The Justification of Technical Feasibility of Using Existing Urban Industrial Objects at the Reprofiling of their Appointment

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Abstract. Establishment of the valid technical condition, research of relationship of cause and effect and hierarchy of the factors influencing use reliability of load-carrying structures of town-planning objects of industrial function at their reconstruction and reprofiling is the main objective of safe and reliable operation. By method of the atomic and emission spectral analysis it is established that separate elements of farms are made of the “boiling” steel that does not conform to requirements of existing rules. Values of movements, efforts on combinations of loads by snow load and ranges of distribution of potential energy of deformation on farm elements are received. The analysis of intense state of strain of roof frames of covering of the inspected industrial buildings has shown that their bearing capacity in zone of possible formation of snow “bag” from height difference and extension to workshop of higher flight is not sufficient. By results of the conducted researches recommendations for safe further operation of roof frames of covering and valid conclusion about degree of their suitability for the planned conversion and modernization of industrial buildings are formulated.

1. Introduction
Practically in each large city it is possible to meet now the industrial enterprise which for one reason or another does not perform the initial function any more. Nevertheless, this object has the essential potential for further development of urban areas. In this case will be reasonable to carry out building reprofiling, to give it new, civilized lines, applying the innovation technologies and minimizing damage caused to the environment. Therefore today there is task: having reconstructed these town-planning objects, to leave them significant for the city, to make functional, eco-friendly, self-organizing. At the same time, industrial building that will be subjected to reprofiling can become unique, not having analogs on the structure and the organization of space. The available building constructions of the building which has lost the initial functionality (farms, cranes, columns, big flights, load bearing walls of considerable thickness, light lamps, etc.), allow the architect to find it space-planning decision at which there will be new forms of space interpretation, dynamism of structure of the building.

At reconstruction of industrial building under object of town-planning of public assignment it can be added with interesting designs from different modern composite materials that will give the
necessary character and unique plastics to facade, will make the building easily recognizable, and in certain cases such building can even become certain dominant of the area or city. At the same time, the scale of such reconstruction will depend on in what degree parameters of technical condition of the building and its designs conform to modern requirements, including safety requirements and reliability.

Reconstruction or modernization of process buildings seldom happens without increase in loads of the existing building constructions or changes of the mode, conditions of their operation and other factors. In this regard often there is question of their strengthening or even replacement [1-14].

Among loads of building constructions, the most changeable are snow. During the winter the snow load on covering of the building accepts values unknown in advance, i.e. is random variable. In addition, the variability in time is characteristic of snow loads. Unfortunately, the available cases of collapse of coverings of public buildings because of snow load lead to the fact that the problem of rationing of snow loads on coverings of constructions becomes very relevant [17-21].

In this work assessment of degree of suitability of load-carrying structures of covering at action of the additional snow loads arising in connection with the planned reprofiling and extension of higher flights to the production body of the former car repair plant in Voronezh is provided.

2. General information about the existing process building of workshop
The workshop building is one-storey, consists of two flights on 18.0 m integrated by insert 4.5 m wide. Flights of workshop are equipped with bridge basic cranes of average operating mode. The general dimensions of the building in the plan – 41.14x106.53 m. In one end face of workshop the two-storied block of administrative accommodation spaces is built-in, to other end face the three-storied block of accommodation spaces with sizes in respect of 9.64x43.88 m is attached. The period of construction of object – the end of the second half of the 50th years of the last century.

The considered flight of workshop is structurally executed with the brick longitudinal load bearing walls strengthened in places of supporting of crane girders by pilasters with a section of 0.66x0.66 m. The size of flight is 18.0 m, height to bottom of load-carrying structures of covering – 8.15 m, to bottom of crane girders – 6.65 m, mark of top of eaves of +8.95 m, parapet top mark in end face of the building of +11.07 m. Covering - from metal farms and small-size asbestos-cement plates on metal runs (figure 1). Asbestos-cement plates of AP-150 and AP-200 brand in accordance with COST 7285-54, 120 mm thick, 0.5 m wide, length - 1.5 and 2.0 m. In hollow plates mineral-cotton heater. Runs from rolling double tees No. 18, 20 and 22 with step 1.5 and 2 meters. Stability of runs of covering from the plane is provided with the struts from the coupled T-shaped corners 45x30x4 located in the middle of flight through a step of runs. The roof is dual-slop, combined, with the outside internal drain which is not organized at the edges and organized between flights. Roof - soft of the built-up rolled material.
For the planned change of functional purpose of this industrial building to the considered workshop, it was going to attach higher parallel flight 20 m wide with height difference in 4.5 m and to execute superstructure in the direction, perpendicular to workshop, over the household body attached from its end face with creation of height difference in 2.3 m. For implementation of this decision predesign inspection of the existing flight of workshop according to the SP 13-102-2003 of "The rule of inspection of the bearing building constructions of buildings and constructions" on the basis of which, among other, bearing capacity of roof frames of covering taking into account additional loadings from formation of snow "bags" is investigated is executed.

