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Performance of Reinforced Concrete Beam under Line Impact Loading

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***Abstract**: There has been a growing interest in the past few decades among the engineering community to understand the response of reinforced concrete structures subjected to extreme loads due to blast and impact. These severe transient dynamic loads are rare in occurrence but for most of the structures, their effect can result in catastrophic and sudden structural failure. Even residential buildings and other dwelling units are very commonly attacked for spreading panic by terrorists using explosive devices. Missiles and inert projectiles of spherical or cylindrical shape, hitting the structures with high kinetic energy are potent threats to the survival of structures. Thus as concrete is our main construction material it is necessary to know its behaviour under such type impact load. Nowadays, with the rising concern for improved protective civilian structures, these design methods are proving uneconomical and require development of the improved procedures and design tools for impact and blast design of conventional structures. In the present research behaviour of conventionally designed RC beam was studied under line impact using impact hammer testing machine.*

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

I. Introduction

Impact is a daily life phenomenon. It happens whenever two bodies collide. The study of projectile impact has been an area of interest for scientists for about two hundred and fifty years. But for the last four decades this field has become very important for both developed and developing countries. As today the power of a nation is judged on the basis of technology. Every country is investing lot of money for the defense sector and India too is one of them. Every country is developing new missile technology and also the safety devices to have a powerful defense sector. The field of impact is not only confined to defence sector but it has a wide field like in production of high speed blanking and hole flanging, in geology where scientists use improved understanding of earth penetration processes to carry out remote seismic monitoring and surveying not only this but also the automobile engineers are too much concerned with this field for good designing of the vehicles to have least harm to the vehicle's main structure and the people sitting over it.

As the penetration of fragments into targets has long been of interest in military applications, different metallic and non-metallic armours having various thicknesses are being used to give protections to vehicles employed for definite roles in the military operations. The phenomenon of projectile penetration can be categorized by several schemes. For example: on the basis of effect impacts can be classified as either:

Hard Impact: when the kinetic energy of the impacting mass is transformed into plastic deformation of the impactor.

Soft Impact: when the impactor's kinetic energy is transformed into deformation energy in both the impactor and the structure.

On the basis of velocity it may be classified under the following heads.

(i) Freely falling bodies (0 – 25 m/s)
(ii) Sub ordinance range (25 – 500 m/s)
(iii) Ordinance range (500 – 1300 m/s)
(iv) Ultra ordinance domain (1300 – 3000 m/s)
(v) Hyper velocity impact (above 3000 m/s)

II. Literature Review

M. Alam [1], worked on quasi – static and drop hammer loading of plain and skin reinforced concrete plates of thickness 25 and 35*mm* and of regular strength 15, 25, 35 *MPa*, with and without edge ring. To reinforce these plates of plain concrete, thin steel sheets (0.15 and 0.2*mm* thick) have been used on rear or on both faces using Araldite glue. Experiments on these plate specimens have been performed using a cylindrical penetrator with spherical nose positioned at the centre of the plate.

M. Kumar *et al.* [2], developed a relationship for computation of dynamic modulus of elasticity using non – destructive testing. It is observed that dynamic as well as static modulii of elasticity of concrete are largely influenced by the age and grade of concrete. However, hale variation has been observed in case of Poisson's ratio regardless of the age and grade of concrete.

A.K.H. Kwan *et al.* [3], studied that the effects of shock vibration on concrete using a newly developed test method that applies hammer blows to prismatic specimens in the longitudinal direction and evaluates the short and long term effects by observing crack formation, measuring the immediate change in ultrasonic pulse velocity and measuring the reductions in 28*days* tensile and compressive strengths. A total of 198 prisms cast of typical concrete mixtures with 28*days* cube strength ranging from 40 to 60*MPa* had been tested at ages of 12*hours* to 28*days*. The tests revealed that the major effect of shock vibration is the formation of transverse cracks. Based on the test results, the shock vibration resistances of the concrete mixtures at different ages were determined and correlated to their material properties. It was found that the single most important material parameter governing of concrete is the dynamic tensile strain capacity finally. Several new sets of vibration control limits, which are less conservative than most existing, ones, have been established.
N. Kishi *et al.* [4] – They worked on “Impact Behavior of Shear-Failure-Type RC Beams Without Shear Rebar”. 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. In these experiments, the impact force excited in the steel weight, the reaction force, and the mid-span displacement were measured and recorded by wide-band analog data recorders. After testing, crack patterns developed on the side surfaces of the RC beams were sketched.

