FEA Aspects of the Local Bending stresses at the HEA-section Runway Beams

Vlada Gašić
Associate Professor
University of Belgrade
Faculty of Mechanical Engineering

Nikola Košanin
MSc Engineer
Novelic d.o.o. Belgrade

Grzegorz Olszyna
PhD Engineer
AGH University of Science and Technology
Faculty of Mechanical Engineering and Robotics

Aleksandra Arsić
PhD Student
University of Belgrade
Faculty of Mechanical Engineering

This paper deals with the local bending stresses at the steel runway beams made of HEA sections. Some aspects of this structural problem are considered here, with usage of finite element analysis (FEA). There are presented three different models and several load cases to obtain the values of local bending stresses which enable the comparison with the results from adopted EN regulative. Specially, it is considered the possible superposition of stresses for adjacent wheel loads. This is done due to restriction in regulative which deals with the geometry of trolley vs. beam width. It is confirmed some inconsistencies in current regulative, along with the occurrence of affected zone in section with possible higher values of stresses near the web. Without consideration of volume, it is noted that distance of adjacent wheels has influence on the level of local stresses.

Keywords : *I-section, runway beam, stress, local bending*

1. INTRODUCTION

Runway beams are vital parts of every industrial facility. It enables the transport of various payloads throughout the hoist with trolley or underhanging crane (fig. 1). Generally, structure of runway is made of I-section beams because they are very appropriate for bending over section major axis. Steel production process has given several types of shapes, eg. HEA, HEB, IPN, IPE, where every type has its own characteristics for usage which are related to design parameters [1].

Figure 1. Runway beam for hoist with trolley

The subject of this paper is runway beam with HEA section. This type of I-section belongs to the class of parallel, wide flange beams and stands for "strong" beam and is used for the case of heavier payloads over "longer" spans. Even considered as simple structural elements, safety requirements for the runway have to be accomplished and calculated in detail. Primarily, this implies the design check of stresses, deflection and lateral buckling [**2**]. On secondary level, it is advised to check the local bending stresses in the bottom flange due to wheel loads. It is highly recommended for beams with HEA section which are more subjected to this phenomenon due to its wider flanges, when compared with other I-sections.

The method of calculation of local bending stresses is given in EC3-6-Crane supporting structures [3]. Along with other requisitions, it is given geometric restriction that distance along the runway beam between adjacent wheels is not less than 1.5*b* where *b* is the flange width. However, it is not explained the situation when this is not the case and there is only recommendation to adopt conservative approach by superposing the stresses calculated for each wheel load acting separately.

Nowadays, finite element analysis is standard engineering guide where is a lack of experimental results, when is needed understanding of local structural effects or to generate extensive parametric studies [4]. Therefore, the aim of this work is to perform the FEA of the local bending stresses at several cases of the runway beams which consider adjacent wheels distance and their influence on the stresses in the bottom flange.

2. THEORETICAL POSTULATION

The problem of local bending of the I-section beams was noticed since the beginning of the industrial usage of runway beams. There are several approaches for calculation of these stresses, which authors will not emphasize here because of the fact that overview is given in literature [5]. Former engineering practice in this field, on national level, was based on calculation method given by Mendel [6]. Currently, it is common to use approach given in EC3-6 for crane supporting structure or EN 15011 for cranes.

Particularly, the EC3-6 represent the phenomenon of local bending with additional stresses in two directions, σ_{ox}, σ_{oy}, fig. 2.

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

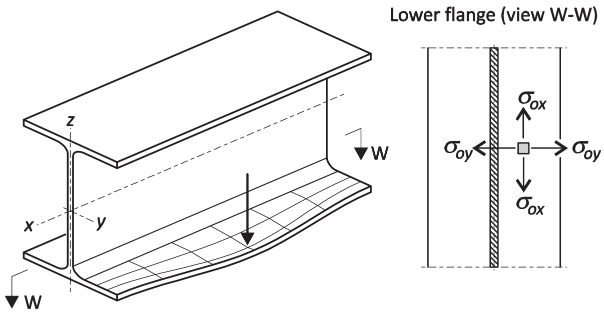


Figure 2. Local bending in the bottom flange

The wheel loads, with intensity noted as $F_{z,Ed}$, produce theses stresses which are considered at three locations: 0 (the web-to-flange transition), 1 (centerline of the wheel load) and 2 (outside edge of the flange). The following picture gives general notation of the studied case, with basic parameters of the HEA section such as web thicknes (t_w), flange thickness (t_f), flange width (b) and load position with the distance from the edge (n).

