Response of Initially Stressed Concrete Targets Under High Rate of Loading

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Prestressed concrete is a highly being used material in the construction of strategic and important structures such as nuclear containments, bridges, storage structures and military bunkers. It is highly durable, fire and corrosion resistant and nonporous. In order to study the influence of prestresing on the ballistic characteristics of concrete targets ballistic experiments have been carried out against ogival nosed (3 CRH) hard steel projectiles. The projectile of 0.5 kg mass were normally impacted on 80 mm thick presstressed concrete targets of plan size 450 mm x 450 mm. The unconfined compressive target strength of concrete was designed 48 MPa. An initial stress of 10% magnitude of compressive strength was induced by 4 mm diameter high tensile strength (1700 MPa) steel wires in prestressed concrete targets. A grid of 8 mm diameter steel bars were inserted in the reinforced and prestressed concrete targets to enable the straight comparison between these concretes. The prestressing in concrete has been found to be effective in reducing the volume of scabbed material as well as the ballistic resistance of prestressed concrete targets. The ballistic limit of prestressed concrete with 10% induced stress was found to be 10.2 % higher than that of the reinforced concrete and 14% higher than the plain concrete target, respectively.

Keywords *Prestressed Concrete, Perforation, Scabbing, Ballistic reistance.*

1. INTRODUCTION

The study of ballistic characteristics of plain and reinforced concrete is extremely important in order to design the important strategic structures such as, nuclear containment, bunkers, bridges, dams. The penetration mechanism of concrete barrier is relatively more complex than the metals due to its complex material behavior. During modern decades the study of the response of plain or reinforced concrete targets under ogive-nosed projectile impact has been enhanced by a number of experimental and analytical works [1-5].

A consistent improvement in strength and performance over the flast few decades transformed the concrete into most suitable construction material worldwide. Hanchak et al. [6] carried out ballistic experiments on 48 MPa and 140 MPa reinforced concrete targets of plan size (610 mm x 610 mm) and 178 mm thickness against ogival nosed 0.5 kg projectiles. The concrete targets were reinforced by three layers of 5.69 mm diameter steel reinforcement grid. They concluded that an increase of compressive strength by three times, had insignificant influence on the ballistic resistance of the target. On the other hand, the ballistic experiments conducted by Shirai et al. [7] on 35 MPa and 57 MPa reinforced concrete targets led to the conclusion that strength plays a major role to stop the projectile penetration and scabbing of material. Hanchak et al. [6] reported that the reinforcement had an insignificant effect on the residual velocities while Haifeng and Jiangou [8] reported that dynamic load carrying capacity of reinforced concrete was significantly dependent upon the magnitude of reinforcement such that the reinforced concrete performed better than plain concrete target at higher ratios of reinforcement while an opposite trend was observed at low reinforcement ratios.

The dynamic crack propagation and impact load carrying capacity of the pre-stressed concrete railway sleepers at varying support conditions and rate of loading [9-12] have been studied under single and repeated impact loads. Under hard track condition (ballast thickness 250 mm) the crack length in sleeper was found to be higher and the propagation of crack faster than in soft track condition (ballast thickness 100-150 mm). Under both of these support conditions however, the failure occurred in flexure and longitudinal splitting. The pre-stressed concrete rock sheds are used in various countries to avoid casualties against falling rocks [13-14]. In an investigation of impact response of T and Γ shaped pre-stressed concrete rock-sheds [14] studied through prototype experiments, the T-shaped frame has been found to rationally disperse the sectional forces over the whole structure and offered 1.7 times more resistance than Γ shaped frame. The study of blast load resisting capacity of the concrete has demonstrated that an initial pre-stressing resulted in reduced deflections (both maximum and residual) in concrete elements, and has also been found to be effective in delaying the appearance and growth of flexural cracks [15]. Pavlovic et al. [16] performed a number of FE simulations of concrete targets against projectile impact.

