A Numerical Study on RC Plates Behavior under Low Velocity Impact

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***Abstract*—Structures may be subjected to impact and blast loading because of various reasons. In recent years, the behavior of structural members under impulsive loading has been investigated both numerically and experimentally. Development in computational engineering has facilitated the modeling of extreme loading conditions. In this study, the behavior of reinforced concrete plates was modeled with ABAQUS commercial finite element software. In finite element model (FEM), Drucker-Prager (DP) material model and Classical Metal Plasticity (CMP) model were used for modeling concrete and reinforcing steel, respectively. The four reinforced concrete plates with fixed and free support were analyzed under impact load. The impact force-time, impact force-mid-span displacement curves and total dissipated energy were obtained numerically. The numerical results were compared with each other. Result showed that span size is effective parameter on impact behavior of reinforced concrete plates.**

***Index Terms*—impact force, ABAQUS, fixed support, reinforced concrete, Drucker-Prager**

I. Introduction

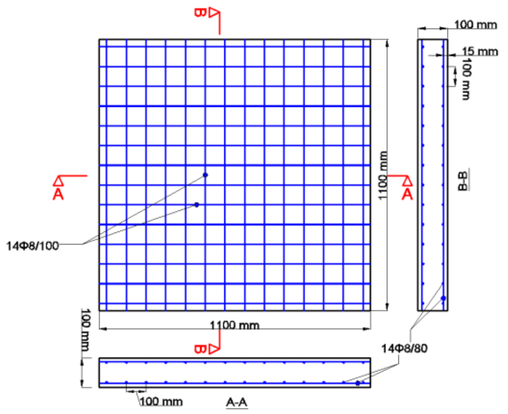
Reinforced concrete (RC) structures have been commonly used in construction industries. These structures usually subjected to static and dynamic loads such as self-weight, earthquake and wind load. However, the structures may be exposed to some impulsive loading. These extreme loading conditions has been divided two main categories. These are impact and blast loading. Generally nuclear plants, airports and military installations are exposed to explosion and impact loads. However, in normal structures, these conditions can be seen due to gas explosion and terrorist attacks. Because of this reason, in RC structures, the effect of impact loads that is gaining popularity should be investigated. In recent years, many researchers have been investigated behavior of reinforced concrete members under impact loading numerically and experimentally. Some of these studies are conducted by Sawamoto et al. [1]. There is an analytical model was developed to determine local strains that can be possibly seen for RC panel elements. RC panels under the impact load which are caused by bullet impact were modeled by applying the discrete element method. Analysis results that are obtained from Discrete Element Method were compared with the results that were obtained from experimental studies. Abbas et.al were made numerically and experimentally studies for defining the non-linear behaviors of RC plates and beams [2]. The study that was conducted by Zineddin and Krauthammer has aims to examine behaviors of RC flooring under impact loads and increasing their element's impact strengths [3].

These researchers searched for effects of impact strengths of RC floorings under different types of reinforcement arrangements. Chen and May conducted a research about the effects of objects by creating impact loads with higher weights and impact in low velocities on RC elements like beams, plates, etc. [4]. Martin searched with numerical modeling for structural behaviors of structural elements under impact load [5]. Finite element models are searched for different structural behaviors under different material models. Effects of soft and hard impact loads were modeled both by deformable and rigid bullets. Studies that are conducted by Trivedi and Singh consist of numerical models to foresee the structural behaviors of RC under local strains that are exposed to impact loads [6]. Similarities of the failure type and the fracture energy (G_f) values were obtained from between the experimental works and FEM analyses were conducted by Zineddin and Krauthammer.

In this study, RC plates with different span sizes are examined numerically. The impact force-time, impact force-mid-span displacement curves and total dissipated energy were obtained. The numerical results were compared with each other.

II. Finite Element Model (FEM)

Reinforced concrete plates were simulated with ABAQUS-Explicit [7]. The reinforcement arrangement and geometrical properties of plate P1, P2, P3 and P4 are given Fig. 1.



