EFFICIENT METHODS FOR BRIDGE STEEL PLATE GIRDERS STRENGTHENING

A gerinclemezes főtartójú acélhidak megerősítésének hatékony módszerei

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Összefoglaló

Az acélhidak fizikai öregedése, főleg a korrózió következtében valamint a szerkezet üzemeltetése során bekövetkezett változások (tengelyterhelés növekedés, sebesség növekedés), sok esetben szükségszerűvé teszik a szerkezet megerősítését.

A szerkezet főtartóinak a teherbíró képessége egyidőben a tartók merevségének a megfelelő szinten tartása hatékonyan megoldható a gerinclemezes tartók övlemezeinek keresztmetszeti megnöveléseivel, vagy pedig a tartó alsó övlemezének kábelek vagy merev feszítőlemez segítségével történő feszítésével.

Ebben a dolgozatban a megerősített főtartó erőjátékát mutatjuk be, a keresztmetszet normál feszültségeinek az eloszlását gyakorlati példákkal illusztrálva. Minden esetben a megerősítést a tehermentesített (hasznos teher) szerkezeten végeztük el.

Abstract

Two methods of strengthening of the steel plate girders are presented in this paper with the aim of carrying capacity increase: one based on tension flange cross section increase and the other using rigid prestressed or unprestressed tie rods added under the bottom flange.

Keywords: steel plate girders, strengthening, prestressing, carrying capacity increase, rigid tie rods

1. Introduction

Static and dynamic physical wear, accidental wear and traffic conditions changes can determine the necessity of some strengthening works which have to be able to ensure the functionality and a safe future use of the bridge structure.

The carrying capacity increase of the steel plate girders, concomitantly with their rigidity increase can be efficiently materialized through the cross flanges section increase or through the rigid prestressed or unprestressed tie rods laid under the tension flange.

The stresses patterns of the strengthened girder are presented in this paper and a numerical example is given here.

2. Stress patterns and deflection size of the strengthened steel plate girders

2.1. Strengthening by flange cross section increasing

Adding strengthening elements on one or on both girder flanges, the increase of the moment of inertia is obtained and implicitly the stresses and deflections under the live loads will diminish.

The stress patterns of the strengthened steel plate girder through a T shape welded element added on the bottom flange are presented in Fig.1.

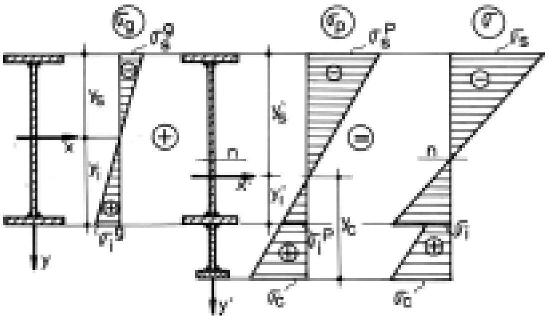

Fig. 1.
Stress patterns of the strengthened girder

The state of stresses is the extreme cross section fibers of the steel girder and in the added element to the bottom flange will be:

$$\sigma_s = \frac{M_g}{I} y_s + \frac{\psi M_P}{I_c} y_s' \tag{1a}$$

$$\sigma_i = \frac{M_g}{I} y_i + \frac{\psi M_P}{I_c} y_i' \tag{1b}$$

$$\sigma_c = \frac{\psi M_P}{I_c} y_c \tag{1c}$$

where:

I_c – moment of inertia of the strengthened section;
ψ – dynamic coefficient of the live loads.

The favorable effects are also obtained with regard to the elastic girder deflection.

For a girder with a variable cross section the deflection can be evaluated by the relation:

$$f = \frac{5{,}5}{48} \frac{M_{\max} L^2}{E I_m} \tag{2}$$

where I_m is the average moment of inertia:

$$I_m = \frac{\sum I_i l_i}{L}$$

The following values of the girder deflection result:

- unstrengthened girder:

$$f = \frac{5{,}5}{48} \frac{\left(M_g + M_P\right) L^2}{E I_m} \tag{3a}$$

- strengthened girder:

$$f = \frac{5{,}5}{48E} \left(\frac{M_g}{I_m} + \frac{M_P}{I_m^c} \right) L^2 \tag{3b}$$

where I_m^c is the average moment of inertia of the strengthened cross section.

