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LOW VELOCITY HARD IMPACT STUDIES ON REINFORCED CONCRETE SLABS

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ABSTRACT

The results obtained from the tests on 28nos. of reinforced concrete slabs of plan dimensions 1100mmx1100mm and two variable thicknesses of 100mm and 70mm under low velocity (less than 10m/s) hard impact loading are presented in this paper. The slabs were reinforced only at the back face. Some of the slabs were provided with local shear reinforcement at the centre contact zone which was found to be very effective. Impact was simulated by a drop weight of 155N.

1. INTRODUCTION.

Complete analytical solution to the impact problem is not yet considered to be completely successful. So there is a need to conduct experimental investigations to study the behaviour of structures under impact loading. This paper presents the results obtained from a testing programme on reinforced concrete slabs under drop weight impact loading.

2. TEST PARAMETERS.

2.1. Test setup and drop weight.

The impact loading was simulated by a drop weight of steel sphere of 127mm diameter, which could be dropped at the centre of the slab from upto a height of 4.35m by using an impact testing setup. (Fig.1.). A load cell was attached to the steel sphere to measure the contact load, the assembly weighing 155N. Static calibration of the load cell was done in a Universal Testing Machine.

2.2. Target properties.

Concrete was prepared by using ordinary portland cement, locally available river sand as fine aggregate and crushed granite passing through 20mm sieve as coarse aggregate. The mix was designed according to the Indian Standard method [1] to get an average 150mm cube strength of $45N/mm^2$ at 28 days under laboratory conditions. The proportion obtained was 1:2.51:3.07 by weight with a water cement ratio of 0.5.

Samples from 8mm diameter cold twisted deformed reinforcing bars when tested gave a 0.2% proof stress of $518N/mm^2$.

The slabs with overall plan dimensions of 1100mmx1100mm and thicknesses of 100mm and 70mm were supported on a stiff steel frame. They were reinforced only at the back face. Table.1.gives the properties of the slabs tested. Slab Nos.21-28 were provided with local shear reinforement at the contact zone. Slab Nos.25-28 were simply supported on two opposite edges only. All other slabs were simply supported on all four edges.

3. EQUIPMENTS AND TESTING.

3.1. Instrumentation.

A load cell was attached to the drop weight to measure the contact force. Carrier frequency amplifier of 50kHz was used as the signal conditioning unit. LVDT displacement transducers and piezo-electric type accelerometers having mounted resonant frequency of above 50kHz were used for displacement and acceleration response measurement respectively. Conditioned signals from the transducers were intercepted and digitised by a fast (31.4kHz) A/D converter (with 12 digit accuracy) which had been interfaced with a personal computer. Fig.2.gives a schematic view of the instrumentation used.

3.2. Test procedure.

The fundamental frequency of the slab was found out by exciting it with the drop weight at the centre.The output signals from the accelerometer mounted at the bottom centre of the slab and the contact loadcell were collected and the free vibration portion of the signal is analysed using an FFT analysis package to identify the first natural frequency. Fig.3.shows one typical output of frequency obtained from the experimental data. The slab was then impacted by dropping the weight from a height of 4.35m till it failed. Failure was identified by observing the damage. Contact force,displacements, accelerations and strains in reinforcement bars at some specified points were monitored during the testing.

4. TEST RESULTS AND DISCUSSIONS.

4.1 Penetration depth and Contact force.

The local effects and global deformation effects are treated independently and hence it is important to obtain the contact force- time relation. As the loadcell is short and stress wave reflection could interfere with the measurements, a comparison of the variation in the contact load is made by collecting an accelerometer data also which was used to measure the deceleration of the impacting rigid mass. Fig.4.shows the overplot of loads obtained from the loadcell and the accelerometer.

From the test results, it is observed that the shape of the contact force time variation can be approximated to be an isosceles triangle with a duration of less than 2.0 milliseconds. The peak contact force get reduced as more damage occured to the slab around the contact zone. Penetration depth was measured after first drop of every tested slab because the Petry formula [2] and the NDRC formula [3] base the evaluation of contact force on the penetration depth. The experimental results obtained and the calculated values from the above formulae are given in Table.2.

