TENSELY- STRAINED STATE AND ALLOCATION TECHNIQUE OF STEEL PROFILED DECKING

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Steel profiled sheets with a trapezoidal cross-sectional form of corrugations are a thin-sheet multi-span spatial system. Theoretical description of the stress-strain state of such a structure during static operation is associated with great difficulties due to the fact that the actual carrying capacity and rigidity of the profiled sheets are significantly affected simultaneously by such factors as the stability of compressed faces, shape variability of the profile cross section over the supports, heterogeneity of the carrying capacity of middle and outer corrugations and a number of others. In this connection, in the first studies, the profiled sheets were somewhat simplistically considered as beam systems operating according to the slit or non-slit scheme depending on the number of spans. In this case, the internal forces arising in the sheets are determined by the rules of structural mechanics, as in elastic systems.

The bearing capacity of the decking in a continuous operation scheme is mainly determined by the stress-strain state above the support part, where the value of the bending moment is greatest and in this place the corrugation wall operates in a complex stress state determined by the action of significant compressive stresses and local normal stresses arising along the contact line of the wall with the surface of the run on which the decking rests. At the same time, longitudinal compressive stresses arise in narrow shelves of the decking, and tensile stresses occur in wide shelves.

With increasing load in the narrow compressed shelves on the support, crumpling occurs; the inclined edges of the corrugations begin to bend into the intra-corrugation space. The height of the corrugation decreases. In the span, wave formation is observed in the compressed wide shelves. At a critical load, there is a stability loss of the corrugations walls, and part of the compressed narrow shelf on the support is turned off from work. This leads to a sharp drop in the moment of inertia of the above-ground section. Therefore, in the decking, there is a partial redistribution of bending moments from the middle supports to the spans and the decking begins to work according to a scheme close to the split one. After the redistribution of moments in the span, deflections increase sharply, and in the compressed wide shelves, the waves become more pronounced. The length of these waves reaches the width of a compressed wide shelf. As the load increases, the wave height increases, and starting from the extreme corrugations, the wide compressed shelf, and then the walls lose stability in the zone of maximum bending moment. The load-bearing capacity of the decking is exhausted instantly, first in one span, and then in the other. [1]

Thus, the bearing capacity of deckings during their operation according to a continuous scheme is largely determined by the operation of the above-support section of the decking, namely the stability of the inclined faces (walls) of the corrugations. After the corrugation walls stability is lost, the most stressed is the stretched wide shelf on the support, which retains a certain indelibility of the decking. However, plastic deformations of wide shelves at this moment can lead to rupture of the waterproofing layer, which is unacceptable according to operational requirements. Therefore, when calculating the decking according to the stability condition of inclined faces of corrugations, it is necessary to take into account all factors affecting the value of the critical load.

In foreign standards, the decking is calculated taking into account the critical operation of its walls, assuming that part of the walls, having lost stability, are shut down (Fig. 1). In this case the working width of the walls is determined by empirical formulas

$$S_{e_1} = 110t/\sqrt{\sigma_{max}} \quad \text{и} \quad S_{e_2} = 159t/\sqrt{\sigma_{max}}$$

In the domestic standards for the decking design is accepted full inclusion of the corrugations walls in the working area.

Ensuring the stability of the corrugation walls will maximize the use of the mechanical properties of the decking material.
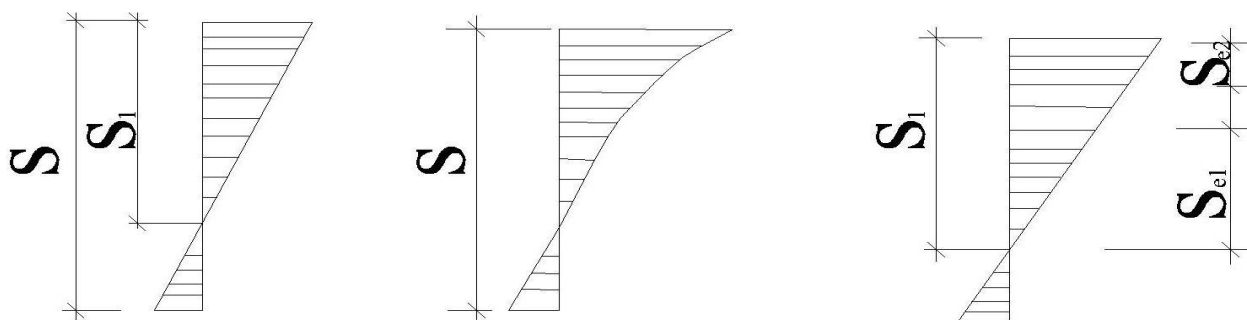

