Experimental and theoretical studies on size effects in concrete and reinforced concrete beams

Ewelina Korol and Jacek Tejchman

Faculty of Civil and Environmental Engineering

Gdańsk University of Technology, 80-952 Gdańsk, Poland

e-mail: esyroka@pg.gda.pl, tejchmk@pg.gda.pl

Abstract

Experimental and numerical investigations on size effect in concrete and reinforced concrete beams of a similar geometry were performed. The laboratory tests were carried out with three different reinforced concrete beams without stirrups subjected to four-point bending. A digital technique called DIC (Digital Image Correlation) was used to observe the evolution of strain localization. The FE analyses of a deterministic and stochastic size effect were performed for concrete and reinforced concrete beams and compared with corresponding laboratory tests. An elasto-plastic model with non-local softening and a characteristic length of micro structure was used.

Keywords: beams, concrete, finite elements method, numerical analysis, stochastic phenomena

1. Introduction

The size effect phenomenon (nominal strength varies with the size of structure) is an inherent property of the behavior of many engineering materials, i.e. the strength and brittleness increase with increasing element size under [1]. Thus, concrete becomes perfectly brittle on a sufficiently large scale. The results from laboratory tests which are scaled versions of the actual structures cannot be directly transferred to them. Two sources of size effects are of a major importance: deterministic and statistical one. The first one is caused by strain localization, whose size cannot be appropriately scaled in laboratory tests. Strain localization is not negligible to the cross-section dimensions and is large enough to cause significant stress redistribution in the structure. The size and spacing of localized zones is related to a characteristic length of micro-structure l_c. The specimen strength increases with increasing ratio l_c/L (L – specimen size). In turn, a stochastic effect is caused by a spatial variability/randomness of local material strength. An increase of the specimen size causes an increase of weak spots what induces a decrease of the material strength.

The aim of our research is to investigate experimentally and numerically a deterministic and stochastic size effect in concrete and reinforced concrete beams under quasi-static bending. The experiments were carried out with three different geometrically similar reinforced concrete beams without stirrups. The specimens had a constant thickness of 0.2 m, a length: 1.5 m, 3.0 m and 6.0 m, and a height: 0.2 m, 0.4 m and 0.8 m, respectively. For each size, three samples were made. The reinforcement ratio was always 1.0%. The beams were subjected to four-point bending and controlled by vertical displacement. The failure mode was of a shear type in concrete. In FE analyses, the concrete behavior was modeled with an elasto-plastic constitutive model. In a tensile regime, a Rankine criterion was adopted. In turn, a Drucker-Prager yield surface was assumed in a compression regime. To describe properly strain localization in concrete elements, a characteristic length of micro-structure was included by means of a non-local theory. The reinforcement was modeled as an elastic-ideally plastic material. Two-dimensional calculations with notched concrete beams, un-notched concrete beams and reinforced concrete beams under plain stress conditions were performed. The deterministic calculations were carried out with a uniform distribution of concrete tensile strength. In turn, the stochastic analyses were performed with random spatially correlated homogeneous distributions of concrete tensile strength. Truncated Gaussian random tensile strength fields were generated using a conditional rejection method for correlated random fields [3]. First, a Monte Carlo method was used to generate a set of samples, next, a Latin Hypercube Sampling technique was applied in order to reduce the number of realizations [4].

2. Experimental investigations

The beams (Figure 1) were placed on roller supports and were loading by controlling the vertical displacement with a velocity of 5 mm/h. During tests, the following parameters were measured by gauges: deflection, support subsidence, width of flexural and diagonal cracks (Fig.2) and strain in a compressions region.

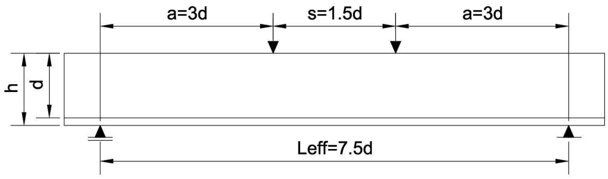

Figure 1: Four-point bending test: geometry and boundary conditions

Figure 3 shows the measured normalized bearing capacity of a small, medium and large reinforced concrete beam. A size effect is pronounced; the beam strength decreases with increasing beam size. The damage of specimens was due to shear only. Initially. perpendicular cracks appeared in the region of a constant bending moment. Next, inclined cracks arose and finally diagonal cracks contributed to failure. The measured width of localized zones was approximately 15 mm.

3. FE investigations

Four unnotched concrete beams subjected to three-point bending were analyzed (h=32-192 cm) [2]. The results were compared to the Bazant size effect laws and similar results for notched beams [2].

