ANALYSIS OF THE EUROCODE PROPOSALS FOR FATIGUE EXAMINATION ON RAILWAY BRIDGES

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SUMMARY

This paper investigates the fatigue effects on railway briges using the Eurocode 3 standard. The study focuses on the fatigue effects of simply supported beams and continuous (elastic and fix) supported beams. It compares the correction factors derived from a simply supported and a continouous beams. On the other hand, it also compares the results provided by the Eurocode 3 traffic types and the Hungarian traffic types.

Keywords: fatigue, railway bridges, steel structures

1. INTRODUCTION

In previous years, Eurocode 3 fatigue examinations on railway bridges were conducted using the UIC proposals on traffic types. In these studies, actual train types replace the ideal (UIC) train loads to yield more realistic results; different train types are used for improving the accuracy, for example, differentiation between passenger trains and carriage trains. This differentiation of load types (4 - 12) catagorize the annual volume of traffic on the railway lines (Eurocode 1, 1994; Eurocode 3, 1997; Forgó, 1995).
This study attempts to answer the following questions:
1- Can the results of the calculation of $\lambda_{1\sigma}$ in the Eurocode 3 proposals be used in Hungary, in spite the differences between the Eurocode 3 and Hungarian load types,?
2- Can the Eurocode 3 proposals, which affirm :

$$\lambda_{1\sigma} \cong \lambda_{1\tau} \qquad (1)$$

be used ?
3- Can the resultes belonging to the simply supported beams be used in the case of the continuous beams?
4- Are the results extracted from the fix supported beams can be used in the case of the elastic?
Referring to the first question, the proposal of Forgó Sándor for railway traffic types was accepted, considering his study in railway traffic of the Hungarian railway company (MÁV) (Forgó, 1995; Jaramani, 1995).

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2. EUROCODE 3 FATIGUE DESIGN METHOD

For steel bridges the safety verification shall be carried out of ensuring that the following condition is satisfied (Eurocode 1, 1994; Eurocode 3, 1997) :

$$\gamma_{Ff} \cdot \lambda \cdot \Theta_2 \cdot \Delta\sigma_{UIC} \leq \frac{\Delta\sigma_C}{\gamma_{Mf}} \qquad (2)$$

where:

γ_{Ff} : is the partial safety factor for fatigue loading, γ_{Ff} =1,00

γ_{Mf} : is the partial safety factor for fatigue strength (minimum 1,25)

$\Delta\sigma_c$: is a reference value of the fatigue strength at 2.10^6 cycles

Θ_2 : is a dynamic factor

$\Delta\sigma_{UIC}$: is the stress range due to the UIC loading 71 being placed in the most unfavourable position for the element under consideration.

λ : is the factor applied to the fatigue strength (correction factor)

The previously mentioned correction factor is included in the empirical analysis to compare the calculated stress with fatigue allowable stress (Eurocode 1, 1994; Eurocode -3, 1997) :

$$\lambda = \lambda_1 \cdot \lambda_2 \cdot \lambda_3 \cdot \lambda_4 \qquad (3)$$

where:

λ_1 : is a function of the span and traffic type

λ_2 : is a factor to take account of the annual volume of traffic

λ_3 : is a factor to take account of the design life of the structure

λ_4 : is a factor to be applied when the structural element is loaded by more than one track

The, λ_2 , λ_3 and λ_4 factors, however do not depend on load types or on the structure elements . Thus, λ_1 is the most important variable, and is a function of normal stress (σ) or shear stress (τ). The λ_1 as shown in this study, can be differentiated into $\lambda_{1\sigma}$ belonging to the normal sterss and $\lambda_{1\tau}$ belonging to the shear stress (Jaramani, 1995; Jaramani, 1998).

3. STUDY ON $\lambda_{1\sigma}$ FACTOR

During the study, the Standard S-N - curve (ie. Wöhler - curve) and Palmgren - Miner cumulative damage calculation are used (Eurocode 1, 1994; Eurocode 3, 1997).

