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M. Sommerstein

R. P. Papazian

R. M. Schuster

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MULTIPLE STIFFENED DECK PROFILES

by

R.P. Papazian[1], R.M. Schuster[2], M. Sommerstein[3]

ABSTRACT

CAN/CSA-S136-M89 and the AISI Specification on Cold Formed Steel Design use different methods to determine the effective width of multiple stiffened compressive elements when no local buckling in the sub-elements occurs. Both methods replace the multiple stiffened element with a flat plate element centered at the neutral axis of the multiple stiffened element. The methods differ in assigning an equivalent thickness to the straight line element. The AISI method provides sufficient thickness to match the moment of inertia of the multiple stiffened element, while the S136 method makes use of orthotropic plate theory, however, dealing only with the elastic buckling component. For a given geometry, they predict different effective widths.

In this paper, experimental data is compared with the predicted values of each method and conclusions are drawn from these comparisons. Representative hat sections were subjected to uniformly distributed loads using a vacuum chamber. Profiles with one, two, three and four intermediate stiffeners were tested, using three material thicknesses for each configuration of stiffeners.

INTRODUCTION

This paper is the result of work initiated while R.P. Papazian was a graduate student enrolled in Civil Engineering 703 - Design in Cold Formed Steel (Professor: R.M. Schuster) at the University of Waterloo, Waterloo, Ontario, Canada. As part of this course, students were required to carry out a project dealing with cold formed steel design, involving some area of the Canadian Standard. The calculation of the effective moment of inertia of sections with multiple stiffened compressive elements was the topic chosen by Papazian.

[1] Civil Engineer, Quad Engineering, Scarborough, Ontario, Canada
Formerly Structural Engineering Graduate Student, University of Waterloo
[2] Professor of Structural Engineering, Department of Civil Engineering, University of Waterloo, Ontario, Canada
[3] Engineering Manager, VicWest Steel Inc., Oakville, Ontario, Canada

The results of the project revealed four inconsistencies [1], two of which were the subject of this paper, i.e.,

1. disagreement between the S136[2] and AISI[3] methods of calculating the effective moment of inertia of a multiple stiffened compressive element when no local sub-element buckling occurs (see Figure 1, lines marked S136 and AISI, for two or more stiffeners), and

2. using the S136[2] method, the effective moment of inertia is increased when adding one intermediate stiffener in comparison to not having a stiffener in the compressive element of the section. However, adding more stiffeners will decrease the effective moment of inertia, which is not consistent (see Fig. 1). In Fig. 1, the width and thickness of the compressive flange, tensile flange, webs and lip stiffeners were held constant. Only the number of intermediate stiffeners was varied.

No test data was found in the literature to determine whether these apparent inconsistencies were predictive of actual member behaviour. Test specimens were fabricated by VicWest Steel Inc. under the direction of M. Sommerstein and testing was carried out at VicWest Steel Inc. under the supervision of the authors.

SECTIONS TESTED

Hat sections with one, two, three and four intermediate stiffeners were tested (See Figure 2 for a typical section). Three material thicknesses were used for each configuration of stiffeners. The spacing of stiffeners was selected individually for each material thickness to prevent local sub-element buckling based on the width/thickness provisions of Clause 5.6.2.5(c) of S136[2]. The sections were also designed such that overall compressive flange buckling would occur before tension flange yielding. The mechanical properties for each material thickness are given in Table 1 and the dimensions of the test sections are given in Table 2.

All of the test sections were formed manually using a break press, therefore, one stiffener size was selected to simplify forming. The dimensions of this stiffener are based on the minimum size required to satisfy the minimum stiffener moment of inertia for all of the sections tested (the controlling case was the thickest material).

TEST SETUP

All specimens were loaded to failure using a vacuum chamber (Figures 3 and 4). The vacuum chamber consisted of a box sealed on all sides except for the top. The test sections were simply supported on beams within the chamber and a polyethylene sheet was used to cover the top of the box along with the test sections. Clamps were used to form an airtight seal between the box and the polyethylene sheet. Vacuum was then applied to the chamber and failure loads were calculated based on the maximum measured vacuum pressure at failure.

The sections with single stiffeners were used to test the experimental setup because their behaviour is well known and there is confidence in the ability of Clause 5.6.2.4 of S136[2] to predict their behaviour.

