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Design of suspended rail reinforcement

The continuous development of coal extraction technology in hard coal mines, including the increased efficiency of the machinery and equipment used in mining, encourages manufacturers to increase the power of these machines. This also entails an increase in their weight. Transporting these machines to their destination, especially to the face, is the task of suspended transport systems, i.e.: a suspended railway system. The proposed solution consists in welding flat bars to the flanges of the I-beam, which will increase the unit weight of the load that can be carried by each car of the transport set moving along the railway. This paper contains a technical description of the modified rail and basic strength calculations, the results of which confirm the advisability of its use.

Key words: *suspended railway system, rail, transport*

1. ZMK "WOSTAL" SP. Z O.O.

The beginnings of Zakłady Mechaniczno-Kuźnicze "Wostal" Sp. z o.o. date back to 1949, where on the site of today's plant was a metal products factory. The company's operating activity included manufacturing mining rolling stock and railway equipment, and metalworking. In 1979, Zakład Produkcji Urządzeń Technologicznych "Polmo" in Wolbrom was merged with three other companies to form Przedsiębiorstwo Projektowania i Dostaw Transportu Technologicznego i Składowania "Techmatrans". The establishment of the company under the name of Zakłady Mechaniczno-Kuźnicze "Wostal" Sp. z o.o. took place in 1922. In 2014, the majority stake in ZMK "Wostal" Sp. z o.o. was purchased by FTT Wolbrom S.A.

Zakłady Mechaniczno-Kuźnicze "Wostal" Sp. z o.o. is a manufacturer of high-quality products and service provider for all branches of the industry.

Long-term collaborations and experience in the mining, engineering and construction industries make the company well-known and respected both on the domestic and foreign markets. The main countries to which the products are exported are Finland, France, Germany, Turkey, the Czech Republic, Slovakia and the United Kingdom. The company employs around 220 people and has three production departments.

The steel construction department has the capacity to produce various types of steel structures weighing up to 20 tonnes. The forging department (Fig. 1) produces drop forgings of up to 12 kg in unalloyed, alloyed and stainless steels.

Fig. 1. Forging department

Drop forging department meets the needs of the Forging Department concerning forging tooling and offers machining using CNC machines (Fig. 2).

Fig. 2. CNC machine

2. ASSUMPTIONS

Suspended railway system elements: slings, stays and rails, are among the basic groups of products manufactured for many years by ZMK “Wostal” Sp. z o.o., and approved by the State Mining Authority in Katowice and the Institute of Mining Technology KOMAG in Gliwice, Poland.

Due to the construction of the suspended railway system, the most commonly used rails are 2 m and 3 m long straight rails (Fig. 3). These are the longest sections, among the various types of rails, e.g. curved rails, transition rails and compromise rails, used. The length of a single rail has a major impact on the construction and operating costs of a track. The use of as long rail as possible is advantageous concerning the number of rails required and the number of track components such as suspension elements and supports. Consequently, as the length of the rail increases, the number of rails and additional elements decreases, which considerably reduces the construction cost of the track.

Fig. 3. Straight rails manufactured by “Wostal” Sp. z o.o.

The use of rail design solutions using I155 I-beam according to [1] without reinforcement allows the transport of a load not exceeding 27.5 kN [2] per one car and with a minimum car spacing of 1.8 m [3] for a 3 m long rail.

The method of increasing the load-bearing capacity of the rail considered in this study consists in using a standard I155 I-beam [1] with an increased section modulus obtained by welding a $b \cdot h = 12 \cdot 50$ mm flat bar to its flanges. The size of the stiffener (flat bar dimensions) is limited by the available space, determined by the necessity to provide sufficient clearance between the car and the lower flange of the I-beam. The dimensions of the flat bar were selected to ensure the above condition and to enable the highest possible load-bearing capacity to be achieved for a 3 m long rail. The calculations presented do not take into account the effects of wear and tear on the rails.

3. CALCULATIONS

The loads in the vertical plane arising from the transported weight and the purpose of the use of two flat bars to increase the section modulus of the rail, presented in the work [4] concerned only the performance parameters directly related to the stress originating from the bending of the rail when there is only one car on it. A limitation on the load capacity of the rail due to the strength of the sling was also considered, and verification of the load capacity of the joint was performed.

