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Experimental study of flax fibre reinforced polymer (FFRP) strengthened concrete plate under impact loading

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Abstract

Devastating impact, e.g. falling parapet on a canopy, during strong earthquakes can cause severe damage to structures in the surroundings or even fatalities. This has been observed in many major earthquakes, especially in the case of unreinforced masonry structures. To prevent damage resulting from such an impact loading mitigation measures need to be developed. In this study protective concrete components strengthened by flax fibre reinforced polymer (FFRP) are considered since the impact behaviour of this natural fibre reinforced concrete has not been investigated. The impact properties of the wrapped FFRP strengthened concrete plate were studied through a series of drop-weight tests. The corresponding plain concrete specimens were used as references. The parameters, i.e. impact force, deflection and damage pattern were considered to assess the behaviour of FFRP strengthened concrete plate under an impact loading. Impact resistance was investigated by evaluating the energy absorption of the specimen. The results show that the impact resistance of FFRP strengthened concrete is significantly higher than that of plain concrete. Damage pattern of FFRP concrete plate is different from plain concrete. The study also reveals the influence factors that control the energy dissipation of the specimen which will be used for developing future environmentally friendly protective structures in earthquake regions.

Keywords: Drop-weight impact, fibre-reinforced concrete, flax fibre reinforced polymer

1. Introduction

Natural fibre reinforced composites have been increasingly studied in recent years due to the advantage of the natural fibres. Natural fibres are considered as environmentally friendly, low-cost and renewable. Many researches have focused on the static properties of natural fibre reinforced concrete. For instance, Majid et al. [1] studied coconut fibre reinforced concrete (CFRC) and concluded that coconut fibre enhanced the tensile strength of the composites. Yan and Chouw [2] carried out research on the properties of flax fibre reinforced polymer (FFRP) tube encased concrete composites. The results indicated that flax fibre reinforced polymer substantially increased the strength of the composite. Li et al. [3] discussed the behaviour of hemp fibre reinforced concrete (HFRC) and recommended that HFRC is suitable for pavements. In recent years, some researchers paid attention to dynamic behaviour of natural fibre reinforced concrete structures under dynamic loading. The impact load can be e.g. falling parapet on a canopy, during strong earthquakes that can cause severe damage to structures in the surroundings. This has been observed in many major earthquakes, especially in the case of unreinforced masonry structures. Consequently, impact behaviour of natural fibre reinforced concrete composites need to be investigated.

Not many studies have been conducted on the impact behaviour of fibre reinforced concrete slabs . Rao et al. [4] compared the impact behaviour of slurry-infiltrated fibrous concrete (SIFCON) slabs of different fibre volume. The results indicated that the energy-absorption capacity of SIFCON slabs increases with the fibre volume. Hrynyk et al. [5] carried out research on the steel fibre reinforced concrete slabs under repeated high-mass low-velocity impact. As anticipated the slabs exhibited superior performances under impact loading when compared with non-fibrous slabs. The failure behaviour of the slabs was determined by the global deformations.

Some studies have been carried out on the impact behaviour of natural fibre reinforced concrete. Impact properties of short discrete jute fibre reinforced concrete (JFRCC) were investigated by Zhou et al. [6], and the study showed that fibre pull-out occurs in JFRCC during impact loading. Wang et al. [7] carried out an impact experiment on bamboo fibre reinforced concrete slab. The results showed that bamboo fibre reinforced concrete can improve the impact strength of the fibre-concrete composite. The impact resistance of the four types of natural fibre (sisal, coir, jute and hibiscus cannebinus) reinforced cement mortar slabs was considered by Ramakrishna and Sundararajan [8]. Their works indicated that coconut fibre reinforced mortar slabs have the highest capability to absorb impact energy in comparison with other types of fibres. Wang and Chouw [9] carried out the preliminary study on the coconut fibre reinforced concrete. The results showed that the addition of the coconut fibre can enhance the impact resistance of the composite. However, the study of concrete components reinforced by both internal fibre and external FRP has not been reported. The study presented in this paper focuses on the behaviour of coconut fibre reinforced concrete slab strengthened by the flax fibre reinforced polymer under the drop-weight impact.

