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EXPERIMENTAL PROCEDURES FOR STUB COLUMN TESTS

Y. Pu, M.H.R. Godley and R.G. Beale[1]

SUMMARY

In this paper a total of 36 stub columns was tested by two different experimental procedures, namely the FEM and AISI procedures, to investigate the difference in the ultimate load between these procedures. Of these 26 were carried out in the pin-ended condition according to FEM, the rest were in the fixed-end condition according to AISI specification. It is shown that the failure loads obtained by the two experimental procedures were very close to each other. Both procedures worked well. The AISI procedure is recommended as the standard procedure.

INTRODUCTION

A stub column test is usually used to determine the effective section area and to investigate the effects of perforations on the local ultimate capacity of a column. The experimental procedures recommended in the European code (FEM) (Federation Europeenne de La Manutention, 1994) and the American code (AISI) (AISI Specification, 1991) are widely used. These two procedures have different end conditions and methods of application of axial load.

In the FEM the end condition is pin-ended, and the position at which the axial load is applied is determined by a trial and error process in order to find out the maximum axial capacity of the stub column. Mulligan and Pekoz (1984) have shown that the effect of eccentricity of the applied load on the ultimate axial load is very strong. This is supported by the results in Miller and Pekoz (1994). Flexural and torsional-flexural failures are excluded in stub column tests by selecting the length of the specimens. This means that the maximum axial load should be achieved when the axial load passes through the effective centroid of gravity of the section. Any axial load applied at other positions can be idealised as an axial load with the same magnitude at the effective centroid of the cross-section and an extra bending moment. It should be kept in mind that the effective centroid of a section depends on not only the shape and dimensions of the section but also the magnitude of the applied load because of local buckling effects. An accurate estimate of the effective centroid at the failure load can only be obtained by experiment, although some approximate methods are available.

The use of FEM code to investigate the effects of perforations on the ultimate capacity of a stub column requires a large number of tests because for every arrangement of column at least five samples are required to determine the optimum position of the axial load.

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In the AISI Specification the ends are fixed, so the column ends can not rotate. Only three specimens are usually needed. This procedure has the advantage that there is no need to optimise the axial load position. This reduces the number of tests and cost required compared with the FEM procedure.

This paper aims at investigating the difference in the ultimate load of stub columns obtained by these two experimental procedures. A total of 36 specimens, in which there were three different thickness covering the practical range of the ratio of the web width to thickness in pallet racking systems, was tested. Among them 26 were carried out in the pin-ended condition according to FEM. The rest were in the fixed-end condition according to the AISI specification.

SPECIMENS

There were three different thickness series, namely 3.0 mm, 1.2 mm and 0.8 mm series, of stub columns. Their cross-section dimensions are listed in Table 1 and shown in Fig. 1. W_1, W_2 and W_3 are the widths of the web, the flanges and the lips respectively, R is the inner radius of the corners and t is the thickness of the columns. According to the requirements in the codes (FEM, 1994 and AISI,1991, etc), the length of the specimens should be greater than three times the largest width of the section and less than twenty times of the least radius gyration of the section. The first requirement is to minimise the end effects during loading; the second requirement is to eliminate overall column buckling effects. The ratio of the web width to thickness of the specimens in three series varied from 29.9 to 115.0, which covers the practical range in pallet racking systems.

The material of 3.0 mm series was a hot rolled steel, cold reduced to enhance the yield stress. The material of 1.2 mm and 0.8 mm series was a cold rolled steel with a finish for general purpose. The yield stresses were 417, 192.9 and 171.3 N/mm^2 for 3.0 mm, 1.2 mm and 0.8 mm respectively.

The specimens of 3.0 mm series were cold roll formed and sheared to the required length. Because of the release of internal stresses caused by the cold-forming process the cross section at both ends of the specimens were slightly distorted. The distortion was corrected in the experiment by using a column endplate at each end of a specimen. The columns of 1.2 mm and 0.8 mm series were made by press braking where the steel sheets were cut into the required size, then bent into the required shape by a mechanically operated bending machine.

