Loading capacity curves for design of I-section runway beams

Vlada Gašić
Assistant Professor
University of Belgrade
Faculty of Mechanical Engineering

Nenad Zrnić
Professor
University of Belgrade
Faculty of Mechanical Engineering

Goran Milojević
Teaching Assistant
University of Belgrade
Faculty of Mechanical Engineering

The capacity curves for specified I-section beams are determined in this work, in order to represent guidance for designers of material handling equipment. Safety requirements for beams are implemented in given algorithm. Specially, the beam model of monorail crane concerns the stress, deflection and lateral buckling proof as main considerations in design of such systems. There are given capacity curves for various I-sections with respect to desired span of runway which enables fast and easy adoption of structural elements. Also, they can be used for capacity estimation of the single girder bridge cranes and other beamlike structures.

Keywords: *beam, I-section, monorail crane, stress, deflection, lateral buckling.*

1. INTRODUCTION

Almost every industrial facility is equipped with monorail crane which is the basic material handling machine. It enables the manipulation of the payload beneath the crane structure. Also, it presents a typical example of runway beam where single hoist/trolley is moving along the structural path, Figure 1.

It is common to use I-section beams for the structure of the monorail cranes or runway beams, which is a family of several tapes of shapes.

Figure 1. Monorail crane

Guides for the design of cranes are defined by national regulative. Regarding bridge cranes and gantry cranes, the European Standard EN 15011:2011 specifies requirements for significant hazards and safety of cranes. There are other indispensable reference documents which are detailed in given standard. However, many requirements are postulated for cranes manufacturers with only few remarks about design process.

The design process of crane structure is related to safety requirements but also there are esthetic criteria and technical parameters of the trolleys with hoists. Nowadays, designers face requests for fast problem solving with adoption of structural elements. Moreover, these decisions have to be accompanied with optimization and rationalization. Thus, it is convenient to have beforehand design guides concerned with safety. Regarding runway beams, the main safety requirements are stress proof, deflection proof and lateral buckling proof. These have to be assured for every case. In addition, one may calculate bottom flange bending of the runway beam, which belong to the second stage of design process [1,2]. Also, it has to be said that design process for material handling systems is accompanied with FEM [3].

This paper gives some practical aspects for the designers of monorail crane structures. It deals with recommendations for initial stage of design process of I-section runway beam for determination of proper beam according to wanted capacity and span, with respect to safety.

Figure 2. Underhang crane with runway

Correspondence to: Vlada Gašić, assistant professor
Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade 35, Serbia
E-mail: vgasic@mas.bg.ac.rs

Generally, these capacity curves can be useful for runway beams for cranes and single girder bridge cranes. However, it has to be pointed here that there are loadings in horizontal direction for general case of runway beam due to inertial/dynamic effects [4]. The common experience with cranes confirms that these influences have smaller effects on structure than weights, but this can't be taken as a rule.

2. STRUCTURAL GUIDES FOR RUNWAY BEAMS

The main parameters of monorail crane are mass of the hoist payload m_H and span l. It is assumed that mass of the hoist is much less then payload. In almost all the cases the I-section beam are used for the structure of monorail crane. Especially, the designer may have choice between the IPN beam (S shape) and HEA beam (H shape), figure 3, where the notation in parenthesis are given to match with engineering practice in America/Canada.

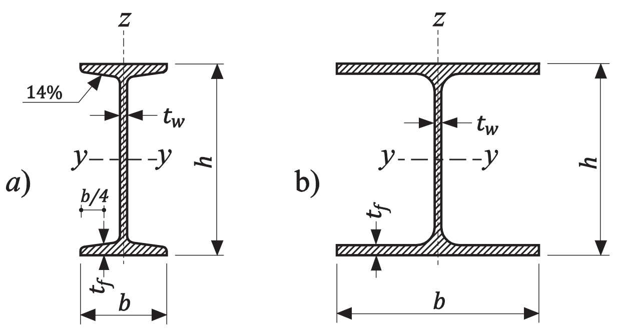

Figure 3. a) IPN beam, b) HEA beam

It is suggested that before the final design, a design criteria document should be prepared by the designer of the structure for approval by the supplier of the steel. Later on, final design of crane has to be done. As a minimum, this document should define the codes and standards, the materials of constructions, the expected life of the structure, crane service classification, loads and load combinations and a record of the design and constructions measures selected.

