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Finite element analysis of RC walls with different geometries under impact loading

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Abstract. Today, buildings are exposed to the effects such as explosion and impact loads. Usually, explosion and impact loads that act on the buildings such as nuclear power plants, airports, defense industry and military facilities, can occur occasionally on the normal buildings because of some reasons like drop weight impacts, natural gas system explosions, and terrorist attacks. Therefore, it has become important to examine the behavior of reinforced concrete (RC) structures under impact loading. Development of computational mechanics has facilitated the modeling of such load conditions. In this study, three kinds of RC walls that have different geometric forms (square, ellipse, and circle) and used in guardhouses with same usage area were modeled with Abaqus finite element software. The three configurations were subjected to the same impact energy to determine the geometric form that gives the best behavior under the impact loading. As a result of the analyses, the transverse impact forces and failure modes of RC walls under impact loading were obtained. Circular formed (CF) reinforced concrete wall which has same impact resistance in each direction had more advantages. Nonetheless, in the case of the impact loading occurring in the major axis direction of the ellipse (EF-1), the elliptical formed reinforced concrete wall has higher impact resistance.

Keywords: impact load; guardhouse; reinforced concrete wall; military facilities; finite element analysis

1. Introduction

Reinforced concrete (RC) is one of the most popular materials used in many engineering applications like nuclear plants, airports, military stations, etc. Sometimes, reinforced concrete structures are subjected to extreme dynamic loadings such as blast and direct impact due to an accidental explosion or terrorist attack. However, these loading conditions cause irreparable loss of lives and property. In recent years, many countries have been attacked by terrorists and such threats are increasingly continuing. Turkey is among those countries that have experienced such attacks quite often. Most of the attacks have occurred on military stations and members. For decreasing and preventing of these threats, the government of Turkey has not only increased border security measures but also improved their conditions. Therefore, reinforced concrete guardhouses have been built in border regions, but many times they have been subjected to terrorist attacks. For this purpose, present guardhouses that is consisted of reinforced concrete walls should be made secure against to blast and impact weight loading, hence, analysis of these structures under blast and impact loading and identification of damage mechanism or modes are of great importance for structural engineering.

Many experimental and theoretical studies related with impact resistance and perforation of reinforced concrete elements subjected to blast and impact loading have been demonstrated by researchers. Nevertheless, full scaled experimental studies of structures and structural elements are very expensive and difficult, and so numerical modeling techniques (finite element method and discrete element models) have gradually gained more importance. Experimental studies have been supported by numerical studies. Martin (1994) gave a review of model of localized concrete behavior when impacted by undeformable missiles with a wide range of incident velocities. According to this study, four important aspects of the prediction of local impact effects on concrete were evaluated such as investigation of strain rate dependence of material parameters, empirical equations for predicting the effects of local impact, a review of analytical models, and computational approaches to impact. Saito *et al*. (1995) aimed to experimentally and analytically clarify the loading capacities, deformations, and failure modes of various types of reinforced-concrete structure subjected to loads applied at various rates. Furthermore, Sawamoto *et al*. (1998) proposed a new analytical approach for assessing local damage to reinforced concrete structures subjected to impact load by applying the discrete element method (DEM) developed by Cundall (1971). The DEM can easily treat fracture mechanics of concrete such as cracking, splitting and crushing. Ong *et al*. (1999) presented effectiveness of fibre concrete slabs containing polymeric (straight polyolefin and straight polyvinyl alcohol) and metallic (hooked-end steel) fibres subjected to low velocity impact loading. In this study, slab specimens 1 m^2 in size

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and 30 mm in thickness were used. The impact was achieved by dropping a projectile of mass 43 kg from a height of 4 m by means of an instrumented impact test facility. The results obtained in the study are specific to the size of specimen tested, the boundary conditions and the test configuration adopted. Moreover, Thabet and Haldane (2000) aimed to develop an approach that took account of the continuity and analytical procedure that can be used to predict the behavior of structural concrete members in the response of concrete structures when subjected to impact loads. The results obtained using the proposed approach show that the failure modes of a number of reinforced concrete beams subjected to impact loading can be predicted to a reasonable degree of accuracy. Abbas *et al*. (2004) who take into consideration a reinforced concrete beam tested for impact at its mid-span by drop weight from Thabet and Haldane's study presented a three-dimensional nonlinear finite element analysis of reinforced concrete targets under impact loading and conducted experimental study in laboratory involving drop hammer loading on circular concrete plates. They showed good agreement between experiments and numerical results.

Meanwhile, Zhang *et al*. (2005) presented results from an experimental study on the impact resistance of concrete with compressive strengths of 45-235 MPa impacted by 12.6 mm ogive-nosed projectile at velocities ranging from ~620 to 700 m/s. In their research, the effects of the compressive and flexural tensile strength of the concrete, the presence of coarse aggregate or steel fibers, and the curing temperature of the concrete are discussed. Tai and Tang (2006) conducted numerical simulation of the dynamic behavior of reinforced concrete plates under normal impact. They used finite element method on the reinforced concrete structural dynamic response and failure behavior when the reinforced concrete subjected to the projectile impacts to different velocities using the test conducted by Hanchak *et al*. (1992). Zineddin and Krauthammer (2007) aimed to examine behaviors of reinforced concrete slabs under impact loads and increasing impact strengths. They researched the effects of different types of slab reinforcements and the applied impact loads on the dynamic response and the behavior of reinforced concrete slabs. Chen and May (2009) conducted a research about the effects of objects by creating impact loads with higher weights and impact in low velocities on reinforced concrete elements such as beams and plates, etc. Martin (2010) searched with numerical modeling for structural behaviors of structural elements under impact loading. Finite element models were developed for different structural behaviors under different material models. Effects of soft and hard impact loads were modeled both by deformable and rigid bullets.

