

# DESIGN, ENGINEERING AND MANUFACTURING OF BEARING ELEMENTS OF THE LOW STEEL WEIGHT

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## INTRODUCTION

Efficiency of projected and erected constructions is directly connected with a structure and features of distribution of stress and deformations of bearing elements. One of the primary goals at projecting is reduction of cost of building, first of all, at the expense of decrease in steel intensity of constructions at the maintenance of their high bearing ability.

In constructions of civil, public and industrial buildings, bridges, platforms, crane beams of production buildings and other constructions, the beams, i.e. the bearing elements receiving action of the bending moments are widely applied.

Bearing elements of solid columns: columns of uniform cross-section on height and over crane parts of stepped columns represent a core subject to compression with a bend.

Sections of bearing elements traditionally accept in the form of compound I-girder. They are made by welded, riveted connections or with application of frictional bolted connections.

Beams of compound section are applied in cases when rolled beam sections do not satisfy conditions of resistance, rigidity, general stability, i.e. under long spans and large bending moments. The beam height is defined by economic reasons, permissible deflection, and in some cases, building height. The construction height of such sections reaches 1500 - 1800 mm and more.



Symmetric sections are usually applied to columns, for example, circular sections. Under large loads, use asymmetrical sections, with the prevailing unilateral bending moment.

## PERFORATION AS A WAY OF REDUCTION OF MATERIAL CONSUMPTION

### Traditional production techniques of a compound I-girder

Among many productions, the classical approach to manufacturing of bearing elements lowered materials consumptions is known: perforation of a wall of a solid rolling or a welded I-girder. However such technology does not always allow an I-girder of large height or to project cores of optimum section. Besides, unification of the constructive elements which are original assembly units on which base projecting of various constructions is possible is practically excluded.

Manufacturing of I-girders of the large height is carried out with application of welding technologies and special equipment. In particular, such special line of automatic welding under a flux material successfully works at the Holding «Protos Companies Group» in the Mogilev district. However the height of the I-girder on this line is limited 1500 mm.

Requirements to resistance, rigidity and to projecting of steel constructions in Belarus and Russia are regulated by Building specifications and rules (BS and R), for example [1, 11].

### Perforation of an I-girder wall

Resistance of beams and columns with cutouts (with the perforated wall), updating of methods of their calculation and rationality of application at different times has been considered by A.R.Rzhanitsyn, A.I.Skljadnev, V.M.Dobrachev, V.M.Daripasko, E.V.Litvinov, A.A.Jurchenko, T.M.Rogatovsky, A.I.Pritykin and other authors. Among foreign authors, it is possible to note works of F. Faltus, R.Nalleuh, I.E. Gibson, Century S. Jenkins, N.J. Gardner, M.Ngabok, A.Vazile and others.

Usually I-girders with perforated wall manufacture in a following order. The wall of a rolled section (figure 1) is cut on a zigzag broken line with a regular step by means of gas cutting or in powerful presses, and then both halves of the cut beam are joined by welding in the flanges of the wall combined among themselves. As a result, from the original rolled section, a beam with windows in the wall is formed.

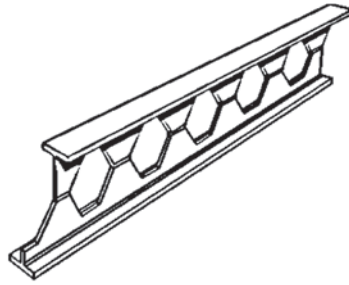


Figure 1. Compound I-girder with a perforated wall

Such an approach is not essentially new. It already has had time to prove its advantages: rationality of distribution of a material in the section at perception of operational loadings, decrease in weight and steel usage.

Constructive decisions of beams and columns with the perforated wall differ in a large variety, defined by variability of patterns of a wall cutting.

Most often the perforated bearing elements apply with regular cutting and identical height of zone I-girders (cores of symmetric section). At the Belarussian-Russian university the design of a column of the ring cross-section [2] made by a way of cutting, separation and welding of a wall of a pipe is offered and investigated.

#### Some features of manufacturing of the perforated elements

The perforated I-girder is made using standard technology, appears more difficult in structure and geometry, than a classical I-girder. If it is a question of sections in height from 0,7 m to 2,2 m for factories metal constructions, manufacture of the perforated products becomes rather unprofitable in connection with occurrence of considerable welding deformations and necessity of performance of special constructive-technological actions for their minimization.

