NON-LINEAR FINITE ELEMENT ANALYSIS OF STEEL FIBRE SELF COMPACTING REINFORCED CONCRETE BEAMS

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ABSTRACT

Steel fibre reinforced concrete (SFRC) may be defined as a composite material made with portland cement, aggregate, and incorporating discrete discontinuous fibres. The role of randomly distributed discontinuous fibres is to bridge across the cracks which provide post-cracking ductility. Through this study, the models of reinforced concrete (RC) beam were developed by using finite element method to observe and simulate the behaviour of RC beam in terms of cracking pattern and the relationship between shear and deflection. The data on mechanical properties such as tensile strength, compressive strength and flexural strength were adopted from the previous study. By using LUSAS Software, a nonlinear analysis is carried out where three beams were modelled considering the different type of concrete mix namely Normal Concrete (NC), Self Compacting Concrete (SCC) and Steel Fibre Self Compacting Concrete (SFSCC). SFSCC was used where the stirrups were reduced to 50% in order to study the possibility of steel fibre to partly replaced normal stirrups. The analysis observed that the addition of 1% steel fibre by volume in plain concrete with the same number of stirrups produced 37.1% increment in ultimate shear load resistance compared to control sample (NC125). Meanwhile, an appreciable increase in strength was also recorded for the beam with increased stirrups spacing, which is 31.8%. The addition of steel fibre in the concrete mix also improved the ultimate deflection of the beam in the range of 15.6% and 35%. The comparative study between Finite Element Analysis (FEA) and the experimental result showed a small difference range, between 8% and 18%, thus, proving the numerical prediction using LUSAS software.

ABSTRAK

Konkrit tetulang dengan gentian keluli (SFRC) boleh didefinisikan sebagai bahan komposit yang dibuat dengan simen portland, agregat, dan menggabungkan gentian yang berasingan. Peranan gentian keluli yang ditabur secara rawak adalah untuk merentasi keretakan seterusnya memberikan kemuluran semasa pasca-retak. Melalui kajian ini, rasuk konkrit bertetulang (RC) dimodelkan dengan menggunakan kaedah unsur terhingga (FEM) untuk memerhati dan mensimulasikan keadaan rasuk RC dari segi corak retakan dan hubungan antara kekuatan ricih dan lenturan rasuk.Ciri-ciri mekanikal seperti kekuatan tegangan, kekuatan mampatan dan kekuatan lenturan diadaptasi dari kajian terdahulu**.** Dengan menggunakan perisian LUSAS, satu analisis tidak linear dijalankan di mana tiga rasuk dimodelkan dengan jenis campuran konkrit yang berbeza iaitu konkrit biasa (NC), konkrit mampatan sendiri (SCC) dan konkrit mampatan sendiri dengan gentian keluli (SFSCC). Untuk mengkaji potensi gentian keluli dalam mengantikan rakap biasa, SFSCC digunakan di mana rakap dikurangkan kepada 50%. Analisis menunjukkan bahawa penambahan gentian keluli sebanyak 1% dalam konkrit biasa dengan bilangan rakap yang sama menghasilkan kenaikan kekuatan ricih sebanyak 37.1% berbanding dengan sampel kawalan (NC125). Sementara itu, peningkatan kekuatan yang ketara juga direkodkan pada rasuk dengan tambahan jarak rakap, iaitu sebanyak 31.8%. Penambahan gentian keluli dalam campuran konkrit juga telah meningkatkan nilai lenturan rasuk iaitu dalam julat 15.6% dan 35%. Kajian perbandingan antara analisis unsur terhingga (FEA) dan hasil eksperimen menunjukkan perbezaan yang kecil, antara 8% dan 18%. Hal ini membuktikan kesahihan ramalan berangka menggunakan perisian LUSAS.

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LIST OF ABBREVIATIONS

RC	-	Reinforced Concrete
NC	-	Normal Concrete
SCC	-	Self Compacting Concrete
SFSCC	-	Steel Fibre Self Compacting Concrete
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
LUSAS	-	London University Structural Analysis System

LIST OF SYMBOLS

A_S	-	Area of main steel reinforcement
A_{sv}	-	Area of links
E	-	Modulus of elasticity
V_{ult}	-	Ultimate shear capacity
V_f		Fibre volume fraction
V_{fd}	-	Shear contribution from steel fibres
V_{wd}	-	Shear resistance provided by shear reinforcement
$V_{Rd,c}$	-	Shear resistance of concrete
f_y	-	Yield strength

