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Objekttyp: **Article**

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

Band (Jahr): **49 (1986)**

PDF erstellt am: **11.08.2024**

Persistenter Link: https://doi.org/10.5169/seals-38300

Behaviour of Thin-Walled Corrugated Sheets and Restrained Beams

Comportement des tôles ondulées à paroi mince et des poutres

Verhalten von wellenförmigen Dünnwandblechen und ausgesteiften Trägern

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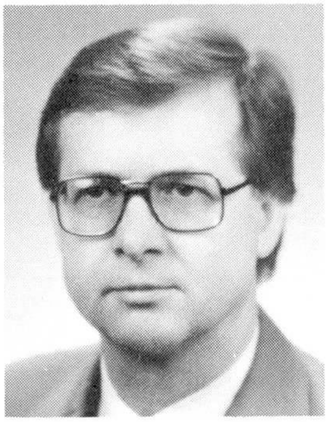

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SUMMARY
The paper provides information on the experimental research programme directed to the problem of local buckling of metal thin-walled corrugated wave-formed sheets under bending moment and to the problem of local and general buckling of beams restrained by sheeting and sag rods. The procedure referred to as the vacuum test (Cornell) method was utilized for the experiments.

RÉSUMÉ
Cet article concerne un programme de recherche expérimentale orienté vers les problèmes de voilement local de tôles profilées en acier à paroi mince sous l'effet d'un moment de flexion; et de voilement local et global de poutres stabilisées par la tôle et des tirants. La procédure expérimentale utilisée est la méthode d'essais sous vide développée à l'Université Cornell.

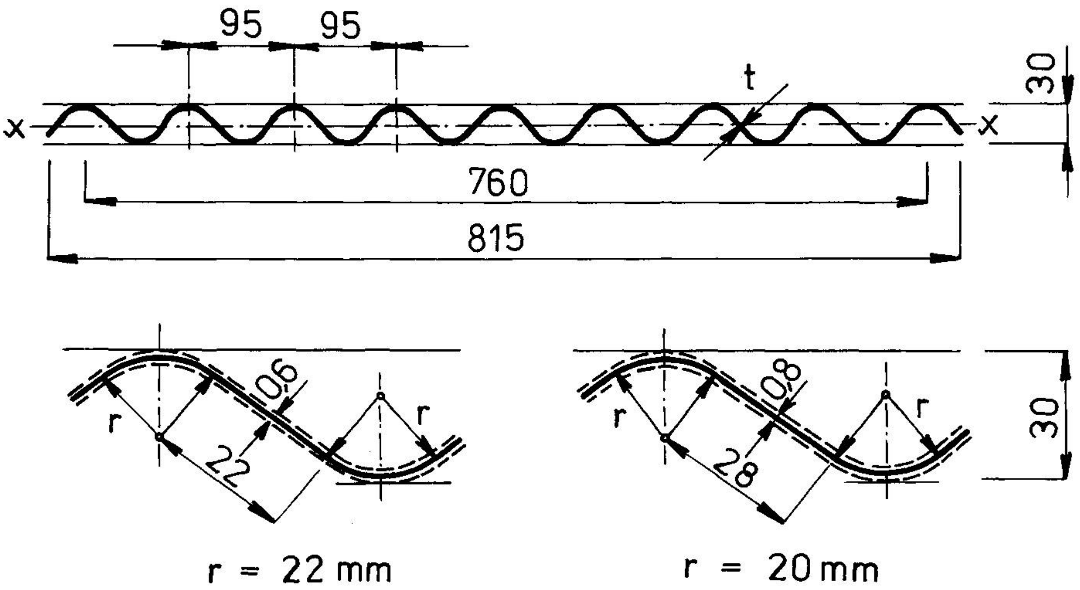
ZUSAMMENFASSUNG
Der Beitrag berichtet über ein Versuchsprogramm, das auf das Problem der lokalen Stabilität von wellenförmigen Metallblechen unter Biegemomenten und auf das Problem der lokalen Stabilität und der Gesamtstabilität von Trägern abzielt, die durch profilierte Bleche und Zugstangen gehalten sind. Für die Versuche wurde die von Cornell entwickelte Vakuumprüfungsmethode angewandt.

