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Alternative engineering of steel girder cages by geometrical methods

Вариантное проектирование стальных балочных клеток геометрическими методами

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Abstract. Steel girder cages are widely used as plant buildings ceilings, bridge vaults, locks of hydraulic engineering constructions and other construction objects. An important task in case of their designing is the search of the most economic constructive decision with the smallest amounts of material. Therefore the great value in construction mechanics is attached to the development of methods of search of the most rational and optimal constructive solutions. The new technique of alternative engineering of steel girder cages with various cell forms, i.e. rectangular, triangular, rhombic and other, is offered. The technique is based on the principles of physicomechanical analogies and geometrical methods of construction mechanics. As a research object for a numerical example the girder cage of 12 x 6 m is considered. It has brick walls supporting. Girder profile is made of rolled sections, flooring is steel and solid. The studies showed that using a rhombic cage is the most economic.

Аннотация. Стальные балочные клетки широко используются в качестве перекрытий промышленных зданий, пролетных строений мостов, затворов гидротехнических сооружений и других объектов строительства. Важной задачей при их проектировании является поиск наиболее экономичного конструктивного решения, на выполнение которого затрачивалось бы наименьшее количества материала. Поэтому большое значение в строительной механике придают разработке методов поиска наиболее рациональных и оптимальных конструктивных решений. Предлагается новая методика вариантного проектирования стальных балочных клеток с различной в плане формой ячейки: прямоугольной, треугольной, ромбической и другой. Методика основана на использовании принципов физико-механических аналогий и геометрических методов строительной механики. В качестве объекта исследования для численного примера рассматривается балочная клетка размерами 12 х 6 м с опиранием на кирпичные стены. Сечения балок из прокатных профилей, настил стальной сплошной. Исследования показали, что наиболее экономичный вариант достигается при использовании ромбической решетки.

1. Introduction

Working platforms and many plants ceilings, bridge vaults, locks of hydraulic engineering constructions are often made in the form of steel girder cages. The design of a girder cage presents system of supporting girders of one or several directions intended for bearing existing loadings and their further transferring to columns or walls. Supporting girders are covered with steel, steel concrete or wooden flooring.

One of the major requirements when designing steel structures is metal economy as material cost makes more than a half of cost of designs. Therefore engineering of girder cages is conducted by comparison of a material capacity of various options of systems of supporting girders. Normal and complicated types of girder cages with a different spacing of flooring and minor girders and a cell are considered. The spacing of girders is set according to the existing loadings, the size of a flight, a type of flooring, purpose of the building, experience of engineering. For girders with steel flooring a usual spacing is from 0.6 m to 1.6 m, with steel concrete flooring it is from 2 m to 3.5 m, for minor girders it makes from

2 m to 5 m. Thickness of steel flooring is accepted from 6 to 40 mm. It is impossible to learn in advance what version of the project will allow the smallest material consumption. Therefore, when designing the supporting constructions the task of development of methods of search of rational and optimal constructive solutions is important [1,2].

Now computer programs of the final and element analysis of the intense deformed condition of designs are widely used as the tool of computing engineers, they are: SCAD, Nastran, Ansys, etc. [3, 4]. In tasks of alternative engineering and optimization of designs of steel girder cages numerical methods are also used [5, 6]. However, direct borrowing of universal numerical optimization methods which in some works are referred to as “search optimization methods” from mathematics leads to a problem of increase in dimension of tasks and significant growth in calculations in case of increase in number of project variables. Development of methodology of nonlinear mathematical programming should be pointed out from mathematical works on optimization methods for the purposes of designing and engineering of constructions. It requires accurate formalization in case of formulation of an optimization problem [7].

A set of methods which can be used when engineering supporting constructions is very broad: from rather universal, such as nonlinear programming and genetic algorithms, to problem-oriented [7-19]. All of them have advantages and disadvantages and means for setup which correct applying can strongly influence the speed of work of methods and even correctness of results.

In this work the new technique of alternative engineering of steel girder cages with various in the plan cell forms with the choice of the most rational constructive decision from a condition of the smallest material costs for its production is offered. The technique is based on use of the principles of physicomechanical analogies and geometrical methods of structural mechanics [20].

2. Methods

Geometrical methods of structural mechanics are based on mathematical analogy and the functional correlation, separate physicomechanical characteristics of the intense deformed status of plane elements of constructions (pressures, sags, oscillation frequencies, critical effort of loss of stability and others) in the form of plates, membranes, bar cross-sections with their geometrical parameters (sizes, angles, a ratio of the sides and so on). For this, it is necessary to choose some characteristic of a geometric shape for plates and membranes or of cross-section for the rods. And if it is proved that it is related to the parameters of the stress-strain state by some function or expression, then it is possible to study the change in the stress-strain state parameters using the chosen geometric characteristic.