3. ALGORITHM POSTULATION

The algorithm in this section, with resulting capacity curves as title problem of the work, includes only main safety requirement for the runway beam: stress, deflection and lateral buckling. There are given only few remarks because this class of problem belongs to basics of steel structures.

3.1. Stress proof

Stress check is the first safety requirement for the structure of the runway beam.

The loads acting on the structure are in the category of regular load, i.e. loads that occur frequently under normal operation: hoisting and gravity effects acting on the mass of the crane and inertial and gravity effects acting vertically on the hoist load. It is known that static model of the simple beam considers middle section for calculation of the internal loads. Thus, bending moment due to action of the hoist load can be presented as:

$$M_{\mathrm{yH}} = \frac{1}{4}(m_{\mathrm{H}} g)\ l\ \phi_2 \qquad (1)$$

where g is acceleration due to gravity and ϕ_2 is the factor due to dynamic effects.

The bending moment due to the beam selfweight can be calculated as

$$M_{\mathrm{yq}} = \frac{1}{8} q\ l^2 \phi_1 \qquad (2)$$

where q is beam self-weight per unit length, and $\phi_1 = 1{,}1$ is the factor due to effect of vibration excitation. These factors in (1, 2) are given by Standard EN 13001-2. However, only ϕ_2 is to be determined with respect to stiffness classes and hoist drive classes. This factor is not included in given algorithm because is dependent of many parameters which are important for detailed design report. For initial design purpose, neglecting this influence one may find only slight mistake which can't be of influence for the design chart as a scope of this work.

The stress limitation is taken to be

$$\sigma_{\mathrm{x,Ed}} = \frac{f_{\mathrm{y}}}{\gamma} \qquad (3)$$

where f_{y} is yield strength for adopted material and $\gamma = 1{,}5$ is partial safety factor.

Maximal longitudinal stress in the structure can be calculated as

$$\sigma = \frac{M_{\mathrm{yH}} + M_{\mathrm{yq}}}{W} \qquad (4)$$

where W is section modulus of the beam.

3.2. Deflection proof

Limit deflection is one of the basic structural parameter for crane girder selection. The main recommendations, given in the term of beam span and considering many authors, are limit deflection of l/400, l/500, l/600 for light and medium cranes while limit deflection goes to l/1000 for heavy duty cranes such as mill cranes. Concerned here, the limit deflection is taken to be:

$$\delta_y = \frac{l}{500} \qquad (5)$$

which stands for design purpose of monorail crane.

With runway beam model, with given assumptions in section 3.1, one may find the maximum deflection of the middle section as:

$$\delta = \frac{1}{48} \frac{m_{\mathrm{H}}\ g\ l^3}{E\ I_{\mathrm{y}}} \qquad (6)$$

where E is modulus of elasticity, as material coefficient, and I_y is second moment of inertia about y-y axis.

3.3. Lateral buckling proof

The structural elements made of I-sections are tailored for bending, one may say. Since they belong to the class of thin-walled open sections they have low resistance to torsion. This can produce unwanted side effects on section, especially on upper flange of I-section which is compressed due to loading and have tendency for buckling [5, 6].

The critical case is given in the terms of the limit stresses due to St Venant torsion and warping torsion.

Also, there are correction factors due to the load cases and supports [7]. The final expression gives the limit stress due to lateral buckling as

$$\sigma_D = \alpha_p \ \chi_D \ f_y \le f_y \tag{7}$$

where factors α_p, χ_D are determined for the case of simple beam with I-section loaded on bottom flange.