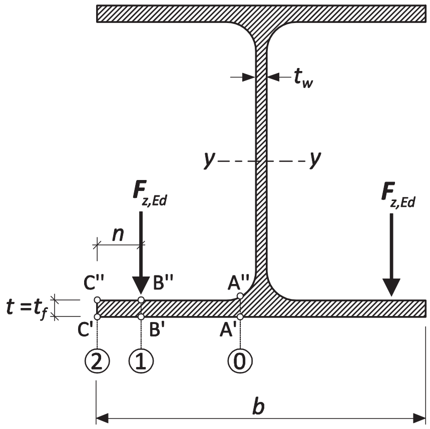


Figure 3. Geometrical postulation

The local longitudinal and transverse bending stresses should be obtained from:

$$\sigma_{ox} = c_x \cdot \frac{F_{z,Ed}}{t^2}, \tag{1}$$

$$\sigma_{oy} = c_y \cdot \frac{F_{z,Ed}}{t^2}, \tag{2}$$

where t is characteristic thickness of the bottom flange, while coefficients c_x, c_y are dependent of the ratio:

$$\mu = \frac{2 \cdot n}{b - t_w}, \tag{3}$$

and calculated for all the three locations, as follows:

$$c_{x0} = 0.050 - 0.580\mu + 0.148e^{3.015\mu}, \tag{4}$$

$$c_{x1} = 2.230 - 1.490\mu + 1.390e^{-18.33\mu}, \tag{5}$$

$$c_{x2} = 0.730 - 1.580\mu + 2.910e^{-6.000\mu}, \tag{6}$$

$$c_{y0} = -2.110 + 1.977\mu + 0.0076e^{6.530\mu}, \tag{7}$$

$$c_{y1} = 10.108 - 7.408\mu + 10.108e^{-1.364\mu}, \tag{8}$$

$$c_{y2} = 0. \tag{9}$$

The above given expressions are used in this form for bottom face of the flange and for upper face it should be used with opposite sign. For clarity purpose, it is given here notation of characteristic points of the three locations with A', B', C' for bottom face and A'', B'', C'' for upper face, fig. 3. From engineering practice, it is familiar to calculate the local stress values for bottom face of the flange due to bigger values of global bending since they are considered together in stress check.

3. FEA MODELS

The physical model is rather simple, as depicted on figure 4, where segment of the runway beam has span L. The payload is located round the mid-section as most critical case for calculation of bending for simple beams. It is assumed that capacity of payload is transmitted on the structure with 4 equal forces, considering that trolleys almost always have 4 wheels. Per each side, the adjacent forces are located with the distance of x_w.

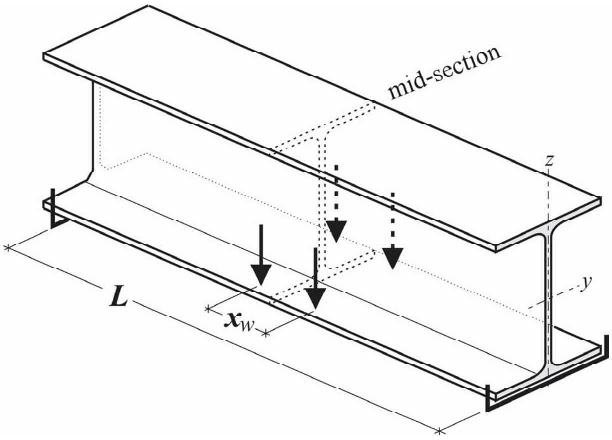


Figure 4. Physical model of the beam segment

There are considered three different models of the beam, HEA 160 (Model 1), HEA 200 (Model 2) and HEA 240 (Model 3), as runway beams are generally made of "small" I-sections. Respectively to chosen beams, the payload of 1 t, 2 t and 3 t are adopted, along with spans of 3 m, 4 m and 6 m. The payload produces forces $F_{z,Ed}$, while span has only physical characters because the intention here is to exclude the global bending. This is done in models with implementation of intermediate supports on the centroid line of the beam.