The uniformly distributed load applied to a test specimen was determined by multiplying the measured vacuum pressure by the loaded width. There was some difficulty in determining the actual loaded width when sections were tested individually as the polyethylene sheet draped from the section to the edge of the chamber (Figure 3(a)). It was difficult to consistently predict the failure pressure of the sections, even though the calculation procedures for a section with a single stiffener are well known. Accurate and consistent results were obtained by loading two sections at a time (Figure 3(b)). Lumber was laid across the top of the sections and the unused portion of the chamber was blocked off. The loaded width was thus easily obtained because there was virtually no draping of the polyethylene sheet. In addition, the error due to any draping that occurred was relatively minor because the draping was small compared with the loaded width. All of the test results listed in Table 3 were obtained using two identical sections to form one specimen, which was then tested to ultimate load in the vacuum chamber.

Two tests of each configuration of stiffeners and material thickness were carried out, each using two specimens, for a total of four specimens.

TEST RESULTS

The failure moments obtained from the test results are shown in Table 3 under the column heading "Test Moment".

The following observations were made:

1. Failure always occurred due to the overall buckling of the compressive flange and not to local sub-element buckling.
2. Failure was sudden.
3. Usually, both sections failed either simultaneously or in quick succession. Rarely did one section fail without the other.
4. The results of the two tests (per configuration of stiffeners and material thickness) differed by less than 8% in each case (See Table 3 - "Percent Difference in Test Results W.R.T. Lesser Value).

COMPARISON OF TEST VS. CALCULATED

Table 3 summarizes the test moments as well as a number of different calculated moment resistances. Figure 5 shows test/calculated (moment) vs. number of intermediate stiffeners. Each of the four sub-graphs (a) through (d) deals with the test/calculated values for a particular method of calculation. These sub-graphs can be used individually to draw conclusions about the performance of a particular method of calculation and how its performance varies with the number of stiffeners and the material thickness.

Figure 6 shows test/calculated (moment) vs method of calculation. Each of the four sub-graphs deals with the test/calculated values for a particular number of stiffeners. These sub-graphs can be used individually to draw conclusions about which method of calculation best predicts with a particular number of stiffeners (for a variety of material thicknesses).

The values used for Figures 5 and 6 are the average of the two test values for each configuration as shown in Table 3.

Figure 5(a) shows that with one stiffener, the test strength is less than 10% greater than that predicted by S136[2]. It is desirable for the calculation method to either match or slightly underestimate the strength of the member. However, with 2 to 4 stiffeners, the experimental test moment is 40 to 65% greater than predicted. The ratio between test and calculated values is relatively consistent for t = 0.56 mm(0.0220in.), and 1.45 mm(0.0571in.), but varies for t = 0.84 mm(0.0331in.). The S136[2] method for a single stiffener section appears good, whereas it grossly underestimates strength with 2 to four stiffeners, regardless of material thickness.

Figure 5(b) shows that the AISI[3] method underestimates the experimental strength by approximately 10% for t = 0.84 mm(0.0331in.), a good result. However, it overestimate strength by approximately 5% for t = 1.45 mm(0.0571in.). The results for t = 0.56 mm(0.0220in.) vary from a slight underestimation of less than 3% with 2 stiffeners to a gross overestimation of over 30% with 4 stiffeners. The AISI[3] method works well with 2 stiffeners, but is erratic with 3 or 4.

The results in Figure 5(c) and 5(d) represent attempts to modify the S136[2] method such that the calculated results are brought in line with the experimental data. Figure 5(c) shows that removing the B_r provision of Clause 5.6.2.5(c) of S136[2] shifts the results from Figure 5(a) such that the test/calculated ratio is reduced by approximately 0.1. The B_r provision reduces the effective width of the multiple stiffened element when sub-element width/thickness ratios exceed 60.

Figure 5(d) shows that including the moment of inertia of the multiple stiffened element about its own center (I_{sf}) in the calculation of the section effective moment of inertia shifts the results from Figure 5(a) such that the calculated value for some material thicknesses now overestimate the section strength by as much as 25%. Neither of these modification provides a satisfactory solution.

Figure 6(a) shows that the AISI[3] method most closely predicts the failure strength of a section with two intermediate stiffeners. It underestimates strength by less than 13% and overestimates by less than 4%. Neither the S136[2] method nor the two proposed modifications to it provide satisfactory predictions of failure strength with two intermediate stiffeners.

