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# NUMERICAL STUDY OF UNIVERSAL BEAM (I SECTION) UNDER BENDING LOAD WITH CRACK

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**Abstract:** *The structural components often contain cracks as a results of applied load. Therefore, these cracks must be studied how they affect the structural behavior and the total service life-time of the component. Bearing beams of the bridges have usually cross-section in the shape of an I-profile. In this contribution, a numerical parametric model was made in order to study the influence of the crack length, Poisson's ratio and web thickness on the stress distribution in the structural element, for which a three-point bending specimen was applied. The model is based on the linear elastic fracture mechanics (LEFM), with focus set on the determination of the stress intensity factor, as it is one of the main parameters used in the description of the stress fields in vicinity of the crack tip.*

**Keywords: Stress Intensity Factor, Linear Elastic Fracture Mechanics, Finite Element Method, I-Profile, Poisson's ratio.**

## 1. Introduction

Structures loaded with cyclic load are built from various structural elements, see e.g. Aisc (2006), Lehner et al. (2019). Particularly, bridge elements have typically I profile used as a cross-section (see, IPE Beams 2009), due to economical aspect as there is less material used around the neutral axis. This is based on the normal stress distribution, while the stresses play minor role ($W << L$), see Fig. 1, where a comparison of the normal stress distribution for the same dimension $W$, force, and material properties, but different cross-sections in a three-point bending (3PB) test is shown.

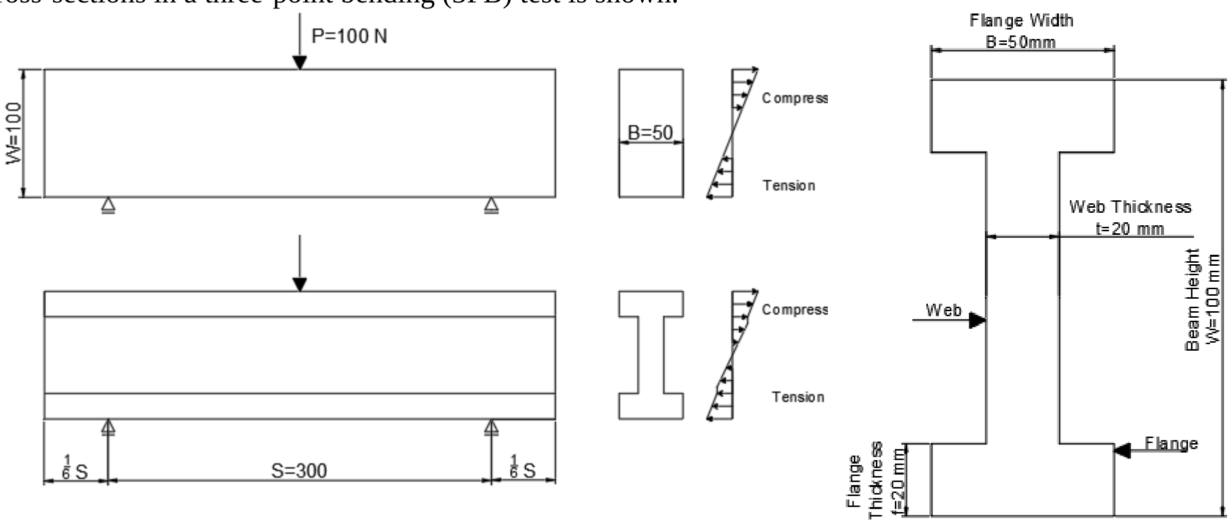


*Fig. 1: Sketch of 3PBT for two different cross sections: rectangular and I-profile for the same width, W and normal stress and typical dimensions of studied I Profile.*

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During the service life of structure, the cracks usually occur due to material inhomogeneity, scratch, imperfections etc. Thus these cracks can start to propagate from the maximal stress, which is produced by cyclic load. Detection of fatigue cracks/notches depends on the used equipment, but usually the detectable crack length is from 1 up to 5 mm. Therefore, during the service life it is very important to have knowledge about the fatigue crack propagation (Klesnil and Lukáš, 1992), (Schijve, 2009). In this sense the linear elastic fracture mechanics (LEFM) is used by application knowledge about the values of the stress intensity factor (SIF), see e.g. (Tada et al., 2000), (Seitl et al., 2017), (Seitl et al., 2018).

The aim of this article is to compare stress field description by SIF for short edge crack of a rectangular cross-section profile with a selected I profile. This was done for various crack lengths, different material properties and web thickness with a constant flange width and thickness, see Fig. 2. Originally, the calibration curves are used for evaluation of experimental data in the form of dimensionless relative crack length *a/W* from 0.2 to 0.8. In this parametric study, numerical solution for relatively short cracks (*a/W* from 0.05 to 0.2) due to limit of the flange thickness, is presented under 3PB load.

