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RESEARCH ARTICLE | SEPTEMBER 01 2023

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AIP Conference Proceedings 2849, 360005 (2023)
https://doi.org/10.1063/5.0162570

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Experimental and Numerical Analysis of Crack Parameters of Reinforced Concrete Beams

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Abstract. This study deals with experimental and numerical cracking analysis of full–scale reinforced concrete (RC) beams. Four RC beams of the rectangular section were tested under a four-point bending configuration. Crack development of test beams was recorded throughout the pure bending zone using an electronic microscope and digital cameras. Crack pattern has been obtained using digital image correlation (DIC) technique. Numerical analysis of experimental elements at macro level was performed using the finite element (FE) software package ATENA considering a plane stress state with non-linear constitutive laws for concrete and reinforcement. Comparison of experimental and numerical results has shown that FE modelling can be considered as a reliable tool for planning experimental research programs. Adequately developed finite element numerical models of RC members provide the possibilities to insight the tendencies and mechanism of possible crack propagation as well as changes of crack parameters.

INTRODUCTION

The increasing design requirements for modern concrete structures, the increasing intensity of external mechanical effects as well as the aggressiveness of surrounding environment highlighted the need for adequate serviceability models for the analysis of reinforced concrete (RC) structures. Reinforced concrete is an exceptional structural material due to two aspects: the extent of its practical use and the complexity of its mechanical behaviour. The latter characterization is attributed to such phenomena as concrete cracking, shrinkage and creep effects, tension stiffening and etc. [1]. The relatively low tensile strength and cracking resistance of concrete can be identified as one of major structural concerns. The crack opening reduces service life of RC due to promotion of corrosion of the steel reinforcement [2].

A large number of analytical as well as numerical techniques for cracking analysis of RC elements have been proposed and presented for the engineering community [2-4]. However, universal approaches have not yet been developed. The existing models differ in their complexity, versatility, and adequacy [2]. Recently the last author have proposed a new concept of crack analysis of RC members at the stage of stabilized cracking. The mean primary crack spacing is calculated by applying innovative methodology based on compatibility of the stress-transfer and mean deformation techniques. Parameters of crack spacing are obtained by equating mean strains of the tensile reinforcement defined by these approaches. For further development of the new approach accurate experimental data

International Conference of Numerical Analysis and Applied Mathematics ICNAAM 2021
AIP Conf. Proc. 2849, 360005-1–360005-4; https://doi.org/10.1063/5.0162570
Published by AIP Publishing. 978-0-7354-4589-5/$30.00

of RC members are necessary. Alternatively, physical experimental studies can be partially replaced by nonlinear numerical analysis of RC members using calibrated finite element models.

This study deals with experimental and numerical cracking analysis of full–scale reinforced concrete (RC) beams. The aim of research to compare experimentally identified crack patterns to that obtained using finite element analysis. Four RC beams of the rectangular section were tested under a four-point bending configuration. Crack development of test beams was recorded throughout the pure bending zone using an electronic microscope and digital cameras. Crack pattern has been obtained using digital image correlation (DIC) technique. Numerical analysis of experimental elements at macro level was performed using the finite element (FE) software package ATENA considering a plane stress state with non-linear constitutive laws for concrete and reinforcement. Comparison of experimental and numerical results has shown that FE modelling can be considered as a reliable tool for planning experimental research programs. Adequately developed finite element numerical models of RC members provide the possibilities to insight the tendencies and mechanism of possible crack propagation as well as changes of crack parameters.

