Analysis of "D" regions of RC structures based on example of frame corners

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Abstract

Calculations of reinforcement of "D" regions of reinforced concrete structures is much difficult than for "B" regions and demands some specific approach. Authors of the paper suggest to use both Strut-and-Tie (S&T) and Finite Element Method (FEM). The first of those methods allows to calculate required reinforcement and efficiency factor. In turn FEM can not only confirm S&T results but also gives information about crack width and pattern, strains and nodal displacement. Sample calculations were performed on example of frame corners under opening bending moment. Parameters of Concrete Damaged Plasticity model of concrete implemented in Abaqus were calibrated in tension and compressions test.

Keywords: concrete damaged plasticity, frame corners, opening bending moment, Abaqus, Finite Elements Method

1. Introduction

Calculations of reinforcement for the reinforced concrete structures depend on a kind of region for which this reinforcement should be established. For the "B" (Bernoulli) regions the distribution of stress is plain and there are well known algorithms which allow to calculate required reinforcement. For the "D" (disturbance) regions the distribution of stress is much complicated and the reinforcement should be established with the help of more advanced methods. Designers have to rely on handbooks and codes what is often insufficient. Authors of this paper suggest to use both Strut-and-Tie (S&T) and Finite Element Method (FEM) in Abaqus software [1] and present some results for frame corners under opening bending moment. Moreover, to establish some important parameters for a Concrete Damaged Plasticity model (CDP) in FEM authors decided to perform numerical test: uniaxial tension and biaxial compression.

2. Frame corners under opening moment

In the paper authors taken into consideration seven sample reinforcement details of frame corners under opening bending moment. These details are presented in the Figure 1 and were taken from laboratory test of Mayfield et al. [4] and Skettrup et al. [6].

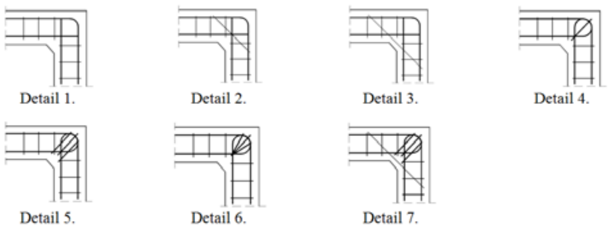

Figure 1: Reinforcement details of corners

3. Research methods

Authors of the paper performed their calculations of corners under opening bending moment using both S&T and FEM. The first method was used to establish a required reinforcement of a corner under opening bending moment and the second method to calculate both ULS (ultimate limit state – maximal stress in concrete and reinforcing steel) and SLS (serviceability limit state – displacements, crack width), first of all crack width and crack propagation. Both methods allowed to determine the corner efficiency factor.

3.1. Strut-and-Tie Method.

The main idea of this method is to replace a reinforced concrete element with a truss composed of concrete struts and steel ties. The S&T Method is a kind of developed Mörsch's truss analogy [5].

3.2. Finite Elements Method in Abaqus software

FEM calculations were performed in Abaqus using CDP model for concrete. In this model the multiaxial behavior of concrete is defined with Equation 1:

$$\boldsymbol{\sigma} = (1-d)\mathbf{D}_{\mathbf{o}}^{\mathbf{el}} : (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_{\mathbf{pl}}) \tag{1}$$

where $\boldsymbol{\sigma}$ is a stress tensor, $\mathbf{D_o}^{\mathbf{el}}$ denotes initial elasticity matrix, d is the damage parameter, $\boldsymbol{\varepsilon}$ and $\boldsymbol{\varepsilon}_{\mathbf{pl}}$ denotes strain tensor and plastic strain tensor respectively. The model demands to input some important material constants and parameters, i.a dilation angle, compressive and tensile behavior of concrete and relaxation time (if viscoplastic properties of concrete are taken into consideration). Authors of the paper performed tension and compression tests to calibrate these parameters and compared gained results with laboratory tests of Woliński [7] (tension test) and Kupfer [3] (compression test).

4. Results

Results gained in S&T method for selected reinforcement details of corners are presented in Table 1. The provided reinforcement was afterwards used in Abaqus. The efficiency factor was calculated as a ratio of maximal compressive stress in struts and nodes of truss model and compressive strength of struts and nodes specified by Eurocode [2]. Corners with diagonal stirrups gained higher values of efficiency factor.

