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Invited Paper

Calibration of the CDP model parameters in Abaqus

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ABSTRACT

The modeling of reinforced concrete structures can be performed using Abaqus software. Authors of this paper decided to use of the concrete damaged plasticity model (CDP) which is implemented in this program. Some parameters of CDP are decisive to obtain proper and realistic results. These parameters are: the viscosity parameter, the dilation angle in p-q plane, the flow potential eccentricity, the ratio of initial biaxial compressive yield stress to initial uniaxial compressive yield stress. Another open issue is a definition of a proper fracture energy of concrete

Authors of this paper perform numerical simulations concerning uniaxial and biaxial compression and uniaxial tension of a sample concrete specimen. The results are compared with experimental tests. After this comparison all mentioned above parameters are determined in a rational way.

1. INTRODUCTION

Authors of the paper have recently examined reinforced concrete corners under opening bending moment in Abaqus (Szczecina and Winnicki 2014, 2015) using CDP model. They have noticed that gained results strongly depend on a choice of some CDP parameters, especially on the dilation angle and the viscosity parameter. Hence arose the need to perform a calibration of these parameters. Some sample results of authors' research are presented in the Figures 1 and 2. The first figure presents a relation between a displacement of a node of the corner and a load parameter. The second one shows a map of equivalent plastic strains in tension (PEEQT) for analyzed corner.

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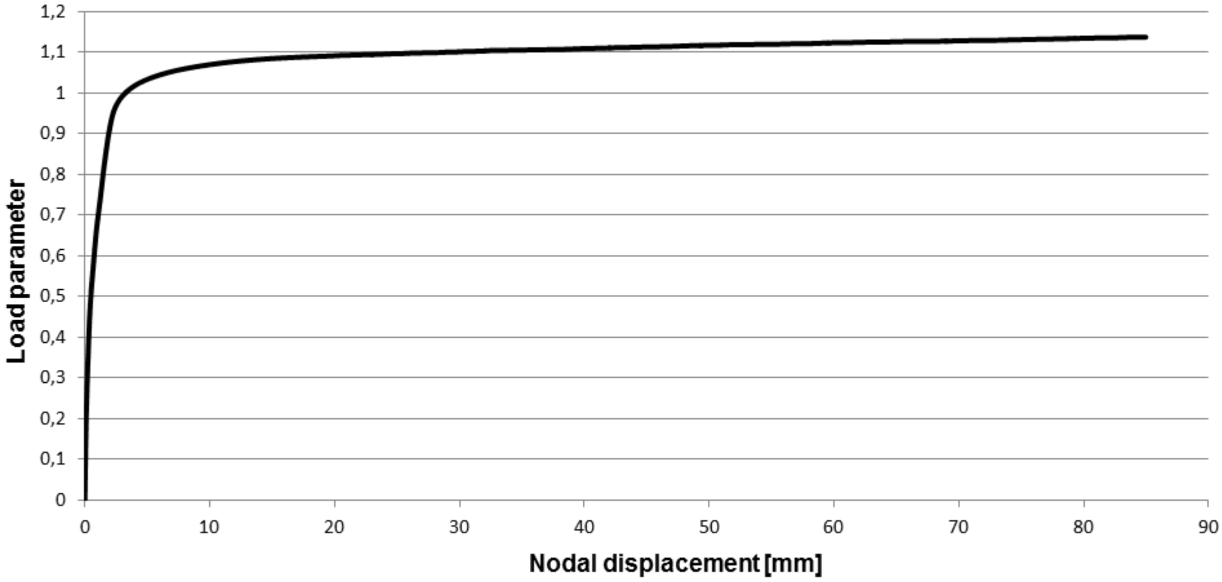