Fig.1. On the method of rationing the decking calculation

Steel profiled decks are usually calculated according to the method developed by the Institute CRI project steel construction and based on experimental data. [2] According to this technique, the stability of the inclined edges (walls) of the corrugations of the decking on the middle supports during its operation according to the continuous scheme is checked with a uniformly distributed load q according to the formula

$$\left(\frac{\sigma}{\sigma_0} + \frac{\sigma_{\text{м}}}{\sigma_{\text{м}_0}}\right) \leq m \qquad (1)$$

here $\sigma = \frac{M}{W} \leq R_y$ – normal bending stresses under the action of a moment $M = K_1 q l^2$

$\sigma_{\text{м}} = \frac{2B_r}{t \cdot \check{Z}}$–local stresses in the decking with thickness t from reaction$B_r = K_2 q l$ нand the middle support width $\check{Z}$

$\sigma_0 \; and \; \sigma_{\text{м}_0}$ – normal and local critical stresses

m – coefficient of working conditions, taken equal to 0,9 or 1,0, depending on the type of supports.

When determining the values of $\sigma_{\text{м}} and \; \sigma_{\text{м}_0}$, the following assumptions were made:
1. The calculated local force, equal to the support reaction, is directed in the plane of the corrugation wall, i.e. its inclination angle is not taken into account.
2. The inclined edges of the corrugations remain absolutely flat until local stability is lost.
3. The pinching degree of the inclined edges of the corrugations at the interface with the flanges is close to zero.
4. The height ratio of the corrugation wall and its thickness does not exceed 120.

Experiments confirming this technique accuracy were carried out mainly on samples of decking with corrugations 80 mm high from steel 1,0 mm thick. According to this technique, the local critical stress $\sigma_{\text{м}_0}$ is determined by the empirical formula

$$\sigma_{\text{м}_0} = 156K_{1c} \cdot K_{2c} \cdot K_{3c} \cdot K_{4c} \cdot \sqrt{R_y} \qquad (2)$$

The values of the coefficients $K_{1c}, K_{2c}, K_{3c}, K_{4c}$are determined according to the tables, depending on the thickness, radius of rounding, height of the corrugation and the width of the shelf of the supporting structure. Currently, a single range of profiled decking has been developed, which includes new profiles with a corrugation height of 40 to 114 mm made of thinner steel with a thickness of 0,6 to 0,8 mm.

The use of profiled decking made of sheet steel with a thickness of 0,6-0,8 mm requires some refinement of the existing methodology when determining local critical stresses. Based on the measurements results of experimental decking samples 0.6-0.8 mm thick before testing, it was established that the corrugation walls have initial roundup not exceeding 1/500 width of the inclined faces. Analysis of the deformed shape of the corrugations of the previously tested samples showed that the inclined edges have partial pinching along the longitudinal edges at the junction of the walls with the shelves. Verification of the local stability of the profiled deck walls at $H/t \geq 100$ ratios, taking into account the initial roundup and partial pinching of the wall edges is more consistent with the actual performance of the deck in transverse bending. As it is known, the load-bearing capacity of compressed elements (according to the stability conditions) is significantly affected by their initial roundup and the conditions of fixing at the ends [3,4]. In the proposed method, the local critical stresses in the wall of the corrugated decking are determined under the following assumptions.
1. The walls are resiliently clamped at the junctions with the corrugated flanges.
2. The walls have an initial roundup not exceeding 1/500 of the corrugation height.
3. The design shear load is determined taking into account the slope of the corrugation wall relative to the horizontal.

4. All bottom flanges of the decking are fixed to the supports by means of point connections (self-tapping screws, welded electric rivets, dowels).
5. The load on the deck is evenly distributed over the upper shelves.

The design scheme of the decking on the support is presented in the form of a Z-shaped element of unit width, the cross-sectional dimensions of which are the same as for the half-wave of the corrugation (Fig. 2).