In addition, Wang *et al*. (2012) aimed to address the scaling of the dynamic response of one-way square reinforced concrete slabs under close-in blast loadings. Trivedi and Singh (2013) conducted a study consists of numerical models to predict the various global failure modes such as flexural, punching shear, and mixed-shear failures along with the local failure modes such as crushing, cracking, spalling, and scabbing under impact loads. Numerical simulation on reinforced concrete slab impacted with cylindrical drop hammer has been carried out using finite element analysis to obtain the failure modes. A comparison has been made to validate the results of numerical simulation with the Zinneddin and Krauthammer experimental results. Atou *et al*. (2013) performed impact experiments using a gun method to evaluate local damages of reinforced columns by the impact of a high-velocity projectile. Effects of an amount of main bar and spacing between hoops were examined and scaling effects were evaluated to ensure the effectiveness of the computer simulations. Wang *et al*. (2013) provided an efficient analytical model to obtain pressure-impulse diagram of one way reinforced concrete slabs under different shapes of air blast loading using single degree of freedom method. Perumal (2014) investigated high-performance steel fiber reinforced concrete under impact loading. According to the experimental results, the additional of steel fibers to silica fume concrete improve impact behavior of high-performance concrete.

Together with these studies it was aimed to search for numerical models with parameters like solution mesh size, strain rate, and behavior of the reinforcing steel. Husem and Cosgun (2016) examined numerically reinforced concrete plates with different span sizes for both free and fixed support conditions. Žmindák *et al*. (2016) created the finite element models in ABAQUS/Explicit software to examine perforation of steel and aluminum plate specimens. Impact load was applied on composite plate with eight layers reinforced by carbon fibers. In simulations, the Johnson-Cook model for strain rate effects in the material and in the compressibility as well as Hashin failure criterion for damage of composite plate were used. Pham and Hao (2016) provided an overview of the impact resistance of the structures strengthened with fiber-reinforced polymer which include reinforced concrete beams, reinforced slabs, reinforced concrete columns, and masonry walls. And then, it reviewed the dynamic properties of fiber reinforced polymer materials. Although some issues still needed to be investigated and clarified, it would be suggested that fiber-reinforced polymer could be used to strengthen and protect structures against impact events or terrorism activities.

Last but not least, this paper investigated damage mechanism or modes of the guardhouses which were generally built as the square plan view and consisted of square cross-sectional reinforced concrete wall units under the impacts of different high-velocity projectiles. In this line, three reinforced concrete walls used in guardhouses which have different geometric form in plan view (square, ellipse, circle, rectangular, and hexagonal) with same usage area (9 m2) were modeled with ABAQUS finite element software. A comparison has been made to validate the results of the numerical simulation with Atou *et al*. (2013) experimental results. The concrete and reinforced concrete steel members were modeled with Concrete Damage Plasticity (CDP) and Classical Metal Plasticity (CMP), respectively. The three configurations were subjected to the same impact energy. As a result of the analyses, the transverse impact forces, dissipated energy, and failure modes of reinforced concrete walls under impact loading were obtained. Based on the numerical results, the geometric form of reinforced concrete walls has been found to be a parameter that has a serious effect on impact behavior. Moreover, the circular form reinforced concrete wall gave higher impact resistance than the other geometric form in the plan view.

2. Material models

2.1 Concrete Damage Plasticity (CDP) model

2.1.1 Constitutive model of concrete

Mechanical properties of concrete were defined by CDP material model in Abaqus FE software. The model is a continuum, plasticity-based, and damage model for concrete. It assumes that the main two failure mechanisms are tensile cracking and compressive crushing of the concrete material. The evolution of the failure surface is controlled by two hardening variables, i.e., ε_c^{pla} and ε_t^{pla}, linked to failure mechanisms under tension and compression loading, respectively (Abaqus 2008). These strains are calculated by Eqs. (1) and (2). Besides, the damage variables (d_c and d_t) were defined together with hardening variables for stiffening degradation behavior. The damage variables can take values from zero, representing the undamaged material, to one, which represents the total loss of strength. If E_o is the initial (undamaged) elastic stiffness of the material, the stress-strain relations under uniaxial tension and compression loading are, respectively

$$\varepsilon_c^{pl} = \varepsilon_c^{in} - \frac{d_c}{1-d_c}\frac{\sigma_c}{E_o} \tag{1}$$

$$\varepsilon_t^{pl} = \varepsilon_c^{ck} - \frac{d_t}{1-d_t}\frac{\sigma_t}{E_o} \tag{2}$$

$$\sigma_c = (1-d_c)E_o(\varepsilon_c - \varepsilon_c^{pl}) \tag{3}$$

$$\sigma_t = (1-d_t)E_o(\varepsilon_t - \varepsilon_t^{pl}) \tag{4}$$

Stress-strain relations of concrete are given Fig. 1.