EXPERIMENTAL INVESTIGATION

The experimental tests were performed in the laboratory of Civil Engineering Faculty at VilniusTECH. The experimental program was aiming at evaluating the effect of section height, reinforcement ratio and bar diameter on cracking, deformation and tension stiffening behaviour of RC beams. The experimental program consisted of testing four full scale reinforced concrete beams by short-term loading. The main characteristics of experimental beams is presented in Fig 1 and Table 1. All specimens were of rectangular section, with nominal span 4000 mm, depth 600 mm and width 310 mm. All beams were tested under a four-point-bending scheme with 1500 mm pure bending zone. The tensile reinforcement consisted of different number of ∅10 mm and ∅20 mm bars assured reinforcement percentage in the range of 0,36% – 1,88%. The clear cover from the longitudinal steel to the nearest concrete surface was 25 mm. All reinforcement bars were fabricated with the steel grade S500. The specimens were cast using an industrially produced C30/37 concrete mix of slump class S4. For determination of the compressive strength and elasticity modulus, Ø150 × 300 mm cylinders were produced. The mean mechanical characteristics of concrete were obtained from the tests of three cylinders.

The monitoring results include continuous identification of cracking process of experimental specimens at different loading levels. These data was recorded on one surface of the beam throughout the pure bending zone using two digital cameras placed on a tripod 0.9–1.2 m from the test specimens. The development of the cracks at each load levels were observed by applying digital image correlation (DIC) technique. The algorithm is based on a comparative analysis of digital images of the structural member captured at different deformation states [5]. A visual detection of the cracks as well as measurements using a digital microscope were also performed in order to verify the data obtained by DIC. Experimentally obtained crack patterns were compared to the results obtained using finite element modelling. The applied load during the test was monitored by load-cell connected to digital data logger.

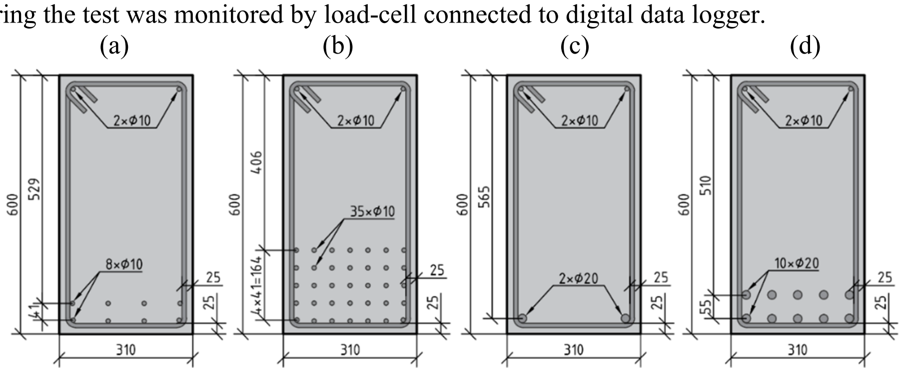

FIGURE 1. Cross section of tested beams: (a) S600-0.37-10; (b) S600-1.81-10; (c) S600-0.36-20; (d) S600-1.88-20

TABLE 1. Main parameters of experimental beams

Beam Notation	h, mm	b, mm	d, mm	a_2, mm	A_{s1}, mm2	A_{s2}, mm2	ρ, %	f_y, MPa	E_s, GPa	Age, days	f_{cm}, MPa
S600-0.37-10	604	308	551	30	628	157	0.37	500	200	48	51.1
S600-1.81-10	605	312	489	30	2749	157	1.81			62	52.5
S600-0.36-20	606	311	565	30	628	157	0.36			47	51.1
S600-1.88-20	605	311	539	30	3142	157	1.88			69	52.5