The originators of geometric methods for solving some applied problems in the theory of elasticity and mathematical physics were the well-known American mathematicians G. Polia and G. Sege [21, 22]. They were the first to adapt the known isoperimetric theorem for applications in physics. The theorem states that of all flat shapes of equal perimeter the circle has the largest area. Assuming this, they have proved that of all plates of a given area with fixed contour, the circular one has the lowest fundamental frequency of vibration. In their studies, as a geometric characteristic of the shape of plates, they used the following isoperimetric quotient [22]:

$$\frac{4\pi A}{L^2}, \quad (1)$$

where *A* is area of a plate; *L* is perimeter.

As geometrical characteristics known also ones are: form coefficient [20], perimeter, inradius, circumradius, second moment of area and some other.

In this work we suggest using of mapping radiuses of the areas restricted to a circuit of plates, membranes, bar cross-sections. Mapping radiuses are the radiuses received in case of conformal mapping of plane area on an interior and exterior of a circle. They are known from the theory of conformal mapping [23, 24]. Where, the mapping of a shape (domain) onto another one, at which two curves, intersecting at an angle at the inner point of the first shape, are transformed into curves intersecting at the same angle at the inner point of the second shape, is called conformal mapping. In Figure 1 show an example of conformal mapping of a triangular domain onto a unit circle.

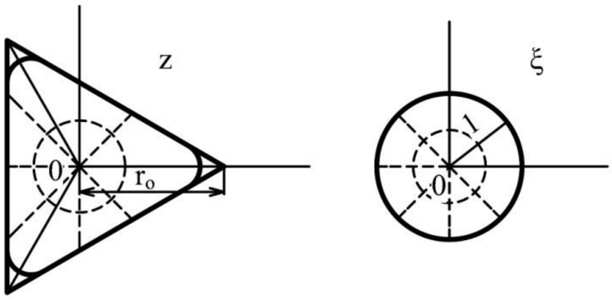

Figure 1. An example of conformal mapping of a triangular domain onto a unit circle

The mapping (Figure 1) is performed by the following function [25]:

$$z=\omega(\zeta)=0.566{,}100\cdot r_0\cdot\zeta+0.094{,}350\cdot r_0\cdot\zeta^4+0.044{,}929\cdot r_0\cdot\zeta^7+0.027{,}956\cdot r_0\cdot\zeta^{10}+ +0.019{,}712\cdot r_0\cdot\zeta^{13}+0.014{,}948\cdot r_0\cdot\zeta^{16}, \quad (2)$$

where z, ξ are the complex variables (the points of the complex plane); r_0 is radius of a circle circumscribed around a triangle.

2.1. Definition of terms

In case of mapping the domain z onto the interior of a circle in the plane ξ, an arbitrary point belonging to domain *z* shifts to the center of the circle. The circle is characterized by an internal mapping radius $\dot{r}$.

If in a simply-connected domain z we consider an infinitely remote point z = ∞, then this domain should be conformally mapped onto the outer domain of a circle in the plane ξ so that the infinitely remote point returns into itself. The radius of the circle is called the outer radius of the domain z and its length is denoted by the symbol $\bar{r}$ [24].

2.2. Formulae

Formulas for finding internal $\dot{r}$ and external $\bar{r}$ mapping radiuses for some singly connected domains take the form [22, 26]:

– for a radius circle *a*

$$\dot{r}=a,\quad \bar{r}=a; \quad (3)$$

1.

– for the correct n-squares

$$\dot{r}=\frac{G\left(1-\frac{1}{n}\right)}{2^{1-\frac{2}{n}}G\left(\frac{1}{2}\right)G\left(\frac{1}{2}-\frac{1}{n}\right)}L,\qquad \bar{r}=\frac{G\left(1+\frac{1}{n}\right)}{2^{1+\frac{2}{n}}G\left(\frac{1}{2}\right)G\left(\frac{1}{2}+\frac{1}{n}\right)}L, \quad (4)$$

where *n* is number of the sides; *L* is perimeter; G(x) is Gamma-function;

– for random triangles with angles $\pi\alpha$, $\pi\beta$, $\pi\gamma$

$$\dot{r}=4\pi\cdot f(\alpha)f(\beta)f(\gamma)\cdot\rho,\qquad \bar{r}=\frac{A}{\pi\dot{r}} \quad (5)$$

where

$$f(x)=\frac{1}{G(x)}\left\{\frac{x^x}{(1-x)^{1-x}}\right\}^{\frac{1}{2}}; \quad (6)$$

ρ is a long radius; *A* is square; *x* is α or β or γ; G(x) is the same that in (4).