The ends of the specimens for 3.0 mm series were filed to refine the flatness which was checked by putting it on a gauge plate. For 1.2 mm and 0.8 mm series the flatness of the column ends was very good.

TEST PROCEDURES

The procedures recommended in both FEM (1994) and AISI specification (1991) were used to carry out the tests in order to investigate the difference between them. The tests were carried out on a testing machine with a maximum capacity of 2000 kN for the 3.0 mm series. Both upper and lower heads of the testing machine could be adjusted for rotation about two horizontal axes and could be fixed by four screws. The upper head assembly could be raised or lowered to accommodate the different sizes of specimen. The load was applied by raising the lower loading head through a hydraulic piston at a speed of 0.15 mm per minute.

For 1.2 mm and 0.8 mm series, an Avery universal testing machine with a capacity of 500 kN was used. In the compression test the upper loading head, which could not rotate, was fixed by four screws and a locking ring on each column. The lower loading head also could not rotate. To provide adjustment about the horizontal axes, a hemispherical bearing was placed at the lower loading head. This could be adjusted for rotation about two horizontal axes and could be locked in position with four screws. The load speed was controlled manually with the help of a load pacer.

The FEM procedure

According to the recommendation of the FEM code the arrangement of the test is shown in Fig. 2. The load heads of the testing machine were fixed, two ball bearings were set at the centre of each load head. Compression was applied through the balls. As mentioned in foregoing sections, the cross-sections of columns were slightly distorted due to release of internal stresses caused by cold-forming process. This distortion was corrected by close fitting a column-end plate at each end of a column. The columns were attached to these column end plates by four small screws, to pull the distorted cross sections into shape. The column-end plates were connected to stiff steel bases by three screws through three rectangular holes in the column-endplates so that the relative position of axial load to the cross-section of the column could be adjusted by changing the positions of column-endplates on the steel bases. The bases were equipped with a countersink to allow the application of load through a ball bearing.

The test samples were divided into two groups. The first group of tests was used to determine the optimum load line, which gave the highest failure load. This was achieved by incorporating in the steel base a facility to adjust the position of the column endplates in relation to the line of action of the load which is described above. Normally five specimens are needed in this group. In the second group of tests, the load line was fixed at the optimum load line determined by the first group. Three further specimens were required. The average failure load of these three specimens was used to give the ultimate failure load.

Theoretically speaking, the highest failure load would be achieved by loading along the effective centroid of the columns. So the distance between the middle surface of the web plate and effective centroid, X_{cgeff}, was estimated according to AISI specification (AISI, 1991), to determine the range of load lines in the first group of tests. The values of X_{cgeff} are listed in Table 2. Based on this, several positions of axial load line have been chosen to determine the optimum line of action for axial load. The results are presented in Table 2.

In the second group of tests, to determine the failure load, the load line was fixed at the optimum load line determined in the first group. There were 4, 3, 3 specimens for 3.0 mm, 1.2 mm and 0.8 mm series respectively.

After the compression tests were completed, samples of the material were cut from undamaged parts of the specimens and subjected to a tensile test to determine the proof stress of the material.

The AISI procedure

The arrangement of the test in accordance to the AISI Specification is shown in Fig. 3. The only difference between this and previous arrangement was that the balls between the steel bases and load heads at both ends of the columns were removed. Therefore the column endplates could not rotate.

The specimens and instruments were installed as follows. For 3.0 mm series the endplates were firstly connected to each end of the column by screws. The assembly of the column was put on the fixed lower load head. The upper load head, which was free to rotation at this moment, was then lowered down. To eliminate possible gaps among the parts of the column assembly a pre-load of 70 kN was applied briefly and then removed. The upper load head was then fixed to prevent any rotation.