## 2. Theoretical Background

In this study the theory of LEFM is used to describe the crack propagation see e.g. (Klesnil and Lukáš, 1992), (Schijve, 2009), (Zerbst et al., 2016). This method uses the Paris-Erdogan's law (Paris and Erdogan, 1963) and defines relation between propagation rate of the crack size $a$, and the range of stress intensity factor $\Delta K$, in front of the crack. The following equation is fulfilled for $\theta = 0$ °, see Tada et al. (2000)

$$K_{\mathrm{I}} = \sigma_{yy} \sqrt{2\pi r}, \tag{1}$$

where $K_{\mathrm{I}}$ is the stress intensity factor for mode I (MPa m$^{1/2}$), where $\sigma_{yy}$ is the applied stress (MPa) and $r$ is the distance from the crack tip [m].

## 3. Numerical Modeling

The profile with an I-shape was modeled as a 3D using the finite element method (FEM) based software ANSYS. The material properties of steel used as inputs for the FEM analysis were following Young's modulus $E$ = 20, 210, 74 and 1 GPa and Poisson's ratio of concrete ($\nu$ = 0.2), steel ($\nu$ = 0.3), aluminum ($\nu$ = 0.34) and clay ($\nu$ = 0.4), respectively. Symmetry conditions were applied to reduce the total number of nodes thus, only half of the beam was model. The boundary and symmetry conditions are shown in Fig. 2. The numerical models were meshed using a tetrahedron elements with a basic size of 5 mm with refinements around the crack tip of 0.1 mm.

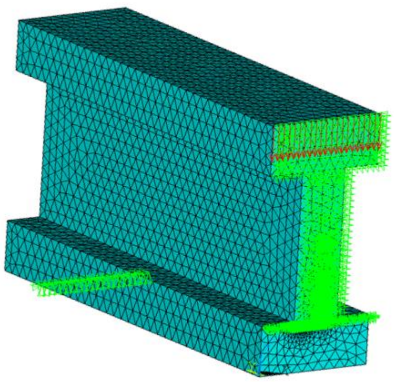

*Fig. 2: Example of mesh with applied boundary conditions prepared in ANSYS.*

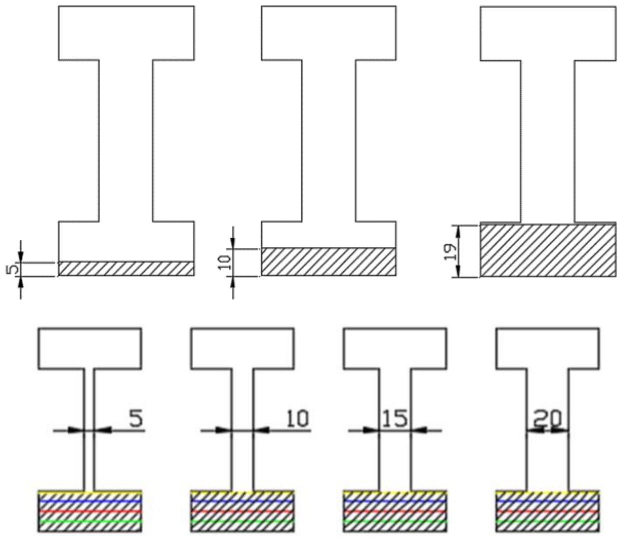


*Fig. 3: Variation of the crack length and thickness of web.*

The relationship between the stress intensity factor and the distance to the crack tip can be approximated by a linear regression Irwin (1957).

## 4. Numerical Results

The aim of this parametric study is to calculate the SIF in the center of the cross section. The variation of the SIF is studied for different geometries of the I profile i.e. by varying the ratio between thickens of the web (*t*) and the flange width (*B*) (please note the other ratio *t*/*B* and *S* = 300 mm, *W* = 100 mm, *P* = 100 N). Firstly, a study has been developed for rectangular profile *t*/*B* = 1, compared with analytical results from handbook Tada et al. (2000). Then width of the web has varied, going to a very thin web, see the results in Fig. 4, where SIF versus relative crack length of the various web thickness is compared. It could be noticed that curves for very short cracks are very close to rectangular profile, but for the longer cracks value of SIF increases rapidly.

