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# AN INFLUENCE OF COLUMN INCLINATION ON THE WORK OF PLANE BAR STRUCTURAL SYSTEMS SUPPORTING SHED ROOF SHEETING

The article presents the results of an analysis concerning changes in strength and stability of flat tubular rigid frame structural systems of sheds caused by changes in their geometric forms. In the considered cases, the examined shape changes consist in changing the inclination of the frame's columns to the vertical, with their bases shifted inside and outside the systems. This is how a few derivative frame systems of special trapezial forms are created in relation to the basic rectangular frame characterized by vertical single-branch columns and a horizontal lattice girder. The specificity of the loads imposed on the flat systems is fastening of each roof cladding with each corrugation to the upper chord of the considered frame girder. Thus, the imposed load should be considered as a uniform distribution over the entire length of the chord. The presented results are to be used in the next steps of the research, where the flat transverse frame systems changing their shapes along the length of a building are to be analysed. The obtained results are going to be implemented in a future method for parametric shaping of unconventional forms of buildings and their optimized structural systems. The elaborated structures constitute a certain uniform area of analysis of flat lattice girders, selected from a large number of areas analysed or planned for research, including related to oblique lattice girders or frames with diversified static schemes.

**Keywords:** flat structural systems, rigid tubular frames, cladding made of corrugated sheets, unconventional forms of buildings

## 1. Introduction

Nominally flat thin-walled folded sheets have specific orthotropic geometric and mechanical properties that allow their large torsional and lateral flexural deformations, thanks to which it is possible to adapt their transverse shapes to different shapes and mutual positions of roof directrices supporting transversely the corrugated sheeting. The roof directrices, adopted transversely to the diversified directions of the roof folds, enforce unconventional spatial form of a folded roof by attaching both ends of the successive folds to the directrices, Figure 1a-b [1]. The same functions as roof directrices can be performed by columns that can also force various unconventional facade forms by fixing them to the columns.

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Fig. 1. A roof composed of repetitive shell segments and its structural system:
(a) an exterior view, (b) an interior view of a building

Flat transverse frame systems are the simplest structural systems for obtaining varied mutual positions of medium-span roof directrices and varied inclination of wall columns supporting folded coverings [2]. An unconventional form of a roof or wall cladding is obtained by modifying an unusual shape of a rectangular transverse frame, including by inclining the roof girder to the horizontal or tilting the elevation columns from their vertical position. The flat transverse frame systems arranged sequentially along the length of a building can force different shell roof and facade forms by varying the mutual inclination of subsequent roof directrices or the mutual inclination of the subsequent wall columns.

As a result of such flat frame form modifications, a change in the nature of their static-strength performance and stability is expected [3]. The imposed load transmitted from a folded roof causes important differences in the work of vertical and tilted columns affecting the stability and stresses of both the columns themselves and some other frame elements. A specific feature of the discussed structures is assembling of each fold of the roof or wall sheeting to the directrices (girders or columns), which dictates the consideration of the imposed loads as uniformly distributed along the entire length of each directrix.

## 2. Critical analysis of the present knowledge

The basic principles of shaping diverse unconventional building forms and their special structural systems have been presented by Abdel et al. [4]. Steel bar systems dedicated to buildings of varied general forms covered by thin-walled corrugated sheets were presented by Reichhart [1]. Bryan and Davis [5] studied in detail the geometric and mechanical properties of the so-called Hypars, that is, made of flat profiled sheets deformed to form of a narrow hyperbolic paraboloids. These researchers described a few ways to shape the above shell corrugated forms, assuming significant limits on the deformation degree. They obtained little diversified narrow hyperbolic-paraboloid roof forms due to the high initial stresses induced by the shape deformation of flat sheets arranged in two-layer folded strips fixed to directrices and oriented in two orthogonal directions. Reichhart [3] developed a method of shaping bar structural systems that allows one to largely bypass the above limitations. The folded roof forms developed by Reichhart are characterized by various free shapes because the deformations of their sheets into rectilinear surfaces are characterized by a relatively great freedom of the width increments of their folds resulting in high degree of their twist about the longitudinal axes passing transversally to the roof directrices.

Abramczyk [3] has developed a few ways of geometric shaping unconventional general forms of buildings covered with thin-walled folded sheets transformed into diversified roof forms. Several examples describing static-strength work of rod structural systems, including flat frames, have been presented by Zang et al. [9] and Lubinski and Zoltowski [7]. Quantitative and qualitative prepositions for shaping tubular bar structures have been given by Marshal [8], Brodka and Broniewicz [3]. In the process of shaping a tubular structure, the strength work and stability of the entire structure [10], including repetitive, braced and little diversified planar transverse frames [2] and their individual elements and joints [11] is considered.

