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Experimental investigation of prestressed and reinforced concrete plates under falling weight impactor

Vimal Kumar[a,*], M.A. Iqbal[a], A.K. Mittal[b]

[a] Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India
[b] CSIR-Central Building Research Institute Roorkee, Roorkee 247667, India

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ABSTRACT

A detailed experimental investigation has been carried out for investigating the influence of induced initial stress on drop impact response of concrete plates. The square shaped (800 mm) concrete plates of 100 mm thickness have been induced an initial stress of 10% of unconfined compressive strength (48 N/mm^2) through pre-tensioning of high strength steel wires. The plates were then impinged at the center point of span through a steel hammer of 243 kg falling freely from 500 and 1000 mm height under the action of gravity. The impact force-time response of falling weight impactor, reaction-time response at supports, displacement-time history, acceleration and force-displacement response of impacted plates were recorded and the post-test damage evaluation has been carried out. The behavior of the prestressed concrete plates thus studied with respect to two different drop heights has been compared and discussed. Further, in order to study the influence of the induced initial stress on the impact response, the results of the prestressed concrete plates have been directly compared with the reinforced concrete plates of equivalent thickness. Peak impact force observed in prestressed concrete plates were 12.2% and 5.4% higher for drop height 500 mm and 1000 mm, respectively. The energy loss in prestressed concrete plates has been found to have reduced to 3.71% compared to 10.57% in reinforced concrete plates with the increase in the drop height.

1. Introduction

It is broadly established that the response of structural concrete member exhibits significant departure from their static behavior as the rate of loading exceeded certain thresholds (0.1 strain/s). These loadings have remarkable variation in the associated strain rate when subjected to conditions originated from earthquake, tsunami, vehicle impact, projectile impact and blast loading. The associated strain rate may be of the order of $10^{-7}\,s^{-1}$ when the structure is subjected to creep loading and it could be as high as $10^{+3}\,s^{-1}$ when the structure is subjected to blast loading. Due to low tensile strength and high intrinsic brittleness, concrete does not always acquire adequate ductility, strength and toughness and may lead to severe structural damage under impact loading. Therefore, investigations of impact resistance capacity and the resultant failure mechanism of concrete are of prime importance [1–7]. Studies have reported increase in load carrying capacity and toughness of concrete specimens due to increase in percentage of steel fiber [1,2], providing high percentage of reinforcement [3–5] and changing reinforcement configuration [5–7]. In contrast to the alteration in reinforcement arrangement, the increase in reinforcement ratio could not have major influence on the energy absorption capacity and damage resistance of reinforced concrete (RC) slabs [5,6] despite the increase in the drop height [8]. The material and bonding characteristics of fibers also governed the impact performance of concrete target. The volume of the ejected debris has been found to have reduced with the increase in slab thickness and change in shape of impactor [4]. Flat shape impactor had shown higher impact force, more ejection of debris and relatively severe damage on both front and rear surface as compared to those occurred on the slabs impacted by hemispherical impactor. The impact resistance capacity of rock-shed protection slab was investigated under the falling weight up to 810 kg from the drop height up to 37 m [9,10]. Specially designed steel supports that could be easily replaced in case of damage were incorporated below the protection slab to minimize structural damage during energy dissipation. The localized damage on concrete member was also reduced by provision of cladding structures and buffer layers of sand and other high energy absorbing material at impact location [11,12]. In another study, the impact resistance capacity of two prestressed concrete rock-shed frames has been investigated under high impact energy caused by dropping a heavy mass up to 5000 kg [13]. The 'T' shaped fully-rigid

* Corresponding author.
E-mail addresses: panchariya.vimal@gmail.com, iqbal_ashraf@rediffmail.com (V. Kumar).

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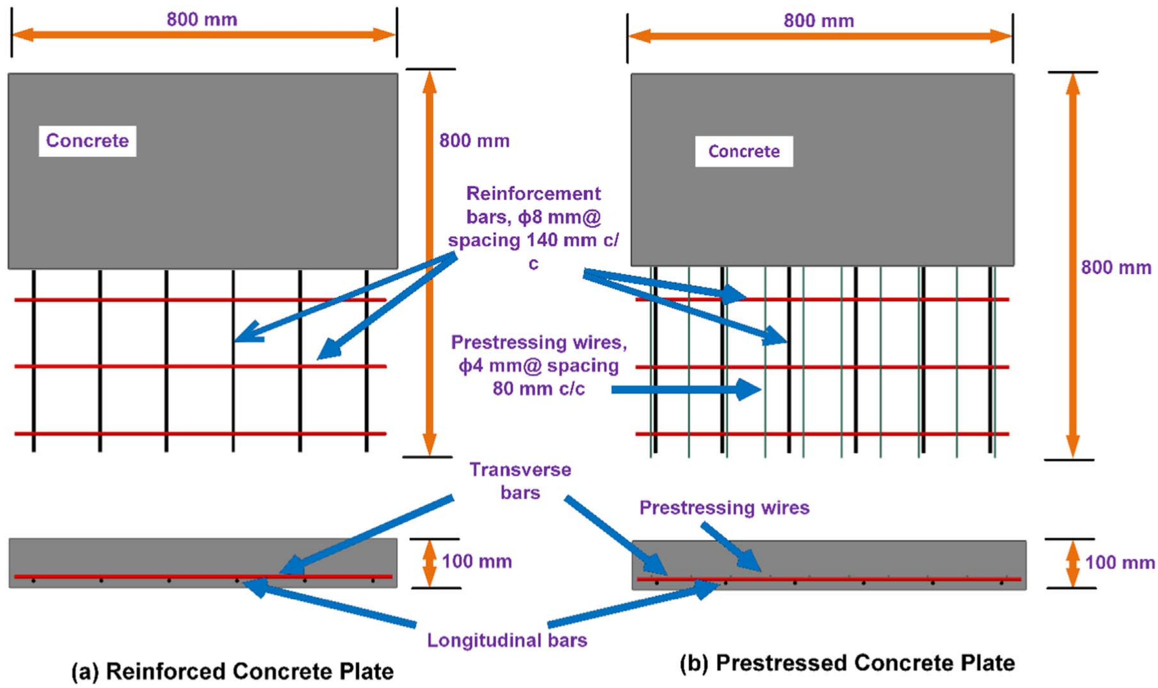