The increase in height of I-girder, without serious reorganization of technological process of their manufacturing, is possible at use of the new technical decision offered in given work [3, 4].

## BEARING ELEMENT OF METAL CONSTRUCTIONS AND METAL CONSTRUCTION ON IT'S BASE

### The basic bearing element

Many constructions of perforated I-girders and design procedures of their resistance and the stability are offered, allowing considering the geometrical

form of perforation, their relative positioning and levels of concentration of tension near them [5–10].

Thus there is not solved a question of simplification of manufacture and installation of perforated I-girders with the big building height.

At the Belarussian-Russian University, in the co-authorship with “MIET” and Holding «Protos Companies Group», the constructive-technological decisions directed on simplification of a design and manufacturing techniques of the bearing element of metal constructions are offered: basic bearing element of metal construction (Figure 2). These offers are issued as demands for delivery of patents [3, 4] on the invention in the Republic of Belarus and in the Russian Federation.

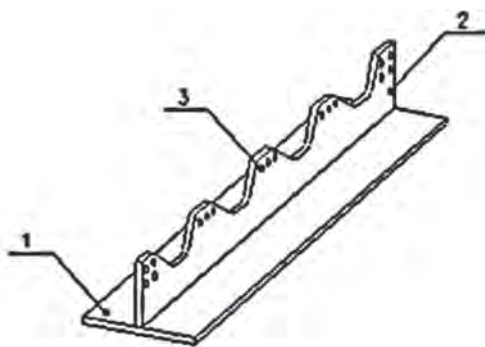


Figure 2. Basic bearing element of metal construction

Basic bearing element of metal construction represents a construction of a beam type of an I-girder. It consists of actually bearing element 1 and a wall 2 which are rigidly connected to each other. The wall 2 is carried out from sheet product with a variable height.

### **Metal construction based on bearing element of metal construction**

Depending on the design diagram and features of the constructive form of a construction, its function and conditions of loading and the maintenance, projected metal construction gathers from separate bearing element of metal construction. Elements, in turn, can install on a miscellaneous conditions in relation to each other and to other constructive elements of metal construction.

Connection of bearing elements of metal construction among themselves can be carried out by both welding, and frictional high-strength bolts with use of covers, plates and (or) braces. For this purpose, depending on the height of a part of an I-girder (Figure 2) one or several apertures of type 3 are carried out.

Thus, on the basis of bearing elements of metal construction structures of the various form and function can be created. Their description is resulted in the text of above mentioned applications. Simplicity of manufacturing, high bearing ability, the optimum constructive form, and optimum steel intensity is thus provided.

### Order of manufacturing of compound I-girder based on bearing element of metal construction

The compound I-girder on the basis of base bearing element of metal construction is shown in Figure 3 on which are marked:

the sizes of parent sheet of a wall:  $h$  – height,  $t$  – a thickness;

the sizes of a window:  $h_{\text{wind}}$  – window height,  $a_{\text{wind}}$  – width of a window,  $w_{\text{wind}}$  – distance between windows;

$h_{\text{perf}}$  – height of the perforated I-girder,  $b$  – width of a flange of an I-girder.

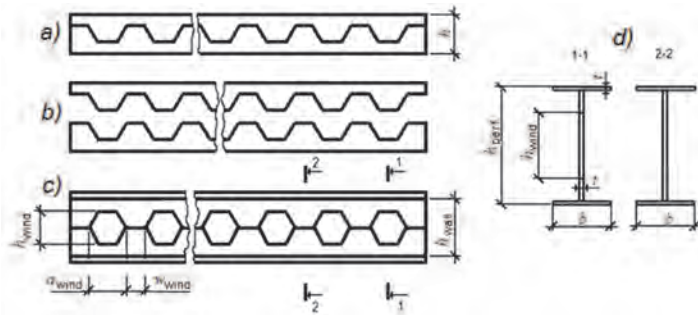


Figure 3. The order of manufacturing perforated girders on the basis of basic bearing element of metal construction (the technology is developed together with "Holding").