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete has high compressive strength but weak in tension. Thus, it is commonly reinforced with material that is strong in tension such as steel. Over the years, reinforcement solutions to plain concrete in the form of steel bar have been studied in many types of research and applications. Reinforced concrete structures consist of a series of individual members that are interconnected to support the load imposed on them. A complete building can comprise the structural elements such as beams, slabs, columns, walls, foundations and stairs. This study focused on the behaviour of the reinforced concrete beam when subjected to the load. Reinforced concrete beam is a structural member that commonly used in the reinforced concrete structure and particularly in precast structures. Generally, a beam is horizontal members carrying lateral loads. Due to lower tensile strength of concrete, the shear strength of beams can be improved with an addition of steel fibres (SF) in the concrete mix to produce Steel Fibre Reinforced Concrete (SFRC). According to its application, fiber volume percentage and fiber effectiveness, the behaviour of SFRC can be classified into three group; i) very low volume fraction of SF (less than 1% per volume of concrete), ii) moderate volume fraction of SF (1% to 2%), and iii) high volume fraction of SF (more than 2%). Furthermore, steel fibre is one of the materials that are strong in tension which can cooperate with the concrete to improve their strength.

However, with the addition of steel fibre, the workability of concrete will decrease. Further to this, the SCC mixes need a proper proportioning method since steel fibres are reported to affect the shear yield stress and viscosity of fresh SCC. Steel Fibre Self-Compacting Concrete (SFSCC) is recent hybrid materials that collectively combine these two concrete types. The combination of SCC and SFRC contribute to superior behaviour in the fresh and hardened state respectively. With an improvement in flowability of concrete, SFSCC allows the concrete to be poured easily and partially replace the traditional reinforcement bars. In fact, if the amount of fibres that being introduced to the concrete is sufficiently high, the shear capacity of SFSCC structure can be improved. Due to its ability to redistribute the stresses and to bridge cracks with an improvement of the post-cracking behaviour and other mechanical performance, SFSCC becomes a common alternative in both conventional reinforced concrete and precast concrete industry.

The work presented in this study aims to examine the shear behaviour of SFSCC reinforced concrete beam using non-linear finite element method. To describe the non-linear behaviour of the beam, the effect of steel fibres is directly modelled into the existing parameter of concrete that has been reported by previous research. Finite element method is a powerful mathematical tool to analyse the structure. It is proved to be effective in structural engineering where the critical analysis with accuracy is an important parameter. In order to construct a mathematical model for this analysis, the parameter of the beam needs to be identified as they may influence the behaviour of the structure. The parameters could be material and geometric properties of the structure, support conditions and applied loads. In this study, models are generated using LUSAS Software as a tool. This study focused on an application of finite element method of analysis for reinforced concrete beams considering the different type of concrete; Normal Concrete (NC), Self Compacting Concrete (SCC) and Steel Fibre Self Compacting Concrete (SFSCC). The structural behaviour is observed and compared with experimental and theoretical calculation.

1.2 Problem statement

A significant number of studies have been conducted on the shear strengthening of RC beams with an addition of steel fibre in the concrete mix. However, most of these studies have been experimentally based and only few researches are available on the numerical modelling of such beams using the finite element method. The lack of in-depth finite element studies is mostly due to the challenging nature of modelling shear cracking in SFSCC beams and the interfaces between different materials. As consequences of lacking in numerical analysis of SFSCC beams, the purpose of the numerical simulation is to verify the experimental result as well as to avoid tedious experimental work of subjecting the structure to numerous fractures in future research. Besides, due to the high cost required to run the experiment, the finite element can be an option to study the shear behaviour of the beams. Thus, in future research, the time and money can be saved.

1.3 Objectives

There are four objectives that need to be assessed in this study. These are:

i. To distinguish the different properties between NC beam, SCC beam and SFSCC beam in term of mechanical properties based on the experimental test that has been conducted from the previous research.

ii. To develop the 2D model of NC beam, SCC beam and SFSCC beam using nonlinear finite element analysis.

iii. To analysis the structural behaviours of the beam in terms of shear resistances, deformations and cracking patterns.

iv. To compare the result from finite element analysis with experimental and theoretical calculation.

1.4 Scope of work

The models of the reinforced concrete beams were developed by using finite element method to observe and simulate the behaviour of the reinforced concrete beam in term of failure mode, the relationship between shear and deflection and the strain in concrete and steel. The properties for design purpose such as tensile strength, compressive strength and flexural strength are adopted from the previous study. The reinforced concrete beam models were analysed by using LUSAS software. For design purpose, the models were assumed to be limited to 2-dimension analysis modelling and the materials for precast concrete corbel were limited to normal concrete (NC), self-compacting concrete (SCC) and steel fibre self-compacting concrete (SFSCC).

REFERENCES

A.Adeyanju, and K. Manohar. Effects of Steel Fibers and Iron Filings on Thermal and Mechanical Properties of Concrete for Energy Storage Application. *Journal of Minerals and Materials Characterization and Engineering*. 2011. 10(15), 1429-1448.

Abdul Ghaffar, Amit S. Chavhan, Dr.R.S.Tatwawadi. Steel Fibre Reinforced Concrete. *International Journal of Engineering Trends and Technology (IJETT).* 2014. 9 (15). 292.

