DESIGN OF SOIL STEEL COMPOSITE BRIDGES ACCORDING TO THE EUROCODE

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Abstract

Soil steel composite bridges are used more and more often in road and railroad bridge construction. Spans have increased and structures with spans over 20 m have been built. At the same time new corrugations as well as new culvert profiles have been introduced. With lower heights of cover the effect of concentrated loads is becoming more pronounced.

In Sweden soil steel composite bridges are designed according to a handbook developed at the Royal Institute of Technology in Stockholm. In design the Eurocode is more and more often required. In such cases the handbook Eurocode section can be used.

In the paper an ultimate limit design procedure for a soil steel composite bridge according to the Eurocode is presented using the Swedish design handbook.

Key words: Soil-steel flexible culvert, soil-steel composite bridge, Eurocode, handbook, ultimate limit state design, low height of cover, live load

1. INTRODUCTION

Instead of national codes, the Eurocode is used in many European countries for bridge design. This is the case also for Soil Steel Composite Bridges (SSCB).

In Sweden SSCBs are designed according to a handbook developed at KTH Royal Institute of Technology (Pettersson, Sundquist 2010). The first edition of the handbook was printed in the year 2000. With the introduction of the Eurocode in Sweden it was necessary to add a Eurocode section to the handbook. The new section deals with ultimate limit state design and is described in this paper. The on-going research at KTH regarding fatigue design of SSCB according to the Eurocode and testing of the fatigue capacity of SSCB bolted connections is described in another paper presented at this conference.

2. ULTIMATE LIMIT DESIGN

2.1. Adaptation of the design principles in the Swedish handbook to Eurocode 3

According to the Swedish handbook, a SSCB, when designed according to the Swedish national standard BSK, is checked in the ultimate limit state according to a thrust moment interaction formula. The same principle is used also when designing according to the Eurocode. However, the interaction expression is formulated in a different and more complex way.

Using the methodology presented in the handbook the design thrust and bending moment from soil and live load are calculated. It should be noted that the notations used in the handbook are not the same as in the Eurocode. Even though the interaction formula in the Eurocode is relatively complicated, considerable simplifications can be made because of the nature of the corrugated steel wall in a Soil Steel Composite Bridge.

Note that equation numbers and figure numbers below follow the numbering used in the Swedish handbook (Pettersson, Sundquist 2010). Also, notations from the Eurocode 3 are not repeated in the notations section of the Swedish handbook.

2.2. Design check 3) in the Swedish handbook section 5.2 (Pettersson, Sundquist 2010): Check against flexural buckling of the upper part of the pipe

The following adaptations should be implemented when using Eurocode 3 for the design of a culvert. Section properties of the plates used for culverts are almost always in cross-section class 1 or 2, meaning that a reduction due to risk for local buckling can be often omitted (for cases with reduction compare below). For notations see **Figure B1.2** – **Figure B1.5** in the handbook. The formulae presented in this section are thus simplified using the assumption that the plates are in cross-section class 2 or lower.

At the ultimate limit state, a check is made on the maximum loaded section using EN 1993-1-1 expression *(6.61)*. As the plate is presumed not to deflect laterally (*z*-axes), $\chi_{\mathrm{LT}} = 1{,}0$ and $\chi_{\mathrm{Z}} = 1{,}0$. Furthermore, the moments $M_{\mathrm{z,Ed}} = \Delta M_{\mathrm{z,Ed}} = 0$ and, as the neutral axis does not change due to local buckling, $\Delta M_{\mathrm{y,Ed}} = 0$.

The expression (*6.61*) in EN 1993-1-1 can thus be simplified to:

$$\frac{N_{\mathrm{Ed}}}{\frac{\chi_{\mathrm{y}} N_{\mathrm{Rk}}}{\gamma_{\mathrm{M1}}}}+k_{\mathrm{yy}} \frac{M_{\mathrm{y,Ed}}}{\frac{M_{\mathrm{y,Rk}}}{\gamma_{\mathrm{M1}}}} \leq 1{,}0$$ (EN1993-1-1, *6.61,* and Table 6.7) (5.b′)

$N_{\mathrm{Ed}}, M_{\mathrm{y,Ed}}$ design value for axial force and bending moment, $N_{\mathrm{d,u}}, M_{\mathrm{d,u}}$. Observe that in certain cases the moment capacity should be reduced according to **Eq. (b1.h)** in the handbook.

$\chi_{\mathrm{y}}=\frac{N_{\mathrm{cr}}}{N_{\mathrm{u}}}$ reduction factor for flexural buckling, see *6.3.1* in EN 1993-1-1

k_{yy} interaction factor according to Table *A.1* and *A.2* in Appendix A in EN 1993-1-1. Note that method 1 is recommended in the Swedish National Annex.

