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The Consolidation of Steel Bridges Superstructures by pre-stressing

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Summary

As the working load increase causes overloading, it is mostly inefficient to consolidate the steel decks of bridges by increasing the girder section attaching new elements. (using great amount of steel, the increase of the bearing capacities is low; see the work: The Consolidation of Steel Bridges Superstructures Without Introducing Initial Stress States).

The more the allowable stress of steel is consumed by permanent load, the more this consolidation is inefficient..

Better solutions of consolidation are obtained when an initial stress state is introduced to act contrary to the stress state produced by loads.

The following consolidation solutions have been taken into consideration:

1. The consolidation by enhancing the base of the girder section with chord plates applied directly on the base of the pre-flexion girder

2. The consolidation with pre-stressed steel rod

KEYWORDS: steel bridge floor, consolidation, consolidation chord plates, pre-flexion, pre-stressed steel rod.

Notation:

- $y_n^s; y_n^i$: the distance from the section centroid of the unconsolidated girder section to the top fibre/bottom fibre;
- y_c^s; y_c^i: the distance from the section centroid of the consolidated girder section to the top fibre/bottom fibre;
- G_n : the section centroid of the unconsolidated girder section;
- G_c : the section centroid of the consolidated girder section;
- Δt : the thickness of the consolidation chord plates applied on the base of the girder section;
- l_t : the length of the consolidation tension rod;

- e : the distance from the section centroid of the consolidation steel tension rod to the inferior base of the girder;
- I_{gn} ; I^{b}_{gn} : the moment of inertia (second moment of area) of the unconsolidated net/rough girder section;
- I_{gc} : the moment of inertia (second moment of area) of the consolidated net girder section;
- A_{gn} ; A^{b}_{gn} : the area of the unconsolidated net/rough girder section;
- A_{t} : the area of the consolidation pre-tension rod;
- R : the girder pre-flexion force;
- X_{1} : the self-tension axial stress from the consolidation tension rod;
- X_{2} : the pre-tension axial stress from the consolidation tension rod;
- M_{gn} : the maximum bending moment given by the weight of the unconsolidated structure;
- $M_{g'}$: the maximum bending moment given by the weight of the consolidation elements;
- M_{p} : the bending moment given by the pre-flexion;
- M_{u} : the maximum bending moment given by traffic loads;
- M_{m} : the weighted average value of the bending moment on the tension rod consolidation length, given by traffic and permanent loads;
- M_{x_1} : the bending moment in the girder given by X_1;
- M_{x_2} : the bending moment in the girder given by X_2;
- σ^{s}_{gn} ; σ^{i}_{gn} : the normal unit stress produced by M_{gn} on the unconsolidated girder section at the top fibre/bottom fibre;
- $\sigma^{s}_{g'}$; $\sigma^{i}_{g'}$: the normal unit stress produced by $M_{g'}$ on the unconsolidated girder section at the top fibre/bottom fibre;
- σ^{s}_{pn} ; σ^{i}_{pn} : the normal unit stress produced by M_p on the unconsolidated girder section at the top fibre/bottom fibre;
- σ^{s}_{pc} ; σ^{i}_{pc1} ; σ^{i}_{pc2} : the normal unit stress produced by M_p on the consolidated girder section at the top fibre/bottom fibre(in the points 1 and 2);
- σ^{s}_{uc} ; σ^{i}_{uc1} ; σ^{i}_{uc2} : the normal unit stress produced by M_u on the consolidated girder section at the top fibre/bottom fibre(in the points 1 and 2);
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- $\sigma_c^s;\sigma_c^i;(\sigma_{c1}^i;\sigma_{c2}^i)$: the total normal unit stress produced on the consolidated girder section at the top fibre/bottom fibre(in the points 1 and 2);
- $\sigma_{\mathrm{I}}^s;\sigma_{\mathrm{I}}^i$: the normal unit stress produced by X_2 on the consolidated girder section at the top fibre/bottom fibre;
- $\sigma_{\mathrm{II}}^s;\sigma_{\mathrm{II}}^i$: the normal unit stress produced by the exploitation load and X_1 at the top fibre/bottom fibre;
- σ_{an}: allowable normal stress of the steel from the unconsolidated girder;
- σ_{ac}: allowable normal stress of the steel from the consolidation elements;
- σ_a^t: allowable normal stress of the steel from the consolidation pre-tension rod;

1. INTRODUCTION

Below are presented two consolidation solutions obtained by pre-stressing, for the main simple web girders of a bridge superstructure with an exceeding bearing capacity and a case study in which the methods used are being explained.

