Oct 23rd

Optimal Orientation of Corrugations in Beam Webs

Vladislav Belyaev

Tatyana Mikhailova

Tenth International Specialty Conference on Cold-formed Steel Structures
St. Louis, Missouri, U.S.A., October 23-24, 1990

OPTIMAL ORIENTATION OF CORRUGATIONS IN BEAM WEBS

Vladislav BELYAEV (1)

Tatyana MIKHAILOVA (2)

SUMMARY : On the basis of experimental investigations it was found out that the stiffeners in the form of closed corrugations in the webs of steel I-beams influenced their bearing capacity. Some beams with a various orientation of stiffeners relative to the chords were investigated. The structure of the beams with the closed, spaced at certain intervals, corrugations normal to the chords demonstrated the highest efficiency.

I. INTRODUCTION

Nowadays roll-formed sections and thin-walled welded beams occupy the more increasing field of application among bearing metal structures of industrial buildings and other constructions. These structures contribute to a considerable decrease of specific amount of metal per a supporting structure concurrently increasing its adaptability to manufacture. In this case, metal economy is closely connected with the problem of roll-formed sections and beams cross-section members thickness reduction which leads to the problem of their local stability to compressive and shear forces influence.

One of the solutions of the latter problem is in the strenghening of thin webs of roll-formed sections by forming closed corrugations spaced at certain intervals. This paper presents the results of the experimental investigation of closed corrugations of various orientation influence on the load-carrying capacity of steel I-beam webs.

II. EXPERIMENTAL TECHNIQUE.

Two specimens from each of six beam types were tested in accordance with the design scheme simulating the uniformly distributed load effect. The test rig was made of two frames, two supports and a distributing beam, which enabled to transform the forces from six jacks to the frame cross-bars. In one of the supporting joints a horizontal movement of the beams at deflection under loading was provided by means of rollers. The beams were anchored with roller stops, mounted on isolated posts in order to prevent the total buckling of the beams. (Fig. 1).

In the process of testing the following parameters were recorded:

- relative deformation of the web and the chords;
- out-of-plane deflection of the web;

---

(1) Chief of department of Central Research and Design Institute of Steel Structures (TSNIIPSK), Moscow, USSR.

(2) Researcher of Central Research and Design Institute of Steel Structures (TSNIIPSK), Moscow, USSR.

- total vertical deflections registered by deflectometers.

The load causing such deformations which increased without growth of the load applied, was taken as a critical one for the beam.

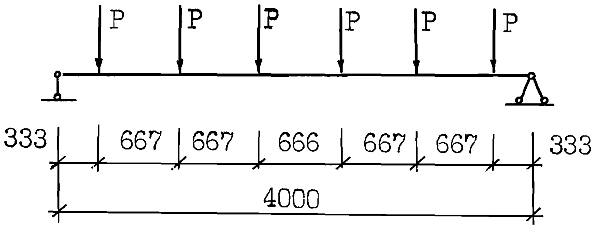

Fig. 1

The sections of high rigidity used as webs of the experimental beams were fabricated from a 1.8 mm thick sheet by forming corrugations at a hydraulic press. All six beam types had equal dimensions and differed either by the corrugations orientation or by their absence. The corrugation cross-section parameters were similar for all the beam types. As a result of some inaccuracy at the die fabrication flat parts of the web acquired a small curvature at forming, which is of a reverse direction relative to the corrugations.

A similar smooth-wall beam was taken for a comparison with a corrugated-wall beam. Max. value of the web initial out-of-plane deflection did not exceed 3 mm and that was an admissible value.

As a result of the determination of the mechanical characteristics of the steel used for the experimental beams the following values were obtained:

Specimen	σ_y MPa	σ_u MPa	δ %	ψ %
- δ = 1.8 mm	270.7	361.9	34.8	-
- δ = 10.0 mm	267.7	390.3	33.0	66.3

III. ANALYSIS OF THE BEAM FAILURE TYPE

At the loading of the beam БШП by the load (P=15 kN) approaching the ultimate load in the web supporting zones diagonal buckling waves of opposite direction developed. At the further increase of loading (up to P=1.8 kN) the waves with a specific "pop" transformed into triangular folds. Due to the buckling of the web the yielding of the upper flange metal began and as a result, the chord heavily deflected and approached the lower chord. The process of the beam deformation became of an irreversible character and the beam failed (Fig.2).