The main parameters are given in following table, where analysis cases (1 to 6) correspond to variation of the distance of adjacent wheels - x_w. The limit distance is adopted as 1.5 b, as given in standard EC3-6, while minimal distance is adopted according to adjacent wheels geometry for common types of trolleys.

Table 1. Analysis cases

Case	HEA b [mm]	$F_{z,Ed}$ [kN]	L [m]	n [mm]	x_w [mm]
1	160	2.5	3	10	240
2					100
3	200	5	4	12.5	300
4					120
5	240	7.5	6	15	360
6					150

Here, FEA is performed for the insight of the local stress state in bottom flange. All the steel members (S235) are modeled with shell (mostly quadrilateral) elements assuming ideal elastic material. The meshing is done to comply with real geometric parameters and with guidelines for aspect ratio in shell elements usage [7]. This postulation shouldn't exclude other finite elements in further modeling.

4. NUMERICAL RESULTS AND DISCUSSION

The deformation round the middle of the span, due to the title problem, is given at following figure and only has descriptive character.

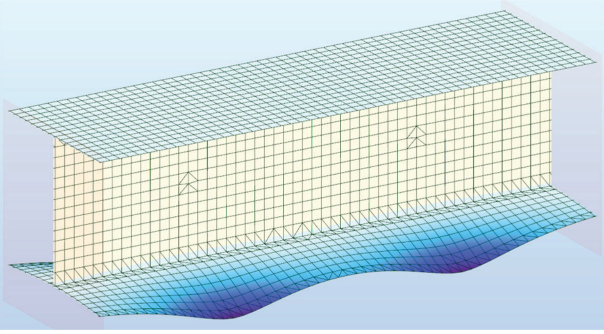


Figure 5. Deformed shape of bottom flange

The stress values are obtained for all the cases. Due to fine mesh the stress values can't be easily visible. Thus, the values are obtained in tabular form for characteristic sections (fig. 6) and corresponding points on the bottom face of flange (i.e. A', B', C'). Moreover, due to symmetry of loads the values are given only for section I and mid-section (the difference of values for section I and II are negligible). The results for Models 1,2,3 are given in following tables.

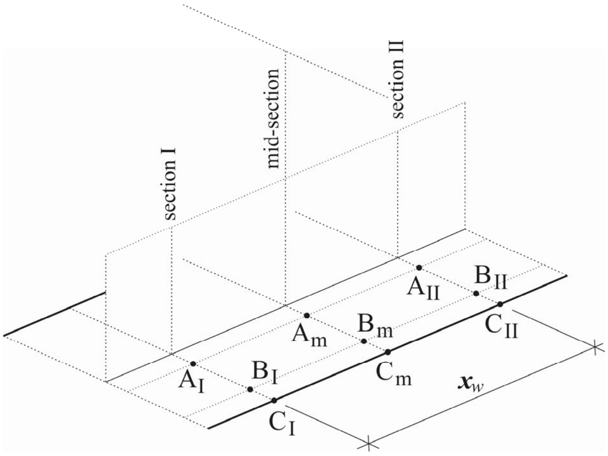


Figure 6. Characteristic points for stress values

Table 2. Model no. 1 – HEA 160

[kN/cm²]	Case 1 – 240 [mm]		Case 2 - 100 [mm]	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	-1.47	-6.65	-2.24	-7.37
A_m	-1.09	-3.31	-2.51	-7.80
B_I	9.14	4.58	8.18	4.28
B_m	-1.77	-0.49	-0.95	-0.77
C_I	7.20	0.97	6.29	0.99
C_m	-1.89	-0.02	-0.91	-0.09