Fig. 1. Nodal displacement versus load parameter

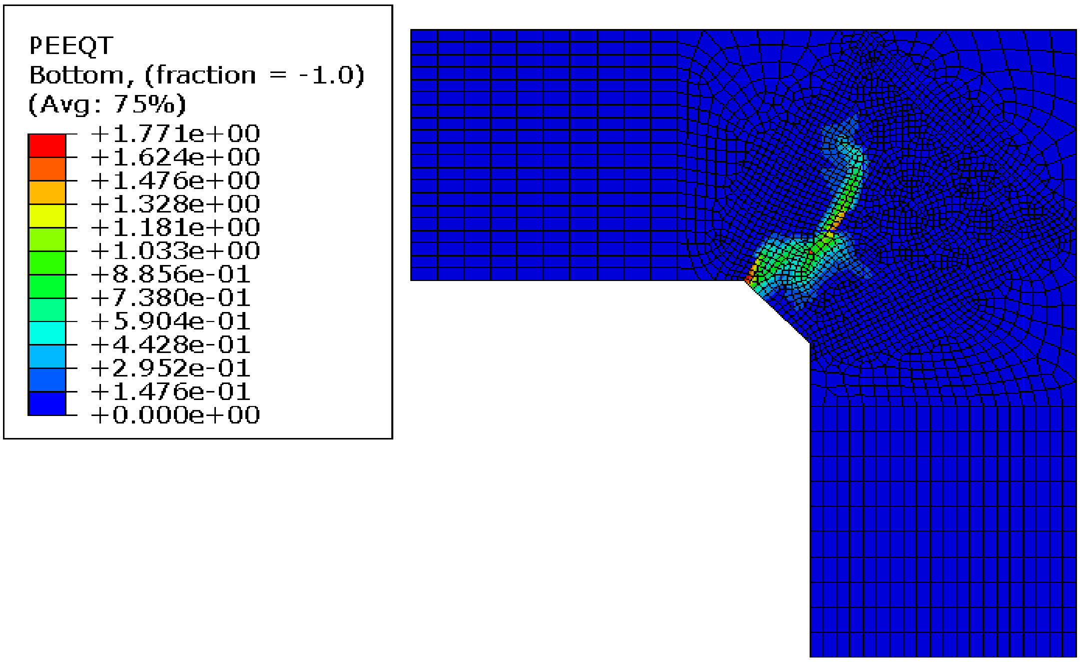

Fig. 2. Equivalent plastic strains in tension

The CDP is currently one of the most popular concrete models used for simulation of concrete behavior in Abaqus. This model was theoretically described in (Lubliner et al. 1989) and developed in (Lee and Fenves 1998). The main assumptions of this model are listed below:

– there are two damage mechanisms: tensile cracking and compressive crushing of concrete,
– material stiffness is reduced by two damage parameters, separately for tension

and compression,
– the yield function is specified according to (Lubliner 1989) and the flow potential is a hyperbolic function (Abaqus User Manual),
– the plastic flow is nonassociated.

For a full definition of CDP model in Abaqus the following obligatory parameters should be input:
– the σ–ε relation for compression of concrete as a set of points,
– tension behavior of concrete as a set of points laying on σ–ε curve or optional the fracture energy G_f,
– dilation angle ψ in the p-q plane,
– flow potential eccentricity ε,
– the ratio fb0/fc0 of biaxial compressive yield stress to uniaxial compressive yield stress,
– the ratio K of the second stress invariant on the tensile meridian to that on the compressive meridian for the yield function.

There are also some optional parameters, namely:
– the viscosity parameter (relaxation time),
– damage conditions for compression and tension.

Authors of this paper focus on the calibration of the following parameters:
– the viscosity parameter in tension test,
– dilation angle in compression test.

Moreover, the influence of mesh size on results of tests is also taken into consideration. The tension test is performed twice, namely with or without tension damage.

2. PROPERTIES OF SPECIMENS

Two different specimens are taken into consideration, namely a disc specimen for uniaxial and biaxial compression (Kupfer 1973) and a notched bar for uniaxial tension (Woliński 1991). The geometry of specimen under uniaxial and biaxial compression is presented in Figure 3 and under tension – in Figure 4. The first specimen is a disc of dimensions 200x200x50mm which is modeled with 3D finite elements. The second specimen is modeled with 2D elements in plane stress state. Two characteristic notches allow to gain one crack localized in a vertical symmetry axis of specimen.

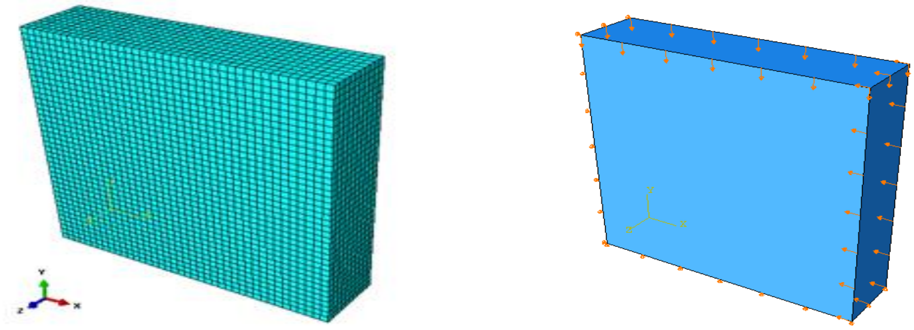

Fig. 3. Setup for the first test (mesh and boundary conditions)

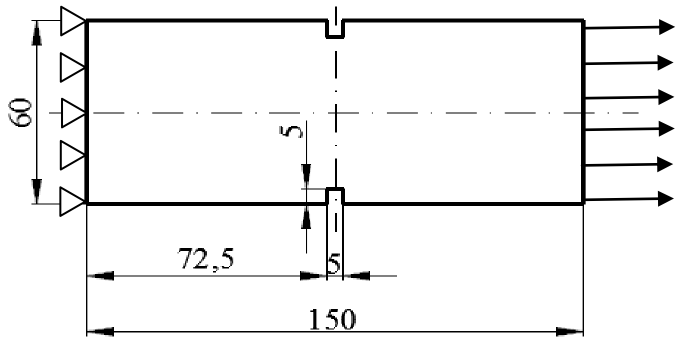

Fig. 4. Setup for the second test (dimensions in mm)

The material properties for both specimens are as follows:
- concrete: f_{ck} =40 MPa, f_{cd} =34.30 MPa, E_{cm}=35 GPa, ν=0.167,

Stress-strain curve in uniaxial compression for the first test is calibrated to match experimental results of Kupfer. The tensile behavior of concrete for the second test is assumed as a linear σ-ε relation for given fracture energy G_f.