First, the influence diagrams of the beams are constructed. Then the UIC load is loaded on to the diagram giving $\Delta\sigma_{UIC}$. Like wise, each train types are also loaded on to the same diagram deriving the corresponding train influence diagrams. Then these diagrams are used to calculate the stress range ($\Delta\sigma_i$) and the load cycles (n_i) using the Rainflow method. Following this, the reference value of fatigue stress at two million cycles ($\Delta\sigma_c$) determined as :

$$\Delta\sigma_c = \frac{1}{\sqrt[3]{2.10^6}} \cdot \sqrt[3]{\sum \Delta\sigma_i^3 \cdot n_i \cdot \varphi_i + \sum \left(\sqrt[5]{\frac{5.10^6}{n_j}} \right)^2 \cdot \Delta\sigma_j^3 \cdot n_j \cdot \varphi_j} \qquad (4)$$

where:

φ_i : is the dynamic coefficient for each service train type.

$$j = 1 + \left(j' + \frac{1}{2} \cdot j'' \right) \tag{7}$$

$$j' = \frac{K}{1 - K + K^4} \text{, With } K = \frac{v}{160} \text{, if } L \leq 20m$$

or

$$K = \frac{v}{47.16 \cdot L^{-0.408}} \text{, if } L > 20m$$

$$j'' = 0.56 \cdot e^{-\frac{L^2}{100}}$$

ν = speed (m/s)

The Eurocode 3 proposal:

$$l_{1s} = \frac{\Delta s_C}{\Theta_2 \cdot \Delta s_{UIC}} \tag{8}$$

was calculated, where:

$$l_{1s\,\max} = \frac{\Delta s_{\max}}{\Theta_2 \cdot \Delta s_{UIC}} \cdot \sqrt[3]{\frac{N_D}{N_C}} = \frac{\Theta_2 \cdot \Delta s_{UIC}}{\Theta_2 \cdot \Delta s_{UIC}} \cdot \sqrt[3]{\frac{5 \cdot 10^6}{2 \cdot 10^6}} = \sqrt[3]{\frac{5}{2}} = 1.4 \tag{9}$$

where:

N_D=5.10^6 sycles

N_C=2.10^6 sycles

3.1. The case of simply supported beams

The $\lambda_{1\sigma}$ s calculated for each center point of 3, 5, 7, 10 and 50 meter span simply supported beams. The volume of traffic is 25 million tonne per annum. As a result, λ_2 = 1 and the design life of the structure is 100 years (ie. λ_3= 1). The structural element is loaded by one track (ie. λ_4= 1). Therefore, λ= $\lambda_{1\sigma}$ (Platthy, Jaramani, 1997).

The study is done by using the Eurocode 3 and the Hungarians train types. The results derived from the Eurocode 3 train types ($\lambda_{1\sigma E}$) are higher than those of the Hungarian train types ($\lambda_{1\sigma M}$), as showen Fig 1. Therefore, the Eurocode 3 proposals can be used in Hungary.

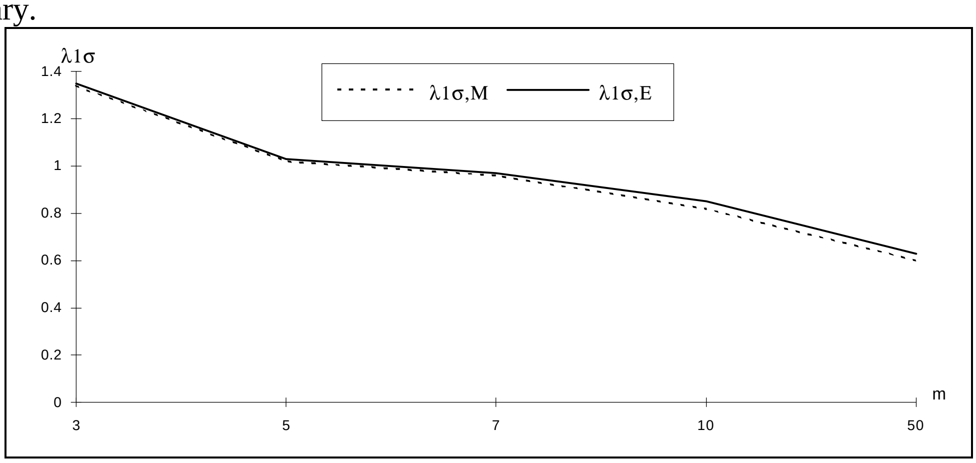

Fig. 1 Results of simply supported beams

3.2. The case of continuous beams

The Eurocode 3 does not include any calculations for the continuous beams, but merely suggests an idea to calculate the value of the correction factor $\lambda_{1\sigma}$ by changing the span length (Eurocode 1, 1994; Eurocode 3, 1997; Jaramani, 1998):

- for a simply supported span, the span length, L
- for continuous spans, the span length, L, for the span under consideration and the mean of the concerned spans for the support section.