For 1.2 mm and 0.8 mm series the column and column endplates were assembled in the same way as for 3.0 mm series. A hemispherical bearing was firstly mounted on the fixed lower load head. The column assembly was then placed on the hemispherical bearing, which was free to rotate. A pre-load of 10 kN and 7 kN for 1.2m and 0.8mm series respectively was applied and then released so that the possible misalignment and gaps among all parts could be reduced to minimum. The hemispherical bearing was then fixed by four screws to prevent any rotation.

It should be noted that the procedure used in the present study was slightly different from AISI procedure. In the original AISI procedure, grout is needed between the column endplates and load heads in order to facilitate full contact between the specimen and the loading heads. It is believed that grout is not necessary provided the load heads of the testing machine can rotate into alignment about the two horizontal axes. The possible misalignment can be compensated by adjusting the load heads instead of using grout, if the specimens have good flatness at the ends. Therefore grout was not used in the present experiment. It will be seen in the following section that the results so obtained were fairly consistent.

TEST RESULTS AND DISCUSSIONS

The results of 26 specimens, which were tested by the FEM procedure, are presented in Table 2, while the results of the others, which were tested by the AISI procedure, are in Table 3.

For the 3.0mm series, 10 specimens were tested by the FEM procedure, in which the first seven specimens were in the first group to find the optimum load line and the last three in the second group. The results in the first group were plotted in Fig. 4, and a second-order polynomial regression was made in order to determine the optimum line of axial load. The optimum load line was at $x_e = 16.1$ mm. The failure mode changed from bending mainly in the web to bending initiated in the flanges and lips when the x_e was increased from 14.5 mm to 18.5 mm. The failure mode of the specimens whose load line was around the optimum line was a combination of bending in both the web and flanges, and the corners in the web were kept nearly straight. The results in the second group were consistent. Their mean value was 233.3 kN.

Four specimens were tested by the AISI procedure. The results were listed in Table 3. It can be seen that the failure loads were very consistent. The mean value is 236.3 kN, which is slightly larger than that obtained by the FEM procedure.

For 1.2 mm and 0.8 mm series 8 specimens were tested by the FEM procedure, in which the first five specimens were in the first group and the last three in the second group. The results in the first group were also plotted in Fig. 4. The same process as in 3.0mm series was used to determine the optimum load line. Three specimens were tested by the AISI procedure.

The results from the FEM procedure were compared with those from the AISI procedure, which was summarised in Table 4, where mean values were used. It is shown that the difference between these two experiment procedures is very small, only about 1.6%. This is much smaller than the possible errors which are normally involved in an experiment. For 3.0mm series the result from the FEM procedure is slightly smaller than that from the AISI procedure, while for 1.2mm and 0.8mm series the results from the FEM is slightly greater than those from the AISI procedure. So it is difficult to conclude which procedure gives a more conservative result. Bearing in mind that the difference between these two procedures is so small (less than 1.6%) that it may well be attributed to the quality of the specimens rather than the testing procedure.

In theory, when the load is applied through the effective centroid of the cross-section the column should have its maximum failure load in the FEM procedure because in this case there is no external bending moment on the cross section. A load applied through any other position will cause eccentricity and produce an external bending moment in addition to the axial load. Therefore, when the stub column is loaded through the optimum load line in the FEM procedure, there should be no rotation at the ends of the column although the ends are free. This condition is achieved by restraining the ends of the columns in the AISI procedure. It is observed that the deformed shape of columns in the AISI procedure was quite similar to those whose load line was near optimum load line in the FEM procedure. This phenomenon may explain why the failure loads obtained by these two different procedures were very close.

CONCLUSIONS

Thirty six tests were carried out to investigate the difference in failure load obtained by different experimental procedures. It showed that the failure load obtained by two experimental procedures were very close to each other. The difference is only about 1.6 percent. Both procedures worked well. Because the FEM procedure normally needs at least five more tests for every layout of column to determine the optimum load line, the AISI procedure described above is recommended as the standard procedure.