For the specimen under compression one of the boundary conditions is a displacement of a top surface (for uniaxial compression) or displacements of both top and lateral surface (for biaxial compression). Also for the specimen under tension one of the boundary condition is defined as a displacement of a shorter edge.

Authors of the paper have tested various values of CDP model parameters. These parameters are listed in the Table 1. Moreover, different meshing has also been taken into consideration. In the next sections selected results are presented.

Fracture energy G_f [Nm^{-1}]:	146.5, 500, 1000
Dilation angle [degrees]:	0, 5, 15, 30
Relaxation time [s]:	0.0001, 0.001, 0.01
Eccentricity:	0.1
fb0/fc0:	1.16
K:	0.667

Tab. 1. CDP model parameters

3. RESULTS OF THE TENSION TESTS

The results for the tension tests are presented as color maps of equivalent plastic strains in tension (PEEQT) and tensile damage variable (DAMAGET) in the Figures 5 to 12. When a value of the tensile damage variable equals 1, it means a total loss of capacity while value 0 means a virgin state of specimen. All the results concern the densest mesh, namely 1mm of finite element size. The analyzed cases vary in viscosity parameter, which assumes values from 0 through 0.0001, 0.001 until 0.01 (i.e. relaxation time in seconds). When a value of the viscosity parameter equals 0 (viscous regularization is not used) we can see a very clear crack along the whole notched cross section of specimen. For all analyzed meshes crack localizes in one row of elements and width of damaged zone depends clearly on assumed FE discretization. This crack is approximately vertical and indicates a clear damage location. When the viscosity parameter grows, crack and damage zone change their characters. For a value of the viscosity parameter equal to 0.0001 a constant damage zone width (about 5mm) is observed for the all used FE discretizations. For larger values of the viscosity parameter damage zone is smeared outside the notched fragment of specimen in a diffuse form. Finally, for the viscosity parameter 0.01 the damage zone takes the circular form. Naturally, this pattern of crack and damage does not match the reality and therefore use of the lowest analyzed value of the viscosity parameter, namely 0.0001 is recommended.