Fig. 1. Detailing of reinforcing bars in (a) reinforced and (b) prestressed concrete plate.

frame described higher energy absorption capacity primarily due to relatively rigid connection at column junction in comparison to the inverted 'L' type frame ('Γ' shaped).

The energy absorption, failure modes and dynamic behavior of prestressed concrete sleepers has been explored under static as well as impact loading conditions [14–17]. Prestressed concrete ties experienced repeated impacts owing to wheel flats or rail abnormalities such as engine burns, rail joint and battered welds. Therefore, crack width and crack patterns were found to be mostly governed by the magnitude of peak impact load, track stiffness and extent of wheel abnormalities. The cumulative damage due to multiple impacts has also seen to have influenced the magnitude of peak impact force and energy absorption capacity of prestressed concrete sleeper. The reduced stiffness of prestressed concrete sleeper under every subsequent impact eventually reduced the load carrying capacity and toughness of the sleeper [15,16]. Moreover, the progressive crack development under hard track conditions had shown rapid crack expansion comparative to softer tracks [17].

The examination of available literature revealed that a number of drop weight impact studies have been performed on plain, reinforced and fiber reinforced concrete and also on concrete-steel composites to identify structural response of beams, slabs and columns. However, attempts to investigate the structural behavior of prestressed concrete are very rare. A few studies reported on prestressed concrete are limited to identification of dynamic response of prestressed concrete sleepers subjected to single and repeated impacts [14–17]. The present study attempts to investigate the importance of prestressing the concrete upon its capacity to resist impact loads. The influence of prestressing and drop height on impact force, reactions, displacements and accelerations has been investigated experimentally and the results thus acquired on prestressed concrete have been compared with the reinforced concrete plates of identical size. The energy absorbed under impact has been derived with the help of force-displacement relationship and the results have been compared.

2. Concrete mix design

The material required for designing the concrete mix was obtained from the regional market. At first, the raw material required for all the concrete batch was prepared to extract any superfluous ingredient present in it. The maximum size of coarse aggregate used was 10 mm to fulfill the requirement of concrete covering and minimum distance between reinforcement bars and prestressing wires. Therefore, the coarse aggregate was first sieved using standard sieve of size 10 mm to segregate bigger particles, washed in water to remove dust and fine sand particle, and thereafter dried at room temperature. Natural sand used as fine aggregate, was also sieved using standard sieve of size 4.75 mm to separate excess size particles. The weigh-batching method of concrete proportioning was adopted for all plate specimens. The ratio of concrete proportioning for various ingredients used to achieve characteristic compressive strength of concrete 40 N/mm^2 was 1:1.74:1.68 (C:FA:CA). However, the final strength achieved after 28 days was 48.4 N/mm^2 with a standard deviation of 1.60. The required quantity of raw material was blended properly in mechanical concrete mixture. Thereafter, water was added adopting a water-cement (w/c) ratio, 0.35. The mixing was then done for 2–5 min to obtain well mixed and uniform concrete. A small quantity of super-plasticizer (0.4% by weight of cement) was also added in the mix to improve the workability of concrete. The cement used for concrete mix design was Ordinary Portland Cement (OPC) of 43 grade with specific gravity 3.15. The specific gravities of the fine and coarse aggregate were 2.73 and 2.74 respectively.

3. Preparation of reinforced and prestressed concrete plates

In this study, impact tests were performed on prestressed and reinforced concrete square plates of size 800 mm and thickness 100 mm. The schematic detail of plate specimens for prestressed and reinforced concrete are shown in Fig. 1. High Yield Strength Deformed (HYSD) steel bars of diameter 8 mm were placed at a spacing of 140 mm along both main and transverse spans of plate in prestressed as well as reinforced concrete plates. The average yield strength of these bars determined under tension on a Universal Testing Machine (UTM) was 609 N/mm^2. The upper layer of the reinforcement was designated as the transverse reinforcement and the bottom layer (close to rear surface) as longitudinal reinforcement. In prestressed concrete plates, 10 number of prestressing wires of diameter 4 mm were provided at a spacing of 80 mm center to center with an eccentricity of 25 mm from