ACKNOWLEDGEMENT

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Appendix. -- References

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Table 1 Dimensions and yield stress of the stub columns

Series No	Number of specimens	W_1 (mm)	W_2 (mm)	W_3 (mm)	R (mm)	t (mm)	L (mm)	Yield stress (N/mm^2)
3.0mm series	14	89.7	40.0	6.7	3.5	3.0	300	417.0
1.2mm series	11	90.4	44.0	12.0	2.8	1.2	360	192.9
0.8mm series	11	92.0	46.4	13.2	2.0	0.8	360	171.3

Table 2 Results in the FEM procedure

3.0mm series			1.2mm series			0.8mm series		
X_{cgeff} = 16.31 mm			X_{cgeff} = 21.36 mm			X_{cgeff} = 21.70 mm		
speci-mens	x_e (mm)	failure load (kN)	speci-mens	x_e (mm)	failure load (kN)	speci-mens	x_e (mm)	failure load (kN)
s3.0-1	14.5	230	s1.2-1	19.6	40.7	s0.8-1	20.4	19.7
s3.0-2	15.0	229	s1.2-2	21.1	42.6	s0.8-2	21.4	21.0
s3.0-3	15.6	230	s1.2-3	22.1	43.2	s0.8-3	22.4	20.3
s3.0-4	15.7	243	s1.2-4	22.8	40.8	s0.8-4	23.9	20.7
s3.0-5	16.0	241	s1.2-5	23.6	39.1	s0.8-5	25.4	19.6
s3.0-6	17.0	236	s1.2-6	21.3	41.9	s0.8-6	22.7	20.9
s3.0-7	18.5	207	s1.2-7	21.3	42.7	s0.8-7	22.7	21.1
s3.0-8	16.1	233	s1.2-8	21.3	42.5	s0.8-8	22.7	20.3
s3.0-9	16.1	229						
s3.0-10	16.1	238						

Table 3 Results in the AISI procedure

3.0mm series		1.2mm series		0.8mm series	
Specimens	Failure load (kN)	Specimens	Failure load (kN)	Specimens	Failure load (kN)
s3.0-11	239	s1.2-9	41.7	s0.8-9	20.4
s3.0-12	236	s1.2-10	41.7	s0.8-10	20.8
s3.0-13	236	s1.2-11	41.8	s0.8-11	20.3
s3.0-14	234				

Table 4 Comparison of maximum load of FEM and AISI

	FEM (kN)	AISI (kN)	difference
3.0mm series	233.3	236.3	1.3%
1.2mm series	42.4	41.73	1.6%
0.8mm series	20.8	20.5	1.5%

