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学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　YIN HOR

学　位　論　文　題　名

Structural Behaviour of Composite RC Members Strengthened with UHPC Subjected to Static and Dynamic Loading
(静的および動的荷重を受ける超高性能コンクリートで補強された鉄筋コンクリート複合部材の構造挙動)

Ultra-high performance concrete (UHPC), a mix of reactive powder concrete with steel fibres, is an advancement in concrete technology. It can be defined by its excellent properties of UHPC including high strength, strain hardening, low permeability and energy absorption. Over the last two decades, UHPC is commonly used in protective structures, as non-penetrable coverings and in elements that must be durable against aggressive environments and severe loadings such as earthquakes, impacts or blasts. In addition, strengthening reinforced concrete (RC) members with UHPC can be an emerging technique for design, strengthening and protecting new or existing structures. Moreover, UHPC has shown high bond strength and good adherence to normal-strength concrete (NSC) substrates. Recently, UHPC has been used for strengthening parts of structures where the outstanding properties of UHPC could be fully exploited in full-scale site applications. Although UHPC has been considered as a potential tool in retrofitting or repairing existing RC structures, investigation on the behaviour of UHPC-concrete composite members is very limited. In addition, research on non-composite UHPC structural members subjected to dynamic loading is relatively scarce, and dynamic response of composite UHPC-concrete members has not yet been performed in the previous literature.

This dissertation aims to further understand the structural behaviour of composite UHPC-concrete members under static and dynamic loading. In order to accomplish this aim, five specific objectives are carried out: (1) to investigate the structural behaviour of composite UHPC-concrete slabs under static loading through the experimental study; (2) to develop the finite element (FE) modelling for the flexural behaviour of UHPC members under static loading; (3) to predict the behaviour of UHPC-concrete slabs using FE modelling under static loading; (4) to figure out the numerical response of composite UHPC-concrete members subjected to dynamic loading; and (5) to evaluate the prediction method for the capacity of composite UHPC-concrete members. In this dissertation, experimental program was carried out for the investigation of the structural behaviour. An FE modelling was developed. For dynamic behaviour in this study, blast simulations were conducted to investigate the influence of UHPC strengthening layer on the blast resistance capacity of composite UHPC-concrete members. Calculation method of the structural capacity of composite UHPC-concrete members was proposed. This dissertation is structured into eight chapters as follows.

Chapter I is the introductory chapter. This chapter clarifies the research background, critical review, and research objectives.

Chapter II presents the experimental program, and results and discussion. In this chapter, UHPC material was developed. After several trials, the best performance of UHPC was chosen and used for casting onto the tension zone of conventional RC members. A total of nine specimens of non-composite and composite RC slabs strengthened with various UHPC strengthening configurations were tested. Of nine specimens, seven slabs were composite UHPC-concrete members. The others were non-composite RC or UHPC members conducted for reference. All specimens were tested under static loading. To evaluate the behavioural response, the specimens were grouped into two series. The first, a rehabilitation series, tested UHPC as patch material for repairing deteriorated concrete structures. The second, a UHPC overlay series, was used to retrofit soffits of RC members. Results showed that UHPC layer, in rehabilitation series, prevented against the diagonal shear cracks shown in conventional RC slabs. The composite UHPC-concrete specimens revealed an excellent energy absorption with extensive deflection hardening and ductility during the post cracking range. In UHPC overlay series, each specimens showed diagonal shear cracks and debonding of UHPC. The ultimate capacity increased as the UHPC overlay thickness increased.

Chapter III addresses an FE model to predict the behaviour of UHPC members under static flexural loading. A concrete damage model based on plasticity constitutive model for concrete and an implicit solver in commercial FE software LS-DYNA were adopted in the numerical simulation. Experimental data for 21 UHPC flexural specimens tested in the present study and in previous works were used to validate the proposed FE model and modelling technique. Results revealed that the developed FE model was able to accurately predict the experimentally obtained ultimate strength, stiffness, and hardening and softening behaviours of the specimens.

Chapter IV focuses on an improved FE model developed for the prediction of the structural behaviour of RC members strengthened with UHPC. The model was validated using experimental data. Accurately representing the interfacial bond characteristics of composite UHPC-concrete members was the main challenge in developing the modelling technique. A novel technique using equivalent beam elements at the interface between UHPC and NSC substrate was proposed for this purpose. The material properties of the equivalent beam elements were defined to represent the equivalent bond characteristics of NSC. The structural response of composite UHPC-concrete members was effectively predicted with good accuracy using the developed FE model.

Chapter V investigates the dynamic behaviour of RC strengthened with UHPC obtained using the developed FE modelling. For dynamic response, blast simulation was performed using explicit method. The blast model was validated with test data of non-composite RC or UHPC members available in the literature. For composite UHPC-concrete member, the blast simulations were carried out to investigate the influence of UHPC strengthening layer on the blast resistance capacity of the composite members. The effectiveness of UHPC layer of composite UHPC-concrete members was demonstrated through comparing the results with reference non-composite RC and UHPC members under same blast loading.

Chapters VI and VII introduce methods based on application of existing design codes for predicting the shear and flexural capacity of composite UHPC-concrete members, respectively. Six different methods were individually investigated for shear strength. Three of them were adopted by converting the volume fraction of steel fibres used in UHPC as an equivalent longitudinal steel ratio. Other three methods computed the shear strength as a sum of two components of shear contributions provided by RC member and by UHPC layer; and each of the components was independently calculated. For flexural strength, a simple method was adopted based on the existing design models. The rectangular stress block diagrams for compression and tension zone of the conventional concrete and UHPC layer in the composite section were assumed, respectively. The proposed methods were found to be able to fairly predict the structural capacity of composite UHPC-concrete members compared to the experimental results.

Chapter VIII is the conclusion chapter. Through the results and discussion in the present study, it could be concluded that the understanding of the behaviour of composite RC members strengthened with UHPC was expanded. The influence of UHPC strengthening layer and the bond strength between UHPC and NSC were figured out. Importantly, it was found that the behaviour of composite UHPC-concrete could be effectively and efficiently predicted using the developed FE model. In addition to the conclusions, this chapter also lists some recommendations for the future study.