Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 49 (1986)

Artikel: Half-barrel shells composed of cold-formed profiles

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DOI: https://doi.org/10.5169/seals-38308

Half-Barrel Shells Composed of Cold-Formed Profiles

Coques hémicylindriques réalisées à l'aide de profilés minces formés à froid

Halbzylindrische Schalen aus dünnen kaltgeformten Profilen

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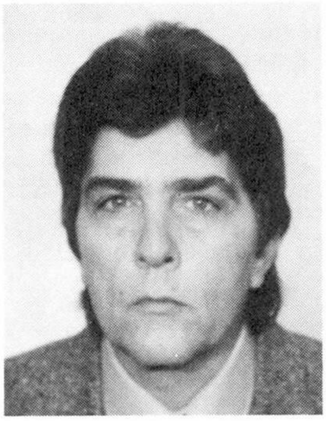

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SUMMARY

This paper reports the first stage of a research programme on static problems of half-barrel shells of cold formed thin profiles. The construction system consists of panels jointed together with a self-propelled sealing machine. The numerical and experimental study of the instability of the compressed «wings» of stiffening ribs is discussed.

RÉSUMÉ

Cette contribution concerne la première phase d'une recherche consacrée aux problèmes statiques posés par les coques hémicylindriques en profilés minces. Le système de construction consiste en des panneaux assemblés entre eux par sertissage à l'aide d'une machine automotrice. L'étude numérique et expérimentale de l'instabilité des ailes comprimées des raidisseurs y est présentée.

ZUSAMMENFASSUNG

Der Aufsatz berichtet über die erste Phase einer Forschungsarbeit betreffend statische Probleme von halbzylindrischen Schalen aus dünnen kaltgeformten Profilen. Das konstruktive System ist aus Blechen zusammengesetzt, die mittels einer selbstfahrenden Falzmaschine verbunden werden. Ein numerisches und experimentelles Studium der Instabilität von gedrückten Flanschen mit Versteifungsrippen wird präsentiert.

1. INTRODUCTION

Over the past several years, thanks to technological developments in industrial processes, cold formed steel sections have increasingly been employed in buildings as a material for integral solutions, and not only as an accessory material to be used for simple coating or cladding. One field of remarkable interest for the application of cold formed profiles is that of self-supporting cover structures for industrial buildings even of considerable span such as are employed, e.g. for industrial or agricultural storage, military hangars and temporary shelters. In these applications, the simplest and most widespread type is the half-barrel shell made of galvanized and prevarnished corrugated steel sheets (Fig. 1a).

The applications in building date back to the turn of the century (first patent 1896 in the USA) and have been extensively developed especially in America. The most currently used system is based on strips of arch-curved, transversally corrugated sheet, with wave depth depending on the different static requirements (Fig. 1b,c); the transverse connection is usually accomplished by bolts, screws or rivets.

In the system considered in the present work the arched panels are connected transversely by a self propelled machine which folds and seals the edges of the panels in a continuous way along the whole length of the arch (Fig. 2a,b).

The result is a semi-cylindrical shell with almost smooth internal surface and regularly spaced transverse external ribs, which consist of a web composed of two adjoining sheets and a folded and sealed wing three times thicker than the component sheet (Figs. 2b and 3). In effect, the need to slightly corrugate the webs of the ribs in the panel curving operation causes the two sheets of the web to be slightly divergent (Fig. 2c).