– for isosceles triangles with angles $\alpha = \beta$ expressions (5) will take the following form:

$$\dot{r} = 4\pi \cdot f^2(\alpha) f(\gamma) \cdot \rho; \quad \bar{r} = \frac{ctg\alpha \cdot h^2}{\pi \dot{r}}, \tag{7}$$

where α is an equal base angle; h is height;

– for rectangular triangles (α = π/2) from expression (5) follows

$$\bar{r} = \frac{\sin 2\alpha \cdot c^2}{4\pi \dot{r}}, \tag{8}$$

where α is angle in case of hypotenuse; c is hypotenuse;

– for rhombs with angle $\pi\alpha$

$$\dot{r} = \frac{\pi^{\frac{1}{2}}}{G\left(\frac{\alpha}{2}\right) G\left(\frac{1-\alpha}{2}\right)} L, \quad \bar{r} = \frac{\pi^{\frac{1}{2}}}{8G\left(1-\frac{\alpha}{2}\right) G\left(\frac{1+\alpha}{2}\right)} L; \tag{9}$$

where G(x) and *L* is the same that in (4);

– for ellipses with semiaxis *a* and *b (a ≥ b)*

$$\dot{r} = \bar{r}\left\{\sum_{n=0}^{\infty} q^{n(n+1)}\right\}^{-1} \left\{1 + 2\sum_{n=1}^{\infty} q^{n^2}\right\}^{-1}, \quad \bar{r} = \frac{a+b}{2}, \tag{10}$$

where

$$q = \frac{(a-b)^2}{(a+b)^2}; \tag{11}$$

– for rectangles with the sides *a* и *b (a* ≥ *b*)

$$\dot{r} = \frac{2}{\pi} b \left(1 + 2\sum_{n=1}^{\infty} q^{n^2}\right)^{-2}, \quad \begin{cases} \dfrac{a}{\bar{r}} = \pi \cos^2 \alpha \displaystyle\sum_{k=0}^{\infty} \frac{\left((2k-1)!!\right)^2}{2^{2k}(k+1)!k!} \cos^{2k} \alpha; \\ \dfrac{b}{\bar{r}} = \pi \sin^2 \alpha \displaystyle\sum_{k=0}^{\infty} \frac{\left((2k-1)!!\right)^2}{2^{2k}(k+1)!k!} \sin^{2k} \alpha, \end{cases} \tag{12}$$

where $q = e^{-\frac{\pi a}{b}}$, α is argument of complex numbers (circle points which images are rectangle vertexes in case of conformal mapping).

2.3. Mathematical functional correlation

Mathematical analogy and the functional correlation of mapping radiuses with characteristics of the intense deformed status of elements of constructions in the form of plates, membranes, bar cross-sections are defined in works [27, 28].

Since the stress state of a plate in bending is under consideration, then, the resulting relationship for the maximum deflection of a plate should be also considered. The maximum deflection of a plate $w_{\max}$ is connected with mapping radiuses $\dot{r}$ and $\bar{r}$ by expression [27]:

$$w_{\max} \le \pi k \left(\frac{\dot{r}}{\bar{r}}\right) \cdot \frac{qA^2}{D}, \tag{13}$$

where k – the numerical constant turning expression into equality for round plates, in case of a hinged fixing of a plate k = 1.96, in case of rigid restraint of a plate k = 0.504; q – uniformly distributed load; A – area of a plate; D – cylindrical rigidity of a plate:

$$D=\frac{Et^3}{12(1-\nu^2)}\ . \tag{14}$$

where E – modulus of elasticity; t – thickness of a plate; ν – Poisson’s coefficient.

The expression (13) shows, that maximum deflection of a plate $w_{\max}$ is directly proportional to mapping radiuses $\dot{r}$ and $\bar{r}$. It means that, the change in maximum deflection $w_{\max}$ for plates of various shapes can be studied by defining the change in mapping radiuses $\dot{r}$ and $\bar{r}$. Mapping radiuses $\dot{r}$ and $\bar{r}$ in expression (13) characterize the geometric shape of a plate.

3. Results and Discussion

In work [29] the technique, an algorithm (Figure 2) and the special computer program “RR Geometric Modeling” the certificate on No 2013613173 patent of Russia (fig. 3) on alternative engineering of plate and rod load-bearing units by geometrical modeling of their form from a condition of equal rigidity was developed.

