ARTICLE IN PRESS
JMADE-02430; No of Pages 16
Materials and Design xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

# Impact behavior of plain, reinforced and prestressed concrete targets

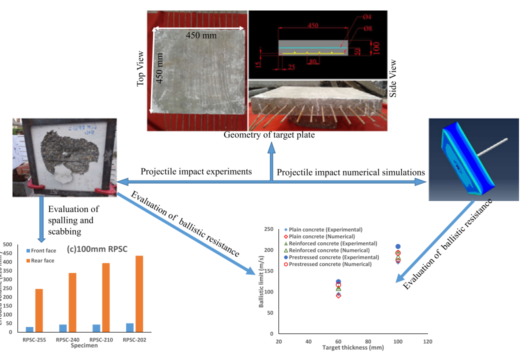
Abhishek Rajput *, M.A. Iqbal

*Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India*

## HIGHLIGHTS

- Plain concrete targets underwent brittle failure with thick radial cracks due to projectile impact.
- Crater size in reinforced and prestressed concrete decreased with increase in projectile velocity.
- Initial prestress proved effective to minimize damage and improve ductility of concrete.
- Prestressed concrete offered highest resistance followed by reinforced and plain concrete.
- FE simulations reproduced the ballistic limit of each concrete within 8% deviation.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 16 June 2016
Received in revised form 16 October 2016
Accepted 29 October 2016
Available online xxxx

*Keywords:*
Prestressed concrete
Ballistic limit
Scabbing
Perforation
Residual velocity

## ABSTRACT

The ballistic enactment of plain, reinforced and prestressed concrete targets of unconfined compressive strength 48 MPa counter to 0.5 kg hard steel projectiles was studied through ballistic experiments and numerical investigation in finite element code ABAQUS. The square targets of dimensions 450 mm × 450 mm and two thicknesses of 60, and 100 mm were subjected to normal impact by 0.5 kg ogive nosed hardened steel projectiles of shaft diameter 19 mm and length 225 mm. An initial stress of around 4–5 MPa (10% of unconfined compressive strength) was also induced in the prestressed concrete targets. The ballistic experiments were carried out at varying striking velocities in the range of 100–255 m/s, and the results thus acquired with respect to magnitude and vicinity of damage, volume of spalling and scabbing as well as ballistic resistance for three different concretes have been compared with their numerical reproductions. The induced prestressing in the concrete, stimulated globalization in deformation and thus enhanced the ballistic resistance of the target. The prestressing in the prestressed concrete has been found most prominent in minimizing the scabbing and spalling of target followed by reinforcement in the reinforced concrete.



## 1. Introduction

Concrete is a unique construction material owing to its high compressive strength, thermal resistance, durability and economy, and is extensively used in almost all types of constructions. The projectile perforation of concrete targets has also drawn widespread attention in defence and strategic infrastructural development [1–5].

The strength is an important factor in enhancing ballistic performance and punching action of concrete, however, the high strength targets seen to have suffered from brittle failure with relatively larger crater and fragmentation [6]. Strength did influence the residual projectile velocity, which affected the resultant load carried by the rear steel liner. Changing strength from 30 to 40 MPa reduced the deformation

* Corresponding author.
*E-mail address:* hiitsme.abhishek@gmail.com (A. Rajput).

http://dx.doi.org/10.1016/j.matdes.2016.10.073


Please cite this article as: A. Rajput, M.A. Iqbal, Impact behavior of plain, reinforced and prestressed concrete targets, Materials and Design (2016), http://dx.doi.org/10.1016/j.matdes.2016.10.073

**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 |

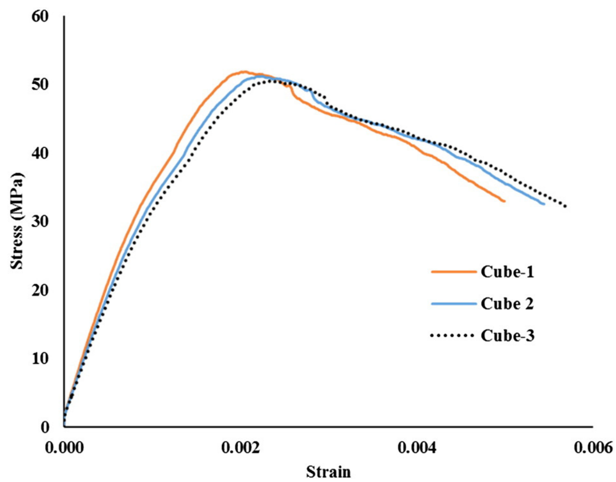



**Fig. 1.** Resultant stress-strain relation of concrete.

of rear steel liner from 110 to 70 mm [7]. The findings of Hanchak et al. [8] on the other hand ruled out the significance of strength (48 and 140 MPa) on ballistic performance of concrete. Double layering the reinforced concrete plate along with an intermediate rubber layer has also been found to have considerable influence on ballistic resistance [9]. The reliability of the reinforced concrete-shielded-steel target against perforation has been found to be dependent on the thickness of both reinforced concrete barrier and steel plate to economically achieve the desired reliability [10]. The stacked layered reinforced concrete target offered higher resistance than the spaced layered target for a given total thickness and projectile velocity. Impact resistance of monolithic target was found higher than the equivalent spaced layered target and the resistance decreased with increase in the number of layers in a layered target, [11]. High velocity impact tests conducted on layered shear thickening fluid (STF) pre-impregnated Twaron fabric showed 30% reduction in depth of projectile penetration compared to dry panels and thus demonstrated direct effect of shear thickening fluid on absorbed energy [12]. The introduction of hybrid-fibers in the concrete also substantially reduced the damaged zone and scabbing due to hemispherical projectile impact [13].

