

BEHAVIOR ANALYSIS OF RC WALL DESIGNED BY STRUT-AND-TIE METHOD

Anka Starčev-Ćurčin¹

Andrija Rašeta²

Đorđe Lađinović³

Danijel Kukaras⁴

Igor Džolev⁵

UDK: 624.07:004.42

DOI:10.14415/konferencijaGFS2017.031

Summary: In this paper, the reinforced concrete wall member, statically simply supported, is analyzed and designed by Strut-and-Tie method in "ST method" program. The nonlinear behavior of member is analyzed on the simplified two-dimensional model with the assumption of plane stress state by Abaqus program. For discretization of concrete member part, 2-dimensional finite elements CPS4 are used, and reinforcement is modeled using the basic finite truss elements.

Keywords: rc wall member, Strut-and-Tie method, "ST method", nonlinear behavior

1. INTRODUCTION

When cracks occur in reinforced concrete member loaded in axial direction, bending, shear, torsion, or their combination, trajectory of the main compressive stress obtain, approximately, the shape of straight-line paths that can be replaced with straight axial compressed elements and, to those, tensioned elements have to be added in order to preserve the system equilibrium. Together, they form truss models that can be of different shapes, due to redistribution of internal forces within the member. Design model that describes such behavior is the Strut-and-Tie model, which can be successfully applied in the areas of complex flow of internal forces. Strut-and-Tie model, as replacement truss model of the real model, dates back to the time of Ritter and Mörsch and is mainly used for analysis, design and detailing of areas where classical dimensioning is not valid. Strut-and-Tie method is the lower static limit of the theory of plasticity, because there is no single model solution for a particular loaded member or part of the girder. This represents a transition from the theory of elasticity to the field theory, so the theory of plasticity gets an advantage. Stress field obtained according to the theory of elasticity satisfies the requirements of equilibrium and static boundary conditions and is only one of the possible static stress fields. Before the appearance of cracks in the concrete structural element there

¹ MSc, Faculty of Technical Sciences, University of Novi Sad, Serbia, e – mail: astarcev@uns.ac.rs

² PhD, Faculty of Technical Sciences, University of Novi Sad, Serbia, e – mail: araseta@uns.ac.rs

³ PhD, Faculty of Technical Sciences, University of Novi Sad, Serbia, e – mail: ladjin@uns.ac.rs

⁴ PhD, Civil Engineering Subotica, University of Novi Sad, Serbia, e – mail: danijel.kukaras@gmail.com

⁵ MSc, Faculty of Technical Sciences, University of Novi Sad, Serbia, e – mail: igordzolev@uns.ac.rs

is an elastic stress field and it can be determined using an elastic analysis. Forming of cracks undermines this stress field, causing a significant redistribution of internal forces that can be modeled by Strut-and-Tie model. Nonlinear behavior of reinforced concrete wall member shown in this paper, designed with "ST method", has been done in Abaqus program. Proposed manner for obtaining of Strut-and-Tie models with software program "ST method", which automatically generates models, calculates forces in elements of equivalent substituting member, designs and controls stress states in elements of the Strut-and-Tie model, is shown in the paper [1]. Behavior model of concrete, which is implemented in Abaqus program, is explained in the next chapter. Analysis was made with the assumption of no bond slip between reinforcement and concrete. Model of stress-strain for reinforcement applied in this paper is bilinear.

2. NONLINEAR BEHAVIOR MODEL FOR CONCRETE AND REINFORCEMENT

Behavior model of concrete that was used in this work, and implemented in Abaqus program, has the name Concrete Damaged Plasticity (CDP) [2]. This model is a continuum, plasticity-based, damage model for concrete, that provides a general capability for modeling concrete and other quasi-brittle materials in structural types, beams, trusses, shells and solids, and uses concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic concrete behavior and it is designed for applications in which concrete is subjected to monotonic, cyclic, and/or dynamic loading under low confining pressures. The plastic-damage model in Abaqus is based on the models proposed by Lubliner et al. (1989) and by Lee and Fenves (1998), and is described in detail in [2] and [6].