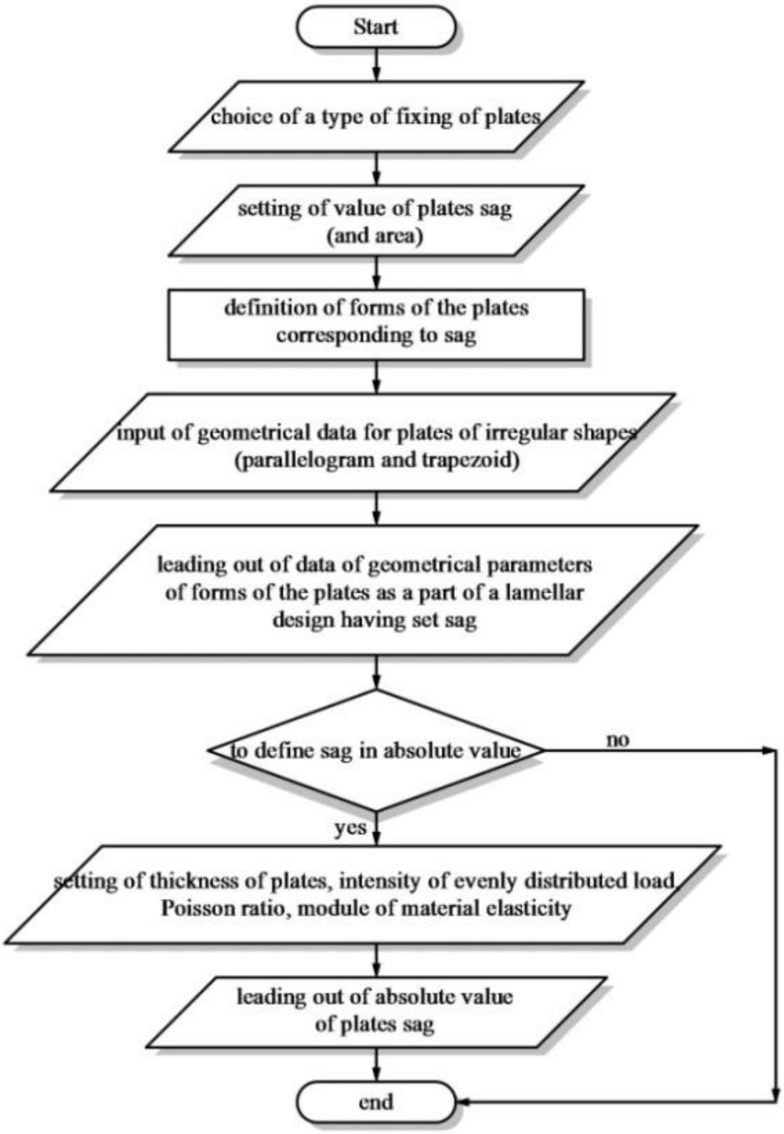

Figure 2. Algorithm of the computer program “RR Geometric Modeling”

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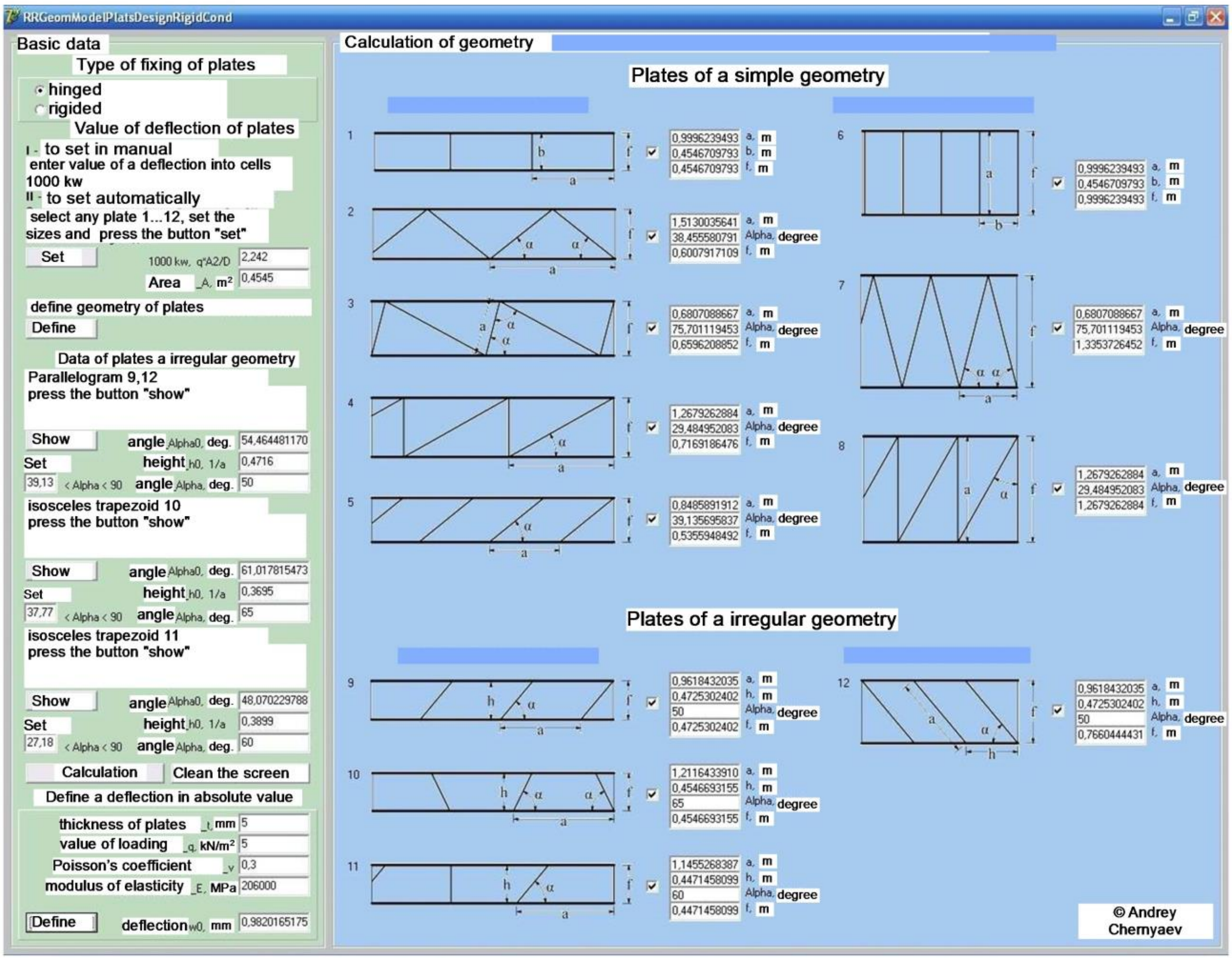