In the earlier author's study, some main geometric and mechanical properties of two types of flat lattice frames were considered. They are rectangular frames called the base configurations and rectangular-trapezoidal frames called derivative configurations (derived from the above base frames). In these studies, an effect of inclination of the lattice girder on mechanical properties of all elements of the frames was considered. Three discrete values of the h parameter, equal to 1.5, 3.0, and 4.5 m, were used, where h is the height of each frame configuration, Fig. 2.

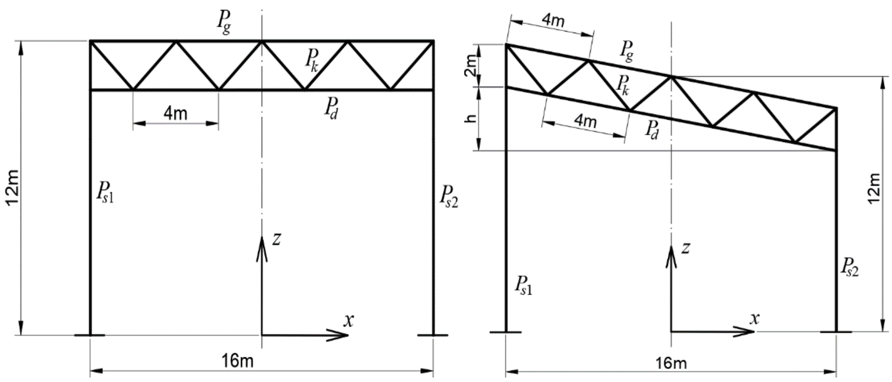


Fig. 2. Diagrams of two types of flat bar frames: rectangular base configuration and rectangular trapezoidal derived configuration

The sizes of the cross-sections of all elements belonging to the analyzed basic and derivative configurations were optimized due to the optimizing condition composed of three following restrictions:

- the permissible stresses due to the yielding of S235 steel,
- the critical load factor as small as possible, but not less than 1,
- the cross-sectional class as'high' as possible, but not greater than 3.

Four types of loads uniformly distributed along the length of the top chords of the lattice girders were used, Fig. 3. The imposed loads were analogous to the loads typical for sheds. The computer program calculated and included the own weight of the bars in the calculations [12].

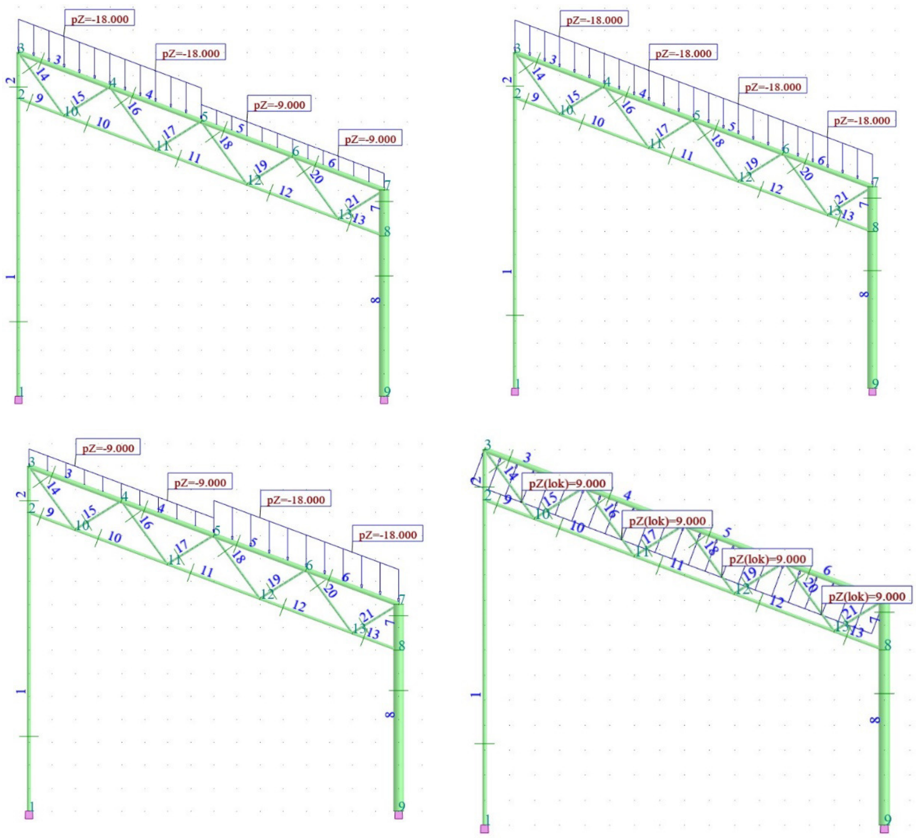


Fig. 3. Four types of loads uniformly and nonuniformly distributed along the length of the upper chords of lattice girders

The three continuous lines from each of the graphs below show the relationship between the strength ratios of the optimized cross sections of the higher $P_{s1}$ and shorter $P_{s2}$ columns and the bottom chord $P_d$ and the inclination of the lattice girder. The slope of the girder of the optimized frames has an adverse effect, as it increase of the optimized cross sections of the individual elements of the tested frames, especially their columns and bottom chords subjected to the adopted types of loads.

