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LONGITUDINALLY UNSTIFFENED PLATE GIRDER WEBS SUBJECTED TO PATCH LOADING

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Summary: *This paper describes the behaviour of the longitudinally unstiffened web plate due to patch loading. The basis of the study are possibilities for numerical modelling of girder and comparison with experimental tests. Patch loading resistance is determined by nonlinear analysis using geometrical and material nonlinear analysis. Numerical model is created using finite element package. Based on the experimental tests the real initial geometric imperfections are taken into account and implemented in numerical model and compared with other shapes of the initial imperfections. The numerical simulations are compared to results from three experimental tests on welded I-shaped girders.*

Keywords: *patch loading, experimental research, ultimate load, numerical test*

1. INTRODUCTION

The main usage of I-shaped steel plate girders in the civil engineering is at numerous steel and composite bridges. Also, such structures are used for the crane girders and for buildings. Broadly speaking, I-shaped steel girders are assembled with slender plates for the webs. According to this, there are issues concerning the overall and local stability of the webs. Patch loading phenomenon is special load case where a concentrated or locally distributed load, in the plane of a web without a vertical (transverse) stiffener bellow the load, is applied on one flange over a distance called patch load length, Figure 1. Local stability under this load case has to be considered in design procedure.
According to experimental research, the behaviour of the I-shaped girders under the patch load is based on geometric and material parameters. The main parameters that have influence on the behaviour of the I-shaped girders are: thickness of the web t_w, thickness of the flange t_f, distance between vertical (transverse) stiffeners b, yield strength of the web (f_{yw}) and flange (f_{yf}), patch loading length c and initial imperfections. Other parameters like structural imperfections or material imperfections have less influence. The usual way to define the patch loading resistance is experimental research. With these experimental tests it is possible to monitor the behaviour of girders until the ultimate load is reached. Also, these tests can be used to explain behaviour and to

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indicate the main parameters that have influence on behaviour of the girders. Besides this, the patch loading resistance can be determined using programs based on FEA (Finite Elements Analysis). During last years this analysis is very popular and it is based on verification of the experimental model.

This paper presents a comparison between experimental investigation and numerical research. Firstly, the results from numerical tests, which include accuracy and convergence for patch load resistance for different types of finite element and element size, are compared with experimental results. For initial imperfections sinus shape (both in the transverse and the longitudinal direction) with maximum amplitude of 5 mm was considered. Secondly, the results obtained in experimental tests were compared with numerical simulations using optimal mesh and finite element type including real initial imperfections.

2. MECHANICAL MODEL

The experimental research includes three tests using different patch load length, c=0, c=25, c=50 mm. These girders are labelled as A15, A12 and A1 in [1]. The experimental tests are accomplished on girders with web depth h_w=500 mm, length of the web panel b=500 (b/h_w=1.0) and web panel thickness t_w=4 mm. The load was applied at midspan, centrically over the web, on the upper flange. For test set-up see Figure 1. The thickness of flanges was t_f=8 mm and width of flanges was b_f=120 mm. For experimental results and geometrical properties of the girders see Table 1.

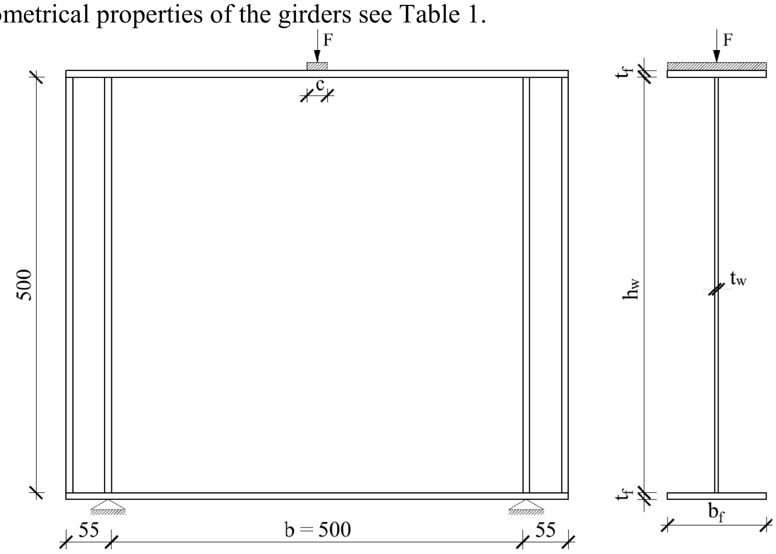
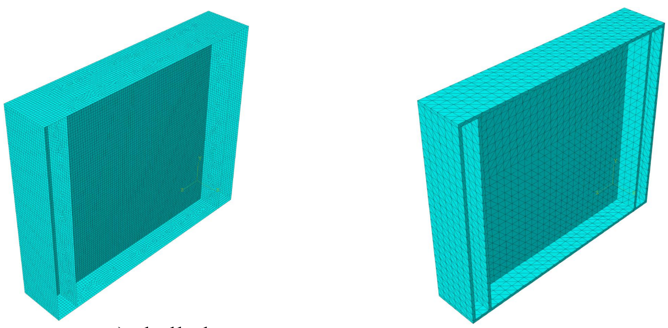


