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Numerical Study on the Response of Reinforced Concrete Wall Resisting the Impact Loading

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***Abstract*—**A numerical analysis of a reinforced concrete (RC) wall under missile impact loading is presented in this study. The model created by Technical Research Center of Finland was used. The commercial finite element code, LS-DYNA was used to analyze. The structural components of the reinforced concrete wall, missile and their contacts are fully modeled. The material nonlinearity with strain rate effects considering damage and failure is included in the analysis. The results of analysis were verified with other research results. The case-studies with different reinforcement ratios were conducted to investigate the influence of reinforcement on the punching behavior of walls under missile impact.

***Keywords*—**Missile Impact, Reinforced Concrete Walls, LS-DYNA, Dynamic Analysis, Punching Behavior.

I. Introduction

A SERIES of studies on RC walls with the dimension of 2.1m*2.1m*0.25m under missile impact loading were carried out by several researching groups of a project called IMPACT. Within these project activities, an experimental setup for a medium scaled impact test was firstly designed by Auli Lastunen et al. [1]. Based on that, Nebojsa Orbovic[2] and A. Vepsa et al. [3] studied the effect of the transverse reinforcement and pre-stressing on the impact response of RC walls.

Although the experimental approach can provide reliable results of behavior of the walls, it is expensive and time consuming. Since finite element analysis is a useful alternative, a number of numerical studies were also carried out by Dino A. Oliveira [4], Jose A. Pires [5], M.Borgerhoff et al. [6], and Genadijs Sagals et al. [7]. The objective of their numerical simulation is to assess the ability of the finite element code to capture the response and behavior of the wall under impact loading.

The main objective of this study is to investigate the influence of the longitudinal reinforcement on the punching response of reinforced concrete walls. The influence of reinforcement with different ratios of longitudinal rebar was investigated.

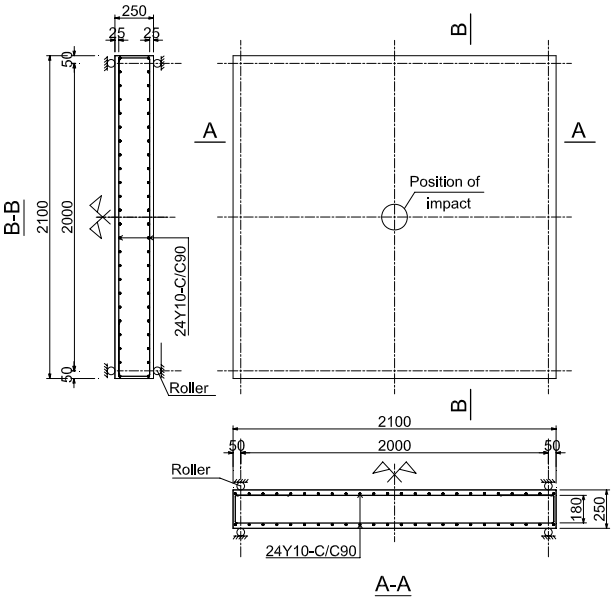
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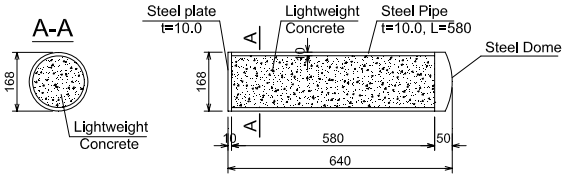
II. Finite Element Model

A. Geometry Description

A schematic representation of a RC wall and a missile is shown in Fig. 1. The two-way wall of 2.1m*2.1m*0.25m, consists of twenty-four rebars with different diameters in each direction as shown in Fig. 1(a). The edges of the wall are covered with the steel plates of 10mm thickness, where the wall is clamped by the frame using the rollers. Fig. 1(b) shows the missile consists of a steel pipe of 10mm thickness, filled with lightweight concrete. The steel pipe has a 50mm long plug of solid steel at the front (missile nose) which impacts the wall. The missile has a total mass of 47 kg, a length of 640 mm, and an external diameter of 168 mm.