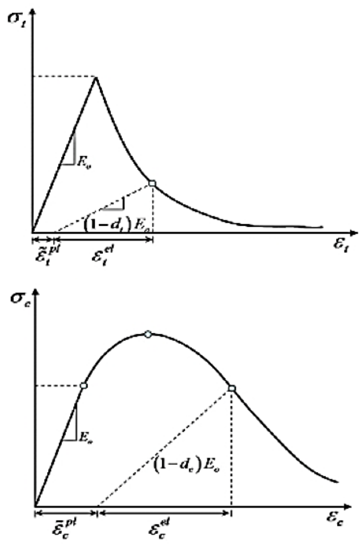


Fig. 1 Stress-strain curves of concrete in CDP model

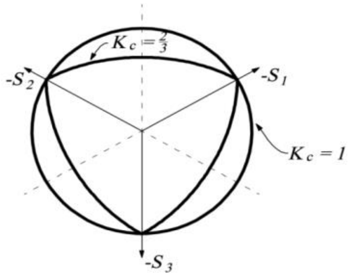


Fig. 2 Yield surface in deviatoric plane for different values (Abaqus 2008)

Yield function was developed by Lubliner *et al*. (1989), with the modifications which were proposed by Lee and Fenves (1998). The yield surface in CDP model is the modified Drucker-Prager material model. The CDP model is developed by adding two independent variables. The first variable is the ratio of biaxial compressive strength f_{bo} to uniaxial compressive strength f_{co}. The second variable is K_c that controls the shape of yield surface in deviator plane (Fig. 2).

CDP model assumes non-associated potential plastic flow. The flow potential G used for this model is the Drucker-Prager hyperbolic function (Abaqus 2008)

$$G = \sqrt{(e.\sigma_{to}.\tan\psi)^2 + \overline{q}^2} - \overline{p}\tan\psi \tag{5}$$

This function is influenced by the three main variables. The first is the eccentricity e, defined as eccentricity in function at asymptotes. The second σ_{to} is the uniaxial tensile stress at failure, taken from the user-specified tension stiffening data. The last variable is the dilatation angle ψ that defines the amount of plastic volumetric strain developed plastic yielding (Malm 2009). The dilation angle measured in the p-q plane at high confining pressure (Abaqus 2008).

2.1.2 Concrete modeling

The behavior of concrete was defined with constitutive properties, yield surface, and plastic flow parameters. The stress-strain relationship, modulus of elasticity, E=32000 MPa, and Poisson's ratio, and υ=0.2 for all elements were defined according to code requirements (Turkish Standard-500). The compressive and tensile strength of concrete were obtained respectively as 30 MPa and 1.9 MPa. The stress-strain curves were implemented in Abaqus CDP model (Fig. 3).

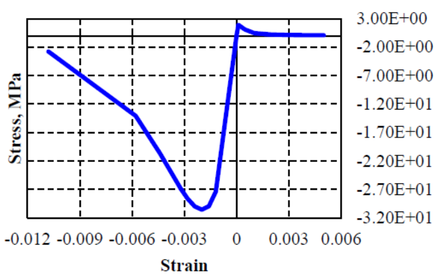


Fig. 3 Tension and compression curve of concrete in CDP model

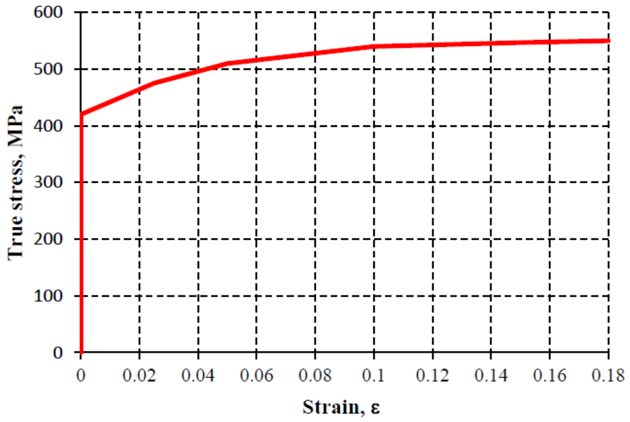


Fig. 4 True stress-strain curves of reinforcement for numerical study

Additionally, the other parameters were defined about yield surface and plastic flow, and the following data was taken:

-Dilatation angle, ψ defines the amount of plastic volumetric strain developed plastic yielding. The dilatation angle varies between 35 and 40 (Malm 2009). It was taken as 35.

- K_c is coefficient about the shape of yield surface in deviator plane. It was taken as 0.667.

- $\left(\frac{f_{bo}}{f_{co}}\right)$ is the ratio of initial biaxial compressive yield stress to initial uniaxial compressive yield stress (Abaqus 2008). The default value of this parameter is 1.16 for normal strength of concrete in Abaqus.

2.2 Classical Metal Plasticity (CMP) model

Classical Metal Plasticity (CMP) is a material model for behavior under uniaxial tensile loading of reinforcing steel. In this model, the elastic and plastic behavior of the material is thought to be separated. The elastic behavior is defined with elastic modulus E and Poisson's ratio υ. Plastic behavior of reinforcing steel is defined as true stress σ_{tru} and plastic strain σ_{pl}. The nominal stress-strain curve can be converted to plastic strain-true stress curve according to Eqs. (6) and (8) (Hibbitt *et al*. 2011).

$$\sigma_{tru} = \sigma_{nom}(1+\varepsilon_{nom}) \tag{6}$$

$$\varepsilon_{tru} = \ln(1+\varepsilon_{nom}) \tag{7}$$

$$\varepsilon_{pl} = \varepsilon_{tru} - \frac{\sigma_{tru}}{E} \tag{8}$$

In this study, the yield strength of reinforcement was 420 MPa. True stress-plastic strain curve of reinforcement steel is given in Fig. 4.

