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Numerical study of the behavior of reinforced concrete beams with different characteristics subjected to impact loads

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ABSTRACT

One of the challenges facing structural engineers is to identify the performance of important structures against heavy impact loads, therefore, the need to investigate this type of load on structures is increasingly felt. The main purpose of this study was to evaluate the effect of support conditions, span length, and strength of concrete and reinforcement percentage on the performance of reinforced concrete beams against the impact load of 50 kg spherical falls on a height of one meter. For this purpose, after validation, a number of reinforced concrete beams with the same cross section but with simple and rigid support conditions, span lengths of 3, 4 and 5 meter, strengths of 25, 30 and 35 MPa, as well as minimum, standard and maximally longitudinal reinforcement values, modeled and analyzed in Abaqus software. The results of this study show that for 3, 4 and 5 m lengths, the boundary conditions change from simple to rigid, reducing the mid beam displacement by 46.91%, 45.55% and 39.46%, respectively. By changing the characteristic strength of concrete from 25 to 35 MPa, the maximum displacement for rigid support and the simple support order of 10.17% and 10.9% reduced. By increasing the amount of reinforcement from minimum to maximum reinforcement, the maximum amount of force applied to the beam for the rigid and simple support reinforcement increased by 33 and 32.66 percent, respectively. The use of stirrups special led to an increase of 13 percent of the beam is tolerable.

Keywords: reinforced concrete beam, impact load, maximum displacement, maximum force applied, strength.

INTRODUCTION

In the field of normal and conventional loading of structures, due to its extensive use from the past to the present, engineers have a wide range of experiences and information, based on which we are witnessing advanced codes in the field of conventional loads today. However, another type of loading introduced in the codes, especially the Iranian code, are unconventional and mainly dynamic loadings, which have been less studied due to their less use and analytical complexity, but in any case, in various cases we are forced to design structures with such loadings. One of these types of loadings is impact loading on structural members. In the real world, we witness the application of such loads, from low-altitude impacts on bridges to very heavy impacts on protective structures such as trenches and slums, and even the protective structures of nuclear power plants. Loads that are a function of time are called dynamic loads (Moradi and Khalilzadeh Vahidi, 2021a).

Static loads are also a special case of dynamic loads that are defined by a constant function. Dynamic loads themselves are also divided into two categories. The first category is periodic dynamic loads for which a periodic period or frequency can be considered. Loads caused by sea tides are one of these types of loads. The second category is non-periodic dynamic loads. Loads caused by earthquakes and loads caused by explosions are among these types of loads (Moradi and Khalilzadeh Vahidi, 2021b). Impact loads are an important category of non-periodic dynamic loads that are suddenly applied to a structure and include a single pulse (Hassanein et al., 2017). Impact loads can cause severe damage to structures, especially reinforced concrete structures. For this reason, in recent years, many researchers have conducted numerical and laboratory studies of structural members under impact loads.

Fouad et al. (2021) conducted a study to evaluate the impact of near-field blast loads on structural elements, particularly reinforced concrete columns, through a numerical investigation using detailed models developed with the LS-DYNA software. The study aimed to compare the effect of seismic reinforcement detailing with conventional reinforcement detailing on the performance of columns under blast loads, as well as to examine the influence of various modelling parameters on the results. The findings revealed that using seismic reinforcement detailing improves the failure pattern and reduces displacements compared to conventional reinforcement detailing. Additionally, the study indicated that decreasing the mesh size, increasing the erosion value, and incorporating air in the modelling enhance the agreement between numerical results and experimental observations. When applied to a multi-story building equipped with protective walls, it was found that using only top and bottom connections for the protective walls with the columns and slabs was more effective in minimizing distortion and failure. This approach significantly increases the chances of protecting the building from collapse and saving lives.

Saleh et al. (2020) conducted a laboratory study of the damage mechanism of reinforced concrete beams with glass composite rebar's. For this purpose, 9 laboratory specimens were subjected to three different levels of energy from impact loads. Their research results show that the type of cracks and their growth pattern depend on the shear capacity of the beams. In beams with high shear capacity, flexural cracks and flexural-shear cracks were observed, and in these specimens, the displacement of the beam centre is less than in other samples. While in beams with low shear capacity, shear cracks were observed.