(a) Reinforced concrete wall



(b)Missile

Fig. 1 Geometry of model (Nebojsa Orbovic et al.[2])

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B. Finite Element Modeling

The finite element code, LS-DYNA (version 971s R5.1.1) [8] was used for analysis. LS-PrePost 3.2X64 2011 was used to build up the geometry and apply constrains, contacts, and loading. Due to the symmetry of geometry and loading, only quarter of the wall and missile was modeled as shown in Fig. 2. Winfrith material model (MAT#084) was used for modeling of the wall and lightweight concrete material. The bi-linear elastic-plastic material model (MAT#003) was used for the reinforcement and other metal parts.

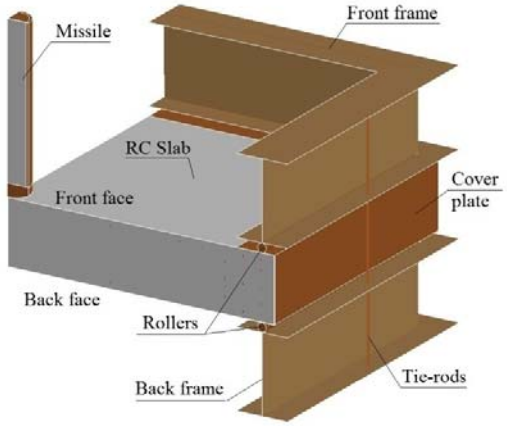
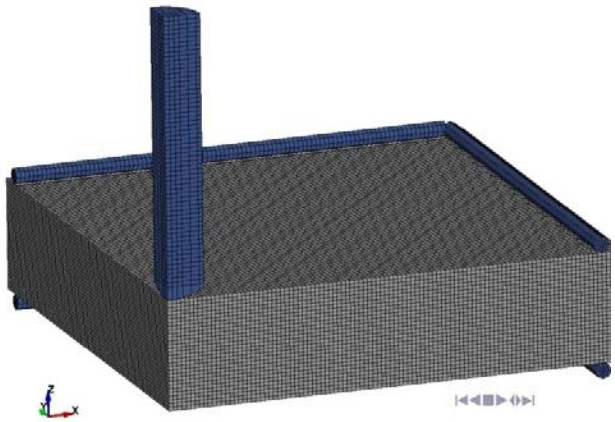
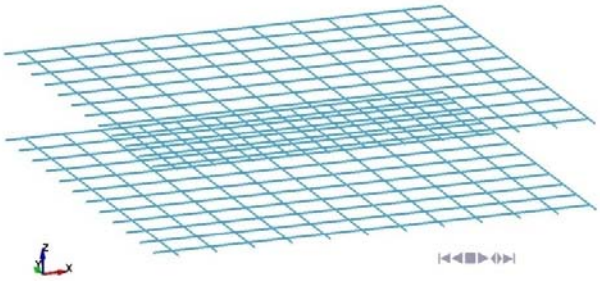


Fig. 2 Quarter of RC wall and missile

The concrete wall was modeled by using the solid element. The rebar were modeled by the truss beam element. The shell element was used to model the cover plates and frame. The boundary conditions for RC wall were applied by using contact between the wall and the rollers. The simply supported boundary condition was applied to the reference node of the rollers. The option *AUTOMATIC_SURFACE_TO_SURFACE was used for missile-wall contact, while *AUTOMATIC_NODES_TO_SURFACE was used for missile-reinforcement contact. The erosion option for damage and failure was considered by using the option *MAT_ADD_EROSION. Fig. 3 shows a quarter models of the RCwall and missile.



(a) Quarter model



(b) Reinforcement

Fig. 3 Finite element model of wall

C. Material Properties

The material tested by A. Vepsa et al. [3] was used in this study. The material properties of the concrete, reinforcement, and other metal parts are listed in Table I.

III. Verification

The results of the analysis were verified by comparing those of twelve other studies as shown in Fig. 4. The velocity-time curve closely matched the experiment. Table II compares the finite element simulation of the model with test results (test P3) obtained by A. Vepsa et al. [3].The concrete damage was also investigated as shown in Fig. 5a. It agreed well with that of the experiment as shown in Fig. 5b.