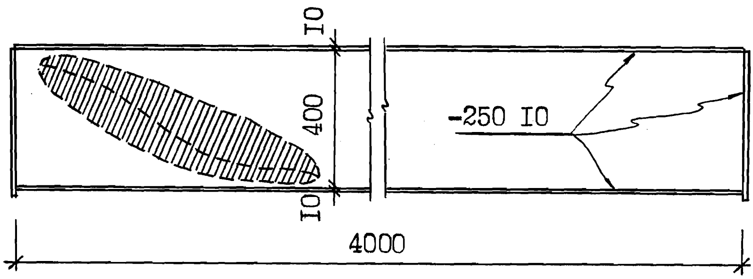

Fig. 2

A failure type of the beam БШВ with vertical corrugations was quite of a different character. Buckling of the web with corrugations began in one of the supporting sections at a relatively small loading. The web buckling gradually increased with the load increasing up to the beam failure (P=22.2 kN), i.e. the web buckling of the first row was not observed (Fig. 3).

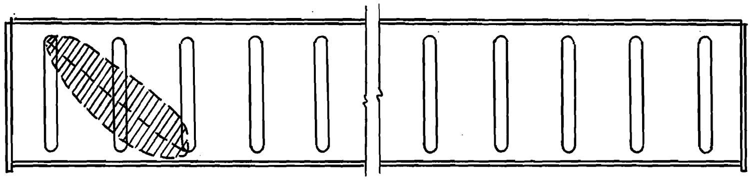

Fig. 3

The failure of the beam БШГ with two horizontal corrugations was caused by normal transverse compressive stresses in the central portion of the beam under the upper chord. In this case, no diagonal buckles in the supporting zones of the web were observed. A deeply formed horizontal corrugation under the upper chord simulated a hinge. As a result, even at a small load P=14.2 kN the upper chord failed according to the flexural-torsional type. As it is known, the more points of excessive bend the bent axis of a rod has, the larger a critical force should be. The web compressed between two corrugations as if between two hinges had only one excessive bend. The chords did not exert any restraint influence on the web (Fig. 4).

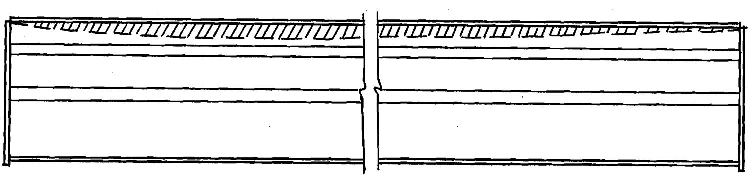

Fig.4

The failure character of the beam БШН was similar to that of the beams with completely corrugated webs. The diagonal buckles developed in one of the supporting zones at the flat portions of the web between the ascending corrugations. The closed corrugation ends in the tensioned zone of the web served as the centers of the buckles formation. When the load increased, the buckling waves spread to the upper corner of the beam through the corrugations. The beam БШН failed due to development of large plastic deformations in the upper chord at the load P=21.2 kN (Fig.5).

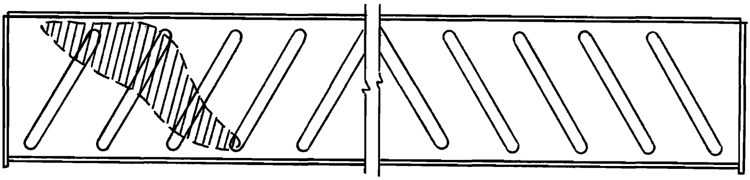

Fig.5

One of the beam БШЗ specimens had ascending supporting corrugations and the other - descending ones. In the first case the local buckling occurred in each supporting zone where two diagonal waves spread through two supporting ascending corrugations appeared. In the other specimen of the beam БШЗ the buckling wave was even more pronounced and propagated through the descending corrugation nearest to the support. In both cases the failure occurred at the load P=11 kN (Fig.6).

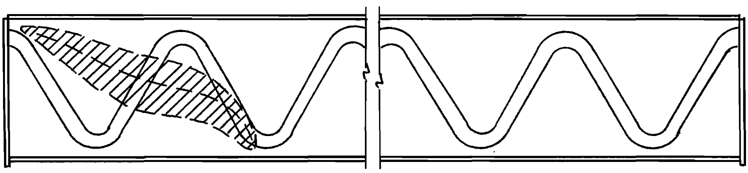

Fig.6

Local buckling of the web of the beam БШК with concentric squares was similar to that of the beam БШВ. At the load P=20.8 kN a diagonal fold developed in the supporting zone and the upper and bottom chords displaced in the approaching direction (Fig.7).