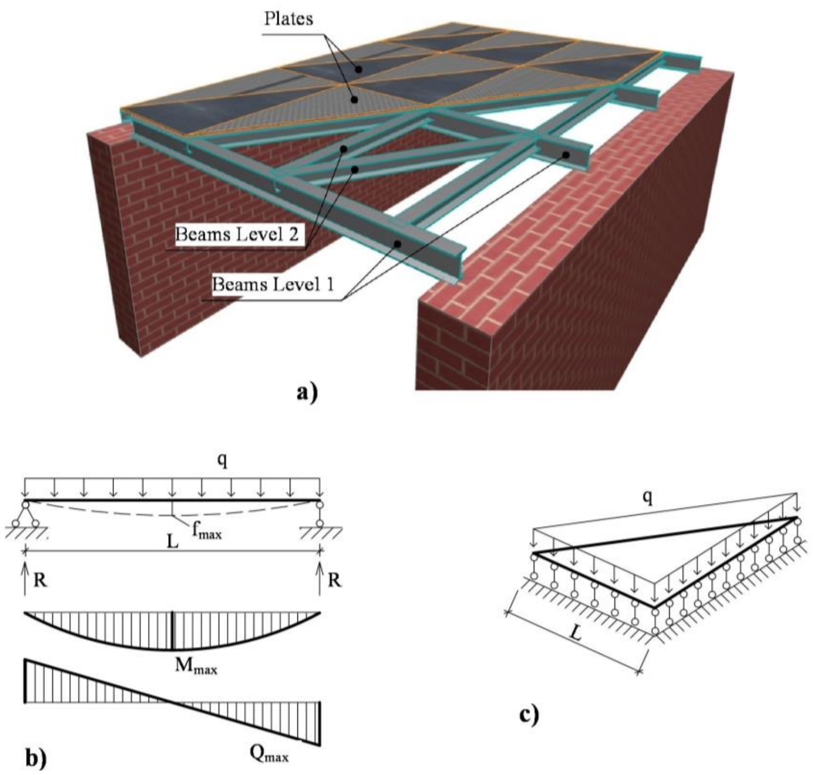
Figure 3. Working window of the computer program "RR Geometric Modeling"

The program performs the following procedure. The method of fixing of plates on a contour is chosen: either hinged fixing or tough jamming. Plates are a part of the supporting panel with two basic parallel guideways (longerons, girders). Plates loading is considered regularly distributed on the entire surface. Restriction for plates sag is set. The program considers plates of various forms in the plan (rectangular, triangular, rhombic, parallelogram, trapezoid) and determines their geometrical parameters corresponding to the set sag. In other words, the program determines geometry of plates (the sizes of sides, corners, sides ratio, etc.) of various forms which provide identical set sag to all the plates.

Let us consider use of this program and a technique [29] for alternative engineering of a steel girder cage.

The model of a steel girder cage represents a cross system of cores of the first and second levels which support plates. Girders are designed in the form of rods; the steel flooring is designed in the form of thin plates. Girders of the first level are freely based on walls, such binding is considered hinged. Girders of the second level are connected to girders of the first level by means of steel slips on bolts, such binding is considered hinged. The steel flooring is welded to flooring girders by means of semi-automatic welding. Strictly speaking, such binding is considered tough, however in calculations such binding is considered hinge fixed in safety margin of material (Figure 4).

