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BEHAVIOR OF REINFORCED CONCRETE SLABS UNDER ACCIDENTAL IMPACTS

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Loads resulting from activities such as rock fall, heavy drop weights (for e.g. equipment's, heavy machines during installation), missile and aircraft interaction with slabs may results in loading intensity which have higher magnitude as compared to static loading. Based on the velocity of the impacting object at the time of contact, these activities may result in impact loading. Therefore, slabs designed should provide resistance to these accidental loading during their entire operational life. In this study, a dynamic non-linear finite element analyses were conducted to investigate the behavior of the reinforced concrete slabs subjected to high-mass low-velocity impacts. For this purpose, initially an already published impact test results were used to validate the numerical predictions. Following validation, a study was conducted to investigate the influence of the impact velocity on the behavior of the reinforced concrete slab. Based on the numerical investigation, it was found that the velocity of the impacting object has a significant influence on the behavior exhibited by slab under impact loading. Furthermore, it was also found that the behavior of slab under impact is both local and global. Local behavior is associated with the damage caused at the contact area of the slab and the impactor, whereas global behavior refers to the overall deformation of the slab when stress waves move away from the impact zone and travel towards the supports.

Keywords: Dynamic analysis, Finite element, Non-linear analysis, Loading rates.

1 INTRODUCTION

Reinforced concrete slabs based on their operational use and location may be subjected to the accidental loading stemming from rock fall, heavy drop weights, missile and aircraft collisions. These loading activities depending on the magnitude of the velocity at the time of collision with the slab may result in impact loading. The behavior of the reinforced concrete slabs subjected to impact loading may result in the three common types of failure (i) perforations, (ii) penetrations and (iii) scabbing (Chen and May 2009).

The behavior of Reinforced Concrete (RC) slabs subjected to impact loads was investigated by Kojima (1991). For this purpose, 12 RC slabs having side lengths of 1200 mm each with five different thicknesses of 60 mm, 90 mm, 120 mm,180 mm and 240 mm were investigated. The impact load was applied by firing a 2 kg missile with three different velocities (i) 100 m/s (ii) 150 m/s and (iii) 200 m/s. It was observed that when slab was impacted with identical impact energy, the size of the spalling area increases with increase in the thickness of the slab. It was also observed that the soft nose missile shows significant deformation due to its contact with RC slab, however no deformation was observed for the case of hard missile. Furthermore, the damage caused to the reinforcing bars, the scabbing and penetration produced due to the soft nose missile collision with slab was less as compared to the hard nose missile collision.

The behavior of reinforced concrete slab under high-mass low-velocity impacts was investigated by Chen and May (2009). For this purpose, six reinforced concrete slabs having two different cross-sectional dimensions were used. In type 1 slabs with cross section of 760 mm x 760 mm and thickness of 76 mm, whereas in type 2 slabs having cross section of 2300 mm x 2300 mm and thickness of 150 mm were used. It was observed that contact force in slabs 1-6 increases until it reaches its maximum value. However, the behavior of Type I (slab 1-4) and Type II (slabs 5 and 6) differ significantly after reaching maximum load. The Type I slabs show a plateau before contact is over, whereas, in Type II (slabs 5 and 6), a number of contacts were formed between slab and impactor before complete separation occurred and impactor rebound.

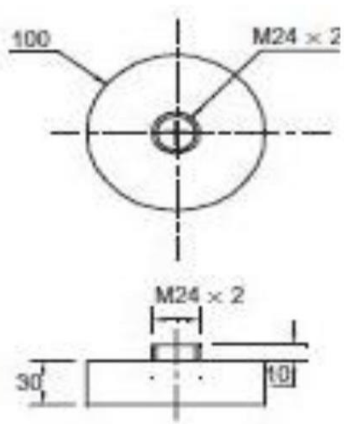
In this study, initially an already published impact test result of Chen and May (2009) were used to validate the numerical predictions. Following the validation, a study was conducted to study the influence of the impact velocity on the behavior of the reinforced concrete slab.