The following order of manufacturing is applied:

- a wall by means of welding connect to with flange sample: receive an I-girder, that is a base of bearing element of the metal construction (see Figure 2);
- parent sheet is cut (loosen) on the broken line which geometrical parameters should correspond the certain project to the form and the sizes of windows in wall of bearing element of metal construction (Figure 3 a). Two samples for a wall of an I-girder (Figure 3 b) receive. The cut geometry represents, for example, an isosceles trapezium with the rounded corners for reduction of influence of concentrators of pressure;

- for receiving of the perforated I-girder (Figure 3 c, section 1-1) manufacture two basic element of the metal construction, connect I-girders with their displacement from each other (Figure 3 d) with welding application, or connect covers on frictional high-precision bolts.

It is possible to manufacture various constructions from the basic bearing element of the metal construction having T-section which basis is made by beams and racks (column).

## TECHNIQUES OF THEORETICAL AND EXPERIMENTAL RESEARCHES OF WELDED I-GIRDERS OF THE NEW CONSTRUCTION

### Calculation techniques

In the given work techniques were used:

- engineering design procedures of beams and columns with a solid wall on the first and second limiting states, recommended by Steel Constructions [1, 11];
- calculation of beams with the perforated wall by a technique of the Kazan State University of Architecture and Engineering [12];
- calculation of columns by E.U.Fomenko's technique [13]: the perforated wall was replaced with solid by reduction of a thickness of the wall counted from equality of the moments of inertia of walls;
- calculations on the basis of platform ANSYS (software package ANSYS® Workbench). At creation of models of I-girders and columns, for definition of distributions of force and deformation fields, following types of final elements [14] were used: SOLID 186 – a three-dimensional element of the volume deflected mode with twenty knots; CONTA 174 - a three-dimensional contact element of type «a surface with a surface» with eight units; TARGE 170 – the three-dimensional reciprocal element having in the units mechanical degrees of freedom.

### Techniques of experimental researches

Reliability of results of calculations was estimated by their comparison with the data of measurements of stress and deformations with the subsequent definition of errors between them. In experiments samples of welded I-girders of the identical height, made on technology of Holding «Protos Companies Group» (Figure 4 a) were used.

In Figure 4 b the section A (0,471 m) is shown, in which normal stresses were defined, and in Figure 4 c - section K, in which the flexure of a column (0,724 m) was measured.

In Figure 5, for an example, the general view of the sample with the perforated wall before test is shown. Supporting elements on which beams were established, had on distance of 50 mm from end faces of the sample. Test samples were loaded with the concentrated force with step 10 kN, applied in the middle of span.

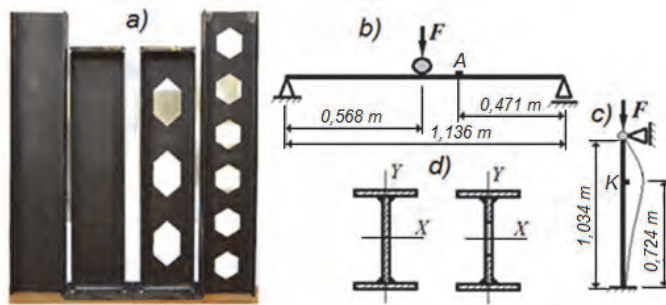
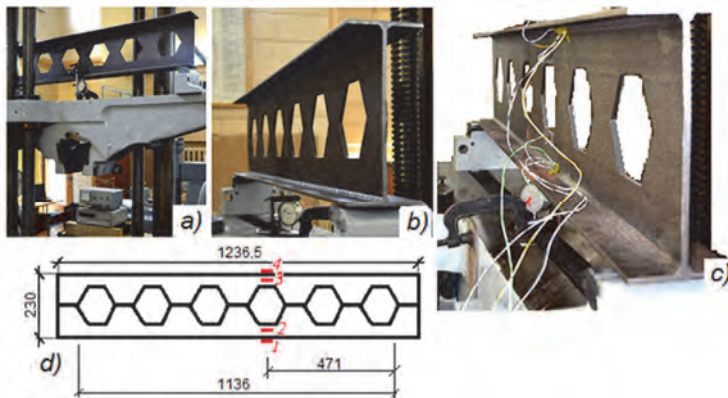


Figure 4. The Experimental samples made on technology of Holding «Protos Companies Group» (a) and test patterns of a bar (b, c)

Flexure was measured by the indicator of hour type «indicating gage-5» with the scale interval of 0,01 mm. Pressure was measured by means of wire resistance strain gages type of 2FPK-10-100-B in accordance with State Standard 21616-76 with resistance 105,34 - 105,66 ohm. They were established according to the pattern (Figure 5 d).



a) – the front view, b) - a side view, c) – a view from outside of resistance strain gages, d) – the installation pattern of resistance strain gages 1 – 4.