Figure 6(b) shows that the AISI[3] method overestimates the strength of sections with 3 stiffeners by as much as 20% (t = 0.56 mm(0.0220in.)). Figure 6(c) shows that the AISI[3] method overestimates the strength of sections with 4 stiffeners by as much as 30% (t = 0.56 mm(0.0220in.)). None of the four methods adequately predicts the failure load when 3 or 4 stiffeners are present.

CONCLUSIONS

1. Clause 5.6.2.5(c) of S136[2] underestimates the failure strength of sections with multiple stiffened compressive elements with 2 to 4 stiffeners and material thickness from 0.56 mm(0.0220in.) to 1.45 mm(0.0571in.) by at least 40%.

2. Modifying Clause 5.6.2.5(c) of S136[2] by removing the reduced effective width ratio (B_r) provision has little effect on the calculated strength and is not a satisfactory solution.

3. Modifying Clause 5.6.2.5(c) of S136[2] by removing the reduced effective width ratio (B_r) provision and including the moment of inertia of the multiple stiffened element about its own center (I_{sf}) in calculating the effective moment of inertia of the section has a significant effect on the calculated strength, but is not a satisfactory solution.

4. The AISI[3] method provides adequate estimates of failure strength for multiple stiffened elements with 2 stiffeners. It underestimates strength by less than 13% and overestimates strength by less than 4% for the material thickness range of 0.56 mm(0.0220in.) to 1.45 mm(0.0571in.).

5. The test/calculated ratio using the AISI[3] method for sections with 3 or 4 intermediate stiffeners is erratic. The AISI[3] method can overestimate failure loads by up to 30%.

RECOMMENDATIONS

1. The AISI[3] method should be used to calculate the effective moment of inertia of sections with multiple stiffened elements with 2 intermediate stiffeners. This applies only to multiple stiffened elements connected to a web on each side.

2. The failure strengths of sections with multiple stiffened elements with 3 or 4 stiffeners should not be determined using S136[2] or AISI[3] provisions. It may be necessary to obtain experimental data for such sections.

FUTURE WORK

Having some experimental data, future work is to find a formulation that can predict the behaviour of a multiple stiffened compressive element with three or more stiffeners. This work will include comparing the experimental data with calculated values from other methods and/or codes. The end result may be the adoption of an existing method, the modification of an existing method, or the formulation of a new method.

ACKNOWLEDGMENTS

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REFERENCES

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2. CAN/CSA-S136-M89, "Cold Formed Steel Structural Members", Canadian Standards Association, Rexdale, Ontario, 1989.
3. "Specification for the Design of Cold-Formed Steel Structural Members", American Iron and Steel Institute, 1986 ed. with 1989 Addendum.

TABLE 1 - MECHANICAL PROPERTIES FOR EACH MATERIAL THICKNESS

GUAGE	MEASURED MATERIAL THICKNESS (t) (mm)	F_y (MPa)	F_u (MPa)	% ELONGATION
24	0.56	345	394	27.0
20	0.84	308	390	28.5
16	1.45	313	355	34.5

Note: Coupon tests were carried out to obtain the results in the table.

TABLE 2 - TEST SECTION DIMENSIONS*
(See Figure 2 for key of dimensions)

TEST #	NO. OF STIFF. (n)	MATERIAL THICKNESS (t) (mm)	"a" TENSION FLANGE WIDTH (mm)	"b" COMP. FLANGE WIDTH (mm)	"c" WEB HEIGHT (mm)	"d" STIFFENER WIDTH (mm)	"e" STIFFENER HEIGHT (mm)
7	1	1.45	76.5	134	54	32.5	14
8	1	1.45	76.5	134	54	33	14
9	2	0.56	76.5	114	51	30	14
10	2	0.56	76.5	114	51	29.5	14
11	2	0.84	53	147	52.5	30	14
12	2	0.84	52	148	52	31	14
13	2	1.45	77.5	206	54	32	14
18	2	1.45	77.5	206	54	31	14
14	3	0.56	75	160	51.5	30	14
15	3	0.56	75	161	51.5	30	14
19	3	0.84	50	198	52.5	30	14
20	3	0.84	50	197	53	30.5	14
25	3	1.45	78	283	54	33.5	14
26	3	1.45	78	283	53.5	33	14
16	4	0.56	76.5	223	52	33	14
17	4	0.56	76.5	223	52	33	14
21	4	0.84	51	252	52.5	30.5	14
22	4	0.84	51	252	51	30.5	14
23	4	1.45	77.5	358	54	33	14
24	4	1.45	77	358	54	33	14

* 1. All dimensions are measured (to nearest 0.5 mm).
2. All dimensions are out-to-out.
3. The dimesions shown are the average of the two sections used per test.
4. The inside bend radii varied from 2 to 3 mm.