1. LOCAL BUCKLING OF CORRUGATED SHEETS UNDER BENDING

In the problem of local buckling of thin-walled metal sheets subjected to bending moment much attention has been given to the trapezoidal (ribbed) profiles. One of our research projects was concerned with corrugated (wave-formed) panels because of a little amount of the information about both the theoretical and experimental results in this field.

1.1 An Experimental Investigation

The experimental research programme was conducted on single-span and two-span steel panels with the nominal cross section geometry and actual characteristics for one wave (i.e. for the width of 95 mm) shown in Fig. 1.



t [mm]	A [mm²]	I_x [mm⁴]	W_x [mm³]
0,6	57,68	5903	415,7
0,8	80,89	8822	607,2

Fig. 1 Cross section and characteristics of the specimens

The steel panels are zinc coated. The actual thickness of the steel sheet was t = 0,52 mm (nominal t = 0,6 mm) and t = 0,72 mm (nominal t = 0,8 mm) respectively.
Totaly 12 specimens were tested, namely 6 simple supported panels with a span of L_1 = 1440 mm and 6 continuous panels of two equal spans of L_2 = 1480 mm. The overall width of wave sheets was 815 mm. The breadth of the transverse support elements was b = 40 mm.

The actual material characteristics were measured in 6 tensile test specimens for sheets of nominal thickness t = 0,6 mm and in 3 specimens for t = 0,8 mm. The mean values of the yield stress and the ultimate tensile strength were R_y = 237 MPa (minimal R_y = 225 MPa; maximal R_y = = 259 MPa) and R_u = 284 MPa (minimal R_u = 272 MPa; maximal R_u = = 304 MPa) for the nominal sheet thickness of t = 0,6 mm and R_y = 264 MPa (minimal R_y = 248 MPa; maximal R_y = 281 MPa) and R_u = 314 MPa (minimal R_u = 298 MPa; maximal R_u = 327 MPa) for the nominal sheet thickness of t = 0,8 mm, respectively.

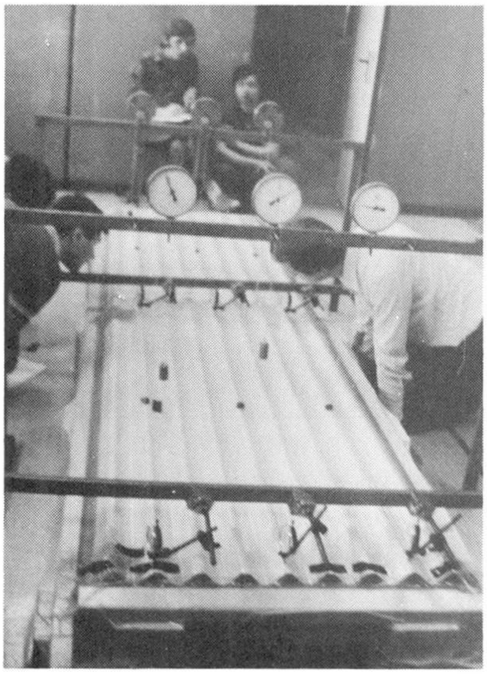


Fig. 2 Test Arrangement

To simulate the behaviour of thin-walled corrugated sheets under uniformly distributed load, an experimental procedure referred to as the vacuum test method was utilized (autor learned the application of this method in the field of steel stability research problems during the study stay by

SPECIMEN	t [mm]	TEST ARRANGEMENT	LOAD BY BUCKLING p_{max} [$kN \cdot m^{-2}$]	
			AT CENTRAL SUPPORT	IN THE SPAN
D 1	0,6	TWO - SPAN PANEL 2 x 1480 mm (width 815 mm)	4,0	7,0
D 3	0,6		4,0	7,0
D 4	0,6		4,0	7,0
D 2	0,8		7,0	11,3
D 5	0,8		7,0	11,5
D 6	0,8		7,2	11,0

Table 1 Two-span Test Results

R.N. White and T. Peköz, Cornell Univ., Ithaca, N.Y.). The method involves producing a vacuum under the test specimen covered by clear plastic, and then measuring the difference in pressure