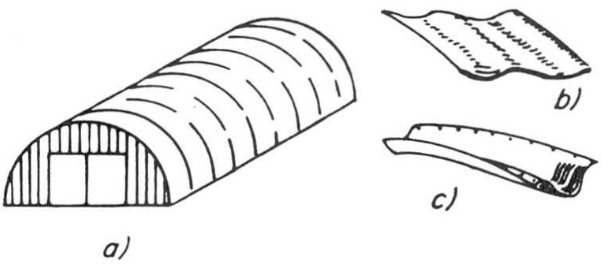

Fig. 1

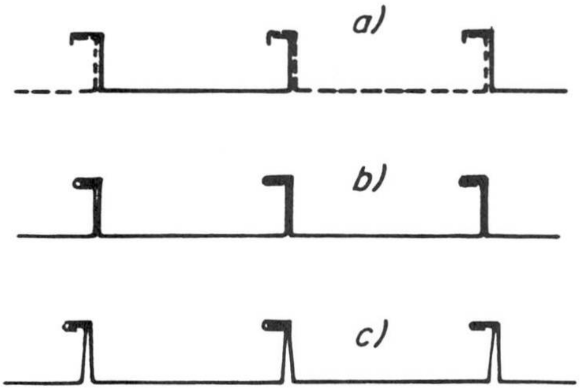

Fig. 2

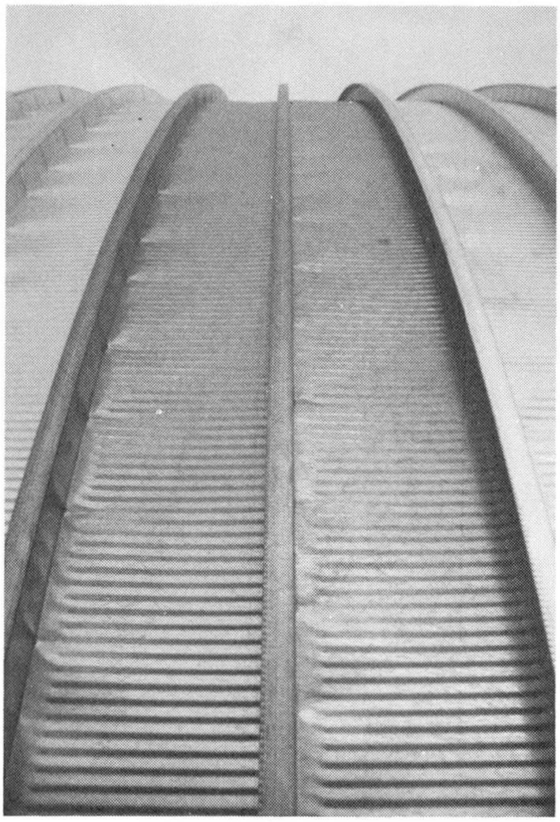

Fig. 3

The building system described above requires fairly short assembling times and, as the drilling of the sheets is avoided, ensures a perfectly watertight cover. With sheets less than 1mm thick and stiffener dimensions of the same order as those indicated in Fig. 5, arches with span of about 15-20 m can be obtained. The present paper reports on the early stages of a research aimed at ascertaining the effective strength of the structure under the usual snow and wind loads and defining with accuracy the maximum spans compatible with the geometry and thickness used.

2. STRUCTURAL ANALYSIS AND OUTLINE OF THE RESEARCH

The analysis of a semicylindrical structure of the type indicated in the preceding section should be performed by theoretical models which take into account the orthotropic behaviour of the shell [1,2,3,4]. The distribution of the loads is generally uniform along the longitudinal direction, and the ratio of length to span of the sheds is often very high, so that in the central zones the disturbance due to end diaphragms - if present - can be considered negligible; it seems therefore sufficiently correct - at least in an early stage of the analysis - to calculate the individual unit module transverse arches as if they were extracted from an infinite series of adjoining modules. In the specific case studied, this simplification appears even more justified in view of the high ratio of transverse to longitudinal stiffness of the sheet.
The distribution of variable loads, determined according to the usual assumptions of the most updated Codes, leads to load distributions such as are illustrated in Figure 4. With reference to the static scheme of the clamped arch, Figure 4 presents the bending moment diagram due to snow and wind loading.
The bending moment, which is associated with axial actions along the length of the arch, is the most important characteristic for the dimensioning of the structure. However, since the structural scheme is hyperstatic, the bending moment is - though to a small extent - a function of the tensional level, which in turn affects the width of the sheet area effective with the stiffener and, hence, the moment of inertia of the section.
The small thicknesses involved make it necessary that the complex stability problems on which the strength of the structure is dependent be analyzed with the utmost accuracy.
A first general problem is to determine the collapse due to the overall buckling of the compressed and bent arch and to check that this phenomenon is not too strongly affected by the progressive and high local deformations.
A second problem is to verify the zones of the arch subjected to the bending moment which compresses the internal fibres, i.e. the flat part of the sheet between the ribs. This is one of the classic issues in the analysis of cold formed profiles with extensive flat zones in their sections; it has been the object of vast theoretical and experimental investigations and has by now been defined and incorporated in the Codes of several countries. The usual approaches to the analysis of the behaviour of the compressed parts adjacent to stiffenings aim at the definition of "an effective width" or a "stress reduction factor" [5,6].