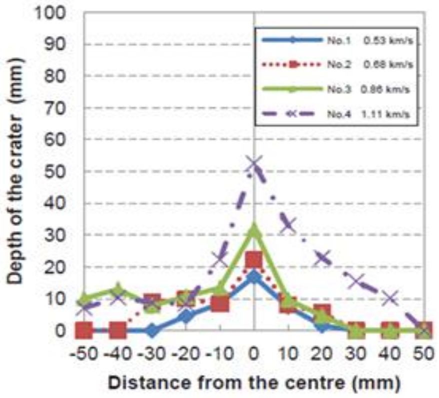
3. Verification study

In this paper, damage mechanisms of reinforced concrete walls in the guardhouses built as in different plan and cross-sectional views under the impacts of different high-velocity projectiles investigated. Finite element analysis was ensured with ABAQUS finite element software. Although the finite element software ABAQUS has been validated extensively against test data on reinforced concrete elements under static and impact loads, additional validations had to be considered for other parameters (e.g., velocity of projectiles, modeling effects, etc.). Unfortunately, none of the studies were undertaken for reinforced concrete walls under different velocity projectiles, neither reinforced concrete elements have been showed stable behavior, as a result the accuracy of finite element analysis for reinforced concrete elements had to be validated. In this sense, the study presented by Atou *et al*. (2013) was chosen as a validation study to ensure the effectiveness of the computer analysis. They tried to evaluate the local damage of the reinforced concrete columns by the impacts of the high-velocity projectiles. As the test specimens, 1/10 scale 5 standard series of RC columns (100×100×280 mm) were mainly used. The projectile was a sphere made of 304 steel, 9.54 mm in diameter. The projectile was accelerated by a single-stage propellant gun and a two-stage light gun to 0.53-1.76 km/s. Table 1 shows specifications of the reinforced concrete column specimens and projectiles used in the impact experiments.

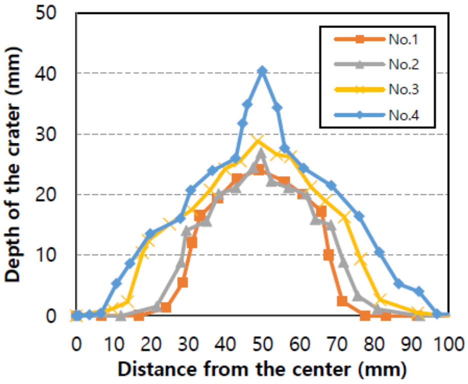
The depth of the damage caused by the impact loading through the element width was obtained numerically. The numerical results were validated with experimental results in the technical literature (Fig. 5). For an appearance of the damage, Figs. 6 and 8 show the experimental and numerical view of the impacted specimens at various velocities (No 2: 682 m/s; No 3: 855 m/s; No 5: 1765 m/s). Similar to

Table 1 Specifications of the reinforced concrete column specimens and projectiles

	Reinforced Concrete Column Specimens											Projectiles			
	Dimension				Concrete	Main Bar			Hoop			Flyer			Impact
No	Scale	b (mm)	D (mm)	L (mm)	Strength (N/mm^2)	Steel Bar (in.)	Cov. Ratio (%)	Yield Strength (N/mm^2)	Arrg.	Cov. Ratio (%)	Yield Strength (N/mm^2)	Weight (g)	Dia. (mm)	Mat.	Velocity (m/sn)
1															533
2															682
3	1/10	100	100	280	40	D-4D	0.56	295	D1@10	0.15	295	3.516	9.64	304 Steel	855
4															1105
5															1765

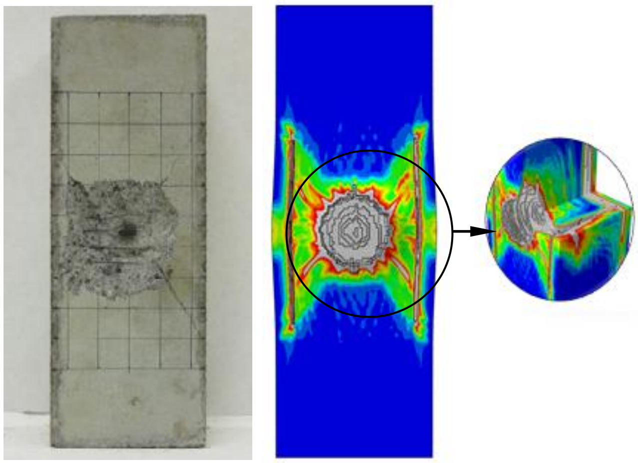


(a)



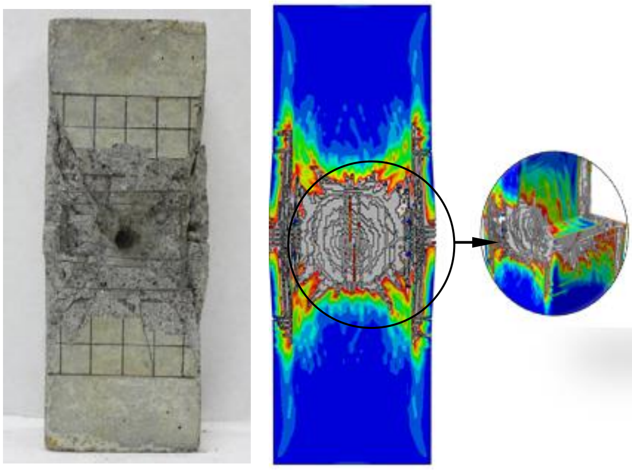
(b)

Fig. 5 Depth profiles of the crater: (a) For experimental study, (b) For numerical study



(a) (b)

Fig. 6 Experimental (a) and numerically (b) impacted No: 2 specimen (velocity=682 m/s)



(a) (b)

Fig. 7 Experimental (a) and numerically (b) impacted No: 4 specimen (velocity=1105 m/s)

experimental study conducted by aforementioned Atou *et al*. (2013), the apparent cratering damage has been observed in the numerical study for No. 2 and No. 4 specimens. Cover concrete spalled from the front side and radial cracks developed from center of the crater to back surface. Amount of spalled concrete increased depending on the velocity of projectiles. When No. 5 specimen is viewed, experimental results were verified. Cover and core concrete completely crushed and spalled. Stirrups on the center of the crater were fractured. Although the main bars on the front side damaged more than the backside, all main bars remained. Fractured stirrups and remained main bars given in Fig. 9. The modeling processes and material models (CDP and CMP) gave suitable results in high strain rate mechanical problems about RC members.