4.2. Plug formation.

For 70mm thick slabs tested, (nos.12,15,19,20), due to a single drop scabbing was observed and the slabs were cut to identify the formation of shear plug. (Fig.5) CEB bulletin [4] gives a nondimensional empirical expression to assess the chances of such a plug formation in low velocity range, <25m/s, using experimental data on solid cylindrical and pipe missiles. For the case of a spherical missile, such as used in the present study, the equivalent diameter does not have a specific meaning and it is taken as equal to the diameter of the sphere. To simplify the expression further, concrete property is expressed by a single parameter by relating the shear stress and concrete modulus to the characteristic compressive cube strength, f_{ck}. The form of the expression suggested is given below.

$$N_{scab} = \frac{5.3\ m^{0.5}\ v_i}{d_o^{0.5}\ e\ (1 + \frac{e}{d_o})\ f_{ck}^{0.25}} \qquad (1)$$

The value of this expression is evaluated for the present testing and given in Table.3. 100mm thick slabs failed in punching shear under repeated impact.(Fig.6).Local shear reinforcement provided against punching was found to be very effective.(Fig.7a,Fig.7b)

4.3. Strain rate measurements.

Strain gauges were bonded on to the reinforcing steel bars before casting the slabs and the data obtained from the test were analysed. It was seen that the rate of strain was in all cases less than 4 s^{-1}. Fig.8 shows one typical output. The strain rate of this order is not much important for global response analysis. [5]

4.4. Global response.

For analysis of overall response, the force-time history is considered to be of isosceles triangular shape. Simplified procedure of analysis using SDOF approximation was done. In some of the cases nonlinear dynamic finite element analysis also was carried out. Details are reported in [6].

5. **CONCLUSIONS.**

From the present investigations, the following conclusions are drawn.

1. On comparing the contact force obtained by Petry formula and NDRC formula with that obtained from the present investigation, it is found that the petry formula gives a better prediction than NDRC formula.

2. Contact force- time history curve for this type of impact can be assumedto be of isosceles trianglular shape with a duration of less than 2 milliseconds.

3. Strain rate in steel observed in this investigation is less than 4/sec.

4. Modificaton suggested for CEB bulletin formula for N_{scab} in the case of hard spherical missile impact predicts fairly well the formation of shear plug and subsequent scabbing.

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Table 1.Properties of slabs tested.

Slab. no:	f_{ck} (N/mm^2)	Steel, Ast/bd (%)	Bound: condn:	Lowest. natural freq. (Hz)	Local shear . reinf.	Thickness (mm)
7	39	0.31	4SS	313	No	100
16	40			314		100
8	35	0.56	"	294	"	100
14	41			333		100
9	47	0.80	"	294	"	100
17	45			-		100
10	37	1.43	"	255	"	100
18	46			294		100
11	44	0.88	"	215	"	70
15	46			255		70
12	40	1.28	"	235	"	70
19	50			235		70
13	36	2.26	"	215	"	70
20	45			209		70
21	40	0.88	"	333	Yes	100
22	38			288		100
23	41	0.88	"	-	"	70
24.	54			261		70
25	41	0.88	2SS	213	"	100
26	54			210		100
27	40	0.88	"	110	"	70
28	38			104		70

4SS - 4 sides simply supported with corners helLd down.
2SS - 2 opposite edges simply supported.

Table.2.Penetration depth and contact force

(a) Experimental results.

Slab no.	Penetration depth, x (mm)	Peak load, P (kN)	Contact Time, t (ms)
7	3.72	242.1	0.76
16	2.38	143.2	1.76
8	2.98	-	-
14	2.88	171.8	1.14
9	2.18	130.2	1.27
17	2.14	-	-
10	3.05	-	-
18	1.69	235.4	0.76
11	-	-	-
15	3.57	138.7	2.53
12	4.12	208.4	0.50
19	4.07	304.5	1.01
13	-	-	-
20	4.13	157.2	2.03
21	2.15	202.7	1.53
22	-	187.5	1.50
23	2.38	193.5	1.78
24	-	159.3	1.02
25	2.05	-	-
26	2.43	114.2	1.27
27	2.56	-	-
28	2.10	284.5	1.27

(b) Values from Petry formula

x = 6.53mm, Peak load = 197.2kN, t = 1.05 ms.

(c) Values from NDRC formula

x = 16.58mm, Peak load = 67.60kN , t = 2.97 ms.

Table. 3. Scabbing values from the suggested expression.