TABLE I
Material Properties

Material	Modulus of elastic E (GPa)	Poisson Ratio v	Density ρ (Kg/m3)	UCS (MPa)	UTS (MPa)	Failure strain (%)	Fract. Energy FE (N/m)
Concrete	27.535	0.17	2400	64.9	3.34	-	85.5
Lightweight concrete	10.6	0.17	1158	3	1	-	85.5
Reinforcement	200	0.3	7800	540	540	18.67	-
Missile steel	200	0.3	7800	758	758	-	-
Cover plate steel	200	0.3	7800	500	500	-	-

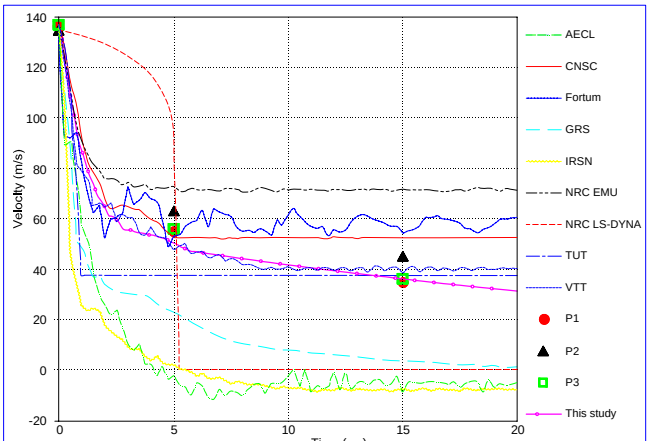
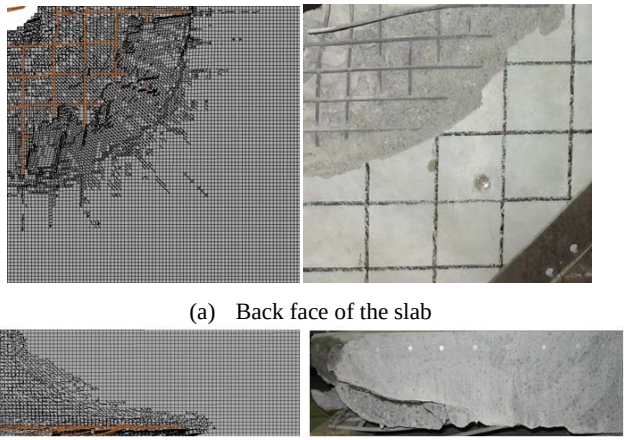


Fig. 4 Missile velocity during the first 20 ms after impact

TABLEII
COMPARISON WITH TEST RESULTS BY A. VEPSA ET AL. [3]

Test	Method	Initial velocity (m/s)	Perforation	Residual velocity (m/s)	Scabbing Area (m^2)
P3	Test	136	yes	36	1.12
This Study	FEM	136	yes	36.1	1.13



(a) Back face of the slab

(b) Cross section

Analysis result Test result (A. Vepsa et al. [2])

Fig. 5 Comparison of damage

IV. CASE-STUDY

A case-study was carried out to investigate the influence of the longitudinal rebar to the punching behavior of RC wall. The eight different longitudinal rebar ratios of 0.45%-3.38% were selected as analysis parameters listed in Table III. The behavior of the analysis model was investigated for the different longitudinal rebar ratios. The numerical simulation was performed with the eight difference diameters of rebar elements from 8mm to 22mm.

TABLE III
EIGHT CASES OF DIFFERENCE RE-BAR RATIOS

Case-studies	Diameter of Re-bars (mm)	Area (m2)	Ratio (%)
1	8	0.0000502	0.45
2	10	0.0000785	0.70
3	12	0.0001130	1.00
4	14	0.0001539	1.37
5	16	0.0002010	1.79
6	18	0.0002543	2.26
7	20	0.0003140	2.79
8	22	0.0003799	3.38

A. Penetration Depth

Fig. 6 shows the penetration depth corresponding to the different longitudinal rebar ratios. The penetration depth rapidly decreased from 1.0m to 0.43m when the longitudinal rebar ratios increased from 0.45% to 2.26%. However, the penetration depth decreased slightly from 0.43m to 0.41m when the longitudinal rebar ratios increased from 2.26% to 3.38%. This is due to the punching resistance of the second layer (or back layer) of the longitudinal rebar.

