



Performance of Reinforced Concrete Beam under Point Impact Loading

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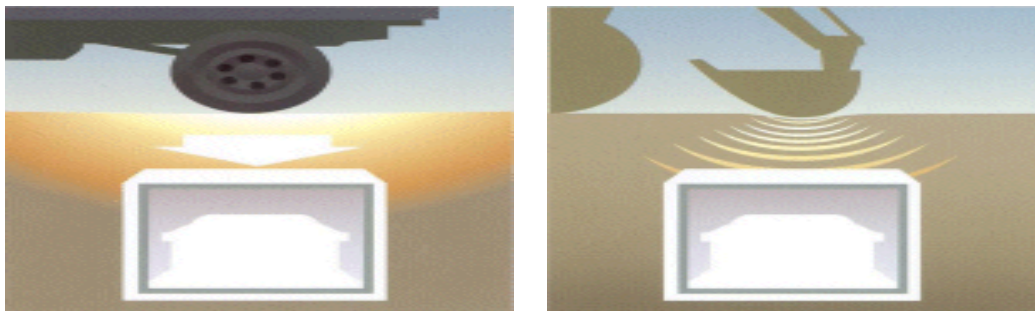
Abstract: In the present study, the impact behavior of reinforced concrete (RC) beam under point impact load up to failure, under falling-weight impact was studied. Nine simply supported rectangular RC beams were used. All RC beams were of 150 mm x 150 mm in cross section, and 500mm overall length. The effective span of the beam was 400 mm from center to center of the support with 50mm overhang on both sides to avoid overturning. Beams were designed in accordance to IS456:2000 as under reinforced, balanced and over reinforced. Three different grades of concrete i.e. M_{20} , M_{25} and M_{30} were used in the casting of beams. An impact load was applied at the mid-span of the RC beam by dropping a free-falling 0.254 kN steel weight.

Keywords: Reinforced concrete, impact load, Impact hammer, Grade of concrete, Shear reinforcement, deflection Crack pattern and Strain energy.

I. Introduction

Reinforced concrete structures are required to withstand high intensity transient dynamic loads caused by impacting objects. Sometimes an impact load can also be in the form of high intensity transient dynamic load on a RC structure. For instance load on burial vaults. The concrete burial vault withstands different types of loads. There are several factors or types of loads that weigh upon a burial vault. The dynamic load (impact load) may act on a burial vaults by the movement of vehicles or trucks or heavy vehicles as shown in Figure 1. This load is transferred to a burial vault as heavy cemetery equipment asses over the grave. An impact or shock load is produced by a mechanical tamper or the dropping of a backhoe bucket and delivers a very concentrated force through the soil as showing in the figure below. This has an extreme effect on a small area of the burial vault cover at shallow grave depths.

Figure 1 Impact on burial vaults



Another functional area of impact loading on reinforced concrete structures is that for the construction of bunkers. In most of the cases the bunkers constructed to withstand the structure against the impact load due to the attack of projectile or earth penetrating weapons. There are several peoples staying in bunkers on the face of the globe just to protect their lives from the attack of the earth penetrating weapons from their enemies. The following Figure 2 shows the damaged bunker at Baghdad.

Figure 2 Damaged RC bunker due to impact force, Baghdad



There are other numerous situations in which the performance of reinforced concrete structures under impact loading is of prime importance for example, turbine blade impact on nuclear containment structures, accidental dropping of objects such as rock fall impact, fuel rods in a nuclear reactor, tornado generated missiles or aircraft impact on nuclear power plant etc. Therefore, provisions of adequate protection to personnel's and equipments within structural targets against impact loading are of considerable importance in protective design of civil engineering structures.

II. Literature Review

N. P. Banthia, and Arnon Bentur [1], performed an investigation on an instrumented impact machine and it was used to carry out impact tests on concrete beams, 150 mm x 125 mm in cross-section and 1400 mm long. The simply supported beams were struck at their midpoints by a 345 kg mass impact hammer, dropped from various heights. The instrumentation included strain gauges mounted on the striking end of the hammer, strain gauges mounted on one support anvil, and three accelerometers placed at various locations along the beam. The data were collected using a 5-channel data acquisition system. Normal strength, high strength, and fiber reinforced concrete beams were tested. In general, it was found that the properties of concrete under the high stress rates associated with impact loading could not be predicted from conventional static tests.