Fu et al. (2020) studied the failure mode of reinforced concrete beams without stirrups under impact. Their research results show that with increasing impact velocity, the energy absorbed in the flexural failure mode increases and in the shear failure mode decreases, which means that the decrease in the energy absorbed capacity in the shear failure mode is probably due to the decrease in the plastic deformation of the reinforcement.

Yılmaz et al. (2020) conducted a laboratory study of the effect of impact load on the behavior of reinforced concrete slabs with different reinforcement percentages. For this purpose, they compared the dynamic behavior and failure mode of 9 reinforced concrete slab samples with simple supports. The results of this study show that with increasing reinforcement percentage, the maximum displacement and residual displacement of the samples decrease. While with increasing energy level due to impact load, the maximum displacement and residual displacement increase.

Ulzurrun and Zanuy (2017) studied the effect of concrete with steel fibers on the performance of reinforced concrete beams without stirrups. They used steel fibers in three forms: simple, hooked, and prismatic, and in three amounts of zero and a half and one percent by volume of aggregate. The results of this study indicate that beams without steel fibers fail in shear. While in beams with half and one percent of steel fibers, the failure is in the form of shear failure after yielding of longitudinal bars and soft bending failure, respectively. Also, samples with hooked steel fibers will show better behavior than other samples against impact load.

Considering that the structural members of concrete buildings (beams, columns and slabs) are always exposed to damage under impact load, it seems necessary to conduct more studies and research in this field in order to obtain sufficient information and understanding of the performance of these members under impact load. In this study, considering the importance of the impact issue in concrete buildings, the effect of impact on the dynamic behavior of reinforced concrete beams is investigated. In this research, the main goal is to find an answer to the question: How much and to what extent will increasing the length of the beam, changing the beam support conditions, increasing the concrete strength, and changing the percentage of reinforcement affect the maximum force on the beam and the maximum displacement of the beam in the middle due to impact load, as well as the growth of cracks and cracking of concrete beams? Obviously, the answer to this question can give engineers a better view of the design of impact-resistant buildings. It can also lead to a better understanding of the cracking and propagation of cracks caused by impact load in reinforced concrete beams.

For this purpose, after an introduction and a review of previous research, in the next step, the experimental sample is validated using the Abaqus finite element software. In the next step, the models under study are modelled and analyzed in the Abaqus software. Finally, the maximum force on the beam, the maximum displacement in the middle of the beam, and the cracking and crack growth patterns in the numerical models are examined and compared.

VERIFICATION

In this study, in order to ensure the results of numerical model modelling in Abaqus software, first a laboratory sample under impact load should be analyzed and the results of numerical modelling and laboratory sample should be compared. For this purpose, the results of laboratory research conducted by Anil et al. (2016) have been used. The laboratory sample selected for verification is a concrete beam with a length of 750 mm and a cross-section of 50×50 mm, which is reinforced by placing two longitudinal reinforcement bars with a diameter of 4 mm along the length of the beam. The sample in question has a fixed support on both sides. Concrete with a compressive strength of 16.6 MPa and rebar with a yield strength of 220 MPa and a modulus of elasticity of 200 GPa have been used to construct the laboratory sample. Also, an aluminium weight with a mass of 9 kg, which falls from a height of 750 mm, is used to apply the impact load to the middle of the beam. The time history of the impact load applied to the middle of the beam is shown in Figure 1.

After selecting the laboratory sample and knowing its details, it is modelled in Abaqus software. Introducing the stress-strain diagram into Abaqus software requires using the results of the direct tensile test. If this curve is not available, the model presented by other researchers can be used. In this study, the stress-strain diagram of steel in a fully elastic-plastic form up to an ultimate strain of 17% has been used (Xu et al., 2020). For the elastic behavior of steel, elastic materials are assumed and for the plastic behavior, kinematic hardening has been used. For the nonlinear behavior of concrete, plastically damaged concrete (CDP) has been used. This method, which is a generalization of the Praeger-Drager criterion, assumes that cracking due to tensile forces and crushing due to compressive forces are the two main aspects of the failure mechanism in concrete (Mohemmi et al., 2020). In modelling the tensile behavior of concrete, the behavioural model of Nayal and Rashid (Moradi and Khalilzadeh Vahidi, 2018), which is simple and has good accuracy, was used (Lu and Aboutaha, 2020), and the behavioural model of Hsu and Hsu was used in modelling the compressive behavior of concrete (Moradi and Khalilzadeh Vahidi, 2018).