Figure 1. Longitudinally unstiffened girder subjected to patch load

Girder	b_f [mm]	t_f [mm]	t_w [mm]	h_w [mm]	b [mm]	c [mm]	F_{exp} [kN]
A15	120	8	4	500	500	0	143.30
A12	120	8	4	500	500	25	154.60
A1	120	8	4	500	500	50	165.00

3. NUMERICAL MODEL

For simulation of numerical model commercial multi-purpose FE analysis software Abaqus was used. Patch loading resistance of the steel plate girder was performed by incremental nonlinear analysis using geometrical and material nonlinearity. Nonlinear static equilibrium states during the unstable phase of the response can be determined by modified Riks method which has been implemented in Abaqus [2]. This method is incremental-iterative procedure and it is suitable for predicting unstable, geometrically nonlinear collapse of a structure including nonlinear materials and boundary conditions. Also, Riks method is used for cases where the loading is proportional (the loading over the complete structure can be scaled with a single parameter). A load whose magnitude is defined in the Riks step is referred to as a reference load, F_{ref}. The current load magnitude F_{ult} is defined multiplying F_{ref} with load proportionality factor (LPF). For output Abaqus prints out the LPF at each increment of load. For suitable incremental procedure the arc-length approach is chosen. For solving the nonlinear equilibrium equations Abaqus uses the Newton-Raphson method as the iterative procedure. According to all this, the Riks method was chosen for determining patch loading resistance. Girders were modelled in full size using different types of elements and varying element size. Two types of element were used. First, girders were created using four node quadrilateral shell elements with reduced integration S4R. Next, the models were generated with six node triangular shell elements STRI65. Second, the girders were modelled with 3D elements using ten node quadratic tetrahedron C3D10. After that, the girders were meshed with four node linear tetrahedron C3D4, Figure 2. Finite element meshes are developed with different element size, for minimum element size 2 mm is accepted.



a) shell elements b) 3D elements

Figure 2. FE models used in numerical test

The supports were designed as simply supported with symmetrically double-sided rigid transverse stiffeners. To implement the real loading conditions like in laboratory tests the load was applied at midspan on the upper flange. The loaded area has width b_f and length c. These nodes (across flange width) were restrained in the x direction (planes perpendicular to the girder axis) and in the direction of the girder axis. Next, at the upper flange one node at each end were restrained in the x direction. The real stress-strain diagram was implemented in FE model and these results are compared. Material was modelled as an isotropic material with a von Mises yield criteria. Young's modulus and Poisson's ratio were accepted to 205 GPa and 0.30 respectively. The yield stress and hardening characteristics are taken from tensile test of girder A12 with values for f_{yw}=f_{yf}=321 MPa.

