NUMERICAL AND EXPERIMENTAL INVESTIGATIONS OF SIZE EFFECT IN RAINFORCED CONCRETE BEAMS SCALED IN ONE DIRECTION

***M. Ostaszewska*[1], *J.Suchorzewski*[1], *E.Korol*[1], *J. Tejchman*[1], *Z.Mróz*[2]**

[1]*Department of Civil and Environmental Engineering*

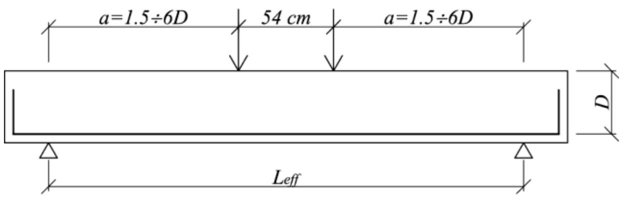
Gdańsk University of Technology, Gdańsk, Poland

[2]*Institute of Fundamental Technological Research*

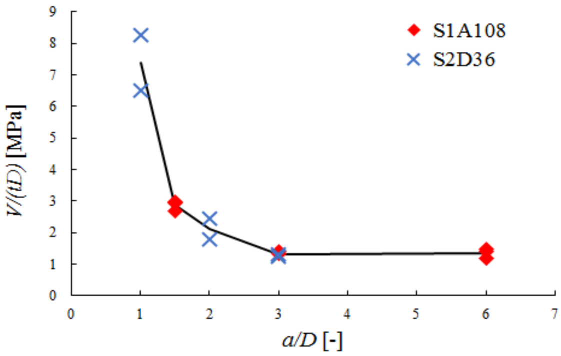
Polish Academy of Sciences, Warsaw, Poland

1. Introduction

A size effect phenomena in quasi-brittle materials like concrete causes that both the nominal structural strength (the measure of the ultimate load expressed in stress units) and structural brittleness vary when changing specimen dimensions. According to Bazant [1-2] the nominal strength and brittleness vary due to: a) the presence of intense strain localization regions with a certain volume contributing to an energetic-deterministic size effect and b) a random distribution of material properties contributing to a statistical size effect. Referring to reinforced concrete beams the size effect is mainly of the energetic (deterministic) type which is described by the analytical size effect law of Type 2 by Bazant. The SEL Type 2 applies to geometrically similar structures failing after a stable crack growth. The geometric similarity of specimens guarantees a similar failure mechanism, as experimentally and numerically verified in our earlier studies on reinforced concrete beams without shear reinforcement [3-4]. Our latest investigations focused on the size-shape effect in reinforced concrete beams scaled in one dimension only that caused a different failure mechanism. First, own experiments were carried out and next FE calculations with an advanced elasto-plastic-damage model with non-local softening were performed.



a)



b)

Figure 1: a) Geometry and loading scheme of beams in series S2D36, b) experimental shear strength *V/(tD)* for series S1A108 and S2D36 against shear span *a* / *D* ratio (*D* – effective beam depth, *a* – shear span, L_{eff} – beam span, *t* – beam thickness, V=0.5P_{max}, P_{max} – maximum vertical force)

