The operation analysis of the stanchion as an open column element

N V Solodov
Belgorod state technological university named after V.G. Shukhov, 46, Kostyukova St., Belgorod, 308012, Russia

E-mail: solodov_niko_v@mail.ru

Abstract. One-story buildings with steel frames are used in many cases for the output production for various purposes. The main vertical bearing element of such frames are the steel columns. With the presence of the technological lifting mechanisms in the building in the form of bridge supporting cranes in such columns, the crane part is designed lattice, and a special step (ledge, beam) is provided in the column design for supporting the crane girders. The columns are determined for a significant proportion of the metal consumed on the steel frame. Reducing the metal columns is an urgent task. Improving the efficiency of the design solutions is possible based on the study of the structures’ actual operation factors, in particular – the columns stability, and the accumulation of data to clarify the standard design methods for sustainability.

Introduction
The crane part of the stepped column constructively represents a spatial multi-rod system. Most of these elements (stanchions as a whole, stanchions as panels between nodes, braces and grid posts) work for central compression under the load, and across the rod as a whole - for off-center compression. The actual work and the design scheme of each element is determined by how the stanchions and the grid are connected and interact with each other under the load. The main factors of the actual work of a particular element are usually reflected in its design diagrams.

The limiting states often determining the bearing capacity of the open crane part of the column, manifest themselves in the form of a loss of stability of the stanchion between the lattice nodes in the frame plane (column grid) or the stanchion as a whole - from the frame plane.

In accordance with the regulatory method, when assessing the stability in the frame plane, the stanchion panel is considered as a rod with a calculated length equal to the geometric length of the panel (the distance between adjacent lattice nodes). From the plane of the frame the stanchion as a whole is considered as a rod, the upper end of which is fixed pivotally in the level of the crane ledge, and the lower end of the foundation is fixed pivotally or rigidly depending on the design of the stanchion base.

A crane part is considered to be rationally designed when the limit loads are equal or close in magnitude according to the stability criterion in the plane and out of the frame plane. Due to the fact that the radii of the rolled I-beams sections inertia, of which the columns are most often designed, can vary in size by times, as well as due to the assortments’ discreteness and other circumstances, the
principle of equal stability is difficult to observe even at the level of the limiting efforts in the stanchions found when calculating by the method of standards [1].

There are proposals to carry out the calculations of the columns open crane parts for stability as a single spatial core system [2, 3]. The exhaustion of the column crane part open rod carrying capacity will be determined by the onset of the limit state for which the stability in the plane or out of the frame plane ([Nx], [Ny]) is obviously less with a pronounced stanchion non-stability. If the values of [Nx] and [Ny] are equal, the case of the carrying capacity exhaustion depends on the stability reserves of the stanchion as a whole or the least stable panel that are not taken into account by the standard methodology.

With close values of [Nx] and [Ny] it is possible to “interact” with two forms of the stanchion stability loss in the process of the open column crane part carrying capacity exhaustion.

**Results and Experimental Data**

A similar effect took place in the testing of the full-scale samples of the columns open crane parts, carried out with the participation of the author [4]. The prototype was a crane part of the brand E10-1 columns of a single-storey industrial building with bridge cranes (Series 1.424.3-7, issue 1).

The test sample carrying capacity exhaustion occurred due to the curvature (loss of stability) of the stanchion from the grid plane. At the same time, within one of the panels, in the stanchion section in the middle of its length between the junction points of the lattices, the flanges of the I-beam stanchions were curved in their own plane (in the lattice plane). The sample picture after the test is shown in Figure 1, the geometrical diagram of the crane part, the calculated diagrams of the stanchion and the loading pattern of the sample are shown in Figure 2.