Inducing initial stress in concrete has been found highly effective in improving load carrying capacity and reducing sections and crack width in structural elements. However, majority of applications of prestressed concrete are confined to conventional structures and the concept of enhancing ballistic performance through initial stress has not been exercised. The pendulum impact tests on precast post-tensioned column described more flexibility than the monolithic column and the segments near impact location would open under high magnitude of impact [14]. Drop impact tests conducted on prestressed concrete beams with un-bonded tendons [15] revealed that the crack in concrete is restricted and finally closed due to residual stress if the tendon remains elastic during impact. However, if the tendon is yielded, the crack is insufficiently restricted and penetrates the beam. The impact load carrying capacity of prestressed concrete railway sleepers at varying support conditions and rate of loading described that under hard track condition the crack length in sleeper is higher and the propagation of crack is faster than in soft track condition [16–19]. Studies on prestressed reinforced concrete beams at different prestress levels against blast loading by using finite element codes LS-DYNA conveyed that the appearance and growth of flexural cracks in concrete is delayed effectively by using prestress. Numerical results concluded that prestressing in RC beams increases their blast loading resistance capacities if the failure is governing by flexural. However, the blast loading

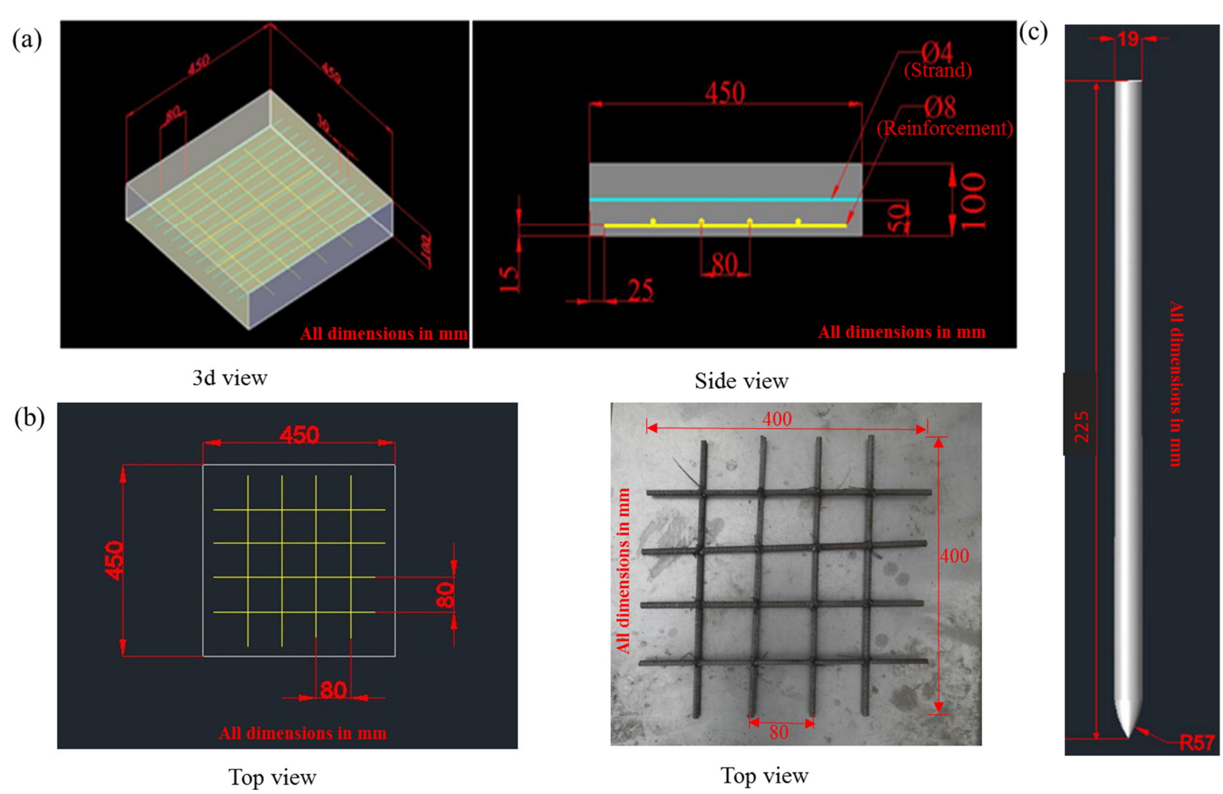



**Fig. 2.** Schematic of (a) prestressed concrete target (b) detail of reinforcement (c) projectile.