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NUMERICAL ANALYSIS OF EXPERIMENTAL BEAMS

A nonlinear numerical analysis was performed using the finite element software ATENA. Two-dimensional finite element models of experimental reinforced concrete elements were created employing constitutive models for compressive and tensile concrete and reinforcement. The behaviour of the reinforcement is represented by an elastic–plastic model corresponding to the yield strength of steel and modulus of elasticity. A parabolic diagram was used to model the compressive concrete. Constitutive models proposed by the authors was used to describe the behaviour of concrete in tension. The 3D Non Linear Cementitious 2 User material model (based on SBETA material model offered by ATENA) was utilized. Concrete without cracks is considered as isotropic and concrete with cracks as orthotropic body. Smeared crack and fracture mechanics approaches are combined in ATENA to assess the nonlinear behaviour of reinforced concrete elements after cracking. In this study, the fixed crack model was used. A fracture mechanics approach employed in ATENA for softening behaviour is based on the crack band model. Such a model substantially reduces mesh sensitivity [6, 7]. Finite element models of experimental beams with ∅10 mm bars (S600-0.37-10 and S600-1.81-10) including the loading and support conditions of the test beams are presented in Fig 2.

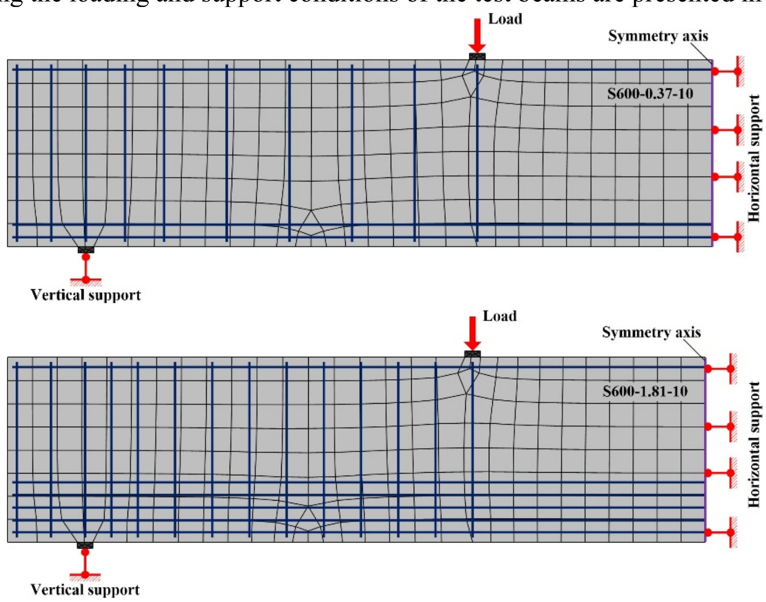

FIGURE 2. Finite element models of beams by ATENA

COMPARATIVE ANALYSIS OF CRACK PARAMETERS

The crack patterns of the pure bending zone of the three selected beams are shown in Fig 3. These schemes were obtained at stabilized cracking stage then all major cracks were formed. The upper patterns were achieved my marking the appeared cracks after testing. The middle obtained by DIC technique. While the bottom were identified using finite elements software ATENA. The comparison of the presented cracks schemes shows good capabilities of DIC and FE applications for cracking analysis of experimental reinforced concrete beams. Both experimentally and theoretically obtained the number of main cracks and the mean distance between the cracks in the pure bending zone are in good agreement. Some slight inaccuracies between the results might be related to the complex cracking processes of the stochastic nature in RC members.

The presented results show that the crack patterns is highly dependent on the diameter and a number of the reinforcement bars. The distance between the cracks decreases with increases in the percentage of reinforcement. It also decreases with decreasing bar diameter. It can be observed that in the beams with a higher reinforcement ratio the major cracks predominate. Meanwhile, in the lightly reinforced beam secondary cracks appear in the zones between the major cracks.