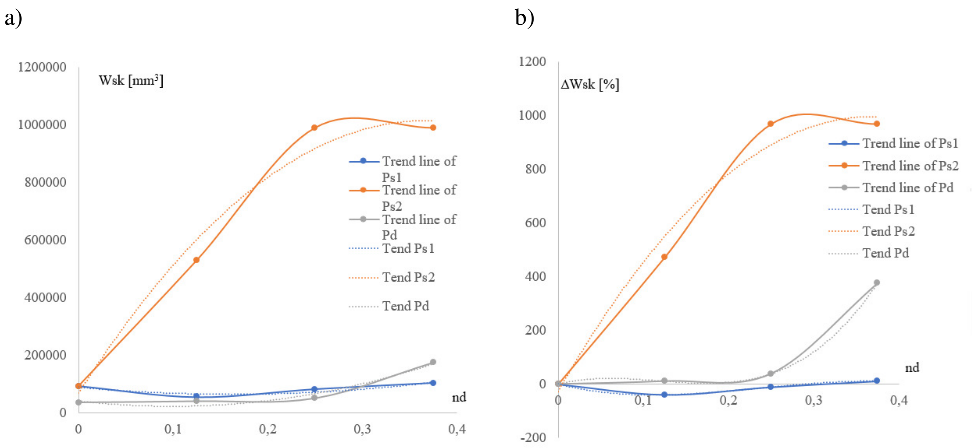


Fig. 4. Calculated strength indices Wsk for all elements whose cross-sections changed the most in relation to the elements of the rectangular configuration

The blue line named Trend Line Ps1 in Figure 4a indicates the relationship between the Wsk section module of the higher columns and the nb lattice girder inclination of the optimized basic and derived configurations. The orange line named Trend Line Ps2 in Figure 4a indicates the relationship between Wsk of the lower columns and nb calculated for the configurations. The gray line named Trend Line Pd in Figure 4a indicates the relationship between Wsk of the Pb bottom chord and the slope of the lattice girders belonging to the examined configurations. The above diagrams show the fundamental influence of the girder inclination on the selection of the cross-sectional sizes of the elements of the considered flat bar frames, mainly their longer columns and the lower chords.

In order to more precisely observe the effect of the above inclination, it was decided to consider the percentage changes in the sizes of the cross-sections of the above frame elements, Figure 4b. The trends obtained in this case indicate even more strongly the significance of the impact the girder inclination on the selection of the cross-sectional sizes of the longer columns and lower chords.

Increasing the girder inclination of the optimized derivative configurations increases the value of the critical load factor. As a result, another of the three constraints assumed in the optimization condition determines the size of the cross sections of the frame’s load-bearing elements. The decisive constraint on the stability of the rectangular frame changes to another constraint related to the maximum permissible strain of the individual frame elements. Thus, increasing the inclination of the girder causes a positive increase in the stability of the frame. The relationship between the critical load factor and the inclination of the lattice girder of the basic and derived configurations is shown in the diagram below.

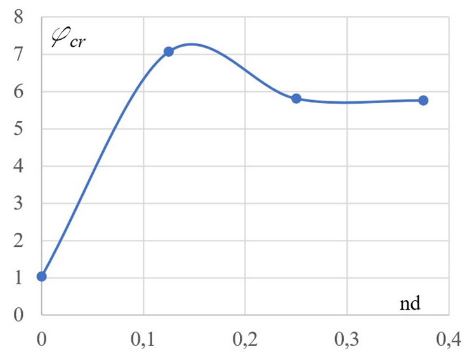


Fig. 5. The relationship between the critical load factor and the inclination of the lattice girder of the optimized basic and derived configurations

## 3. Aim

The aim is to present the results of the analysis related to the impact of changes in the columns' inclination of the investigated derivative frame configurations intended for structural systems of sheds on the strength work and stability of these systems. The analysis is related to an optimization of the bar cross-sections of all elements belonging to the studied frames in view of their selected mechanical properties, as well as the ability to maintain the overall stability of these frames loaded with uniformly distributed loads characteristic for the sheds roofed with nominally flat thin-walled folded sheeting transformed into shell shapes.

## 4. Research concept

The research consisted of creating simplified bar models in Robot [12] and performing computer simulations with using the incremental FEM method. In nonlinear incremental calculations, the assumption geometric nonlinearity was established, so big displacements and P-Δ effect were made. The idealized FEM model of a rod is a section divided regularly into finite elements having a length not exceeding 0.5 m. The accuracy of geometric modeling of the position of the longitudinal axis of the bars of the frame systems is 1mm.