2. CONSOLIDATION METHODS

2.1. The consolidation by enhancing the base of the girder section with chord plates applied directly on the base of pre-flexion girder

From a technological point of view the working stages are as follows:

- scaffoldings are placed under the girders which are stressed (the pre-flexion) using presses applied on the scaffoldings;
- the rivet heads from the inferior base of the girder are cut (without taking out the cut rivets) on the area on which new steel plates are to be attached;
- the new steel plates are placed in the correct position, regarding the position of the existing rivets;
- the cut rivets are taken out one by one and are replaced with the new ones, which are installed in the rectified holes;

As regards the calculation, it results the following the following stress states result, which when combined give the final girder stress state:

a) On girders' unconsolidated section develops a stress state produced by the bending moment given by the weight of the unconsolidated structure and of the

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new introduced elements and the bending moment given by pre-flexion (the initial stress state) (Figure 1);

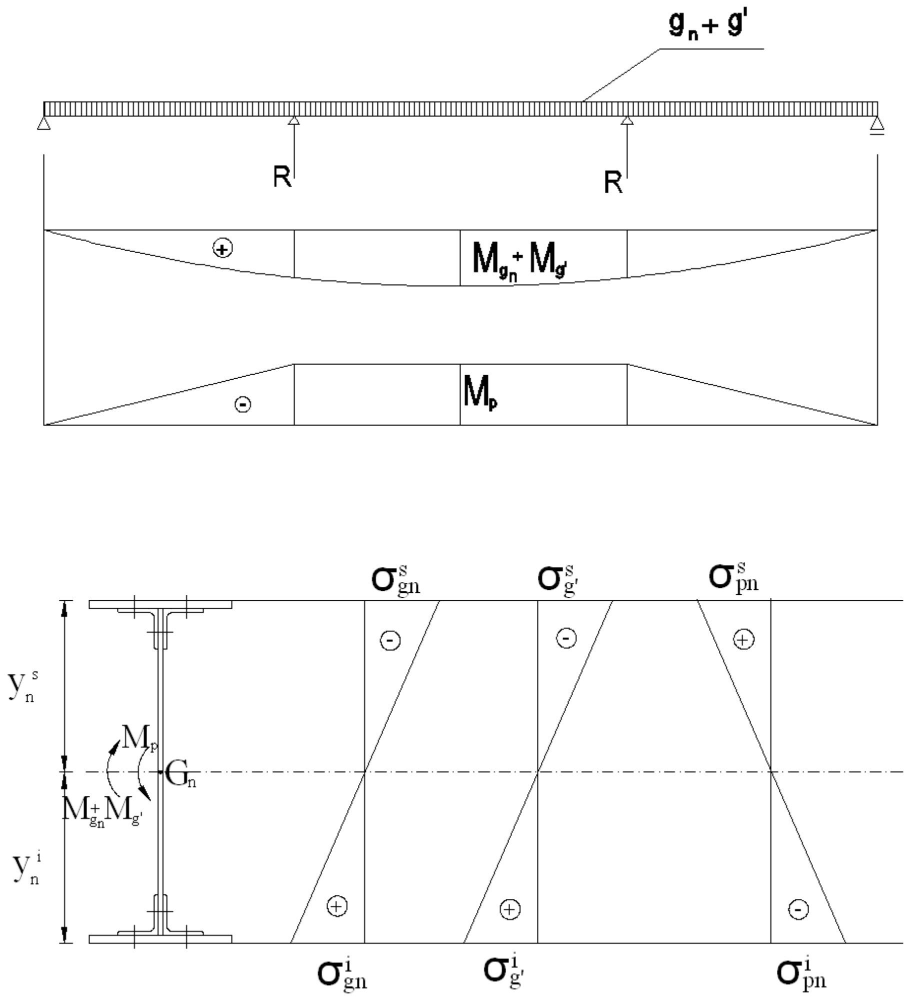

Figure 1.