Rods and plates under the influence of vertical loading experience the intense deformed condition of a cross bend. In case of this type of the intense deformed condition determination of the necessary sizes of bar cross-sections and plates is conducted from strength conditions (on the allowed stress) and rigidity (on the allowed deflection) [30, 31].



a) general view, b) model of flooring beams, c) model of a flooring

Figure 4 Steel girder cage supported by walls

At loading $q < 50$ kN/m^2 flooring strength is provided and its rigidity is calculated. The maximum permissible ratio of span of beam L to its thickness t is determined by A.L. Teloyan's formula [1]:

$$\frac{L}{t} = \frac{4 \cdot n}{15}\left(1 + 72\frac{E_1}{n^4 \cdot q}\right), \tag{15}$$

where E_1 – flooring cylindrical rigidity:

$$E_1 = \frac{E}{1-\nu^2} = \frac{2.06 \cdot 10^4}{1-0.3^2} = 2.26 \cdot 10^4 \, \frac{kN}{cm^2},$$

where $E = 2.06 \cdot 10^4$ kN/cm^2 – modulus of elasticity of steel; ν = 0.3 – Poisson's coefficient of steel; n – quantity inverse to a limit relative flooring sag; q – uniformly distributed load of a flooring.

The equation of strength of flooring girders has a form [30]:

$$\sigma = \frac{M_{max}}{c_1 W} < R_y \gamma_c, \tag{16}$$

where σ – normal stress; M_{max} – the maximum bending moment; c_1 – coefficient considering development of plastic deformations in section; W – moment of resistance of cross section; R_y – proof strength; γ_c – condition load effect factor of a girder.

The maximum bending moment (Figure 4, b) [1]:

$$M_{max} = \frac{qL^2}{8}. \tag{16}$$

From a formula (16) we define the required moment of resistance of girder cross section:

$$W = \frac{M_{max}}{c_1 \cdot R_y \cdot \gamma_c}, \tag{18}$$

The condition of flooring girders rigidity has a form [1]:

$$f_{max} = \frac{5}{384} \cdot \frac{q \cdot L^4}{E \cdot J} < f_u . \tag{19}$$

where f_{max} – maximum deflection of beam; J – moment of inertia of girder cross section; f_u – allowed deflection.

The maximum deflection of a plate $w_{\max}$ is connected with mapping radiuses $\dot{r}$ and $\bar{r}$ by expression (13).

Normal σ_x, σ_y, and tangent τ_{xy} stress are defined through sag w plate by means of the known formulas of the theory of elasticity [18]:

$$\begin{cases} \sigma_x = -\dfrac{E\gamma}{1-\nu^2}\left(\dfrac{\partial^2 w}{\partial x^2} + \nu \dfrac{\partial^2 w}{\partial y^2}\right), \\ \sigma_y = -\dfrac{E\gamma}{1-\nu^2}\left(\dfrac{\partial^2 w}{\partial y^2} + \nu \dfrac{\partial^2 w}{\partial x^2}\right), \\ \tau_{xy} = -\dfrac{E\gamma}{1+\nu}\dfrac{\partial^2 w}{\partial x \partial y}. \end{cases} \tag{20}$$

where $\dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2}$ - Laplacian operator; x, y, γ - working space coordinates.

We will carry out the search of versions of constructive solutions for steel girder cages in the following sequence.

1. Restriction for flooring sag is set according to existing rules [31].

2. By a formula (15), flooring thickness is defined according to a range on the operating loadings.

3. By means of formulas (20) flooring stress through a sag are defined.

4. By means of the special computer program (Figure 3) the sizes of plates of various forms in the plan are defined: rectangular, triangular, rhombic, parallelogram, trapezoid. All plates have the identical maximum stress and a sag, the identical area, but a different form and sizes.

5. Cross sections of girders of the second level are defined. For this purpose loads of girders transferred from flooring are gathered. By means of a formula (18) the required girder section is defined. Section is accepted according to a range of rolled iron. The condition of rigidity is checked (19).

6. Cross sections of girders of the first level are defined. For this purpose loads of girders transferred from above from girders of the second level and flooring are gathered. Similarly, by means of a formula (18) the required section of a girder is defined and is accepted according to a range.

7. Ceiling is done with the received variants of girder cages.

8. We determine the mass of material which is spent for each option of a girder cage. We compare material capacity and choose the variant with the smallest material consumption. This option will be the most economic.