Eurocode 3 also did not factor in the effects of elasticity nor the fixibility of the supported beams to the results. Thus, we further investigate the reliability of their suggestions by examining their effects. Due to such assumptions, we believe that the Eurocode 3 fails to represent realistic results for the continuous beams.

3.2.1. The case of continuous fix support beams

In our study we used continuous beam with uniform spans (L), as seen in Fig 2.

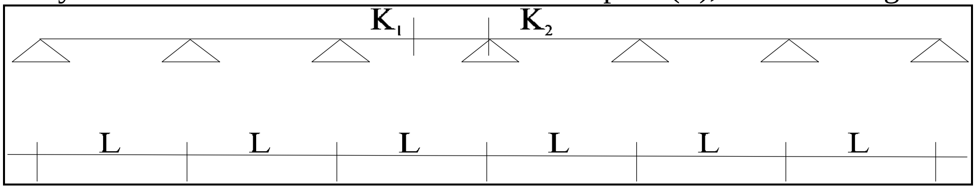

Fig. 2 Model of continuous fix support beams

Using the Eurocode 3's suggestion for the continuous beams,values of $\lambda_{1\sigma}$ for the cross sections K_1 (mid-cross section) and K_2 (supported section) are the same as the $\lambda_{1\sigma}$ of the simply supported beams. In order to verify the validity of this assumption, we examine 3, 5, 7m fix continuous beams using the Eurocode 3 and Hungarian traffic types.

