Methodology and Calculation of Horizontal Rigid Ribs in Bunkers for Storing Bulk Materials

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Abstract. In industrial production for the storage or processing of various bulk materials such as compound feed, grain, coal, crushed stone, sand, rocks, etc. use different containers and bins. Depending on the physical and mechanical properties of materials, containers and bunkers of various types are used.

When designing tanks and bunkers, various engineering solutions are used to save material and reliable strength of the entire structure of tank structures. One of these solutions is the installation of stiffeners on the surfaces of the hoppers, which gives additional rigidity to the entire structure and saves material by reducing the thickness of the hopper walls.

In order to select the required stiffeners, a number of studies are required. The purpose of these studies is to establish the most optimal parameters of stiffeners, such as width, thickness, spacing, steel strength class, as well as to assess and substantiate the economic feasibility of using the selected ribs in the structures of tanks and bunkers.

A technique has been developed that allows one to determine the main parameters of stiffeners, setting constant parameters set depending on economic and technological conditions. In our case, the geometric dimensions of the bunker and the spacing of the ribs were used as constant parameters.

1. Introduction

In industrial production for the storage or processing of various bulk materials such as compound feed, grain, coal, crushed stone, sand, rocks, etc. use different containers and bunkers [1-3]. Depending on the physical and mechanical properties of materials, different types of structures, containers and bunkers are used. An important role is played by the material from which the bunker is made, namely steel and its parameters, which affect the strength of the structure and the economic feasibility of choosing this material [4].

2. Relevance

When designing tanks and bunkers, various engineering solutions are used to save material and reliable strength of the entire structure of tank structures. One of these solutions is the installation of stiffeners on the surfaces of the hoppers, which gives additional rigidity to the entire structure and saves material by reducing the thickness of the hopper walls. Another important aspect is the properties of steel, the design itself and the geometric parameters of the stiffeners performed [5,6].
3. Formulation of the problem
In the industrial production of tanks and bins, it is necessary to ensure the required structural strength and reduce material consumption. All this is solved by using different stiffeners, both in design and in material. In order to select the required stiffeners, a number of studies are required. For research, a square-section tank filled with bulk material (ore with a density of 2 t/m³) will be used.

The purpose of these studies is to establish the most optimal parameters of stiffeners, such as width, thickness, spacing, steel strength class, as well as to assess and justify the economic feasibility of using the selected ribs in the structures of tanks and bunkers.

Based on the design experience and having studied the features of the device of these structures in the technical literature [1-6], a bunker was developed for storing and processing ore with subsequent installation at a production enterprise. A sketch of the hopper is shown in Figure 1.

![Figure 1. Sketch of the bunker.](image)

The hopper is a frame consisting of profiles 2 forming a frame of rigidity, which are attached to each other and installed on the posts 1. The hopper has four vertical walls and four inclined walls. Vertical walls are reinforced with stiffeners 3, and inclined walls are reinforced with stiffeners 4.

4. Theoretical research
The purpose of the calculation: To determine the optimal parameters of the stiffeners, such as width, thickness, spacing, steel strength class, as well as to assess and justify the economic feasibility of using the selected ribs in the structures of tanks and bunkers.

Initial data for the calculation. To find the optimal parameters of the stiffeners, it is necessary to make some parameters constant. Constant parameters are set by the customer based on production and economic conditions. The customer set the following constant parameters: a square bunker with dimensions in the plan of 5 m by 5 m, height of a section with straight walls 2.4 m, height of a section with inclined ribs 2.4 m, total height 4.8 m, wall thickness of the bunker 10 mm, rib thickness 10 mm, spacing of stiffening ribs 600mm.

To determine the width of the ribs and the maximum stress arising in the walls and ribs of the bunker, it is necessary to determine the pressure of the ore on the walls of the bunker.