(a) P1, P2

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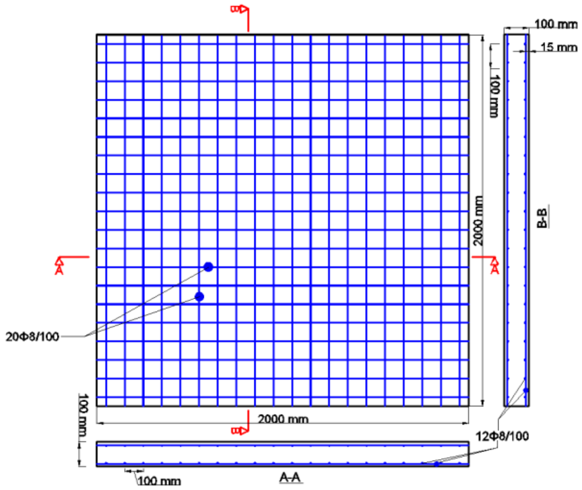


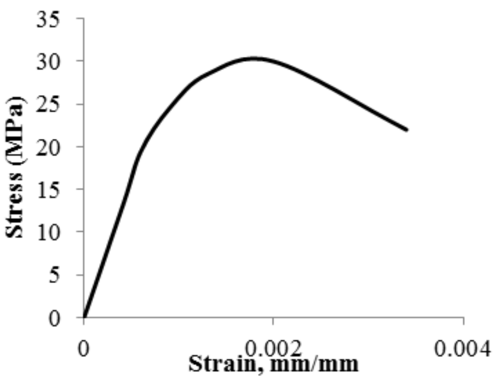
(b) P3, P4

Figure 1. Reinforcement plan for typical RC plates.

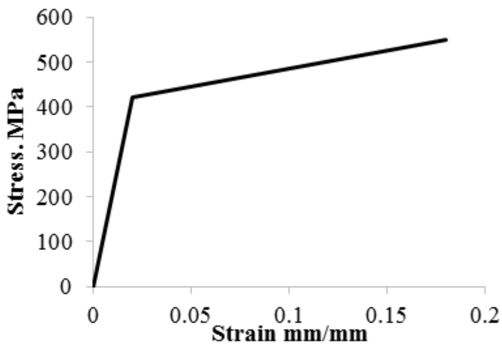
The concrete plate and reinforcing steel were modeled with C3D8R and T3D2 elements, respectively. C3D8R element that is used in more accurate finite element model dominated by inelastic behavior. In FEM, C3D8R finite element was preferred. Because, this element shows accurate results in nonlinear behavior of structure systems. Concrete plate model that was created by using the combination of C3D8R and T3D2 elements. The bond between concrete and reinforcing steel was assumed fixed. The impact loading was simulated as a mass dropped from certain height. Therefore, the velocity (V_d) was defined to the steel cylindrical mass (100 kg). The velocity of steel cylindrical object was calculated for the mass dropped from three-meter height, as in (1).

$$V_d = \sqrt{2gh} = \sqrt{2x9.81x3} = 7.67\ m/s \tag{1}$$

Drucker-Prager (DP) material model was used for modeling of concrete plates. The two main parameters must be defined in ABAQUS for DP. The compressive strength of concrete was selected 30 MPa. These are internal friction angle (30) and dilation angle (15) of concrete. Furthermore, the stress-strain relation of concrete (Fig. 2a) was converted to DP hardening behavior in compression. The yield strength of reinforcing steel was selected 420 MPa. CMP model was used for modeling of reinforcing steel (Fig. 2b).



(a) Concrete



(b) reinforcing steel

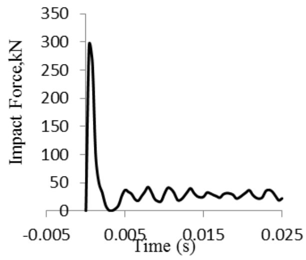
Figure 2. Stress-strain curves.