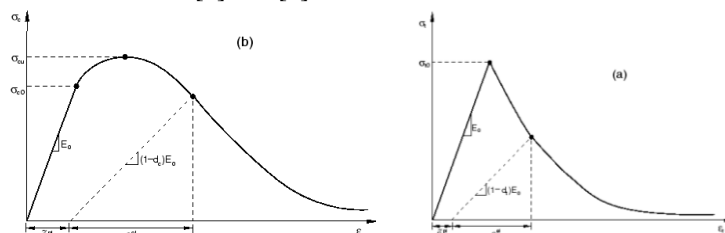


Fig.1. Response of concrete to uniaxial loading in compression (left) and tension (right) [2]

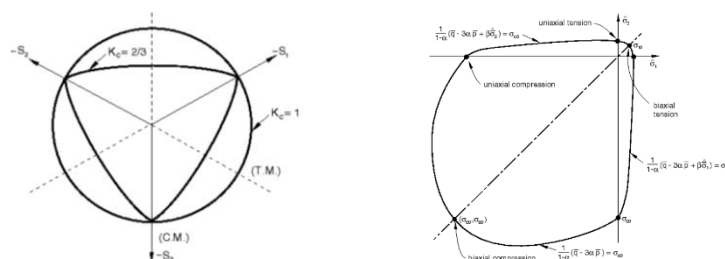


Fig.2. Yield surfaces in the deviatoric plane (left) and yield surface in plane stress (right) [2]

The main failure mechanisms are cracking in tension and crushing in compression. Concrete behavior in uniaxial tension and pressure is shown in Fig. 1, and in Fig. 2 yield surfaces in the deviatoric plane (left) and yield surface in plane stress (right) are shown. For the modeling of the concrete part of the member 2-dimensional finite element CPS4 (assumption of plane stress state) is applied, and for reinforcement modeling finite element T2D2 is applied, [2].

3. NUMERICAL ANALYSIS

Reinforced concrete wall, with a thickness of 40 cm, simple supported member and loaded with ultimate concentrated force of 5000kN in the member middle, is analyzed in this paper, Fig. 3 (left). For the analysis, concrete of class C25/30 is used and reinforcement of quality B500B. Forces in the truss elements of Strut-and-Tie model, and model obtained by "ST method" program, are shown in Fig. 3 (right). Dimensions of bearing plates, rods and nodal zones in Strut-and-Tie model are adopted to satisfy stress and geometric limits that method requires [1].

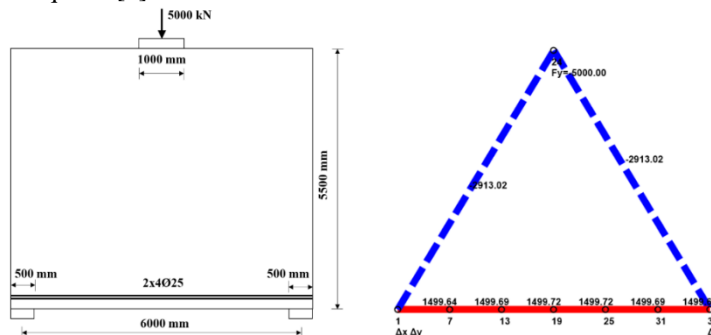


Fig. 3. RC member (left), Strut-and-Tie model (right)

Nonlinear behavior of the wall, with geometrical characteristics as shown in Fig. 3 (left) and the accepted amount of reinforcement obtained by Strut-and-Tie method ("ST method" program), is analyzed by Abaqus program. Relationship between stress and strain for concrete and reinforcement are shown in Fig. 4 in form of Engineering Stress – Engineering Strain. Model parameters of stress-strain relationship for concrete in tension is determined according to the guidelines provided in [5] and [6], Fig. 5.

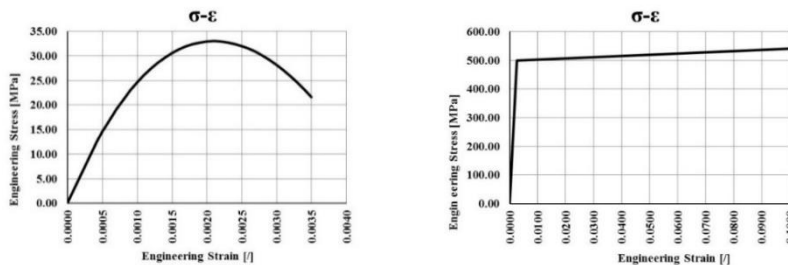


Fig. 4. Stress-strain concrete relationship in pressure (left) and reinforcement (right) in form of Engineering Stress – Engineering Strain [10]