![Sample Picture](image-url)
Figure 1. A photo of a prototype: a) a general view of the column after the test; b) the stanchion panel

The length of the column was equal to 11800 mm, the sections of the stanchions are made of rolling I-beams 30 SH1. In accordance with the test tasks, the sample type grid was replaced with an individual one in the sample: instead of single rolling angles welded in the I-beams flanges planes, the braces had a cross section of two paired 63x5 angles welded by means of sheet gussets to the I-beam wall along the stanchion section gravity center. The geometrical grid design corresponded to the typical one, the length of the panel was 2400 mm.

The sample was tested according to the scheme shown in Figure 2, which provided a different level of load on the stanchions and a variable value of the longitudinal force along the length of the stanchion. More loaded stanchion had the maximum longitudinal force from the base of the column.

Before the tests, the calculated values of the limiting efforts of the stanchion were calculated. The limiting effort according to the criterion of stability from the grid plane, in accordance with the calculation according to the method of norms (for rectangular diagram N), was 1,560 kN, and taking into account the equivalent trapezoidal diagram, 1708 kN [5]. According to the criterion of stability in the lattice plane in the area between its nodes - 1752 kN.
Figure 2. Scheme of the column loading: a) loads application; b) - longitudinal force diagram in a more loaded stanchion, kN; c) stanchion calculation schemes

Marginal forces are calculated taking into account the actual values of the steel strength. The value $R_y$ was taken equal to the yield strength. For this purpose, from the shelves of the I-beam in the panel with a smaller value of the longitudinal force (from the crane beam side), the samples tested in tension with the construction of the $\sigma$-$\epsilon$ diagram were cut. The value $\sigma$ was equal to 315.5 MPa, which corresponds to steel 14G2, from which the rolled I-beams 30SH1 were made.

To control the magnitude of the force in the stanchion sections, including the panel where the shelves’ curvature occurred, the resistance strain gauges were glued. On the basis of their indications, the actual value of the longitudinal force in the third panel with the loss of stability was equal to 1860 kN. Figure 3 shows the experimental diagrams of normal stresses in the I-stanchion of the stanchion along the loading steps.
The exhaustion of the carrying capacity of the test sample occurred due to the loss of the stanchion from the grid plane at a loading level of 105% of the maximum calculated.

After unloading the prototype, both stanchions had residual curvatures from the grid plane. The maximum curvature pointer in the more loaded stanchion was 52.9 m, and the less loaded one was 19.65 mm. At the same time the cross section with the maximum curvature of the more loaded stanchion was at a distance of 0.688l from the base of the column, and that of the less loaded stanchion — by 0.5l. In the more loaded stanchion, the value of the curvature pointer was 1 / 223l.

A comparison of the calculated and experimental (see Fig. 2) limiting values of the magnitude of the longitudinal force shows that the actual value exceeds the calculated one. According to the criterion of stability from the lattice plane: by the method of standards (rectangular diagram N) - by 19.2%; taking into account the trapezoidity of the equivalent diagram of the longitudinal force of the stanchion was- by 8.9%. The partial explanation of the stanchion bearing capacity reserve (8.9%) is due to the presence of the supporting effect of the less loaded stanchion on the stability of the more loaded one. The analytical solution of the stability problem with the presented factor was given in [6]. According to the stanchion stability criterion in the plane of the grid when calculated in accordance with the rules was- by 6.2%.

The comparison results suggest that the regulatory calculation method provides sufficient reliability in the design, even taking into account the actual indicator of the strength of steel in terms of $\sigma_t$.

Figure 4 shows a stanchion within the panel where its stability was lost and warped. The beginning of the curvature is offset from the lattice nodes centers by 260 and 270 mm, this is actually equivalent to the calculated length of the stanchion in the lattice plane of 1870 mm.
Taking into account the effect of reducing the calculated length in determining flexibility gives the following result. With a standard design length of 2400 mm, the flexibility of the \( \lambda \) stanchion in the grid plane is 51.7 and with the actual length - 40.3, which is 22% less. The effect of reducing the calculated length on the stanchion limiting force value according to the criterion of stability in the lattice plane will not be so significant. So, the value of buckling coefficient \( \varphi \) for flexibility 51.7 (at \( \sigma_t = 315 \) MPa) is equal to 0.812, and for the flexibility - 40.3 - 0.871. The difference is 7.3%, which is explained by the nonlinear dependence of \( \varphi \) on \( \lambda \).