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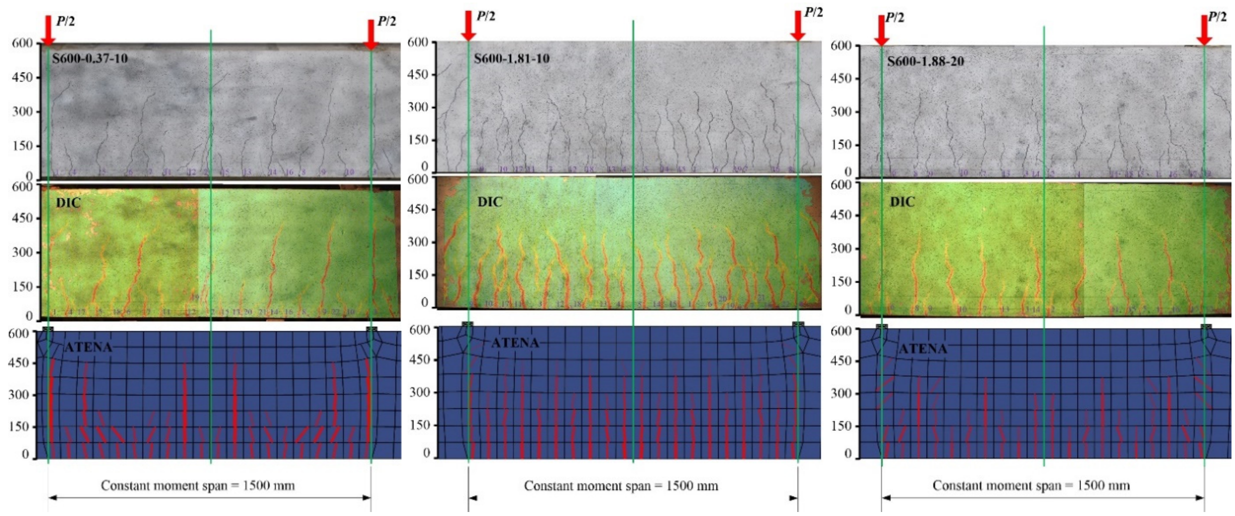

FIGURE 3. Comparison of crack patterns obtained using different methods

The obtained results correspond to the trends in fundamental reinforced concrete mechanics. The achieved accurate results using different techniques have a primary importance for the developing of adequate and innovative mathematical models for cracking analysis of RC members. In this regard, finite element models can serve as a reliable tool for planning experimental research programs. Adequately developed finite element numerical models of RC members provide the possibilities to insight the tendencies and mechanism of possible crack propagation as well as changes of crack parameters.

CONCLUDING REMARK

The study carried out at Vilnius TECH reports test results on cracking of four full-scale RC beams of the rectangular section subjected to a short-term loading under a four-point bending configuration. The monitoring results include continuous identification of cracking propagation of experimental specimens at different loading levels. The development of the cracks at each load levels were observed by applying digital image correlation (DIC) technique. A visual detection of the cracks as well as measurements using a digital microscope were also performed. Experimentally obtained crack patterns were compared to the results obtained using finite element modelling. A nonlinear numerical analysis at macro level was performed using the finite element software ATENA. Experimentally and numerically obtained results are in good agreement and correspond to the trends in fundamental reinforced concrete mechanics. Comparison of experimental and numerical results has shown that adequately developed finite element numerical models of RC members provide the possibilities to insight the tendencies and mechanism of possible crack propagation as well as changes of crack parameters.

ACKNOWLEDGMENTS

The study was performed within project No 09.3.3-LMT-K-712-01-0145 that has received funding from European Social Fund under grant agreement with the Research Council of Lithuania (LMTLT).

REFERENCES

1. G. Kaklauskas *et al*. Constr. Build. Mater. **189(2018)**, 736-744 (2018).
2. G. Kaklauskas, J. Struct. Eng., ASCE **143(9)**, (2017).
3. A. Borosnyoi and G. L. Balazs, Struct. Concr. **6**, 53–62 (2005).
4. R. Ramanauskas, "Primary crack spacing model of reinforced concrete elements," PhD thesis, Vilnius Gediminas technical university, Lithuania, 2019.
5. J.-F. Destrebecq, E. Toussaint and E. Ferrier, Exp. Mech. **51**, 879–890 (2011).
6. D. Rumšys *et al.*, ACI Struct. J. **116(5)**, 17-28 (2019).
7. D. Bačinskas et al., Materials 13(1), 1-13 (2020).

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