$$\begin{aligned}\sigma^s_{gn}+\sigma^s_{g'}-\sigma^s_{pn}&=\frac{M_{gn}+M_{g'}-M_p}{I_{gn}}y^s_n\\ \sigma^i_{gn}+\sigma^i_{g'}-\sigma^i_{pn}&=\frac{M_{gn}+M_{g'}-M_p}{I_{gn}}y^i_n\end{aligned}\qquad(1)$$

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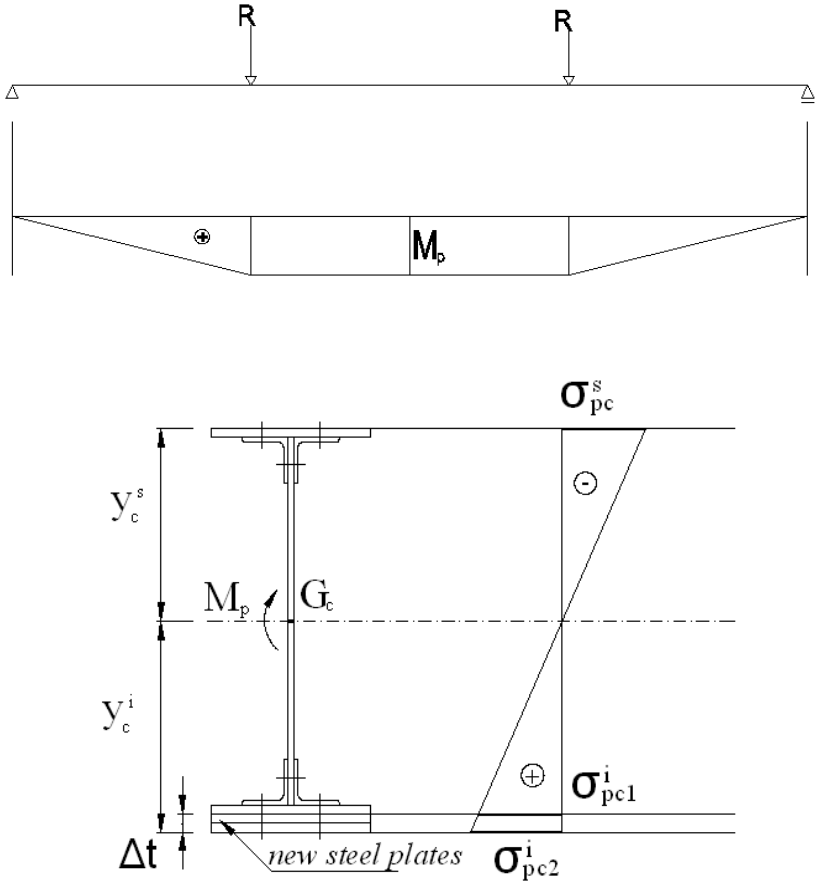
b) After the chord plates have fastened on the pre-stressed structure, the presses are removed, which is equivalent to load the girders with the pre-flexion forces R; the consolidated girder section takes over the bending moment given by R forces. (Figure 2);



$$\sigma^{s}_{pc} = \frac{M_p}{I_{gc}} y^{s}_{c}$$

$$\sigma^{i}_{pc1} = \frac{M_p}{I_{gc}} (y^{i}_{c} - \Delta t) \qquad (2)$$

$$\sigma^{i}_{pc2} = \frac{M_p}{I_{gc}} y^{i}_{c}$$

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c) The consolidated structure is put in use - the consolidated girder section takes over the bending moment given by traffic loads. (Figure 3);