Each considered transverse system is a flat rigid tubular frame consisting of a horizontal lattice girder connected by an upper and lower chord with a single-branch column on each side. In an initial concept, the cross-sections calculated for the optimized basic rectangular Kb frame configuration, Figure 2a, were employed in the process of shaping and testing some selected physical properties of the trapezoidal derivative Kp_j configurations (j=1-8), Figures 2b-c. Each Kp_j was built on the basis of Kb by tilting the vertical position of both opposite columns. This action resulted in the displacement of the columns' bases to the inside or outside of the frame.

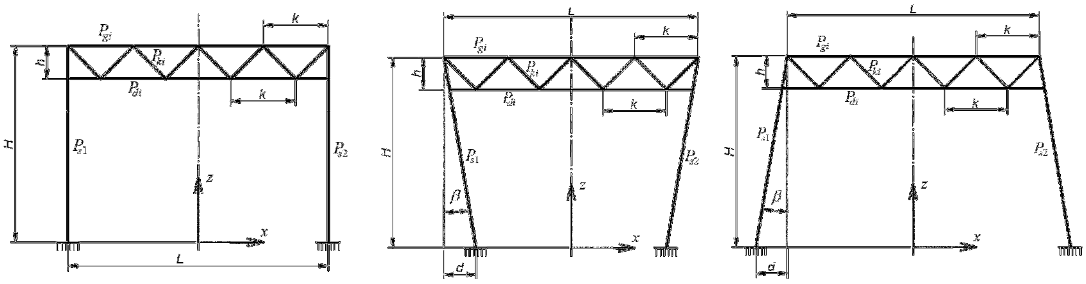


Fig. 6. Diagrams of three different types of tested flat frames consisting of single-branched columns $P_{s1}$ and $P_{s2}$, girders with parallel chords $P_{di}$ and $P_{di}$, and V-type cross-bracing $P_{ki}$: (a) rectangular layout, (b) inverted trapezoidal layout, (c) trapezoidal layout

The girder chords are horizontal and connected by V-type cross-braces inclined to the vertical at an angle of $45^o$. The columns are restrained in the foundation. Bars of one type, for example all the bars of $P_{ki}$ cross-braces, have identical cross-sections.

In the first stage of the study, a preliminary cross-sections of all elements of an initial rectangular Ko1 frame configuration was adopted, and next, optimized for the sake of obtaining the highest possible stress of these elements and sufficient stability of Ko1 as a result of successive selecting different discrete sizes of the cross-sections by means of the ”trial and error” method. The height H of the each frame is 12 m, the width L = 16 m, the height of the girder h = 1/8L = 2 m, the pitch of the cross-bracings k = 4 m, Figure 6, and the pitch of the successive transverse frame systems b = 6 m.

The dead load of each frame was derived from the cross-sectional size of each bar and calculated using the computer’s internal algorithm. It was assumed that: 1) the vertical characteristic load of a roof directed downward to the base is 3 kN/m$^2$, thus, it is possible to calculate the imposed load uniformly distributed along the top chord of each girder, which equals $q = b \cdot 3$ kN/m$^2$ = 18 kN/m, Figure 7a, 2) the load uniformly distributed on the roof, directed downward perpendicularly to its surface, corresponding to the wind suction and lifting the roof up, calculated per one meter of the top chord is equal to $r = 6$ m $\cdot$ 1.5 kN/m$^2$ = 9 kN/m, Figure 7b, 3) the vertical asymmetric characteristic load of the roof directed downward to the base is adopted to be 3 kN/m$^2$ and 1.5 kN/m$^2$, so it is possible to calculate the imposed load uniformly distributed along one half of the top chord of the girder: $q = b \cdot 3$ kN/m$^2$ =18 kN/m, and the uniformly distributed load acting along second half of the same top chord: $q / 2 = b \cdot 1.5$ kN/m2 = 9 kN/mb, Figure 7c. Due to the exploratory nature of the tests performed, the load and material reduction factors postulated by codes were not used.