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.
Total nine beams of size 150*mm*x150*mm*x500*mm* were cast. Each group of three beams were cast with $M_{20,}$ M_{25} and M_{30} grade concrete and beams in each group were designed as under , balanced and over reinforced sections in accordance to IS 456:2000. During test beams were provided simple supports with centre to centre distance of supports as 400*mm* and an overhang of 50*mm* on both sides to avoid overturning during testing.
The line impact test on concrete beam was done with the help of impact hammer testing machine, the impact hammer of equivalent weight 25.4*kg* at the level of point, where it strikes the beam with a velocity of 4.14 *m/s*. The line impact hammer was initially kept horizontal as shown in Figure 1(b) and then allowed to fall freely under gravity to strike the beam horizontally as shown in Figure 1(c). The hammer was lifted manually and was anchored to a wooden trigger, from where it was dropped by trigger a side. The position of trigger was properly marked so that every time hammer is dropped, the height of fall remains constant. At the point of striking a rod of 16 *mm* was fixed on the impact hammer so that the load acts as a **Line** load on beam.
In the impact hammer testing machine the beam to be tested was clamped with the help of steel rod and plates of diameter 20*mm* and thickness of plates 12*mm*. The steel rod had threads at its end which were fastened by bolts. Proper care was taken at the time of experiment to avoid loosening of bolts by wrapping the cotton thread on rod. Wooden packing was also put to avoid any type of slippage.

Figure 1 Testing of beam under line impact load

(a)Arrangement for line impact (b) Hammer in horizontal position (c) Testing of beam

B. Observation and Test Results

For the beam cast with M_{30} grade concrete and designed as balanced section and designated as $M_{30}B$, deflection and physical condition of the beam after each line impact or blow is shown in the Table 1. These were also recorded for other type of beams viz. $M_{20}B$, $M_{20}O$, $M_{25}U$, $M_{25}B$, $M_{25}O$, $M_{30}U$, 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. Test results like strain energy and theoretical deflection etc. obtained by analysis is shown in Table 2 for the beam cast with $M_{30}B$. Crack patterns observed during line impact test for beam $M_{30}B$ is shown in Figure 2.

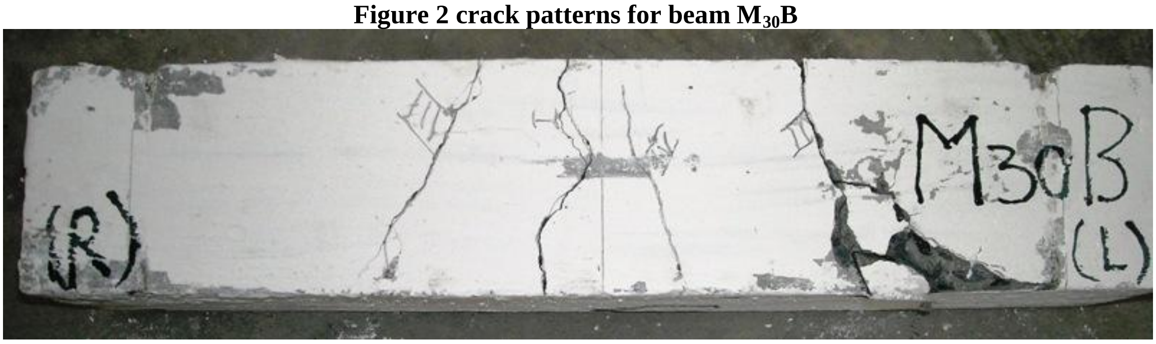
Table 1 Deflection and physical condition of beam $M_{30}B$