Rigid pinching in the design scheme is taken at the point of fixing the bottom flange of the decking on the support. Fastenings in the form of paired rods in the middle of the upper (usually wider) flange of the corrugation imitate its pliability in the vertical plane from the action of the moment of the discarded part of the corrugation. [5]
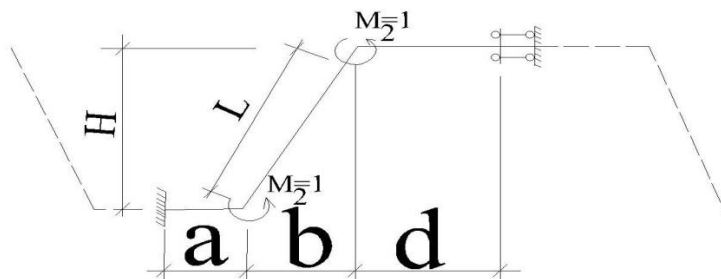
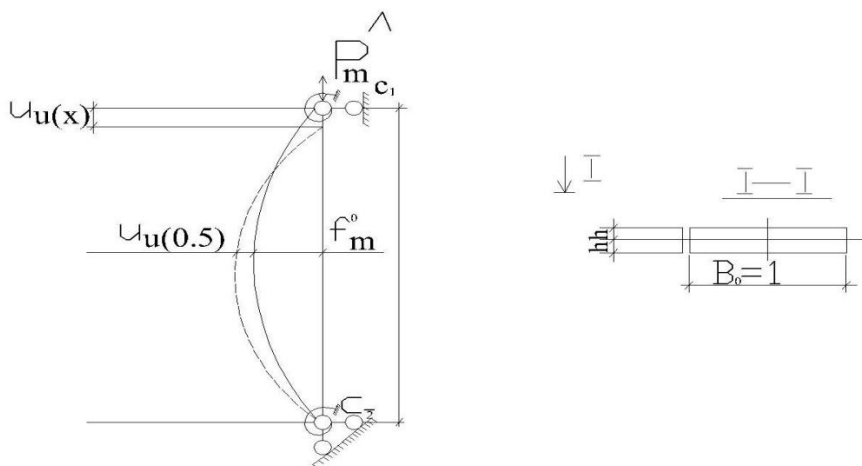Fig.2 Calculation scheme of the decking on the support

Fig.3 Design model of a compressed bent bar

Thus, the calculation scheme represents a doubly statically indeterminate system. The stiffness of the wall pinching in nodes 1 and 2 is expressed as the inverse of the rotation angles of these nodes φ_1 and φ_2 from the unit moments M_1 and M_2 applied in them. When solving this problem by the force method and using the Mohr formula, the rotation angles depending on the geometric dimensions of this system are determined. To determine the critical load value, the stress state over the supporting section of the wall is considered. This section of unit width is presented as a compressed curved rod, elastically restrained at the ends of the section characterized by the values $C_1 = \frac{1}{\varphi_1}$ and $C_2 = \frac{1}{\varphi_2}$ (Fig. 3).

The rod has an initial one-sided roundup, which corresponds to the possible waviness of the corrugation walls allowed by SS. A similar design model for the operation of a profiled decking on a support was adopted on the basis of experimental studies carried out earlier by various specialists, which showed a close to uniform distribution of transverse stresses along the wall length in its most stressed part with a width of 10-20 above the support. At the same time, it was found that with the loss of stability of the walls of the corrugated decking above the support, the plastic zone of destruction in the form of a buckling wave has a large length, reaching 2÷3 of the height of the profile wall. Based on this, the accepted design model of the wall above the support is quite legitimate. To solve this problem, a program was used, compiled in the PL-1 language and developed in the Laboratory of metal structures reliability of the Central Research Institute named after Melnikov, the project became a structure. The problem was solved by the method of initial parameters. To describe the stress-strain state of a rod with an initial roundup, a system of Kirchhoff-Clebsch differential equations for curved rods was used, generalized by the author of [5], for the case of physical nonlinearity of the material

For the calculation on a computer, the initial parameters were set as:

1. Relative stiffness of rod ends $\tilde{C}_1, \tilde{C}_2$ (dimensionless parameters) determined by formula

$$\tilde{C}_{1,2} = \frac{C_{1,2} \cdot L}{E J_0} \qquad (3)$$

here J_0 − characteristic moment of the section inertia

E − material modulus of elasticity

2. Prandtl diagram for the deck material.
3. The shape of the initial curvature of the rod axis along a half-wave sinusoid with a given amplitude f_m^0.
4. Relative dimensions of a rectangular section of a rod of unit width.
5. The flexibility of a rod of rectangular cross section, equal to

$$\lambda = \frac{L\sqrt{3}}{h} \qquad (4)$$

here h − half of the rod section height (Fig. 3).