The stanchion deformation between the nodes of the lattice occurred in fact in flexural-torsion form. The pointer of the curvature of one of the shelves was 25.8 mm, and the other -3.5 mm, which indicates the cross-section’s rotation. The shelf had large deformations, the stresses in which (see Fig. 3) were large, taking into account its increase in added stress from the stanchion longitudinal force and the eccentricity from the stanchion curvature from the plane as a whole. In the limit state in a more curved shelf, the average normal stresses were 302 MPa, and in the opposite - 239 MPa.

The test results analysis
The experimental data analysis gives grounds to assume that the exhaustion of the carrying capacity of the open rod occurred according to the following scenario.

As the longitudinal force in the stanchion increased to the values close to the limiting ones by the criterion of stability from the lattice plane, the stanchion began to bend along its entire length with the appearance of a bending moment in the cross section.

In the middle, the third from the base stanchion panel, the eccentricity of the longitudinal force had the maximum value. As the design limit states are approached, the stanchion in the area between the lattice nodes actually worked for eccentric compression. The longitudinal force in this panel was close in magnitude to its calculated limit value by the stability criterion in the grid plane. Normal stresses in the more compressed shelf of the I-beam reached 98% of the yield strength. Plastic deformation of the shelf fiber occurred. The reliance section of the stanchion decreased, the pointer of the curvature of the stanchion from the plane of the lattice increased.

Upon reaching the longitudinal force of the stanchion value 105% of the limiting calculated value, the stanchion stability reserves were exhausted according to the criterion from the frame plane and the stanchion as a whole lost its stability.

In the conditions of the stanchion curvature pointer grid plane further growth, the bending component in the middle panel operation and the stress in the more compressed shelf of the I-beam increased. Since the value of the longitudinal force of the middle panel was only 6% less than the calculated limit value for central compression, the stanchion stability reserves were also exhausted by the criterion in the grid plane.

Summary
Thus, the analysis of the sample testing results the crane part of an open column of a natural size is well illustrated and confirms that its actual work as it approaches the ultimate state and deformation in the process of exhaustion of the carrying capacity have a pronounced spatial character. With close values of the actual marginal efforts according to the stanchion stability criteria in the plane and from the grid plane (1752kN and 1708kN respectively), the sample’s carrying capacity is exhausted during the two processes interaction: deformation (curvature) of the more loaded stanchion from the grid plane and deformation of the stanchion panel (first of all on the shelves) in the area between adjacent lattice nodes in its plane. For the stanchion panel, the quantitative parameters of the pinching influence in the lattice nodes are established (due to the rigidity of the sections of the stanchion in the adjacent panels).

Acknowledgements
The work is realized in the framework of the Program of flagship university development on the base of the Belgorod State Technological University named after V.G. Shukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov.

References
[1] SNiP II-23-81 *. 1988 Steel construction. Design standards (Stroyizdat, Moscow).
[2] Razdolsky A G 1982 Critical force for a through-rod of I-stanchiones (Construction mechanics and structure calculation) 2 71-73.
[3] Gorev V V 1978 On the question of the stability of longitudinally compressed through rods (Construction mechanics and structural analysis) 4 30-33.
[4] Levitansky I V, Bekkerman M I, Solodov N V, Kondakov A I 1990 Experimental study of through columns (Construction and architecture) 2 7-12.
[5] Bekkerman M I, Dubrovensky A A, Tikhonov V D 1984 Improving the method of calculating the lattice crane parts of columns of industrial buildings (Central Scientific Research Institute Moscow, Moscow) 75-88.
[6] Solodov N V, Piriyev Yu S 2016 The estimated length of the stanchiones of the through steel columns from the frame plane (Bulletin of BSTU named after V.G. Shukhov) 3 13-16.