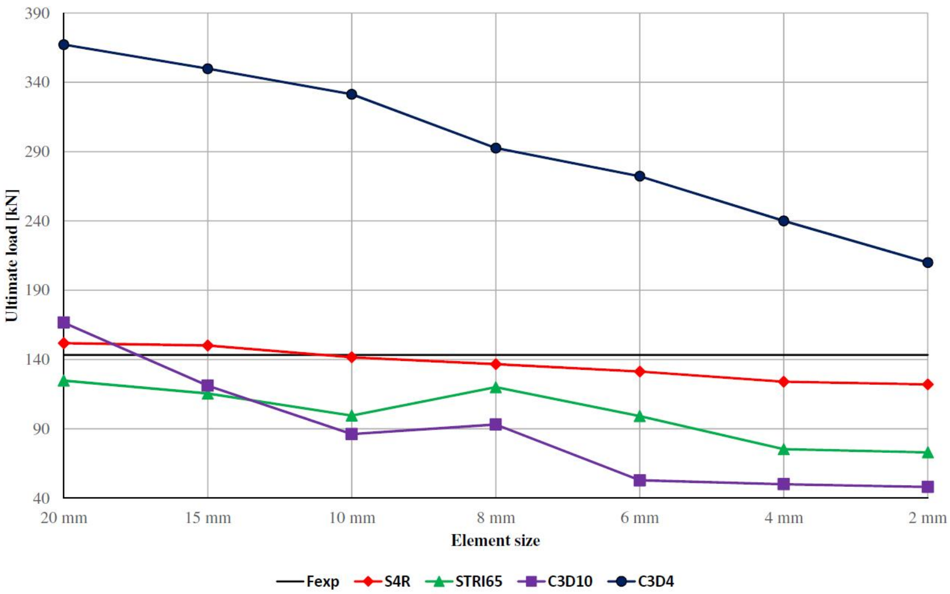


Figure 3. Convergence of ultimate load for girder A15

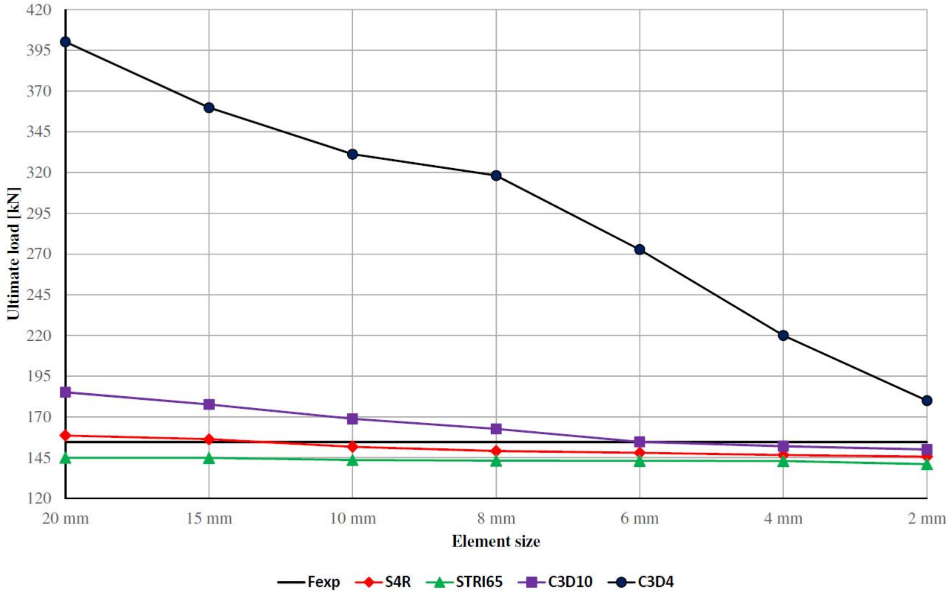


Figure 4. Convergence of ultimate load for girder A12

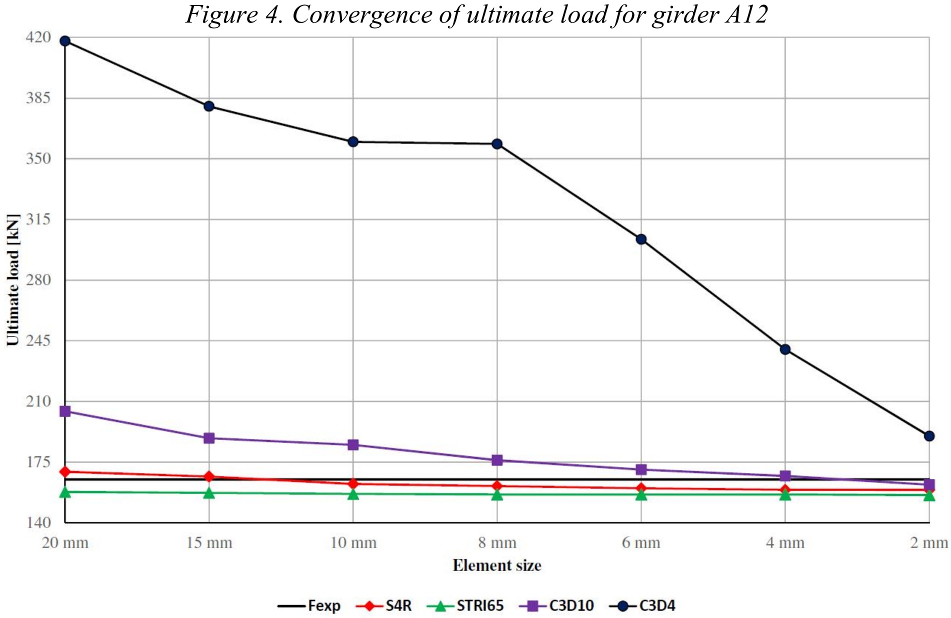


Figure 5. Convergence of ultimate load for girder A1

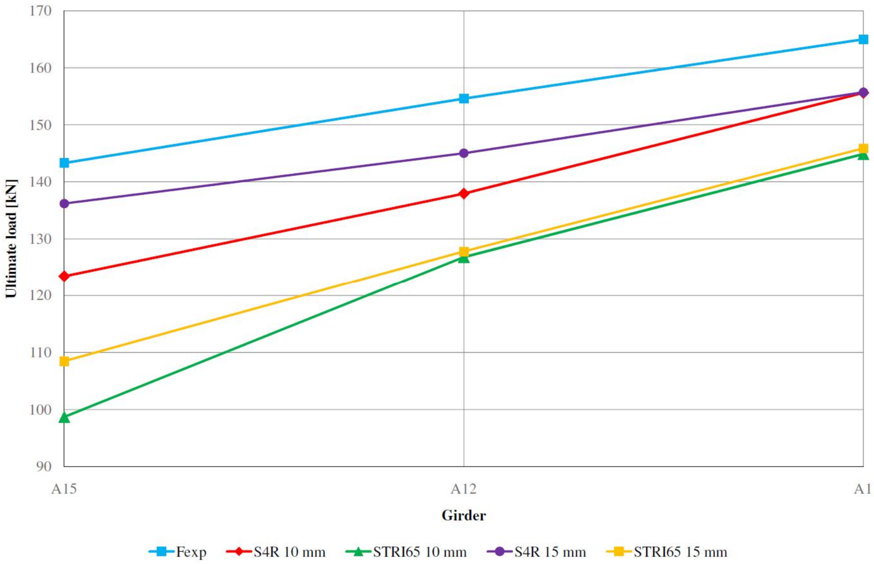


Figure 6. Experimental vs. numerical results for element size of 10 mm and 15 mm

4. CONCLUSIONS

Possibilities for numerical modelling of I-shaped steel girders subjected to patch loading were demonstrated in this work. Patch loading resistance was defined using finite element analysis, which includes two types of finite element (shell and 3D element) and varying element size. Numerical simulations were calibrated with three experimental tests using different patch load length. Convergences for ultimate load for all three girders are displayed. Furthermore, ultimate loads have been compared systematically for experimental and numerical results, which include real initial imperfections, using optimal element type and element size. From presented research several remarks should be pointed out:

- experimentally and numerically obtained ultimate load including real initial imperfections is given on Figure 6. Experimental value of ultimate load is slightly greater than numerical value, maximum/minimum relative error of 13.88/4.97% for S4R and 31.13/11.59% for STRI65,
- real initial imperfections can be taken into account using sinus shape,