For modelling concrete and rebar, eight-node continuous element with reduced integral (C3D8R) and truss element (T3D2) were used,

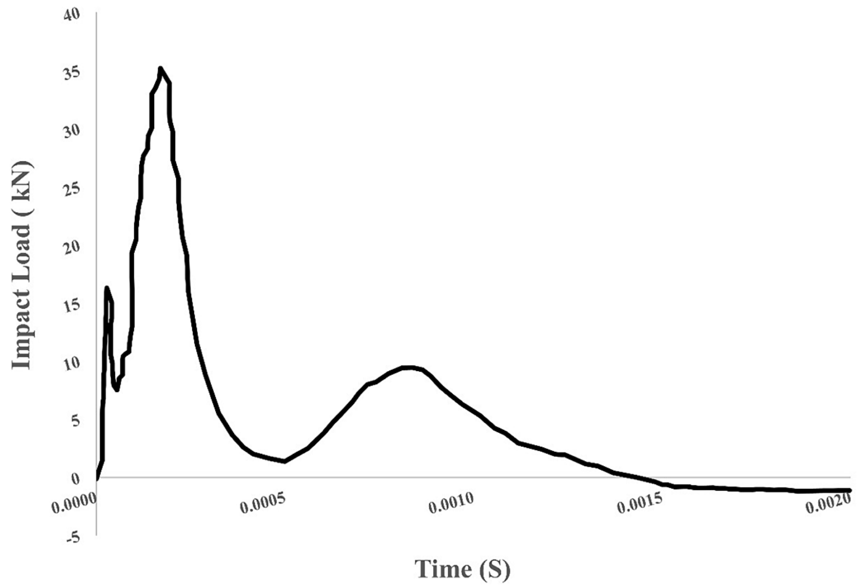

Figure 1. Loading protocol and weight drop height

respectively (Vahidi and Moradi, 2019). Beam element can also be used for rebar, but this is not recommended due to the number of input parameters and increased solution time (Qu et al., 2020). Mesh dimensions for steel and concrete were selected as 25 and 50 mm, respectively. The buried zone constraint was used for the interaction of steel and concrete. According to previous studies, the effect of rebar sliding in concrete is not considered in the buried zone constraint (Tahnat et al., 2020).

However, it can be said that the effect of this phenomenon is considered in the way it is in the tensile hardening of steel and concrete. The time history diagram of the displacement of the middle of the beam due to a single fall of the aluminium weight for the numerical and experimental samples is compared in Figure 2. Because in this study, the maximum displacement of the middle of the beam in the numerical samples is compared, the main criterion in showing the accuracy of the numerical modelling of the experimental sample is the maximum displacement of the middle of the beam. According to Figure 2, the numerical model of the experimental sample has shown the displacement of the middle of the beam with almost adequate accuracy. However, the displacement of the middle of the beam in the numerical sample and the experimental sample is somewhat different. The reason for the difference in residual displacement is the assumptions that have been used to simplify the prediction of the nonlinear behavior of the materials.

CHARACTERISTICS OF THE STUDIED MODELS AND MODELLING ASSUMPTIONS

Given that the main goal of this research is to study the behavior of reinforced concrete beams under impact load, it has been tried to investigate most of the parameters effective in their performance under impact load. For this purpose, a reinforced concrete beam with a width of 30 and a height of 40 cm and with simple and fixed support conditions, a span length of 3, 4 and 5 meters, a characteristic strength of 25, 30 and 35 MPa, as well as the percentage of minimum, normal and maximum longitudinal reinforcement are evaluated.