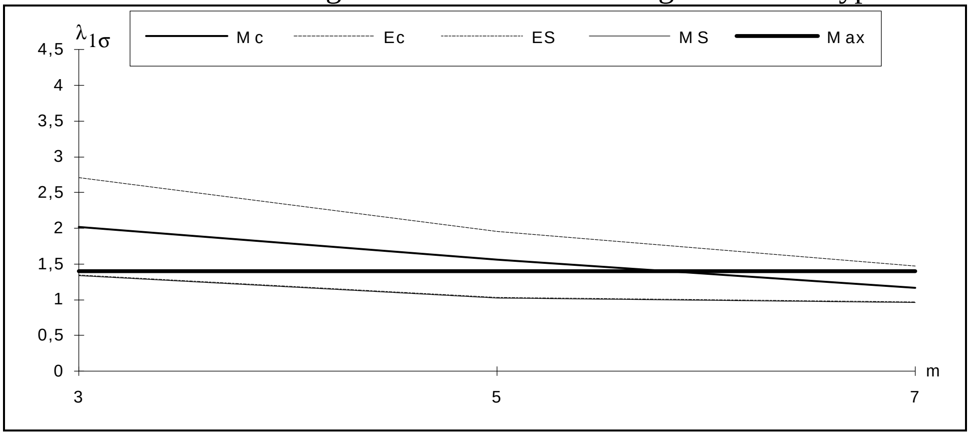

Fig. 3 Results at mid cross section

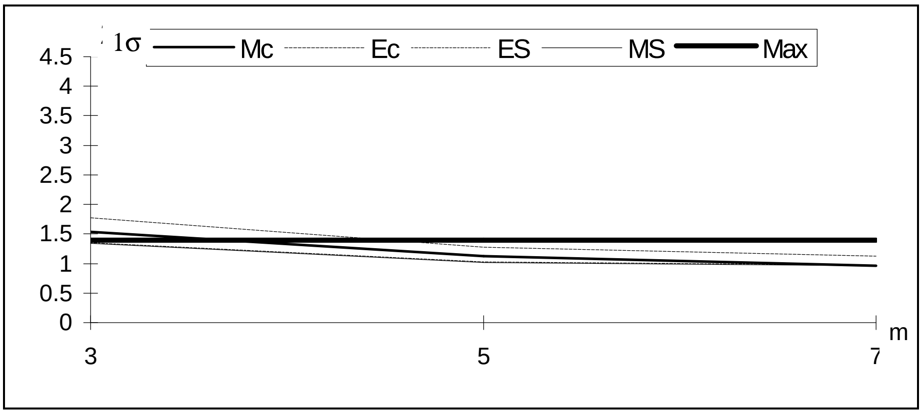

Fig. 4 Results at support section

Figure 3 plots the results of K_1 (mid cross section), and figure 4 plots the results of K_2 (support section). These graphs show that the results for the simply supported beams (ES) and the fix continuous beams (Ec) are not equal. Thus, we prove that, Eurocode-3's suggestion is invalid. The figures also show that the results derived from Eurocode-3 train types are higher than those of Hungarian train types (Mc). Thus, if Eurocode 3 had the results for the continuous beams, we can use them in place Hungarian train type results. However Eurocode 3 have not published such results. To avoid such extensive examination for the continuous beams, we suggest, for such cases, using the maximum value of the correction factor (Max).

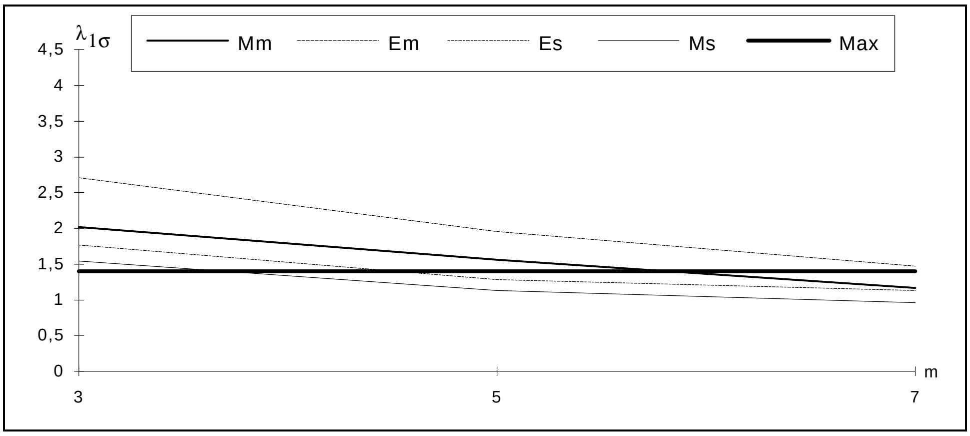

Fig. 5 Comparing the results at mid and support section

In Fig 5, we compare the results at the mid cross section (Em, Mm), and the results at the support section (Es, Ms). It shows that the results at mid cross section are higher than the results for the support section. This means we do not need to make a different calculation for the support section, but we can not use the maximum value of the correction factor (Max).

3.2.2. The case of continuous elastically supported beams

From this study, we assume that the continuous supported beams will yield yet another result for the model in Figure 2, adding to it an elasticity factor (continuoius supported elastic beams, where, we assumed the value of the springs by deriving them from typical cross-beam bending rigidity: $C_0=C_6=0,0010$ m/kN, $C_1=C_2=C_3=C_4=C_5=0,0015$ m/kN). Therefore, we re-examine our case study using the same procedure and parameters with an addition of an elasticity factor.

Figure 6 plots the results of K_1 (mid cross section), and figure 7 plots the results of the K_2 (support section). These graphs show that the results for the simply supported beams (Es) and the elastically continuous beams (EC) are not equal. They have different tendency as well. Thus, we prove that, Eurocode 3's suggestion is invalid. The figure also shows that the results derived from Eurocode 3 train types are higher than those of Hungarian train types (MC). Thus, if Eurocode 3 had the results for the continuous beams, we could have used them in place Hungarian train type results. However, Eurocode 3 have not published such results. To avoid such extensive examination for the continuous beams in the case of mid cross section, we suggest using the maximum value of the correction factor (Max), but for a support section we can not use the (Max).