3. Results of inspection of farms of covering

Roof frames are executed from the coupled rolling corners, have triangular outline with broken bottom flange and the ascending drag struts (figure 2).

Height of farms in the middle of belts – 2.0 m, tilt angle of upper belt – 9.3°. The bottom of roof frames is on marks of +8.136…+8.210 m. Flight of farms of 17.63 m.

Nodes of farms are executed welded, with corner plates 10 mm thick. Joints of belts of farm are solved in nodes by means of welding of pads from rolling corners.

Roof frames are located with step of 5.4 m. The system of communications of covering consists of horizontal cross communications in the plane of upper belts of farms, vertical cross communications between farms on the center of flight and struts for bottom flanges of farms in the middle.

During visual and tool survey of roof frames it is established that relative deflections of farms of covering were in range of 3 … 36 mm also did not exceed maximum permissible values on norms.
Lack of penetrations or overburning of welds in nodes of farms are not revealed. In places, there were insignificant sites of spalling of painting structure and superficial corrosion of metal of farms. Separate branches of horizontal and vertical communications on farms of covering had bend from stability loss. 

Check of distances between connecting levels (crackers) ensuring team work of two corners has shown shortage on one level for two drag struts. Besides, for number of compressed rods of upper belt, racks and drag struts of some farms only about one level, instead of recommended by norms not less than two is established.

4. Definition of the brand and mechanical characteristics of steel

Sampling of metal of roof frames was made for definition of the brand and mechanical characteristics of steel. The chemical composition of samples of steel was defined by method of the atomic and emission spectral analysis by means of emission spectrometer of "SPAS-02" of COST P 54153-2010 "Steel. Method of the atomic and emission spectral analysis". Definition of strength indicators at stretching of samples of steel was made on test machine of Instron 5982 by the technique stated in COST 1497.

By results of testing of samples it is established:

− steel of upper belt of farms corresponds to the St5sp brand;
− steel of racks of farm corresponds to the St4ps brand;
− steel of drag struts of farm corresponds to the St3kp brand;
− steel of bottom flange of farms corresponds to the St4kp brand, has liquid limit of 225 MPa, temporary resistance of 399 MPa, elongation of 18.2%.

Rated resistance of steel was determined by liquid limit according to items 6.1 and 18.2.4 of the SP16.13330.2011 COST 1497-84. "Metals. Test methods on stretching" on formula:

\[ R_y = \frac{R_{yn}}{\gamma_m} \]  

where \( R_{yn} \) - normative resistance of steel - was defined on the basis of tests of samples for stretching in accordance with COST 1497, or was appointed according to steel grades of the inspected designs on the norms operating during smelting of the studied steel (item 8.4.4 of SP 13-102-2003);

\( \gamma_m = 1.1 \) - reliability coefficient on material (item 18.2.4 of SP 16.13330.2011 "Steel structures") for the designs made during the period from 1932 to 1982 and for steels with liquid limit is lower than 380 MPa.

5. Static calculation of farm

The design model of farm is executed on the basis of finite element method [5-10]. For modeling final elements No. 1 "Element of plate girder" with two degrees of freedom in node were used. Boundary conditions – the motionless hinge in the left basic node, the mobile hinge in the right basic node. The nomenclature of rigid characteristics is accepted according to results of inspection and tool control of elements of the bearing farm. The type of design model is presented on figure 3.

![Figure 3. Design model.](image-url)
In calculation the permanent loads operating on covering and including the mass of roof determined by results of its opening, runs, roof frames and communications of covering were considered own farm designs. Running design permanent load at step of roof frames of B=5.54 m is equal \( q = 7.98 \text{kN/m} \).

Live loads from snow cover were considered by three options for different schemes of snow loads:
- taking into account the weight of snow "bag" in zone of height difference (h=4.5m) at extension of higher parallel flight to workshop (figure 4);
- taking into account snow "bag" in zone of height difference (h=2.3m) from influence of higher household body in the perpendicular direction of the building attached to workshop in end face;
- without taking note of extension (on the existing loadings).

Calculation of loading from snow bag in height difference zone at extension of higher flight to workshop is executed in compliance with the scheme B.8 (a) of appendix B of the SP 20.13330.2016 (figure 3).