III. Results-Discussions

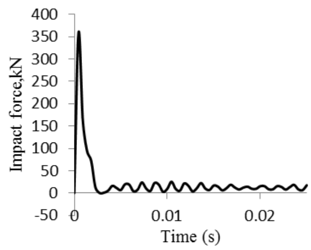
In this study, two different support (fixed and free) and four RC plates in two different dimensions in 100 kg of mass and 7.67 m/sec velocity were used. In this study, transient impact load and mid span deflection of RC plates were obtained. Changes in P1, P2, P3 and P4 plates with impact loads were given in Fig. 3. All impact analysis of the plates within the scope of this study are given in Table 1 for maximum impact force and maximum displacement values. When the maximum impact loads were compared with corresponding values in literature, numerical result of RC plates showed more rigid behavior. The cause of this situation is considered that DP material model cannot be represented behavior of concrete under impulsive loading

TABLE I. Summary of Numerical Results

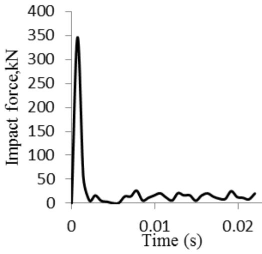
Plates Name	Support type	Dimensions (mm)	Maximum Impact force(kN)	Maximum displacement (mm)
P1	free	1100x1100x100	294.1	10
P2	fixed	1100x1100x100	358.7	8.2
P3	free	2000x2000x100	346	8.5
P4	fixed	2000x2000x100	403	7.3



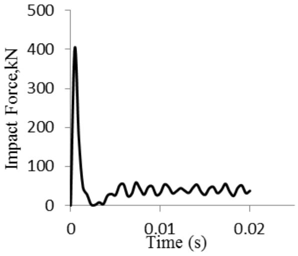
(P1)



(P2)

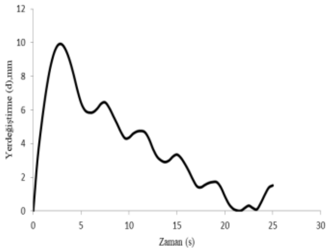


(P3)

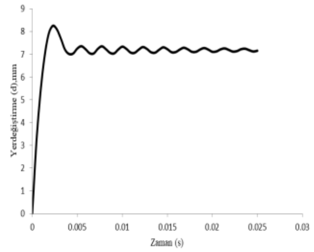


(P4)

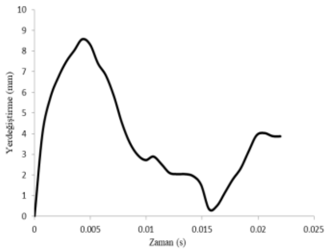
Figure 3. Impact force-time curves of RC plates(kN-s).



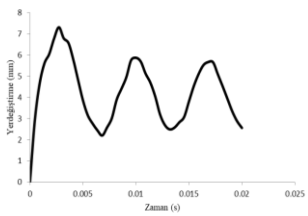
(P1)



(P2)



(P3)



(P4)

Figure 4. Mid-span displacement-time curves of RC plates (mm, s).

As it can be seen in Figure 3-4 and Table 1, maximum of the impact load of P2 plate is %22 higher than the maximum impact load of P1, maximum impact load gained from P4 plate is %16.5 higher than the maximum impact load of P3. When the mid-span of the plates is considered, maximum displacements were changed in important levels in accordance with the support conditions. Maximum displacement of P1 is %22 higher than P2. Maximum displacement of P3 is %16 higher than P2. The maximum impact loads were obtained fixed support RC plates. According to numerical results, both span size and support condition are important parameters for impact behavior of reinforced concrete plate.

IV. CONCLUSION

The behavior of four RC plates under impact loading were examined numerically. The RC plates were modeled with two different support conditions and two different span sizes. Impact load-time curves and maximum mid-span displacement were obtained. The numerical result was compared and discussed each other. The conclusion drawn from the results obtained in this study are as follows:

- Numerical results showed that both span size and support condition are important parameters for impact behavior of RC plates.
- Comparison of two plate series showed that increasing of the span size led to higher impact resistance. This result is not acceptable analytically. Because, the increasing span size reduce bending stiffness of plates. Because of this reason, the modeling must be made for different span size and material models in further studies.
- When the maximum impact loads were compared with corresponding values in literature, numerical result of RC plates showed more rigid behavior. The cause of this situation is considered that DP material model cannot be represented behavior of concrete under impulsive loading.
- When the analysis results examined together, maximum impact resistance of fixed-support plates are higher than free support plates.
- When maximum mid-span deflections are compared, the maximum mid-span displacement values of fixed-support plates are lower than free-support plates.

The numerical studies have been carried out with different material model and RC plate dimensions. Furthermore, the experimental studies are still in progress.

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