The rail structure is shown in Figure 4.

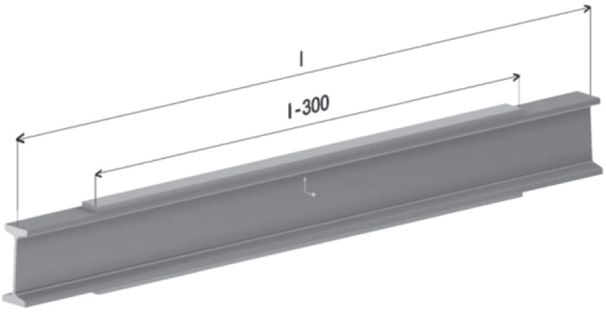

Fig. 4. Rail 155 reinforced using flat bars welded to the outer surfaces of the lower and upper part

It was assumed that the flat bars would be welded in an a6-100x(100) fillet weld. The I-beam material was S355J2G3 steel, while the flat bars were made of S355JR steel. These types of steel differ slightly from each other, particularly in terms of impact strength.

Due to the very frequent use of 2.4 m and 3 m rails, calculations of the maximum load capacity of the rails were carried out simultaneously for these two lengths. The load diagram for the suspended rail is shown in Figure 5.

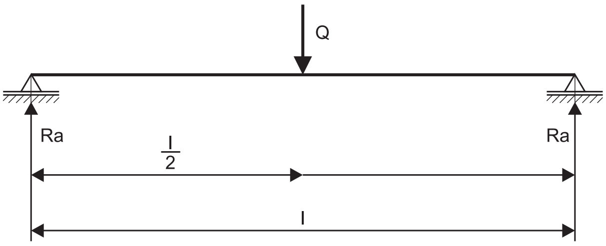

Fig. 5. The load diagram concerning force applied at the mid-length of the rail

The minimum tensile strength of the materials used to construct the rail is $R_m = 490$ MPa, and the value of the determined section modulus of the rail with reinforcements $W_x = 222.5 \cdot 10^{-6}$ m^3. The rail lengths taken for calculations were $l = 2.4$ m and $l = 3.0$ m, respectively. The condition for the maximum permissible rail load $Q_{\max}$ due to the minimum tensile strength of the rail material R_m is presented in the formula:

$$\frac{M_{g\_\max}}{W_x} \le R_m \tag{1}$$

where the maximum bending moment is:

$$M_{g\_\max} = \frac{Q_{\max} \cdot l}{4} \tag{2}$$

On the other hand, after determining the maximum load, the equation is:

$$Q_{\max} \le \frac{R_m \cdot W_x \cdot 4}{l_{\max}} \tag{3}$$

After substitution and calculation, the maximum load on the rail was:

- 181.7 kN for a rail length of 2.4 m,
- 145.3 kN for a rail length of 3 m.

The maximum load calculated from condition (3) must be reduced because the value of the safety factor must be taken into account. This results in a formula from which the payload can be calculated:

$$Q \le \frac{Q_{\max}}{n} \tag{4}$$

By substituting the data into equation (3) and calculation, the values of the payload was:

- for a rail length of 2.4 m, $Q = 60.6$ kN,
- for a rail length of 3 m, $Q = 48.4$ kN.

Based on the calculated permissible load on the rail, taking into account the required safety factor, the following values of the permissible loads from the car were adopted for further calculations:

- for a rail length of 2.4 m, $Q = 60.0$ kN,
- for a rail length of 3 m, $Q = 48.0$ kN.

In order to avoid exceeding the permissible loads of the rail joints, the minimum distances between the cars were determined. The load diagram shown in Figure 6 was adopted for the calculations. The design considered consisted of two rails between three slings. The load Q in this model was considered to be at mid-length between the wheels of a car, for each of the three cars, measured along the rail. The middle car was located exactly at the joint between the rails under consideration. In this model, the distances between the Q are the same and equal to L. The joint (sling) with the highest load was the one between these rails.