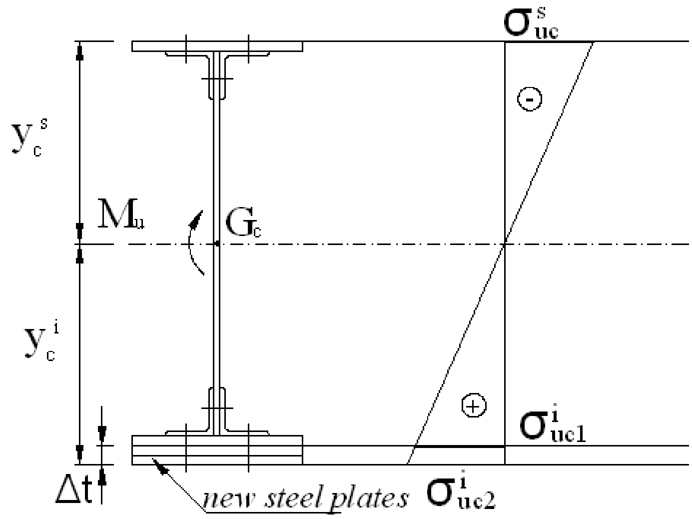

Figure 3.

$$\sigma_{uc}^{s} = \frac{M_u}{I_{gc}} y_c^s$$
$$\sigma_{uc1}^{i} = \frac{M_u}{I_{gc}} (y_c^i - \Delta t) \qquad (3)$$
$$\sigma_{uc2}^{i} = \frac{M_u}{I_{gc}} y_c^i$$

d) The final stress state on the consolidated section (Figure 4);

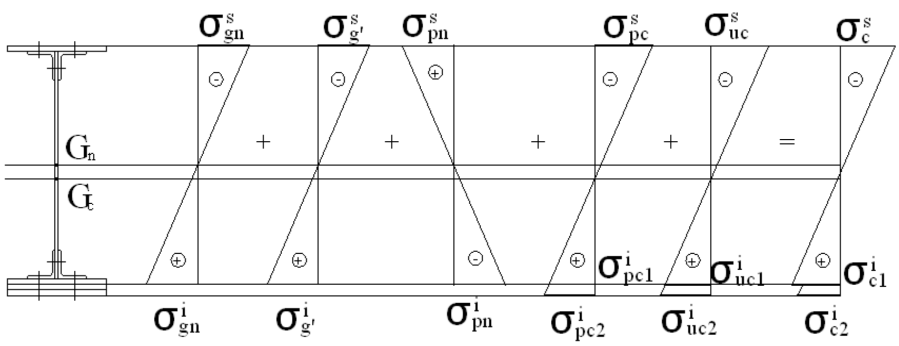

Figure 4.

The strength condition for the consolidated structure is:

$$\begin{aligned}
\sigma_c^s &= \sigma_{gn}^s + \sigma_{g'}^s - \sigma_{pn}^s + \sigma_{pc}^s + \sigma_{uc}^s \le \sigma_{an} \\
\sigma_{c1}^i &= \sigma_{gn}^i + \sigma_{g'}^i - \sigma_{pn}^i + \sigma_{pc1}^i + \sigma_{uc1}^i \le \sigma_{an} \\
\sigma_{c2}^i &= \sigma_{pc2}^i + \sigma_{uc2}^i \le \sigma_{ac}
\end{aligned} \tag{4}$$

2.2. The consolidation with pre-stressed steel rod

One or several steel pre-tension rods which will introduce an advantageous initial stress state for the structure, will be attached to the unconsolidated main girders.

The simplest solution suggests to introduce a rectilinear steel tension rod is introduced under the inferior base of the main girders.

Inside the steel tension rod which is being applied develops a tensile force, produced by the traffic loads (self-tensile force), which is determined on the girder-tension rod structure once statically indeterminate. (Figure 5);

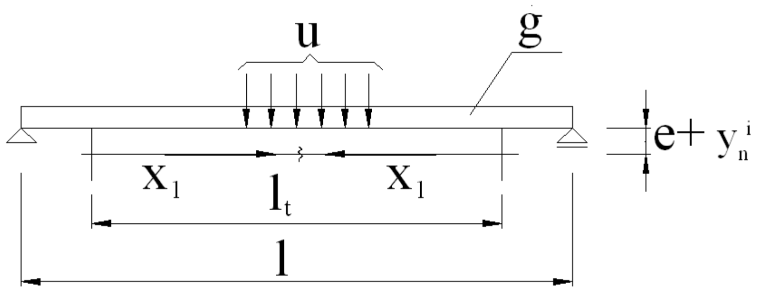

Figure 5.