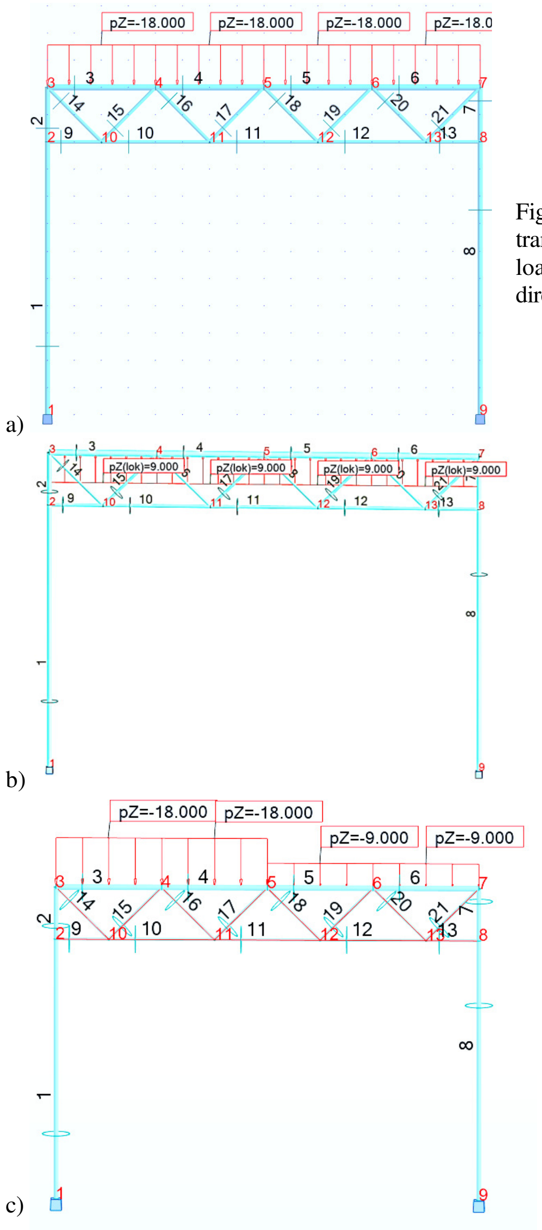


Fig. 7. Combinations of load of the considered transverse support frame systems, (a) vertical load directed downward, (b) vertical load directed upward, (c) asymmetrical vertical load

In terms of the strength work of bars made of S235 steel, stresses coming from compressive and tensile forces resulting from the above-mentioned different load configurations were analyzed. The local stability of bars was preserved by adopting the appropriate section class of each type of bar. The overall stability of single planar frame systems was studied by means of the critical load factor assumed to be greater than or equal to 1.0, for systems intended to operate safely, whereas the analyzed frames are called ”perfect” structures in theoretical research analysis. This paper considers issues related to the influence of the shape of transverse systems on their strength work and stability in the elastic range, neglecting analysis related to statics, strength and stability of nodes (joints).

Carrying out the study according to the preliminary planned concept prescribing the optimization of only the base rectangular frame configuration and using all the calculated cross-section sizes of its elements in the derivative frame configurations turned out to be impossible due to very large differences in the stresses appearing in the columns of the subsequent derivative configurations. Therefore, it was decided to carry out the optimization process also for each studied derivative configuration, and then instead of studying the trends of changes in the stress levels appearing in the bars, it was decided to study the trends of changes in the area and moment of inertia of each cross-section type. In the end, the specific trends appearing during the changes in the values of the section modules of the bar cross-sections and the critical load factor of the whole frames subjected to the optimization processes were considered due to the obtained results presenting a large increase in the values of the stresses occurring in the subsequent derivative configurations (characterized by increasing slope of the columns).

## 5. Results

Taking into account the adopted loads, it was possible to obtain the following frame configurations, in which the most stressed bars belong to the upper chord $P_g$, lower chord $P_d$ and cross-braces $P_k$. On the other side, the size of the cross-sections of the columns $P_s$ has a decisive influence on the ability to maintain the stability of the considered frames. The final cross-sections of the optimized elements were calculated as a result of many successive attempts made during the process of computational shaping the basic configuration of the frame. The main geometric and mechanical characteristics calculated for all elements of the Kb configuration taking into account the above-mentioned load combinations are shown in Table 1.

Table 1. The basic geometric and mechanical quantities of bars of each of the four elements calculated from the optimization of the basic configuration Kb

| No | Element | Cross-section [mm x mm] | D/d | $\sigma_c$ [MPa] | $\sigma_r$ [MPa] | |
|---|---|---|---|---|---|---|
| 1 | $P_s$ | 177.8 x 4 | 44 | 207 | -98 | |
| 2 | $P_d$ | 114.3 x 4 | 29 | 108 | -236 | |
| 3 | $P_g$ | 219.1 x 4.5 | 49 | 238 | -130 | |
| 4 | $P_k$ | 114.3 x 3 | 38 | 157 | -232 | |
| 5 | $\varphi_{cr}$ | | | | | 1.04 |

The cross-sectional characteristics included in Table 1 were used in the creation of the arbitrary derivative configurations Kpj (j=1-8) employed to optimize the final derivative configurations Kpj. The results obtained for Kpj are given in Tables 2-3.