Weight of missile (N)	Velocity of drop (m/s)	Dia. of missile (m)	Slab thick: (m)	f_{ck} (pascal)	Scab. value	Remarks
103	9.23	0.127	0.10	30×10^6	33.62	NS
155	9.23	0.127	0.10	46×10^6	37.12	NS
155	9.23	0.127	0.07	40×10^6	63.19	S
155	8.85	0.127	0.07	36×10^6	62.21	S
155	7.67	0.127	0.07	44×10^6	51.29	IS
72*	4.85	0.123	0.05	43×10^6	34.52	NS

NS - no scabbing, S - scabbing, IS - incipient scabbing
* - from ref. [2]

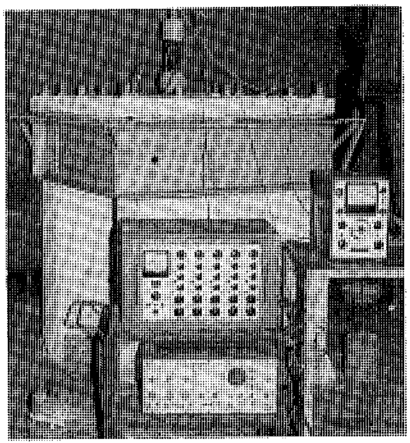

Fig. 1 Experimental Setup.

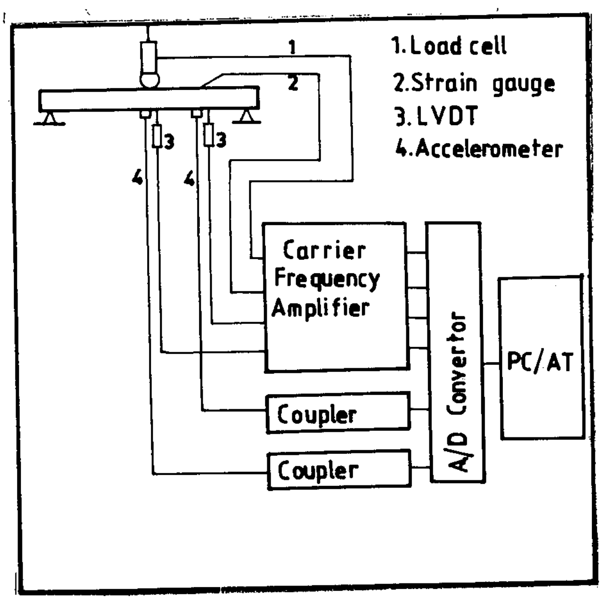

Fig. 2 Schematic view of Instrumentation.

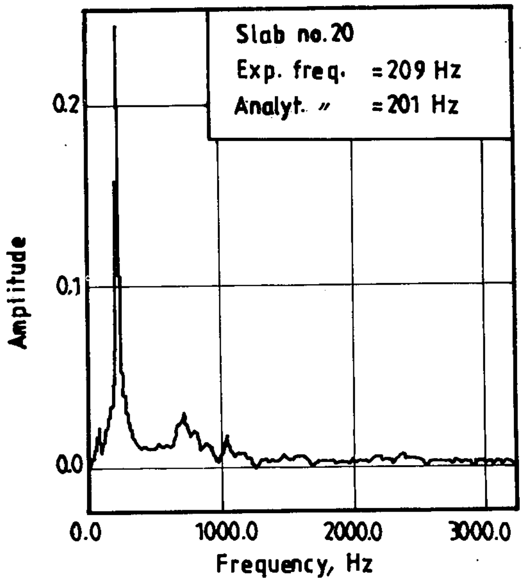

Fig. 3 Spectrum of accelerometer data in natural frequency test.

