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THE MODERNISATION OF STEEL CONSTRUCTION BEAM
GANTRY FOR THE WORK OF TRANSPORT SUSPENDED –
USING THE EXAMPLE OF TRACK LENGTH EXPANSION
BY A SHORT BRACKET

MODERNIZACJA STALOWEJ KONSTRUKCJI
BELKI SUWNICOWEJ DLA PRACY TRANSPORTU
PODWIESZONEGO – NA PRZYKŁADZIE ROZWINIĘCIA
DŁUGOŚCI TORU O KRÓTKI WSPORNIK

Abstract

This paper discusses the design of an additional, short steel bracket as an extension of an existing track steel load-carrying beam continuity which was performed by the author in 2011. Eurocodes were introduced in 2010.

Keywords: steel structures of halls, technical cranes, gantry beams

Streszczenie

Artykuł dotyczy doprojektowania krótkiego wspornika stalowego jako przedłużenia ciągłości istniejącej stalowej belki nośnej toru, którego autor dokonał w 2011 roku, tj. po wprowadzeniu Eurokodów (2010).

Słowa kluczowe: konstrukcje stalowe hal, dźwignice techniczne, belki suwnicowe

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1. Introduction

The structures created at the time when Polish standards were in force have to comply with the current legislation in such a manner that after being modernised, the entire system has to be assessed against the Eurocodes. This task may be executed exactly in the manner illustrated in this article. These are quite laborious processes, demanding from a designer knowledge of both design systems.

1.1. Classification of lifting equipment

Lifting equipment used most frequently in industrial halls includes [1]:

- hoisting winches and hoists;
- underslung cranes;
- supported cranes;
- cantilevered cranes;
- gantry cranes;
- self-propelled wheeled equipment.

1.2. Description of underslung crane track structure

Unlike the tracks of supported cranes, compressed flanges of underslung cranes are not directly loaded with static or dynamic action of the hoisting winch or crane wheel. The wheels of these piece of equipment move on a lower shelf which is subjected to tensile stress. The lower flange transmits the concentrated loads generated by the hoisting winch wheels which cause bending of the shelf in the cross-sectional plane of the crane beam. The lower shelf is also exposed to abrasion by the wheels of the transporting equipment moving over it. Considering the latter effect, the reduction of the flange thickness is recommended.

2. Dimensioning of the structure system at the time of erection – in the context of PN standardisation

The ultimate load-bearing capacity limit [1, 2] is determined in two stages. As usual in such cases, decide the most adverse set of stress of the following two:

- skew bending with potential compression and shearing, taking into account the loss of general stability (buckling, warping);
- bending of a beam, taking into account torsion and local bending of flanges.

The stress conditions were interpreted in stress formulas in the upper and lower flanges:

- for the upper flange (bending with torsion – Fig. 1);

$$\sigma^{(4)} = \frac{M_{x,P}}{W_x^{(4)}} + \frac{M_{y,HP}}{W_y^{(4)}} + \frac{B \cdot \omega_4}{I_\omega} \leq f_d, \quad (1)$$

- for the upper flange (bending with torsion – Fig. 1);

$$\sigma^{(1)} = \frac{M_{x,P}}{W_x^{(1)}} + \frac{M_{y,H_P}}{W_y^{(1)}} + \frac{B \cdot \omega_4}{I_\omega} \leq f_d, \quad (2)$$

- for the lower flange (bending of the whole beam with local bending of the lower flange (Fig. 1);

$$\sigma^{(3)} = \frac{M_{x,V}}{W_x^{(3)}} + \frac{1.4P}{t^2} \leq f_d. \quad (3)$$

In formulas (1–3), the sectional moduli W_x and W_y relate to the entire underslung beam section.

The pair of wheels generating the load P are located on one side of the beam web. It should be noted that the trolley gear of underslung cranes usually has four wheels (two on each side of the track axis).

