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Procedia Engineering 144 (2016) 124 – 131

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Experimental study of plain and reinforced concrete targets subjected to impact loading

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Abstract

In order to study the influence of the plain concrete and reinforced concrete on ballistic performances. Penetration tests were conducted on different thicknesses of plain concrete and reinforced concrete plates having 40 Mpa unconfined compressive strength and reinforcement of 8mm diameter steel mesh in reinforced concrete plates is incorporated. The plates were 450mm of diameter and 60mm, 80mm, 100mm thicknesses are studied. The plates were subjected to an impact of hard steel projectile with ogive nose weighing 1kg with diameter 19mm and length of 450mm. The projectiles were accelerated by the laboratory pneumatic gun to velocities range between 28m/s to 102m/s. impact and residual velocities were measured by the high speed digital camera system. Ballistic resistance of plain concrete and reinforced concrete at different thicknesses had been find out in the experiments and compared with already proposed analytical formula. The results thus obtained are presented and influences there on due to the variation in the concrete plate thicknesses to the projectile impact are discussed. The ballistic limit was found to increase with an increase of target thickness.

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: Ballistic limit; scabbing; residual velocity; impact velocity

1. INTRODUCTION

Concrete structures have been widely used in construction of civilian structures and important structures such as bunkers, nuclear power plants, buildings, brides, dams, tunnels etc. for those structures important criteria is to with stand against impact load produced by projectiles. So many researchers did perforation experiments on high strength

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Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.05.015

concrete slabs, beams, grouts etc. Hanchak and Forrestal's [1-4] have done projectile impact on different grade of concrete and varying diameters of concrete plates and grouts they found striking velocities corresponding to maximum depth of penetration, effect of concrete target diameter on depth of penetration. Shirai and ohno [5] presented a method to improve the impact resistance of reinforced concrete plates against projectile impact they reported to reduce local damage due to impact load provide steel plate lining at impacted and rear surface, double layered RC plates can be expected to have higher impact resistance than the standard one.Damage evaluation of concrete plates at higher impact velocities was also studied by Beppu and ohno [7]. The launch acceleration in the gun bore and the deceleration during the perforation event was recorded with an acceleration transducer. Several perforation tests using concrete targets of different thicknesses were conducted with a nominal striking velocity of 400 m/s. The residual velocity and kinetic energy consumed versus the target thickness was analysed. The perforation limit was also obtained by Li Jinzhu and Lv Zhongjie [8]. In this study perforation experiments have been done on varying thicknesses 80mm, 100mm of low strength concrete having compressive strength of 40Mpa with hard steel projectile of 1 kg and 19mm diameter validated with already proposed formulae. The projectiles were accelerated by the laboratory pneumatic gun to velocities range between 28m/s to 102m/s. impact and residual velocities were measured by the high speed digital camera system. Ballistic resistance of plain concrete and reinforced concrete at different thicknesses had been find out in the experiments. Damage pattern of concrete also discussed.

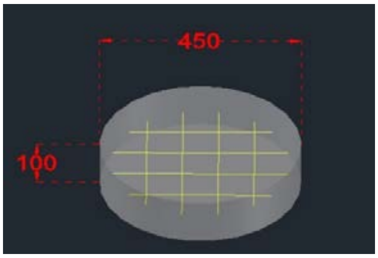
2. CONCRETE TARGETS

In previous studies many researchers have studied with high strength concrete and low strength concrete and also normal strength concrete but they have found that there is very minor effect in performance of the concrete targets with respect to their compressive strengths. The target materials used were M40 plain concrete see Table 1, Different thicknesses of 80mm and 100mm of M40 grade concrete had been casted, and 5 cube of dimension (150*150*150) mm also casted. The samples for the compressive strength tests were allowed to cure for at least 28 days. After curing of concrete cubes had been tested on compression testing machine which gives unconfined average compressive strength of 48 Mpa.

Table 1. Constituents of concrete

Cement	water	Aggregate (10mm)	Sand	admixture
437.9	166.4	1040.92	720	0.25%

Diameter of concrete plates was taken constant 450mm and different thickness concrete plates were casted, 80mm, 100mm. Geometry of the concrete plate is shown in Fig 1(a). The experiments were conducted on a pneumatic gun with 1 kg projectile as shown in Fig 1(b), was launched up to an incidence velocity 200 m/s. The length of the barrel was considered 18 m to enable adequate acceleration of the projectile for obtaining the required velocity see Fig 2. The angle of incidence was considered normal to the target.



a) Circular concrete plates

b) projectile

Fig. 1. Geometry of concrete plate and hard steel projectile

3. Experimental setup

A 19mm diameter and 12m long barrel was used to launch the projectile to hit the target plates at normal incidence. The concrete plates were hit at normally at incidence velocities 53-200 m/s. The incidence velocity of the projectile was varied by the pneumatic pressure gun attached with 18 m long seemless steel barel see Fig. 2, however impact and residual velocities were measured with the help of phantom high speed video camera system. In the experiment 2 non flickering LED lights were used to ensure the visibility of perforation phenomenon.