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To compare the non-linear response of material, the simulations have been carried out based on RHT material models available in different commercial FEM codes. The RHT material model available in LS DYNA predicted the experiments in agreement and hence it was found most suitable model to simulating the projectile impact on concrete targets. Pavlovic and Fragassa [17] carried out finite element simulations to study the ballistic performance of flexible curtains. They confirm that the flexible curtains (PVC or PU) with height of 200, 300 and 400 mm may retain the 100-gram projectile upto 70 m/s incidence velocity.

Zivkovic et al. [18] studied the influence of basalt and flax natural fiber on the impact properties under dry and salty water conditions. The hybrid (basalt/flax) composite of basalt fiber reinforcement (BFR) and flax fiber reinforcement (FFR) significantly improved the impact properties of composite in comparison to that of single composite matrix. In a further study [19] drop test were carried out on hybrid composite of basalt and flax fibers with vinylester resin to obtain the impact characteristics of composite. Further the tensile and flexural properties of the composite have acquired to model the falling weight impact response of composite. The energy dissipation also obtained through force-displacement curve under impact loading

A detailed modelling technique of viscoelastic response of ceramic materials using finite element codes. A time-depending problem such as viscoelasticity has merged with a temperature-depending situation [20-21]

The present experimental investigation aims to explore the possible influence of the initially induced stress on the ballistic response of pre-stressed concrete target against projectile impact. The pre-stressed concrete plates of dimension (450 mm x 450 mm x 80 mm) were subjected to 0.5 kg ogival nosed (3 CRH) hard steel projectiles at normal incidence.

2. PREPARATION OF TARGET

The concrete mix was prepared as per Indian Standard; IS10262 to obtain 28 days unconfined compressive target strength of 48 MPa. A number of trials were conducted with many configurations of cement, potable water, river sand and coarse aggregate. The final composition of the concrete mix had 440 kg cement, 0.4 water cement ratio, 730 kg river sand and 1050 kg coarse aggregate of size 10 mm in one cubic meter concrete, see Table 1. The typical uniaxial compression tests performed on 150 mm cube specimens after 28 days curing in tap water resulted an average unconfined compressive strength 46-51 MPa.

The square concrete specimens of span 450 mm and thickness 80 mm were introduced a unidirectional pre-stress of 10% of unconfined compressive strength through pre-tensioning of high strength (1700 MPa) steel wires of 4 mm diameter. The target was also reinforced with 8 mm deformed steel bars of tensile yield strength 415 MPa @ 80 mm c/c both ways with a clear cover of 15 mm, Fig. 1(a). The ogival nosed (3 CRH) hard steel projectiles of mass 0.5 kg has been prepared on lathe machine, see Fig. 1(b).

Table 1. Constituents of concrete

Cement (kg/m^3)	W/C ratio	Water (kg/m^3)	Aggregate (kg/m^3)	Sand(kg/m^3)
440	0.40	180	1050.4	730

Table 2. Calculation of effective stress for inducing initial pre-stress in the target

Target Thickness (mm)	Effective Cross-sectional Area (mm^2)	No. of Wires	Force in Each Wire (kN)	Initial Stress in Target (MPa)	Losses (15% of Initial Stress) (MPa)	Effective Stress in Target (MPa) = Initial Stress in Target –Losses
80	36000	13	14	5	0.76	4.24