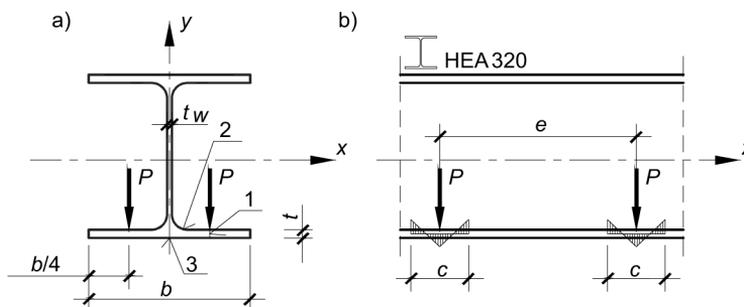


Fig. 1. Load of underslung crane track: a) cross-section of a beam, b) view of a beam with distribution of moments in lower flange (elaboration according to [1], figure from the archive of the author)

The local bending of flanges is determined approximately, assuming that the length of the flange on which the wheel of the crane is acting fulfils the following conditions:

$$c \leq 10t \text{ and } c < e \quad (4)$$

The bending moment on a conventional length of lower flange may be estimated according to the formula:

$$M_d = 0.23P \cdot c = 0.23 \cdot P \cdot 10 \cdot t = 2.3P \cdot t. \quad (5)$$

Estimation of the flange length sectional modulus in bending plane:

$$W_x = \frac{10 \cdot t \cdot t^2}{6} = \frac{10 \cdot t^3}{6}. \quad (6)$$

To recapitulate, the additional stress created as a result of lower flange local bending reaches the value:

$$\sigma_{x,d}^{(3)} = 2.3 \cdot \frac{P \cdot t}{10 \cdot t^3} \cdot 6, \quad (7)$$

$$\sigma_{x,d}^{(3)} = 1.4 \cdot \frac{P}{t^2}. \quad (8)$$

Summing the stress members ($M_{x,V}$ and P) contained in formula (3) results from them occurring jointly as loads present along the axis parallel to the length of the rolling track.

The real reflection of the lower flange connection with the web is the infinitely resilient strand. The real stress condition in the lower shelf (items 2 and 3 in Fig. 1) results from the flat stress with a value lower than that resulting from formulas (3) and (8).

The process of the beam's lower flange abrasion during its usage entails the necessity of its thickness reduction. This value is taken into account in calculations typical for the beam cross-section.

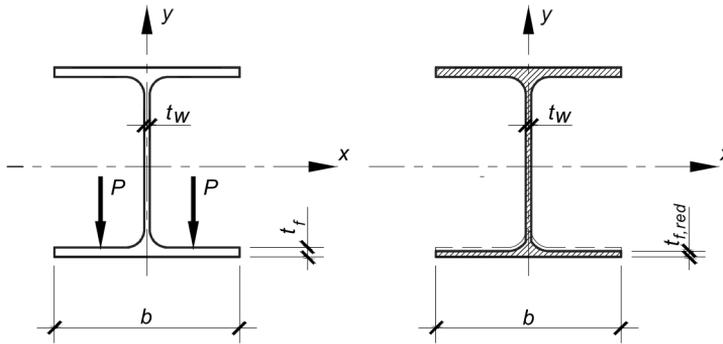


Fig. 2. The real and reduced cross-section of the lower flange (elaboration according to [1], figure from the archive of the author)

Taking into account that a beam's period of use may amount to over 35 years, it is recommended to reduce the flange thickness by at least 20%. It should be clearly noted here that the reduction discussed is significant for estimating the stress $\sigma_{x,d}^{(3)}$, formulas (7) and (8).

For the load capacity conditions determined according to [1], the influence of warping is taken into account, together with the potential buckling of the compressed zone in interaction with skew bending. Similarly, as in the case of supported cranes and for dimensioning underslung crane tracks, it is prohibited to use the plasticity reserve and supercritical load capacity.

3. Dimensioning system structure during modernisation – in the context of PN-EN standardisation

3.1. General remarks

The load capacity of sections and elements for underslung crane beams is determined according to the methods provided in the standard [3]. Warping (general stability) should be considered [3] after taking torsional moments into account. For single-rail hoists and

underslung cranes, it is not recommended to consider the stabilising effect of bending moments due to the influence of the vertical load, due to the possibility of lifting and moving the diagonal load on the crane the mounting hanger. The vertical loads should be applied at the level of the upper surface of the track rolling zone.

3.2. Influence of the vertical pressures of wheels on the values of stress and load capacity of underslung cranes or hoist lower beam – flanges

3.2.1. Stress from local bending of the beam's lower flange

The local stress when bending the lower flange of a beam made of a I-beam shape (any type) are determined in three places of the load carrying profile of the lower flange: “0” – close to web, “1” – under crane wheel, “2” – on the edge of the flange (Fig. 3).