Table 2. Compressive stress $\sigma_c$ / ten sile stress $\sigma_r$ calculated for the most stressed bars of each element of the derivative inverted trapezial configuration Kpj (j=1-4)

| **Configu-ration** | **Kp1** | **Kp2** | **Kp3** | **Kp4** |
|---|---|---|---|---|
| Element | Cross-section | Cross-section | Cross-section | Cross-section |
| $P_s$ | 177.8 x 5.6 | 244.5 x 4 | 273 x 4.5 | 323.9 x 4.5 |
| $P_d$ | 114.3 x 4 | 114.3 x 4 | 114.3 x 4 | 114.3 x 4 |
| $P_g$ | 219.1 x 4.5 | 219.1 x 4.5 | 219.1 x 4.5 | 219.1 x 4.5 |
| $P_k$ | 101.6 x 3 | 88.9 x 3 | 88.9 x 3 | 88.9 x 3 |
| Stresses | $\sigma_c$ / $\sigma_r$ [MPa] | $\sigma_c$ / $\sigma_r$ [MPa] | $\sigma_c$ / $\sigma_r$[MPa] | $\sigma_c$ / $\sigma_r$ [MPa] |
| $P_s$ | 210/-121 | 218/-127 | 222/-148 | 214/-150 |
| $P_d$ | 179/-235 | 177/-233 | 195/-231 | 207/-228 |
| $P_g$ | 230/-131 | 217/-128 | 210/-129 | 228/-158 |
| $P_k$ | 179/-236 | 207/-233 | 209/-228 | 211/-222 |
| $\varphi_{cr}$ | 1.26 | 2.11 | 2.79 | 6.24 |

Table 3. Compressive stress $\sigma_c$ / ten sile stress $\sigma_r$ calculated for the most stressed bars of each element of the derivative trapezial configuration Kpj (j=5-8)

| **Configu-ration** | **Kp5** | **Kp6** | **Kp7** | **Kp8** |
|---|---|---|---|---|
| Element | Cross-section | Cross-section | Cross-section | Cross-section |
| $P_s$ | 177.8 x 4.5 | 193.7 x 4.5 | 193.7 x 5.6 | 273 x 5 |
| $P_d$ | 114.3 x 4 | 114.3 x 4 | 114.3 x 4 | 127 x 4.5 |
| $P_g$ | 244.5 x 4 | 244.5 x 4 | 244.5 x 4 | 273 x 4.5 |
| $P_k$ | 114.3 x 3 | 114.3 x 3 | 114.3 x 3 | 101.6 x 3 |
| Stresses | $\sigma_c$ / $\sigma_r$ [MPa] | $\sigma_c$ / $\sigma_r$ [MPa] | $\sigma_c$ / $\sigma_r$[MPa] | $\sigma_c$ / $\sigma_r$ [MPa] |
| $P_s$ | 211/-132 | 235/-160 | 233/-171 | 228/-153 |
| $P_d$ | 135/-236 | 140/-236 | 141/-236 | 129/-218 |
| $P_g$ | 222/-104 | 223/-104 | 225/-105 | 221/-91 |
| $P_k$ | 156/-223 | 176/-232 | 175/-226 | 206/-228 |
| $\varphi_{cr}$ | 1.23 | 1.29 | 2.02 | 4.37 |

## 6. Analysis

Since the columns are primarily bendable frame members, their strain is affected by the magnitude of the strength index of their cross sections. Therefore, the section modules of the calculated cross-sections were calculated to obtain the possibility of the optimization of the structural performance

of the columns. As a result of multiple iterations of calculations related to obtaining optimal cross-sections satisfying the conditions defined in Section 2 and also adopted for the research presented in the current article, discrete values of the above indices were obtained for the studied frame configurations.
The calculated values of the strength indices of the optimal cross-section sizes correspond to the dots on the diagram presented in Figure 8a-b. Then two Wn and Zn broken lines were drawn through the points thus determined representing the dependences between the inclination and the mechanical properties (section modules) of the pole cross-sections of the inverted trapezial and trapezial frame configurations.

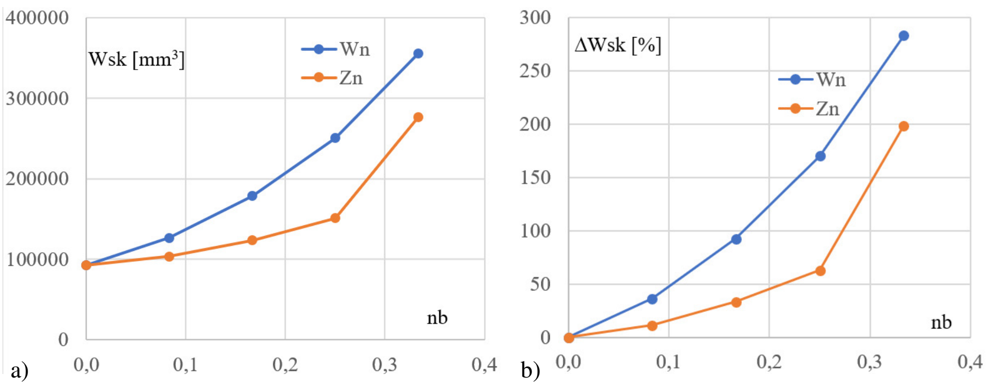


Fig. 8. Lines Wn and Zn showing the relationship between the magnitude of the Wsk section module of the cross sections of the inverted trapezial configurations of the Kpj (j=1-4) configuration – line Wn and trapezial Kpj (j=5-8) configuration – line Zn and the slope nb of these columns: (a) absolute values of the Wsk index, (b) relative increments of the Wsk section module.

