27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#67**, pp. 25–28, doi: 10.21495/51-2-25

THEORETICAL AND EXPERIMENTAL ANALYSIS OF REINFORCED CONCRETE T-BEAM BEFORE STRENGTHENING

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Abstract: *The paper deals with numerical analysis and experiment of shear stress and resistance of reinforced concrete beam with T cross-section. The analysis aims to determine the stress level of critical components of the beam before additional strengthening. The determination of reinforcement utilization, angle of shear crack and its development derived from truss models according to Eurocode 2 with using non-linear numerical analysis and experiment. A three-point test with an asymmetrically placed load is analyzed. The specimen is made of reinforced concrete with a length of 4.2 m with a T shape cross-section height of 0.3 m and width 0.4 m. Four beams were experimentally tested, of which reference one was loaded up to failure to obtain the shear resistance of the basic cross-section. The other 3 specimens were loaded until the shear crack appeared. The cracked beams will be further used for research various methods of strengthening reinforced concrete cross-sections in shear.*

Keywords: Strengthening, T-beam, Experiment, Analysis, Reinforcement.

1. Introduction

Shear resistance of reinforced concrete elements is a more complex physical phenomenon compared to bending or axial cross-sectional resistance. For a concrete cross-section with shear reinforcement, the dominant influence which affects the shear resistance is, in addition to the dimensions of the cross-section, the amount of shear reinforcement. However, other components also contribute to the shear resistance, such as the shear resistance of the compression zone, the interlock of aggregate grains in a shear crack, or the dowel effect of longitudinal reinforcement. However, these effects are not included in the analytical models and their contribution to overall resilience is difficult to assess.

The additional strengthening of RC members makes modeling of analytical models more difficult. The main problem is to properly model interaction between specimens and the additional strengthening. Another problem is assumed correct level of the stresses caused by initial load. The analysis of various shear reinforcement methods has been dealt by P. Harsányi and N. Randl from Austria (Randl et. al., 2019), the Polish scientific team of M. Kaszubska, R. Kotynia and J. A. O. Barroso (Kaszubska et al., 2019) and also, e.g., N. Hemstapat, T. Nakamura, R. Yanagida and J. Niwa of the Japan Institute of Technology (Hemstapat et al., 2019).

Before strengthening reinforced concrete cross-sections is necessary to correctly set the level of cross-sectional stress and particularly stresses of steel reinforcement. Thus, for shear stress, there is a question of the stress in the shear reinforcement in the critical sections near the support. It depends on the inclination of the angle of the inclined compressive struts, which according to Eurocode 2 (EC 2) is considered in the range of 26° to 45°. The recommended value for the design of reinforced concrete beams is between 39° and 42°. The structural engineer chooses this value and thus influences the amount of shear reinforcement

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that will pass through the theoretical shear crack. The paper aims to analytically verify these values using nonlinear analysis and compare them with the experiment.

2. Description of specimens

The experiment and FEM analysis were developed for a T-beam. The upper flange of the T-section will allow the anchoring of additional new stirrups, as is common in practice for strengthening. The length of the beam is 4.2 m. The geometry of the beam is shown in *Fig.1*. A three-point test was performed on the proposed beam with an asymmetrically placed loading between the supports. The theoretical length between supports during the test is 2.9 m. The position of the supports and the applied force is shown in *Fig.2*. The arrangement of supports and force allow testing one beam two times. The stages of testing are shown in *Fig.2*. Beam reinforcement consists of shear and longitudinal reinforcement. Shear reinforcement is formed by stirrups with a diameter of 6 mm in the web of the T-section. In the transverse direction, the flange is reinforced with a 6 mm diameter stirrup, which does not affect the shear resistance. The distance of the stirrups in a longitudinal direction is 150 mm. The bending reinforcement consists of three longitudinal reinforcements with a diameter of 20 mm at the lower surface of the web and six longitudinal reinforcements with a diameter of 8 mm placed in the flange of the beam.

