CREATING A MORE ACCURATE MODEL - OPTIONS TO REDUCE THE USE OF MATERIALS IN TRAMWAY TRACK STRUCTURES

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Since the 1990s, road rail has once again become a key element of public transport in liveable modern cities. The design of these structures is greatly complicated by their complexity and the limited availability of data on the pouring material. While the railway designer typically deals only with the rails and the pouring material, the structural engineer, ignoring these elements, often considers only the supporting beam as a single structural element. Breaking with this approach, a method is presented that, when implemented in an MS Excel environment, can be used to create an efficient tool for the joint analysis of the embedded rail structure and its supporting beam. The internal forces in the beam obtained by this method are more favourable than those calculated by the conventional method and thus provide the opportunity to optimise (minimise) the amount of material used. In this article, we present the potential applications of the complex model and, based on the calculations performed, highlight the material savings that can be achieved in the design of the supporting beam, which also proportionally reduces the costs, which are limited in the changing economic environment.

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1 Introduction

In the case of an embedded rail structure, it is generally accepted practice to consider the supporting beam as infinitely rigid when calculating the stresses and deflections of the rails. When the beam is designed, this can be done as a resiliently embedded support. In general, the beam is investigated for stresses from concentrated loads, which is an approximation in favour of safety, but leads to significant oversizing, since the load-distributing effect of the rails is not present. In this paper, we present a solution to more accurately determine the stresses on the beams. Taking the original derivation further, we have implemented the solution in MS Excel and created a program that allows us to take into account not only the effects of a single axis, but also those of groups of axes.

2 Theoretical Background

The general knowledge of ballastless tracks is discussed in the book Feste Fahrbahn (Darr and Fiebig, 2006). The special design of these structures, such as green tracks for urban environments, is discussed in detail in Kappis et al. (2014). The designing of slab tracks with discrete rail supports is presented in Freudenstein et al. (2018). In the paper by Yen and Lee (2007), the practical case where an "infinite" long rail is supported by an "infinite" long beam is described. The system of differential equations describing the problem is summarized in Equations 1 and 2. While the problem is illustrated in Figures 1 and 2.

$$E_S I_S \frac{d^4 y_1}{dx^4} = p_1 \quad , (1)$$

$$E_C I_C \frac{d^4 y_2}{dx^4} + p_1 = p_2 \quad . (2)$$

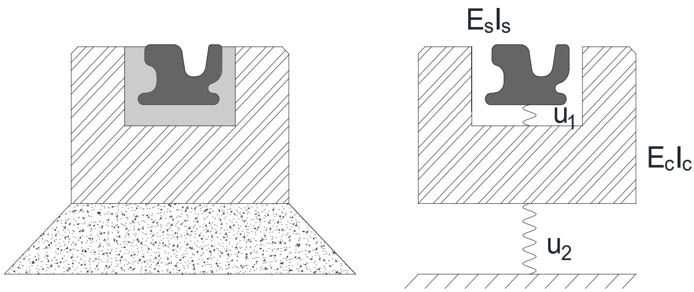

Figure 1: Schematic diagram of the problem under study 1
(source: author's own illustration)

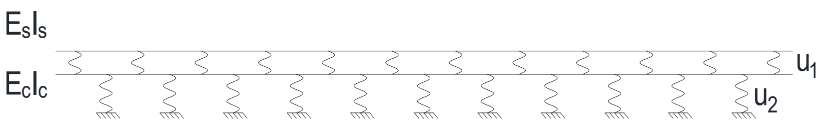

Figure 2: Schematic diagram of the problem under study (2.)
Source: author's own illustration

The factors in the derivation, the input parameters of the model:

- E_sI_s: the bending stiffness of the rail [kNm²],
- E_cI_c: bending stiffness of the beam [kNm²],
- u_1: support stiffness of the rail [kN/m/m],
- u_2: support stiffness of the beam [kN/m/m].

The differential equation system can be solved by following the steps below:

Step 1: Determine the auxiliary quantities needed to simplify the calculation.
Step 2: Calculate the Zimmermann's influence functions.
Step 3: Calculate the deflection and bending moment of the beam.
Step 4: Transform the original functions to take into account the effect of the axis group.
Step 5: Determination of the shear force function by applying the finite difference method.