B. Krishna Rao and V. Ravindra. Steel Fiber Reinforced Self-Compacting Concrete Incorporating Class F Fly Ash. *International Journal of Engineering Science and Technology*. 2010. 2(9), 4936-4943.

Bajic, R. O. and Vasovic, D. Self-Compacting Concrete and Its Application in Contemporary Architechtural Practise. SPATIUM International Review. 2009.20: 28–34.

Banthia, Nemkumar Bindiganavile, Vivek Jones, John Novak, Jeff. Fiber-reinforced concrete in precast concrete applications: Research leads to innovative products. *PCI Journal.* 2012. 33-46

C. Eckard. (2000). Advantages and disadvantages of fem analysis in an early state of the design process. Second Worldwide Automotive Conference. USA.

C.X. Qian, P. Stroeven. Development Of Hybrid Polypropylene Steel Fibre Reinforced Concrete. *Cement and Concrete Research.* 2000. 30, 63–69

Chanh, Nguyen Van. Steel fiber reinforced concrete. *Construction.* 2004. 25(1). 108-116.

D. Fall. R. Rempling, A. Jansson et al. (2012) Non-Linear Finite Element Analysis of Steel Fibre Reinforced Beams With Conventional Reinforcemen. *Befib 2012.* March 2010. Gothenburg, Sweden. 1-12.

Dehn, Frank Holschemacher, Klaus Weibe, Dirk. Self-Compacting Concrete (SCC) Time Development of the Material Properties and the Bond Behaviour. *Leipzig Annual Civil Engineering Report (LACAER).* 2000. 115-124

Gordon Batson. Steel Fiber Reinforced Concrete. *Materials Science and Engineering.* 1976. 25. 53 – 58.

Hamid Pesaran Behbahani. Steel Fiber Reinforced Concrete: A Review. *ICSECM 2011*. 2015. 1(10), 274-276.

J. Yang, J. Lee, Y. Yoon et al. Influence of Steel Fibers and Headed Bars on the Serviceability of High-Strength Concrete Corbels. *Journal of Structural Engineering.* 2012. 138(1), 123-129.

Juli Asni. Shear Strength of Steel Fibre Self-Compacting Concrete In Precast Concrete Corbels. PhD Thesis. Universiti Teknologi Malaysia; 2017.

Keivan Noghabai. Beams of Fibrous Concrete in Shear and Bending: Experiment and Model. Journal of Structural Engineering. 2000. 126(2), 243-249.

L. Xu, Y. Chi, J. Su et al. Nonlinear finite element analysis of steel fiber reinforced concrete deep beams. *Wuhan University Journal of Natural Sciences.* 2008. 13(2). 201-206.

LUSAS. *Modeller Reference Manual- Lusas Version 14.3: Issues 1*. UK: FEA Ltd. 2008.

Okamura, Hajime Ouchi, Masahiro. Self-Compacting Concrete. *Journal of Advanced Concrete Technology*. 2011. 1(1). 5-15.

Ozawa, K. and Ouchi, M. State of the art report on Self-Compactability Evaluation, Materials & Design, Construction, Manufacturing & Concrete 278 Products and Summary of Recommendations & Manuals for Self-Compacting Concrete in Japan. Proceedings of the International Workshop on Self- Compacting Concrete. 1999.

P.L. Domone. A review of the hardened mechanical properties of self compacting concrete. *Cement and Concrete Composites.* 2007. 29(1), 1-12.

Petra Van Itterbeeck, Benoit Parmentier, Bart Craeye and Lucie Vandewalle. Shear Behaviour of Steel Fibre Reinforced Self-Compacting Concrete. *Materials and Structures.* 2016. 38(277), 343-351.

Qian, C., & Stroeven, P. Development of hybrid polypropylene steel fibre reinforced concrete. *Cement and Concrete Research*. 2000. 63–69.

R. Narayan and I. Y. S. Darwish. Fiber Concrete Deep Beams in Shear. *Structural Journal.* 1988. 85(2), 141-149.

S. Cangiano, G. Plizzari, E. Cadoni et al. (2005) On durability of steel fibre reinforced concrete. *International Conference on Cement Combinations for Durable Concrete.* Switzerland.

S. Syed Mohsin, A. Abbas , D. Cotsovos. (2014) Shear Behaviour Of Steel-Fibre-Reinforced Concrete Beams. *11th International Conference on Concrete Engineering and Technology. 12-13 June* 2012. Putrajaya, Malaysia.

Schutter, G. De., Bartos, P. J. M., Domone, P. and Gibbs, J. Self-Compacting Concrete. Scotland, United Kingdom: Whittles Publishing. 2005.

V. Jagota, A. Sethi, K.Kumar. Finite Element Method: An Overview. IOSR Journal of *Dental and Medical Sciences.* 2013. 10(1), 1-8.

Yining Ding, Wolfgang Kusterle. Compressive stress strain relationship of steel fibre-reinforced concrete at early age. *Cement and Concrete Research.* 2000. 30. 1573-1579.