SPECIMEN	t [mm]	TEST ARRANGEMENT	p_{max} [$kN \cdot m^{-2}$] LOAD BY BUCKLING IN THE SPAN
X 1 (D 2)	0,8	SINGLE-SPAN PANEL 1 x 1440 mm (width 815 mm)	9,5 (10,2)
X 2 (D 5)	0,8		9,4 (9,6)
X 3 (D 6)	0,8		9,5 (9,6)
X 4 (D 1)	0,6		6,0 (6,2)
X 5 (D 3)	0,6		6,0 (5,1)
X 6 (D 4)	0,6		5,8 (5,9)

Table 2 Single-span Test Results

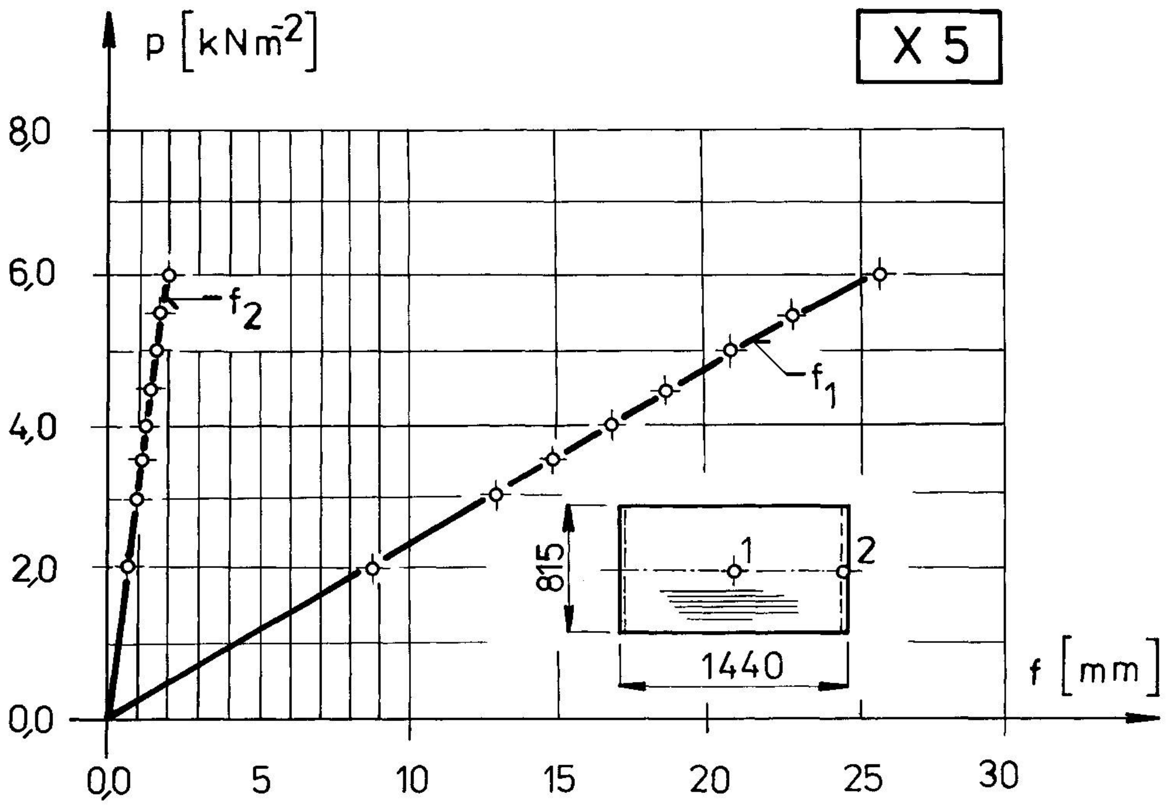


Fig. 3 Load - Deflection Relationship for Single-span Panel

between the outside atmospheric pressure and inside the test frame. The test setup and instrumentation are shown in Fig. 2. The support settlements and maximum span deflections were measured using a stroke dial gages.

The description of specimens and the experimental results are summarized in Table 1 and Table 2.

