FORECASTING DISASTER HAZARD IN BOLT JOINT CONSTRUCTIONS

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The classical method of the calculation of dissipation energy in the process of transformation of the geometrical invariable scheme of construction into the kinematic chain, geometrical variable, does not lead to correct disaster forecasts. Serious errors occur in the estimation of the state of effort when the kinematic chain is created through the formatin of the articulations in the joints whose elements work in the uniaxial stress. In such articulations it is necessary to calculate the dissipation of inner power by the utilization of the strain hardering effect of the material of the connectors.

The paper provides documentary evidence for the correctness of the presented conception by forecasting the disaster of the steelwork for the roof of the industrial bay which has been shaped as a frame

1.Generalization of the algorithm of the kinematic method by the strain hardering method

Functional stage, which is the state of static equilibrium where each increase in load is connected with increase in strain, is transformed into a stage of the limit capacity. Therefore the construction loses its ability to take over the increase in load and becomes a geometrical variable system. Such a process takes place in the conditions which are defined by the power balance

$$L = D \tag{1}$$

where

L - power of external load computed with taking into account the velocity of prepared displacements,

D - power of internal forces on prepared strain velocities.

Powers, which occur with equation (1), are computed from the formulae

$$L = \sum_{j=1}^{n} \int_{0}^{l} q^{j} \cdot w_j \cdot dl, \tag{2}$$

$$D = \sum_{j=1}^{p} M_{gr}^{j} \cdot \varphi_j , \tag{3}$$

where

q - generalizable external load,

w - prepared displacement velocity,

n - number of rods with prepared relocation,

M_{gr} - boundary moment of the section bent,

φ - velocity of angular strain connected with relocation velocity w,

p - number of articulations transforming the geometrical invariable system into mechanism.

The boundary value of the moment for bending rods is computed with the help of some elements of the teory of plasticity [1] as follows

$$M_{gr} = W_{pl} \cdot \sigma_{pl} \tag{4}$$

W_{pl} - plastic bending section modulus,

σ_{pl} - stress characteristic for the initial stage of the plastic flow process.

In the theory of plasticity a material is taken as

$$\sigma_{pl} = R_e \tag{5}$$

which can be seen in Fig 1. In the bent section the moment M_{gr} is the greatest moment which is able to transfer an element. It results from the stress pattern in the totally plastic section. Then the curvature may grow in an unlimited way without any increas of the moment.

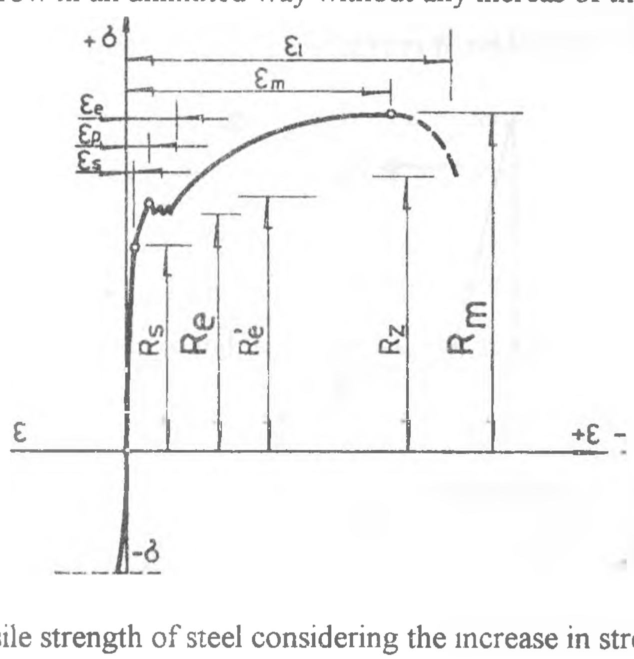

Fig.1. Diagram of the tensile strength of steel considering the increase in stress to value R_m

The diagram of stress consist of two rectangles as shown in Figure 2b, and the elastic core, presented in Figure 2a, undergoes degeneration.

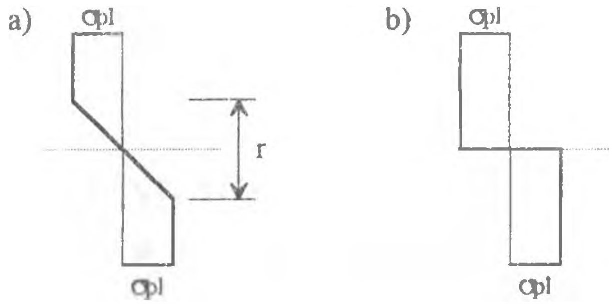

Fig.2. The stress pattern in elastic-plastic and plastic material

Such a dependence is determined by the relation between the height of the core "r" and the curve $y^{//}$

$$r = \frac{2\sigma_{pl}}{E \cdot y^{//}} \tag{6}$$

If the articulation, which transforms the geometrical invariable system into mechanism, forms in the point which has been created with the help of the bolts [7], then the analogical moment up to the point defined by formula (4), can be computed by formula (7)

$$M_{gr} = \frac{N_{gr} \cdot \sum_{1}^{i} h_i^2}{h_1} = \frac{A \cdot \sigma_{pl} \cdot \sum_{1}^{i} h_i^2}{h_1} = \frac{A \cdot R_e \cdot \sum_{1}^{i} h_i^2}{h_1} \tag{7}$$

where

A - cross-section area of bolts,

h - dimention presented in Figure 3.