Table 1: Results gained in S&T method

Detail Nº	Reinforcement		Efficiency
	main	stirrups	factor
Detail 1.	4 ϕ 20	-	0.83
Detail 4.	4 ϕ 16	ϕ16	1.13
Detail 5.	4 ϕ 16	$\phi16 + 2\phi12$	1.44

Some results gained in Abaqus are presented in Figures 2 to 5. The first two of these figures present equivalent plastic strains in tension (PEEQT) for the reinforcement details 1. and 5. The use of diagonal stirrups caused that a cracked zone is limited. A relationship between nodal displacement and load parameter λ in plane stress state and plane strain state for all details is presented in Figures 4 and 5. Undoubtedly the use of diagonal stirrups allows to gain higher values of load parameter.

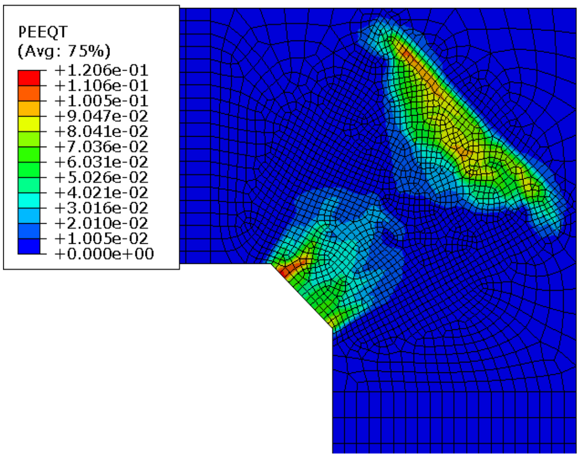

Figure 2: PEEQT for the detail 1.

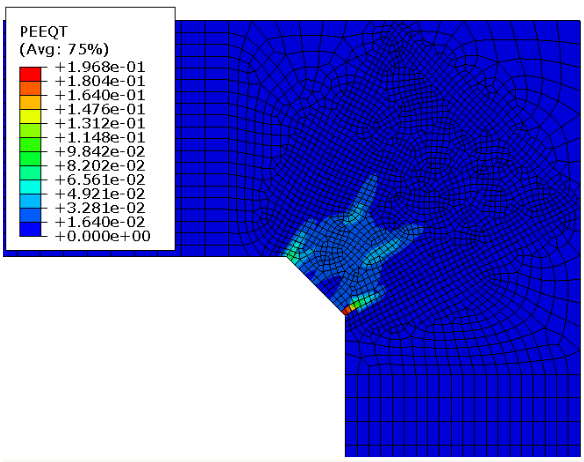

Figure 3: PEEQT for the detail 5.

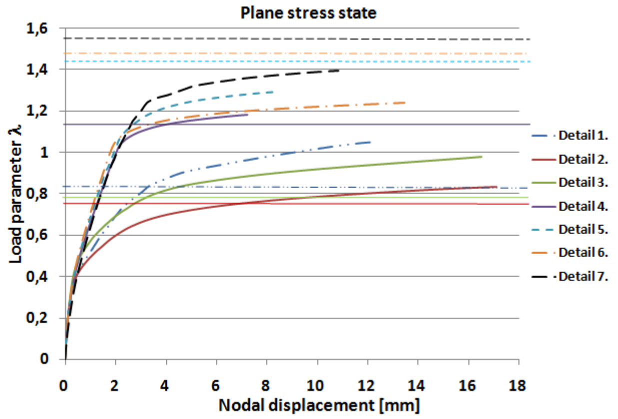

Figure 4: Nodal displacement for all details in plane stress state.

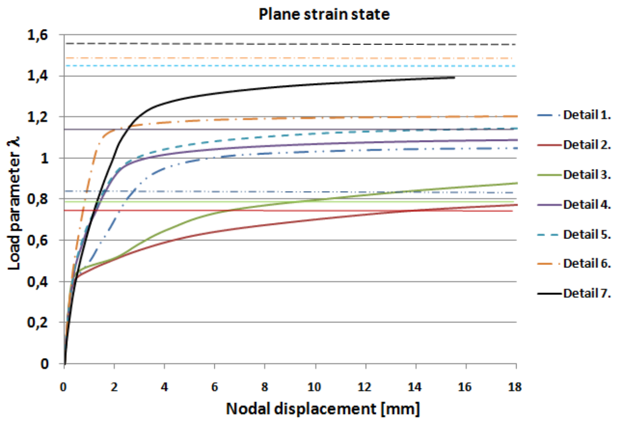

Figure 5: Nodal displacement for all details in plane stress state.

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