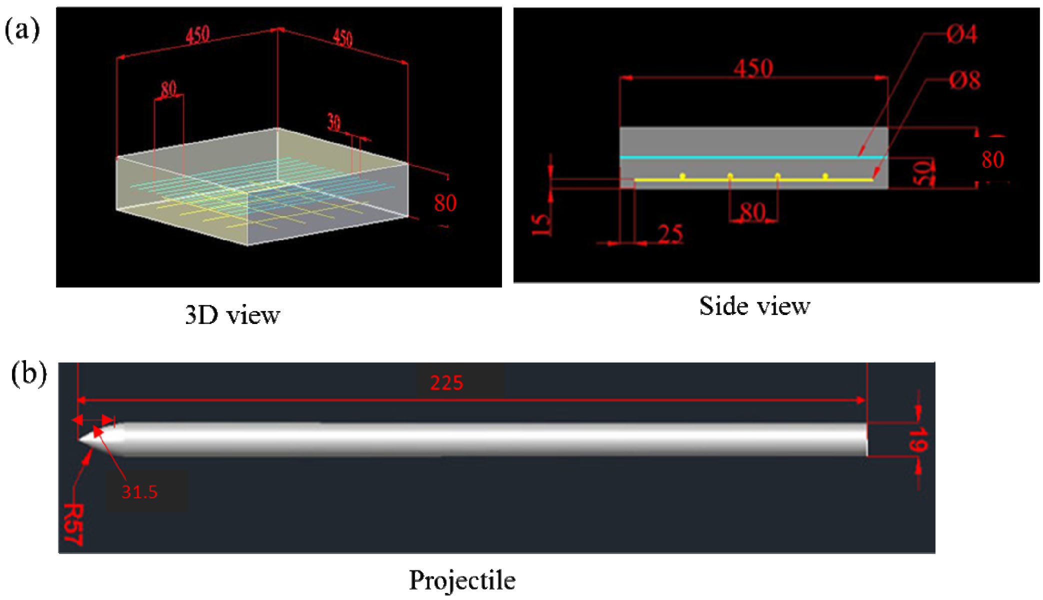

Figure 1 Detailing of (a) pre-stressed concrete target (All dimensions in mm) (b) projectile

A total number of 13 strands were inserted in the target to induce 10% pre-stress, see Table 1. Each strand, anchored at one side and was stretched from the next end with the help of a hollow hydraulic jack. Thus, the initial stress of about 5.0 MPa was induced in the (450 x 450 x 80 mm) target, at anchorage take up, see Table 1. The strands were held in position with the help of steel wedges. The total losses in pre-tress due to elastic shortening, friction, creep and shrinkage were assumed to be 15% of the initial stress (at anchorage take up) as per the recommendation of IS 1343 1980. The effective pre-stress in the target after deducing the losses was calculated to be 4.24 MPa, see Table 2. The concrete was poured in the square steel molds, compacted with the needle vibrator and the concrete surface was finished. The curing of concrete targets was done with the help of wet gunny bags for 28 days, see Fig. 2(a) and (b). The wedges were then released to transfer the stress in the concrete.

3. BALLISTIC EXPERIMENTS

The projectile impact experiments were conducted with the help of pneumatic gun capable to launch 0.5 kg projectile 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. The angle of incidence was considered normal to the target. 0.5 kg ogival nosed hardened steel projectiles impacted on pre-stressed concrete targets at impact velocities in the range 90 – 225 m/s. The projectile striking and residual velocities were recorded through a high speed video camera, Phantom V411. The projectile after perforation was safely collected in a robust steel box placed at 1.5 m behind the target. The projectile followed its central axis and struck at target center.