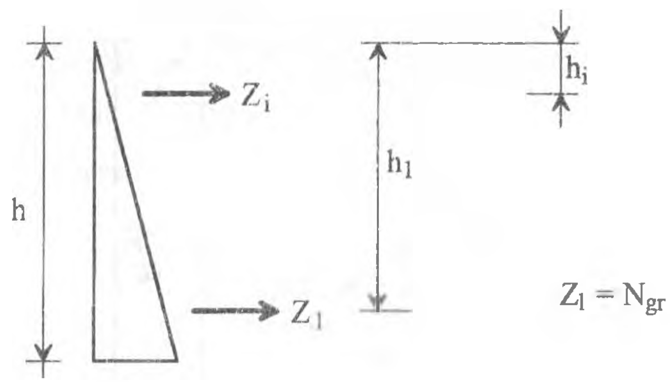

Fig.3. Distribution of forces in the bolts of the joint bent

The boundary moment obtained from formula (7) and is denote by $M_{gr}(R_e)$. For two rows of bolts such a moment amounts to

$$M_{gr}(R_e) = \frac{N_{gr} \cdot (h_1^2 + h_2^2)}{h_1} \tag{8}$$

The power of dissipation energy in a bolt joint with the number "j" has the following value

$$D_j(R_e) = M_{gr}^j(R_e) \cdot \varphi_j \tag{9}$$

but solution of equation (1) fails to transform the system into the geometrically variable one. It results from the fact that in the uniaxial stress, strains of bolts are finite, despite stress formation $\sigma_{pl} = R_e$, which is presented in Figure 1. Maximum load capacity of the moment, which corresponds to the effect of strain hardering material [2] is computed for the stresses R_m, which exist at the Norm [6]. Then the boundary moment of a joint is calculated from the formula

$$M_{gr}(R_m) = \frac{A \cdot R_m \cdot \sum_{1}^{i} h_i^2}{h_1} \tag{10}$$

and the power of the dissipation energy amounts to

$$D_j(R_m) = M_{gr}^j(R_m) \cdot \varphi_j \tag{11}$$

The degree of disaster hazard "k"should be calculated from the formula

$$L = D(R_m), \tag{12}$$

hence

$$k = \frac{L}{D(R_m)} \tag{13}$$

and the disaster will take place in consrtuctions characterized by inequality

$$k \geq 1 \tag{14}$$

2. Example estimation of the degree of disaster hazard of an industrial bay

The disaster which had taken place in one of the industrial enterprises was analysed on the basis of this method. Geometrical invariable schem of the analysed construction is presented in Figure 4.

The joints on the supports were made by mounting the steel girders on the reinforced columns. The ties were made of rods 2ϕ22mm of metric thread M22 of steel St3S and of cross-sectional area $A_c = 3,03\ cm^2$ On the basis of the non-destructive methods it was possible to ascertain the class of concrete of the columns in the zones of supports, which amounted to B20. The joint in the span centre of the steel girder was made of bolts 4M24 class 5.6 in such a way that spacing h_1 and h_i, presented in Figure 3, amounted to