2.2. Girder strengthening using rigid tie rods

Strengthening with tie rods consist in adding of a rigid the rod under tension flange made up by laminated elements: L, U, O or welded sections.

The tie rods can be laid horizontally or polygonal under the bottom flange, Fig.2.

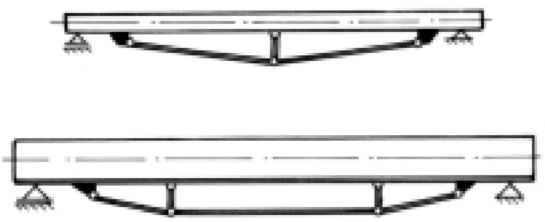

Fig. 2.
Girders strengthened with rigid tie rods

The tie rods can be prestressed or unprestressed, the prestress of the ties increase their efficiency but complicates the strengthening achievement.

Strengthening design with straight tie rods

The stress pattern can be followed in Fig.3 with regard to the strengthening steps.

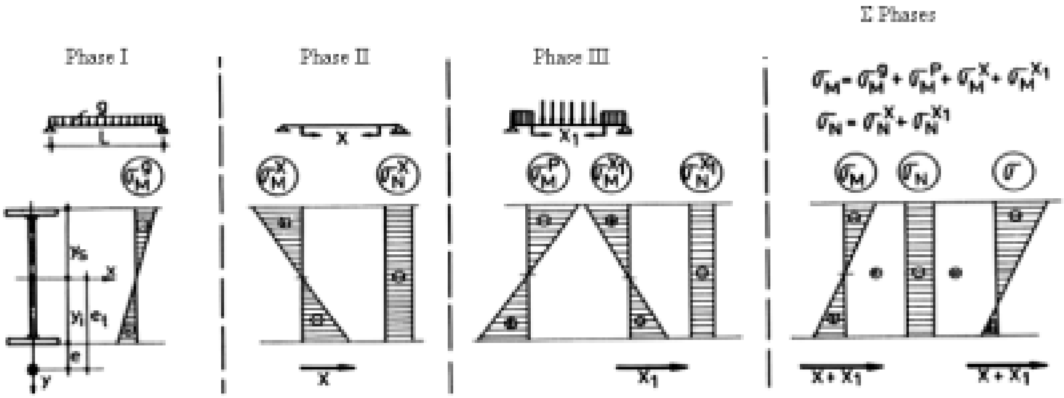

Fig. 3.
State of stresses in the strengthened girder using a rigid tie rod

The state of stresses in girder and in the tie rod taking into account the dynamic effect of the traffic loads will be:

- top flange:

$$\sigma_s = -\frac{X + \psi X_1}{A} - \frac{M_g + \lfloor \psi M_p - (X + \psi X_1)e_t \rfloor}{I} y_s \tag{4a}$$

- bottom flange:

$$\sigma_i = -\frac{X + \psi X_1}{A} + \frac{M_g + \lfloor \psi M_p - (X + \psi X_1)e_t \rfloor}{I} y_i \tag{4b}$$

- tie rod:

$$\sigma_t = \frac{X + \psi X_1}{A_t} \tag{4c}$$

Selftension effort evaluation

The effort X_1 can be determined by using the static force method to solve the condition equation of the statically indeterminate system, Fig.4.

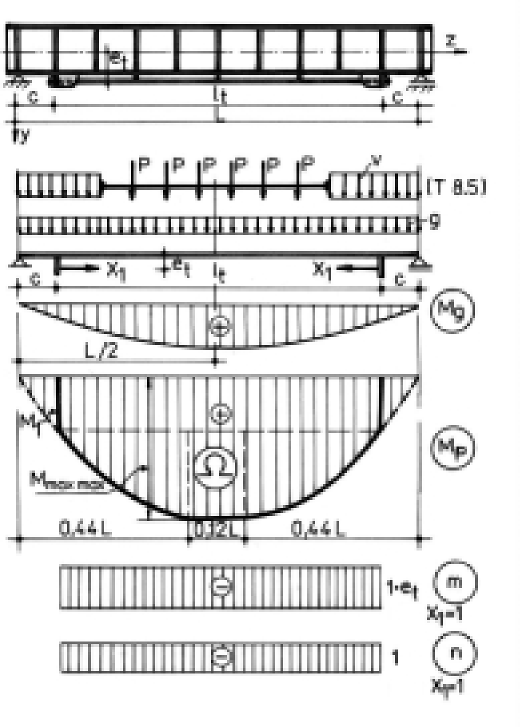

Fig. 4.
Selftension effort evaluation in the tie rod

$$\delta_{11}X_1 + \Delta_{1P} = \Delta_{X1} \tag{5}$$

where:

$$\delta_{11} = \int_0^{l_t} \frac{m^2}{EI}dx + \int_0^{l_t} \frac{n^2}{E_t A_t}dx = \left(\frac{e_t^2}{EI} + \frac{1}{E_t A_t}\right) l_t$$

$$\Delta_P = \int_0^{l_t} \frac{M_P m}{EI}dx = -\frac{e_t}{EI}\Omega$$

$$\Delta_{X1} = -\frac{l_t}{EA}X_1$$

It is obtained:

$$X_1 = \frac{\dfrac{e_t}{EI}\Omega}{\left(\dfrac{e_t^2}{EI} + \dfrac{1}{EA} + \dfrac{1}{E_t A_t}\right) l_t} \tag{6a}$$

where:

M_p – bending moment diagram given by traffic loads on statically determinate system;

m, n – bending moment and axial force diagrams given by X_1=1 on statically determinate system;

Ω – bending moment diagram area given by traffic loads on the tie rod length.

If the tie rod is a rigid element than E_t=E and relation (6a) becomes:

$$X_1 = \frac{\frac{e_t}{I}\Omega}{\left(\frac{e_t^2}{I}+\frac{1}{A}+\frac{1}{A_t}\right)l_t} \tag{6b}$$

Tie rod effect on the deflection.

The girder deflection is determined with respect to the maximum bending moment taking into account the tie rod reduction effect:

$$f = \frac{5{,}5\left(M_g + M_P\right)}{48EI_m}L^2 - f_t \tag{7a}$$

where:

$$f_t = \int_0^L \frac{M_t m}{EI_m}dx = \frac{X_t e_t}{8EI_m}\left(L^2 - 4c^2\right) \tag{7b}$$

$$X_t = X + X_1 .$$

The deflection f_t given by the negative bending moment $M_t = X_t e_t$ (relation 7b) is obtained by using the Mohr-Maxwell method, Fig.5.

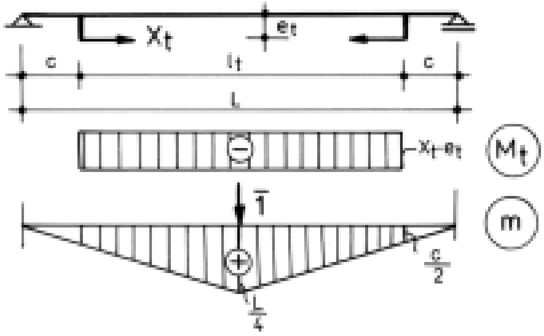

Fig. 5.
Deflection calculation from tie rod effect

3. Numerical example

The state of stresses on the main girders of a steel railway bridge with the span L=20m, Fig.6. , is analyzed.

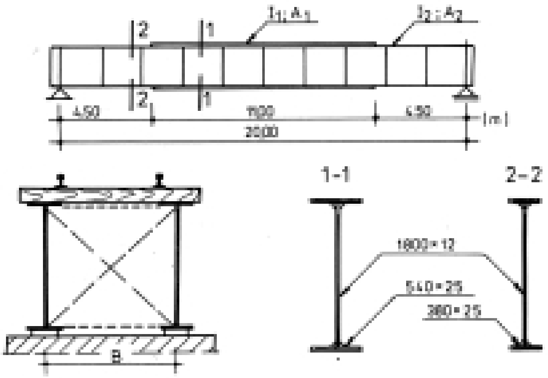

Fig. 6.

