

**BEHAVIOUR OF REINFORCED  
ULTRA-HIGH PERFORMANCE  
CONCRETE COMPONENTS  
SUBJECTED TO LOW-VELOCITY  
IMPACT LOADING**

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the degree of

**Doctor of Philosophy**

under the supervision of Doctor Jun Li and Professor  
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## **CERTIFICATE OF ORIGINAL AUTHORSHIP**

I, Jie Wei declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environment Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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## **Abstract**

Key load-bearing reinforced concrete (RC) members might be against accidental impact loadings during their service period. The impact resisting-performance of these structural components shall therefore be properly evaluated for accidental dynamic loads. To ensure the structural safety, there is an increasing need to improve the crashworthiness of key structural components which are at risk from dynamic impact loads. Ultra-high performance fibre reinforced concrete (UHPC) with superior mechanical properties and damage tolerance demonstrated good impact and blast resistance. As an emerging material with a specially formulated mixture, a thorough understanding of its mechanical performance against quasi-static and impulsive loadings is deemed necessary. Towards this aim, a series of well-instrumented experimental tests and high-fidelity numerical studies are conducted in this study. UHPC and its application in structural protective design against low-velocity lateral impact loads are systematically studied.

Chapter 1 presents the background, motivation, objective and outline of the current work.

Chapter 2 provides a literature review on current study of impact load induced structural responses of RC and UHPC members.

In Chapter 3, axially loaded UHPC and RC components with mono fibre reinforcement were tested against lateral impact loads. The drop weight test was carried out through a drop hammer collided the component from varying heights. UHPC components exhibited minor flexural damage, whereas RC components failed primarily by shearing. To further interpret the experimental data, associated numerical simulation was proposed. A Continuous Surface Cap Material model (CSCM) that

considered material triaxial strength, strain rate behaviour, compressive and tensile properties was developed for UHPC material. After numerical validation, the residual loading capacity of the UHPC members after impact loads was investigated through plenty of numerical tests. Impact mass-velocity (M-V) diagram and its equations were proposed to quick assess the damage of UHPC members.

After confirming the effectiveness of UHPC components in resisting the lateral impact loads, fibre reinforcement effect in UHPC was studied to achieve better cost-effectiveness. In Chapter 4, material property tests were conducted on UHPC with varying fibre reinforcing schemes. As compared to mono type fibre reinforcement, hybrid fibre reinforcement demonstrated better mechanical strength, especially the flexural strength. With notched three-point bending test results, tensile softening curves of UHPC were obtained, which was then used to quantify the fracture energy of UHPC strengthening with hybrid fibres. Then, the dynamic behaviour of RC members and UHPC members with mono and hybrid fibre reinforcement were experimentally characterized through the drop weight tests.

The high mechanical strength and material ductility of UHPC enables structural design with reduced section size and alternative reinforcement. New structural designs, including hollow-core UHPC columns, steel wire mesh reinforced UHPC columns, are investigated against impact loads in Chapter 5. The impact performances of these UHPC members were experimentally and numerically examined. With the validated numerical model, energy absorption curves, dynamic shear force and bending moment distribution diagrams were derived. Based on current data, the cracking and shear failure mechanisms of UHPC members were studied.

To date, the application of UHPC in construction is hindered by the raw material cost and lack of design guidelines. Towards a more effective use of UHPC in structural protective design, in Chapter 6, structural strengthening with UHPC overlay was investigated based on drop-weight impact testing. Bonded and unbonded UHPC overlay with the RC component was considered. While both designs can improve the shear resisting performance of RC components, the unbonded strengthening design prevented early tensile cracking in the UHPC overlay; hence maximised the impact resistance and energy absorption of the strengthening overlay.

Chapter 7 summaries the overall findings of the study and discuss future research work.

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## List of Publications during the Candidature

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Wei, J., Li, J., Wu, C., Liu, Z., Li, J., 2021. Hybrid fibre reinforced ultra-high performance concrete beams under static and impact loads. *Engineering Structures*, 245, 112921.