L − length of the rod, defined as the width of the flat part of the inclined face of the corrugation without edge notches (Fig. 2)

The calculation is performed on an EC-1050 computer. The calculation time of one task is 3-4 minutes.

As a result of the calculation, the nonlinear dependences of the rod ends approach on the longitudinal force were obtained (Fig.4). These dependences were expressed in dimensionless parameters, equal to

$$\widetilde{P}_m = \frac{P \cdot L^2}{EJ_0}; \widetilde{U}_x = \frac{U_x}{L}; \qquad (5)$$

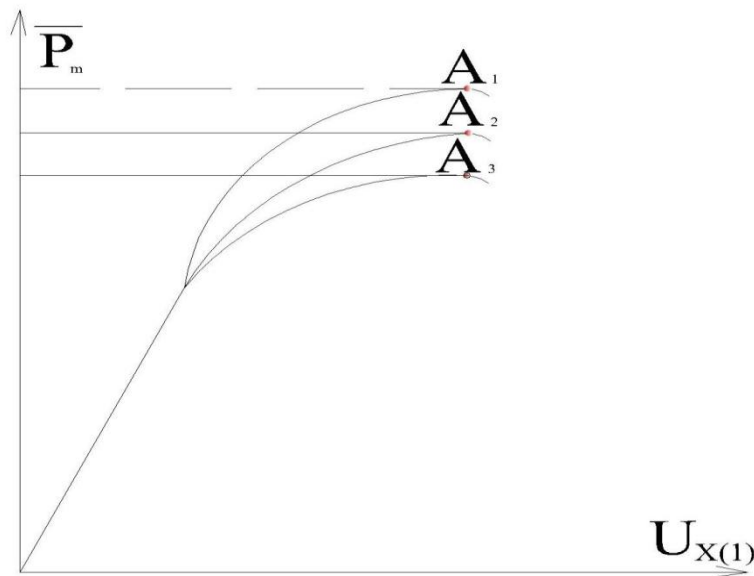A_1, A_2, A_3 points in (Fig. 4) characterize the dimensionless value of the limit load.

Fig.4 Dependence of rod end convergence on the longitudinal force

$$\widetilde{P}_m - U_{x(1)}$$

Counting is carried out until the maximum dimensionless value $\widetilde{P}_m$ is reached. The critical load value for the bar is determined by the formula

$$P_{кр} = \frac{\widetilde{P}_m \cdot E \cdot A}{\lambda^2} \qquad (6)$$

here A − cross-sectional area of a rod of unit width.

The local critical stresses $\sigma_{м0}$ for the wall, taking into account its initial roundup and elastic pinch along the longitudinal edges, we obtain by the formula

$$\sigma_{м0} = К \cdot \frac{P_{кр}}{A} = К \cdot \frac{P_m \cdot E}{\lambda^2} \qquad (7)$$

here K − empirical coefficient, which takes into account jamming of the element along the length due to discarded part of the corrugation wall.

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Determining the value of σ_{M0} (7) and substituting it in (1), we obtain the values of the calculated uniformly distributed load q_p, corresponding to the local loss of walls stability of the corrugations on the support. To assess the effect of the initial roundup and elastic pinching of the corrugation walls on the critical load, parametric studies were carried out using the developed program.

As a result of these studies, critical load values were obtained for deckings with a thickness of 0,6, 0,7 and 0,8 mm under the following conditions.

1. The stiffness of elastic clamping of the wall along the upper and lower edges is the same $\tilde{C}_1 = \tilde{C}_2$ and is characterized by values in the range from 1 to 9 with an initial roundup $f_m^0 = \frac{1}{1000}L$.

