Penetration Response of Ultra-High Performance Concrete (UHPC) under Projectile Impact

Jian LIU

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School of Civil and Environmental Engineering
Faculty of Engineering and Information Technology
University of Technology Sydney, Australia

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Jian Liu declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

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Print Name: Jian LIU

Signature: Production Note: Signature removed prior to publication.

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ABSTRACT

In recent decades, terrorism activities are becoming increasingly more frequent throughout the world. Terrorist attacks that target military and civil buildings will not only cause structural damages, but also lead to massive casualties and property loss. Therefore, the development of new construction materials with excellent performance to resist extreme loadings has been attracting much attention from researchers and engineers.

Evolving from reactive powder concrete (RPC), novel ultra-high performance concrete (UHPC) materials with nano-material and fibre addition have been developed by many universities and government agencies in these years. With the purpose of enriching the knowledge of UHPC materials subjected to high-velocity projectile penetration, this thesis presents a number of experimental and numerical research findings on UHPC materials in journals.

Prior to real high-velocity projectile impact tests, numerical approaches in simulating the impact response of UHPC targets under projectile penetration are presented. The numerical models of UHPC targets are validated against the uniaxial compressive and four-point bending testing results. With the validated numerical models incorporating dynamic increase factors (DIF), parametric studies on the effects of target compressive strength, projectile striking velocity and projectile Calibre Radius Head (CRH) ratio on depth of penetration (DOP) and crater diameter of UHPC targets are discussed. Based on the simulation data on DOP, an empirical model to predict DOP of UHPC targets is proposed.

High-velocity projectile impact tests are then conducted on UHPC targets reinforced with 3 Vol-% ultra-high molecular weight polyethylene (UHMWPE) fibres and UHPC targets with 3 Vol-% steel fibres. Under the same loading scenarios, plain concrete targets without the addition of fibres are also tested as control specimens for comparative purpose. Dynamic behaviours of concrete targets involving DOP, crater diameter, volume loss as well as abrasions and damages of projectiles after impact are observed and compared with the numerical results. Also, DOPs of UHPC targets are compared with the previously proposed empirical model and the fair agreement is achieved in terms of UHPC targets with steel fibres.

Although UHPC reinforced with steel fibres has been a promising material with excellent impact resistance which can be directly used in the structural components in civil and military constructions, the high cost of steel fibres may limit the use of UHPC in military and civil constructions, so an extended investigation of steel wire meshes with relatively low cost to replace steel fibres in UHPC is necessary. In this thesis, the impact responses of 44-layer steel wire meshes reinforced RPC targets such as DOP, crater diameter, volume loss as well as abrasions and damages of projectiles after impact are investigated under the same loading environment as UHPC targets.

In order to comprehensively understand the effects of steel wire meshes on the impact response of reinforced RPC targets, parametric studies are conducted after validating numerical models, in which the variables include configuration of whole steel wire meshes, number of layers, space between two layers, space between two steel wires per layer as well as the diameter and tensile strength of steel wires. Based on the results of parametric studies, an empirical model derived from the simulation data is proposed to predict DOP of reinforced RPC targets.

Simultaneously, optimal structural designs with effective reinforcement configurations are under extensive investigation to enhance the impact performance of UHPC targets. A numerical approach is used to investigate the impact response of uniformly distributed ceramic balls as a shielding structure on UHPC targets under high-velocity projectile penetration. Parametric studies are conducted on thin UHPC slabs to explore the influence of impact location, diameter, spatial arrangement and material properties of ceramic balls on impact response. Perforation and ballistic limits of ceramic balls protected thin UHPC slabs are obtained. Besides, DOPs of thick UHPC slabs protected with 6-layer ceramic balls with a diameter of 20 mm in a hex-pack arrangement are compared with existing UHPC targets.

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LIST OF PUBLICATIONS

1) Liu, J., Wu, C., Li, J., Su, Y., Shao, R., Liu, Z. and Chen, G., 2017. Experimental and numerical study of reactive powder concrete reinforced with steel wire mesh against projectile penetration. *International Journal of Impact Engineering* **(Impact Factor: 2.938)**, 109, pp.131-149.
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2) Liu, J., Wu, C., Su, Y., Li, J., Shao, R., Chen, G. and Liu, Z., 2018. Experimental and numerical studies of ultra-high performance concrete targets against high-velocity projectile impacts. *Engineering Structures* **(Impact Factor: 2.755)**, 173, pp.166-179.
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3) Liu, J., Wu, C. and Chen, X., 2017. Numerical study of ultra-high performance concrete under non-deformable projectile penetration. *Construction and Building Materials* **(Impact Factor: 3.169)**, 135, pp.447-458.
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4) Liu, J., Wu, C., Li, J., Su, Y. and Chen, X., 2018. Numerical investigation of reactive powder concrete reinforced with steel wire mesh against high-velocity projectile penetration. *Construction and Building Materials* **(Impact Factor: 3.169)**, 166, pp.855-872.
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