The expresion for X_1 is:

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$$X_1 = \frac{M_m}{\left(e + y_n^i\right) + \frac{I_{gn}^b}{\left(e + y_n^i\right)\left(\frac{1}{A_{gn}^b} + \frac{1}{A_t}\right)}} \tag{5}$$

The relation (5) will be used for any position of the permanent and traffic loads on the structure if a a weighted average value M_{um} is considered for the bending moment they produce on the girder tension rod consolidation length, in these conditions the free term Δ_{1p} of the static balance equation:

$$X_1\delta_{11} + \Delta_{1p} = 0$$

has invariable form.

Knowing X_1, X_2 will be determined:

$$X_2 = A_t\sigma_a^t - X_1 \tag{6}$$

The stress states from the structure are the following:

a) The stress state from the girder in the rod pre-tension stage (stage I), produced by X_2 (Figure 6);

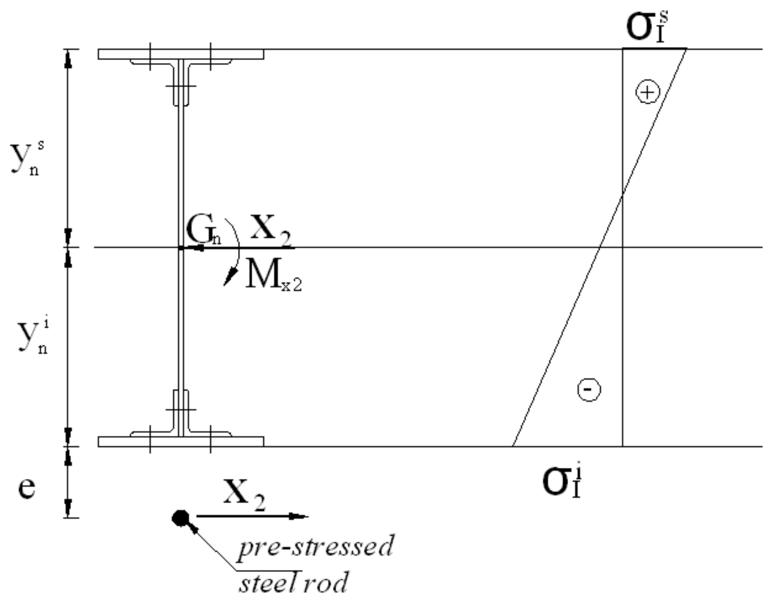

Figure 6.

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$$M_{x2} = X_2\left(e + y_n^i\right)$$
$$\sigma_I^s = -\frac{X_2}{A_{gn}} + \frac{M_{x2}}{I_{gn}} y_n^s \qquad (7)$$
$$\sigma_I^i = -\frac{X_2}{A_{gn}} + \frac{M_{x2}}{I_{gn}} y_n^i$$

b) The stress state from the pre-stressed girder, given by permanent and traffic loads and X_1 (stage II);