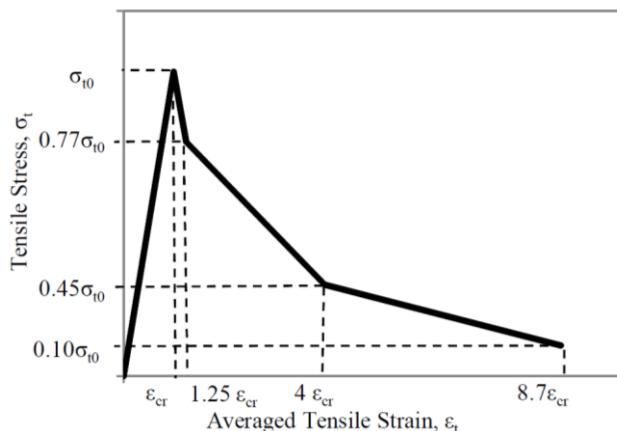


Fig. 5. Stress-strain concrete relationship in tension [5] and [6]

Numerical analysis in Abaqus program was performed on a model with the assumption of a plane stress state. Finite element mesh for concrete part of the member (the size of the finite element is 100x100 mm) and for reinforcement (the size of the finite element is 100 mm) are shown in Fig. 6 (left). Characteristics of the applied CDP model in Abaqus program are determined according to recommendations given in [13] and [14]: $\psi = 56^\circ$, $\epsilon = 0.1$, $f_{bo}/f_{co} = 1.16$, $K_c = 0.667$ and $\mu = 0.0001$. The degraded response of concrete is characterized by two independent uniaxial damage variables, d_c and d_t which can take values in the range from zero (undamaged material) to one (fully damaged material). Values d_c and d_t are determined according to recommendations given in [13].

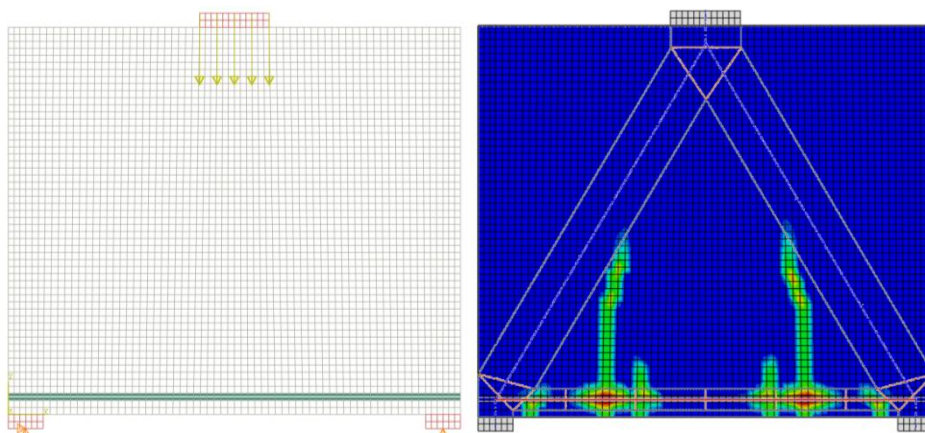


Fig. 6. Finite element mesh (left) and cracks layout and Strut-and-Tie model (right)

Damages layout in concrete part of the member, cracks, are shown in Fig. 6 (right). Also, the final dimensions of the Strut-and-Tie model elements are shown. Fig. 7 shows the graph for the vertical displacements in the middle of the lower member edge. Nonlinear response force-displacement is observed.