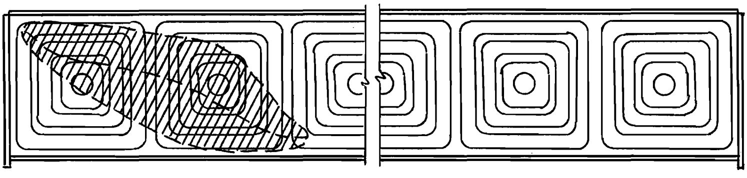

Fig.7

IV. EXPERIMENTAL RESULTS.

In the Table given below experimentally found values of ultimate load $P_{exp.}$ at each of six jacks corresponding to the failure of the beam tested are given. In the third column of this Table a uniformly distributed load value q_{exp} is given, which corresponds to six concentrated loads P, given in the second column. Two lines for each beam type correspond to two specimens of the given type.

Beam type	P_{exp}, kN	q_{exp}, kN/m	$\frac{P_{exp}}{P_{exp}^{БШП}} \cdot 100$, %
БШВ	22.0	33	125
	22.5	33.8	122
БШГ	13.7	20.6	78
	14.7	22.0	80
БШН	19.1	28.6	108
	23.3	35.0	126
БШЗ	11.0	16.5	62
	11.0	16.5	60
БШК	20.8	31.2	113
	20.8	31.2	113
БШП	17.6	26.4	100
	18.4	27.6	100

As it is obvious from Table, the beams БШВ with vertical corrugations possessed the largest average load-carrying capacity which exceeded that of the beams БШП by 23.5%. Such a result was obtained due to the fact that the web with vertical corrugations prevented the approaching of the chords when the beam was under loading in the higher degree than the flat web. That means that vertical corrugations considerably increased the local stability of the web.

The beams БШН with inclined corrugations and the beams БШК with concentric corrugations showed a slight decrease of a load-carrying capacity. However, the gain in their load-carrying capacity in comparison with the smooth-wall beams was 17%. That verifies the sound practice of inclined and concentric corrugations application. However, their 6% less in comparison with vertical corrugations effect may be due to the horizontal projection in the corrugation orientation, which leads to the reduction of the beams load-carrying capacity. Thus, for example, the buckling of the beams БШГ with horizontal corrugations occurred at the 20% lower load compared with the beams БШП. Such a behaviour of the corrugated webs depends on the parameters of their section. A deep section corrugation is alike a fold which does not work in the transverse loading. On the other hand, a deep corrugation allows a rotation of the flat parts of the web about it as if about a hinge.

The beams БШЗ demonstrated the lowest load-carrying capacity (P=16.5 kN which constituted 61% of the smooth-wall beam bearing capacity). In this case, Z-shaped corrugations reduced the strength of the beam section by simulating initial deformations in the direction coinciding with the diagonal buckling wave.

The largest rigidity at the loading near the critical level, i.e. the least buckling, demonstrated the beams БШВ with vertical and concentric corrugations. The smooth-wall beams showed the most buckling resistance at the preliminary stage of their loading. However, at the further increasing of the loading their rigidity turned to be worse than that of the beams with vertical corrugations. Z-shaped corrugation beams demonstrated the worse rigidity.

On the basis of above mentioned failure types of the experimental beams maximum stress intensity of the webs was observed in the supporting zones at the buckling diagonals.

As to the beams with vertical and inclined corrugations their stress intensity increased slowly with the load increasing unlike the beams with horizontal corrugations where the stress intensity increased mostly quick.

V. CONCLUSIONS

The carried out transverse bend testing of beams with various corrugations allowed to make a choice of optimal orientation of the web corrugations. The most effective turned to be a beam with vertical spaced at certain intervals corrugations. Its bearing capacity was higher than that of a smooth-wall beam by about 23.5%. This value for the beams with inclined and concentric corrugations constituted 17%, which verified the effectiveness of such types of corrugations. A negative result was obtained for the beams with horizontal and Z-shaped corrugations. This enables to consider a corrugation with such parameters as a fold, which does not work in a transverse loading.

The normal and tangential stresses acting in the web section had a Z-shaped character. Maximum stresses were observed at the crests of the corrugations. The stresses registered at the flat portions of the web corresponded to the smooth-wall analogues and were even lower. The main peculiarities of the webs with corrugations spaced at certain intervals lie in the fact that in the places of the corrugation ends the web is subjected to considerable local bending accompanied with a biaxial stress and a high degree concentration of local stresses. Simultaneously, an eccentric transfer of the forces in the web to the corrugation causes a reduction of normal stresses at the corrugation edges and at its crest comparing with the flat webs.

On the whole, the deformability of beams with corrugations (i.e. deflections and buckling of the web) was lower compared with the smooth-wall beams at a similar loading. That is due to the corrugations contributing to the beams rigidity.