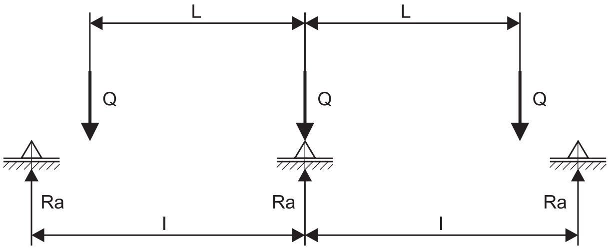

Fig. 6. Diagram showing the load of three cars acting on two adjacent rails

Further calculations were carried out for an assumed constant sling load-bearing capacity of $R_a = R_b = R_c = 100$ kN. The permissible load from the suspension, limited by the load capacity of the slings, as well as the loads coming from the cars determined above $Q = 60$ kN and $Q = 48$ kN were taken into account.

The vertical load-bearing capacity of the rail joint was:

$$3 \cdot Q - 2 \cdot R_a \le R_b \tag{5}$$

where the reaction of R_a:

$$R_a = \frac{Q \cdot L}{l} \tag{6}$$

The general equation is:

$$\frac{3 \cdot Q - R_b}{2} \le \frac{Q \cdot L}{l} \tag{7}$$

After substitution, for rails with maximum length $l = 2.4$ m, the distance L between the cars was:

$$L \ge 0{,}667 \cdot l \tag{8}$$

The above relationship was presented in the form of a graph (Fig. 7). It shows the applicability of the minimum spacing of the cars for the 2.4 m rail with the permissible load for a single car $Q = 60.0$ kN.

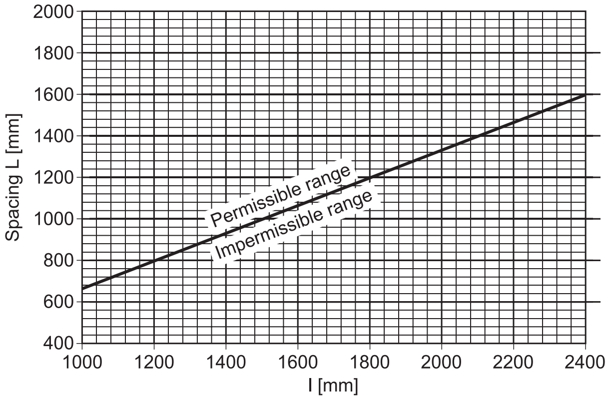

Fig. 7. Graphical representation of an inequality (8) for a 2.5 m rail

After substitution, for rails with maximum length $l = 3.0$ m, the distance L between the cars was:

$$L \geq 0,458 \cdot l \tag{9}$$

The relationship (9) is shown as a graph in Figure 8. It presents the applicability of the minimum car spacing for the 3.0 m rail with the permissible load for a single car $Q = 48.0$ kN.

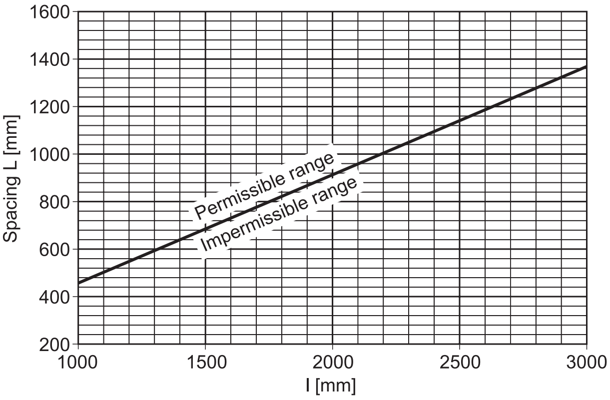

Fig. 8. Graphical representation of an inequality (9) for a 3.0 m rail

4. SUMMARY

The applied design solution increased the permissible load on the rail from 27.5 kN for a rail made of an unreinforced I-beam to 48.0 kN for a rail made of an I-beam reinforced with flat bars. The developed solution has been implemented within the design of the ZMK 160W reinforced railway created at Zakłady Mechaniczno-Kuźnicze "Wostal" Sp. z o.o., which has been approved for use in underground hard coal mines. It is anticipated that rails made using the technology described will also be supplied to new mines currently under construction outside the country.

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