1. Typical reinforcement amount:
- $6\,\phi\,20$

2. Minimum longitudinal reinforcement by regulation:
- $\rho_{\min} = \dfrac{0.25}{F_y} \quad \rightarrow \quad 6\phi12$

3. Maximum longitudinal reinforcement by regulation:
- $\rho_{\max} = 0.025 \quad \rightarrow \quad 6\phi32$

As shown in Figure 3, the amount and arrangement of longitudinal reinforcement for all three reinforcement conditions (normal, minimum and maximum code) is in the form of three tension reinforcement at the bottom and three compression reinforcement at the top of the concrete beam with different diameters. For the stirrups, reinforcement with a diameter of 8 mm is used. The density of stirrups is different in different areas of the beam, near the support and

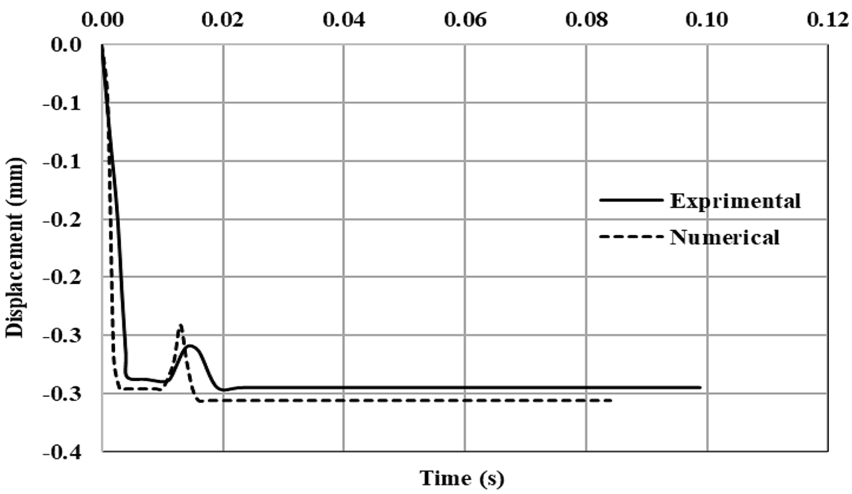

Figure 2. Comparison between the time histories of the displacement of the center of the span of a concrete beam obtained from the Abaqus software and the reference experiment (Anil et al. 2016)

up to a distance of 800 mm from the support, the transverse spacing of the reinforcements is 80 mm, and in the remaining areas of the beam, the spacing of the stirrups is 150 mm. In investigating the effect of the amount of longitudinal reinforcement on the behavior of the reinforced concrete beam, a numerical model with normal reinforcement with special stirrups is considered, that is, in addition to the common stirrups in other numerical models, hooks are also considered at the ends of the beam. Figure 3 shows the arrangement of longitudinal and transverse reinforcements made of A3 steel along the length of the beams studied in this paper.

In this study, the mass and height of the weight fall were calculated by equating the energy that will cause the concrete beam to crack with the potential energy resulting from the weight fall. For this purpose, a concrete beam with a length of 4 m, a cross-section of 30×40 cm and a characteristic strength of 25 MPa with a fixed boundary condition was considered. The stress and cracking moment of the beam can be calculated as relations (1) and (2), respectively.

$$F_r = 0.6\sqrt{f_c'} = 0.6 \times \sqrt{25} = 3 \text{ MPa} \quad (1)$$

$$M_r = \frac{I \times F_r}{y_{max}} = \frac{\frac{b \times h^3}{12} \times F_r}{\frac{h}{2}} =$$

$$= \frac{\frac{300 \times 400^3}{12} \times 3}{\frac{400}{2}} = 24 \times 10^6 \text{ N.mm} \quad (2)$$

Now, using the relationships of maximum bending moment and maximum static deflection of a double-ended beam, the maximum crack-corrosion threshold force (P_{max}) and maximum deflection (δ_{max}) of the concrete beam will be calculated according to relationships (3) and (4).

$$M_{max} = \frac{PL}{8} = M_r \quad \rightarrow \quad \frac{P \times 4000}{8} =$$

$$= 24 \times 10^6 \quad \rightarrow \quad P_{max} = 48 \times 10^3 \text{ N} \quad (3)$$