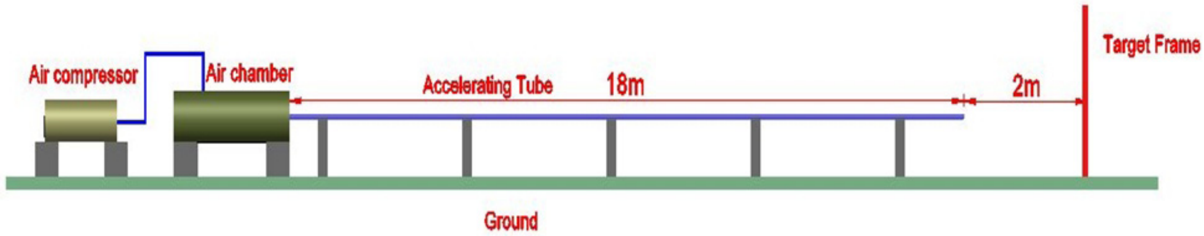


Fig.2- Experimental setup of pneumatic gun

4. Projectile impact experiments

The projectile with the different striking velocity of has perforated into the plain concrete plates and residual velocity is measured using high speed digital camera system sample is shown in the Fig. 4 after perforation of projectile. The rear face of the plain concrete plate has minor scabbing with low radial cracking and there are cracks occurred in the sample. When the speed of projectile is high then the projectile penetrates in to the plates with minor local effects that’s why in this sample there are minor local damage occurred. While Fig. 3 shows rear face of 80mm thick plain and reinforced concrete plate impacted at 100m/s and 120m/s respectively. However Fig. 4 shows rear face of 100mm thick plain and reinforced concrete plate impacted at 192m/s and 200m/s respectively.

Fig. 3. 80 mm thick (a) and (b) plain concrete target and (c) and (d) reinforced concrete

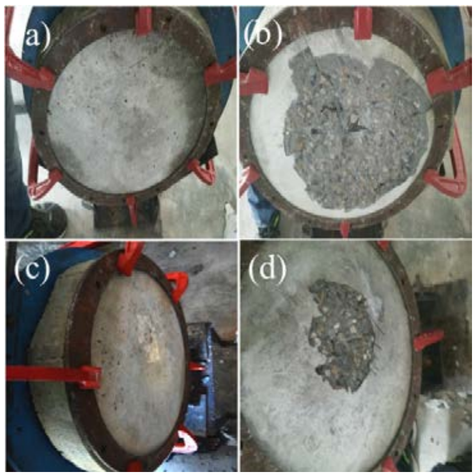


Fig. 4. 100 mm thick (a) and (b) plain concrete target and (c) and (d) reinforced concrete

5. Perforation phenomenon

1kg steel projectile of 19mm diameter and 450mm length has been impacted on varying thickness 80mm, 100mm of M-40 grade of plane concrete and rienforced concrete plates. in Fig. 5(a) and 5(b) shows perforation process of 80mm and 100mm thick concrete plate captured With help of high speed camera system, also impact velocities and residual velocities have been measured.

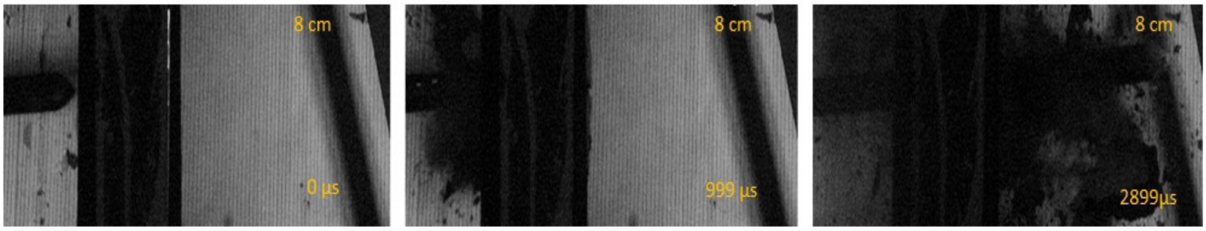


Fig. 5a. perforation process of 80mm thick concrete plate impacted by 1 kg steel projectile

Fig. 5b. perforation process of 100mm thick concrete plate impacted by 1 kg steel projectile

