Impact Analysis on Slabs – A Review

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Abstract - *Impact loads have gained attention in the past few years. It is important to analyse strategic important buildings like nuclear reactors, military establishments, etc. A lot of research is being conducted in the field of impact loads. This paper gives an introduction to impact loading, its types and responses. A few of the experimental investigations carried out in the impact analysis on slabs have been reviewed and summarized.*

Key Words: Impact analysis, Slabs, Drop weight

1. INTRODUCTION

A civil engineering structure is subjected to many type of loads in its lifetime, of which impact load is a significant but not frequent loading case. Impact loads may be caused due to accidents like rock fall, vehicle or ship or aircraft collision, and terrorist or military conditions like missile impact and blast waves due to explosions, etc. Impact loads are extreme loading case with very little probability to occur during the lifetime of a structure. But, due to increased occurrences of terrorist activities, impact analysis has gained importance in the past few decades to ensure safety of the structures.

The impact loads on a structure can be classified into two limiting cases – hard impact and soft impact. A soft impact is where the resisting structure remains undeformed and the kinetic energy of the striking body is completely converted into deformation. Hard impact can be defined as where the striking body is rigid and kinetic energy of the striking body is completely or partially converted to the deformation of the resisting structure.

The response of a structure to an impact load is significantly different than to static and seismic loads. The duration of loading is very short leading to a comparatively higher strain rate. The modes of structural deformation and failure is also different leading to a much complex dynamic response making it difficult to analyse using traditional computational methods. Hence, many researchers have worked on the behaviour of concrete and concrete composites under impact in the past few decades.

2. EXPERIMENTAL IMPACT ANALYSIS

Aravindan and Kurian[2] (1993) studied the impact characteristics of reinforced concrete slabs under low velocity (less than 10 m/s) hard impact loading. 28 slabs of size 1100×1100 mm and thickness 100 and 70 mm and reinforced only at back face were tested under drop weight impact. A steel sphere of size 127 mm diameter and weight 155 N was dropped from a height of 4.35 m at the centre of the slab. The slabs were supported using a stiff steel frame. A load cell was attached to the drop weight to measure the contact force. Displacement transducers and accelerometers were used for displacement and acceleration response measurement respectively. The slabs were impacted till failure and contact force, displacements, accelerations and strains in reinforcements at some specified points were recorded. It was observed that the contact force-time history plot for the impact is an isosceles triangle with duration of less than 2 milliseconds. The strain rate in steel was less than 4/second.

Ong et al.[3] (1999) studied the impact resistance of fibre concrete slabs under low velocity projectile impact with different types of fibres and volume fraction. Straight polyolefin, polyvinyl alcohol and hooked-ended steel fibres were used with volume fractions of 0, 0.5, 1 and 2%. The slabs were 1 m square and 50 mm thick. The slabs were simply supported on all four sides over a span of 900 mm in both directions. The impact was achieved by a hemispherical nose shaped projectile of mass 43 kg dropped from a height of 4 m. The impactor had accelerometer to measure the impact loads. All slabs were subjected to single impact only. Steel fibre concrete slabs showed better cracking characteristics, resistance to shear plug formation, energy absorption and integrity as compared to polyolefin and PVA fibre reinforced slabs. PVA fibre concrete slabs showed better energy absorption capacities than polyolefin fibre concrete slabs. It was observed that polyolefin fibres failed both by pull-out and rupture while PVA and steel fibres failed by pull-out only.

Chen and May[4] (2009) experimented on the high-mass low-velocity impact behaviour of reinforced concrete slabs. Four slabs of 760 mm square and 76 mm thickness and two slabs of 2320 mm square and 150 mm thickness were tested under drop weight impact loading. Three 760 mm square slabs had a steel ratio of 0.6% and one had 1.1% with all concrete cube compressive strength of 60 MPa. The 2320 mm square slabs had a steel ratio of 0.5%. The slabs were clamped at all four corners with both horizontal and vertical movements restrained. Two types of impactors were used, one was stainless steel impactor with 90 mm diameter and a hemispherical profile of 125 mm radius, and the second of mild steel with a 100 mm diameter and flat contact face. The impact forces were measured using a load cell placed between the mass and the impactor. Acceleration at various points on the slab was recorded using accelerometers. It was observed that there is little difference between the phases of two accelerations measured at different points on 760 mm square slabs. In 2320 mm square slabs, the difference in phases of acceleration is evident for first 5 milliseconds but reduces thereafter. The accelerometers were kept farther apart in the larger slabs than in the smaller slabs, owing to the lag in response. There was more scabbing in 76 mm thick slabs than in 150 mm thick slabs due to proportionally more impact energy in thinner slabs. Penetration was also significantly more in the thinner slabs.