2 NUMERICAL INVESTIGATION

In order to study the behavior of reinforced concrete slabs subjected to impact loading a numerical investigation is conducted herein. Abaqus (2013) was used to carry out dynamic nonlinear finite element analysis (DNLFEA). Initially the predictions obtained were validated using the test data of Chen and May (2009). Furthermore, an investigation was also carried out to study the influence of the impact velocity on the behavior of the reinforced concrete slabs under impact loads.

2.1 Description of The Problem

Chen and May (2009) investigated the behavior of slabs under high mass low velocity impact. Drop weight impact tests were carried out on 6 reinforced concrete slabs. The emphasis of numerical investigation presented herein focuses on studying the behavior of slab having length of 760 mm on both sides and a thickness of 76 mm. Impact (drop-weight) test was carried out by allowing a 98.7 kg to drop on the surface of slab with an impact velocity of 6.5 m/s and impact energy of 2.1 kJ. Figure 1 shows the geometry of impactor and test setup used in the experimental study.



(a)

(b)

Figure 1. (a) Cross-sectional dimensions of impactor (b) impact test setup (Chen and May 2009).

2.2 Development of The Finite Element Model

The dynamic NLFEA were carried out using Abaqus (2013). Figure 2 represents the FE model used in this investigation. A finer mesh was used at the contact area of the slab and impactor in order to capture the variation of stresses and strains more accurately, however, coarser mesh having a uniform size of 60 x 60 was used for the slab away from the impact region as the variation of the stresses and strains are not significant.

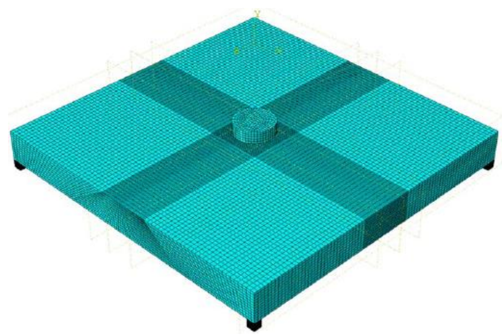


Figure 2. Finite element model used to investigate the behavior of the reinforced concrete slab.

3 VALIDATION OF THE NON-LINEAR DYNAMIC FINITE ELEMENT ANALYSIS

Figure 3 shows the comparison of the contact force time histories obtained from the impact tests and the DNLFEA. The comparison shows very good agreement between the numerical predictions and the corresponding impact test results for the case of the maximum contact force. Furthermore, the contact force time history curves corelate very well from the start of the impact event i.e. When the impactor come into contact with the slab to the maximum contact force (see Figure 3). However, diversions between the numerical predictions and the impact test results were found after maximum contact force has been attained, as in experimentally recorded contact force a plateau of contact duration has higher magnitude and contact duration as compared to that exhibited numerically. The diversion was also found between the total impact duration exhibited experimentally and numerically.