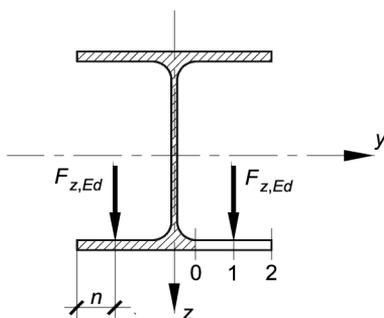


Fig. 3. The points in which the stress coming from local bending (0, 1, 2) should be considered (elaboration according to [1], figure from the archive of the author)

The values of tensile stress on the lower surface of the flange resulting from local bending of the flange caused by the load $F_{z,Ed}$, are as follows:

- longitudinal stress (parallel to the double axis of the flange);

$$\sigma_{0X,Ed} = c_X F_{z,Ed} / t_f^2, \quad (9)$$

- transverse stress (in the normal direction for the double axis of the flange);

$$\sigma_{0Y,Ed} = c_Y F_{z,Ed} / t_f^2. \quad (10)$$

where:

$F_{z,Ed}$ – vertical interaction of one crane wheel (if the wheel track is greater than $1.5b$),

c_X, c_Y – coefficients depending on the μ parameter, I-beam shape type and direction of stress.

For longitudinal stress, parallelepiped I-beam shape and for stress in the point “1” of flange:

$$c_{X1} = 2.230 - 1.490\mu + 1.390e^{-18.33\mu}, \quad (11)$$

and for transverse stress:

$$c_{y1} = 10.108 - 7.408\mu + 10.108e^{-1.364\mu}. \quad (12)$$

Positive signs of stress $\sigma_{0X.Ed}$ or $\sigma_{0Y.Ed}$ (positive signs c_{X1} or c_{Y1}) indicate tensile stresses on the lower surface of the flange, while the opposite signs are indicative of tensile stresses occurring on the upper surface of the flange loaded with rolling equipment. Local stress should be determined at a distance from the end of the beam greater than the flange width b , because the full bending of the track flange is then possible.

If the wheel track of the rolling equipment x_w is lower than $1.5b$, then the superposition of both wheels' operation should be considered. This approach is different from that in the case of determining the influence of the wheels' thrust according [4], because there is no such boundary there.

3.3. Load capacity in the vicinity of the fender beam, bracket ends, and at supported ends – stiffened

The local influence of the lower – flange bending is given by determining the computational load bearing capacity $F_{z.Ed}$ of the local – flange section (Fig. 5).

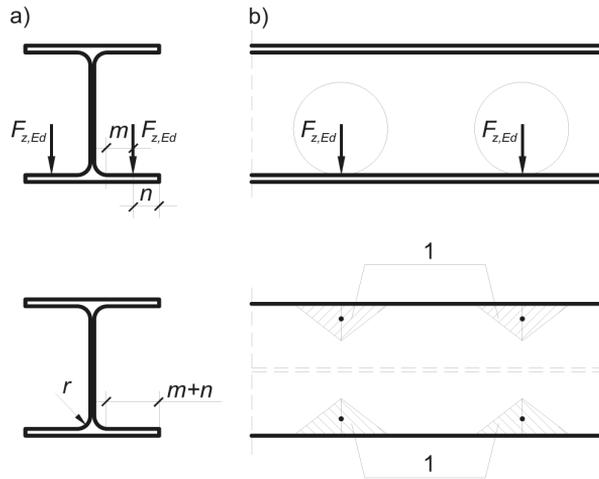


Fig. 4. Local bending of the lower flange: a) longitudinal view and section of the underslung beam loaded flange, b) cross-section of beam with symbols used in the formula (15); areas of the flange taking up the force of the wheel thrust $F_{z.Ed}$ (elaboration according to [1], figure from the archive of the author)

The computational load capacity $F_{f,Rd}$ under the influence of the underslung crane or travelling crane concentrated thrust $F_{z.Ed}$ is determined from the following formula:

$$F_{f,Rd} = \frac{l_{eff} \cdot t_f \cdot f_y / \gamma_{M0}}{4 m} \left[1 - \left(\frac{\sigma_{f,Ed}}{f_y / \gamma_{M0}} \right) \right], \quad (13)$$

where:

$\sigma_{f,Ed}$ – stress in axis of the flange, resulting from the bending moment within the considered beam cross-section,

t_f – flange thickness,

l_{eff} – effective range of local bending, determined based on the wheel position (concentrated thrust) relative to the beam end and on wheel track x_w and position of a wheel on the shelf m .