Rao et al.[5] (2010) experimented on the behaviour of slurry-infiltrated fibrous concrete (SIFCON) slabs under impact loading. The slabs were 600×600×50 mm in dimensions. Thirty slabs were tested in total of which nine were SIFCON slabs without conventional reinforcement, nine were SIFCON slabs with conventional reinforcement, three were fibre reinforced concrete slabs (with 2% fibre) without conventional reinforcement, three were fibre reinforced concrete slabs with conventional reinforcement and three were plain concrete slabs. The conventionally reinforced slabs had 8 mm diameter Fe 415 HYSD steel bars at 150 mm spacing in both directions. The compressive strengths of SIFCON specimens were in the range 44.93 to 54.77 MPa and tensile strength varied from 10.75 to 12.91 MPa. All slabs were clamped on all four edges to simulate fixed end condition. The impact was achieved by dropping an iron ball of 100 mm diameter and 50 N weight falling on the centre of the slab from a height of 450 mm. The drop weight was attached to a CAM through a rope and pulley system. The CAM was capable of providing 55 blows per minute using an electric motor. The number of blows to first crack and ultimate failure was recorded. The energy absorption at first crack and ultimate failure were calculated. The modes of failure of the slabs were also noted. It was found that SIFCON slabs are better in energy absorption at first crack and ultimate failure than FRC and RCC slabs. The energy absorption of SIFCON slabs further increased with addition of reinforcement and fibres.

Elavenil and Knight[6] (2012) investigated the dynamic behaviour of steel fibre reinforced concrete plates under drop weight impact loading. 18 plate specimens of size 600×600 mm were tested with thickness of 20, 25 and 30 mm and three steel fibre contents of 0.5, 0.75 and 1%. 0.7 mm diameter steel fibres were used with aspect ratios of 50, 75 and 100. The plates were tested with all sides fixed. The drop weight consisted of a 61.5 mm stainless steel ball of weight 0.5 kg and a cylindrical drop weight of 4.5 kg connected to a tensile wire that can be manually controlled and kept vertically by a steel wire fixed to the frame. The drop weight was falling from a height of 750 mm. The number of blows for the first crack and failure was noted. An iron square plate of 20×20 mm was placed under the centre of the plate while casting to pick up impact effects. The pick-up leads to an accelerometer and then to a computer. The displacement-time history, velocity-time history, acceleration-time history and crack widths were recorded. It was observed that the energy absorption increased with increase in aspect ratio and steel fibre content. The steel fibres resisted development and propagation of cracks in the post-cracking phase. The crack width decreased with increase in aspect ratio and steel fibre content.

Elavenil and Knight[7] (2013) also reported the impact behaviour of steel fibre reinforced concrete plates under pendulum impact. Ten plate elements of size 600×600 mm and thickness 20, 25 and 30 mm were tested. 0.7 mm diameter steel fibres were used with aspect ratios of 50, 75 and 100 in volume fractions of 0.5, 0.75 and 1%. The slabs were mounted vertically in a vertical frame and impacted using a pendulum of weight 18 kN at three different inclinations of 11°, 22° and 33° to the vertical. A small iron chip was placed while casting which was connected to an oscilloscope. Time, frequency, acceleration and impulse was recorded. It was observed that amplitude increased by 30% for plates fixed on two sides as compared to plates fixed on all four sides. Increase in aspect ratio of steel showed higher frequency. Smaller the thickness of the plate, higher was the frequency.