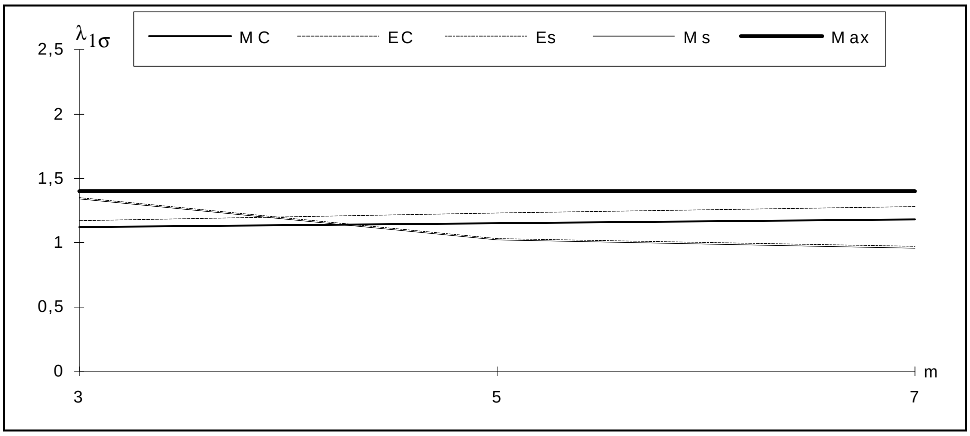

Fig. 6 Results at mid cross section

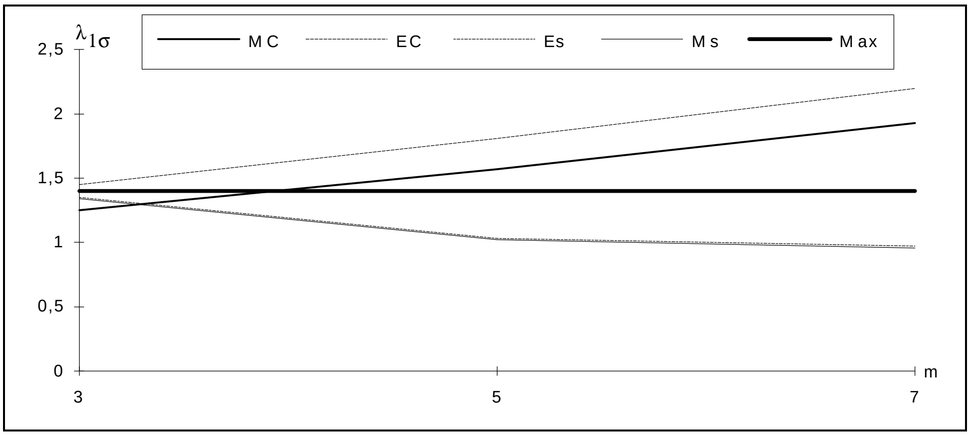

Fig. 7 Results at the support section

In Fig 8, we compare the results at the mid cross section and the results at the support section. It shows that the results at support section are higher than the results for the mid cross section, this gives the opposite of the hypothesis we have made in the case of the fix beams. This means in the case of the elastic beams, we do not need to make a different calculation for the mid cross section.

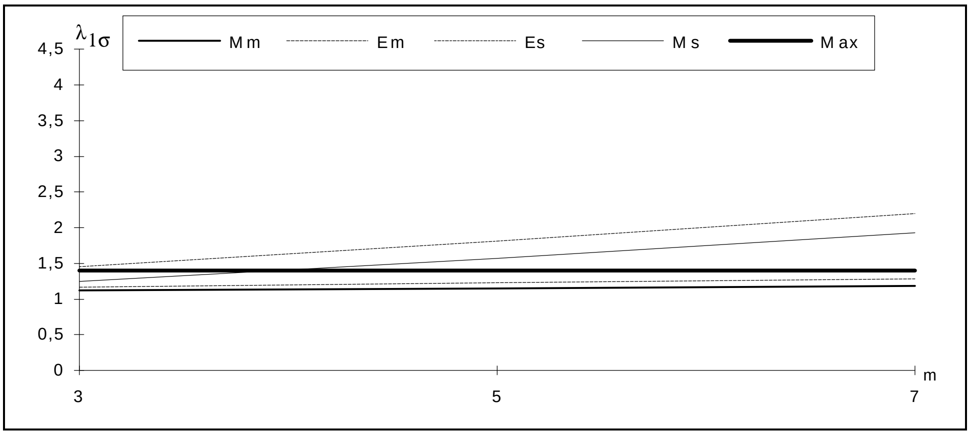

Fig. 8 Comparing the results at the mid and support cross section

4. STUDY ON $\lambda_{1\tau}$ FACTOR

Calculating the correction factor($\lambda_{1\tau}$**):** The same proccedure is used as with the correction factor belonging to the normal stresses, but the reference value of fatigue stress at two million cycles ($\Delta\tau_c$) is determined as :

$$\Delta t_c = \frac{1}{\sqrt[5]{N_c}} \cdot \sqrt[5]{\sum \Delta t_i^5 \cdot n_i \cdot j_i} \tag{10}$$