Table 3. Model no. 2 – HEA 200

[kN/cm²]	Case 3 - 300 [mm]		Case 4 - 120 [mm]	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	-2.83	-10.92	-3.75	-12.00
A_m	-1.60	-5.28	-3.96	-13.02
B_I	14.78	7.43	13.25	7.02
B_m	-2.84	-0.90	-1.22	-1.04
C_I	11.68	1.29	9.66	1.64
C_m	-3.08	-0.01	-1.16	-0.02

Table 4. Model no. 3 – HEA 240

[kN/cm²]	Case 5 - 360 [mm]		Case 6 - 150 [mm]	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	-2.28	-9.46	-3.28	-12.42
A_m	-1.85	-5.26	-4.02	-12.82
B_I	14.70	6.97	13.29	6.81
B_m	-2.94	-1.31	-1.64	-1.56
C_I	12.76	0.94	9.47	1.88
C_m	-3.30	0.07	-1.60	0.05

First, it is done tabular comparison of obtained FEA results with the results for local stresses calculated with EC3-6, (1) - (9). This is done for all the three basic models and given in tables 5, 6 and 7.

Table 5. Model no. 1 – HEA 160

[kN/cm²]	EC3-6		Case 1	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	0.6	-5.7	-1.47	-6.65
B_I	6.7	2.1	9.14	4.58
C_I	5.7	0	7.20	0.97

Table 6. Model no. 2 – HEA 200

[kN/cm²]	EC3-6		Case 3	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	1	-9.2	-2.83	-10.92
B_I	10.8	3.4	14.78	7.43
C_I	9.3	0	11.68	1.29

Table 7. Model no. 3 – HEA 240

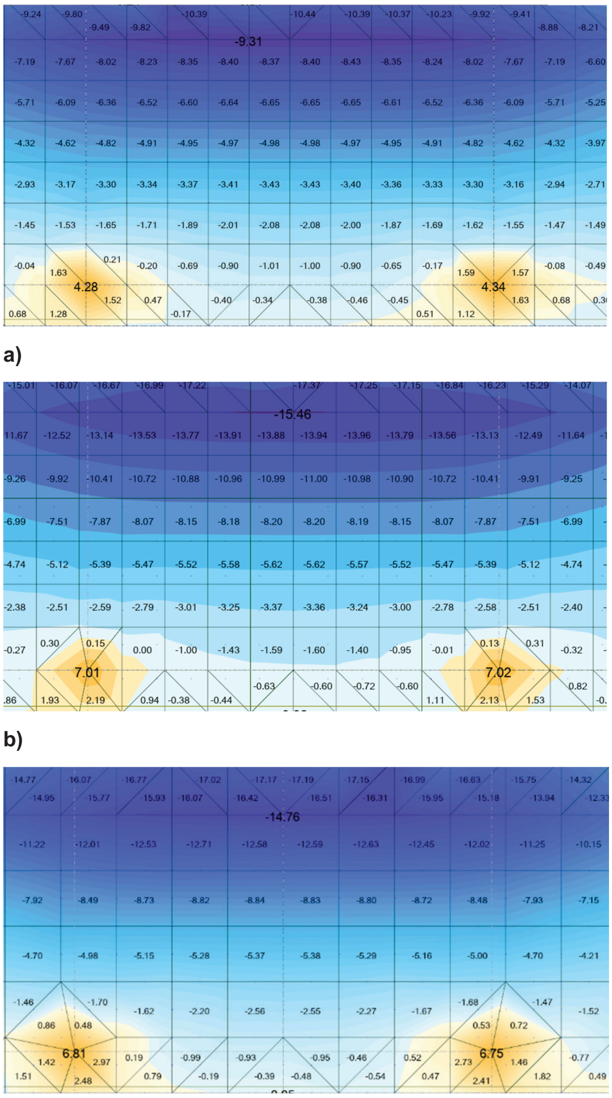
[kN/cm²]	EC3-6		Case 5	
	σ_{ox}	σ_{oy}	σ_{ox}	σ_{oy}
A_I	1	-9.6	-2.28	-9.46
B_I	11.3	3.5	14.70	6.97
C_I	9.8	0	12.76	0.94

One may see that values obtained with two different methods are in the same range of numbers which stands for basic verification. The results from FEA have generally higher values for all the models and can be considered as the worst case of the title problem due to following: (1) - the section structural plates are modeled as plane shells which elongates the "cantilever" effects for y-direction, and the "free" zone for x-direction (2) - the intermediate supports are located in the planes of load action which disable "distribution" of the strain for x-direction.