2. Experimental work

2.1 Materials

In this study, two kinds of fibres were used, i.e. coconut fibre and flax fabric. The coconut fibre is mixed with the concrete as an internal reinforcement. The properties of the coconut fibre are shown in Table 1. The flax fabric is bonded to the concrete component using epoxy resin. The properties of the flax fabric and the epoxy are displayed in Table 2.

Table 1 – Mechanical properties of coir fibre [10]

Properties	Coconut fibre
Average diameter (mm)	0.25
Length (mm)	50

Density (g/cm^3)	1.20
Tensile modulus (GPa)	2.74
Tensile stress at break (MPa)	286
Tensile strain at break (%)	20.8

Table 2 – Properties of the flax yarn, epoxy and flax/epoxy composites

Material	**Flax yarns**	**Epoxy system**	
		Resin	**Hardener**
Density (g/cm^3)	1.43	1.123	0.936
Mix ratio by weight (%)	--	100	26
Tensile strength (MPa)	145	73	
Tensile modulus (GPa)	16	3.5	

2.2 Specimens preparation

The coconut fibre reinforced concrete (CFRC) is consisted of the following materials: ordinary cement, sand, aggregate, water and coconut fibres. The size range of aggregates is 7-13 mm. The mix ratio of CFRC was 1:0.48:2:2 for cement: water: sand: aggregate, respectively. The fibres were added to the mixture and the same amount of aggregates was deducted from the total mass of aggregates. The fibre amount of 3% is calculated by cement mass. Preparation procedures of CFRC can be found in detail in the article by Ali et al. [1]. The test specimens include CFRC and FFRP-CFRC slabs with a dimension of 300 x 300 x 100 mm.

The FFRP-CFRC specimen is made by the CFRC panel with flax fibre reinforced polymer (FFRP) attached throughout the tensile side. Two-layer of FFRP with a thickness of about 3 mm were considered. Preparation of FFRP was conducted using hand lay-up method.

2.2 Drop-weight Impact Test

Impact tests were carried out using a drop weight on the strong floor in the test hall of the University of Auckland. Fig. 1 shows the drop-weight impact test setting up. This impact device can reach a maximum drop height of 2600 mm. The drop weight can be varied between 30 kg and 200 kg. The measurement system includes PCB dynamic load cell and accelerometers, which were monitored to record the impact force as well as the acceleration of the specimens, respectively. The load cell was put at the centre of the specimen, which has a measurement range of 222.4 kN and the frequency limit is 30 kHz. The accelerometer, with a capacity of ±10000 g, was affixed underneath the centre of plates using epoxy. The data acquisition system consists of a signal conditioner (Model 482C05 by PCB Piezotronics) for dynamic cells, an accelerometer signal conditioner (assembled by the Department of Civil Engineering, University of Auckland) and a computer. The data acquisition was at a rate of 50 kHz for this study.

In this experiment, a drop weight hammer with a flat striking face with a diameter of 100 mm was used, with a mass of 40 kg was applied. The specimen was clamped at the four corners. A dynamic load cell was put at the centre of the sample to measure the impact force induced by the drop weight. For the impact test, a drop height of 300 mm was used. Repeated impact was conducted till the failure of the specimen.