The range of the local bending zone l_{eff} in the case of a wheel on a free bracket end of the beam is determined from the equation:

$$2(m + n), \quad (14)$$

where:

$m + n$ – as in Fig. 4.

The value m for rolled beams is established as follows:

$$m = 0.5(b - t_w) - 0.8r - n, \quad (15)$$

where:

m , n and r – described in Fig. 4.

4. Determination of the 2nd ultimate limit state conditions (usability condition) according to PN-90/B-03200 [2]

Absolute displacements are calculated as follows:

4.1. Limit vertical deflections should not exceed (L_b – beam span length)

For underslung cranes (or supported cranes), which are manually controlled:

$$\frac{1}{400} L_b. \quad (16)$$

4.2. The horizontal limit deflections calculated from the horizontal brace should not be greater than

For underslung cranes (or supported cranes), manually controlled:

$$\frac{1}{600} L_b, \quad (17)$$

For the remaining cranes:

$$\frac{1}{1000} L_b, \quad (18)$$

The 2nd condition of the ultimate limit state for the longitudinal system is as follows: Horizontal longitudinal displacement (under the load H_r – horizontal along the track and the load resulting from the function of vertical braces of poles) should meet the condition:

$$\delta_b'' \leq \frac{1}{1000} h_s, \quad (19)$$

5. Determination of usability conditions according to Eurocode 3 (PN-EN 1993-6)[5]

5.1. General remarks

The usability conditions, contained in Eurocode 3 [5], discussed with a division deformation limit:

- horizontal;
- vertical.

Limit values [3] concerning the beams and poles of the transverse system are described as being absolute and relative.

5.2. Limit conditions for horizontal strains

The absolute horizontal limit strains are determined in the following manner: horizontal deflection relative to the line of supports (poles):

$$\delta_y \leq \frac{1}{600} L, \quad (20)$$

horizontal displacement of the beam together with the frame pole (checking of the hall transverse system) on the level of the contact line beam horizontal brace (h_c):

$$\delta_y \leq \frac{1}{400} h_c. \quad (21)$$

5.3. Limit conditions for vertical strains

The absolute vertical limit strains are as follows: vertical deflection relative to line of supports:

$$\delta_z \leq \frac{1}{600} L, \quad (22)$$

whereas:

$$\delta_z \leq 25 \text{ [mm]} \quad (23)$$

when the erection sag is assumed in the structural system, the total deflection can be decreased by its value.

The deflection caused only by the load deadweight relative to the line of supports for beams of single-rail hoists should meet the following condition:

$$\delta_{pay} \leq \frac{1}{500} L. \quad (24)$$

The relative vertical limit deflections (difference of vertical deflections) of travel track beams (on both sides of the spatial system) should meet the inequality:

$$\Delta h_c \leq \frac{1}{600} s, \quad (25)$$

where:

s – axial spacing of crane tracks.

5.4. Additional limitations – local deflection of crane beam webs

Eurocode 3 [5] imposes a further limitation concerning the local deflection of webs in the supercritical state. It should be noted that this phenomenon is called the “breathing of webs”. In the case of webs with thickness t_w (without longitudinal ribs) condition (26) is met and the local instability in the form of local web deflection does not occur:

$$\frac{b}{t_w} \leq 120, \quad (26)$$

where:

b – the lesser dimension of the height and spacing of web transverse ribs.

Therefore, only for the 4th class of profile should such slenderness ratio be additionally analysed. This promotes fatigue and affects the interactions of the web and flange. Computational condition, determining the ultimate limit state of stress at which the local imperfection phenomenon occurs in the form of web deflection takes the form:

$$\left[\left(\frac{\sigma_{x,Ed,ser}}{k_\sigma \cdot \sigma_E} \right)^2 + \left(\frac{1.1\tau_{Ed,ser}}{k_\tau \cdot \sigma_E} \right)^2 \right]^{0.5} \leq 1.1, \quad (27)$$

where:

k_σ, k_τ – linear parameters of elastic instability of walls, established in the rolling-mill standard,

$$\sigma_E = \frac{190,000.0}{\left(\frac{b}{t_w} \right)^2} \text{ [N/mm}^2\text{]},$$

- $\sigma_{x,Ed,ser}$ – longitudinal stress in the web of the beam,
 $\tau_{Ed,ser}$ – shearing stress in the web of the beam.