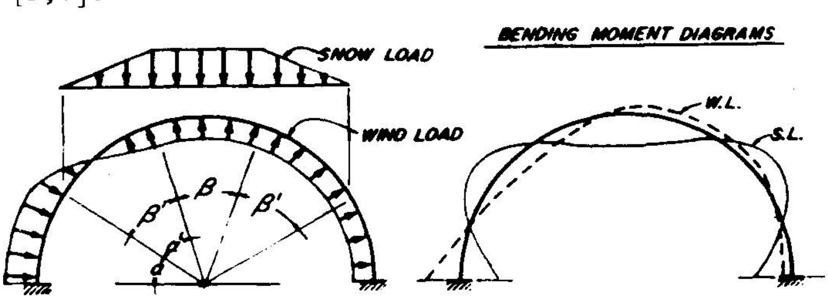

Fig. 4

The research under way will include experimental flexural tests to check the validity of these approaches and evaluate the influence of the slight transverse corrugations originated in the flat parts of the panels as a result of the curving operation.

The main problem tackled in the first stage of the research is the instabilization of the stiffener in those zones where the sign of the bending moment is such that the external fibres become compressed [7]. The study of this problem is similar to that of the behaviour of purlins for which the section (at I,Z,[) can no longer rotate torsionally in a free way because of the continuous connection between the upper flange and the roof sheet [8,9,10]. In the case under study, the problem is further complicated by the presence of the axial action associated with bending action (both of them being variable) and by the curvature of the structural elements.
The main purpose of the first stage of this research is to develop a numerical model based on the use of shell-type finite elements, in a geometrically non--linear field. The reliability of the model is verified through a series of tests on models of different span subjected to different distributions of the bending action. A numerical model taking into account also the hypothesis of non-linearity of the material seemed unnecessary because of the extremely limited capability of plastic redistribution in the structure. To facilitate the development of the above mentioned numerical approach, the first experiments were carried out on models with rectilinear axis obtained by using the panels before the curving operation.

3. EXPERIMENTAL ANALYSIS

The sheets used for the tests were 0.75 mm thick, without considering galvanizing and prevarnishing. The yielding stress, ultimate tensile stress and strain at fracture of the material were 305 N/mm^2, 370 N/mm^2 and 21%, respectively. Prior to the tests, the effectiveness of the transverse sealing of the sheet modules was verified: slip occured at a force about 1.05 kN per length of 100 mm.

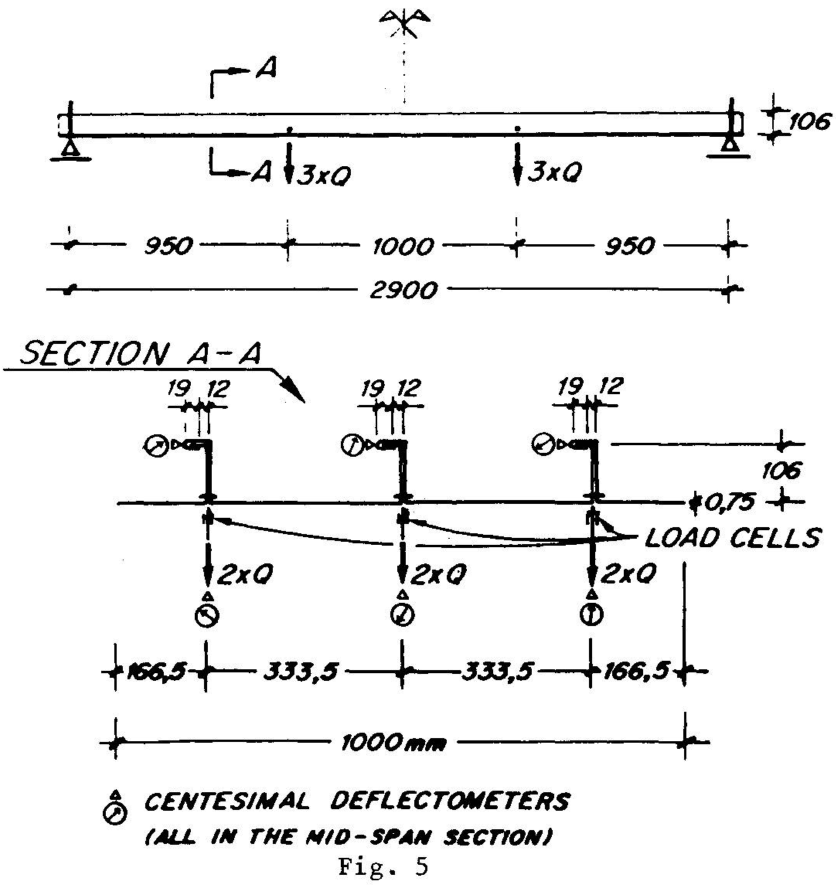

Fig. 5

The first models tested, were simply supported and consisted of three sheet modules, connected transversely but without edge supports, suitable to ensure the real structural continuity (Fig.5). In this way the tests were easier to perform, but the response was obviously characterized by more pronounced deflections (Fig. 6b), different than would have occured in an indefinite succession of modules (Fig. 6a). The ultimate load was, of course, much less than the value corresponding to the real situation.
In the tests, with deformation control, the load was applied progressively by means of pins, placed at the base of the webs, in