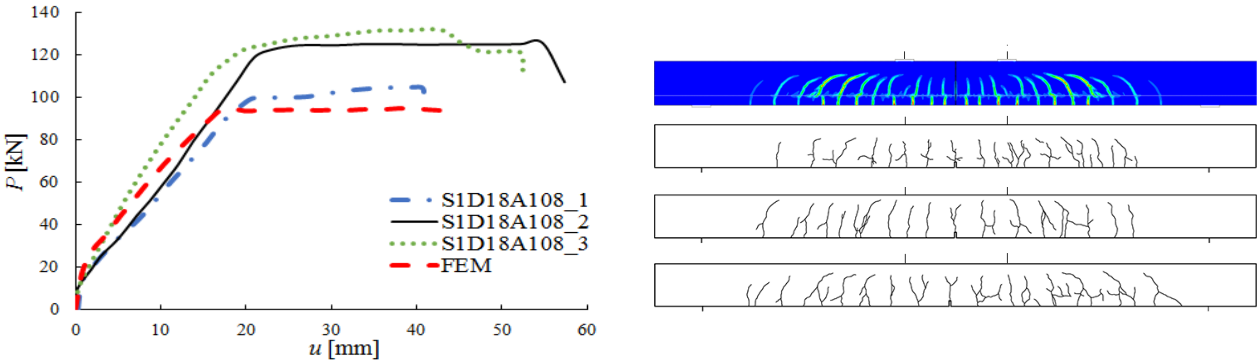
2. Experimental tests

Experimental investigations of a size-shape effect were performed on reinforced concrete beams under four-point bending. Two series of beams denoted as S1A108 and S2D36 were tested with specimens scaled in the height *D* or length L_{eff} direction. The series S1A108 (Fig.1a) included beams with a constant span L_{eff}=270 cm and a different effective depth *D*=16, 36 and 72 cm. While the series S2D36 (Fig.1a) included beams with the constant effective depth *D*=36 cm and varying span L_{eff} = 126, 198 and 270 cm. The reinforcement consisted of ribbed bars of the 20 mm diameter and was designed so as to reach 1.4% of the cross-section area of each beam. The failure mechanism included steel yielding, diagonal tension or shear-compression failure depending on the *a*/*D* ratio (*a* - shear span, Fig.1a). The lower *a*/*D* ratio (i.e. when beam slenderness decreases), the higher the nominal shear strength *V*/(*tD*) (*t* – beam thickness) was obtained in experiments (Fig.1b).

3. Numerical simulations

The 2D FE analyses were performed on two-dimensional reinforced concrete beams with a geometry from the experiments (Fig.1a). A coupled elasto-plastic-damage constitutive model was used for concrete [5] and a perfect elasto-plastic von Misses model for 1D steel bars. Concrete model combined elasto-plasticity with scalar isotropic damage assuming the strain equivalence hypothesis. It assumed a different stiffness in tension and compression and a positive-negative stress projection operator to simulate crack closing and crack re-opening. A non-local theory was adopted to avoid a mesh dependence and to include a characteristic length of micro-structure l_c which was calibrated based on results obtained with the DIC technique (Digital Image Correlation).

Figure 2a presents the calculated force-deflection diagrams for the beam *D*=18 cm (series S1A108) which failed due to steel yielding as compared with the experimental results. A direct comparison of the contours of the non-local tensile softening parameter ($\overline{\kappa_1}$) in the beams with the experimental cracks is shown in Fig.2b. The calculated load-displacement curves and localized zones were close to the experimental findings.



a) b)

Figure 2: Reinforced concrete beam S1D18A108: a) force-deflection diagram from FE analyses (red dashed line) compared with experimental outcomes (continuous, dotted and dashed-dotted line) and b) contours of calculated non-local tensile softening parameter compared with experimental crack paths

4. References

[1] Z.P. Bazant and J. Planas (1998). *Fracture and Size Effect in Concrete and Other Quasibrittle Materials*, CRC Press LCC.

[2] Z.P. Bazant (1984). Size effect in blunt fracture: concrete, rock, metal, *J. Eng. Mech.*, **110**, 518-35.

[3] E. Syroka-Korol and J. Tejchman (2014). Experimental investigations of size effect in reinforced concrete beams failing by shear. *Eng. Struct.*, **58**, 63–78.

[4] E. Syroka-Korol, J. Tejchman and Z. Mróz (2014). FE analysis of size effects in reinforced concrete beams without shear reinforcement based on stochastic elasto-plasticity with non-local softening. *Finite Elements in Analysis and Design*, **88**, 25-41.

[5] I. Marzec and J. Tejchman (2012). Enhanced coupled elasto-plastic-damage models to describe concrete behaviour in cyclic laboratory tests: Comparison and improvement. *Arch. Mech.*, **64**, 227-259.