Figure 5. The General view of the perforated beam before test for a bend

## STRESS AND DEFORMATIONS OF BEARING ELEMENTS I-GIRDER SECTION

### Bending experiment

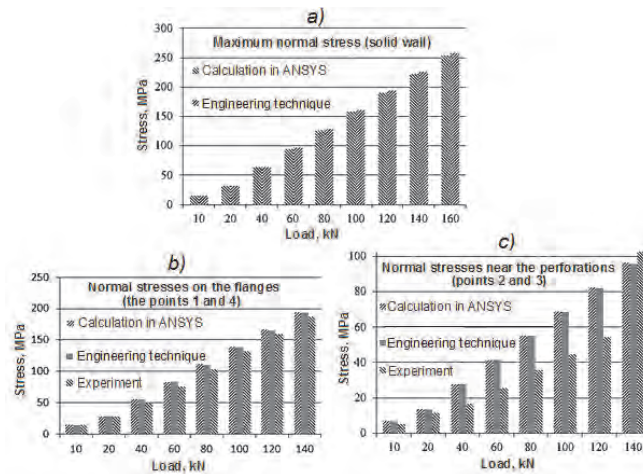
Results of experiments are stated in detail in [15]. According to calculation of bearing ability of samples on the first limiting state at a bend, the maximum rated loading makes: for an I-girder with a solid wall is 167,3 kN, with the perforated wall is 162,3 kN.

In Figure 6 results of calculation of the normal pressure, executed in ANSYS and by engineering technique, and also the experiment data (strain gauging) for a beam with the perforated wall are shown. Stresses were defined by their average values. The accuracy of results of calculations practically is absent. The error of measurements of the stress on flanges (the points 1 and 4) makes: with engineering calculation is 5,3 %, with calculation in ANSYS is 5,7 %. In the perforated wall (points 2 and 3) an accuracy above – accordingly 31,9 % and 32,4 %.

Sufficiently high convergence of calculations by applied techniques and experiments allows using confidently enough finite element method on the basis of complex ANSYS for the analysis of the deflected mode of constructions without carrying out of additional experimental researches.

### Stability experiment of a core

Columns in height of 1,075 m with solid and with the perforated wall were investigated. The test arrangement is presented in Figure 4c.



a) – maximum normal stress in the solid wall (midspan of the beam); b), c) – normal stresses in the perforated wall (layers of cross section of the beam weakened by perforation, see figure 5d): the points 1 --4 (b) and points 2 and 3 (c)

Figure 6. Normal stresses depending on loading

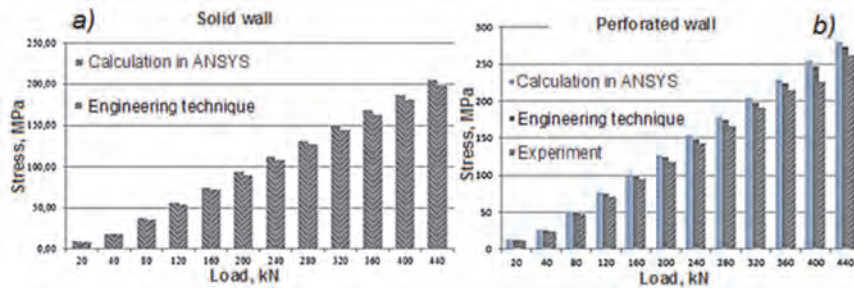


Measurement of normal stresses was spending in section of the perforated wall. Resistance strain gages at the height 0,537 m were symmetrized on either side of a window.

In the section of a column weakened by perforation, engineering calculation gives critical load 466,01 kN, in ANSYS – 460,82 kN. Critical load, by results of experiment, makes 440 kN.