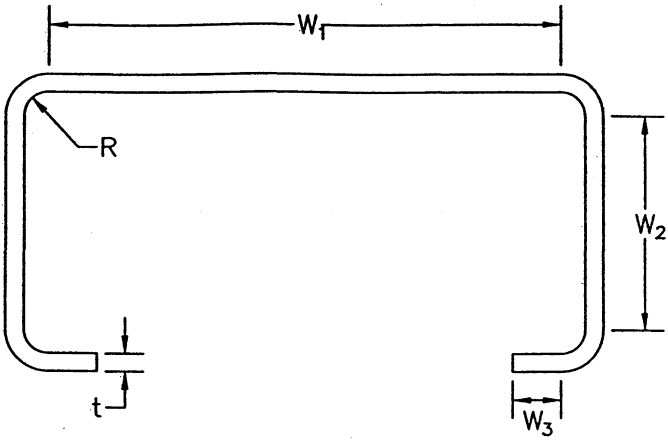
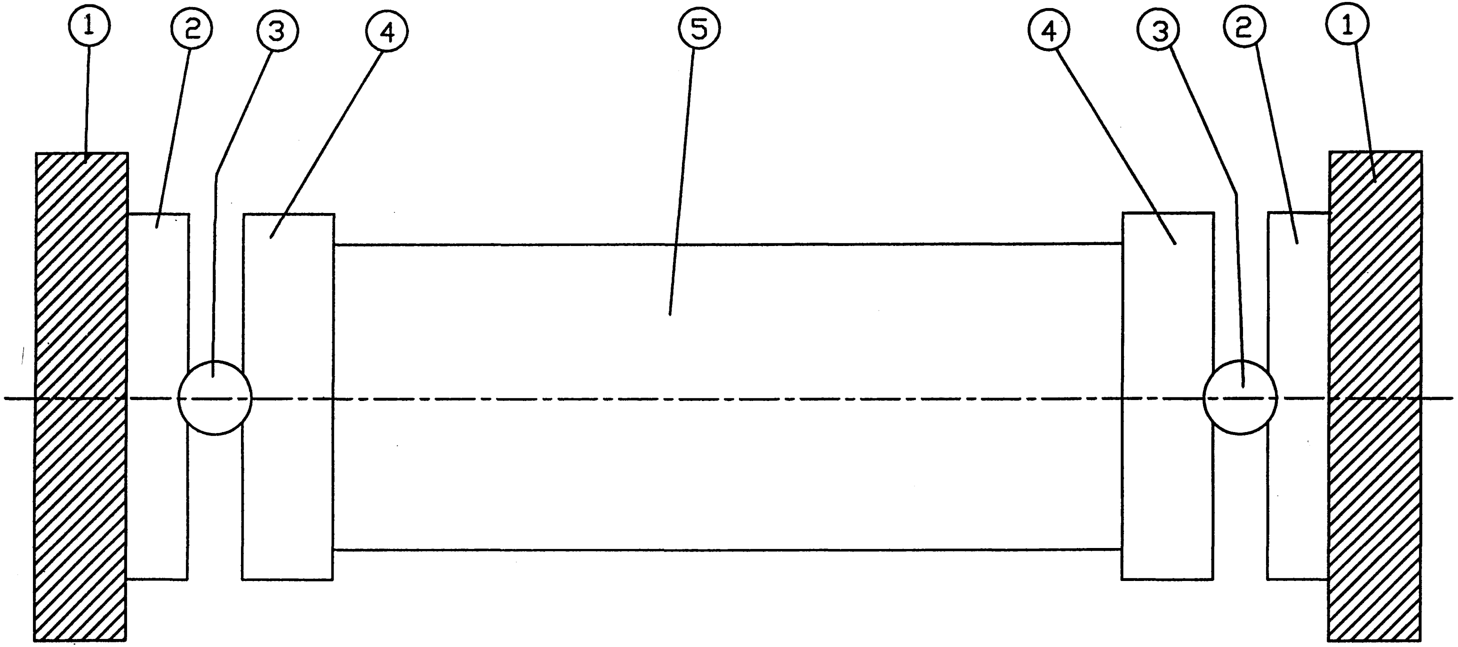
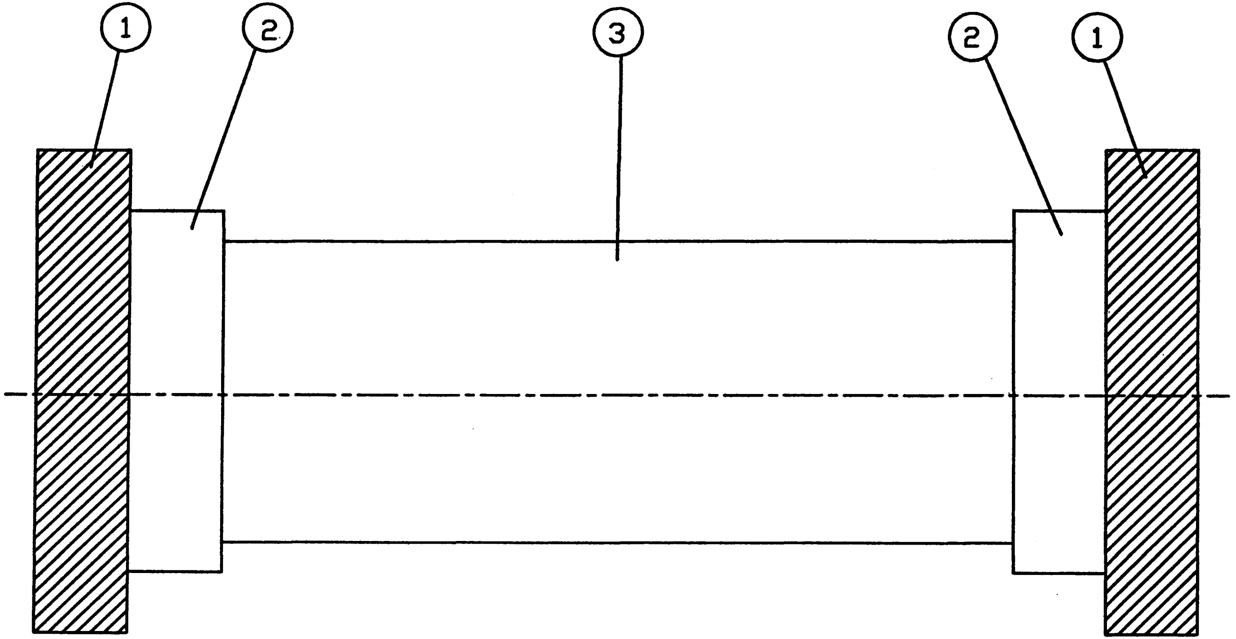