Batarlar[8] (2013) studied the behaviour of reinforced concrete slabs under low-velocity impact loads. Six RC slabs with dimensions 2015×2015×150 mm and 25 mm clear cover were tested in pairs, one under impact load and its pair in static load, to compare static and impact behaviour of specimens. Reinforcements were provided in the form of meshes obtained by bending 8 mm diameter bars at the middle to form top and bottom reinforcements. The tension reinforcement ratios of 0.2, 0.3 and 0.4% were adopted for the pairs of slabs. Concrete with peak compressive stress of 20.9 MPa and steel with yield strength of 420 MPa was used. The specimens were supported simply at 20 locations along the perimeter. The specimens were analysed with 20 load cells at each support location, 24 displacement transducers, 6 accelerometers and 12 strain gauges fixed to the reinforcing bars. Dynamic data was captured and recorded at a rate of 250 kHz per channel using a high speed data acquisition system. In static tests, the slab was loaded at midpoint with a hydraulic jack at the bottom of the slab and loading upwards through a circular steel plate of 200 mm diameter. An extra load cell was placed between the jack and the specimen to measure the applied load. Loading was continued till the specimens failed by punching. In impact tests, impact load was applied by free falling drop weight falling from 2.5 m height and impacting at the midpoint of the specimen at 7 m/s contact velocity at the instant of impact. The drop weight had a steel circular flat bottom of 200 mm diameter, identical to the static loading case. Two drop weights were used, one with 210 kg and another with 320 kg mass. The slab with 0.4% reinforcement ratio was impacted with 210 kg drop weight once followed by 320 kg drop weight twice. The slab with 0.3% reinforcement ratio was impacted only once with 320 kg drop weight. The slab with 0.2% reinforcement ratio was impacted twice with

210 kg drop weight. The specimens were tested till failure and crack profiles sketched. Static load results showed that increasing reinforcement ratio influences ductility and static load capacity. The slab with 0.4% reinforcement ratio showed resisted maximum load but the failure was brittle. In impact loading, the impact is resisted by the inertial forces of the slab in the initial phases. Support reactions become significant in the post-impact phase and equilibrium is observed at this stage. The support reactions developed during static loading is lower than under impact loading.

Madheshwaran et al.[9] (2014) studied the impact behaviour of reinforced geopolymer concrete slabs with and without steel fibres and compared with ordinary Portland cement concrete slabs. Two specimens each of GPC and OPCC with and without fibre of dimension 1000×1000×60 mm were tested. Slabs were reinforced with 2 mm welded wire mesh in the central portion to avoid punching shear failure in the early stages of loading. Glued Dramics Steel fibres of 30 mm length were used. The slabs were hinged at the supports. Accelerometers were fixed to the bottom surface of slabs at centre and quarter points. Strain gauges were fixed on slab surfaces. An instrumented impact hammer of mass 8.4 kg with a dynamic load cell was used to impact the slab at the centre of the slab. A pulley system with rope and vertical guides was used to drop the hammer from desired height. For each drop, impact load, strain and acceleration were recorded. It was observed that the measured impact forcing function is triangular in shape. As the height of drop increased, measured peak impact load increased along with decreased contact duration due to increased rebound velocity. GPC panels showed higher impact energy absorption than OPCC panels. Addition of fibres also improved the resistance to impact. For a given height of drop and at a specified number of drops, OPCC slabs experienced higher acceleration than GPC slabs. Fibre reinforced slabs showed lower acceleration as compared to plain slabs due to increased damping effects. Plain slabs failed by perforation while fibre reinforced panels showed scabbing failure.