- for girders A12 and A1 (c=25 mm and c=50 mm) all presented finite elements can be used in numerical modelling except C3D4. In this case the maximum relative error of 12.12% for C3D10 and minimum relative error of 1.55% for S4R using element size 10 mm or 14.91% and 1.06% for element size 15 mm,
- For girder A15 (c=0 mm) the best suitable element type is shell element S4R with element size of 10 mm, relative error of 1.19%.

Further research for patch loading will be continued.

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ПОДУЖНО НЕУКРУЋЕНА РЕБРА ГРЕДНИХ НОСАЧА ОПТЕРЕЋЕНИХ ЛОКАЛИЗОВАНИМ ОПТЕРЕЋЕЊЕМ

Резиме: *Рад описује понашање подужно неукрућеног ребра гредних (лимених) носача оптерећених локализованим оптерећењем (patch loading). Основа рада представља могућности нумеричког моделирања носача и поређење са експерименталним тестовима. Отпорност на patch loading је одређена нелинеарном анализом укључујући геометријску и материјалну нелинеарност. Нумерички модел је направљен користећи софтверски пакет на бази коначних елемената. На основу експерименталних тестова стварна почетна геометријска имперфекција је узета у обзир и имплементирана у нумерички модел и поређена са другим облицима почетних имперфекција. Нумерички тестови су поређени са два експериментална теста на завареним I носачима.*

Кључне речи: *локализовано оптерећење, експериментално истраживање, критично оптерећење, нумерички тест*