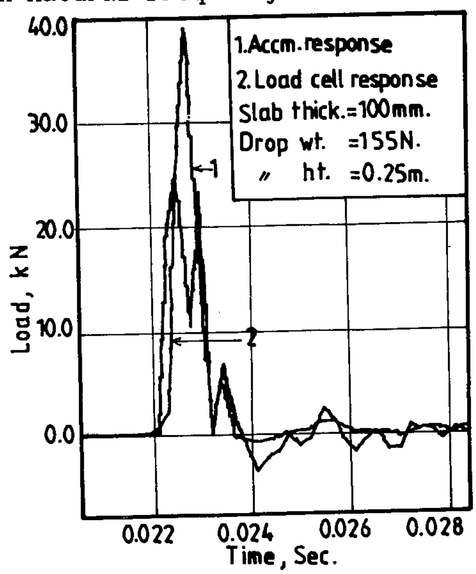

Fig. 4 Accelerometer response and loadcell response overplotted

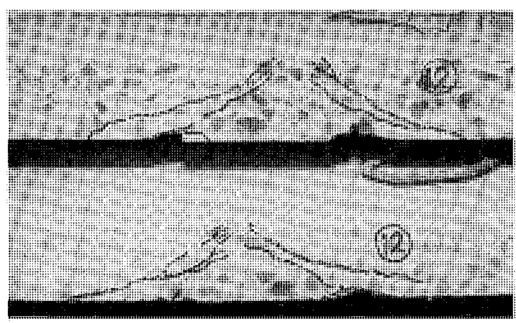

Fig. 5 Section of slab failed in punching shear

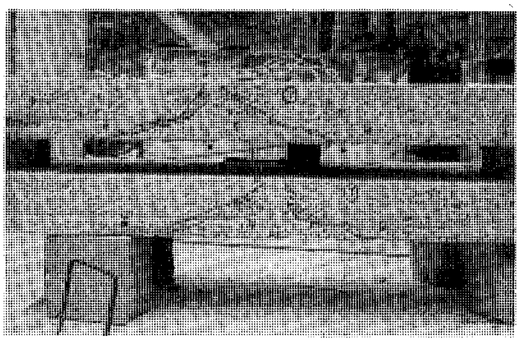

Fig. 6 Section of Slab failed in punching shear.

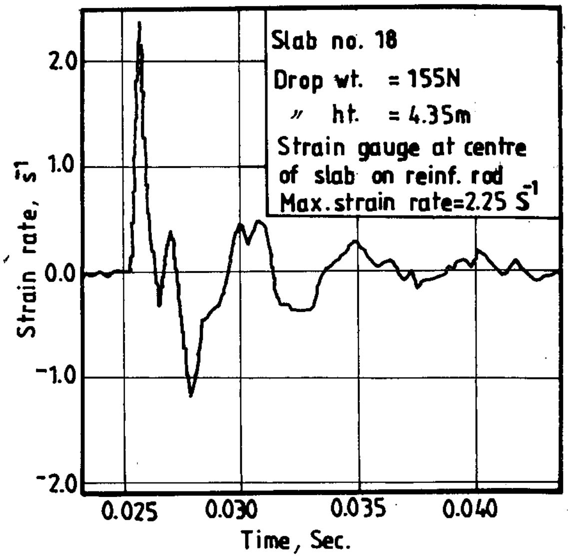

Fig. 8 Typical strain rate output for a slab.

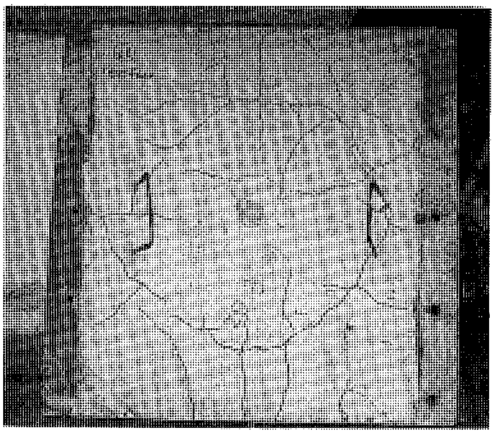

Fig. 7a Front face of slab with shear reinf. after test.

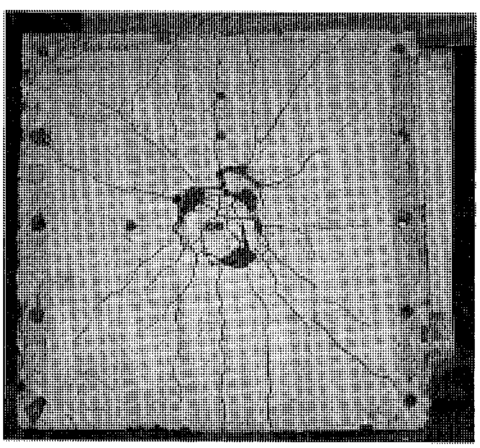

Fig. 7b Back face of slab with shear reinf. after test.