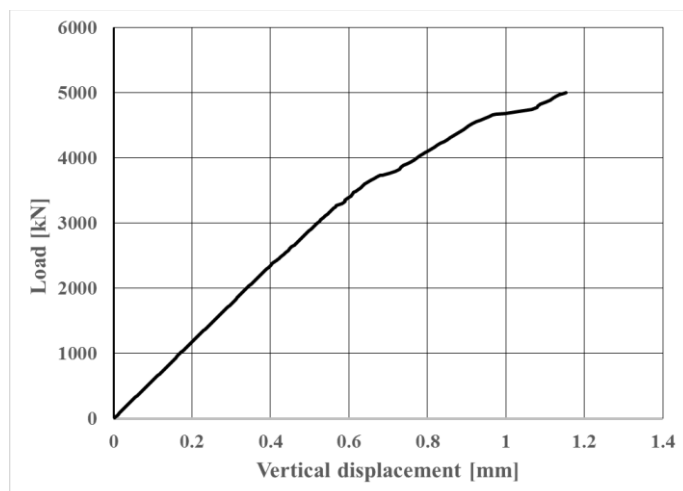


Fig. 7. Vertical displacement in the middle of the lower member edge

Based on the results shown in Fig. 6 (right) it can be concluded that the widths of the Strut-and-Tie model are in accordance with the layout of cracks. It means that damages do not occur in the struts. Also, in the ultimate load achieving, concrete crushing under pressure not happened. Tensile stress in reinforcement during ultimate load is 140MPa. Based on this it can be concluded that there is a substantial reserve in the member capacity of the RC member dimensioned using Strut-and-Tie method. This is consequence of the fact that the Strut-and-Tie model consists of straight elements, connected with hinges. In contrast to such model, in the applied model of RC member in Abaqus program, based on the stress-strain state, it can be notice the shape and position of the Strut-and-Tie model elements, but as these elements are part of the monolithic concrete mass, there is a redistribution of stress and strain within the wall. This has the consequence that in the load transferring, larger member zones are engaged than those included in Strut-and-tie model. Thus stresses and strains will be less then stresses and strains of the Strut-and-Tie model.

4. CONCLUSION

Cracks occurrence in reinforced concrete member distorts elastic stress field which had previously existed, causing a significant redistribution of internal forces. This behavior can be analyzed by Strut-and-Tie model that can be used for the analysis, design and detailing areas in which classical dimensioning is not valid.

Based on the results presented in this paper, it can be concluded that the dimensions of the elements of Strut-and-Tie model determined by "ST method" program are in accordance with the layout of damages obtained with nonlinear analysis of the member behavior in Abaqus program. Also, it can be concluded that there is a substantial reserve in the capacity of RC member designed with Strut-and-Tie method, because in the load transferring, larger member zones are engaged inside the wall analyzed by Abaqus program, compared to zones that are included in the Strut- and-Tie model.

ACKNOWLEDGEMENTS

The research has been conducted within the scientific research project TR 36043, funded by the Ministry of Science of Serbia.

REFERENCES

- [1] Starčev-Ćurčin A., Rašeta A., Brujić Z.: The program ST Method for determining the Strut-and-Tie models of RC plane members, Technical Gazette 23, 1(2016), pp 291-300, ISSN 1330-3651(Print), ISSN 1848-6339 (Online), DOI: 10.17559/TV-20140818132418.
- [2] ABAQUS 2016 Theory Guide, © Dassault Systèmes, 2015.
- [3] Lee, J., and G. L. Fenves: Plastic-damage model for cyclic loading of concrete structures, J. Eng. Mechanics 124(8), pp. 892-900, 1998.
- [4] EN 1992-1-1: Design of Concrete Structures, General Rules and Rules for Buildings, European Committee for Standardization, 2004.
- [5] Wahalathantri, B.L., Thambiratnam, D.P., Chan, T.H.T., & Fawzia, S. (2011) A material model for flexural crack simulation in reinforced concrete elements using ABAQUS., Queensland University of Technology, Brisbane, Qld, pp. 260-264.
- [6] Gilbert, R., & Warner, R. (1978). Tension stiffening in reinforced concrete slabs. Journal of the Structural Division, 104(12), 1885-1900.
- [7] Francisco Lopez-Almansa, Bashar Alfarah, Sergio Oller: Numerical Simulation of RC Frame Testing With Damaged Plasticity Model Comparison With Simplified Models, Second European Conference on Earthquake Engineering And Seismology, Istanbul, Aug. 25-29, 2014.
- [8] Sergio Oller: Nonlinear Dynamics of Structures, Springer, ISBN: 978-3-319-05194-9 (e-book), 2014.

ANALIZA PONAŠANJA AB ZIDA DIMENZIONISANOG STRUT-AND-TIE METODOM

Rezime: U ovom radu analiziran je armiranobetonski zidni nosač statičkog sistema proste grede dimenzionisanog metodom pritisnutih štapova i zatega pomoću programa "ST method". Nelinearno ponašanje nosača prikazano je kroz numeričke analize urađene na pojednostavljenom dvodimenzionalnom modelu sa pretpostavkom o ravnom stanju napona u programu Abaqus. Za diskretizaciju betonskog dela nosača primenjeni su 2-dimenzionalni konačni elementi CPS4, a armatura je modelirana primenom osnovnih štapnih konačnih elemenata.

Ključne reči: ab zidni nosač, Strut-and-Tie metoda, ST method, Abaqus