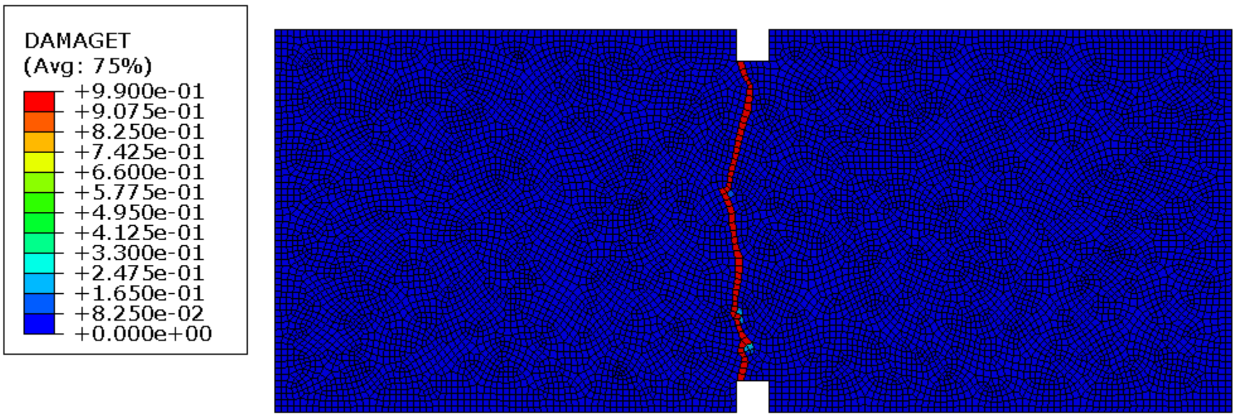

Fig. 5. DAMAGET for viscosity parameter = 0

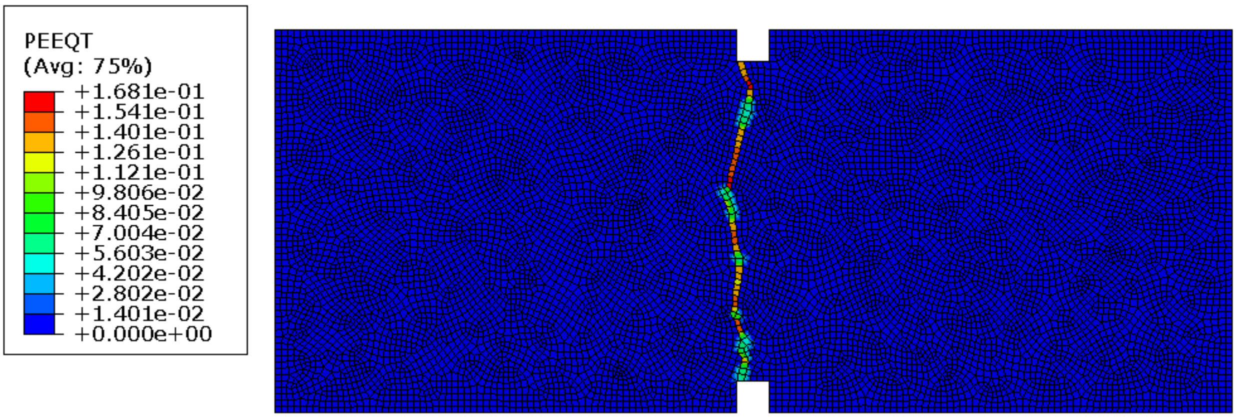

Fig. 6. PEEQT for viscosity parameter = 0

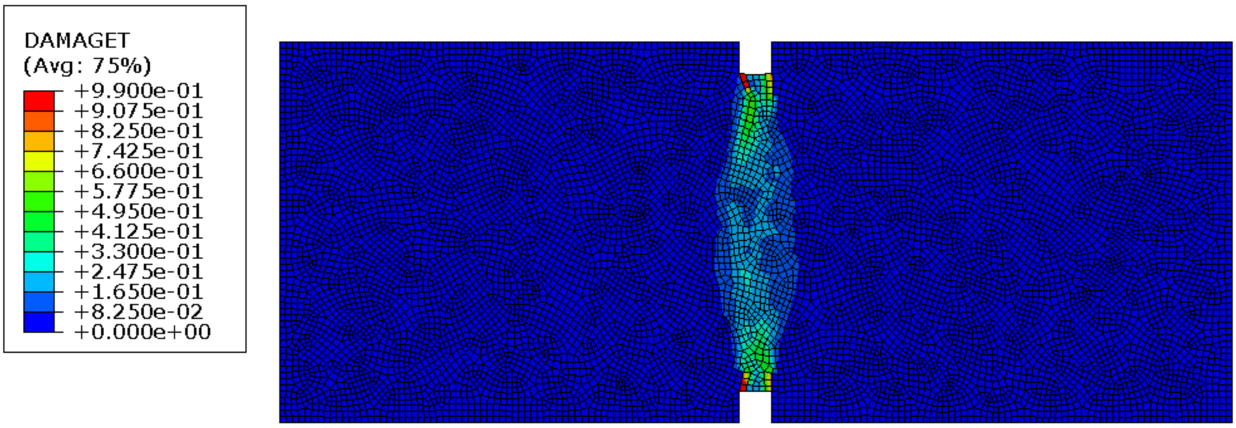

Fig. 7. DAMAGET for viscosity parameter = 0.0001

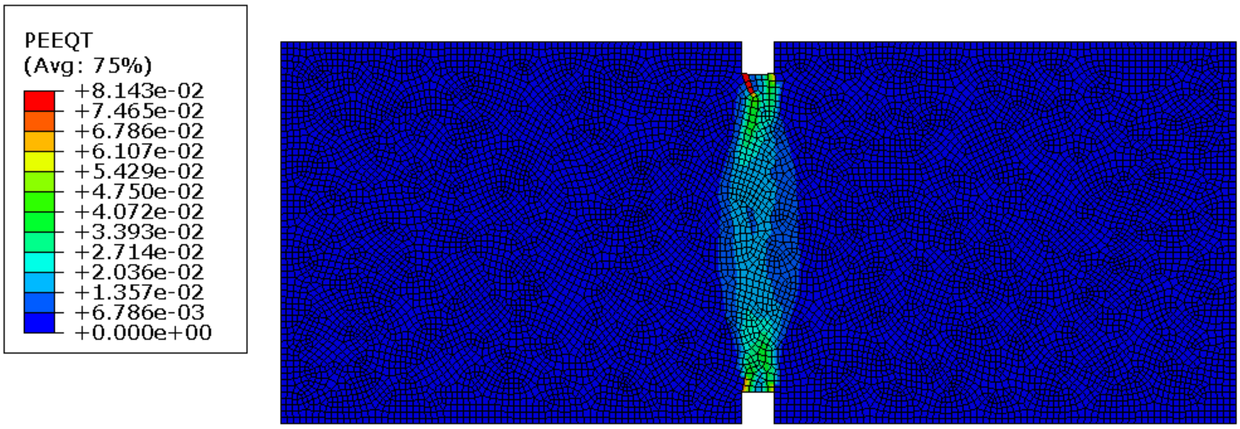

Fig. 8. PEEQT for viscosity parameter = 0.0001

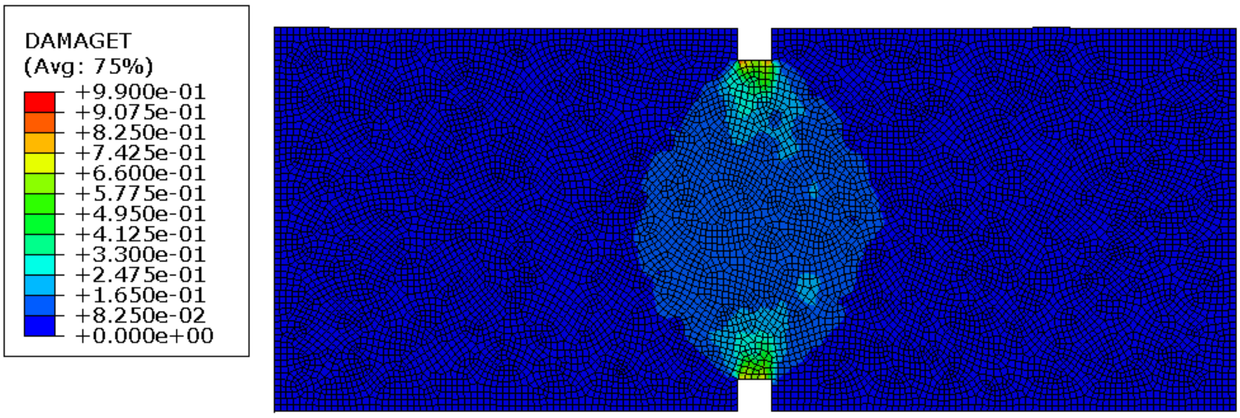

Fig. 9. DAMAGET for viscosity parameter = 0.001

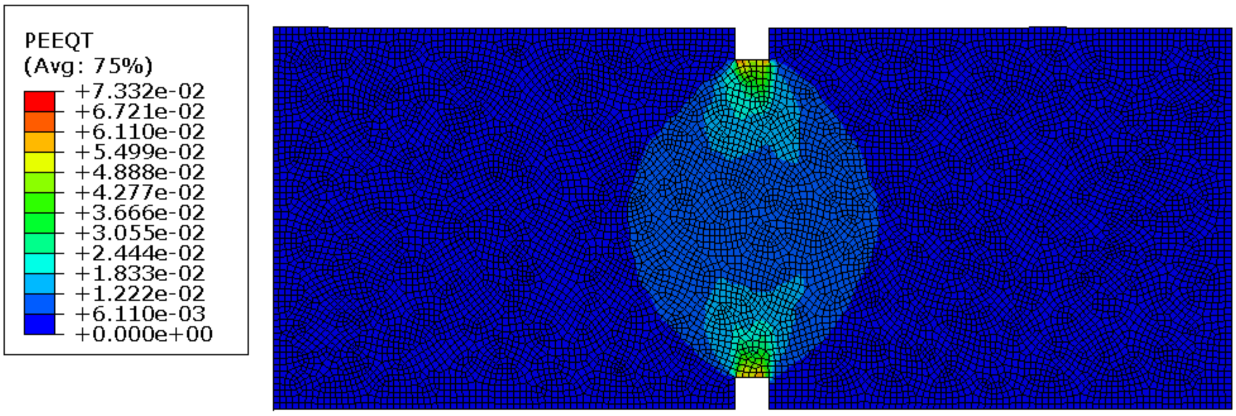

