Numerical Assessment of Ultra-high Performance Concrete Material

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Abstract. This paper presents numerical assessment of ultra-high performance concrete (UHPC) material using finite element (FE) method. Since UHPC is a relatively new material with superior strength and energy absorption, the concrete models on UHPC in FE analysis are not fully capturing behavior of UHPC. In this study, the calibration of concrete models for UHPC is exploited. The calibrated models show their capability to capture the response of UHPC material quite well compared with experiment. More details of results are discussed.

1. Introduction

Ultra-high performance concrete (UHPC) is a new advancement material in the construction industry. UHPC offers superior properties, such as ultra-high strength of 150–200 MPa, extremely less voids, low permeability, durability enhancement and energy absorption \cite{1-3}. Because of its exceptional properties, UHPC is suitable for the protective structures under severe loading such as earthquakes or blasts \cite{4} and its use has recently been extended into the rehabilitation of concrete structures \cite{5}. An overview on UHPC from recent research studies has been provided in this paper. To understand the behavior of such structures in finite element (FE) method, prior study of UHPC material may be necessary because of its unique properties and until now there is no general solutions in FE calculation. Therefore, more research on calibrated models for UHPC is needed. This paper is intended to report the results from numerical analysis of UHPC material in FE model calibration. More information about the calibrated models are further discussed.

2. Overview on UHPC

2.1. UHPC as Rehabilitation Material for RC Structures

Rehabilitation and strengthening of deteriorated concrete structures is a relatively new technique. There are several studies on mechanical properties of UHPC and its strengthening applications \cite{5-8}. Brühwiler and Denarie \cite{5} carried out four applications of UHPC for the protection of crash barrier wall, strengthening of highway bridge, bridge piers, and industrial slabs. Later, the studies on UHPC strengthening RC members have been conducted extensively \cite{6-8}. The results showed that UHPC enhanced overall response of structures.

2.2. Structural Response of UHPC.
Many of the structural tests on UHPC were under static loading condition [9]. Beyond affordability for full-scale tests, only a handful of them were conducted under impact or blast loads [4, 10, 11]. In general, the resistance of structural UHPC elements have demonstrated to be superior in terms of strength, durability and ductility compared with normal and high strength concrete.

2.3. Vibration Control of UHPC Structures
A tuned mass damper (TMD) is often used to reduce vibration affecting the structures. Due to its superior properties, UHPC structures can significantly minimize the height of the bridge decks which could be more vulnerable to the vibrations. Chin et al. [12] have introduced TMD on the parapet of the UHPC pedestrian cable stayed bridge. Based on their record, TMD reduced the acceleration about 30% when two pedestrians were crossing the bridge [12]. This implies that combinations of UHPC material and vibration control techniques, such as tuned mass dampers (TMDs), make it possible to construct thin and long span bridge structures. In addition, high strength fiber reinforced concrete members are expected to be used as a hysteretic damper for energy dissipation against strong earthquakes owing to its high ductility [13]. The application of vibration control technology and use as a vibration damping device, both sides of the development can be expected to UHPC structures.

3. FE Model of UHPC Material
In this study, finite element (FE) method was employed by using commercial computing software, LS-DYNA [14]. LS-DYNA is often used to simulate severe loading such as impact or blasts in explicit FE calculation numerically [4]. However, it can also be used for static loading condition by activating implicit control cards. Owing to the unique properties of UHPC, the calibration model is needed. In this paper, the calibrated model was based on three-point bending tests conducted in laboratory in Universiti Teknologi PETRONAS, Malaysia, to assess its performance. This specimen has a standard size with cross-section of 100 by 100 mm and a clear span of 400 mm.

Several concrete material models are available in LS-DYNA. In this study, only a concrete damage model, also known as Karagozian & Case (K&C) model [15] (MAT_73R3 in LS-DYNA) was used.

3.1. Automatic Generation of Parameters
The advantage of K&C model is that it requires only the compressive strength of concrete to input the material cards. All remaining parameters may be calculated as functions of the concrete strength. However, some parameters are changeable to represent the actual material test results such as tensile strength of concrete, FT, and tensile softening parameter, b2. The default parameters generated from K&C model are based on the concrete compressive strength of 45.4 MPa, but in this study the compressive strength of UHPC of 138.8 MPa is highly different. Therefore, a study on model calibration in this context may be needed. One possibility is to study, for instance, the effect of b2. The tensile strength of UHPC is set to 11 MPa.

3.2. Equation of State (EOS)
EOS tabulated compaction is required for the K&C model. This EOS is written in form of pressure-volumetric strain relationship as follows:

\[ P = C(\varepsilon_v) + \gamma T(\varepsilon_v)E \]  

(1)

where \( \varepsilon_v \) is the volumetric strain given by the logarithm of the relative concrete volume. Bulk modulus is a function of volumetric strain. Because Young’s modulus may be calculated in corresponding to bulk modulus, thus, the technique of using EOS model reflects the Young’s modulus resulting in development of the correction of the UHPC stiffness as seen in Fig. 1(b). Detailed description of notations in Eq. (1) above could be found in [16].
4. Analytical Results and Discussion

Fig. 1 shows the analytical results of load-displacement relationships obtained from numerical FE model compared with laboratory experiment. A test damage and a graphic presentation of effective plastic strains from FE model are shown in Fig. 1(c) and (d), respectively.

From Fig. 1(a) and (b), the results obtained from FE model based on the default value of parameter, b2, (b2 = 1.35) are illustrated in different responses. As seen in Fig. 1(a), use of automatic parameter generation gave a stiffer stiffness compared to experiment; meanwhile in Fig. 1(b), use of EOS shifted the model curve very closely to the actual experimental result. However, both cases showed significantly lower peak loads than those obtained from the experiment.

Several cases of modified b2 were further investigated in this study. Results of the effect of b2 obtained from the automatic parameter generation and from the use of EOS are shown in Fig. 2 and 3, respectively. From Fig. 2 among all the cases, b2 = -25 gave a reasonable result compared to the experiment. When the load increased from zero up to about 25 kN, the stiffness was similar to other cases of b2; but above 25 kN, the analytical result of b2 = -25 has shifted to the experimental position and agreed very well to the peak load as seen in Fig. 2(d). It can be also noted that negative values of b2 influenced very much on the peak load result.

On the other hand, Fig. 3 shows the results of another simulation method by using EOS to adjust the stiffness of element. From this analysis, results demonstrate a very good agreement on the UHPC stiffness for all studied values of b2, except b2 = -25. In Fig. 3, the best fitting curve goes to Fig. 3(b) which b2 is equal to -5. Similarly, to the automatic parameter generation, the peak load was influenced very much by b2 compared to the default value of b2 (b2 = 1.35).
5. Conclusions

UHPC is a novel material in construction industry and it has potential for use in protection and strengthening of structures. In this paper, FE model calibration using LS-DYNA for UHPC material based on the three-point bending tests was presented. From this study, the following conclusions could be made:

1. The results from the FE models showed that the K&C model with the automatic parameter generation was capable of simulating the peak load of UHPC material with a good agreement to experimental results by setting of appropriate b2 parameter.

2. The analysis based on equation of state (EOS) tabulated compaction in the K&C model showed very good results for both the peak load and the stiffness of UHPC material.

6. References

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