$N_{\mathrm{Rk}}=f_{\mathrm{y}} A$ and $M_{\mathrm{Rk}}=f_{\mathrm{y}} W$ resistance for axial force and bending moment.

$\gamma_{\mathrm{M1}}=\gamma_{\mathrm{n}}$ in compliance with the design methods suggested in this manual. (Using the Swedish Standard $\gamma_{\mathrm{M1}}=1{,}0$)

The interaction factor k_{yy} can be simplified considerably. For cross-section classes 1 and 2 it is:

$$k_{\mathrm{yy}}=\frac{C_{\mathrm{my}}}{\left(1-\chi_{\mathrm{y}} \frac{N_{\mathrm{Ed}}}{N_{\mathrm{cr,y}}}\right) C_{\mathrm{yy}}} \qquad (5.b'')$$

where $C_{\mathrm{my}}=C_{\mathrm{my,0}}$ is a correction factor allowing for the distribution of the moment along the arch according to Tables *A.1* and *A.2* in SS-EN 1993-1-1. For simplicity, it can be assumed that $C_{\mathrm{my}}=1{,}0$. $N_{\mathrm{cr,y}}=N_{\mathrm{cr,el}}$ according to **Eq. B5.b** in the handbook.

For cross-section classes 1 and 2 the correction factor C_{yy} is added. As $\bar{\lambda}_0 = 0$ and $\bar{\lambda}_z = 0$, the expression for C_{yy} in Table *A.1* can be simplified to:

$$C_{yy} = 1 + \left(w_y - 1\right)\left[\left(2 - \frac{1,6}{w_y} C_{my}^2 \bar{\lambda}_y \left(1 + \bar{\lambda}_y\right)\right) \cdot n_{pl}\right] \quad (5.b'')$$

and

$$C_{yy} \geq \frac{W_{el,y}}{W_{pl,y}} \quad (5.b^{IV})$$

where $w_y = \dfrac{W_{pl,y}}{W_{el,y}} \leq 1,5$ is the quotient between plastic and elastic section modulus. The relative slenderness $\bar{\lambda}_y$ is given by:

$$\bar{\lambda}_y = \sqrt{\frac{N_u}{N_{cr,el}}} \quad (5.b^{V})$$

where N_u, $N_{cr,el}$ and N_{cr} are given in **Appendix 5** of the handbook. Using the equations above the interaction according to the Eurocode equations can be calculated.

Finally a check should also be done according to **Section 5.2** in the handbook, point *3)* with ξ calculated according to **Appendix 5, Eq. (B5.e)** testing the relation $\left(\dfrac{N_{d,u}}{\omega f_y A}\right)^{\alpha_c} \leq 1,0$.

3. SUMMARY

When developing the Swedish handbook for the design of Soil Steel Composite Bridges the Swedish national steel code BSK was used as a basis for the ultimate limit state design. The ULS design was done using a thrust moment interaction expression. When the Eurocode was introduced in Sweden, a section with the adaptation of the design principles to the Eurocode for the ultimate limit state was added to the handbook. Even though the Eurocode also uses a thrust moment interaction formula, the interaction is expressed in a different way compared to the Swedish national steel code BSK. However, the input data necessary for performing the interaction calculations according to the Eurocode are available in the Swedish handbook for Soil Steel Composite Bridges.

REFERENCES

Pettersson, L. and Sundquist, H., *Design of soil steel composite bridges*, Trita-BKN, Report 112, 4th Edition, Royal Institute of Technology, Department of Structural Design and Bridges, Stockholm, Sweden, 2010.

Streszczenie

Kompozytowe konstrukcje gruntowo-stalowe są wykorzystywane coraz częściej w roli mostów drogowych i kolejowych. Rozpiętość tych konstrukcji wzrasta; powstają nawet konstrukcje o rozpiętości przekraczającej 20 m. Jednocześnie wprowadzane są nowe profile fal oraz przepustów. Przy niższej wysokości naziomu oddziaływanie skupionych obciążeń staje się coraz wyraźniejsze.

W Szwecji konstrukcje tego typu są projektowane zgodnie z podręcznikiem opracowanym w Królewskim Instytucie Techniki w Sztokholmie. Podczas projektowania coraz częściej wymaga się stosowania Eurocode. W takich przypadkach stosuje się rozdział podręcznika dotyczący Eurocode.

Praca przedstawia procedurę projektowania mostu gruntowo-stalowego w oparciu o stany graniczne zgodnie z Eurocode, z zastosowaniem szwedzkiego podręcznika projektowania.

Słowa kluczowe: gruntowo-stalowe podatny przepust, kompozytowy most gruntowo-stalowy, Eurocode, podręcznik, projektowanie oparte o stany graniczne, niski naziom, obciążenia zmienne