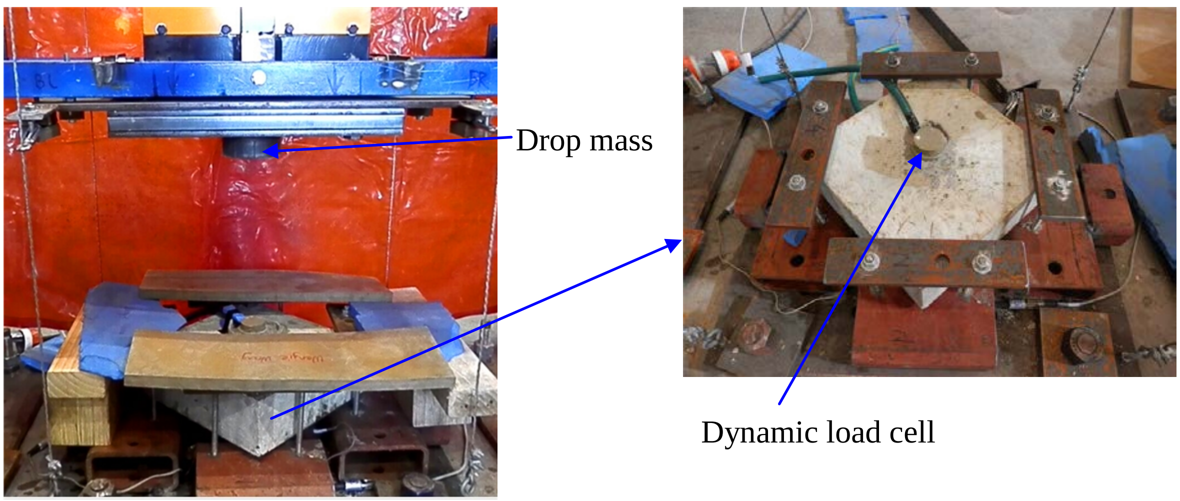


Fig. 1 – Setting up of the drop-weight impact test

3. Results and Discussion

3.1 Force-time history

Fig.2 shows the impact force history of the CFRC slab. Only one impact was applied on the CFRC slab and the specimen failed. The impact duration is about 0.002 s and the measured peak impact force was about 100 kN. Compared with the FFRP-CFRC slab, the impact force develops differently. Firstly, the FFRP-CFRC slab experienced three times of impact loading (Fig. 3). With the 1st impact loading, the maximum impact force measured was about 110 kN. The maximum impact force decreased with the numbers of impact. The maximum forces were about 100 kN and 80 kN with the 2nd and 3rd impact, respectively. This phenomenon could be due to the damage to the specimen. The degree of damage to the specimen increased gradually with the increasing of the numbers of the impacts, resulting in a decrease of the impact load bearing capacity. In addition, the impact duration of FFRP-CFRC slab is different from that of the CFRC slab. The impact lasted about 0.004 s, which is much longer than that of the CFRC slab.