Blow no.	Deflection (mm)	Formation of Cracks	Remark
1	8.135	Two vertical cracks	First crack on left hand side
2	11.162	First and second increased and third crack also formed	Second crack on right hand side
3	12.522	Cracks width increased	First crack distance 5*cm* and second crack distance 10*cm* from support
4	13.283	Cracks width increased	Third crack on left hand side
5	13.872	Cracks width increased	Third crack distance 7.5 *cm* from support
6	14.082	Fourth crack formed	Fourth crack on right hand side
7	14.550	Cracks width increased	Fourth crack distance 2*cm* from support
8	14.654	Maximum width of cracks	Beam failed

Table 2 Strain energy and theoretical deflection values for beam $M_{30}B$

Blow No.	Deflection (*mm*)	W (*kN*)	Strain Energy 'U' (*kJ*)	Theoretical Deflection (*mm*)
1	8.135	58.38	0.024	0.832
2	11.162	42.55	0.0128	0.606
3	12.522	37.93	0.0102	0.540
4	13.283	35.76	0.009	0.509
5	13.872	34.24	0.008	0.487
6	14.082	33.73	0.008	0.48
7	14.550	30.54	0.006	0.43
8	14.654	30.34	0.006	0.432

Figure 2 crack patterns for beam $M_{30}B$



IV. Conclusions

On the basis of experimental testing and analysis of reinforced concrete beam under line impact load following conclusions have been drawn:

1. Beam $M_{20}U$ failed at third blow, $M_{20}B$ failed at fifth blow and $M_{20}O$ failed at eight blow.
2. Beam $M_{25}U$ failed at fifth blow, $M_{25}B$ failed at seventh blow and $M_{25}O$ failed at ninth blow.
3. Beam $M_{30}U$ failed at sixth blow, $M_{30}B$ failed at eight blow and $M_{30}O$ failed at twelfth blow.
4. The maximum experimental deflection in beam $M_{20}U$ is 18.23*mm*, in beam $M_{20}B$ is 17.92 *mm* and in beam $M_{20}O$ is 17.28*mm*.
5. The maximum experimental deflection in beam $M_{25}U$ is 17.94*mm*, in beam $M_{25}B$ is 16.26*mm* and in beam $M_{25}O$ is 15.58*mm*.

6. The maximum experimental deflection in beam $M_{30}U$ is 15.70 *mm*, in beam $M_{30}B$ is 14.65*mm* and in beam $M_{30}O$ is 12.67*mm*.
7. The maximum theoretical deflection in beam $M_{20}U$ is 3.16*mm*, in beam $M_{20}B$ is 2.90*mm* and in beam $M_{20}O$ is 1.46*mm*.
8. The maximum theoretical deflection in beam $M_{25}U$ is 1.58 *mm*, in beam $M_{25}B$ is 1.62*mm* and in beam $M_{25}O$ is 1.22*mm*.
9. The maximum theoretical deflection in beam $M_{30}U$ is 0.90*mm*, in beam $M_{30}B$ is 0.85*mm* and in beam $M_{30}O$ is 0.74*mm*.
10. The scabbing started in beam $M_{20}U$ at second blow, in beam $M_{20}B$ at third blow and in beam $M_{20}O$ at fourth blow.
11. The scabbing started in beam $M_{25}U$ at third blow, in beam M_{25} B at fourth blow and in beam $M_{25}O$ at fifth blow.
12. The scabbing started in beam $M_{30}U$ at fourth blow, in beam $M_{30}B$ started at fifth blow and in beam $M_{30}O$ started at sixth blow.

In view of the above results it can be concluded that with the increase in the grade of concrete and quantity of steel more number of blows are required to cause failure in the beam, whereas maximum experimental and theoretical deflection reduces with the increase in the grade of concrete and quantity of steel. Scabbing in the beams started at increased number of blows as grade of concrete and steel increases in the beam.

Thus we can say that impact load carrying capacity of the beam improve by increasing in the grade of concrete and quantity of steel.

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