N Kishin; H Mikami *et. al.* [2], to establish a rational impact-resistant design procedure of shear-failure-type reinforced concrete (RC) beams, falling-weight impact tests were conducted. Twenty-seven simply supported rectangular RC beams without shear rebar were used. All RC beams were of 150 mm width and 250 mm depth in cross section, with rebar and shear-span ratios taken as variables. An impact load was applied at the mid-span of the RC beam by dropping a free-falling 300 kg steel weight.

Y. Chen and I.M. May [3], conducted experimental studies to investigate the high-mass, low-velocity impact behaviour of reinforced concrete members including beams and slabs, and to provide high-quality input data and results to validate numerical modelling. Fourteen 2.7 m and four 1.5 m span beams, four 0.8 m square 76 mm thick and two 2.3 m square 150 mm thick slabs were tested under impact loads using a drop-weight facility. Measurements included transient impact loads, accelerations and strains in the steel reinforcement.

Degen, *et al.* [4], performed structural analysis and design of nuclear power plant building for air craft crash effects. The objective of this investigation is to assess the effect of a large commercial airplane crashing perpendicularly on the surface of a spherical reactor building dome. Safety solutions are discussed from the viewpoint of penetration, cracking and collapse modes of failure, where, primarily, the carrying capacity of the structure under an equivalent statical load is considered. Based on the investigation performed and the comparison of results recommendations were given for the practical design and development of structural detail.

III. Testing of Materials, Beam Specimens and Test Results

A. Test Set up and Testing

Materials like cement, fine and coarse aggregates, steel and concrete were tested in accordance with Bureau of Indian Standard (B.I.S.) codes and their properties were found to be within the prescribed limits. Impact test on concrete beams were done with the help of impact hammer testing machine, with impact hammer of equivalent weight 25.40 kg at the level of point including weight 0.675 kg of the impact tool fixed with the impact hammer as showing in the Figure 3 whereas it strikes the beam with a velocity of 4.14 m/s. During test maximum deflection at the centre of beam was recorded with the help of LVDT and crack patterns were also observed after each blow.

Figure 3 Testing of beam under point impact load

(a) Arrangement for point impact load



(b) Testing of beam



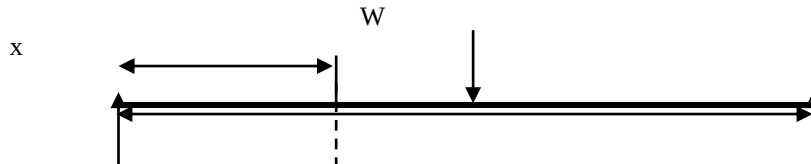
B. Mathematical Formulation

Strain energy due to impact load is calculated by the relation obtained by integrating the energy equation for beam shown in Figure 4 and given below:

$$U = \frac{1}{2} \int_0^l \frac{M_x^2}{E_{eq} I_{cr}} dx$$

$$\text{For whole span } U = \frac{1}{2} \int_0^l \frac{M_x^2}{E_{eq} I_{cr}} dx$$

Figure 4 Simply supported beam with point load at the center



where, $M_x = \frac{W}{2} x$

On putting the value of M_x in above equation we get:

$$\begin{aligned} &= \int_0^{\frac{l}{2}} \frac{W^2 x^2}{4 E_{eq} I_{cr}} dx \\ &= \frac{W^2}{4 E_{eq} I_{cr}} \left[\frac{x^3}{3} \right]_0^{\frac{l}{2}} \\ &= \frac{W^2}{4 E_{eq} I_{cr}} \left[\frac{l^3}{24} \right] \\ &= \frac{W^2 l^3}{96 E_{eq} I_{cr}} \end{aligned}$$

This is the equation used for the calculation of strain energy.

In the above equation

W = equivalent static load in kN is given as $\frac{2PH}{\delta}$

Where,

$P = 0.255kN$ (25.4 kg)

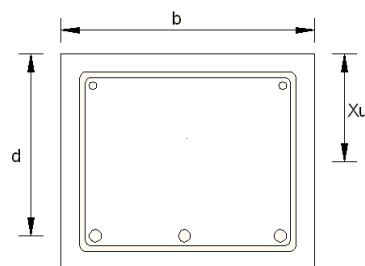
$H = 0.93m$ (height of fall)