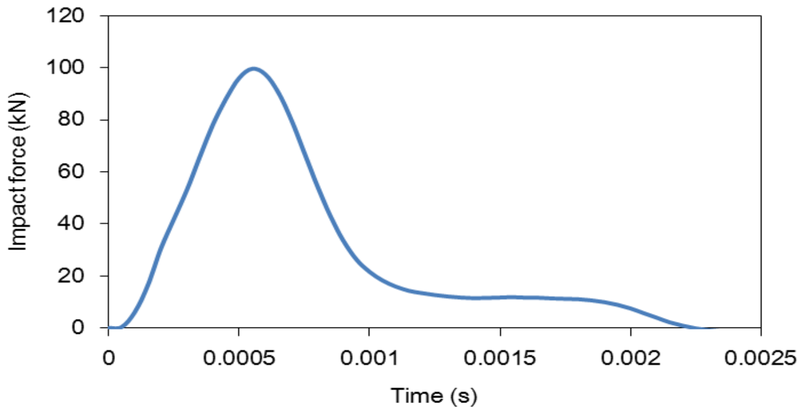


Fig. 2 –CFRC slab force time history

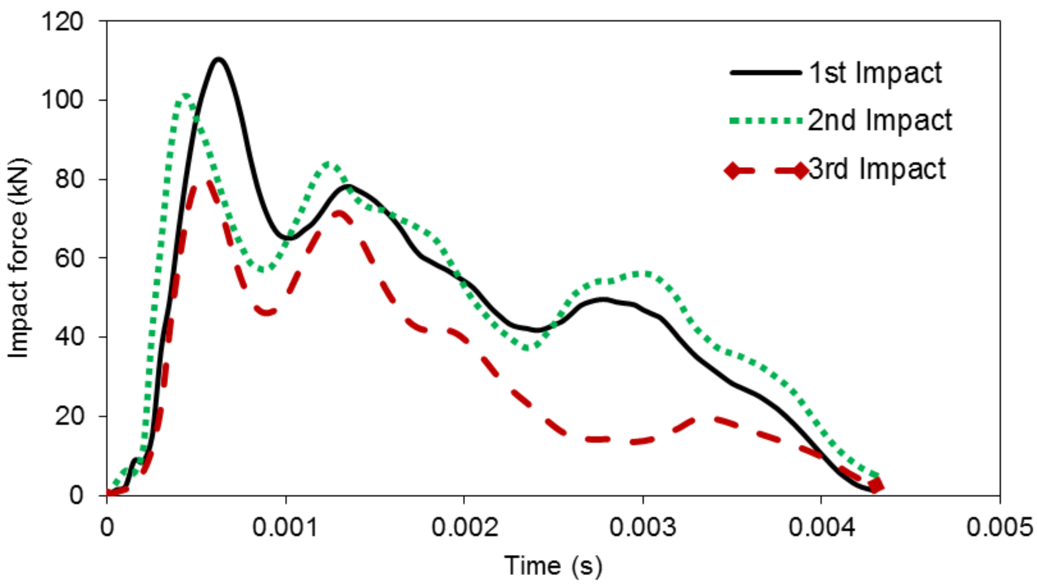


Fig. 3 – FFRP-CFRC slab force time history

3.2 Accelerations and force-deflection curves of the FFRP-CFRC specimen

The accelerometer was attached at the mid-point of the FFRP-CFRC slab to measure deformation. The velocity and deflection histories at the mid-point were obtained by integrating the acceleration history with respect to time using the following equations:

$$\dot{u}(t) = \int \ddot{u}(t)dt \tag{1}$$

$$u(t) = \int \dot{u}(t)dt \tag{2}$$

where

$\ddot{u}(t)$: Acceleration measured from the mid-span

$\dot{u}(t)$: Velocity at the mid-span

$u(t)$: Deflection at the mid-span

Taking into account the noise influence during the high-frequency impact, the frequency-domain analysis was applied to obtain smooth and reliable data [11]. The original acceleration data were filtered in a digital low-pass filtering with a cut-off frequency of 4 kHz. It is observed that the velocity and deflection curves derived from filtered data are similar to those obtained from original data. The results confirmed that the signal at high frequency could be ignored as its slender influence on the specimen response, and therefore a set of 4 kHz of cut-off frequency can be applied in the following analysis.

The measured accelerations of the FFRP-CFRC slab with three impacts were displayed in Fig. 4. Fig. 5 shows the deflection-force curves of the specimen due to three impacts. It is observed that the specimen had the largest impact force but smallest deflection under the 1st drop-weight impact loading. With the 2nd impact, the impact force decreased to 100 kN but the deflection showed the largest value. The specimen showed a similar deflection in the 3rd impact as that during the 2nd impact, while the 3rd impact force was the smallest at this case with the fracture of the slab. This can be explained by the deflection development of the specimen. The load bearing ability related with the deflection of the slab. With the repeated impact, the specimen deformed gradually till the ultimate deformation was achieved. Under the 1st and 2nd impact, the specimen had a relatively high load bearing ability between 100-110 kN and the deformation increased to 0.5 mm at the 2nd impact. However, in the 3rd impact the force decreased to 80 kN, the deflection decreased to 0.4 mm and the specimen fractured at the 3rd impact. This indicates that the specimen had achieved its ultimate deformation and failed .