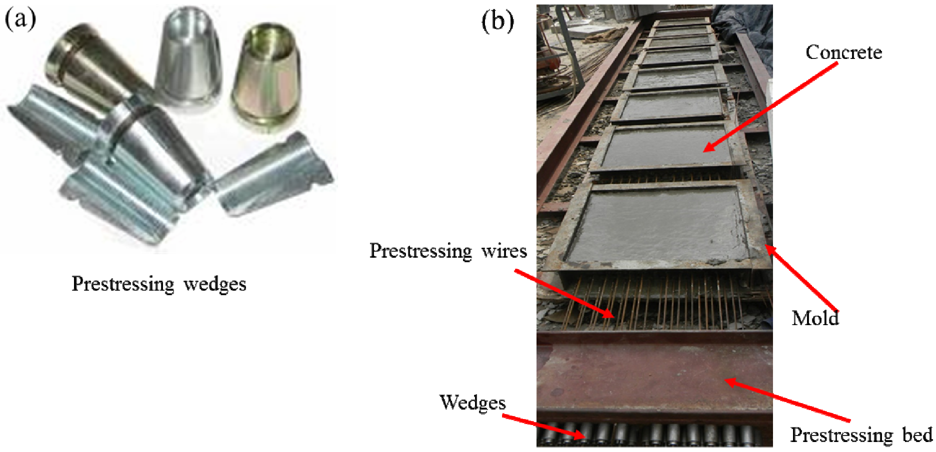

Figure 2 Details of prestressing (a) Steel wedges (b) Casting of Prestressed concrete

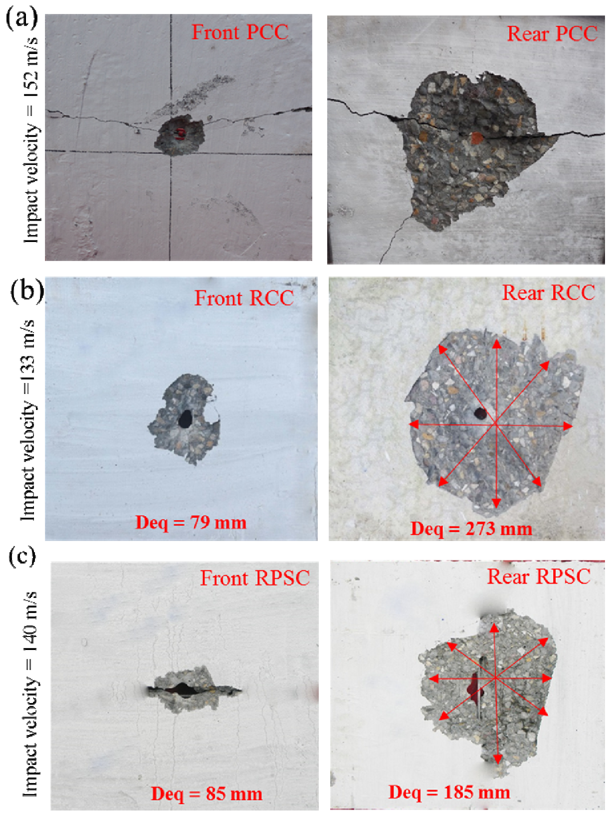

Figure 3 Tested specimens of 80 mm thickness (a) plain (b) reinforced and (c) prestressed concrete

The obtained results were compared with the existing experimental findings [22]. The failure modes of the targets were found to be dependent upon the type of concrete, and the incidence velocity of projectile. The plain concrete targets experienced brittle failure. Thick radial cracks, 3 – 7 mm wide, originating from the impact location, developed across the target thickness and traversed over entire span leading to brittle failure of the target. However, there was no visible cracks could be found in the reinforced and pre-stressed concrete targets, see Fig. 3.

4. QUANTIFICATION OF DAMAGE AND BALLISTIC RESISTANCE

The equivalent diameter of the front and rear surface crater was acquired as the average of four diameters measured in different orientations and presented in Table 3. It has been observed that the damage at the front surface was low and its variation with respect to projectile incidence velocity and type of concrete was insignificant. The rear surface crater on the other hand had a significant influence of incidence velocity. For a given concrete, the diameter of the rear surface crater decreased with the increase in projectile velocity. For a given incidence velocity, the size of crater was found higher in case of pre-stressed concrete target followed by reinforced and plain concrete targets. However, it should be noticed that the depth of rear surface crater was found shallow (in depth) for pre-stressed concrete target.