Fig. 1 Dimensions of the cross-section of the columns



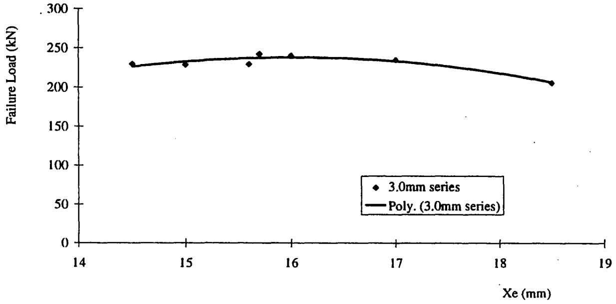
1: Load heads 2: Bearing plates 3: Ball bearings 4: Steel Bases 5: Column

Fig.2 The arrangement of FEM procedure

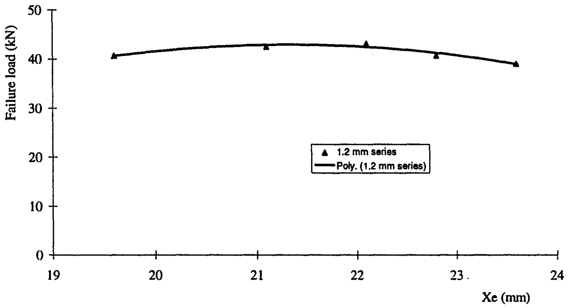


1: Load heads 2: Steel bases 3: Column

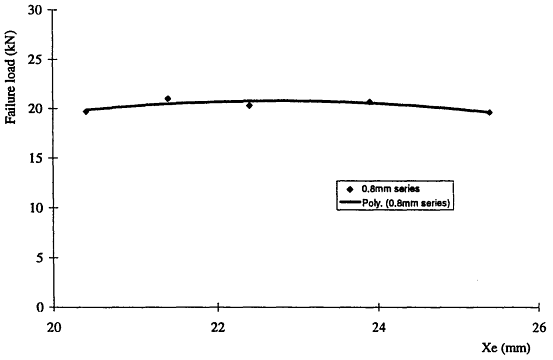
Fig.3 The arrangement of AISI procedure



(a) 3.0mm series



(b) 1.2mm series



(c) 0.8mm series

Fig. 4 Results in the first group