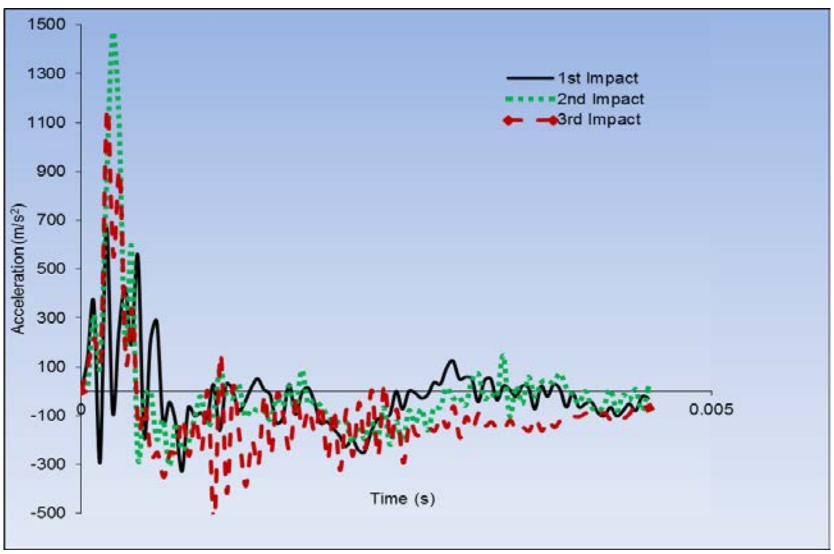


Fig. 4 – FFRP-CFRC slab acceleration time history

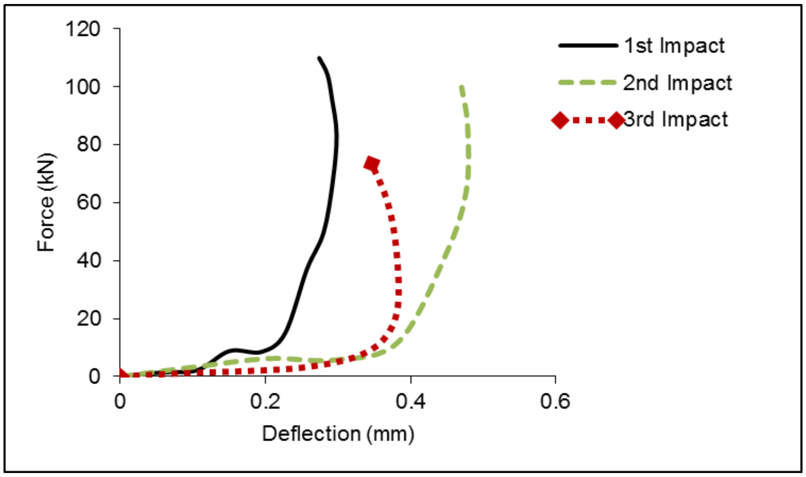
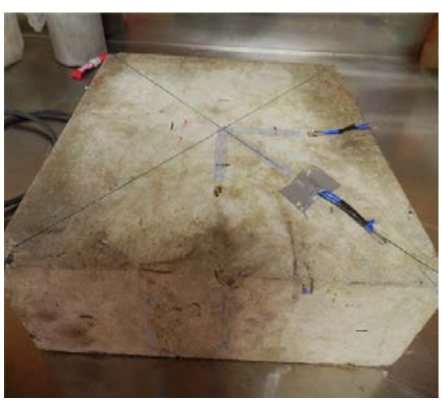


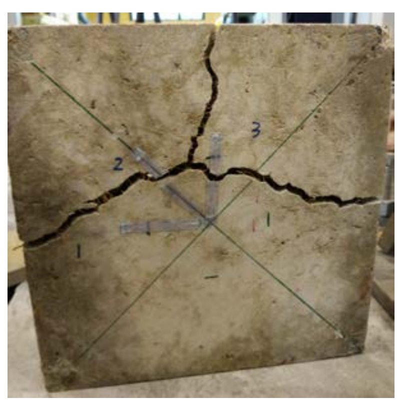
Fig. 5 – FFRP-CFRC slab force-deflection curves

3.3 Damage pattern of CFRC and FFRP-CFRC slabs

Figs. 6 and 7 show the damage pattern of the CFRC and FFRP-CFRC slabs, respectively. In Fig. 6, CFRC specimen fractured at the first impact, with the brittle and long cracks at the non-impact side of the specimen. In the case of FFRP-CFRC slabs there was no visible damage following the 1st impact. The second impact caused damage in form of cracks (Fig. 7 (b)). The length of the crack is about 35 mm. The crack developed along the depth of the specimen, with an angle between the crack and the horizontal position is around 60 degree. In the 3rd impact the FFRP-CFRC slab failed with the fracture of the CFRC part and without the failure of the FFRP laminate. The FFRP laminate de-bonded from the CFRC at the third impact. Comparing the failure pattern between the CFRC slab and FFRP-CFRC slab, it is obvious that the CFRC endured only one blow of impact and fractured with the specimen crushed into three pieces. However, with the FFRP adhered at the tensile side of the slab, the FFRP-CFRC endured three times of impact and the damage extent (the cracks extended along the specimen but non-fragmentation occurred) is less severe than the CFRC. If the impact resistance is assessed using the numbers of blows applied on the specimen, it can be concluded that FFRP-CFRC had better impact resistance than the CFRC.