TABLE 3 - TEST RESULTS AND CALCULATED DATA

TEST #	NO. OF STIFF. (n)	t (mm)	TEST MOMENT (kN.m)	PERCENT DIFF. IN TEST MOMENT W.R.T LESSER VALUE	TEST/ S136-M89 (kN.m)	TEST/ AISI (kN.m)	TEST/ S136-M89 NO Br (kN.m)	TEST/ S136-M89 NO Br w/Isf (kN.m)
7	1	1.45	3.696	4.4	1.095	N/A	N/A	N/A
8	1	1.45	3.540		1.054	N/A	N/A	N/A
9	2	0.56	1.082	1.8	1.609	1.032	1.567	0.875
10	2	0.56	1.063		1.570	1.003	1.527	0.856
11	2	0.84	1.627	7.7	1.472	1.071	1.431	1.020
12	2	0.84	1.752		1.600	1.179	1.554	1.121
13	2	1.45	3.666	1.0	1.374	.968	1.332	0.943
18	2	1.45	3.701		1.389	.976	1.347	0.952
14	3	0.56	1.076	0	1.616	.792	1.501	0.831
15	3	0.56	1.076		1.604	.787	1.490	0.825
19	3	0.84	1.563	1.7	1.461	1.062	1.363	1.018
20	3	0.84	1.589		1.475	1.076	1.378	1.03
25	3	1.45	3.628	1.4	1.388	0.942	1.285	0.922
26	3	1.45	3.678		1.426	0.965	1.319	0.945
16	4	0.56	1.014	0.1	1.569	0.666	1.375	0.742
17	4	0.56	1.013		1.567	0.666	1.374	0.742
21	4	0.84	1.664	0.8	1.603	1.103	1.432	1.061
22	4	0.84	1.677		1.660	1.139	1.482	1.095
23	4	1.45	3.636	5.0	1.434	0.938	1.263	0.915
24	4	1.45	3.462		1.375	0.906	1.212	0.885