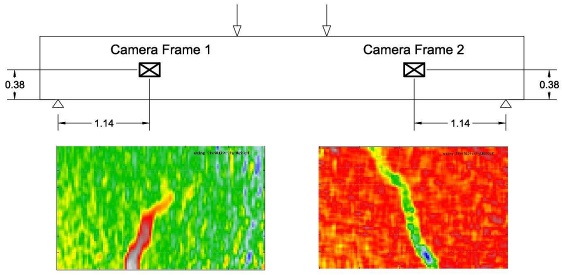

Figure 2: Arrangement of cameras for large beam and measured diagonal localized zones

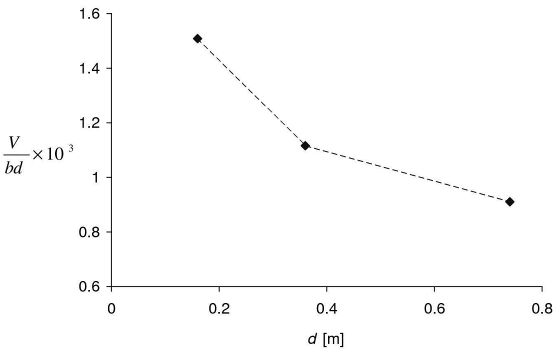

Figure 3: Nominal shear strengths for small, medium and large beams versus beam height

The FE results show that both beam strength and beam ductility increase with decreasing beam size (Fig.4). A pronounced deterministic and stochastic size effect occurs in agreement with the size effect model laws by Bažant [1] (Figure 5). For the beam height of h=192 cm, the mean stochastic force is smaller by 20% than the deterministic value. The width of a calculated localized zone is about 15 mm (Figure 6).

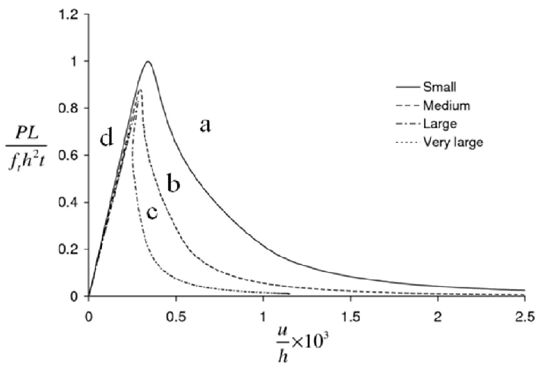

Figure 4: Normalized force-displacement curves with constant values of concrete tensile strength for 4 unnotched concrete beams under three-point bending: a) small, b) medium, c) large, d) very large beam

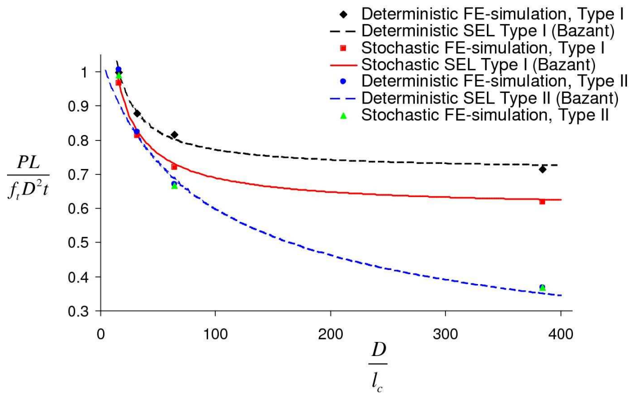

Figure 4: Calculated size effect in notched and unnotched concrete beams compared to model laws by Bazant

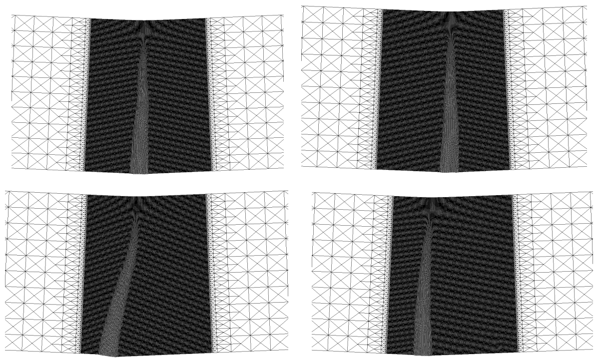

Figure 6: Four arbitrary deformed FE meshes for large-size unnotched beams (h=32 cm, u/h=1‰) with random distribution of concrete tensile strength

4. Conclusions

A significant size effect occurs in concrete beams and reinforced concrete beams without stirrups (where failure takes place in concrete).

The deterministic size effect is very pronounced in notched and unnotched concrete beams In turn, the stochastic size effect is strong in unnotched concrete beams only.

References

[1] Bazant, Z. and Planas, J. *Fracture and size effect in concrete and other quasi-brittle materials*. CRC Press LLC, 1998.

[2] Bobiński J., Tejchman J. and Górski J. Notched concrete beams under bending - calculations of size effects within stochastic elasto-plasticity with non-local softening. *Achives of Mechanics*, 61, 3-4, 283–307, 2009.

[3] Walukiewicz, H., Bielewicz, E. and Górski, J. Simulation of nonhomogeneous random fields for structural applications, *Computers and Structures*, 64, 1-4, pp. 491-498, 1997.

[4] Tejchman, J. and Górski, J. Computations of size effects in granular bodies within micro-polar hypoplasticity during plane strain compression. *Int. J. for Solids and Structures*, 45, 6, pp. 1546-1569, 2008