δ = Maximum deflection of beam

I_{cr} = moment of inertia of cracked section as shown in Figure 5 is taken as:

$$b \frac{x_u^3}{3} + m A_{st} (d - x_u)^2$$

Figure 5 Cross section of reinforced concrete beam



x_u = depth of neutral axis

E_{eq} = Elasticity modulus of composite section given as

$$E_c + (m - 1) \frac{E_s A_{st}}{bd}$$

E_c = Elastic modulus of concrete

A_{st} = Area of steel in mm^2

m = molecular ratio taken as $\frac{E_s}{E_c}$

E_s = Elasticity modulus of steel

b = Width of beam

d = depth of beam

Theoretical deflection is calculated as $\frac{Wl^3}{48EI}$

C. Results

In Table 1 maximum deflection and physical condition of beam after each impact or blow whereas in Table 2 calculated theoretical deflection and strain energy has been shown for only beam $M_{20}U$ (beam of M_{20} grade concrete and designed as under reinforced). These were also recorded for other type of beams viz. $M_{20}B$, $M_{20}O$, $M_{25}U$, $M_{25}B$, $M_{25}O$, $M_{30}U$, $M_{30}B$, and $M_{30}O$ where M_{20} , M_{25} and M_{30} are grades of concrete and U, B and O stands for under, balance and over reinforced sections respectively. Maximum deflection obtained experimentally was also compared with the theoretical value obtained analytically. The crack and failure pattern of beam $M_{20}U$ in tension and compression zones is shown in Figure 6.

Figure 6 Crack pattern of beam $M_{20}U$

(a) In tension zone



(b) In compression zone



Table 1 Deflection and physical condition of beam $M_{20}U$

Blow No.	Deflection (mm)	In tension zone	In compression zone
1	16.53	No crack	Few aggregates parted away
2	18.97	No crack	Few aggregates parted away
3	19.07	No crack	Few more aggregates parted away
4	15.41	First crack	Few more aggregates parted away
5	4.96	First crack	Near failure
6	4.96	Cracks increased	Failed

Table 2 Strain Energy and Theoretical Deflection for Beam $M_{20}U$

Blow No.	Deflection (mm)	Weight, W(kN)	Strain energy, U (kJ)	Theoretical deflection (mm)
1	16.53	28.73	0.014	0.99
2	18.97	25.04	0.011	0.87
3	19.07	24.90	0.011	0.86
4	15.41	30.82	0.016	1.07
5	4.96	95.76	0.159	3.31
6	4.96	95.76	0.159	3.31

IV. Conclusions

On the basis of experimental testing and analysis it have been concluded that:

1. In most of the cases, failure occurred both in compression and tension zones but major failure was observed in compression zone due to disturbance of course aggregates.
2. With the increase in the grade of concrete mix it was observed that, crack width was reduced in tension zone and aggregates were separated out in compression zone.
3. In the case of lower grade concrete beams, no scabbing was observed, but the width of cracks was larger in tension zone for the same impact energy.

4. In the case of low-grade concrete beams, it is observed that the separation of aggregates in compression zone was more, but in the case of high grade of concrete beams number of cracks and crack width were reduced in tension zone.
5. Beam M₂₀U required 6 numbers of blows to cause failure and maximum deflection noted was 19.07mm, the strain energy calculated was 0.011kJ theoretical deflection as 0.86mm for the third blow. But in the case of high grade concrete beam M₃₀O we require 10 blows to cause failure in the specimen and the maximum deflection observed was 11.65mm at fifth blow and corresponding strain energy and theoretical deflection calculated were 0.007kJ and 0.35mm respectively. It shows that the higher grade concrete will improve impact carrying capacity of the beam. When the grade of concrete increases, more number of blows were required to cause failure.
6. For M₂₀ grade concrete beams, the maximum deflection observed as 19.07mm, 15.90mm and 13.21 mm for under reinforced, balanced and over reinforced sections respectively. The corresponding strain energy and theoretical deflection noted were 0.011kJ, 0.86 mm in under reinforced, 0.012kJ and 0.77 mm in balanced section and 0.011kJ and 1.22 mm for over reinforced sections. It indicates that the impact carrying capacity of the beam can be improved by increasing the area of steel in the beam. When area of steel increases in tension, beam becomes stronger and the absorption of the energy also become more.
7. Damage decreases with increase in the grade of concrete. Thus it can be concluded that by increasing the grade of concrete as well as quantity of steel, the impact load carrying capacity of the beam can be improved.

V. References

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