Let us consider a numerical example. It is necessary to design a steel girder cage of a plant building with sizes in axes: length is 12 m, width is 6 m. Basic data:

Material – C245 steel, calculated resistance R_y = 23 MPa [30].

Flooring – solid steel in accordance with State Standard Specification 19903-74 on sheet steel.

Girder section of a flooring of the second level – equilateral angle in accordance with state standard specification 8509-93.

Girder section of a flooring of the first level – either flange beam in accordance with state standard specification 8239-89, or a channel in accordance with State Standard Specification 8240-89.

Load of ceiling – q = 5 kN/m^2.

Solution.

1. According to the operating construction regulations [31] the flooring and girders sags of designs of coverings and ceilings mustn't exceed extreme value which depends on flight. For a flooring flight width, as a rule, doesn't exceed L = 3 m. For this flight the permitted sag constitutes 2 cm.

2. We determine the required thickness of flooring by a formula (15):

$$\frac{L}{t} = \frac{4 \cdot n}{15}\left(1+72\frac{E_1}{n^4 \cdot q}\right) = \frac{4 \cdot 150}{15}\left(1+72\frac{2.26 \cdot 10^4}{150^4 \cdot 5 \cdot 10^{-4}}\right) = 297, \quad (15)$$

where n = 150 is quantity inverse to a limit relative sag of flooring according to [31].

So, $t = \frac{L}{297} = \frac{300}{297} = 1.01$ cm. In accordance with State Standard Specification 19903-74 we accept t = 10 mm.

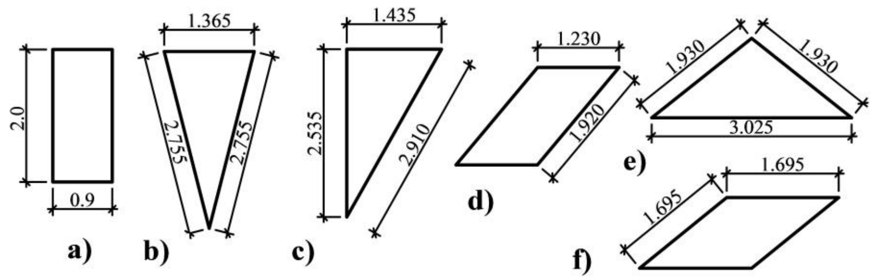
Taking into account dead load flooring load will constitute:

$$q_1 = q + g_1 = 5 + t \cdot A \cdot g_{steel} = 5 + 0.01 \cdot 1.8 \cdot 78.5 = 5 + 1.41 = 6.41 \text{ kN/m}^2,$$

where A = 1.8 m^2 – we set the area of plates, g_{steel} =78.5 kN/m^2 – dead load of steel.

3. According to formulas (20) we will receive the maximum operating stress in the middle of flooring of $\sigma_x = 40.4$ MPa, $\sigma_y = 18.5$ MPa, $\tau_{xy} = 18.4$ MPa.

4. With the help of the computer program "RR Geometric Modeling" (Figure 3) we determine the sizes of plates of a various form (Figure 5). All plates have identical values of the maximum tension of 40.4 MPa, sag of 2 cm and identical area A = 1.8 m^2.



a) rectangular, b) isosceles triangular extended down, c) rectangular triangular, d) parallelogram, e) isosceles triangular extended across, f) rhombic

Figure 5. Plate of various forms of identical strength and rigidity

5. Loading which is transferred to flooring girders of the second level along perimeter of plates P will make:

$$q_2 = \frac{q_1 \cdot A}{P} = \frac{6.41 \cdot 1.8}{P} = \frac{11.54}{P}. \quad (21)$$

Perimeter of a rectangular plate (Figure 5, a):

P = (2+0.9) *2 = 5.8 m,

perimeter of an isosceles triangular plate (Figure 5, b):

P = 2.755*2+1.365 = 6.875 m,

perimeter of a rectangular triangular plate (Figure 5, c):

P = 2.535+2.910+1,435 = 6.88 m,

perimeter of a parallelogram plate (Figure 4, d):

P = (1.920+1.230) *2 = 6.3 m,

perimeter of an isosceles triangular plate (Figure 5, e):

P = (1.930+3.025) *2 = 6.88 m,

perimeter of a rhombic plate (Figure 5, f):

P = 1.695*4 = 6.78 m.