The graphs show the variation of mechanical properties (section module) of optimized successive frames whose columns have a variable inclination to the vertical. Thus, a single line illustrates the way in which a change in the angle of inclination of the columns makes it necessary to change the size of the cross-sections of these columns (section module) in order for their work to be optimized according to the adopted load-carrying capacity and stability criteria.

As the nb inclination (the abscissa axis) of the columns increases in the derivative configurations, the stresses of their rods significantly increase above the maximally acceptable levels predicted for S235 steel while maintaining the sizes of the cross-sections calculated for the optimized Kb. Therefore, for the successive derivative configurations of Kpj, the sizes of the cross-sections (and their section modules - the ordinate axis) of their selected elements were changed to obtain the highest possible permissible stresses appearing in their columns.

The Wn and Zn big dots, shown in Figure 9a-b, result from the calculations made for discrete configurations of frames and can represent the dependences between the inclination and mechanical properties of the cross-sections of the cross braces belonging to the trapezial frame configurations. The presented dotted straight lines representing two groups of points and named Trend Wn and Trend Zn, see Figures 9a-b, show the trends in the change in the values of the section modules calculated for the optimized cross-sections of the cross braces of the successively tested rectangular basic configuration Kb and trapezial derivative configurations Kpj for j = 1-4, see line Wn, and j = 5-8, see line Zn.

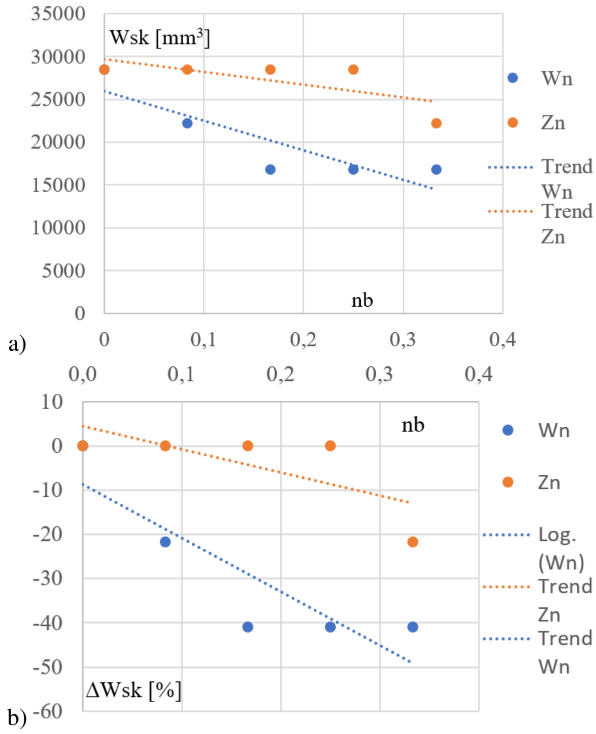


Fig. 9. Lines Wn and Zn showing trends between the magnitude of the Wsk section module of the cross sections of inverted trapezoidal cross-sections of Kpj (j=1-4) - Trend Wn or trapezoidal Kpj configurations (j=5-8) – Trend Zn and the slope of the cross-sections: (a) absolute values of Wsk, (b) relative increments of Wsk

The variation in the results obtained in this case was small in relation to the possible accuracy of the calculations, hence unjustified local extremes would appear if the points were connected by a broken line. Therefore, it was decided to determine simple trends (dotted straight lines) depicting trends of small changes in the size of optimized cross sections of the cross braces.

An important trend in the qualitative mechanical changes of the analyzed configurations can be seen in Figure 10. The changes in the value of the critical load factor caused by the change in the inclination of the columns start with the value of about 1.0 and increase relatively fast.