However, for all the models, there is clear difference of signs for σ_{ox} stresses at point A, when EC3-6 results is compared with values obtained with FEA. Thus, these values can't be validated which corresponds with the conclusion in [8].

With previous restrictions, the intention here is to give overview of the possible superposition of the stresses near the mid-section (tables 2 - 4). Cases 1, 3 and

5 show that corresponding points of mid-section has lower values of stresses than for section I where load is applied. Since those cases deal with the distance of x_w=1.5 b, the results are preserved to comply with EC3-6. Cases 2, 4 and 6, on the other hand, show clear difference. Mainly, the stresses for points B and C has similar values (mostly lower) for both the distances. This can't be validated due to expected level of mistakes with usage of FEA. However, the difference is bigger for point A where one may find increase of stresses for lower distance of adjacent loads. The corresponding point A_m has also higher values of stresses which show that there is affected zone between the wheels, near the web of section. For example, it is illustrated on following picture for relevant cases with lower distance of adjucent wheels.


a)

b)

c)

Figure 7. Half-flange stresses σ_{oy}, : a) Case 2, b) Case 4, c) Case 6

5. CONCLUSION

FEA is performed here for calculation of local bending stresses of HEA section runway beams. With six cases included, the results are compared for two characteristic distances of adjacent wheels. Values for σ_{ox} for point near the web confirm aspect of inconsistence in EC3-6. Thus, it is advised to check results with previous method, such as given in [9]. Additional validation of this issue has to be done, preferably with theoretical background or with extensive experimental testing on several types of section.

The numerical study in this paper shows possible superposition of adjacent loads. In certain case this corresponds to restriction in EC3-6, because of the affected zone between the wheels, near the web. The authors consider this study as the first step in observing this phenomenon. The general conclusions and large numbers of given values stand for further investigation of local effects of the bottom flange subjected to wheel loads.

ACKNOWLEDGMENT

This work is a contribution to the Ministry of Education, Science and Technological Development of Republic of Serbia founded project TR 35006.

REFERENCES

[1] Seesselberg, C.: *Kranbahnen-Bemessung und konstruktive Gestaltung nach Eurocode*, Beuth Verlag GmbH, Berlin, 2014.

[2] Gašić, V., Zrnić, N., Milojević, G.: Loading capacity curves for design of I-section runway beams, XXI International Conference MHCL 15, Vienna, 2015.

[3] EN 1993-6: Design of steel structures – Part 6: Crane supporting structures, European Committee for Standardization, 2007.

[4] Kindmann, R., Kraus, M.: *Steel Structures-Design using FEM*, Wilhelm Ernst&Sohn, Berlin, 2011.

[5] Petersen, C.: *Stahlbau*, Vieweng Verlag, 3. Auflage, Wiesbaden, 1994.

[6] Mendel, G.: *Berechnung der Tragerflansch-beansprung mit Hilfe der Plattentheorie*, Fordern und Heben, 14/1972.

[7] Spyrakos, C., Raftoyiannis, J.: *Finite Element Analysis in Engineering Practice*, Algor, Pittsburgh, 1997.

[8] Cvijović, A., Bošnjak, S.: The impact of the transition radius lower flange-web on local stress of monorail crane girder, Trans. FME, Vol. 45, No. 4, pp. 543-547, 2017.

[9] Gašić, V., Zrnić, N.: Comparative overview of stress field of HEA section runway beams according to bottom flange bending, IX International Conference DEMI, Banja Luka, 2009.