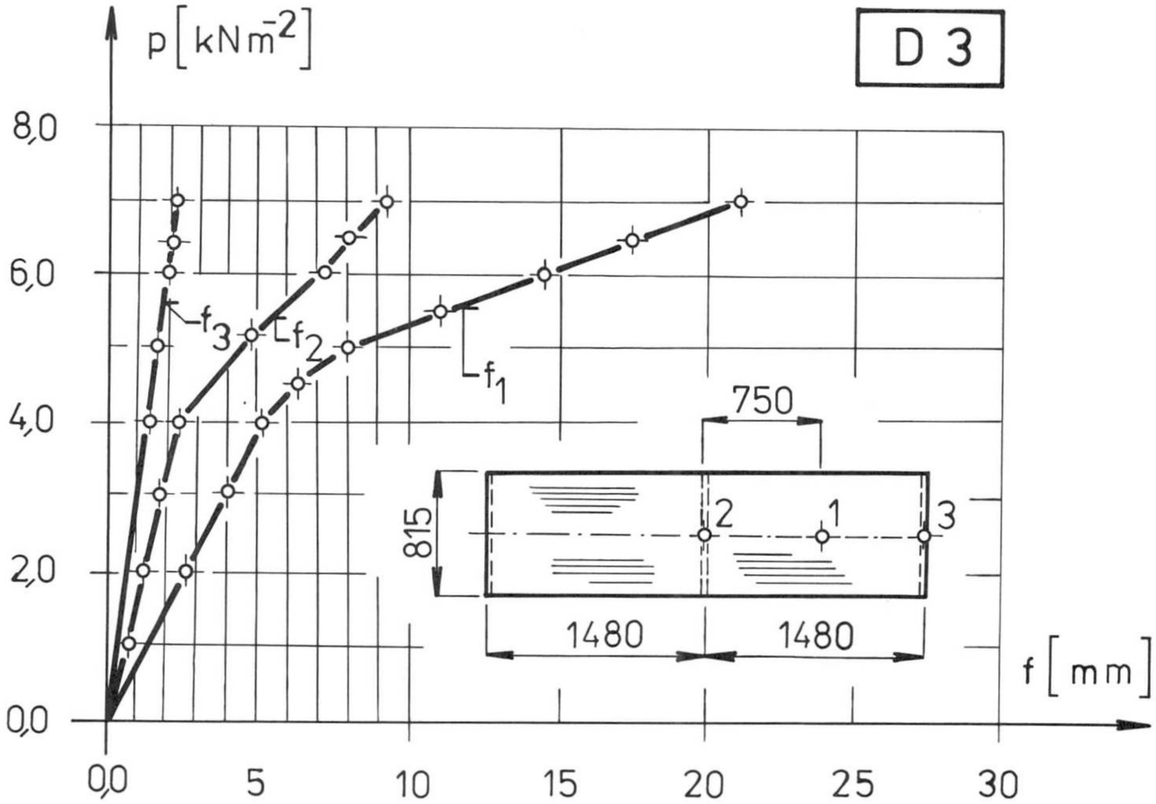


Fig. 4 Load - Deflection Relationship for Two-span Panel

Fig. 5 Span Buckling

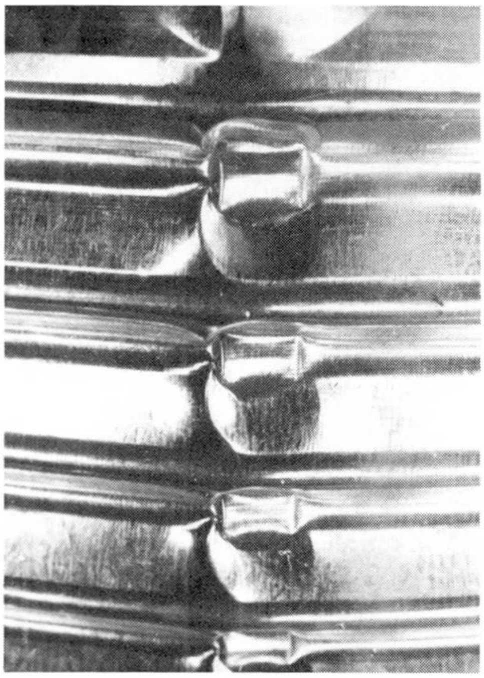


Fig. 6 Support Crippling

The typical example of applied uniform load "p" plotted against the maximum span and support deflections "f" is for the single-span specimen X5 in Fig. 3 and for the two-span specimen D3 in Fig. 4.

The influence of the plastic hinge arising, combined with web crippling at central support of two-span specimen can be clearly seen from Fig. 4. None of significant effect of the sheet support deformation upon the ultimate load carrying capacity of single span specimens was observed.
The behaviour of the corrugated sheets at ultimate load was characterized by outright and abrupt local buckling of the compression cross-section part in the span (see Fig. 5). After sheet waves deformation and bearing on the central support (see Fig. 6) the process of load increasing had been stabilized again until local buckling occured in the span.