2. The initial roundup of the wall is taken in the range from $1\frac{1}{500}L$ to $\frac{1}{1000}L$ with the stiffness of its pinching $\tilde{C}_1 = \tilde{C}_2$ equal to zero and $\tilde{C}_1 = \tilde{C}_2$ equal to 5.

3. The design resistance of the wall material was taken within the range of 230 to 300 MPa, with the same $f_m^0 = \frac{1}{1000}L$ roundup, height-to-thickness ratio of the wall from 40 to 90, elastic pinch along its lower edge - $\tilde{C}_1 = 4$. The parameters of pinch stiffness accepted in the calculation correspond to the cross-section dimensions of the profiled decking.

The results analysis of a parametric study showed that with an increase in the decking thickness, the effect of pinching the wall edges on the critical load increases. With an increase in the stiffness parameters of the wall pinching from 1 to 5, the critical load increases significantly more intensively than with $\tilde{C}$ value greater than 5. The $\tilde{C}$ parameter for most of the known profiled decking does not exceed 5. The initial roundup in the wall of the accepted limits affects the value of the critical load to a much lesser extent than the stiffness of elastic pinching of its edges. With an increase in the thickness of the wall of the decking in the range from 0,6 to 0,8 mm, its initial roundup effect on the critical load value increases regardless the pinching stiffness (Fig. 5).
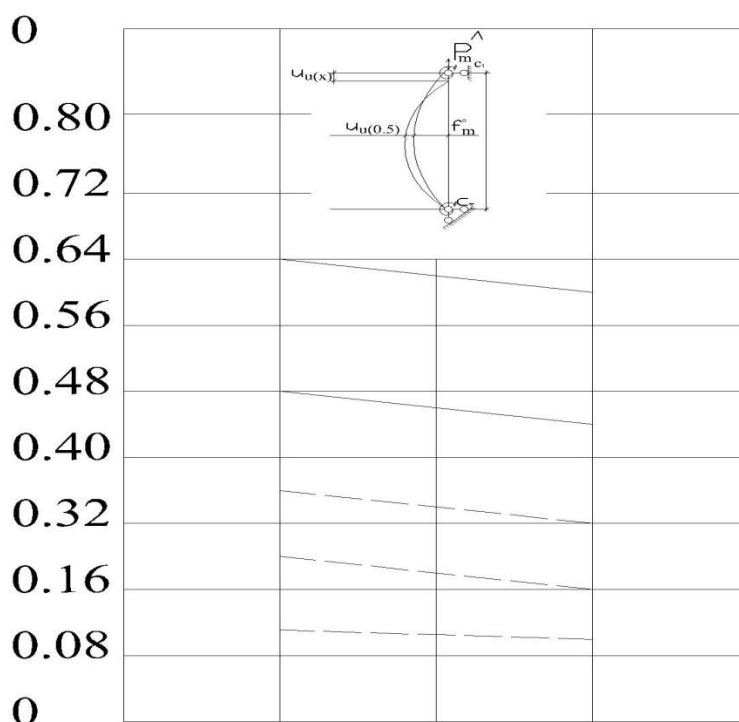

Fig. 5 Dependence of the critical load on the initial roundup of the corrugation wall

These calculations also showed that the critical load value of the walls with the accepted dimensions practically does not depend on the strength properties of the profiled decking material (Fig. 6). With a decrease in the walls flexibility, the critical load value increases sharply and reaches the yield strength of the decking material with a flexibility of about 40. The proposed calculation method was used in determining the critical loads for profiled decking with a standard form of corrugations according to SS 24045-80, made of steel thickness 0,6; 0,7 and 0,8 mm.

CONCLUSIONS

1. The proposed calculation method makes it possible to determine the value of local critical stresses for the corrugations walls of profiled decking, taking into account the initial deflection and elastic pinching in the shelves.

2. With a wall thickness of the corrugations from 0,6 to 0,8 mm, the influence of the initial deflection, which does not exceed its permissible value of $\frac{1}{500}L$, on the critical stresses value is insignificant.

3. The magnitude of the critical stresses for the corrugations walls largely depends on the stiffness of pinching their longitudinal edges, which increases with increasing the decking thickness.

4. The strength characteristics of the decking material within its elastic operation practically do not affect the critical stresses for the corrugation walls on the supports

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