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Modified empirical formulas for predicting the thickness of RC panels under impact loading

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HIGHLIGHTS

- Novel modified formulas for predicting of RC panel thickness are proposed.
- Effects of reinforcement on RC panel thickness are taken into account.
- Parametric investigation is carried out using numerical simulation.
- A number of experimental data are also used for the purpose of this investigation.

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ABSTRACT

Most existing empirical formulas available in the current literature do not take into account the effect of reinforcement in predicting penetration depth and perforation thickness of reinforced concrete (RC) panels subjected to impact loads. In this paper, novel modified empirical formulas are proposed for better prediction. For the purpose of this study, finite element (FE) simulation using a commercial software LS-DYNA is employed. A nonlinear model of materials involving the strain rate effect is considered. Recent impact test results are used for the validation of FE results. Parametric analysis with different longitudinal and shear rebar ratios is then performed to investigate their influence on the penetration depth and perforation thickness of RC panels and to derive the modified empirical formulas. It is shown that the proposed formulas accurately predict the penetration depth and perforation thickness of the RC panels subjected to the impact with velocities in the range of 50 m/s–250 m/s.

1. Introduction

The local structural response of RC panels subjected to projectile impact loading has been of interest to researchers. For instance, perforation of reinforced concrete target subjected to hard missile impact loading was studied by Huang et al. [1] and Wu et al. [2]. Whereas, Polanco-Loria et al. [3] performed the numerical study on predicting the ballistic limit of RC slab under impact loading. Moreover, a numerical investigation on cratering and scabbing of concrete target under missile impact were also carried out by Kong et al. [4].

Prediction of local damage of RC panels subjected to missile impact is an important part of the practical design process. Numerous empirical formulas have been proposed for prediction of the damages of RC target such as penetration depth and perforation thickness, e.g., see Kosteski et al. [5] and Li and Tong [6]. In aforesaid formulas, the strength of the material was taken into account by considering the compressive strength of concrete. A few empirical formulas considered the concrete tensile strength when defining the impact factor I since the tensile strength was found to be more appropriate than compressive strength in predicting both penetration and perforation of concrete, e.g., see Hughes [7] and Riera [8]. However, the effect of reinforcement has hardly been considered in most of the existing empirical formulas.

Nevertheless, recent studies show that the reinforcement has major effects on the local damage of RC structures. Thai and Kim [9,10] found that the reinforcement (longitudinal and transverse rebar) significantly improves the punching resistant capacity of the panels. Whereas, Orbovic et al. [11,12] stated that the transverse reinforcement in the form of T-headed bars presented a slight influence on improving the perforation resistance of RC panels under hard missile impact. Based on the evaluation of punching shear capacity of a RC flat slab, Micallef et al. [13] also admitted that a slab with reinforcement had a higher punching capacity than

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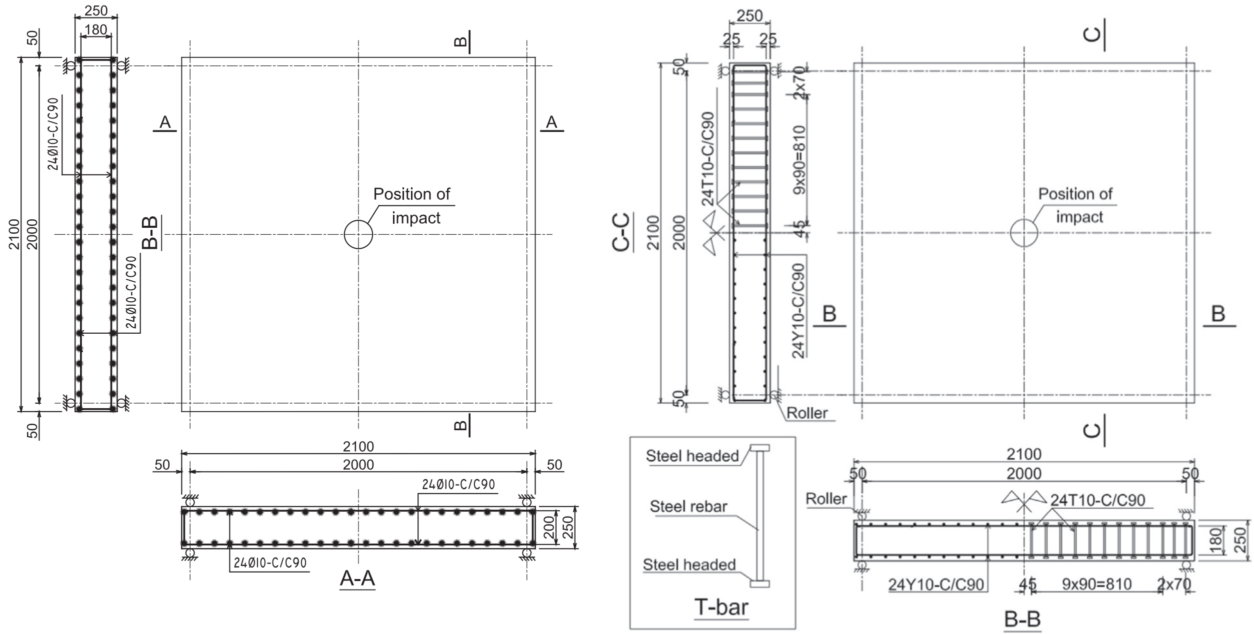