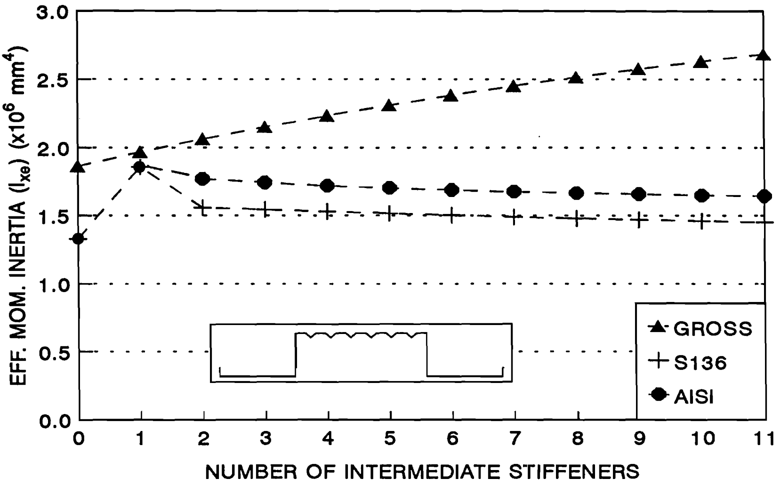


FIGURE 1 - EFFECTIVE MOMENT OF INERTIA vs NUMBER OF INTERMEDIATE STIFFENERS

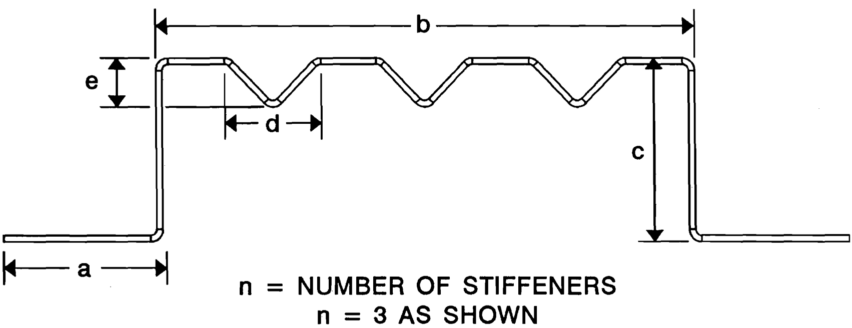


FIGURE 2 - TEST SECTION DIMENSIONS

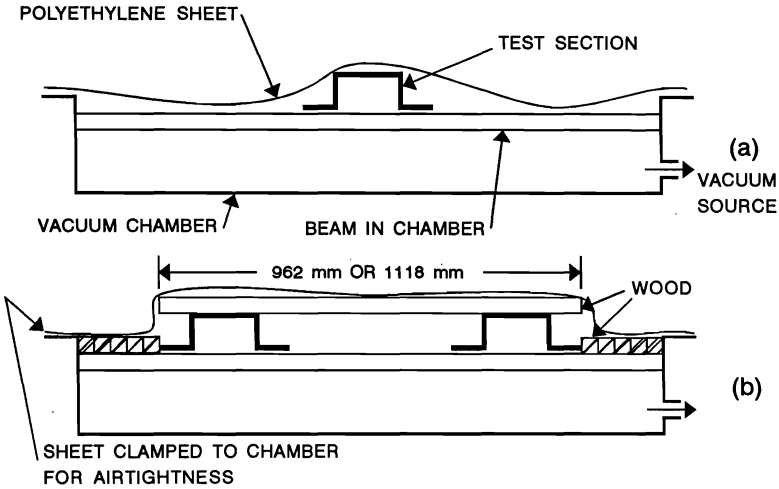


FIGURE 3 - TEST SETUP - CROSS-SECTION THROUGH MEMBERS

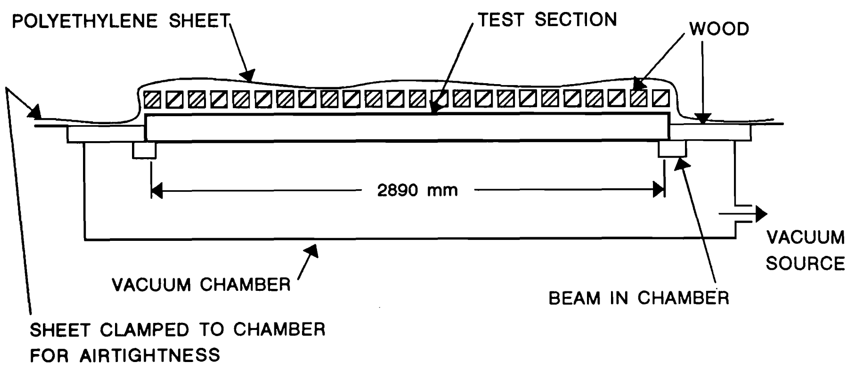


FIGURE 4 - TEST SETUP - VIEW ALONG MEMBER