The horizontal pressure of the filled material on the vertical walls is found by the formula:
\[ p_g = n k \gamma h, \]  

where \( n \) is the overload factor;  
\( \gamma \) - density of the filled material, \( \text{t} / \text{m}^3 \);  
\( h \) - height from the top of the bunker to the design point, \( \text{m} \);  
\( k \) is the lateral pressure coefficient, which is equal to:

\[ k = t g^2 (45^0 - \frac{\phi}{2}), \]  

where \( \phi \) is the angle of internal friction of the bulk material.  
The pressure of the filling material on the inclined walls is determined by the formula:

\[ p_n = m_0 \gamma h, \]  

where \( m_0 \) is found by the following formula:

\[ m_0 = \cos^2 \alpha + k \sin^2 \alpha, \]  

where \( \alpha \) is the angle of inclination of the walls to the horizon.  
Since our ribs are at a height, we find the pressure for each rib at its height and enter the data in Table 1. The data for calculating the pressure at different heights are as follows: \( n = 1.2, \gamma = 2 \text{ t} / \text{m}^3, \phi = 360, \alpha = 500 \). Based on the drawing (Figure 1), we determine the length of the ribs and the load area for each rib. Knowing these parameters, we find the load that acts on each edge. Having found the loads for each rib, we can determine the maximum moment developing in the rib [5,6-10]. We will enter the obtained data into table 1.

**Table 1. Parameters of stiffeners and loads acting on them.**

| Rib type   | Distance from the top of the bunker to the rib, [m] | Pressure at a given height, [kN/m²] | Rib length, [m] | Load acting on the rib, taking into account the load area, [kN/m] | The moment arising in the rib, [kNm] |
|------------|-----------------------------------------------|-----------------------------------|----------------|-------------------------------------------------|-----------------------------------|
| Vertical wall ribs | 0.6                                     | 6.84                               | 5              | 4.1                                              | 12.83                             |
|             | 1.2                                     | 13.86                              | 5              | 8.32                                             | 25.99                             |
|             | 1.8                                     | 20.7                               | 5              | 12.42                                            | 38.81                             |
| Sloped wall ribs | 3                                       | 75.21                              | 4              | 69.95                                            | 139.89                            |
|             | 3.6                                     | 90.37                              | 3              | 84.04                                            | 94.55                             |
|             | 4.2                                     | 105.34                             | 2              | 97.97                                            | 48.98                             |

The data given in Table 1 are necessary to calculate what stresses will occur at each horizontal section of the bunker. To calculate the stresses in the ribs, we will use the Section Constructor program. Knowing the moments occurring in the ribs, we will change the width of the ribs and see what stresses will arise in ribs of different widths (Figure 2) [11-21].
Changing the ribs in width with a gradation of 30 mm, and obtaining the stress values using the "Section Designer" program, we summarize the obtained data and present them in graphical form (Figure 3, 4).

Figure 2. Stresses arising in a rib 240 mm long in a vertical wall at a distance of 1.8 m from the top of the bunker.

Figure 3. Nomogram for vertical wall ribs.
Figure 3 shows a nomogram for determining the arising moments and stresses in the ribs of the vertical wall and allows you to determine the width of the rib at the required distance from the top of the bin according to the maximum allowable stresses. The nomogram consists of two parts, on the left side there is a straight line showing what moment occurs at a given distance from the top of the hopper, the right side of the nomogram shows what stress occurs at a certain moment and at a certain rib width. After finding the voltage, the strength class and steel grade are selected.

For example, it is necessary to pick up an edge at a distance of 1.8 m from the top of the hopper made of steel of strength class C245, C345, C355. On the left side of the nomogram, we draw a vertical line, until it intersects with a straight line, at the intersection point we set aside the horizontal, we look at what moment occurs at a given height, it is 38.81 kNm. Further, on the right side, we look at what permissible stress we need for the strength class C245, C345, C355, these are, respectively, 240 N / mm², 340 N / mm², 350 N / mm². Therefore, along these boundaries we select the cross-section of the ribs, for the strength class C245, an rib with a section of 240x10mm is suitable, and for C345, C355, the cross-section of the rib can be reduced to 210x10mm.