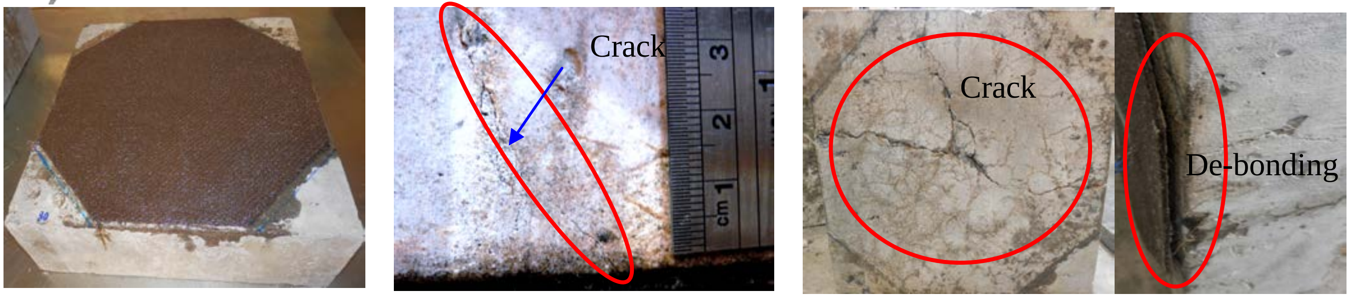


Before impact



After impact

Fig. 6 – Damage pattern of the CFRC slab



(a) Before impact (b) Second impact (c) Third impact

Fig. 7 – Damage pattern of the FFRP-CFRC slab

4. Conclusions

The behaviour of CFRC and FFRP-CFRC slabs under drop-weight impact loadings have been investigated experimentally. The study reveals:

(1) The impact force history is different between CFRC and FFRP-CFRC;

(2) The FFRP-CFRC slabs have clearly a better impact resistance than that of CFRC;

(3) The damage pattern of CFRC and FFRP-CFRC is different. CFRC shows a relative brittle fragmentation, while FFRP-CFRC indicates more ductile behaviour with the cracks development till the ultimate failure.

This study indicated that the FFRP composites played a positive role in enhancing impact resistance of the concrete structure, which could be considered as environmentally friendly protective structures in earthquake regions. More works are necessary to have a better understanding of the impact behaviour of FFRP-CFRC composites.

5. Acknowledgement

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6. References

[1] Ali M, Liu A. Sou H, Chouw N. (2012): Mechanical and dynamic properties of coconut fibre reinforced concrete. *Construction and Building Materials*, 30, 814-825.

[2] Yan L, Chouw N. (2013): Experimental study of flax FRP tube encased coir fibre reinforced concrete composite column. *Construction and Building Materials*, 40, 1118-1127.

[3] Li Z, Wang X, Wang L. (2006): Properties of hemp fibre reinforced concrete composites. *Composites part A: applied science and manufacturing*, 37(3), 497-505.

[4] Rao HS, Ghorpade VG, Ramana NV, Gnaneswar K. (2010): Response of SIFCON two-way slabs under impact loading. *International Journal of Impact Engineering*, 37(4), 452-458.

[5] Hrynyk TD, Vecchio FJ. (2014): Behavior of steel fiber-reinforced concrete slabs under impact load. *ACI Structural Journal*, 111(5), 1213.

[6] Zhou X, Ghaffar SH, Dong W, Oladiran O and Fan M. (2013): Fracture and impact properties of short discrete jute fibre-reinforced cementitious composites. *Materials and Design*, 49, 35-47.

[7] Wang XD, Zhang C, Huang Z, and Chen GW. (2013): Impact experimental research on hybrid bamboo fiber and steel fiber reinforced concrete. *Applied Mechanics and Materials*, 357, 1049-1052.

[8] Ramakrishna G. and Sundararajan T. (2005): Impact strength of a few natural fibre reinforced cement mortar slabs: a comparative study. *Cement and Concrete Composites*, 27(5) 547-553.

[9] Wang W, Chouw N. (2014): An experimental study of coconut fibre reinforced concrete under impact load. *New Zealand Society for Earthquake Engineering (NZSEE) Annual Technical Conference*, *Auckland, New Zealand*.

[10] Yan L, Chouw N, Jayaraman K. (2014): Effect of column parameters on flax FRP confined coir fibre reinforced concrete. Construction and Building Materials, 55, 299-312.

[11] Wu M, Chen Z. and Zhang C. (2015): Determining the impact behavior of concrete beams through experimental testing and meso-scale simulation: I. Drop-weight tests. Engineering Fracture Mechanics, 135, 94-112.