a) RC panel with bending rebar only b) RC panel with T-headed bars

Fig. 1. Description of RC panels (Orbovic et al. [11,12]).

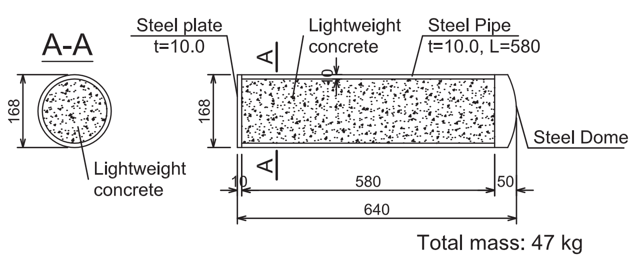

Fig. 2. Description of hard missile (Orbovic et al. [11,12]).

that of a slab without reinforcement. As a consequence, it is observed that the reinforcement plays an considerable role in the punching resistance of RC panel, and that it should be taken into account in predicting the local damage of an RC panel subjected to impact loading.

To address the shortcomings of the aforementioned problems, this work presents a numerical study based on FEM in which novel modified empirical formulas are derived for the purpose of better predicting the penetration depth and perforation thickness of RC panels under hard missile impacts. By accomplishing that purpose, a numerical simulation method is employed for the analysis. A number of recent test results, conducted by Orbovic et al. [11,12], Vepsä et al. [14], and Pires et al. [15] are used to validate

Table 1
Summary of selected impact tests and corresponding material properties.

No.	Test name	Bending rebar	Shear bar	Missile		Reinforcement		Concrete	
				Missile weight (kg)	Impact velocity (m/s)	Yielding strength (MPa)	Failure Strain (%)	Modulus of elastic (GPa)	Comp. strength (MPa)
I.	Bending reinforcement only								
1	Test A (2009)	D10c/c90	None	47.00	103.0	500	17.90	29.184	70.04
2	Test P1 (2011)	D10c/c90	None	47.38	136.0	540	18.67	29.429	67.10
3	Test P2 (2011)	D10c/c90	None	47.46	135.0			27.535	64.70
4	Test P3 (2011)	D10c/c90	None	47.32	136.5			27.535	64.90
5	Test No.1 (2015)	D10c/c90	None	47.40	102.2	550	17.90	26.224	56.55
6	Test G (2011)	D10c/c90	None	47.50	110.0	500	17.90	29.782	72.94
II.	Bending and shear reinforcement								
1	Test D (2009)	D10c/c90	D12c/c90	47.20	99.7	500	17.90	28.169	65.25
2	Test 699 (2011)	D10c/c90	D10c/c90	47.00	100.0	535	20.00	32.500	54.00
3	Test No.2 (2015)	D10c/c90	D12c/c90	47.40	102.2	550	17.90	26.224	56.55
4	Test H (2011)	D10c/c90	D12c/c90	47.50	144.0	500	17.90	30.571	76.85