3.1. Preliminary design elements

Loads evaluation

- track weight (STAS 1489-78)

$$g_1=800 \text{ daN/m}$$

- structure dead weight (STAS 1489-78)

For a trough plate-girder bridge with a span L < 30 m, for load train T 8,5:

$$g_2=44L+650=1530 \text{ daN/m}$$

The structure weight is affected by a correction factor k_8=0,75 for 30welded structures and so it results:

$$g = g_1 + k_8 g_2 = 1948 \text{ daN/m}$$

The total dead load is considered: g=1950 daN/m=19,50 kN/m
The maximum bending moment given by dead loads is:

$$M_g = \frac{gL^2}{8} = \frac{19{,}5\times 20^2}{8} = 975 \text{ kNm}$$

The maximum bending moment given by load train T 8,5 can be evaluated by the relation:

$$M_{maxmax}= \left(10{,}65L^2 + 106{,}8L - 320\right) = 6076 \text{ kNm}$$

The train loads have to be multiplied by the dynamic coefficient ψ, which for welded track is:

$$\psi = 1{,}10 + \frac{17}{35+L} = 1{,}41$$

The maximum bending moment will be:

$$M_{tot} = M_g + \psi M_{\max\max} = 9542 \text{ kNm}$$

and for one girder is:

$$M = \frac{M_{tot}}{2} = 4771 \text{ kNm}$$

The girder resistance characteristics are given in Table 1.

Section	**Moment of inertia I [cm^4]**	**Modul of resistance W [cm^3]**	**Cross section area [cm^2]**	**Average moment of inertia I$_m$ [cm^4]**	**Average cross section area A$_m$ [cm^2]**
mid-span (1-1)	2 831 490	30 611	486	2 531 718	450
end-span (2-2)	2 165 330	23 409	406		

Resistance capacity checking:

$$\sigma_{\max} = \frac{M}{W} = \frac{4771\times 10^4}{30611} = 1556 \text{ daN/cm}^2 < \sigma_a \quad \sigma_a = 1600 \text{ daN/cm}^2$$

Rigidity (deflection) checking:

$$M_f = \frac{1}{2}\left(M_g + M_{\max\max}\right) = 3225{,}5 \text{ kNm}$$

$$f = \frac{5{,}5}{48}\frac{M_f L^2}{EI_m} = 2{,}72 \text{ cm} < f_a = \frac{L}{500} = 4\,\text{cm}$$

3.2. Main girder strengthening by increasing the cross section of the tension flange

For a trough plate-girder bridge the strengthening solution adopted consist in a ⊥ shape welded member under the bottom flange, Fig.7. and the strengthened section characteristics are presented in Fig.8.

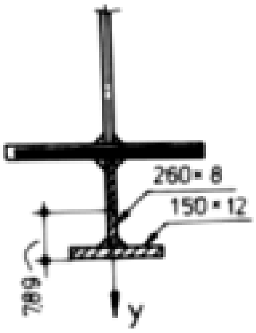

Fig. 7.

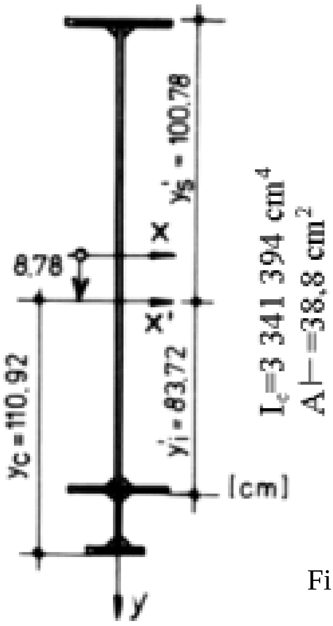

Fig. 8.

The bending stresses will be:

– top flange:

$$\sigma_s = \frac{M_g}{W} + \frac{\psi M_P}{I_c} y_s' = 1451 \text{ daN/cm}^2$$

– bottom flange:

$$\sigma_i = \frac{M_g}{W} + \frac{\psi M_P}{I_c} y_i' = 1232 \text{ daN/cm}^2$$

– strengthening element:

$$\sigma_c = \frac{\psi M_P}{I_c} y_c = 1422 \text{ daN/cm}^2$$

The strengthened girder deflection is:

$$f \cong \frac{5{,}5}{48E}\left(\frac{M_g}{I_m} + \frac{M_P}{I_c}\right) L^2 = 2{,}40 \text{ cm}$$

3.3. Main girders strengthening using a simple rigid tie rod

The state of stresses in the main bridge girders is analyzed, by using as a strengthening method a tie rod made up by 2L 100x100x10 at 250 mm distance from the bottom flange, with a length of 17 m, Fig. 9.