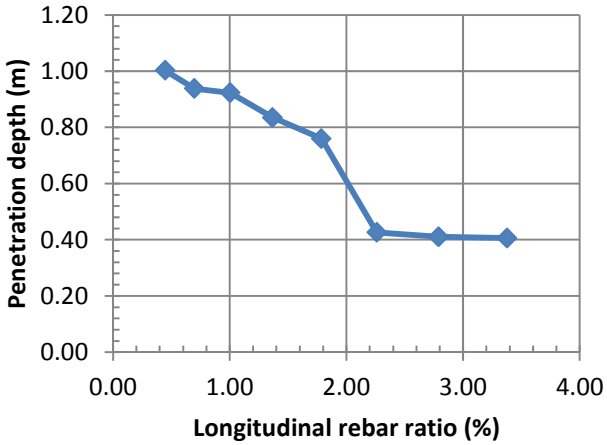


Fig. 6 Penetration depths corresponding to rebar ratio

B. Residual Velocity of the Missile

Fig. 7 shows the effect of the longitudinal rebar ratio to the residual velocity of the missile. Residual velocity also decreased very rapidly when the longitudinal rebar ratios increased from 0.45% to 2.26%, and it was equal zero when the ratio exceeded 2.26%. It is concluded that the reinforcement plays the important role to reduce the velocity of the missile.

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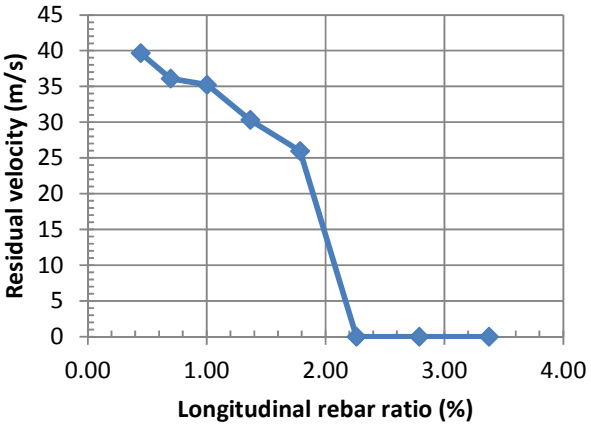


Fig. 7 Residual velocities corresponding to rebar ratio

C. Scabbing Area

The longitudinal rebar ratio also significantly influences the scabbing area on the back face of the walls as shown in Fig. 8. The analysis result shows that the scabbing area increases as the longitudinal rebar ratio increases. The scabbing area slightly increases from $0.92m^2$ to $1.81m^2$ when the longitudinal rebar ratios increase from 0.45% to 1.79%. But the scabbing area rapidly increases from $1.81m^2$ to $3.14m^2$ and bigger when the longitudinal rebar ratios increase from 1.79% to 2.26% and greater since the wall, specifically the back longitudinal rebar, resists to be perforated. The local scab appeared around the impact point when longitudinal rebar ratios were smaller than 1.79%, but the scab appeared on almost all of back face of the wall when these rebar ratios were greater than 1.79%. The deformation of the back layer of longitudinal rebar makes scabbing area larger due to the bond between the reinforcement and concrete.

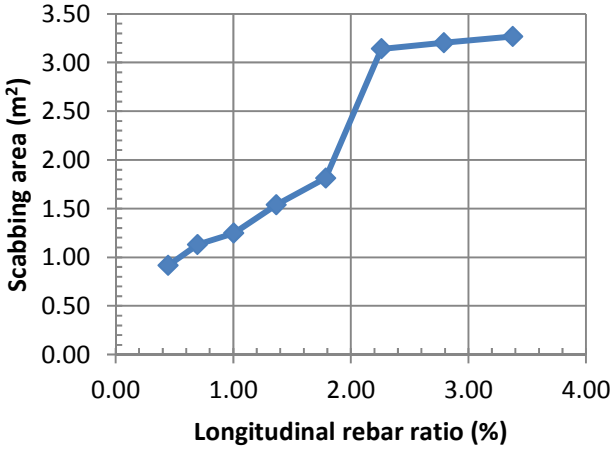


Fig. 8 Scabbing areas corresponding to rebar ratio

V. Conclusion

The structural components of the impact test and their contacts were fully modeled. The bi-linear material model considering strain-rate effects and erosion of concrete was used in the analysis. The finite element model was verified against the experiment. Case studies of the different longitudinal rebar ratios were conducted to investigate the influences of that reinforcement on the punching behavior of reinforced concrete walls. The analysis results showed that the reinforcement ratio has a strong influence on the penetration and damage in the reinforced concrete wall.

Acknowledgment

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