In Figure 7 distribution diagram of normal stresses along an axis of columns with solid and with the perforated wall are presented.

The calculation error in ANSYS and results of experiment makes 4,73 %, engineering calculation on the resulted thickness and results of experiment is 24,5 %, engineering calculation in the section weakened by perforation and results of experiment is 5,9 %.



the column with a solid wall (a) and with perforated wall (b)

Figure 7. Distribution of normal stress along an axis of a column depending on loading

## COMPARISON OF BEARING ABILITY OF I-GIRDERS OF IDENTICAL STEEL INTENSITY

Bearing ability was estimated on the first (on the maximum normal stresses) and to the second (on the maximum deflections) limiting states. Steel intensity of the I-girder beam at a bend, at identical thickness of applied sheet product  $h$  and width of flanges is defined by height of a wall of an I-girder.

For comparison of bearing ability the I-girder in height of 200 mm is considered. At a thickness of sheet product of 4 mm and width of flanges of 100 mm, height of a solid wall is 192 mm.

The compound I-girder with the perforated wall from basic welded sections (on technology of bearing element of metal construction) is received by dissolution of sheet in height of 192 mm, with the subsequent welding of walls with flanges. Two sections gather with shift on flexures, and then their welding is carried out. The height of the received I-girder is 264 mm at height of a wall

of 256 mm. Thus, the height of an I-girder has increased in 1,33 times. Steel intensity has not changed.

By calculations in ANSYS the maximum normal stresses (figure 8) and flexures in the midspan (figure 8 b) in the I-girder with a solid wall and in compound I-girder and with the perforated wall are defined.

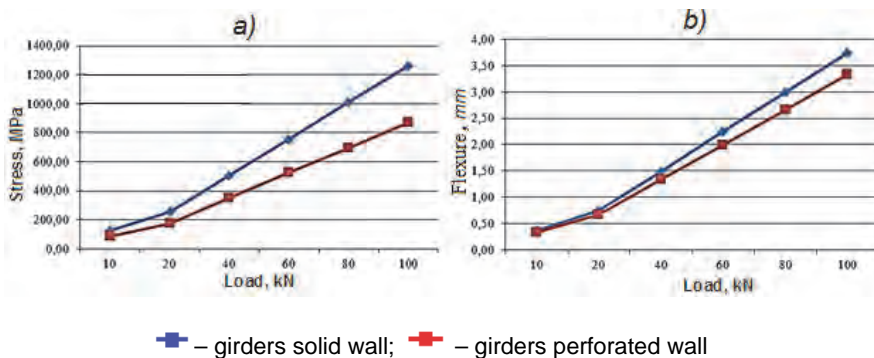


Figure 8. The maximum normal stresses and flexures in the midspan in the I-girder of identical steel intensity with the solid and perforated wall

The perforated construction on the basis of bearing element of metal construction (welded sections) wins not only on flexures (the difference in favour of the perforated wall makes 12,29 %), but also substantially on the maximum normal stresses in the flange (decrease on 44,75 % also in favour of the perforated wall).

The economy of metal of I-girder with the perforated wall in comparison with the I-girder with a solid wall, at their identical height, will make, depending on accepted geometrical parameters of dissolution of a wall, from 10 to 25 %.

## CONCLUSION

The new constructive-technological decision of forming of the constructive elements with the optimum geometrical parameters is offered, allowing reducing steel intensity of projected designs without decrease of their bearing ability.

The basis of constructive elements is the base bearing element of metal construction, which make by dissolution of sheet sample on the broken line which geometrical parameters should correspond to the form and the sizes of windows in wall bearing element of the metal construction, defined by the project. Two samples for a wall of an I-girder receive. The wall, by means of welding, incorporates to flange sample: receive an I-girder that is a base of bearing element of metal construction.

Sufficiently high convergence of calculations by various techniques with the data of calculation in the ANSYS is proved that allows using finite element method on the basis of complex ANSYS for the analysis of the deflected mode of constructions without carrying out of additional experimental researches.

Offered constructive-technological decisions allow to lower steel intensity of beams at least on 25 % (at identical height of a wall standard of I-girder sections and received on offered technology). Steel intensity of columns can be lowered on 15–25 % in comparison with the expense of metal on columns from rolling I-girders.

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