This verification results indicated that ABAQUS finite element software can be used to simulate the response of the reinforced concrete members under impact loads and that the results would be acceptable.

4. Finite element models of reinforced concrete guardhouses and impact loading

In this study, three reinforced concrete wall used in guardhouses that have different geometric forms (square, ellipse, and circle) with same usage areas were modeled with Abaqus 2016 finite element software. Plan views of the guardhouses, which have a usage area as 9.0 m^2, were given in Fig. 10. Geometric form, reinforcement arrangement, usage area, and other properties of RC walls were given in Table 2. Three-dimensional meshes were used for reinforced concrete wall, reinforcement steel and missile in finite element models (FEM) of RC guardhouses. C3D8R finite element was used to model the RC walls and missile. The C3D8R element is a general-purpose linear brick element, with reduced integration (1 integration point). The reinforcement steel was modeled with B31 two-node beam element. Finite element mesh sizes for the RC walls and reinforcement steel were selected as 30 mm to obtain accurate results. This process causes that analyses are time-consuming and so half of the RC guardhouse models were considered in modeling. The impact loading was applied to half-height (1.50 m) of RC walls with cylindrical missiles that have the same impact energy (311.0 kJ). Boundary conditions of the models and the properties of the missiles having a weight of 62.5 kg and a diameter of 200 mm were depicted in Fig. 11.

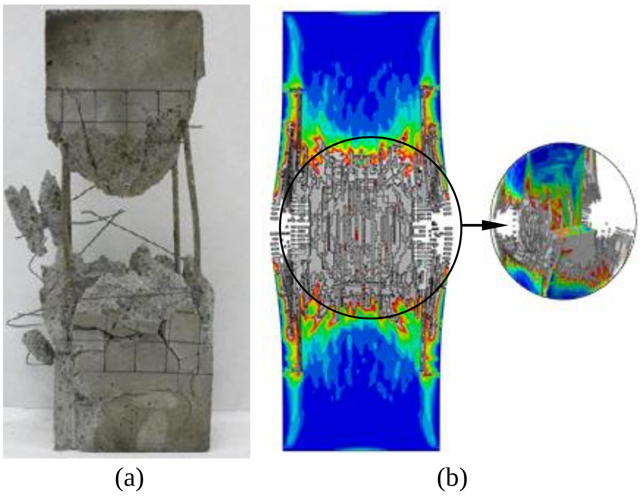


Fig. 8 Experimental (a) and numerically (b) impacted No: 5 specimen (velocity=1765 m/s)

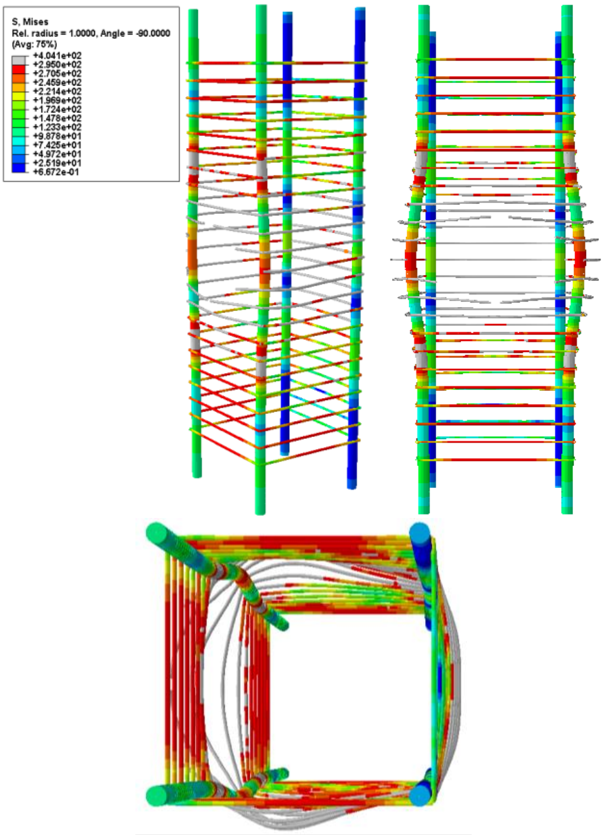


Fig. 9 Fractured stirrups and remained main bars in numerical model for No:5 specimen