Fig. 10. PEEQT for viscosity parameter = 0.001

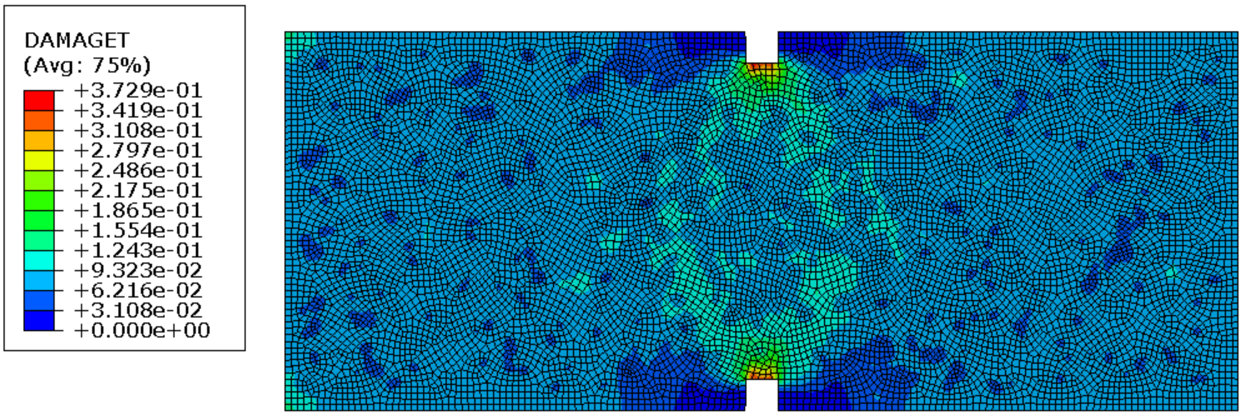

Fig. 11. DAMAGET for viscosity parameter = 0.01

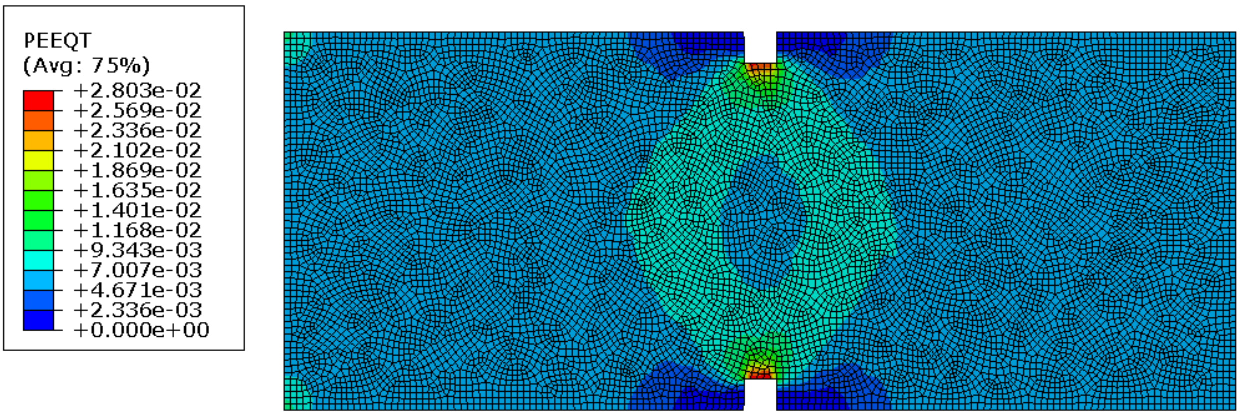

Fig. 12. PEEQT for viscosity parameter = 0.01

Figure 13 presents the relationship between the edge displacement and the resultant reaction at this edge. If the viscous properties of concrete are not taken into consideration, the examined relationship seems to satisfy the bilinear σ–ε curve for concrete in linear tension. If the viscosity parameter is higher than 0, all the paths in post-critical phase gain an almost horizontal fragment (plateau) and the ultimate bearing capacity of the specimen increases. This fact corresponds with PEEQT maps shown in previous figures, where damage zone is smeared to many finite elements. It means that the use of the non-zero viscosity parameter can lead to dubious results and a choice of this parameter value in practical computations using CDP model should be done with great care.