6. Damage evaluation

The damage induced in the plain and reinforced concrete targets during experimentation has been quantified by measuring the volume of material removed from the front and rear target surface. The equivalent diameter of the spalled and scabbed area was calculated as indicated in Fig. 6 in four different direction and the mean diameter has been obtained. Table 3 and Table 2 shows the variation in the spalling and scabbing diameters as a function of incidence velocity of projectile for 80 and 100mm thickness, respectively. It has been found that equivalent scabbing diameter increases with decrease in impact velocity until ballistic limit. It may therefore be concluded that the global deformation has decreased with increase in projectile velocity. The spalling of material however is not influenced significantly by the incidence velocity.

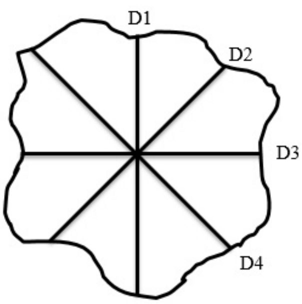


Fig. 6. Equivalaent diameter measurment of affected area after perforation

$$D_{equivalent} = \frac{D1 + D2 + D3 + D4}{4}$$

The volume of spalling and scabbing has also been calculated as a function of incidence velocity and the variation thus obtained and variation has been plotted in Fig. 7 and Fig. 8 respectively for 100 and 80 mm thickness. The volume of material removed due to scabbing has been found to increase almost linearly with decrease in incidence velocity for both target thicknesses. The volume of spalling however remained almost constants for both the thicknesses in the considered velocity regime. For a given incidence velocity, the volume of scabbing has been found to be higher in the smaller thickness. For a given thickness however, the volume of both scabbing and spalling of material has been found to be comparatively lesser in reinforced concrete target compared to plain concrete target. This is due to the fact that the pressure wave propagation in reinforced concrete was very slow due to confinement of concrete hence the cracks were very small. On the other hand, in case of plain concrete cracks wide and long cracks were observed. Equivalent diameter at front and rear face of the impacted specimen have been measured in four different direction and find out the mean of that four diameters in in four direction which is termed as equivalent diameter at front and rear face. It is found that equivalent diameter was increases with decrease of the impact velocity till ballistic limit however at low velocity higher global deformation had been found when compare to higher velocity for the same specimen.

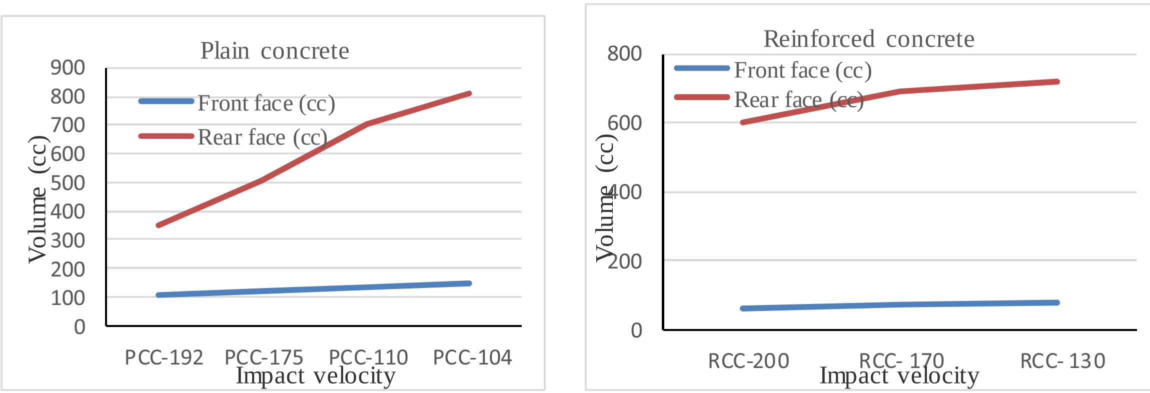


Fig.7 volume erosion of front face and rear face of 10cm thick concrete plate after impact a) plane concrete (PCC) b) reinforced concrete (RCC)