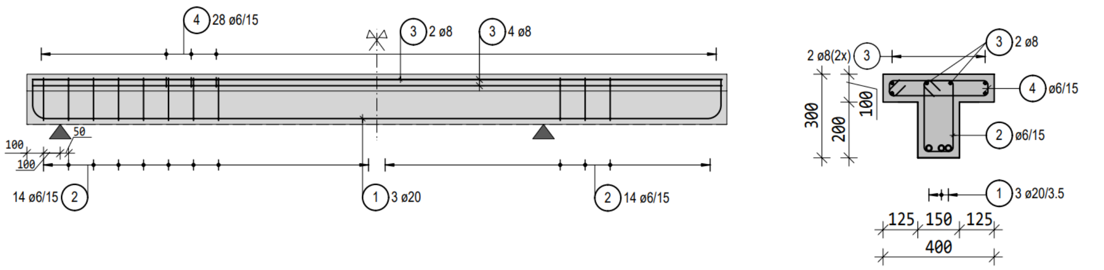

Fig. 1: Reinforcement of beam

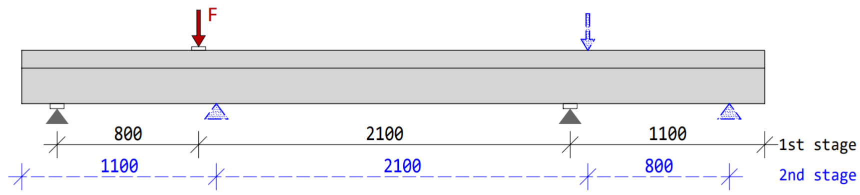

Fig. 2: Test setup – Position of supports and forces in different stages

2.1. Shear resistance V_{Rs}

The angle between concrete compressive strut and the beam axis has an important role in the calculation of the shear resistance of the analytical beam. The graph in *Fig.3* shows the theoretical shear resistance of the beam according to an angle of the shear crack. If the shear crack angle is between 22° and 28° the shear crack passes through 4 stirrups of the specimen. The shear resistance of specimens according to the model EC 2 was assumed by *eq. 1*.

$$V_{Rs} = \frac{A_{sw} . z . f_{yw} . cot\theta}{s} \tag{1}$$

Where: A_{sw} is an area of the shear reinforcement, z is the inner lever arm, f_{yw} is the yield strength of shear reinforcement, θ is the angle between concrete compressive strut and the beam axis, s is a distance between stirrups.

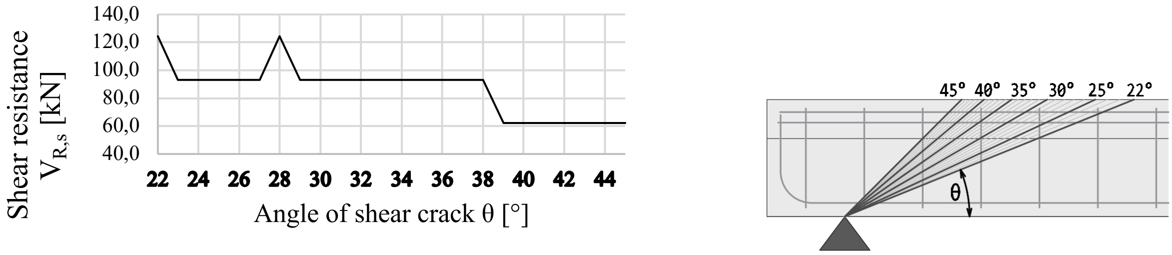

Fig. 3: Shear resistance depending on the shear crack angle

3. Non-linear finite element analysis - NLFEA

3.1. Model description

To develop a nonlinear analysis of a concrete beam, a model was created in the Sofistik software (Sofistik SOFiMSHA,2022) using Brick elements. The support of the beam was modelled through a line of compression springs with a length of 150 mm supported by a rigid steel plate 20 mm thick made of steel class S355. The plate was connected to the beam elements by rigid springs. The line of compression springs is on the axis of the support. The support allows rotation of the beam at the support point as shown in *Fig. 4*. The concrete elements were modelled from a 2D cross-section model using the extrusion function. The steel reinforcement is modelled as beam elements.

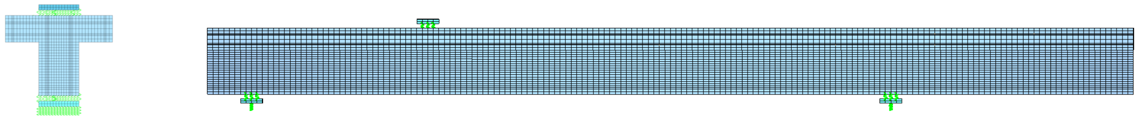

Fig. 4: FE model – cross-section and side view

3.2. Material description

The strength and deformation characteristics of the materials used were adjusted from the standard characteristics based on samples tested in the laboratory. Their values are given in *Tab. 1*. The LADE (Sofistik AQUA,2022) module was used for concrete modeling, which is recommended by software for solving the nonlinear analysis of concrete elements.

Tab. 1: Properties of used materials

Reinforcement				Concrete		
Bar diameter		6 mm	20 mm			
f_{yk}	[MPa]	500	500	f_{ck}	[MPa]	20.63
MAX $R_e(R_{p02})$	[MPa]	521	565	f_{cm}	[MPa]	28.63
$f_y = R_e(R_{p02})$	[MPa]	518	542	f_{ctm}	[MPa]	2.26
Class		B500A	B 500C	E_{cm}	[MPa]	29063

3.3. Load description

The load was applied by force method and displacement method. The force method was simulated in steps of 5 kN to a maximum force of 270 kN. The displacement was induced by a group of springs placed on a 150 mm line acting on the steel plate. The increment of the deformation loading step was 0.25 mm until the global deformation reaches the expected limit value of 30 mm.