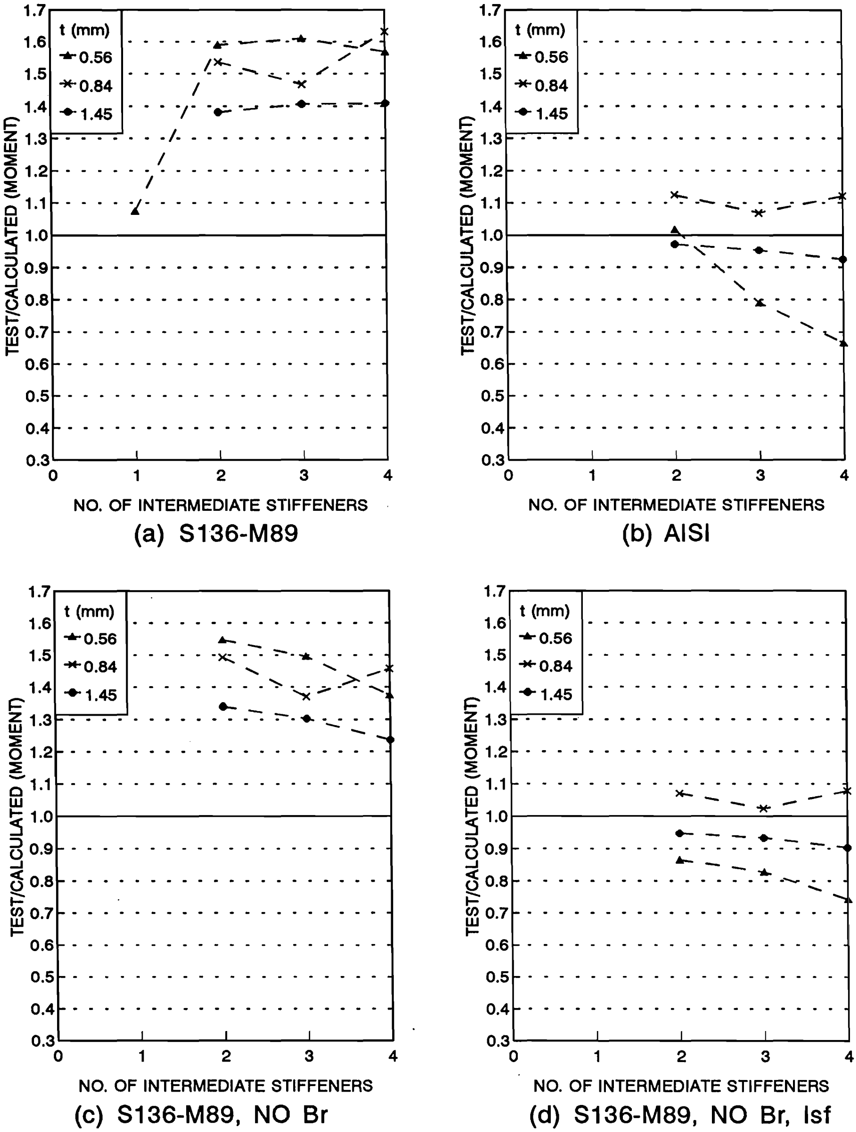
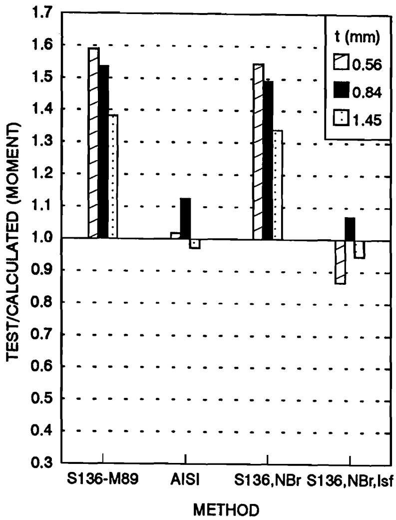
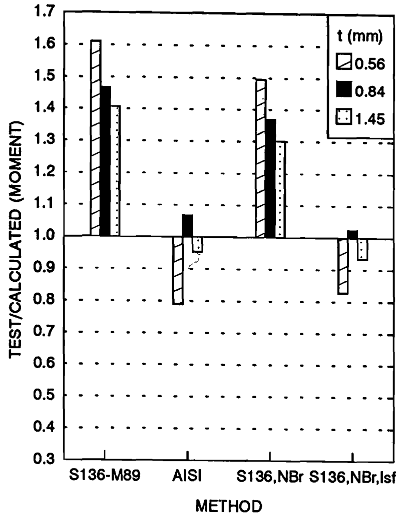


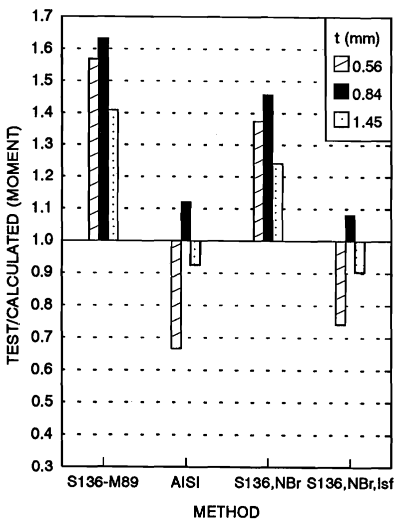
FIGURE 5 - TEST/CALCULATED (MOMENT) vs NUMBER OF INTERMEDIATE STIFFENERS



(a) WITH 2 STIFFENERS



(b) WITH 3 STIFFENERS



(c) WITH 4 STIFFENERS

FIGURE 6 - TEST/CALCULATED (MOMENT) vs METHOD OF CALCULATION