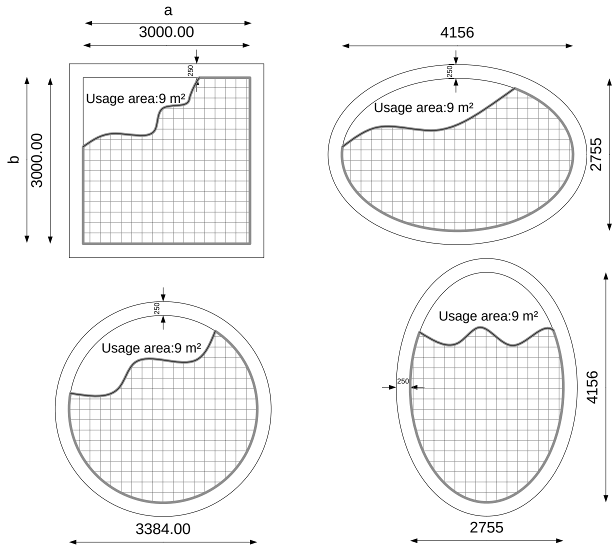


Fig. 10 Plan view of the RC guardhouses

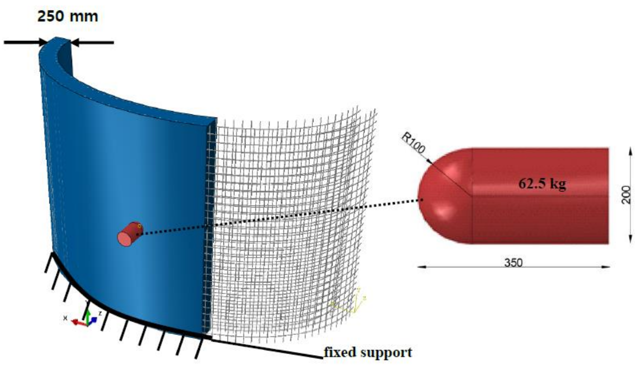


Fig. 11 Properties of the missile (dimension in mm) and boundary conditions

For contact modeling, there are many contact laws that can be applied in ABAQUS. In this study, hard contact algorithm was chosen for that matter. In this method, the contact constraint is applied when the clearance between two surfaces becomes zero. There is no limit in the contact formulation on the magnitude of contact pressure that can be transmitted between the surfaces. The surfaces are separated when the contact pressure between them becomes zero or negative, then the constraint is removed (Abaqus, 2008). This behavior is referred as “hard” contact (Fig. 12). In this paper, the missile and RC walls were set as the master surface and slave nodes, respectively.

Table 2 Properties of RC walls and guardhouses

Geometric form in plan view	Reinforcement Arrangement (horizontal)	Reinforcement Arrangement (vertical)	Usage area, m^2	Dimensions in plan view (*a*/*b*), mm	Height, m	Thickness, mm
Circular form (CF)	Ø 10/10	Ø 10/10	9.0	3384/3384	3.0	250
Elliptic form (EF-1)	Ø 10/10	Ø 10/10	9.0	2755/4156	3.0	250
Elliptic form (EF-2)	Ø 10/10	Ø 10/10	9.0	4156/2755	3.0	250
Square form (SF)	Ø 10/10	Ø 10/10	9.0	3000/3000	3.0	250

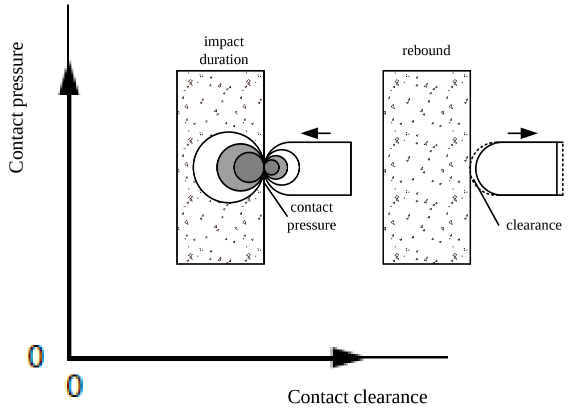


Fig. 12 Pressure-clearance relationship for “hard” contact in Abaqus

If the dynamic increase factor (DIF) is taken into account, the strength of the concrete and steel will increase and then the impact resistance of RC walls will increase. However, the DIF was not taken into account in this study, since the effect of the geometric properties of reinforced concrete walls on the impact strength is examined. The relative differences between the analysis results do not change whether the DIF is taken into consideration or not.

5. Numerical application

The purpose of this study is to determine the geometric form that gives the best behavior under the impact loading. The reinforced concrete guardhouses that have three different geometric configurations were subjected to same impact energy. As a result of the analyses, the transverse impact forces and failure modes of reinforced concrete walls under impact loading were obtained. Fig. 13 shows the impact force-time response of the guardhouses. The impact force values of the circular and elliptic formed guardhouses reached to the maximum under the 10.0 ms. However, the impact force-time response of the square formed guardhouses showed fluctuating behavior during the impact loading. The maximum impact force and backside displacements were summarized in Table 3.

In the EF-1 and EF-2 models, the missile was moved in the line of the major and minor axis direction of elliptic form, respectively. As shown in Table 3 and Fig. 13, the lowest impact force was obtained from EF-2. When EF-1 and EF-2 were compared, the impact resistance of EF-1 was determined to be 88% higher than that of EF-2. The minor axis direction of the elliptic form is relatively weaker impact behavior than major axis direction. These results showed that the guardhouses with the same elliptic geometry show a very different impact behavior when subjected to the same impact energy in different impact directions. Maximum impact force of the CF was obtained greater than EF-2 about 45.8% and less than EF-1 about 28.8%. However, the CF is more advantageous compared to the elliptic geometry because the impact resistance in each direction is the same. Impact force-time relation for SF model was depicted in Fig. 13. SF model presented quite unstable behaviors as compared to the others. Because the geometric form of the SF did not reflect the fixed boundary condition, the RC wall behaved like a cantilever reinforced concrete plate under impact loading. During the period of 10.0 ms, the impact force values for SF model were below those of guardhouse with other geometric forms.

