary tests, than that for light-sized columns.

2. Full-size tension tests of heavy shapes, as recommended by ECCS, do not seem to provide additional information to that given by small specimens when taken at several locations over the cross section.

3. The measured residual stresses in the flanges of all of the eight specimens were seen to be closely consistent in pattern and in magnitude. The variations of residual stresses through the thicknesses were not significant.

4. The depth-width ratio criterion, which is one of the determining factors in selecting the column curves, is seen to be marginal for the specimens used in this investigation and consequently assigns different column curves to what are essentially identical shapes. It is recommended that this criterion be reviewed, as it could also be marginal for other heavy shapes.

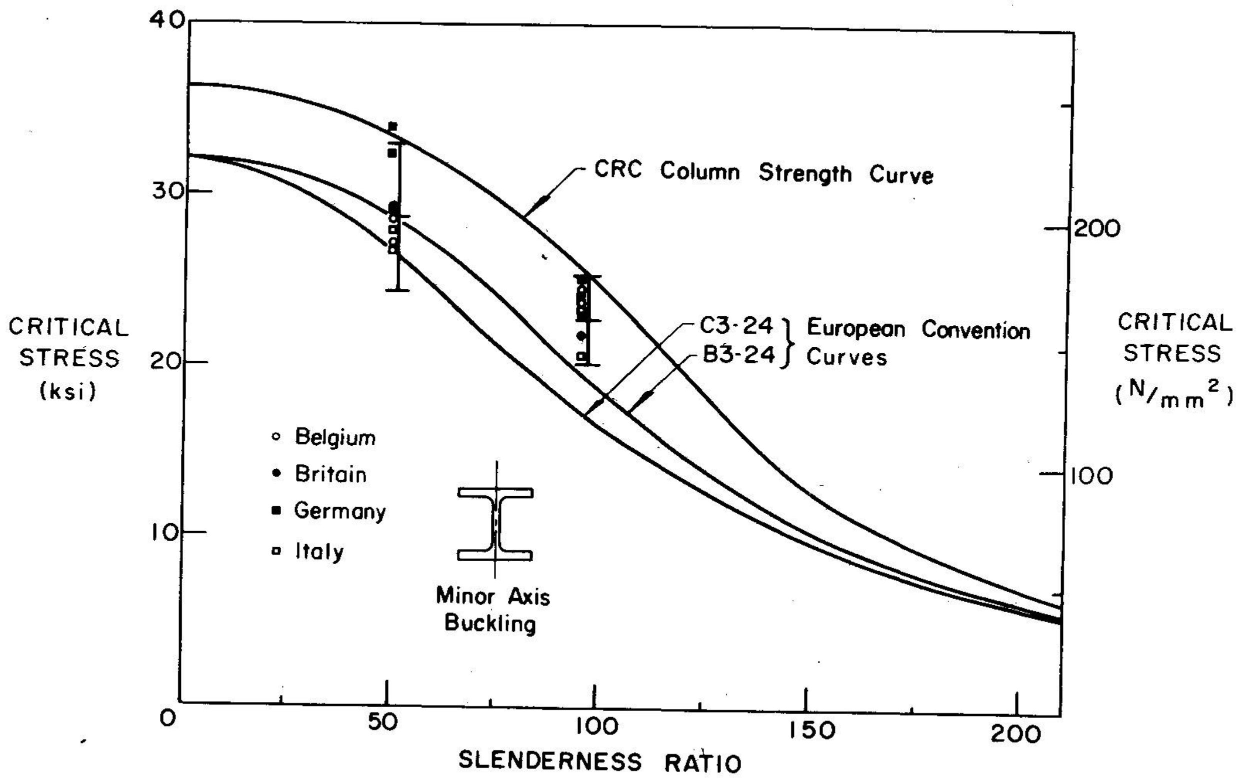


Fig. 10 Comparison of Column Test Results and the Proposed European Convention Column Curves

5. The European Convention Column Curve (B2-24) is compared with the test results. A good correlation for the columns of L/r = 95, and an unconservative prediction for L/r = 50, are observed.

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