In order to further study the extent of the damage induced in the different concrete targets, the volume of craters was obtained for each concrete target, see Table 4. The volume of spalling has been found to be relatively low and its disparity also could not be distinguished with respect to velocity and type of concrete. The volume of scabbing has been found to have major influence of incidence velocity followed type of concrete respectively, the volume of scabbing increased with the decrease in incidence velocity for a given concrete. The volume of scabbing was highest in the plain concrete followed by reinforced, 10% pre-stressed concrete, see Figs. 4(a)-(c).

The initial pre-stressing has proved to be effective in minimizing the damage and improving ductility of concrete. It should be noted that the damage in the target due to projectile impact occurred due to the development of tensile stresses. However, due to the induction of initial compressive stresses, the magnitude of tensile stresses reduced. Therefore, the pre-stressed concrete underwent comparatively lesser damage in comparison to reinforced and plain concrete targets.

The impact and residual velocity of projectile presented in Table 5 has been measured with the help of high speed video camera. The ballistic resistance of a given concrete has been found to be increased with the decrease in projectile incidence velocity, see Fig. 5. The increase in the target resistance with the decrease in projectile velocity was found most prominent for pre-stressed concrete followed by reinforced and plain concrete respectively. The ballistic limit has been obtained as the average of highest velocity giving partial penetration and the lowest velocity giving complete perforation of the target. The ballistic limit of pre-stressed concrete with 10% induced stress was found to be 10.2% higher than that of the reinforced concrete and 14% higher than the plain concrete target, respectively, see Table 6.

Table 3. Equivalent crater diameter in different concrete targets

Target Thickness (mm)	Specimen No. – impact velocity (m/s)	Front Surface					Rear Surface				
		D1 (mm)	D2 (mm)	D3 (mm)	D4 (mm)	Equivalent Diameter (mm)	D1 (mm)	D2 (mm)	D3 (mm)	D4 (mm)	Equivalent Diameter (mm)
80	PCC-160	64	89.27	68.85	87.15	**77.31**	240.7	158	261	221.4	**220.2**
80	PCC-140	82.4	65.57	64.8	78.85	**72.90**	161.8	159.5	175.7	141.0	**159.5**
80	PCC-124	62.4	71.1	60.75	61.42	**63.91**	170.1	124.8	152.2	167.2	**153.6**
80	RCC-160	67.2	82.95	72.9	92.96	**79.00**	195.0	134.3	208.8	91.84	**157.4**
80	RCC-145	60	52.93	64.8	63.08	**60.20**	182.6	135.0	167.0	188.6	**168.3**
80	RCC-140	88	78.21	63.18	73.87	**75.81**	187.5	158.0	179.2	154.1	**169.7**
80	RPSC-182	104	90.8	88.2	86.3	**92.36**	147.7	169.8	139.2	131.2	**146.99**
80	RPSC-166	92	75.8	72.9	99.6	**85.08**	132.8	189.6	221.8	196.8	**185.26**
80	RPSC-155	96	89.2	85.0	103	**93.51**	141.1	158	261	221.4	**195.37**
80	RPSC-146	80	101	95.5	107	**96.14**	204.1	189.6	248.8	170.5	**203.29**

Table 4. Volume of material Eroded from different concrete targets

Target Thickness (mm)	Specimen No.	Front Surface ($\times 10^3$ mm^3)	Rear Surface ($\times 10^3$ mm^3)
80	PCC-180	54.4	309.4
80	PCC-152	71.4	424.1
80	PCC-124	96.9	589.9
80	RCC-170	50.1	249.9
80	RCC-145	28.9	385.9
80	RCC-133	28.9	521.9
80	RPSC-182	28	275
80	RPSC-166	33	288
80	RPSC-155	44	313
80	RPSC-146	45	334

Table 5. Incidence and residual projectile velocities for different concretes and target thicknesses

Type of concrete	Initial velocity (m/s)	Residual velocity (m/s)
Plain Concrete (PCC)	180	76
	160	50
	152	38
	140	21
	124	0
Reinforced Concrete (RCC)	170	59
	160	42
	145	28
	140	15
	133	0
Prestressed Concrete (RPSC)	182	62
	166	32
	155	14
	146	0