1.2 Analysis of the Test Results

This part of the paper is aimed to the problem of local buckling strength in the span of the wave-formed sheets. The critical moment and corresponding buckling stress follows directly from the ultimate load of single-span specimens. In the case of two-span panels the critical moment in the span is influenced by actual value of negative moment at central support. This moment obviously depends on cross section deformation cau-

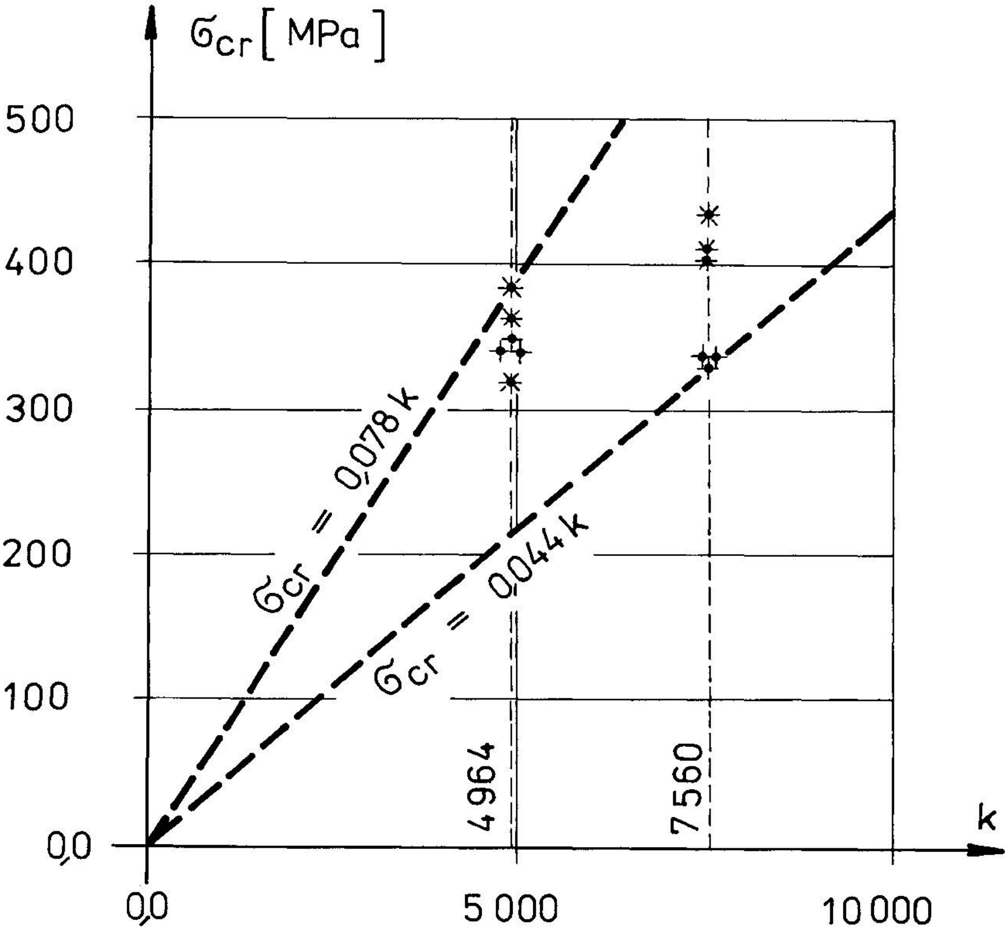


Fig. 7 Test Results Evaluation

sed by web crippling and can be easily determined using the measured values of maximum deflection in the span. Thus the ultimate buckling load for a conventional single span panel can be derived from the tests of two-span specimens. The corresponding specimen descriptions and conventional buckling loads are summa-

rized in parentheses, Table 2.
Based upon the theory of local buckling of unstiffened cylindrical shells [1] , [2] , [3] , the buckling stress of ondulated plates is given by the following general equation:

$$\sigma_{cr} = \alpha \frac{E\ t}{r} = \alpha \cdot k \quad . \qquad (1)$$

The buckling coefficient α for the range of parameters k considered in this study varies from α = 0,044 to α = 0,078 (see Fig. 7, where the star-symbols indicate the test results for the two-span specimens). The value of measured ultimate buckling load includes the influence of both the imperfections and material non-linearity. The experimental results are in a good agreement with [4] where α = 0,06 for ondulated plates is proposed.