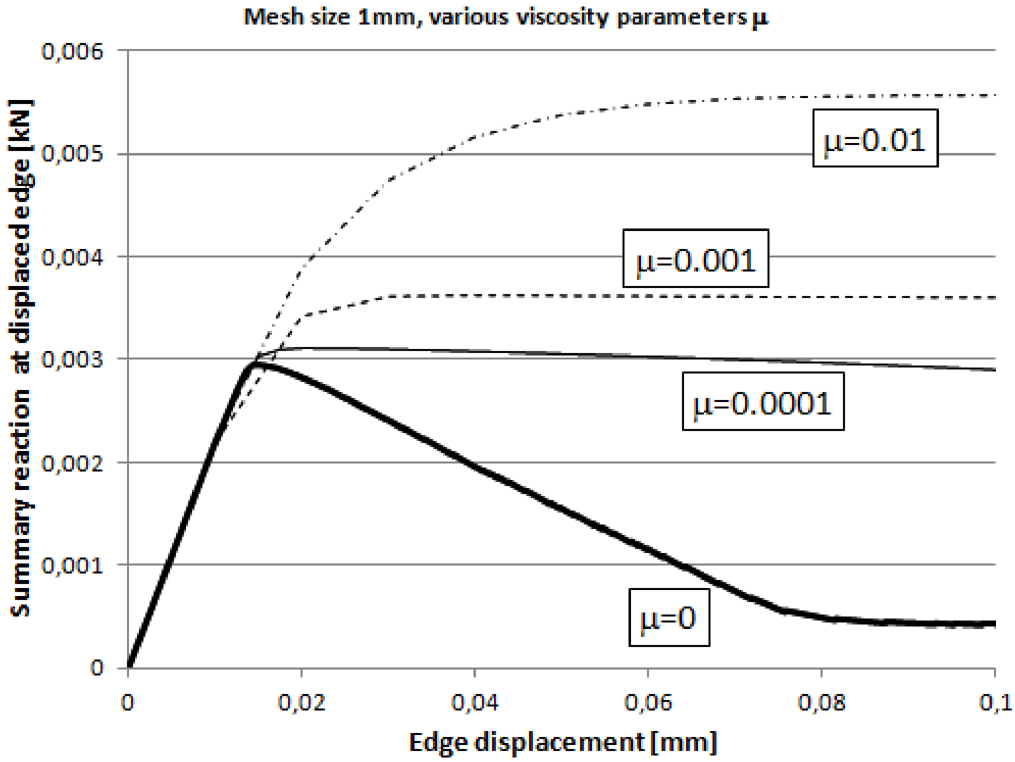

Fig. 13. Displacement vs summary reaction for 1mm mesh size

4. RESULTS OF THE COMPRESSION TESTS

The main goal of uniaxial and biaxial compression tests is to establish a reasonable value of dilation angle. The examined values differ from 0 through 5, 15 till 30 degrees. For biaxial test two different cases are taken consideration, namely 1:1 and 1:0.5 tests (ratios 1:1 and 1:0.5 mean proportion between imposed displacements in two perpendicular directions in a loading plane). In the Figures 14 to 16 relationship between volumetric strain ε_v and linear strain ε_{11} are shown.

For all assumed values of dilation angle (even for 0 degrees) the volumetric strains obtained in numerical computations are much larger than those of Kupfer. In experiments volumetric strains are always negative (compaction). In numerical computations volumetric strains remain negative for dilation angle in range 0-15 degrees. For dilation angle equal to 30 degrees excessive dilatancy is observed (large positive values of volumetric strains in postcritical range). Therefore authors of the paper recommend to set low values of dilation angle, for example 5 degrees. The use of relatively high values of this angle may cause too optimistic results for stiffness and bearing capacity of concrete element (especially when confinement appears, for example in plane strain case).