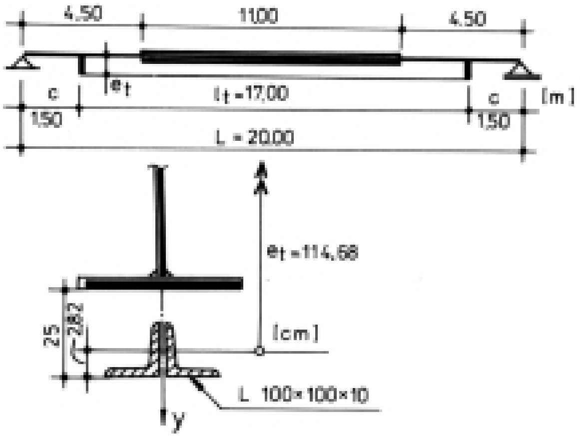

Fig. 9.

The tie rod excentricity is:

$$e_t = 92{,}5 + 25 - 2{,}82 = 114{,}68 \ \text{cm}$$

The diagrams for the tie rod selftensioning effort are presented in Fig.10, where:

$$M_x = \frac{M_{\max\max}}{0{,}1936}\left(0{,}88\frac{x}{L} - \frac{x^2}{L^2}\right) \ \text{and} \ M_1 = M_x(x = 1{,}5) = 977 \ \text{kNm}$$

It is obtained (Fig.10):

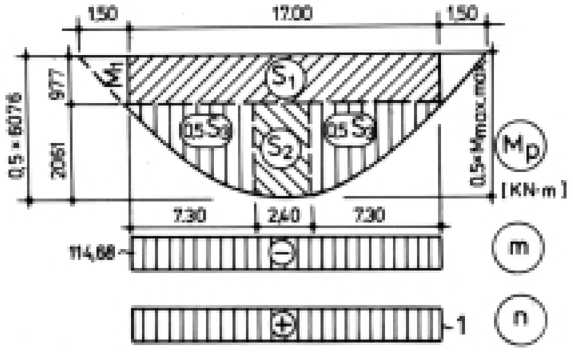

Fig.10.

$$\Omega = S_1 + S_2 + S_3 = 41973 \ \text{kNcm}^2$$

where:

$$S_1 = M_1 l_t = 16609$$

$$S_2 = (M_{\max\max} - M_1) \times 0{,}12L = 5017$$

$$S_3 = \frac{2}{3}\left(M_{\max\max} - M_1\right)\left(0{,}88L - 2c\right) = 20347$$

The selftension effort in the tie rod is:

$$X_1 = 330{,}2 \text{ kN} \qquad \text{(rel. 6b).}$$

The stresses will be:

- in girder (rel. 4a, 4b):

$$\sigma_s = -1245 \text{ daN/cm}^2$$

$$\sigma_i = 1054 \text{ daN/cm}^2$$

- in tie rod:

$$\sigma_t = 1212 \text{ daN/cm}^2$$

The tie rod effect on the girder deflection is:

$$f_t = 0{,}348 \text{ cm} \qquad \text{(rel. 7b)}$$

$$f_{tot} = f - f_t = 2{,}43 \text{ cm}$$

4. Conclusions and observations

The state of stresses and deflection of the initial girder and of the strengthened girder by using the two analyzed methods are presented in Table 2.

Case	σ_s **(reduction [%])**	σ_i **(reduction [%])**	f **(reduction [%])**
Initial girder	1556	1556	2,78
Strengthened girder by bottom flange increase	1451 (93 %)	1232 (79 %)	2,40 (86 %)
Strengthened girder using a simple rigid tie rod	1245 (80 %)	1054 (68 %)	2,43 (87 %)

From the numerical analysis performed here above the following conclusions can be mentioned:

- the strengthening of the steel girders using a rigid tie rod is more efficient in comparison with flange cross section increase at the same material consumption, because the material can be distributed more conveniently;
- the consolidation with rigid tie rod involves a reduced handwork because it is fixed only at the end-span and in some intermediate points, in comparison with a continuous welded element.

5. References

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