$$h_1 = 29,0\ cm, \quad h_i = h_2 = 5,0\ cm.$$

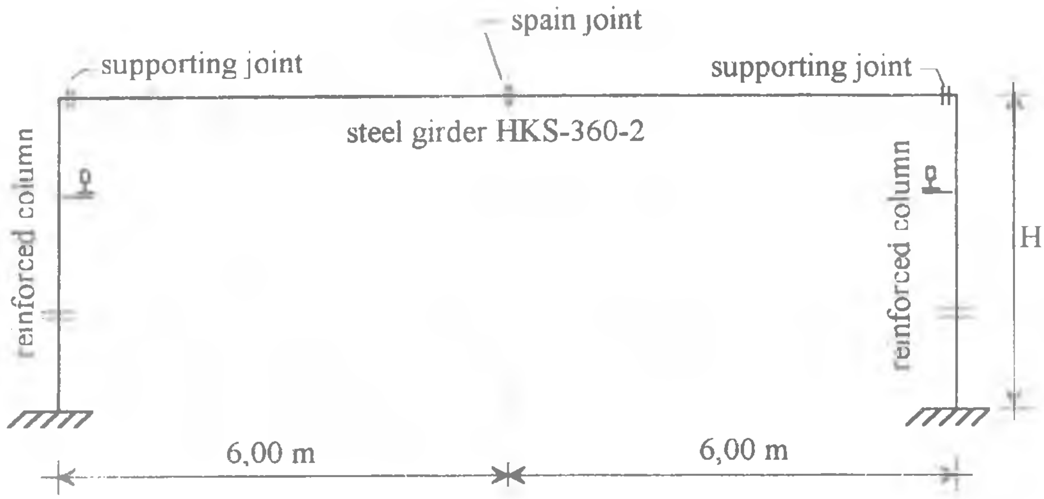

Fig.4. Geometrical scheme of the industrial bay construction

At the points where forces Z_1 and $Z_i = Z_2$ worked, sets of two bolts M24 with the cross-sectional area $A_c = 3,53\ cm^2$ for each "Z" were placed.

The stage of failure to transfer the load followed the destruction of the spandrel beam at the points where the joints had been made. The spandrel beam was loaded by concentrated forces P and uniform load q, as shown in Figure 5.

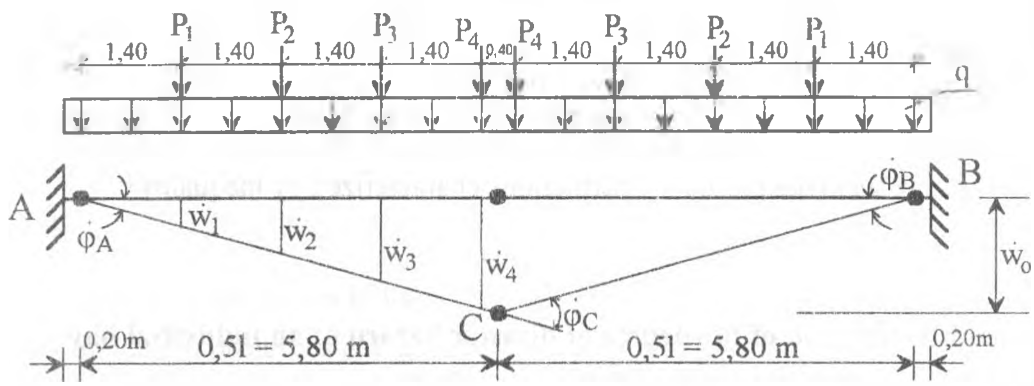

Fig.5. The kinematic scheme of the destruction of the roof construction

Kinematically permissible state of the velocity increments of the displacements of the girder axle is presented as w_o and in the bolt joints such a state causes the increments in velocity of angular displacements $\dot{\varphi}_A, \dot{\varphi}_B, \dot{\varphi}_C$

The power of the internal forces for the limiting values of moments $M_{gr} = M_{gr}(R_m)$ amounts to

$$D = M_{gr}^A \cdot \dot{\varphi}_A + M_{gr}^C \cdot \dot{\varphi}_C + M_{gr}^B \cdot \dot{\varphi}_B = D(R_m) \tag{14}$$

The power of external loads caused by the action concentrated forces amounts to

$$L(P) = 2 \cdot (P_1 \cdot w_1 + P_2 \cdot w_2 + P_3 \cdot w_3 + P_4 \cdot w_4) \tag{15}$$

and the power of the external continuous load is equal to

$$L(q) = 2 \cdot q \cdot l \cdot 0,5w_0 . \tag{16}$$

The total power of the external load is a sum

$$L = L(P) + L(q). \tag{17}$$

Dissipation of energy has taken place only in joints A, B, C. The velocity of relocation w_0 correspond with the velocities of relocations $w_1 = 0,24w_0$, $w_2 = 0,48w_0$, $w_3 = 0,72w_0$, $w_4 = 0,97w_0$ and with the velocities of angular relocation

$$\varphi_A = \frac{w_0}{l},\ \varphi_B = \frac{w_0}{l},\ \varphi_C = 2 \cdot \frac{w_0}{l}.$$

The boundary moments amount to $M_{gr}^A = M_{gr}^B = N_s \cdot z$ where N_s means the force transfered by two bolts M22, while the arm of external forces "z" derived from the equiation of equilibrium for the depth of the compressive zone of concrete x = 2,84cm amounted to z = 8,58cm. Stresses R_m for the steel with class A-0 amounts to R_m = 375MPa. As a result we have

$$N_s = 2 \times 3,03 \times 3750 = 22725 \text{ daN},$$

$$M_{gr}^A(R_m) = 22725 \text{ daN} \cdot 8,58 \text{ cm} = 19,50 \text{ kNm}.$$

Analogically the boundary moment in joint C with utilization the formula (10) was calculated. For the bolts with class 5.6 strength amounts to R_m = 419MPa and the boundary moment computed for force