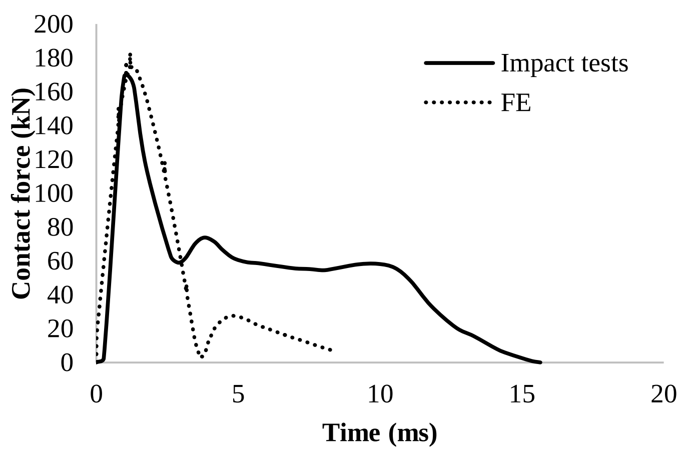
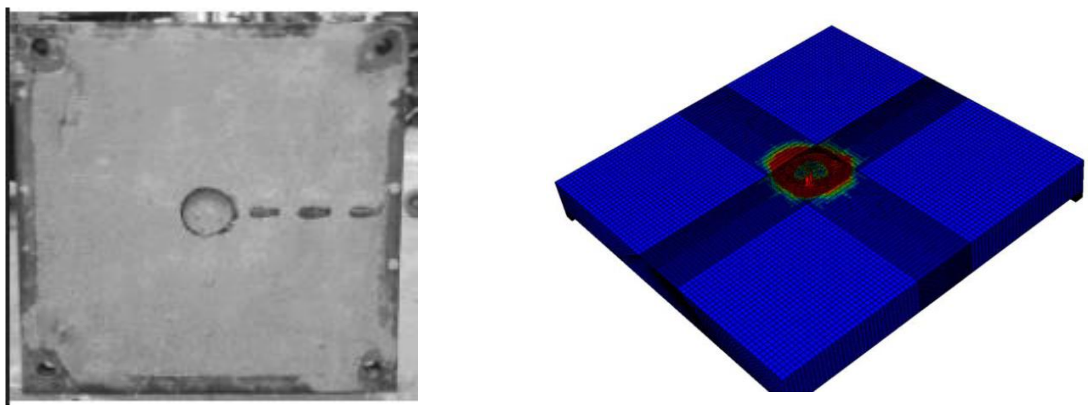
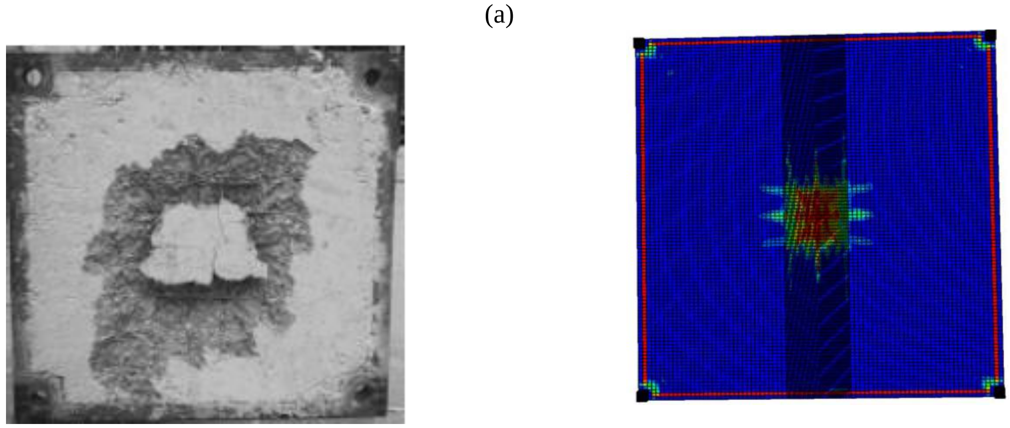


Figure 3. Comparison of the contact force time histories exhibited experimentally and numerically.

Figure 4 shows the damage caused to the slab due to the impact load exhibited experimentally and numerically. As can be seen from Figure 4 that good agreement was observed between the experimentally and numerically exhibited failure caused to the slab at its top and bottom surface. It was also observed that the damaged caused to the slab at its top surface due to the impact load is localized at the impact area, however, the damage significantly reduces away from the contact area of the slab and impactor. Furthermore, it was also observed that the intensity of damage caused to the slab due to the impact load was higher at the bottom face as compared to its top face. As can be seen from Figure 4 that concrete cover teared off and reinforcement was exposed at the bottom face of the slab due to the impact load in the contact area of the slab and the impactor.



(a)



(b)

Figure 4. Comparison of the damage observed at the (a) top and (b) bottom surface of slab exhibited experimentally and numerically.

4 INFLUENCE OF VELOCITY

In order to investigate the effect of velocity with which the impactor strikes the slab on the impact behavior of the RC slab a study was also conducted. For this purpose, three different impact velocities having magnitude equal to the experimental (Chen and May 2009) (case study 1), half of the experimental (case study 2) and twice of the experimental (case study 3) were used to study numerically the influence of the impact velocity on the behavior of the slab.