2. LOCAL AND GENERAL BUCKLING OF RESTRAINED BEAMS

The contemporary trend in the development of structural design procedures is characterized by a successive transition from the analysis of the "ideal member incorporated into the ideal structure" to the problem of "actual member incorporated into the actual structure". In the theory of beams braced by discrete and

Fig. 9 Restrained Buckling

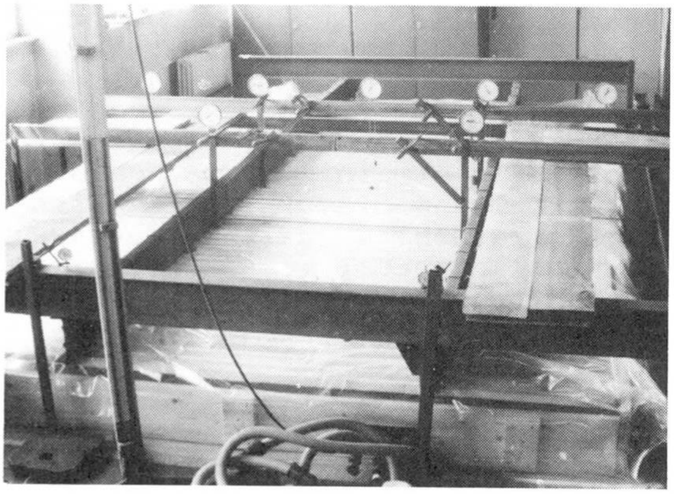


Fig. 8 Test Setup

continuous restraints (H. Nylander, T. Peköz, T. Höglund, N.S. Trahair, D.A. Nethercot, G.J. Hancock and others) a fair progress was made in the last period. But more attention to check the validity of the several assumptions and simplifications by experiments is needed. Interesting results of research in this field are for example in [5] , [6] .
At Technical University of Brno the experimental programme directed to the behaviour of restrained beams is presently being conducted. The full-scale specimens arrangement is typical of those used in the metal building industry. The procedure referred to as vacuum test method is used, as well. The span of the beams tested is 6 m and the total loading breadth of the two parallel members is 3 m (Fig. 8).

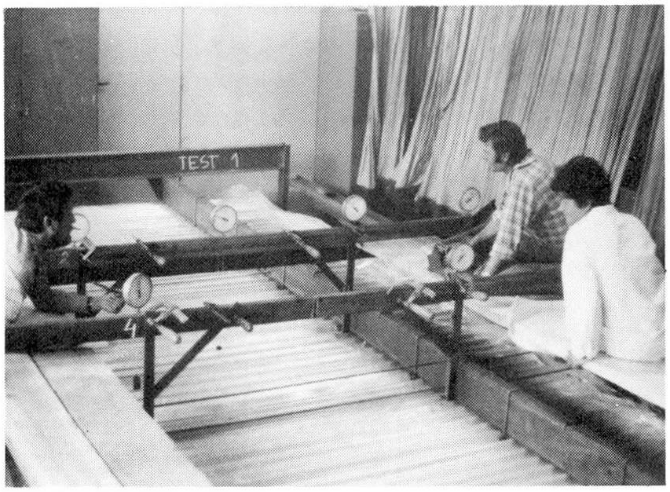


Fig. 10 Shot of Testing

The influence of sheeting and sag roads upon the behavior of restrained beams is studied under the conditions corresponding to the effect of wind uplift loading upon the secondary roof or wall structures.

Fig. 11 Local Buckling

Typical example of restrained general buckling of hot-rolled I - section is presented in Fig. 9. Also the general and local buckling tests of thin-walled cold-formed steel channel flexural members are being conducted (see examples in Fig. 10 and Fig. 11). From the test results follows that the ultimate buckling strength of restrained beams could be associated with conciderable lateral and distorsional deflections, their limitation should be respected deriving the design (specified) limit state. In thin-walled beams restrained by sag rods at third-point along the span the local buckling of compression flange can govern the ultimate strength in bending.

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