5.5. Additional limitations – concerning vibrations of lower flanges

Lower flanges in travel beams should not be too slender – spacing of supports L for these flanges constitutes the basis for determining the slenderness ratio of flanges, considering the possibility of transverse vibration excitation, which endangers the operation of beams and poles, particularly when considering their fatigue.

Eurocode 3 [5] precisely states that this phenomenon is not dangerous if the slenderness ratio for the flange falls within the limits of inequality:

$$\frac{L}{i_z} \leq 250, \quad (28)$$

where:

- i_z – flange radius of inertia relative to its vertical axis,
 L – distance between fixing point of diagonal struts.

It should be clearly mentioned here that, based on the experiments performed in Poland [1], the limitation described above should be stricter. It is therefore recommended that

$$L/i_z \leq 200. \quad (29)$$

6. Testing the fatigue load capacity

The fatigue load capacity can be determined with the given inequalities provided below. The variability range of normal and tangent fatigue stresses ($\Delta\sigma$ and $\Delta\tau$) is stated in Eurocode 3 [4], according to which:

- for normal stress;

$$\frac{\Delta\sigma_{E,2}}{\Delta\sigma_C} \cdot \gamma_{Ff} \cdot \gamma_{Mf} \leq 1.0, \quad (30)$$

- for shearing stress;

$$\frac{\Delta\tau_{E,2}}{\Delta\tau_C} \cdot \gamma_{Ff} \cdot \gamma_{Mf} \leq 1.0, \quad (31)$$

- for complex stress: $\Delta\sigma_{E,2}$, $\Delta\tau_{E,2}$;

$$\left(\frac{\Delta\sigma_{E,2}}{\Delta\sigma_C} \cdot \gamma_{Ff} \cdot \gamma_{Mf} \leq 1.0 \right)^5 + \left(\frac{\Delta\tau_{E,2}}{\Delta\tau_C} \cdot \gamma_{Mf} \cdot \gamma_{Mf} \leq 1.0 \right)^5 \leq 1.0. \quad (32)$$

The following designations are present in formulas (30–32):

- $\Delta\sigma_{E,2}$, $\Delta\tau_{E,2}$ – equivalent ranges of constant amplitude stress variability (for $2 \cdot 10^6$ cycles),
 $\Delta\sigma_C$, $\Delta\tau_C$ – normative fatigue strength (for $2 \cdot 10^6$ cycles), whose numerical value is attributed to a specific notch and direction of stress,

γ_{Mf} – partial coefficient of fatigue strength,

γ_{Ff} – partial coefficient at constant amplitude stress variability $\Delta\sigma_c$, $\Delta\tau_c$ (the variability determined for the maximum number of cycles n_{max}).

The value $\Delta\sigma_c$ should be reduced using the scale effect coefficient k_s for elements of significant thickness or large overall dimensions.

It should be clearly mentioned here that the computational approaches provided by Polish Standards and Eurocode packages are discrepant. The more unfavourable effects for the structural system result from the recommendations provided in the standard for steel [2].

8. Author's modernisation of travel beam steel structure

After a dimensional and technical study (Fig. 5–10), the determination of data based on the technical equipment log book and the design of the travel track beam and fender beam of hoist, an extension to an existing track with a short bracket was designed on the grounds of applicable standards and technical conditions. The modernisation of the existing structural system was performed because of technical reasons, due to the crane being replaced with a newer model. The scope of the track modernisation resulted from the operating nature of the new travelling crane. The elaboration included the load carrying structure of the travelling crane track extension, with total allowable lifting capacity $Q = 2.5$ [t], together with the location (relocation) of the existing fender beam. The travel beam, extending the track of the travelling crane with the above-mentioned lifting capacity, was designed as a steel load-carrying structure made of S235 shaped steel, joined in a mounting node with groove welds. The components of the structure modernisation included: load-carrying beam (track) made of HEA 320 wide-flange I-section, beam according to the existing design, connections (Fig. 11), welded connection made during the assembly (Fig. 12). After integration and cleaning, the elements of the load-carrying structure were painted with phthalate paint for priming and a top coat in the colour of the existing track.