Table 6. Calculated ballistic limit from the experiments

Target Thickness (mm)	PCC	RCC	RPSC
80	132	136.5	150.5

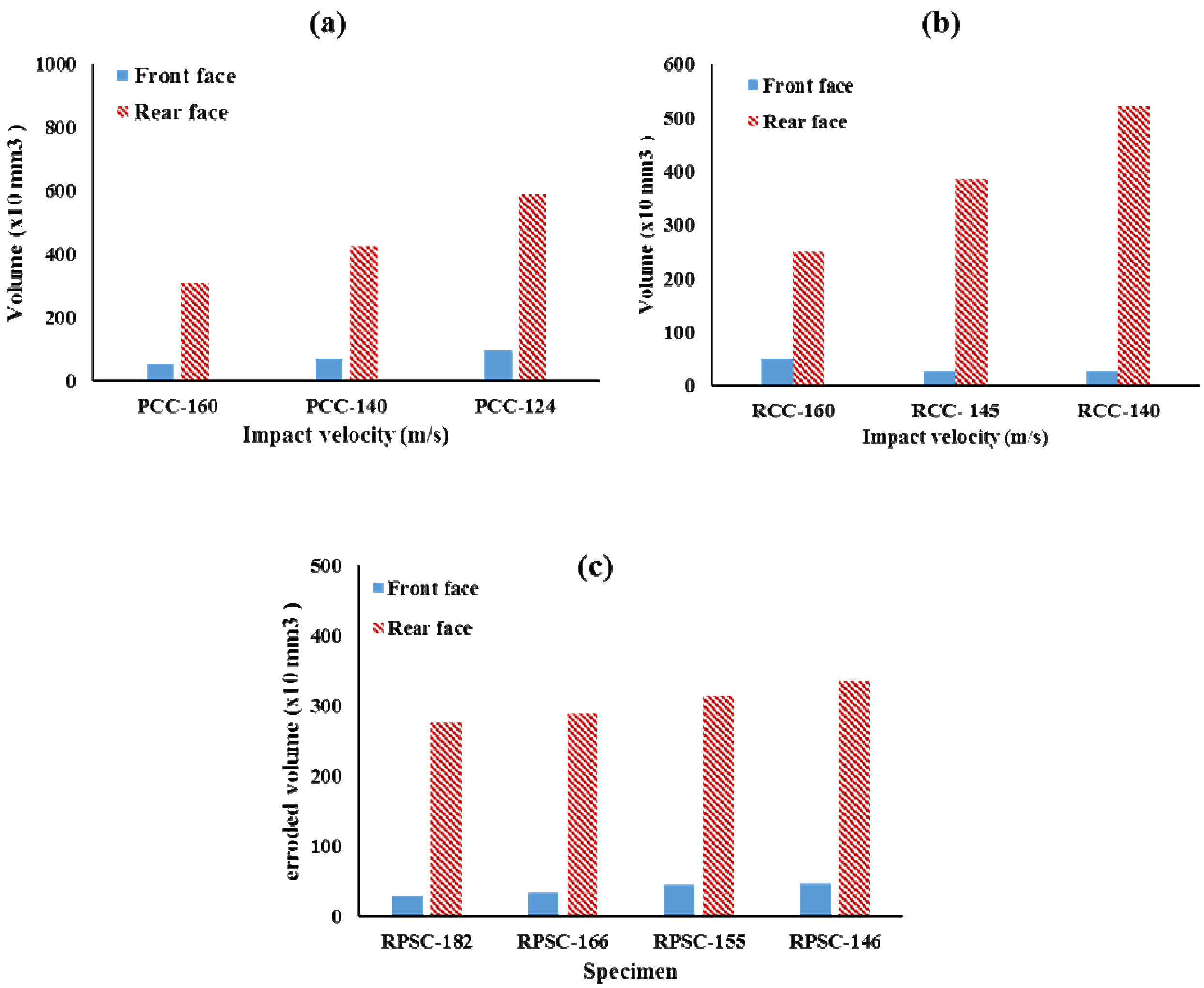

Figure 4 Scabbing and spalling of 80 mm thick target (a) plain (b) reinforced and (c) prestressed concrete