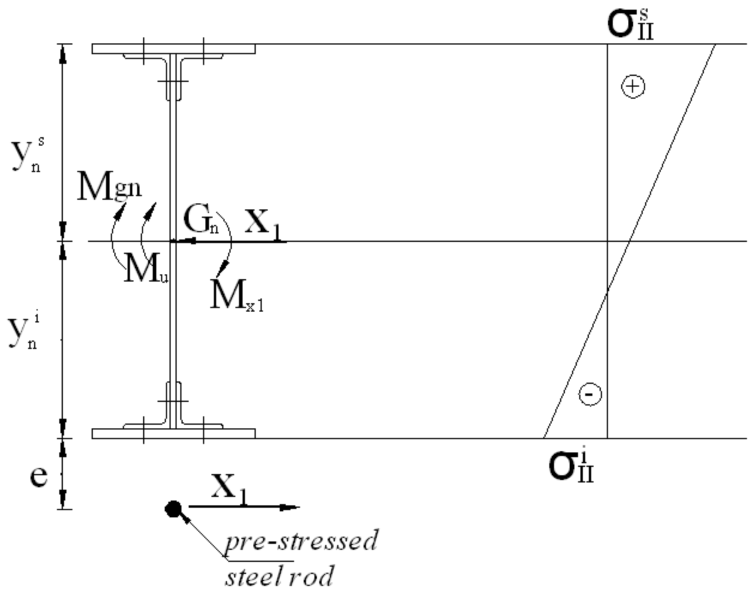

Figure 7.

$$M_{x1} = X_1\left(e + y_n^i\right)$$
$$\sigma_{II}^s = -\frac{M_{gn} + M_u}{I_{gn}} y_n^s - \frac{X_1}{A_{gn}} + \frac{M_{x1}}{I_{gn}} y_n^s \qquad (8)$$
$$\sigma_{II}^i = -\frac{M_{gn} + M_u}{I_{gn}} y_n^i - \frac{X_1}{A_{gn}} + \frac{M_{x2}}{I_{gn}} y_n^i$$

c) The final stress state in the consolidated girder results:

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$$\sigma_c^s = \sigma_{\mathrm{I}}^s + \sigma_{\mathrm{II}}^s \le \sigma_{an}$$
$$\sigma_c^i = \sigma_{\mathrm{I}}^i + \sigma_{\mathrm{II}}^i \le \sigma_{an} \qquad (9)$$

The stress state in the structure modifies if the tension loss caused by braces slidings and rod steel relaxation are taken into consideration.

3. CASE STUDY

The two consolidation methods are applied for the main girder of a bridge with the following characteristics (Figure 8):

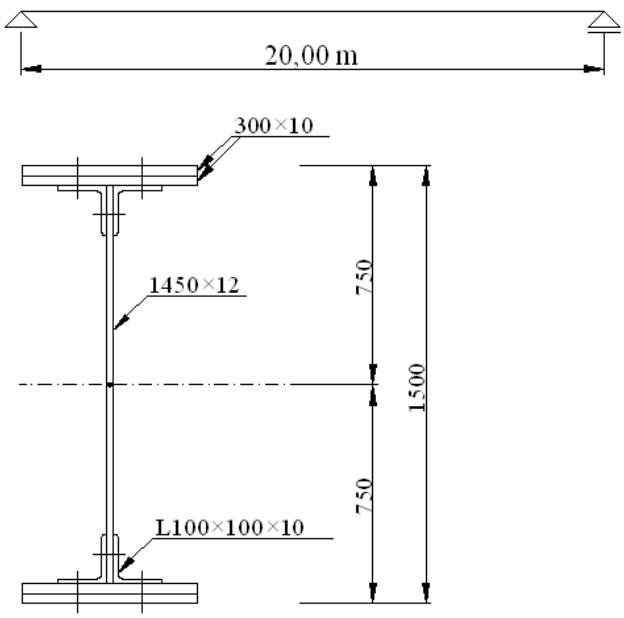

Figure 8.

$$M_{gn} = 1112 KNm$$
$$M_u = 1440 KNm$$
$$\sigma_{an} = 150 \, N/mm^2$$
$$A^b_{gn} = 37080 mm^2$$
$$A_{gn} = 34320 mm^2$$
$$I^b_{gn} = 1340240 \times 10^4 mm^4$$
$$I_{gn} = 1191138 \times 10^4 mm^4$$

The maximum unit stress of the girder produced by the bending moment given by the permanent and traffic loads is up to 160,8 N/mm^2.

3.1. The consolidation according to 2.1.

The inferior base of the girder is consolidated with two 300×10 mm steel plates (Figure 9) from OL 37.2 (σ_{ac}=145 N/mm^2) steel.