Nagan and Mohana[10] (2014) investigated the resistance of geopolymer mortar slabs to impact loading. 24 slabs of size 230×230×25 mm were cast and tested under drop weight impact loading. 4 sets of 3 specimens were tested each for ferrocement and geopolymer ferrocement mixes. The first set had no reinforcement. The second set was provided with 4 layers of chicken mesh. The third set had 2 layers of weld mesh. The fourth set had 1 layer of weld mesh and 4 layers of chicken mesh. The wire woven chicken meshes had a hexagonal opening of size 12 mm and wire thickness of 0.72 mm. The weld mesh had a rectangular grid opening size of 76.2×38.1 mm with a thickness of 2.45 mm in transverse direction and 3.45 mm in longitudinal direction. Ultimate tensile strength of weld mesh and chicken mesh were 440 and 270 N/mm^2 respectively. The cement mortar had a cube compressive strength of 35.67 MPa and geopolymer mortar had 48.53 MPa. The impact was caused using 0.6 kg steel ball falling freely from a height of 400 mm through a guide at the centre of the slabs. The slabs were simply supported. The mass was repeatedly drop and the number of blows required for the first crack and failure were noted. The impact energy absorbed was also calculated. The damage was localized at the point of impact, with cracks forming at the bottom surface and propagating to top and widening further. Identical failure pattern was observed in both ferrocement and geopolymer ferrocement slabs independent of reinforcement. Increase in volume fraction of reinforcement increased energy absorption and residual impact strength of both ferrocement and geopolymer ferrocement. Geopolymer ferrocement slabs had better impact resistance characteristics, higher energy absorption and better post-cracking behaviour.

3. CONCLUSIONS

Impact loading has gained significance in the fields of reactor technology and military applications in the past few decades. Lot of research is being carried out in the impact analysis of slabs. The major drawback of the experimental researches conducted currently is that there is no unifying criteria for the tests. Each researcher uses different standards for their experiments. If there are standard specifications for these impact tests, it would have been easier to compare the results obtained by various analysis. However, the intense research carried out on different concrete and concrete composites have indicated that the improved concrete composites have better impact resistance than conventional plain concrete.

REFERENCES

[1] Laurent Daudeville and Yann Malecot, “Concrete Structures under Impact”, *European Journal of Environmental and Civil Engineering*, Vol. 15, pp. 101-140, 2011.

[2] P. K. Aravindan and E. Kurian, “Low Velocity Hard Impact Studies on Reinforced Concrete Slabs”, *Transactions of the 12th International Conference on Structural Mechanics in Reactor Technology*, pp. 303-308, August 1993.

[3] K. C. G. Ong, M. Basheerkhan and P. Paramasivam, “Resistance of Fibre Concrete Slabs to Low Velocity Projectile Impact”, *Concrete and Concrete Composites*, Vol. 21, pp. 391-401, 1999.

[4] Y. Chen and I. M. May, “Reinforced Concrete Members under Drop-Weight Impacts”, *Proceedings of the Institution of Civil Engineers – Structures and Buildings*, Vol. 162, Issue 1, pp. 45-56, February 2009.

[5] H. Sudarsana Rao, Vaishali G. Ghorpade, N. V. Ramana and K. Gnaneswar, “Response of SIFCON Two-Way Slabs under Impact Loading”, *International Journal of Impact Engineering*, Vol. 37, pp. 452-458, 2010.

[6] S. Elavenil and G. M. Samuel Knight, “Impact Response of Plates Under Drop Weight Impact Testing”, *Daffodil International University Journal of Science and Technology*, Vol. 7, Issue 1, pp. 1-11, January 2012

[7] S. Elavenil and G. M. Samuel Knight, "Steel Fibre Reinforced Concrete Slabs to Pendulum Impact Test", *American-Eurasian Journal of Scientific Research*, Vol. 8, Issue 5, pp. 198-205, 2013.

[8] Baturay Batarlar, "Behaviour of Reinforced Concrete Slabs Subjected to Impact Loads", M. S. Thesis, Graduate School of Engineering and Sciences, Izmir Institute of Technology, July 2013.

[9] Madheswaran C. K., J. K. Dattatreya, P. S. Ambily and P. R. Karansingh, "Investigation on Behaviour of Reinforced Geopolymer Concrete Slab Under Repeated Low Velocity Impact Loading", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, Issue 7, pp. 10775-10786, March 2014.

[10] S. Nagan and R. Mohana, "Behaviour of Geopolymer Ferrocement Slabs Subjected to Impact", *Iranian Journal of Science and Technology – Transactions of Civil Engineering*, Vol. 38, pp. 223-233, March 2014.