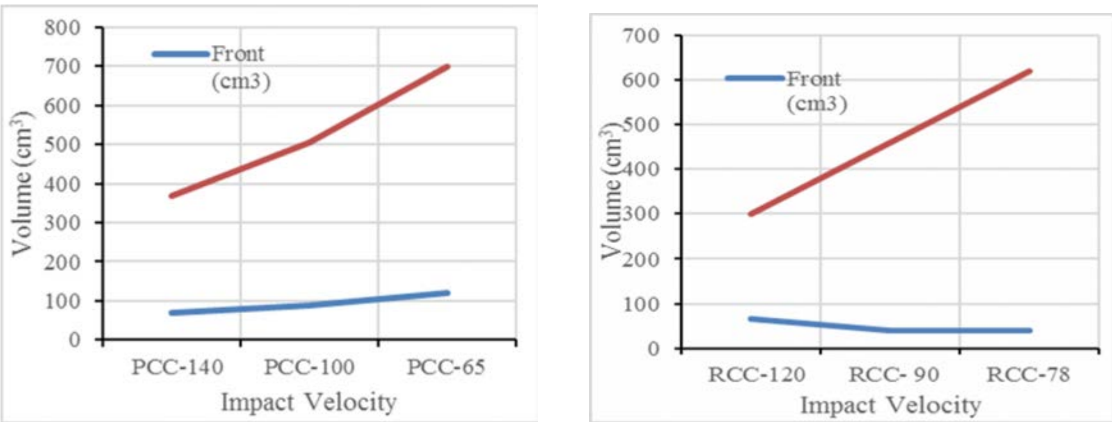


Fig.8 volume erosion of front face and rear face of 8cm thick concrete palte after impact a) plane concrete (PCC) b) reinforced concrete (RCC)

Table 2. Equivqlent diameter of 10 cm thick PCC and RCC plate after Impact

		Front Diameter (mm)					Rear Diameter (mm)				
Specimen Thickness (mm)	Test Specimen	D1	D2	D3	D4	Equivalent (D)	D1	D2	D3	D4	Equivalent (D)
100	PCC-192	113	121	123	85	**110.5**	214	203	220	189	**206.5**
100	PCC-175	128	131	125	110	**123.5**	202	224	232	212	**217.5**
100	PCC-110	130	145	124	115	**128.5**	195	253	210	238	**224**
100	PCC-104	130	146	128	116	**130.0**	263	281	253	272	**267.2**
100	RCC-200	84	81	84	85	**83.5**	300	300	304	260	**291**
100	RCC-170	92	90	124	111	**104.2**	277	340	330	273	**305**
100	RCC-130	170	157	160	165	**163.0**	325	370	280	410	**346.2**

Table 3. Equivqlent diameter of 8 cm thick PCC and RCC plate after Impact

		Front Diameter (cm)					**Rear Diameter (cm)**				
Specimen Thickness (cm)	Test Specimen	D1	D2	D3	D4	Equivalent (D)	D1	D2	D3	D4	Equivalent (D)
8	PCC-140	10.4	8.3	8.8	9.4	**9.2**	19.4	20.3	20.1	17.1	**19.2**
8	PCC-100	8.2	11.5	8.6	10.8	**9.8**	28.0	21.0	32.0	29.0	**26.1**
8	PCC-65	7.6	9.2	7.2	7.2	**7.8**	20.4	15.5	17.3	20.2	**18.4**
8	RCC-120	7.3	6.5	8.2	7.8	**7.5**	22.0	17.5	19.4	23.2	**20.52**
8	RCC- 90	8.3	10.4	9.1	11.3	**9.7**	23.2	17.1	24.2	11.6	**19.1**
8	RCC-78	11.0	9.9	7.8	8.9	**9.4**	22.6	20.0	20.6	18.8	**20.5**

7. Result and discussion

Projectile experiment had been carried out successfully on different thicknesses 80mm, 100mm of plain and reinforced concrete plates, impact and residual velocities have been measured with the help of high speed phantom video camera system. Impact and residual velocities of projectile impact experiments on various thicknesses are shown in Table 4. Results of impact and residual velocities for plain and reinforced concrete plates have been plotted in Fig 9(a) and 9(b) however variation of impact and residual velocities along the thicknesses have been plotted in fig.10a and 10b for plain and reinforced concrete plate respectively. Equivalent diameter was increases with decrease of the impact velocity till ballistic limit however at low velocity higher global deformation had been found when compare to higher velocity for the same specimen. spalling of the impacted concrete plate were almost equal at different velocities however scabbing were increase with decrease of the velocities till ballistic limit of the specimen.