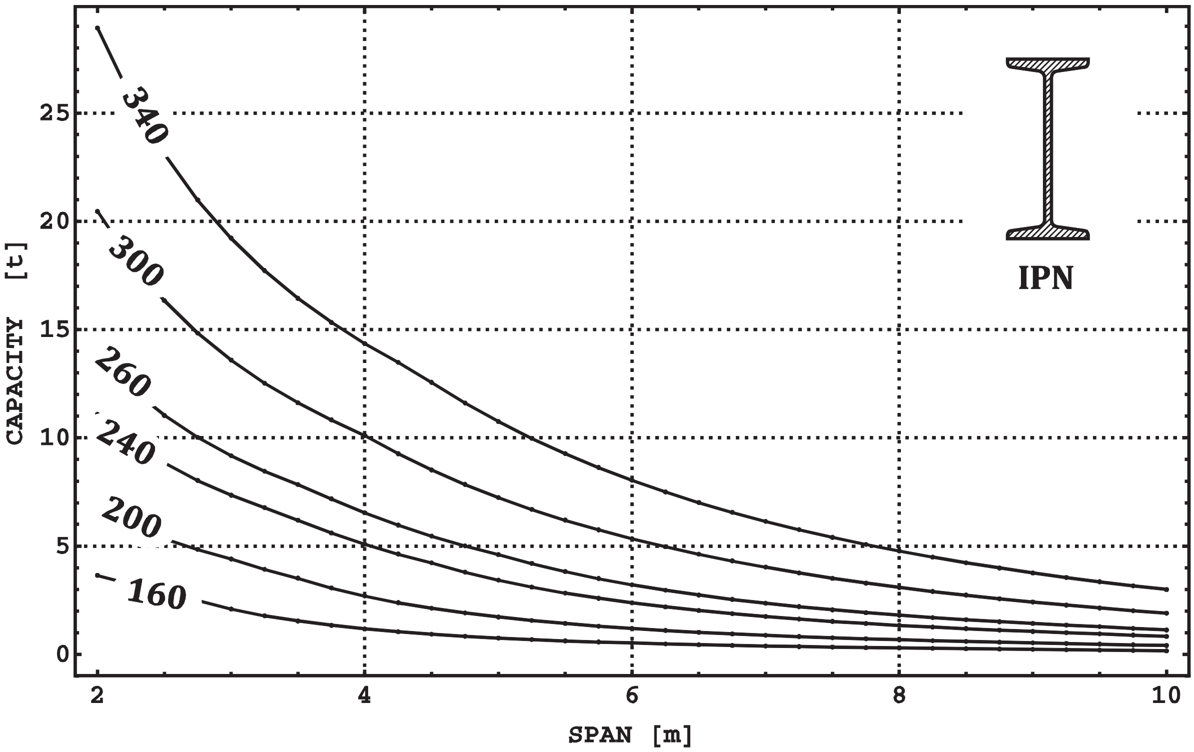

Figure 4. Diagram of capacity curves for IPN beams

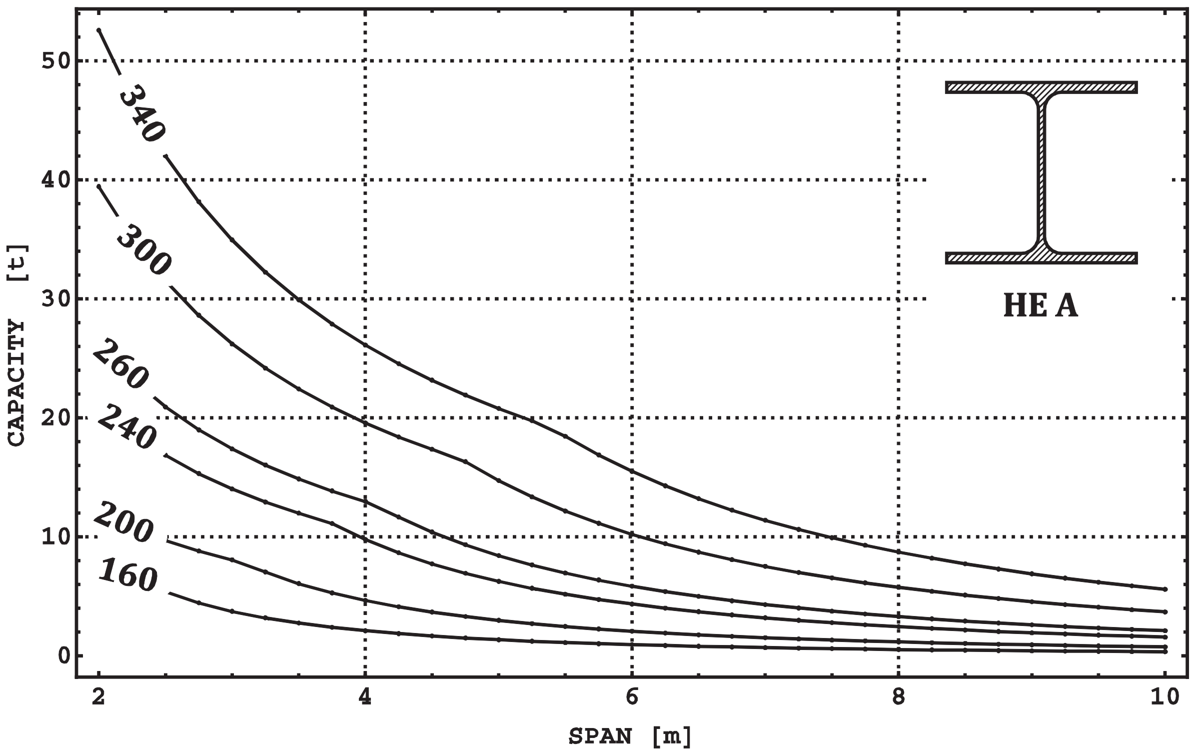

Figure 5. Diagram of capacity curves for HEA beams

Design guides for lateral buckling of the beams, in this paper, are given according to experience of usage of national standard JUS U.E7.101/1996.

The maximum longitudinal stresses are gained by notes given in section 3.1, with (4).

4. RESULTS

Finally, with presuming the critical state occurs when values (4,6,4) reach limitation values (3,5,7), respectively, one may found capacity-maximal allowed mass of the payload for each condition and chose minimum as design parameter.

The algorithm in chapter 3 is used for obtaining the capacity guidance for chosen IPN and HEA beams with the diagrams shown at figures 4 and 5, respectively. The sizes of the beams are 160, 200, 240, 260, 300, and 340. The span of the beam is given in range of 2 m to 10 m, which is generally situation in practice.

Results are given for material S235 according to EN 10025-2. For other materials one may take only estimation of the capacity in ratio of yield stresses of that material and one given here.

5. CONCLUSION

The diagrams on figures 4 and 5 are given as design guidance for beams of IPN and HEA shapes. The capacity, due to the span, is determined according to the proof of stress, deflection and lateral buckling.

Thus, it is given possibility in design process of the monorail crane/runway beam to:

- find appropriate structural beam
- perform fast check of built up runway beam
- compare the IPN and HEA sections for the case of montage of trolley with hoist.

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NOMENCLATURE

l	span of the runway
m_H	mass of the payload
M_{yH}	bending moment due to payload
M_{yq}	bending moment due to self-weight
ϕ_1, ϕ_2	inertial factors
f_y	yield stress
γ	partial safety factor
$\sigma, \sigma_{x,Ed}$	longitudinal (bending) stresses
W	section modulus
δ_y	limit deflection
δ	middle beam deflection
E	modulus of elasticity
g	gravity acceleration
I_y	second moment of inertia
σ_D	limit stress due to lateral buckling
α_p, χ_D	lateral buckling factors