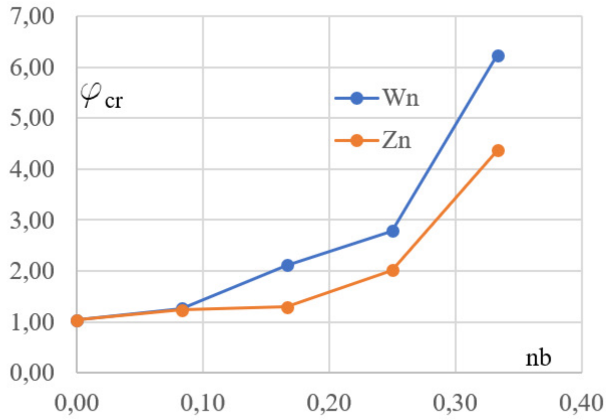


Fig. 10. Dependencies of the critical load factor $\varphi$ on the inclination nb of the columns calculated for: inverted trapezoidal configurations Kpj (j=1 to 4) – line Wn and for trapezoidal configurations Kpj (j=5 to 8) – line Zn

The value of the critical load factor $\varphi_{cr}$ = 1.04 (form Table 1) obtained during the optimizing process of Kb results in the column strength that has to be limited to $\sigma_c$ = 207 MPa.

## 7. Discussion

From the analysis of the values given in Tables 1-3 and the properties of the lines shown in Figures 8-9 presented in previous sections results that there is: 1) a strong, significant influence of the inclination of the columns on their strength work – lines Wn and Zn, Figure 8a-b, 2) an insignificant influence of the inclination of the columns on the strength of the cross-braces of the derivative trapezial configurations – the line Trend Zn, Figure 9a-b, 3) a significant effect of the inclination of the columns on the cross-braces strength of the of the derivative inverted trapezoidal configurations – the line Trend Wn, Figure 9a-b.

An increase in inclination nb (Figure 9a-b) of the columns of the frames causes the increase in the stresses of these columns, so their cross-sections have to be optimized. Therefore, for the successive derivative configurations of Kpj, the sizes of the cross-sections of their selected elements were changed to restrict the levels of the stresses appearing in their columns, so as not to exceed the plasticity limit of the material. Thus, for example, for the Kp2 (nb = 1/6) configuration, the section module of the column cross-sections had to be increased by 100 %, and for Kp4 (nb = 1/3) by as much as 280 %, see line Wn, Figure 8b.

The obtained dependencies are strongly non-linear and testify to the increasingly strong influence of the increase in the inclination of columns on the size of the optimal cross-sections of the columns, and to a lesser extent, on the size of the cross-braces. The analogous relationship obtained for the trapezoidal configurations is clearly weaker than that for the inverted trapezoidal configurations. The other elements of the studied frame configurations do not tend to change in the optimal cross-sections caused by the inclination of the columns to the vertical.

The decisive role in the optimization of the Kb basic configuration performs the overall stability of the basic frame configuration due to the need to limit the frame stability factor to above 1. This limitation reduces the column effort by about 10%. However, this value is not very safe and it should be increased to two or three, the consequence of which is the need to increase in the values of the columns' cross-sections and section modulus. Therefore, in the case of rectangular frames loaded in accordance with the adopted assumptions, it is advisable to look for other geometric and static as well as stiffening solutions.

In the case of the Kpj derivative configurations, the maximum strength of the columns is decisive. The observed trends in the change in the mechanical properties of the simulated frames are usually nonlinear. In this case there is no need to limit the load-bearing capacity of the frame due to the loss of stability under the influence of the assumed loads. Higher capacity and overall stability are observed especially for the trapezial derivative configurations compared to the inverted trapezial configurations.

## 8. Conclusions

The change in the column's inclination to the vertical causes a significant nonlinear increase in the column stresses and critical load factor of the entire flat frame loaded by the assumed load types. However, the change causes the need to significant increase in the rod cross-section size and section module of the columns.

The increase in the column inclination to the vertical causes a greater increase in the section module values of the selected rod element cross-sections for trapezial frames than for the inverted trapezial frames. The change in the column inclination nb from 0 to 1/3 causes the increase in the value of the section module by 200% for trapezial configurations, and by 280% for the inverted trapezial configurations.

The analyzed mechanical changes of the frames caused by changes in the inclination of their columns are not only quantitative but also qualitative even for trapezial frames with a small column inclination to the vertical. This is due to the fact that the decisive condition regarding the minimum size of the cross-sections of the rectangular frame columns are the critical loads and the ability of these frames to lose the overall stability caused by the types and values of loads used. In contrast, in the case of the trapezial and inverted trapezial frames with a relatively small tilt of their columns to the vertical, yielding of the steel is the decisive condition limiting the minimum size of their cross-sections.

The increase in the columns' inclination also has rather small effect on the changes in the size of the cross-sections of the considered cross braces. The change in their section modules riches up to 20% for the trapezial configurations and up to 40% for the inverted trapezial configurations. This increase also causes a relatively insignificant change in the size of the optimal cross-sections of the bars belonging to the other elements of the frames studied.

The obtained large changes in the mechanical properties of the considered frames caused by changing the inclination of the columns or girders justify conducting further studies to optimize the performance of various flat frames in view of their load magnitude. Thus, the analysis carried out should lead to a parametric procedure that allows one to optimize the cross-sections of the elements of the considered types due to their maximum loads. For this purpose, artificial neural networks are planned to be used.

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