Table 4. Incidence and residual projectile velocities for different concretes and target thicknesses

Experimental Results of 1 kg projectile impact on M40 grade concrete plate				
	Plain concrete		Reinforced concrete	
Plate thickness (mm)	Initial velocity (m/s)	Residual velocity (m/s)	Initial velocity (m/s)	Residua velocity (m/s)
80	140	77	120	34
	100	43.6	105	26
	80	19	90	13
	63	0	79.2	0
100	192	134	200	80
	175	120	170	35
	110	10	132	0
	101	0		

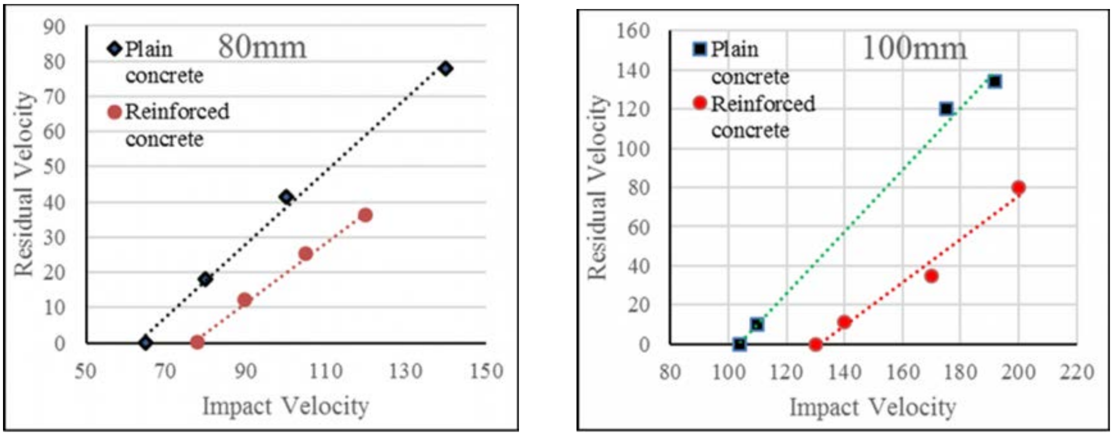


Fig.9- Impact velocity vs residual velocity a) 80mm and b) 100mm thick plate

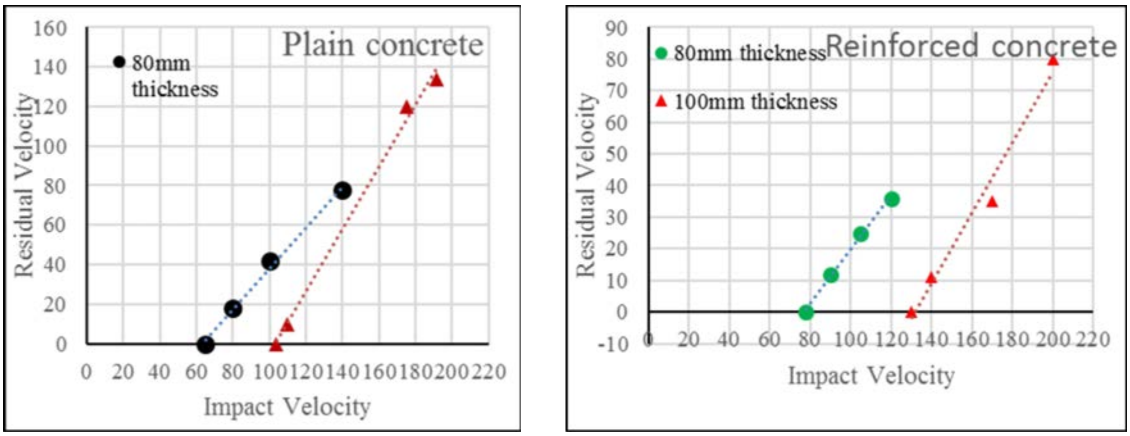


Fig. 10- Impact velocity vs residual velocity of different thicknesses of a) Plain concrete b) Reinforced concrete plates

8. CONCLUSION

Conducting ballistic performances on plain concrete and reinforced concrete plates taking 40MPa as unconfined compressive strength of the target specimen for both plain concrete plates and reinforced concrete plates and taking diameter as 450mm for both plain concrete and reinforced concrete plates and studied parameters for thickness 80mm, 100mm for both plain concrete and reinforced concrete plates. from the experiments it is found that ballistic limit of the reinforced concrete plates is increased 20%, 25% for 80mm, 100mm thicknesses respectively, when compared to plain concrete plates. Also Residual velocities for reinforced concrete plates are decreased when compared to plain concrete plates. Due to the incorporation of reinforcement in the concrete plates there is very huge decrease in the scabbing however when striking velocity of the projectile is low then scabbing in the rear face of the concrete plate is high for plain concrete plates and as well as reinforced concrete plates.it is also found that pressure wave propagation is very slow due to confinement of concrete so cracks were very small while in case of plain concrete cracks were wide and long. Spalling is almost same for plain concrete plates and reinforced concrete plates. Scabbing were increase with decrease of the velocities till ballistic limit of the specimen. Global deformation was higher at lower velocities while at higher velocities local deformation was found.

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