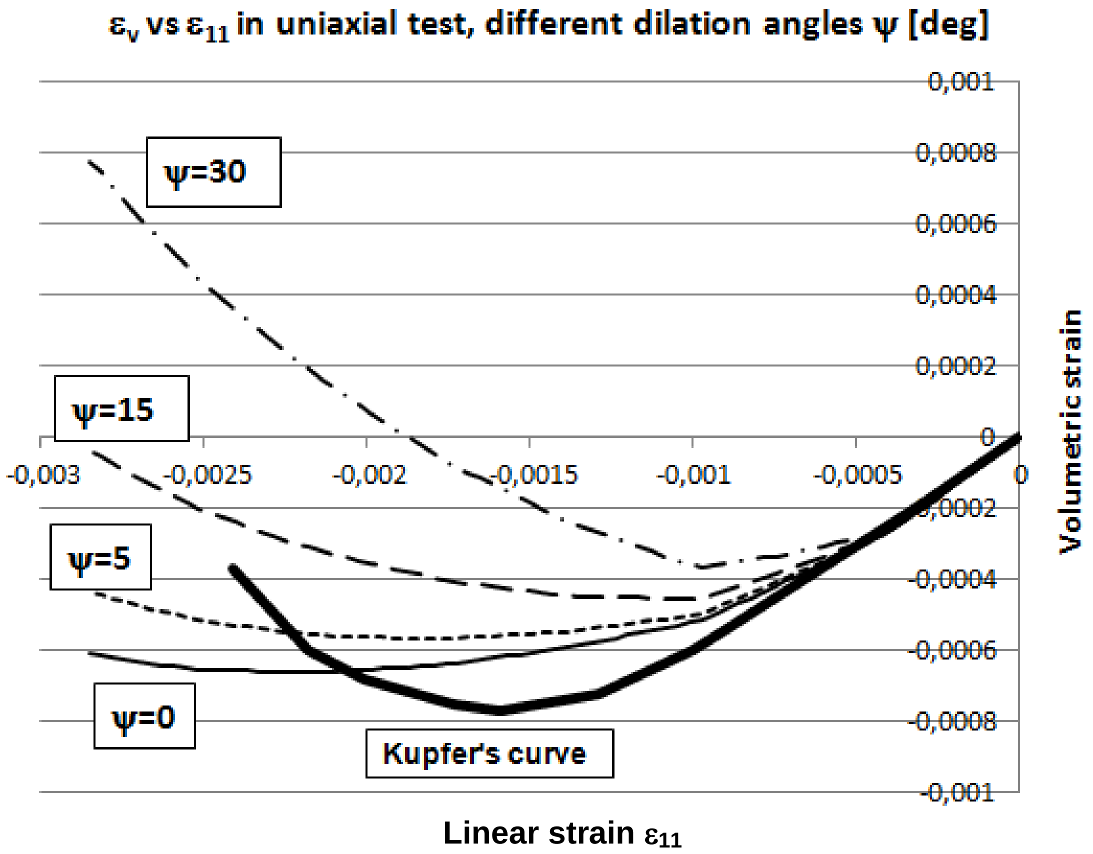

Fig. 14. Volumetric strain in uniaxial compression test

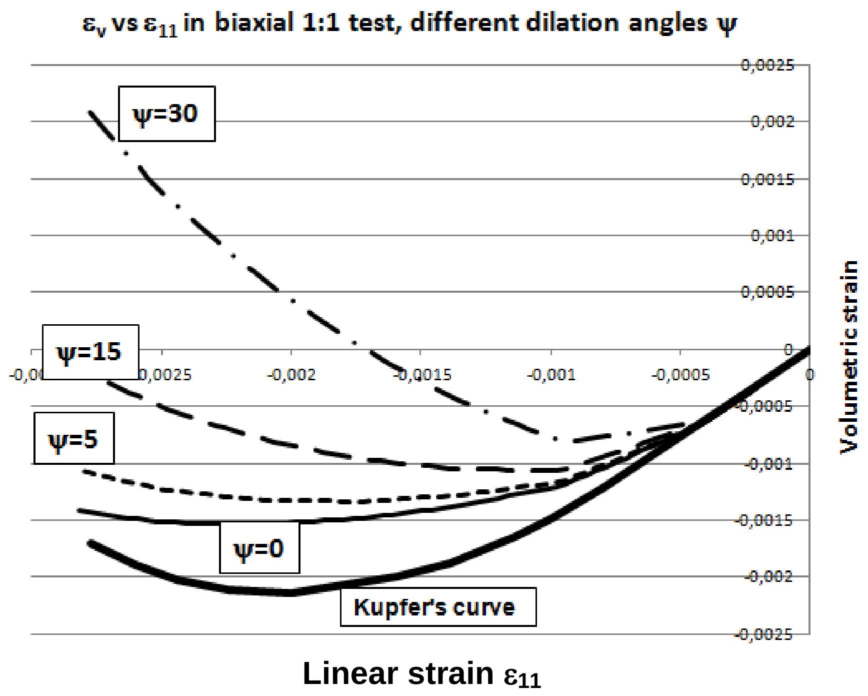

Fig. 15. Volumetric strain in biaxial 1:1 compression test

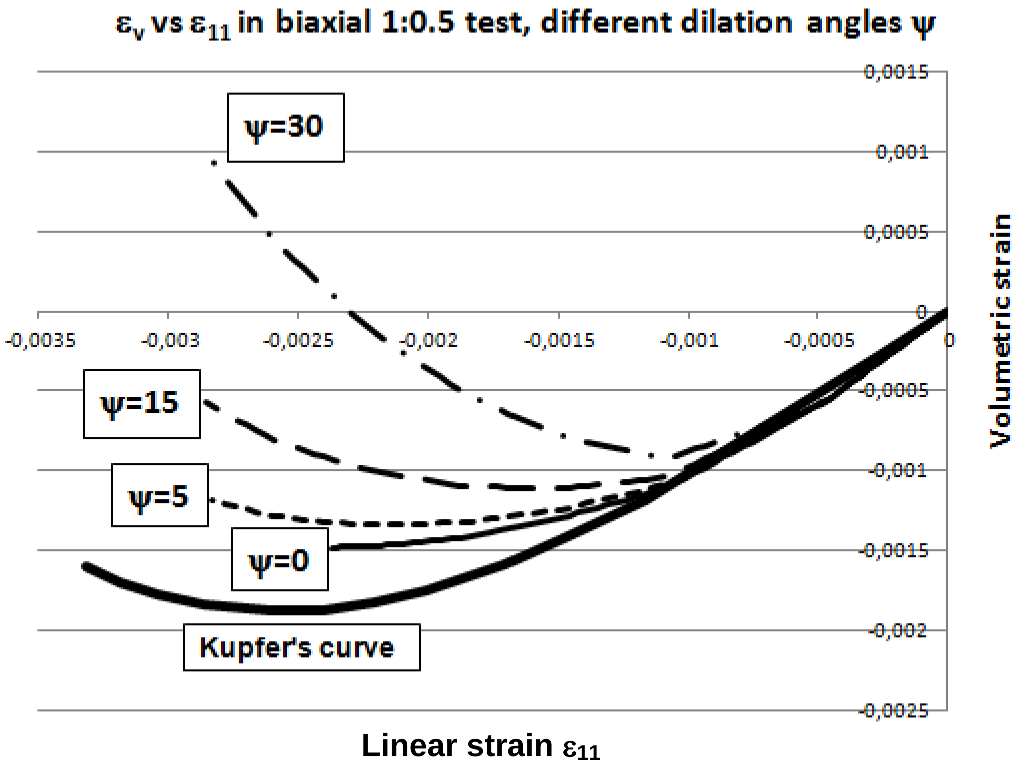

Fig. 16. Volumetric strain in biaxial 1:0.5 compression test

5. CONCLUSIONS

The presented results of numerical tests show that a proper choice of CDP model parameters should be done very carefully, possibly examining the assumed values performing numerical tests at the material point level compared with the available experimental results. This stage of modeling of reinforced concrete structures seems to be the most important and crucial for obtaining realistic results. Authors of the paper recommend the following values of parameters:

- viscosity parameter as 0.0001,
- dilation angle 5 degrees.

When applying higher values of viscosity parameter it is almost sure that the damage zone spreads to many finite elements leading to diffuse pattern of cracking and limiting crack propagation, whereas the higher values of dilation angle may lead to positive volumetric strains in compression zone causing artificial increase of bearing capacity in the case of confinement.

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