Knowing the internal forces, the designer has the opportunity to design the the beam. You can modify the dimensions and material quality, design the reinforcement for bending and shear. With a design that matches the internal forces more and more, it can ensure the minimum use of materials, which can result in less environmental impact. Furthermore, it can also reduce the amount of transport in the urban environment. Smaller intra-city transportation disturbs traffic less, causes less noise and vibration, and also reduces the emission of air pollutants.

3 Methodology

For problem validation implemented in MS Excel environment, two models were prepared and their results were compared with the results reported by the Axis VM finite element modeling (FEM) program. In one of them we used SA42 rail and in the other one we used 60Ri1. The beam has a cross section of 70x40 cm. In both cases the support stiffness of the rail is 50 N/mm/mm. The bedding factor under the beam is 0.05 and 0.20 N/mm^3 respectively (the support stiffness under the beam is thus 35 and 140 N/mm/mm.) The applied load is a single 125 kN wheel load. The results are summarized in Table 1.

Table 1: Calculated and modelled (FEM) results

C=0.2 N/mm^3	Analyst	FEM	
SA42	27.39	27.46	kNm
60Ri1	17.53	17.55	kNm
C=0.05 N/mm^3	Analyst	FEM	
SA42	44.38	44.41	kNm
60Ri1	32.62	32.60	kNm

The obtained values show that the accuracy of the derived relations is equal to the accuracy of the finite element models, so they can be used for approximate dimensional surveys and inspections.

4 Results

Our validated program has also been applied to groups of axles to verify the effectiveness of the load-distributing effect of the rail. In the model, 4 wheel forces of 75 kN were placed at a distance of 2.2 m from each other, which corresponds to the static value according to the Hungarian regulations. A 60Ri1 rail was used in the model. The supporting beam has a cross section of 70x40 cm. The supporting stiffness of the rail is 30 N/mm/mm. The bedding factor under the beam is 0.10 N/mm^3 (the supporting stiffness under the beam is thus 70 N/mm/mm). The calculation was performed both with and without the load-distributing effect of the rail, which is possible with our software. The results are shown in Figures 3 to 6, while the calculated values are summarized in Table 2.

Table 2: Results calculated by the programme

	Without load distribution	With load distribution	
Bending moment (+)	20.94	6.99	kNm
Bending moment (-)	8.31	6.94	kNm
Shear force (+)	31.81	8.24	kN
Shear force (-)	31.81	8.24	kN

The results in Table 2 show that the model selected and applied at the site can significantly reduce the calculated results and thus the amount of material used.

Figure 3 shows the bending moment calculated without considering the load distribution. The location of the individual axes can be clearly seen in the figure. Significant positive bending moment peaks appear here. On the other hand, in Figure 4, where we took into account the distribution of the loads, these peaks disappear and the resulting positive values are significantly reduced. On the other hand, there is no significant difference in the magnitude of the negative values in the two figures.

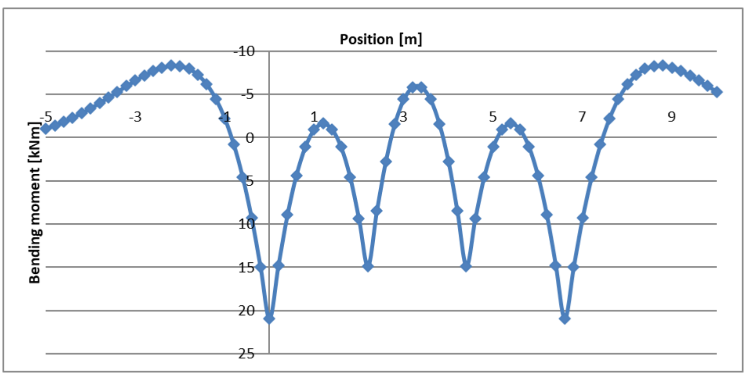

Figure 3: Bending moment in the beam without load distribution on the rail
Source: the result of our program

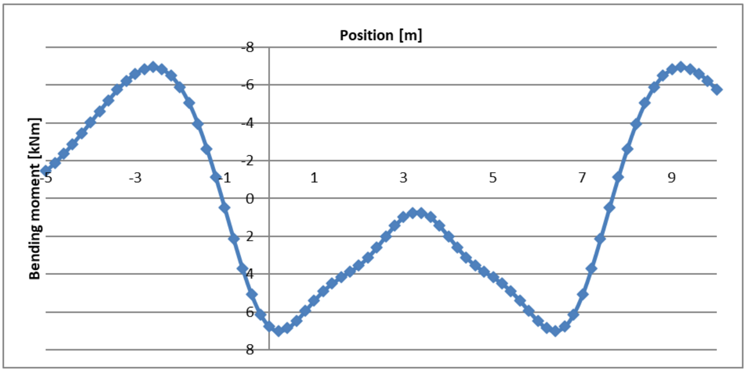

Figure 4: Bending moment in the beam with load distribution of the rail
Source: the result of our program