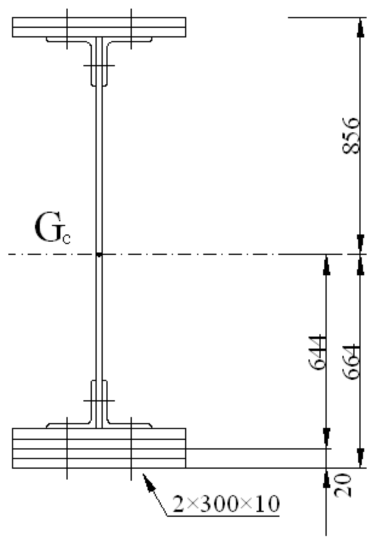

Figure 9.

$$M_{g'} = 23,55 KNm$$
$$I_{gc} = 1446893 \times 10^4 mm^4$$

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The pre-flexion is performed by two forces R=200 KN symmetrically aplied on the structure, at 5 metres from the bearings.

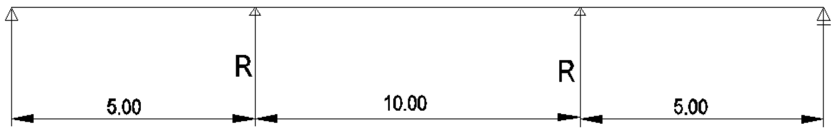

Figure 10.

$$M_p = 1000 KNm$$

The following values are obtained with (1), (2), (3) and (4):

$$\sigma^s_{gn} = \sigma^i_{gn} = \frac{1112\times10^6}{1191138\times10^4}750 = 70,1\,{}^{N}\!/_{mm^2}$$

$$\sigma^s_{g'} = \sigma^i_{g'} = \frac{23,55\times10^6}{1191138\times10^4}750 = 1,5\,{}^{N}\!/_{mm^2}$$

$$\sigma^s_{pn} = \sigma^i_{pn} = \frac{1000\times10^6}{1191138\times10^4}750 = 63,0\,{}^{N}\!/_{mm^2}$$

$$\sigma^s_{pc} = \frac{1000\times10^6}{1446893\times10^4}856 = 59,2\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{pc1} = \frac{1000\times10^6}{1446893\times10^4}644 = 44,6\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{pc2} = \frac{1000\times10^6}{1446893\times10^4}664 = 45,9\,{}^{N}\!/_{mm^2}$$

$$\sigma^s_{uc} = \frac{1440\times10^6}{1446893\times10^4}856 = 85,2\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{uc1} = \frac{1440\times10^6}{1446893\times10^4}644 = 64,1\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{uc2} = \frac{1440\times10^6}{1446893\times10^4}664 = 66,1\,{}^{N}\!/_{mm^2}$$

$$\sigma^s_{c} = 70,1 + 1,5 + 63,0 + 59,2 + 85,2 = 153,0\,{}^{N}\!/_{mm^2} < \sigma_{an} + 3\% = 154,5\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{c1} = 70,1 + 1,5 - 63,0 + 44,6 + 64,1 = 117,3\,{}^{N}\!/_{mm^2} < \sigma_{an} = 150,0\,{}^{N}\!/_{mm^2}$$

$$\sigma^i_{c2} = 45,9 + 66,1 = 112,0\,{}^{N}\!/_{mm^2} < \sigma_{ac} = 145,0\,{}^{N}\!/_{mm^2}$$