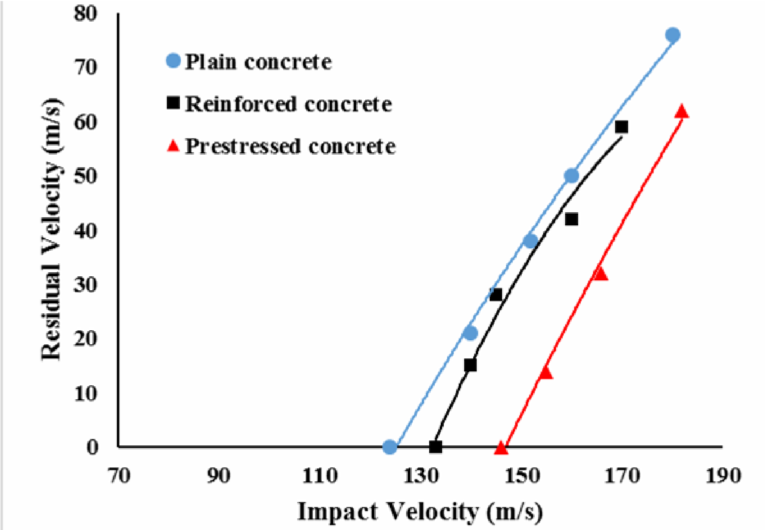

Figure 5 Ballistic performance of different type of concrete

5. CONCLUSION

The projectile impact experiments have been performed on the pre-stressed concrete (48 MPa) targets and compared with the experiments earlier carried out by [22] on the plain and reinforced concrete targets. Due to the introduction of pre-stresses in the concrete plates a very huge decrease was noticed in the volume of scabbing. The initial pre-stressing has proved to be effective in minimizing the damage and improving ductility of concrete. It is found that the highest ballistic resistance was offered by the pre-stressed concrete target followed by reinforced and plain concrete targets.

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Use the singular heading even you have many acknowledgments. Also put in this section sponsor and financial support acknowledgments.

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ОДГОВОР ПРЕДНАПРЕГНУТОГ БЕТОНА НА ВИСОКЕ НАПОНЕ

А. Рајпут, М. Икбал, А. Павловић

Преднапрегнути бетон је материал са широком употребом у изградњи стратешких и важних објеката као што су нуклеарне централе, мостови, објекати за складиштење и војни бункери. Овај материајал је веома издржљив, непорозан, отпоран на ватру и корозију. У циљу испитивања утицаја преднапрезања на балистичке карактеристике бетона, балистички експерименти су спроведени са челичним пројектилом са острим врхом (3 CRH). Пројектил масе 0,5 kg обично су ударали на преднапрегнути бетон дебљине 80 mm величине 450 mm x 450 mm. Коришћена је чврстоћа бетона на сабијање од 48MPa. Почетни напон од 10% од величине чврстоће је изазван челичном жицом пречника 4 mm високе затезне чврстоће (1700 Mpa) у преднапрегнутом бетону. Мрежа од 8 mm пречник челичних шипки је убачена у армирани и преднапрегнути бетон да би омогућила директно поређење чврстоће између ових бетона.

Утврђено је да је преднапрезање бетона ефикасно у смањењу обима красти материјала као и балистички отпор преднапрегнутог бетона. Балистичка граница преднапрегнутог бетона са 10% изазваног напона је 10,2% већа него код армираног бетона и 14% већа него у обичном бетону.