Basic data:
- the snow area on card 1 of appendix E to SP 20.13330.2016 - III;
- the weight of snow cover of Sg on 1 m² of horizontal earth surface according to table 10.1 [5] is equal to 1.5 kN/m². Safety factor on snow load \( \gamma_l = 1.429 \);
- height of difference of h=4.5 of m;
- length of the upper site of covering \( l_1 = 19.4 \text{ m} \), lower - \( l_2 = 42.5 \text{ m} \);
- tilt angle of the upper site of covering \( \alpha_1 = 6^\circ \), lower - \( \alpha_2 = 9.3^\circ \).

The normative value of snow load on horizontal projection of covering was determined by formula 10.1 of SP 20.13330.2016 "Loadings and influences". The coefficient considering demolition of snow from coverings under the influence of wind or other factors is accepted according to 10.7 \( c_e = (1,2 - 0,4\sqrt{k}) \cdot (0,8 + 0,002l) = 0,84 \). Thermal coefficient of \( C=1.0 \).
Figure 4. The scheme of snow load for buildings with difference of height.

The coefficient $\mu$ was determined:

$$
\mu = 1 + \frac{1}{h} \left( m_1 \cdot l'_1 + m_2 \cdot l'_2 \right) = 1 + \frac{1}{4.5} \left( 0.4 \cdot 19.4 + 0.4 \cdot 42.5 \right) = 6.5 \, m,
$$

where $t_1$ and $m_2$ - shares of the snow windborne to height difference: 0.4 - for flat covering with $\alpha \leq 20^\circ$ and 0.3$^\circ$ - for flat covering $c > 20 \alpha^\circ$. In our case $m_1 = m_2 = 0.4$.

Length of zone of the raised snow deposits $b$ is defined as follows:

$$
b = \frac{\mu - 1 + 2m_2}{2h / S_0 - 1 + 2m_2} \cdot 2h = 9 \, m \leq 16.0 \, m.
$$

Check of condition of G.8 SP 20.13330.2016 according to which the coefficient $\mu$ has to be no more:

$$
\frac{2h}{S_0} = \frac{2 \cdot 4.5}{1.5} = 6 \, (\text{where} \, h \, \text{- in m;} \, S_0 \, \text{in kPa}),
$$
If the lower covering is covering of the building and \( l_1' + l_2' \leq 48 \) m, then maximum value \( \mu = 4 \); if the lower covering is canopy or covering of the building and \( l_1' + l_2' > 72 \) m, then maximum value \( \mu = 6 \). Intermediate values are determined by interpolation.

In our case, at \( m_{l,9.61} = \), we accept coefficient \( \mu = 5 \).

Coefficient \( \mu_1 = 1 - 2m_2 = 1 - 2 \times 0.4 = 0.2 \).

![Figure 5. General lay-out and sizes of snow load.](image)

For calculation for this scheme of loads the cargo area of average farm is 5.54 m (figure 5). Calculation of loading from snow bag in zone of influence of higher building of the household body attached in end face of workshop is executed in compliance with the scheme G.8 (b) of appendix G of SP 20.13330.2016 "Loadings and influences" (figure 3).

Basic data are similar the above, behind exception:
- height of difference of \( h=2.3 \) m;
- length of the upper site of covering \( l_1' = 6.0 \) m, lower - \( l_2' = 106.5 \) m;
- tilt angle of the upper site of covering \( \alpha_1=0^\circ \), lower - \( \alpha_2=0^\circ \);
- tilt angle of the lower site of covering in transverse direction \( \varphi=9.30^\circ \).

Coefficient \( \mu \)

\[
\mu = 1 + \frac{1}{h} (m_1 \cdot l_1' + m_2 \cdot l_2') = 1 + \frac{1}{2,3} (0,4 \cdot 6,0 + 0,4 \cdot 106,5) = 19,5,
\]

where \( m_1=0.4 \) and \( m_2=0.4 \), with width of the lowered covering \( a \geq 21 \) m.

Length of zone of the raised snow deposits \( b \) is defined as follows:

at \( \mu = 19,5 \geq \frac{2h}{S_0} = \frac{2 \cdot 2,3}{1,5} = 3,07 \);

\[
b = \frac{\mu - 1 + 2m_2}{2h / S_0 - 1 + 2m_2} 2h = 30,9 \text{ m}, \text{ but no more } 5h \text{ and no more than } 16.0 \text{ m. We accept } b = 5 \times 2.3 = 11.5 \text{ m.}
\]

According to condition G.8 annexes SP 20.13330.2011 coefficient \( \mu \) we adopt no more \( \frac{2h}{S_0} \):

\[
\mu = \frac{2h}{S_0} = \frac{2 \cdot 2,3}{1,5} = 3,07.
\]

Coefficient \( \mu_1 = 1 - 2m_2 = 1 - 2 \times 0.4 = 0.2 \).
For calculation of extreme edge farm for this scheme of loads the cargo area is 2.77 m (figure 6). Calculation of snow load on covering without taking note of extensions is executed according to scheme B.5 of appendix B of SP 20.13330.2016 "Loadings and influences" (figure 7). We accept the 1st version of the scheme of snow load with coefficient $\mu=1$ as covering tilt angle $\alpha=9.3^0 \leq 15^0$.