Fig. 14 shows the reduction in kinetic energy of the missile. For all models, dissipated initial kinetic energy of the missile was the same amount in the 10.0 ms. During the time 0.6 ms, the reduction in kinetic energy in all types of RC walls have been the same amount. However, under the

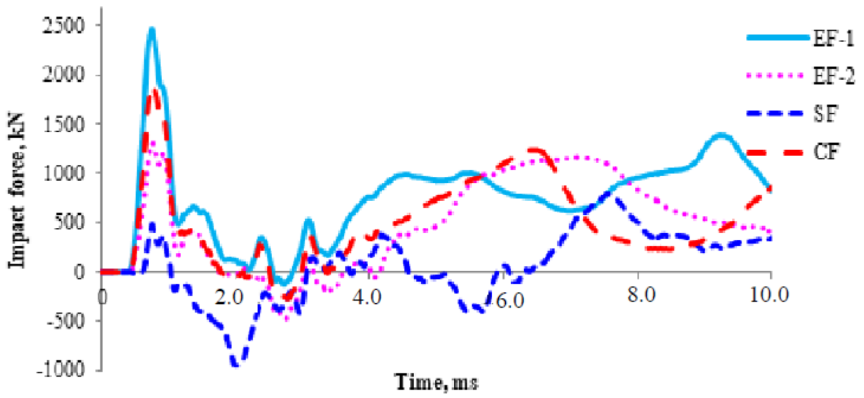


Fig. 13 Force versus time of the RC guardhouses

Table 3 Summary of analyses results

Geometric form in plan view	Response time interval (ms)	Max. impact force (kN)	Max. displacement on the back side (mm)	Damage area on the back side (m^2)
CF	0-10.0 ms	1916.785	162.6	1.60
EF-1	0-10.0 ms	2470.308	136.9	0.30
EF-2	0-10.0 ms	1313.930	161.2	1.20
SF	0-10.0 ms	-	189.7	2.50