6. Loading which is transferred to flooring girders of the first level from girders of the second level will constitute:

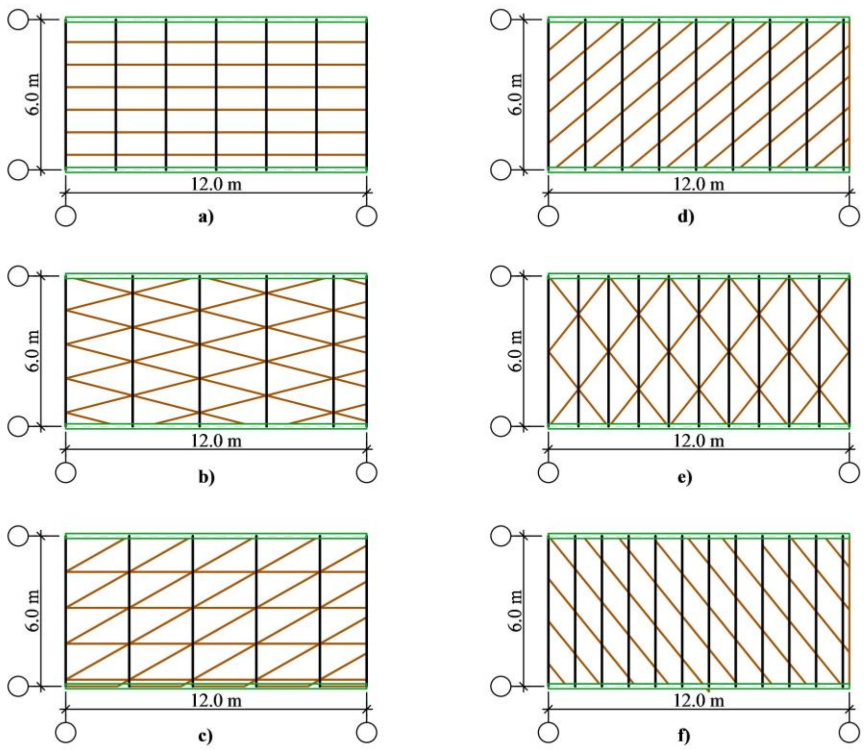
$$q_3 = \frac{Q_{max}}{n_1}. \quad (22)$$

where Q_{max} – bearing reaction of girders of the second level (Figure 4, b), n_1 – spacing of flooring girders of the second level.

Results of determination of cross sections of flooring girders of the first and second levels from a condition of strength (15) in the maximum bending moment M_{max} in the middle of flight (Figure 4, b) and conditions of rigidity (16) are given in table 1. In Figure 6 the received options of girder cages are shown.

Table 1. Results of calculations

A girder cage variant (fig. 6)	Thickness of flooring t, mm	Section of girders of the second level	Section of girders of the first level	Materials consumption, kg
1	2	3	4	5
a)	10	angle 70x7	flanged beam No 24	1,679
b)		angle 90x7	flanged beam No 27	2,053
c)		angle 90x8, 75x9	flanged beam No 27	1,973
d)		angle 70x6	channel No 22	1,637
e)		angle 75x5	channel No 20	1,657
f)		angle 70x4.5	channel No 18a	1,616



a) rectangular, b) isosceles triangular extended down, c) rectangular triangular, d) parallelogram, e) isosceles triangular extended across, f) rhombic

Figure 6. Obtained options of steel girder cages with various cells

The analysis of a material consumption of the received options (column 5 of Table 1) shows that the most economic option is reached when using a rhombic cells.

The reliability of the offered new technique is confirmed by numerical studies. Test problems were solved to determine the variants of girder cages with different cells in terms of different loads. The resulting girder cages were created in the form of a finite-element plate-rod model in the SCAD program [3]. Using the built-in module for checking the bearing capacity of steel structures on the set of rules "Steel structures", the load-carrying capacity of the floor girder, secondary girders and flooring for the calculated combinations of forces from the payload and the load from its own weight was checked. The check confirmed the use of the bearing capacity of the selected cross sections and plates close to the maximum with coefficients of use of 0.9-1 depending on the number of the rolling section. A deflection was checked for the flooring. The values deduced in the SCAD program for plates of various shapes were approximately the same with an error of 5–10 %, for plates with sharp angles somewhat higher. They corresponded to the given permissible deflection. When the model was shattered by a smaller grid, a smaller error was achieved. The material capacity was automatically counted in the SCAD program [3] and manually.

4. Conclusions

1. There was offered the new technique of alternative engineering of steel girder cages with various in the plan cell forms with the choice of the most rational constructive decision on a condition of the smallest material costs for its production, on the basis of geometrical methods of structural mechanics.

2. Numerical example of alternative engineering of steel girder cage of plant building shows the possibility of real engineering of designs of this kind on the basis of the developed technique.

3. The offered technique can be used when designing this sort of constructive systems.

4. The reliability of the offered new technique is confirmed by the solution of the test problems of designing steel girder cages of various shapes for different loads and by comparing the obtained results with the results of numerical studies obtained using the SCAD Office software.

5. Shows that the most economic option is reached when using small cells.

6. It is shown that the use of a fine grid in comparison with a large grid allows saving material of steel for producing a girder cage up to 20 %.

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