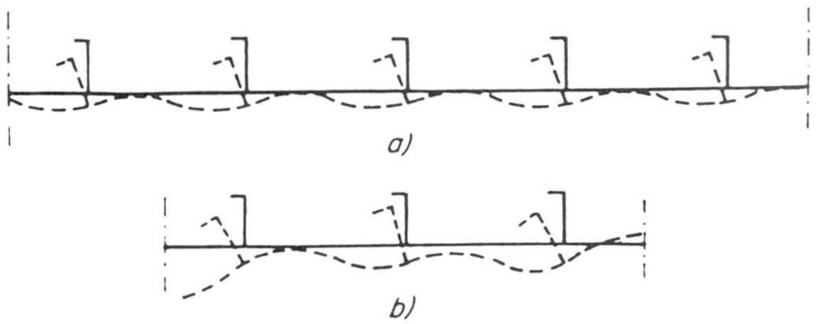

Fig. 6

two sections near the thirds of the span, and was nearly the same for the three stiffeners. The loading device was obtained through a particular system of pulleys, suitable to subdivide the total load into six equal parts. Load cells were located at each of the six points where the loads were applied. A series of centesimal deflectometers (Fig. 5) and of electrical strain gauges (Fig. 7) were placed in the midspan section.
Failure occured under a total load of 9.5 kN; yielding occured at the web-wing bend of one of the lateral stiffeners (Fig. 8) where the compression stresses due to both vertical and horizontal deflections add together.
The lateral deflection is much more marked in the lateral stiffeners, since the torsional rotation of the webs is strongly affected by the rotational stiffness of the tensile flange, which in the model is considerably lower at the edges.
The tests performed so far have confirmed the repeatibility of the phenomenon and the good accuracy of the theoretical model adopted to define the main features of the response of the structure.
The behaviour of the system is characterized by a sufficiently moderate and gradual geometric non-linearity, so that it can be easily followed through a non-linear numerical model based on the usual solving procedures which combine incremental methods with iterative techniques.

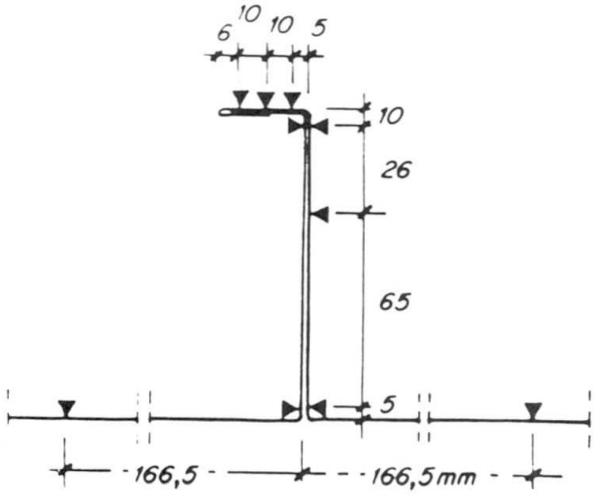

Fig. 7

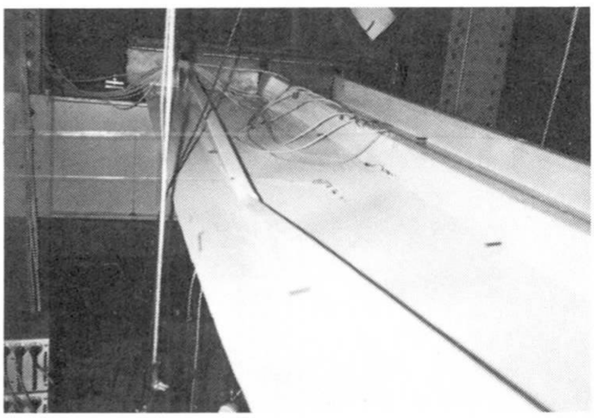

Fig. 8

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