$$Z_1 = N_s = 2 \times 3,53 \times 4190 = 29581 \text{ daN},$$

$$M_{gr}^C(R_m) = 176,66 \text{ kNm}$$

As a result of the aplication of the loads including the impact of the dead weight and the load by snow it was determined that the value of the external loads amounted to

$$P_1 = P_2 = P_3 = 2517 \text{ daN},$$

$$P_4 = 1560 \text{ daN},$$

$$q = 169 \text{ daN/m},$$

and the powers of the external loads, calculated from the formulae (15), (16), (17), amounted to

$$L(P) = 102,74 \text{ kN} \cdot w_0, \qquad L(q) = 9,80 \text{ kN} \cdot w_0, \qquad L = 112,54 \text{ kN} \cdot w_0.$$

The power of the energy dissipation in joints was computed using formula (14) and it amounted to

$$D(R_m) = 2 \cdot 19,50\ \mathrm{kNm}\ \frac{w_o}{5,80\mathrm{m}} + 176,66\ \mathrm{kNm} \cdot 2 \cdot \frac{w_o}{5,80\mathrm{m}} = 67,64\ \mathrm{kN} \cdot w_o.$$

The degree of disaster hazard of the construction during winter time amounts to

$$k = \frac{L}{D(R_m)} = \frac{112,54\ \mathrm{kN} \cdot w_o}{67,64\ \mathrm{kN} \cdot w_o} = 1,66$$

The disaster will come into being undoubtedly because inequality (14) is satisfied.

An analysis of the degree of disaster hazard of the construction during summer time, when the construction is not loaded by the weight of snow [4], was also carried out. Then the values of external loads are reduced and amount to

$$P_1 = P_2 = P_3 = 967\ \mathrm{daN},$$

$$P_4 = 564\ \mathrm{daN},$$

and load q, which defines the dead weight of the spandrel beam type HKS remains unchanged

For the load defined in such a way the power of external loads amounts to

$$L(P) = 38,78\ \mathrm{kN} \cdot w_o,$$

and hence

$$L = L(P) + L(q) = (38,78 + 9,80)\mathrm{daN} \cdot w_o = 48,58\ \mathrm{daN} \cdot w_o.$$

The degree of disaster hazard during summer time amounts to

$$k = \frac{48,58\ \mathrm{kN} \cdot w_o}{67,64\ \mathrm{kN} \cdot w_o} = 0,72$$

Since inequality (14) is not satisfied the disaster is not likely to take place

3. Conclusions

The thesis, stated at the beginning, concerning the faults of the classical method of using the dissipative energy in the process of transformation of the invariable scheme of construction into a kinematic chain in order to evaluate the safety of a construction, appears to be correct.

The authors think that the method introduced here can be well applied in practice [3] and the above conclusion results from the logical and coherent relations presented in chapter 1. The relations were used in the analysis and formulation of the causes of the disaster, which had occurred in the one of the erected industrial objects. The calculations, presented in chapter 2, proved to be coherent with the real behaviour of the construction, which operated at the limit of safety during summer time but collapsed when the degree of hazard reached the value greater than one during winter time.

The degree of disaster hazard "k", depending on the computed value, can be used to find out if the construction is in a pre-emergency state or if it is necessary to immediately protect the object from the access of users and undertake precautionary measures specified in the building law.

REFERENCES

1. **Brunarski L., Kwieciński M.**: Wstęp do teorii sprężystości i plastyczności. Wydawnictwa Politechniki Białostockiej, Warszawa 1964.
2. **Jankowiak W.**: Konstrukcje metalowe. Państwowe Wydawnictwo Naukowe, Warszawa-Poznań 1983.
3. **Kobiak J.**: Błędy w konstrukcjach żelbetowych. Arkady, Warszawa 1971.
4. PN-80/B-02010: Obciążenia w obliczeniach statycznych. Obciążenie śniegiem.
5. PN-85/B-03264: Konstrukcje betonowe, żelbetowe i sprężone. Obliczenia statyczne i projektowanie.
6. PN-90/B-03200: Konstrukcje stalowe. Obliczenia statyczne i projektowanie.
7. PN-85/M-82101: Śruby ze łbem sześciokątnym.

ПРОГНОЗ УГРОЗЫ АВАРИЕЙ СТРОИТЕЛЬНОЙ КОНСТРУКЦИИ С БОЛТОВЫМИ СОЕДИНЕНИЯМИ

Резюме

В статье предложен метод определения коэффициента степени угрозы аварией строительной конструкции. Зависимости определено путём преобразования геометрически неизменяемой системы в кинематическую цепь. Коэффициент угрозы аварией определено на основе уравнения баланса мощности внешней нагрузки с учётом виртуальных перемещений и мощности внутренних усилий с учётом скорости деформации.