Figure 4 shows a similar diagram for the ribs of the inclined wall of the silo. Based on the given nomograms (Figure 3, 4), the following sections of the stiffeners were taken (Table 2).

| Rib type          | Distance from the top of the bunker to the rib, [m] | Strength class of steel | Stiffening ribs section, [mm] | Stress arising at this level [N / mm²] |
|-------------------|--------------------------------------------------|-------------------------|-------------------------------|--------------------------------------|
| Vertical wall ribs| 0.6                                              | C245                    | 150x10                        | 169                                  |
|                   | 1.2                                              |                         | 210x10                        | 182                                  |
|                   | 1.8                                              |                         | 240x10                        | 212                                  |
| Sloped wall ribs  | 3                                                |                         | 450x10                        | 233                                  |
|                   | 3.6                                              |                         | 390x10                        | 208                                  |
|                   | 4.2                                              |                         | 270x10                        | 214                                  |
5. Results
To check our calculations and dependencies in the Structure CAD program, finite element fragments of the bunker, the vertical and inclined wall of the bunker with stiffening ribs were built (Figure 5, 6) [11-16].

Figure 5. Stresses in the finite element model of the vertical bunker wall.

Figure 6. Stresses in the finite element model of the inclined wall of the bunker.
Figure 5 shows that the maximum stresses 206-225 N / mm² fall on the lower edge, so in this place the pressure on the vertical wall reaches its maximum of 20.7 kN / m². These monograms show similar results for this section, namely the stress equal to 212 N / mm². In Figure 6, the situation is slightly different, as we see the maximum stress in the region of the two upper ribs and at the very bottom of the bunker wall, without affecting the zone of attachment of the lower rib and is in the range of 204-238 N / mm². This can be explained by the fact that the two upper ribs have the longest in the inclined wall and in this zone there is the greatest moment equal to 139.89 kNm. The nomogram for this loaded area shows a stress of 208-233 N / mm², similar to the stress shown on the finite element model of the bin wall.

6. Conclusion
A technique has been developed that allows one to determine the main parameters of stiffeners, setting constant parameters set depending on economic and technological conditions. In our case, the geometric dimensions of the bunker and the spacing of the ribs were used as constant parameters. Using this technique, we determined the required cross-section of the stiffeners for the vertical and inclined walls of the bunker, with the strength class of steel C245. Also, using this technique, you can choose the smallest cross-section of the ribs, increasing the strength class of steel. This technique allows you to change the constant parameters and calculate the required cross-section of the ribs based on the new parameters.

7. References
[1] Mandrikov A P 1991 Examples of calculation of metal structures (Moscow) Stroyizdat p 431
[2] Vasiliev A A 1976 Steel structures (Moscow) Stroyizdat p 424
[3] Melnikov N P 1980 Steel structures (Moscow) Stroyizdat p 776
[4] Murashko N N, Sobolev Yu V 1987 Metal structures of industrial agricultural buildings (Minsk) Higher school p 278
[5] SP 43.13330.2012 Buildings of industrial enterprises
[6] 1983 Guidelines for the calculation and design of reinforced concrete, steel and combined bunkers (Moscow) Stroyizdat
[7] SP 16.13330.2017 Steel structures
[8] SP 20.13330.2016 Loads and impacts
[9] GOST 19281-2014 2019 High-strength rolled products
[10] Manual for the design of metal structures.
[11] Karpilovsky V S, Kriskunov E Z, Perelmuter A V, Perelmuter M A, Trofimchuk A M 2000 SCAD for the user (Kiev: GDP "Compass") p 332
[12] Girenko S N, Kriskunov E Z, Perelmuter M A 2003 KOKUN Determination of stress concentration factors Electronic reference book (version 1.1) SCAD Soft p 35
[13] Anokhin N N 2000 Structural mechanics by examples and problems Part 2 Statically indeterminate systems (M.: Publishing house ASV) p 464
[14] SP 53-101-98 1998 Production and quality control of building metal structures
[15] Wilson E L 1997 3D dynamic structural analysis Berkeley: Computer and Structures, Inc.
[16] Eurocode-8 (1995 version): Earthquake Resistant Structural Design Brussels: European Committee for Standardization p 56
[17] GOST 19903-2015 Hot-rolled sheet metal
[18] GOST 27772-2015 Rolled steel for building structures
[19] SP 11-110-99 1999 Designer supervision over the construction of buildings and structures
[20] GOST 14771-76: Gasshielded arc welding, Welded connections, Basic types, structural elements and dimensions
[21] GOST 23518-79: Gasshielded arc welding, Welded joints at sharp and obtuse angles Basic types, structural elements and dimensions