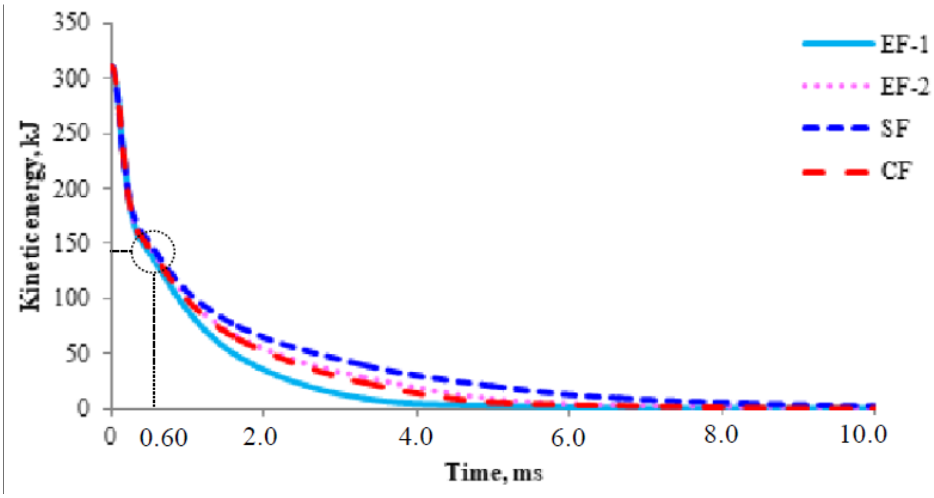


Fig. 14 Reduction in kinetic energy of the missile versus time

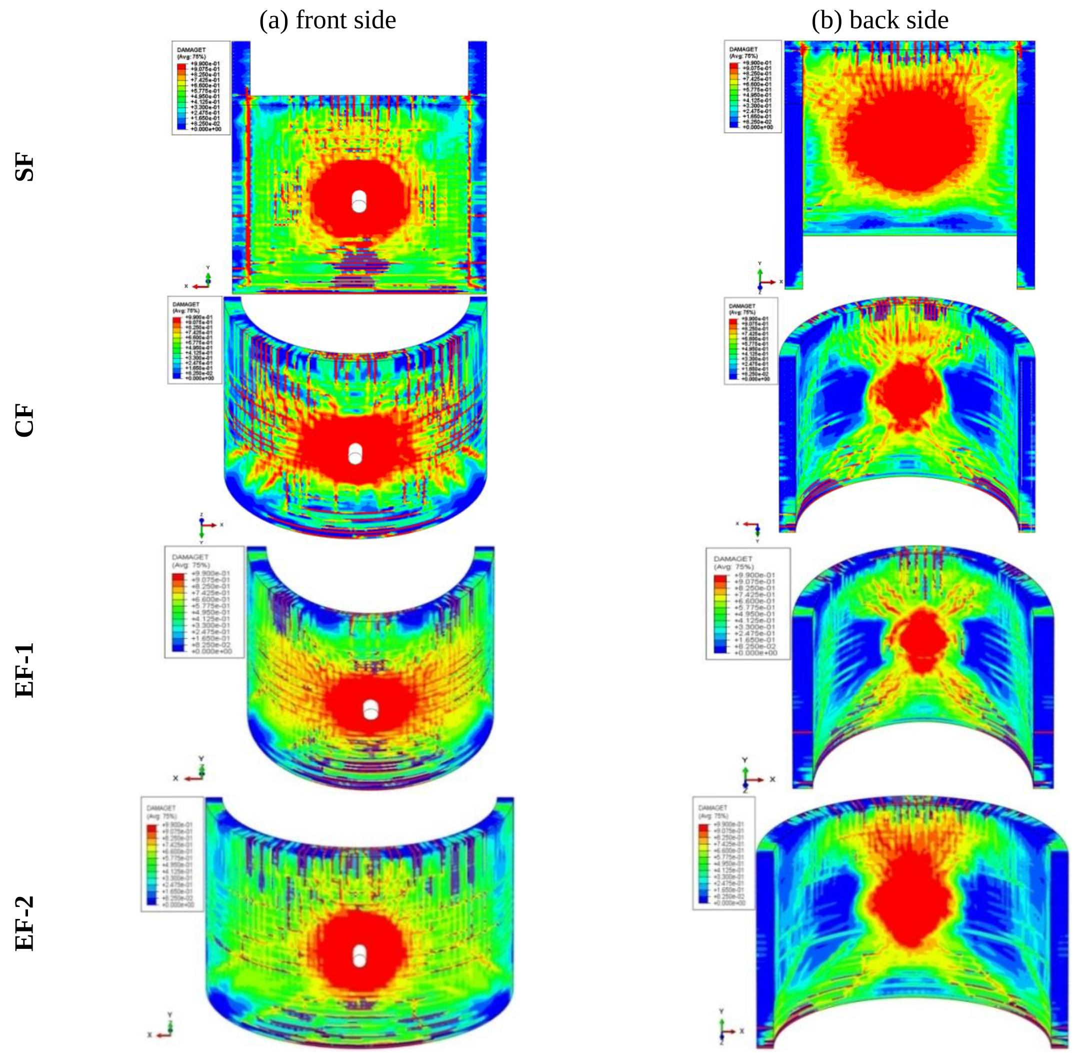


Fig. 15 Ultimate tensile damage of the RC guardhouses

same impact energy, after 0.6 ms, each RC wall behaved differently according to its geometrical properties (Fig. 14). EF-1 exhibited more defensive behavior under impact loading. The kinetic energy of the missile was absorbed earlier than the other geometric forms.

The ultimate tensile damage of RC guardhouses that were obtained numerically was depicted in Fig. 15. Also, the intensity of the damage on the backsides of RC guardhouses was superposed in Fig. 15. Under the same impact energy, the projection of the damaged surface area

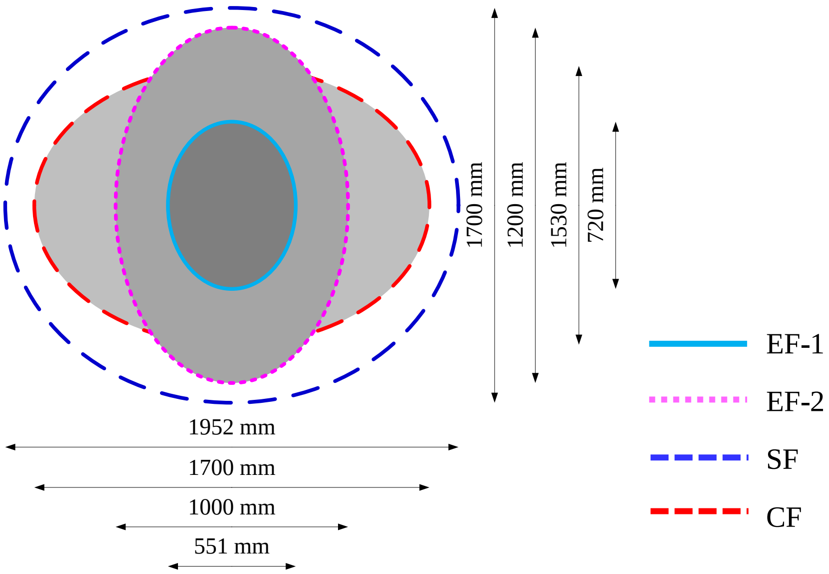


Fig. 16 Projection of the damaged surface area of RC guardhouses (back side)

of SF (2.50 m^2) was found to be more than the others (Fig. 16). EF-1 has minimum damage area that was obtained as 0.30 m^2. The geometric type that has the least damaged area among guardhouses is EF-1. The approximate damaged areas of CF and EF-2 were given in Table 3.

5. Conclusions

In this study, three reinforced concrete guardhouses with different geometric forms (square, ellipse, and circle) and same usage areas were modeled with Abaqus finite element software. The three configurations were subjected to same impact energy to determine the geometric form that gives the best defensive behavior under the impact loading. The concrete and reinforced concrete steel members were modeled with Concrete Damage Plasticity (CDP) and Classical Metal Plasticity (CMP), respectively. The conclusions drawn from the results obtained in this study are as follows:

• Square formed (SF) reinforced concrete guardhouse showed unstable behavior during the 10.0 ms. Moreover, less impact resistance was obtained from the SF.
• When EF-1 and EF-2 were compared, the impact resistance of EF-1 was determined to be 88% higher than that of EF-2. The minor axis direction of the elliptic form has relatively weaker impact behavior than major axis direction. These results showed that the guardhouses with the same elliptic geometry show a very different impact behavior when subjected to the same impact energy in different impact directions.
• EF-1 exhibited more defensive behavior under impact loading. The kinetic energy of the missile was absorbed earlier than the other geometric forms.
• In case of the impact loading occurring in major axis direction of the ellipse (EF-1), the elliptical formed reinforced concrete wall had higher impact resistance.
• Circular formed (CF) reinforced concrete wall which has the same impact resistance in each direction had more advantages than others.
• When damage areas on the backsides of RC walls were compared under the same impact energy, the damaged area on the backside of EF-1 (major axis direction of the ellipse) was the minimum. Nevertheless, the constructions of all side of RC guardhouses are difficult such as an EF-1 form. For this reason, it is more advantageous to prefer circular form (CF) when the damaged areas are taken into consideration.
• The depth of the damage caused by the impact loading through the element width was obtained numerically. The numerical results were validated with experimental results from the relevant technical literature. The modeling processes and material models (CDP and CMP) gave proper results in high strain rate mechanical problems about RC members.

In the future, the experimental studies of the RC walls should be performed with suitable test setups to verify the numerical results. Furthermore, the more in-depth comparisons between experimental test and numerical results need to be carried out.

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