Based on the values in Table 2, it can be seen that with the correct choice of the calculation model, the positive bending moment values dropped to 33.3%. In this case, the positive and negative bending moment values are almost the same. Sizing for these internal forces results in a much smaller use of concrete and steel, which results in a significant cost reduction. In addition to these, the smaller use of materials also reduces the environmental impact.

Figure 5 shows the shear force calculated without considering the load distribution. The location of the individual axes can be clearly seen in the figure. Here, significant peaks appear on the shear force diagram. On the other hand, in Figure 6, where we took into account the distribution of the loads, these peaks disappear and the resulting values are significantly reduced.

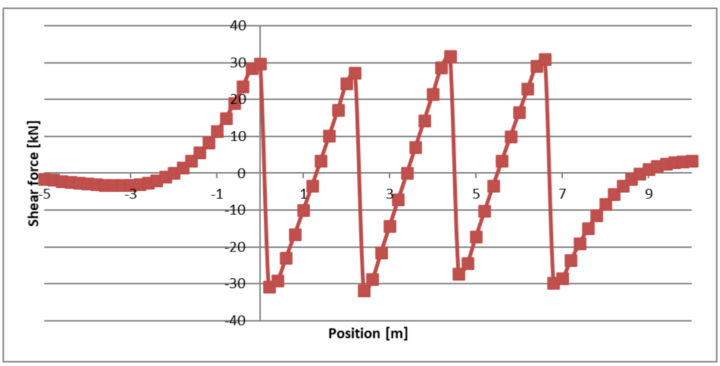

Figure 5: Shear force in the beam without load distribution of the rail
Source: the result of our program

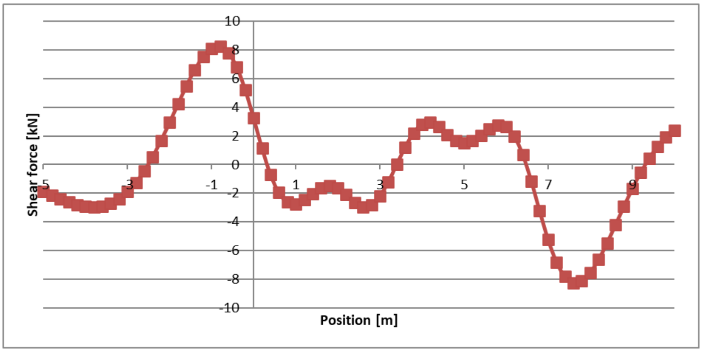

Figure 6: Shear force in the beam with load distribution of the rail
Source: the result of our program

Based on the values in Table 2, it can be seen that with the correct choice of the calculation model, the maximum value of the shear force dropped to 25.9%. Sizing for these internal forces results in a much smaller use of concrete and steel, which results in a significant cost reduction. In addition to these, the smaller use of materials also reduces the environmental impact.

5 Discussion

In our article, we only looked at the impact of the model on the demand and were able to draw conclusions on the expected material savings. In our further research, we want to get a more precise picture, so we want to obtain quantifiable values for both the concrete and reinforcing steel used by sizing the beams precisely, in order to create a kind of structural optimisation to reduce the environmental impact. This requires not only an analysis of the behaviour during the as-built phase, but also during the whole life cycle, the main aspects of which are detailed by Gáspár et al. (2011). The methodological development of this research would be facilitated by the use of the Intenscope method (Kocsis 2014).

6 Conclusions

In this paper, we present an adaptation of a calculation method in MS Excel environment that allows to calculate more accurate internal forces than the traditional practice, while taking into account the load-distributing effect of the rails. Based on the results calculated by us, it can be seen that a significant decrease can be seen in the examined case both in the bending moment values and in the shear force values. In the case of the bending moment, the value is 66.7% lower, while in the case of the shear force, the value is 74.1% lower using the more accurate model. As a result, the amount of materials used can be effectively reduced, which results in a lower environmental impact (Major et al., 2023) and a reduction in construction costs.

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