Fig. 5. Support frame (photograph from the author's archive)



Fig. 6. View of the technical crane. The lower flange of the wide-flange HEA 320 beam constitutes the travel track (photo. from the author's archive)



Fig. 7. Study of the load-carrying system (photo. from the author's archive)



Fig. 8. Front view of the box bracket (connected to 4M 8.8), securing the load-carrying beam of the travel track (photo. from the author's archive)



Fig. 9. Free end of the track beam together with the box bracket, fastened to the framework system. Study of the load-carrying system (photo. from the author’s archive)



Fig. 10. Product from a steel mill prepared for installation in the existing suspended transport system – wide-flange HEA 320 I-section (photo. from the author’s archive)

SCHEME OF THE EXISTING SYSTEM

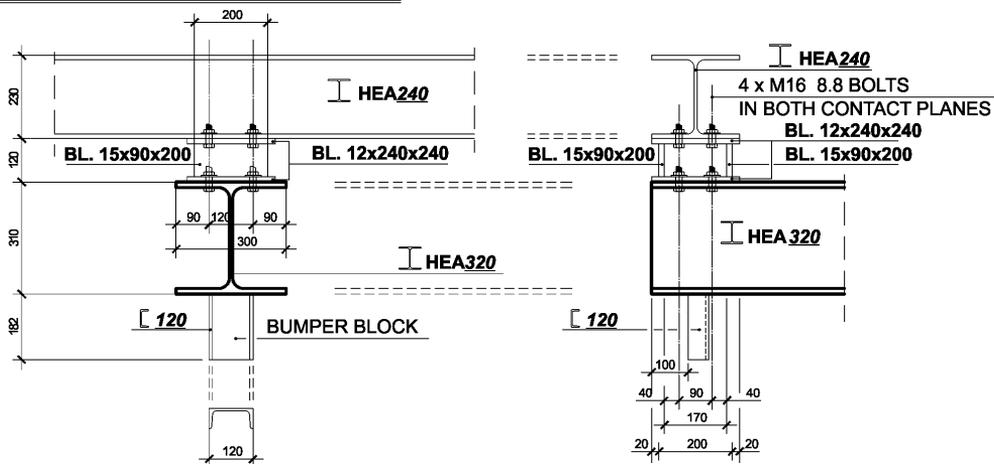


Fig. 11. Scheme of the existing structure system (drawing from the author’s archive)

Schemat ustroju istniejącego = Scheme of the existing system

Koziół odbojowy – Bumper block

Po 4 śruby M16 8.8 w obu płaszczyznach styku = 4 x M16 8.8 bolts in both contact planes

SCHEME OF THE DESIGNED SYSTEM

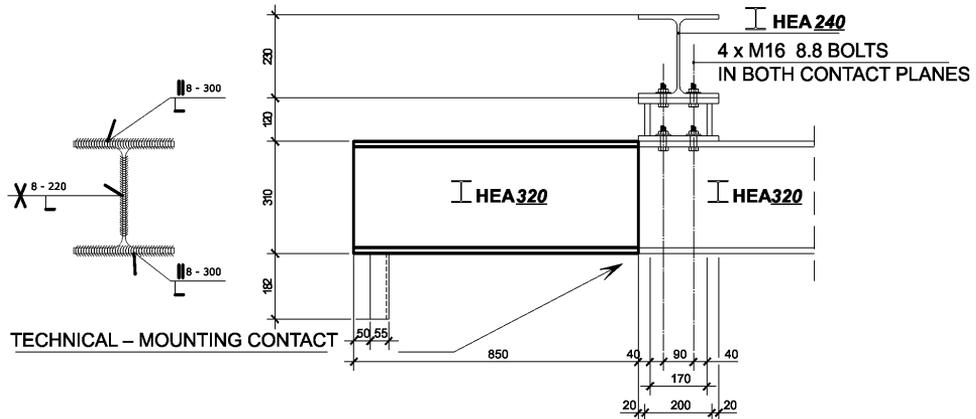


Fig. 12. Scheme of the structure system being designed (drawing from the author's archive)
Styk techniczno-montażowy = Technical – mounting contact

9. Conclusions

The recommendations provided in Eurocode 3 regarding this type of system differ significantly. This poses a substantial issue from the standpoint of the modernisation of building structures. The system erected prior to legislative changes introducing the Eurocodes has to now comply with these standards. Therefore, considering the static computations, it is necessary to recalculate the structure according to the package of Polish Standards in the first step, while in the second, to dimension the structure according to recommendations given in Eurocode 3 for steel. In this case, the so-called 'load-capacity reserve' can be relied on, as provided by the author during the design process of the structure. However, if this is not the case, firm means of strengthening the structure system have to be provided in the modernisation process, thus simultaneously meeting the requirements of the applicable unified European building codes.

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