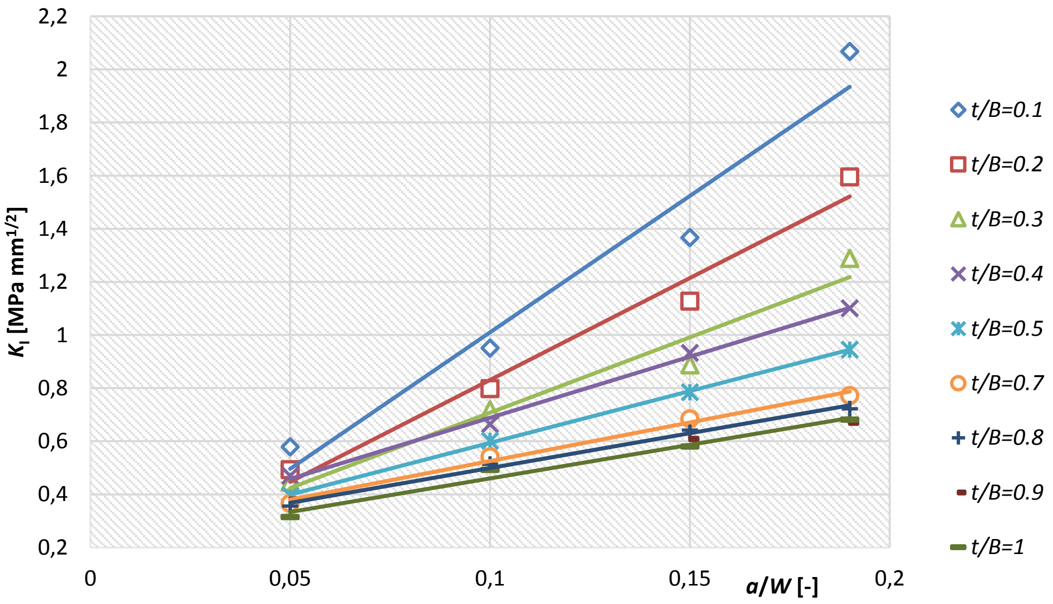


*Fig. 4: Stress intensity factor versus relative crack length of the various web thickness.*

Moreover, a study has been developed for the I profile with a web *t* = 20 mm in which the only variables where materials properties. The Young's modulus does not influence the value of SIF, but the value of Poisson's ratio influence on the SIF can be observed. The materials with a lower Poisson's ratio have lower values of SIF than the ones with higher ratio. However, this difference is relatively small.

*Tab. 1: Quantification of SIF increase due to change of web thickness.*

| *t/B* | *0.1* | *0.2* | *0.3* | *0.4* | *0.5* | *0.7* | *0.8* | *0.9* | *1* |
|---|---|---|---|---|---|---|---|---|---|
| **Increase of SIF** | 184 % | 157 % | 149 % | 142 % | 126 % | 116 % | 113 % | 111 % | 100 % |
| | 193 % | 162 % | 148 % | 135 % | 122 % | 110 % | 104 % | 100 % | 100 % |
| | 236 % | 194 % | 153 % | 161 % | 135 % | 118 % | 111 % | 105 % | 100 % |
| | 304 % | 234 % | 189 % | 162 % | 139 % | 113 % | 106 % | 103 % | 100 % |

These dependences can be important for sensitivity analysis of civil engineering steel structures with I profile under the cyclic load, when the calibration curves are utilized as input parameters, see Kala (2019a), Kala (2019b).

## 5. Conclusions

In the present study the numerical parametric analysis was performed to study the influence of various geometries of the edge crack in a beam (I Section) under the bending load. From the obtained results, the following conclusions can be drawn:

- The stress distribution in cross section is influenced by existing edge crack.

- According to our expectation, the wider the web the lower values of the SIF for every relative crack length.
- The difference gets smaller when the crack is smaller up to 85 % and for longer crack from up to 200 %, see Tab. 1.
- The influence of the Poisson's ratio shows that for materials such as concrete with *v* = 0.2 the stress intensity factor is smaller than for materials such as aluminum with *v* = 0.34 for the same crack length. However, this difference is quite slight.

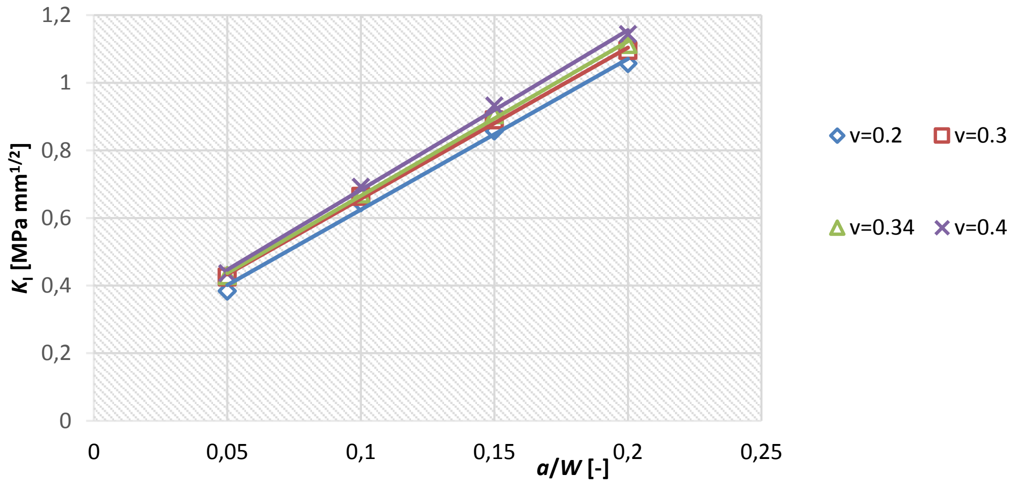


*Fig. 5: Stress intensity factor versus relative crack length for different material properties.*


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