Running snow load at step of roof frames of $B=5.54$ of m

$$p = c_e \cdot c_r \cdot S_g \cdot \mu \cdot B = 0.84 \cdot 1.2, 16 \cdot 1, 0 \cdot 5, 54 = 10.05 \text{kH/m}.$$ 

6. **Analysis of results of calculation**

As a result of calculation of steel roof frame the following results have been received:
- values of movements on three specified combinations of загруженіе;
- values of efforts on three specified combinations of загруженіе;
- values of utilization coefficients for farm elements at different types of snow load;
- ranges of distribution of potential energy of deformation on farm elements.
Values of vertical movements and axial forces in the existing operative conditions are presented on figure. 8-9.

**Figure 8.** Vertical movements of $f$, mm.

Values of vertical movements and axial forces in case of extension to workshop of higher parallel flight are presented on figure 10-11.

**Figure 10.** Vertical movements of $f$, mm.

The maximum vertical movement of nodes of farm of $Z_{\text{max}} = 38.3$ mm does not exceed the maximum allowed deflection of SP 20.13330.2016 "Loadings and influences" $f_{\text{max}} = l/250 = 72$ mm.

Values of vertical movements and axial forces for the farm of covering, extreme from end face of workshop, which is in zone of possible formation of snow "bag" are presented on figure 12-13.

**Figure 12.** Vertical movements of $f$, mm.
The maximum vertical movement of nodes of farm of $Z_{\text{max}} = 56.05$ mm does not exceed the maximum allowed deflection of SP 20.13330.2016 "Loadings and influences" $f_{\text{max}} = l/250 = 72$ mm.

Assessment of bearing capacity of rods of farm was conducted by technique of SP 16.13330.2011 by means of utilization coefficient. Parameter of utilization coefficient allows to evaluate durability and stability of design according to all necessary requirements of SP 16.13330.2011 "Steel structures". For satisfaction to requirements for durability and stability size $K_i$ should not exceed units.

By results of calculation it is established that bearing capacity of farms is sufficient for perception of the loadings existing at the time of inspection. Values $K_i$ of elements of farm did not exceed 0.72. Thus, margin of safety was 28%. Values of utilization coefficient are given in figure 14.

Exception is the covering farm, extreme from end face of workshop, which is in zone of possible formation of snow "bag" from height difference with the existing building of the household body. This farm needs to be strengthened. Values $K_i$ for elements of bottom flange of farm exceed units (figure 15). Key parameter on which these elements do not meet requirements of SP 16.13330.2011 "Steel structures" is durability at influence of longitudinal force of $N$.

In case of extension to workshop of higher parallel flight, bearing capacity of farms of covering will not be provided. The extreme element of the lower belt does not meet requirements for durability (figure 16). Besides, at the adjoining elements margin of safety is insufficient.
energy, it is possible to predict what constructive parts are required to be strengthened first of all. In figure 17-18 ranges of distribution of potential energy are given in the existing operative conditions and in case of extension of parallel flight of big height.

Figure 17. Range of distribution of potential energy in the existing operative conditions of $E_p$, kJ.

Figure 18. Range of distribution of potential energy in case of extension of parallel flight of big height of $E_p$, kJ.

6. Conclusion
On the basis of the conducted examination, tests and the executed calculations of roof frames of covering of the production body, it is possible to conclude the following:

1. Grades of the "boiling" steel St3kp and St4kp from which drag struts and bottom flanges of farms are executed do not conform to requirements of SP 16.13330.2012, table B.1. This steel is inclined to fragile destruction at low temperatures, is characterized by the small resistance to fragile destruction and applied in the least responsible designs. Taking it into account, further operation of rafter roof structures at reprofiling of this town-planning object of industrial function in public is admissible only on condition of the organization of systematic control of their state and operating conditions [15, 16].

2. Bearing capacity of farms of covering is sufficient for perception of the loadings existing at the time of inspection, except for extreme in step from end face of workshop of the farm which is in zone of possible formation of snow "bag" from height difference with the existing building of the household body.

3. In case of extension to workshop of higher parallel flight with the planned height difference of 4.5 m, bearing capacity of roof frames in zone of possible formation of snow "bag" will not be provided. Therefore, the planned extension without work on strengthening or replacement of load-carrying structures of covering in workshop is impossible.

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