4. Experiment

To verify the predicted resistance of the analyzed beam, an experiment was performed on a group of 4 specimens A, B, C, D divided to two stages 1 and 2. Specimen A was a reference specimen and was loaded up to failure, to verify the predicted specimens shear capacity before strengthening. The beam support was created by steel plates and cylindrical bearing to allow rotating the specimens at the point of support. Force gauges were placed under the supports. The loading was performed in steps of 5 kN until the first cracks occurred and then continued in steps of 10 kN until the specimens failed. The first crack was observed at a force of 60 kN. The shape of the cracks as well as the angle of the shear crack are shown in *Fig. 5*.

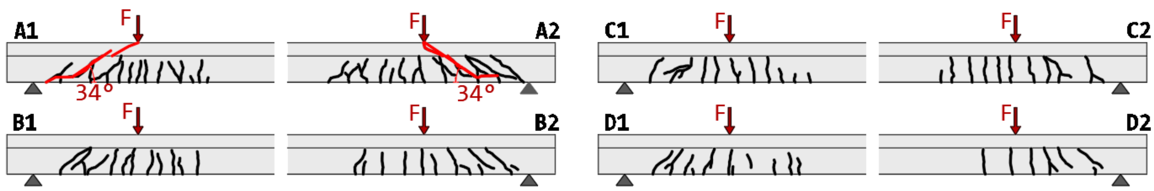

Fig. 5: The crack pattern on specimens stages

The failure of the specimen occurred when the load reached the value of 185 kN in the first stage A1 and 220 kN in the second stage A2.

5. Conclusion

Based on the experiment, the maximal reached force *F* was 180 kN on stage A1 and 220 kN on stage A2 of reference specimen A. The difference between the individual specimens in the experiment is attributed to the uneven distribution of the stirrups in the shear crack zone. The highest shear capacity $V_{R,s}$ achieved in analytical models was 110 kN. The graph in *Fig.6* shows the relation between reaction in support – shear force *V* and mid-span beam deflections according to experimental specimens and NLFEA models.

Depending on measurements from the experiment the maximum loading force *F* of specimens was determined to be 220 kN. Therefore, the other specimens prepared for strengthening were loaded with force equal to 110 kN.

From many analytical models when using specimen concrete properties, the maximum load did not exceed 100 kN. The LADE material model used in NLFEM needs to be detailed analyzed to achieve optimal results.

The results from stage A1 and stage A2 of reference specimen A will be use to set maximum resistance of other three specimens B, C, D before strengthening and will be comparing with results after strengthening.

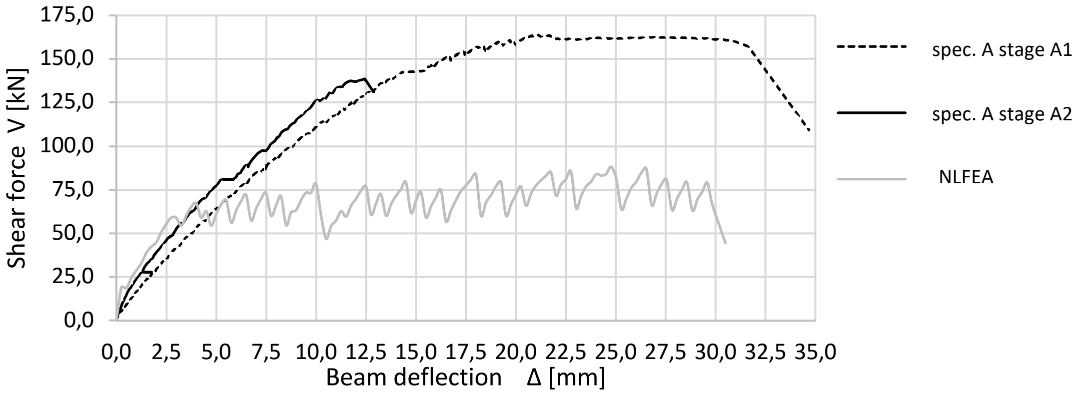

Fig. 6:Dependency graph of deflection and support force

Acknowledgement

The authors acknowledge company Skanska SK for their help with the production of experimental specimens. This work was supported by the Scientific Grant Agency VEGA under the contract No. VEGA 1/0645/20. This work was supported by the Slovak Research and Development Agency under the contract No. APVV-17-0204.

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