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Blast Analysis of Normal Concrete, High Strength Concrete and Ultra-High Performance Concrete Members

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B.Eng

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Doctor of Philosophy

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Abstract

The understanding of different failure modes of reinforced concrete members is essential in the blast analysis and design of civil and defence structures. Normal concrete (NC) is a widely used material in structures; high strength concrete members (HSC) is undergoing widespread use in civil engineering and construction processes and ultra-high performance concrete (UHPC) is deemed to be a promising material due to its high ductility, impact resistance and energy absorption capacity and it has drawn intense interests for the purpose of blast resistant design of structures. This thesis contains five journal papers, which aim to extend, or produce new analytical techniques for investigating both shear and flexural failure modes of structural members made of these three kinds of materials by considering both experimental and theoretical studies. The thesis has been divided into three chapters. Chapter 1 is the introduction and problem statement of this research work. Chapter 2 contains two journal papers and it provides the absence of method for assessing direct shear failure mode of reinforced concrete (RC) members against blasts. Chapter 3 includes three journal papers, which present experimental and theoretical study of failure modes of high strength reinforced concrete (HSRC) members and ultra-high performance fibre reinforced concrete (UHPFRC) members under explosion loads. Finally, Chapter 4 presents conclusions of this research program.

The experimental investigations on behaviour of reinforced concrete structures subjected to blast loading have revealed that direct shear mechanisms play an important role in the overall response and failure mode of structures. However, most of previous studies are based on the assumption that only flexural response dominates failure mode without taking shear failure into consideration. Therefore, the first journal paper in Chapter 2 is to use single degree of freedom (SDOF) system as a tool for predicting direct shear response of blast loaded reinforced concrete members. In addition, as there are no design provisions that are available to predict shear stress to slip relationship for design of NRC members, the second journal paper assesses direct shear response of NRC members is numerically evaluated using finite element software LS-DYNA, which has not been investigated in the previous literature. The two papers in Chapter 2 provide new insights concerning the mechanics of dynamic shear failure of NRC members against blast loading.

Chapter 3 presents a blast testing program on ultra-high performance fibre reinforced concrete (UHPFRC) and high strength reinforced concrete (HSRC) columns and a one dimensional (1D) finite element model (FEM) is then adopted for further investigations, due to its inherent accuracy and stability despite its numerical efficiency. The third journal paper represented herein is devoted to investigating experimentally the mechanical properties and dynamic responses of ultra-high performance twisted steel fibre reinforced concrete and HSRC columns under both quasi-static and blast loads. Afterwards, the fourth journal paper gives a detailed investigation of the capabilities of ultra-high performance micro steel fibre reinforced concrete columns and high strength reinforced (HSRC) columns against close-in blasts. To achieve this objective, a series of blast tests were conducted to investigate the behaviour of UHPFRC columns HSRC columns subjected to blast loading. Lastly, the fifth journal paper uses 1D FEM to accurately analyse the response of UHPFRC and HSRC columns subjected to blasts.

This thesis deals with a broad range of topics in analysing the static and dynamic response of structural members including RC members, HSRC and UHPFRC columns. The static loading regimes include the direct shear response. The dynamic loading regimes include impulse loading due to real blast experiments. The failure modes under blast loading conditions have been addressed in great details both in experimental study and numerical simulations.

Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Juechun Xu Date

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Finally, I dedicate this thesis to my parents, Xiangming Xu and Buke Zhang who has provided me with the confidence and support to complete my PhD journey to the best of my abilities.

List of Publications

A number of manuscripts, which have been published in, or accepted in, or submitted to, internationally recognised journals and international conferences, have been list as below.

Journal papers:

1. **Xu J.**, Wu C., and Li Z.X. (2014). "Analysis of Direct Shear Failure Mode for RC Slabs under External Explosive Loading". International Journal of Impact Engineering, 69:136-148.
2. **Xu J.**, Wu C., Li Z.X. and Ng C.T. (2015). "Numerical Analysis of Shear Transfer across an Initially Uncrack Reinforced Concrete Member". Engineering Structures, 102:296-309.
3. **Xu J.**, Wu C., Xiang H., Su Y., Li Z.X., Fang Q., Hao H., Liu Z., Zhang Y. and Li J. (2015). "Behaviour of Ultra High Performance Fibre Reinforced Concrete Columns Subjected to Blast Loading". Submitted to Engineering Structures. (tentatively accepted subject to revision)
4. **Xu J.**, Wu C., Su Y., Li Z.X. and Li J. (2015). "Experimental Study on Blast Resistance of Ultra High Performance Twisted Steel Fibre Reinforced Concrete Columns". Submitted to Cement and Concrete Composites.
5. **Xu J.**, Wu C., Li J. and Cui J. (2015). "Simplified FEM Analysis of Ultra-High Performance Fibre Reinforced Concrete Columns under Blast Loads". Submitted to Advances in Structural Engineering (Invited Special Issue paper).

Conference papers:

1. **Xu J.** and Wu C. (2012). "Analysis of the Direct Shear Failure Mode for Elastic Structural Member under External Blasts". The 6th International Composites Conference (ACUN6), 14-16 November 2012, Melbourne, Victoria, CD-ROM.
2. **Xu J.** and Wu C. (2014) "Static and Dynamic Performance of a Newly Developed Steel Fibre-reinforced Self-Compacting Concrete". The 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23). 9-12 December 2014, Byron Bay, Australia, pp.71-76.

3. **Xu J.** and Wu C. (2014). "Experimental Study on the Response of Ultra-High Performance Reinforced Concrete Columns under Blast Loading". The 6th International Conference on Protection of Structures against Hazards, 16-17 October 2014, Tianjing, China, CD-ROM. ***[Highly commendable paper award]***
4. **Xu J.** and Wu C. (2014). "Static and Dynamic Performance of Ultra High Performance Reinforced Concrete Columns". The 13th International Symposium on Structural Engineering (ISSE-13), 24-27 October 2014, HeFei, China, CD-ROM.
5. **Xu J.** and Wu C. (2015). "Experimental Analyses of Ultra-high performance Reinforced Concrete Columns under Blast Loading". The 11th International Conference on Shock & Impact Loads on Structure, 14-15 May 2015, Ottawa, Canada, 393-398, CD-ROM.