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# Table of Contents

Abstract .....	1
Chapter 1 Introduction.....	11
1.1 Background .....	11
1.2 Objectives.....	15
1.3 Outline .....	16
Chapter 2 Literature Review.....	18
2.1 Impact Load and Its Effects on Reinforced RC Structures.....	18
2.1.1 Impact loads.....	18
2.1.2 Flexure .....	20
2.1.3 Shear .....	29
2.2 Ultra-high Performance Concrete .....	33
2.2.1 Material compositions and properties.....	33
2.2.2 Fibre effect .....	38
2.2.3 Dynamic material behaviour of UHPC.....	41
2.3 Application of UHPC in Protective Design .....	44
2.3.1 UHPC components subjected to impact loads.....	44
2.3.2 Structural strengthening with UHPC.....	47
2.4 Summary and Identification of the Gap.....	49



Chapter 3 Behaviour of Reinforced Conventional Concrete and Ultra-high Performance Concrete Columns under Impact Loading.....	51
3.1 Introduction.....	51
3.2 Experimental Program.....	52
3.2.1 Concrete preparation.....	52
3.2.2 Sample preparation.....	55
3.2.3 Drop weight test setup.....	56
3.2.4 Impact test results.....	58
3.3 Numerical Simulation.....	60
3.3.1 Numerical test setup.....	60
3.3.2 Material properties.....	61
3.3.3 Modelling results.....	74
3.4 Mass-velocity Diagram for UHPC Columns.....	80
3.4.1 Damage criteria for UHPC columns.....	80
3.4.2 M-V diagram for the UHPC columns.....	83
3.4.3 Parametric studies.....	85
3.4.4 Proposed formulae to generate M-V diagram.....	89
3.5 Summary and Identification of the Gap.....	93
Chapter 4 Behaviour of Hybrid Fibre Reinforced Ultra-high Performance Concrete Beams under Impact Loading.....	95
4.1 Introduction.....	95

4.2 Experimental Test Program .....	97
4.2.1 Materials and preparations.....	97
4.2.2 Material test setup and instruments .....	99
4.2.3 Drop hammer impact test.....	102
4.3 Material Test Results and Discussion.....	105
4.3.1 Compressive behaviour .....	105
4.3.2 Flexural behaviour.....	107
4.4 Drop Hammer Impact Test Results and Discussion .....	120
4.4.1 Crack patterns.....	120
4.4.2 Impact force time history .....	122
4.4.3 Mid-span displacement time history.....	128
4.4.4 Discussion.....	130
4.5 Summary and Identification of the Gap.....	131
Chapter 5 Behaviour of Hollow-core and Steel Wire Mesh Reinforced Ultra-high	
Performance Concrete Columns under Impact Loading.....	133
5.1 Introduction .....	133
5.2 Methodology .....	134
5.3 Experimental Investigation.....	135
5.3.1 Material properties .....	135
5.3.2 Specimen construction .....	138
5.3.3 Testing setup.....	141

5.3.4 Impact test results .....	142
5.4 Finite Element Modelling .....	143
5.4.1 Finite element model.....	143
5.4.2 Convergence test and modified boundary condition .....	147
5.4.3 Numerical validation and discussion .....	149
5.4.4 Residual axial capacity test for post-impact column.....	160
5.5 Parametric Study .....	162
5.5.1 Numerical simulation matrix .....	162
5.5.2 Effects of major parameters .....	166
5.6 Summary and Identification of the Gap.....	170
Chapter 6 Behaviour of Ultra-high Performance Concrete Strengthened Reinforced Concrete Beams under Impact Loading .....	172
6.1 Introduction.....	172
6.2 Experimental Program .....	172
6.2.1 Materials.....	172
6.2.2 UHPC-NSC interfacial strength test .....	175
6.2.3 Fabrication and preparations of test specimens.....	179
6.2.4. Test setup and instrumentation .....	180
6.2.5 Test results.....	183
6.3 Numerical Modelling Tests .....	191
6.3.1 Material models.....	191

6.3.2 Numerical simulation drop hammer impact tests.....	194
6.4 Parametric Study .....	207
6.4.1 Numerical simulation matrix .....	207
6.4.2 Effect of key parameters .....	208
6.5 Summary and Identification of the Gap.....	212
Chapter 7 Conclusions and Recommendations for Future Works.....	214
7.1 Brief Summary.....	214
7.2 Conclusion Remarks.....	214
7.3 Recommendations for Future Works .....	215
References.....	217