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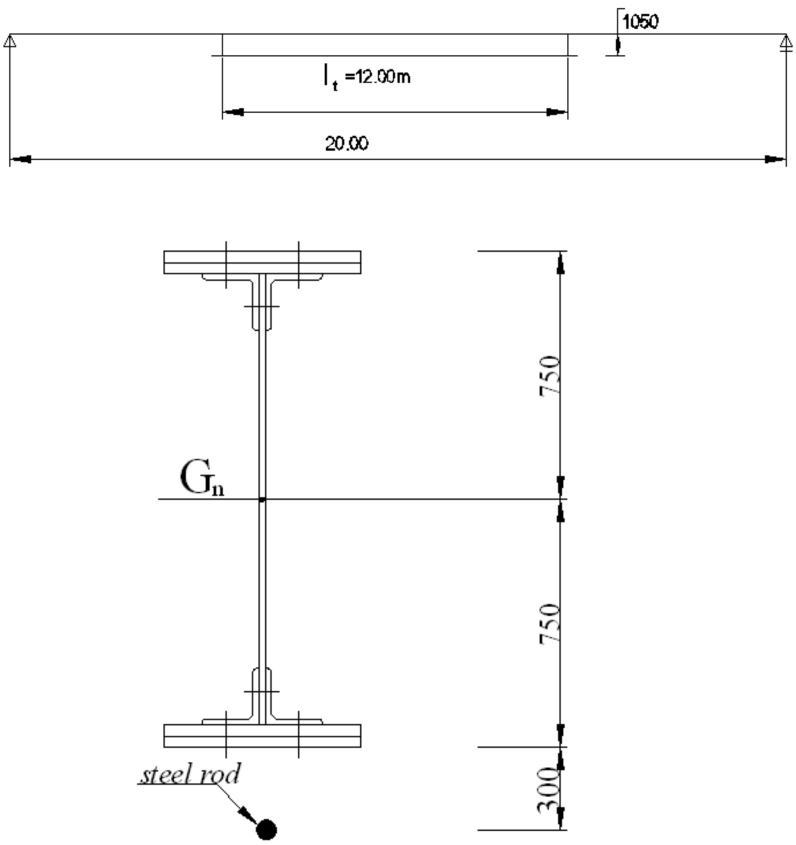
3.2. The consolidation according to 2.2.

The inferior base of the girder is consolidated with pre-stressed steel rod consisting of 24 Ø7mm SBP I wires, located under the girder base at a distance of e = 300 mm (Figure 11).



$$A_t = 24\frac{\pi \times 7^2}{4} = 923,6mm^2$$

$$\sigma_{at} = 1000\, N/mm^2$$

$$M_m = 2024KNm$$

The length on which the girder is consolidated (the length of the consolidation tension rod) is l_t = 12.00 m.

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X_1 is calculated with relation (5):

$$X_1 = \frac{2024\times10^6}{(300+750)+\frac{1340240\times10^4}{300+750}\left(\frac{1}{37080}+\frac{1}{923,6}\right)} = 133030N$$

X_2 is calculated with relation (6):

$$X_2 = 923,6\times1000-133030 = 790570N$$

The normal unit stress produced by X_2 in pre-tension stage is determined with relations (7):

$$\sigma_I^s = -\frac{790570}{34320}+\frac{790570(300+750)}{1191138\times10^4}750 = 29,3\,{}^{N}\!/_{mm^2}$$

$$\sigma_I^i = -\frac{790570}{34320}-\frac{790570(300+750)}{1191138\times10^4}750 = -75,4\,{}^{N}\!/_{mm^2}$$

The normal unit stress produced by exploitation load and X_1 is determined with relations (8):

$$\sigma_{II}^s = -\frac{11120\times10^6+1440\times10^6}{1191138\times10^4}750-\frac{133030}{34320}+\frac{133030(300+750)}{1191138\times10^4}750 = -15,58\,{}^{N}\!/_{mm^2}$$

$$\sigma_{II}^i = \frac{11120\times10^6+1440\times10^6}{1191138\times10^4}750-\frac{133030}{34320}-\frac{133030(300+750)}{1191138\times10^4}750 = 148,0\,{}^{N}\!/_{mm^2}$$

The final stress state is determined with relations (9):

$$\sigma_c^s = 155,8-29,3 = 126,5\,{}^{N}\!/_{mm^2} < \sigma_{an} = 150,0\,{}^{N}\!/_{mm^2}$$

$$\sigma_c^i = 148,0-75,4 = 72,6\,{}^{N}\!/_{mm^2} < \sigma_{an}$$

4. CONCLUSIONS

If the results obtained through the consolidation methods discussed are analysed, the following conclusions can be drawn:

1. The comparison of this work with “The Consolidation of Steel Bridges Superstructures Without Introducing Initial Stress States” shows that the consolidation methods when an initial stress state is introduced in the structure are more efficient because the steel consumption needed for the consolidation is lower.

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2. The comparison between the two methods of the present work shows that the consolidation with pre-stressed steel rod is very efficient, even if the execution is more difficult (the pre-stressing).

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