Using the previously mentioned method, the Eurocode 3 proposal for correction factor belonging to the shear stress (Jaramani, 1995; Jaramani, 1998) :

$$l_{1t} = \frac{\Delta t_C}{\Theta_2 \cdot \Delta t_{UIC}} \tag{11}$$

the maximum was also calculated:

$$l_{t\,\max} = \frac{t_{\max}}{\Theta_2 \cdot \Delta t_{UIC}} \cdot \sqrt[5]{\frac{N_D}{N_C}} = \frac{\Theta_2 \cdot \Delta t_{UIC}}{\Theta_2 \cdot \Delta t_{UIC}} \cdot \sqrt[5]{\frac{8 \cdot 10^8}{2 \cdot 10^6}} = \sqrt[5]{\frac{800}{2}} = 3.32 \approx 3.4 \tag{12}$$

where:
$N_D = 8.10^8$ sycles
$N_C = 2.10^6$ sycles

4.1. The case of simply supported beams

The Eurocode 3 does not include any calculations for the correction factor belonging to the shear stress ($\lambda_{1\tau}$), but merely suggests an proposal which affirm:

$\lambda_{1\sigma} \cong \lambda_{1\tau}$

We further investigate the reliability of their suggestions by using the same parameters and the same calculation method we used for the case of ($\lambda_{1\sigma}$).
To contrast $\lambda_{1\sigma}$ with $\lambda_{1\tau}$, the following ratio was used (Jaramani, 1998) :

$$a = \frac{l_{1t}}{l_{1s}} \tag{13}$$

The results of this calculation are shown in Fig. 9. The figure shows the ratio is valid in the case of short span simply supported beams, but is not valid for a long span of beams. This means the Eurocode 3 proposal can be used in short spans.

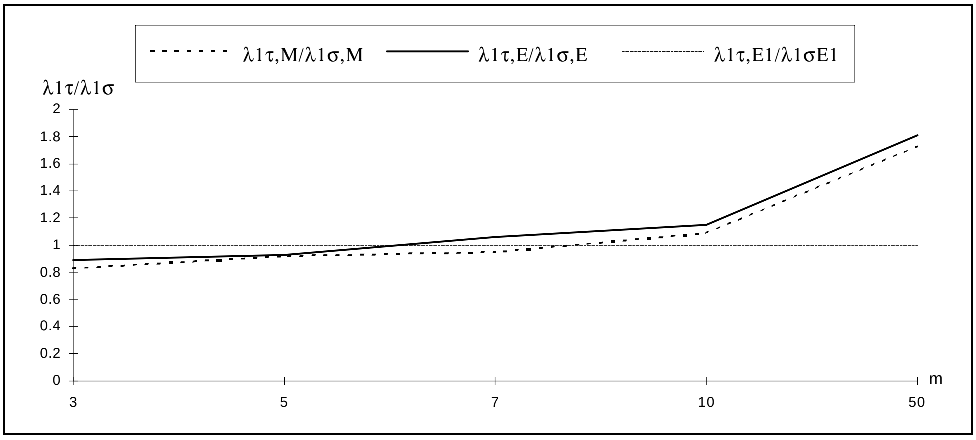

Fig. 9 Results of a ratio

5. CONCLUSIONS

• The results of this study show that the Eurocode 3 proposals for moment induced fatigue in simply supported beams can be used in Hungary, but the seggestions for shear forces induced fatigue can not be used.

• Our study shows that the (α) ratio is valid in the case of short span simply supported beams, but for a long span is not valid.

• The comparison between calculated results in simply and continuous supported beams at mid and support cross section are not equal. Thus, we prove that Eurocode 3's suggestion is invalid, and the results derived from Eurocode 3 train types are higher than those of Hungarian train types. Thus, if Eurocode 3 had the results for the continuous beams, we could have used them in place of Hungarian train type results. However, Eurocode 3 has not published such results.

• The comparison of the results of fix and elastically supported beams at the mid and support cross section are not equal.

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