Figure 5 and Figure 6 shows the comparison of the contact force time histories and damage exhibited numerically for the case of slabs impacted with velocity equals to (a) experimental (case study 1), (b) half of the experimental (case study 2) and twice of the experimental (case study 3) respectively. It was observed that with the increase in the impact velocity the magnitude of the maximum contact force also increases and impact duration decreases (see Figure 5). It was also observed that with the increase in the impact velocity the damage caused to the slab increases at the contact area of the impactor and the slab. Although damage increases with the impact velocity but its influence is negligible away from the contact area (see Figure 6).

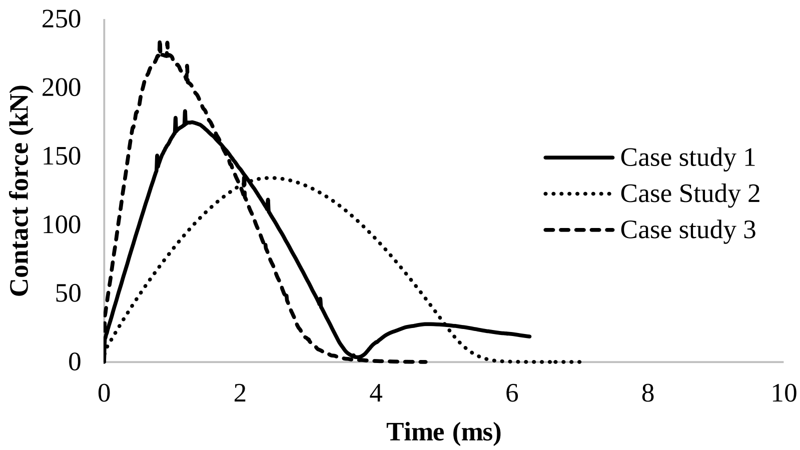
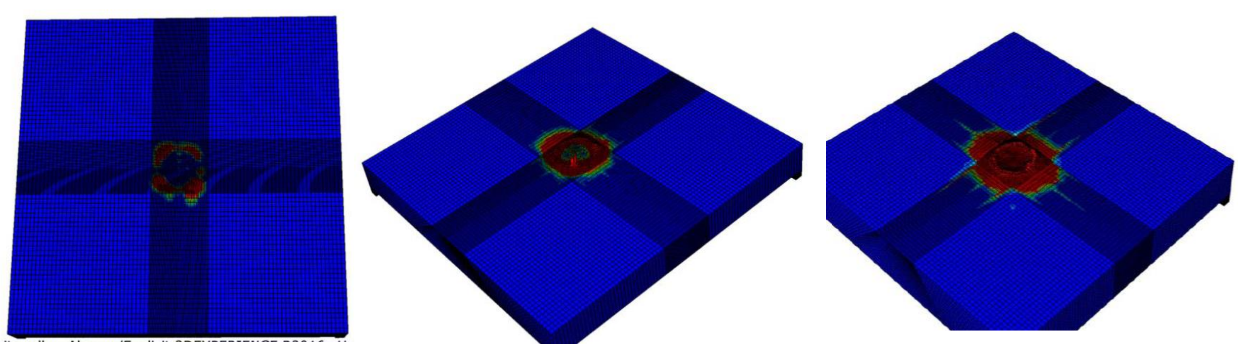


Figure 5. Comparison of the contact force time histories exhibited numerically for the case of slabs impacted with velocity equals to (a) experimental (case study 1), (b) half of the experimental (case study 2) and twice of the experimental (case study 3).



(a) (b) (c)

Figure 6. Comparison of the damage exhibited numerically for the case of slabs impacted with velocity equals to (a) experimental (case study 1), (b) half of the experimental (case study 2) and twice of the experimental (case study 3).

5 CONCLUSIONS

Based on the numerical investigation, it was found that the velocity of the impacting object has a significant influence on the behavior exhibited by slab under impact loading. Furthermore, it was also found that the behavior of slab under impact is both local and global. Local behavior is associated with the damage caused at the contact area of the slab and the impactor, whereas global behavior refers to the overall deformation of the slab when stress waves travels away from the contact area and move towards the supports. It was also found that with the increase in the impact velocity the damage caused to the concrete in the impact region also increases.

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