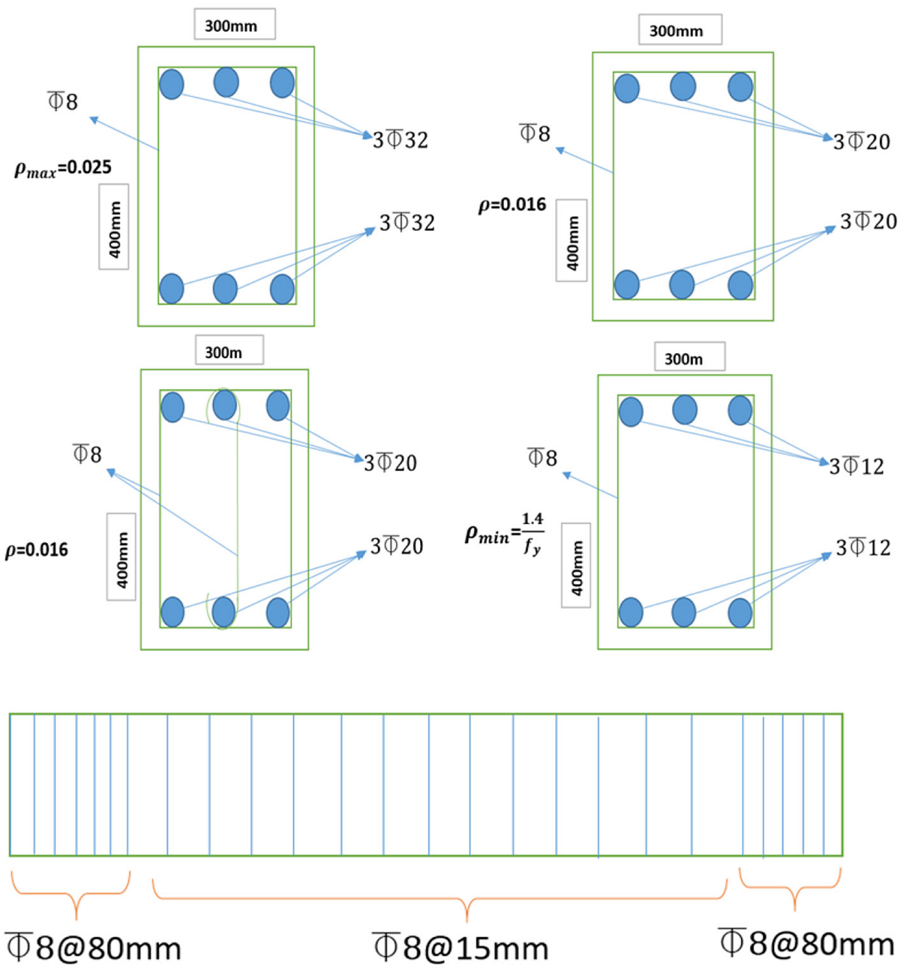

Figure 3. Schematic representation of geometry and simple boundary condition of concrete beam

$$\delta_{max} = \frac{PL^3}{192EI} = \frac{P_{max} \times L^3}{192 \times 5000\sqrt{f_c'} \times \frac{b \times h^3}{12}} = \frac{48 \times 10^3 \times 4000^3}{192 \times 5000\sqrt{25} \times \frac{300 \times 400^3}{12}} = 0.4 \text{ mm} \quad (4)$$

The energy stored in the structure is obtained according to equation (5).

$$E = \frac{1}{2}P\delta = \frac{1}{2} \times 48000 \times 0.4 = 9600 \text{ N.mm} \quad (5)$$

If an energy of 9600 N.mm is applied to the structure, the structure will crack. Now, if the height of the fall is considered to be one meter, by equating the energy stored in the structure with the energy resulting from the fall, the mass of the weight can be calculated according to equation (6).

$$E = mgh \xrightarrow{h=1\,m} 9600 = m \times g \times 1000 \rightarrow \rightarrow mg = 9.6 \text{ N} \xrightarrow{g=9.81\,m/s^2} m \approx 1 \text{ kg} \quad (6)$$

Therefore, dropping a one-kilogram weight from a height of one meter will put the concrete beam on the verge of cracking. Therefore, for optimal performance of the beam and observation of the cracking process and real stress distribution, the weight mass is considered to be 50 kg. In this study, as in the modelling of the laboratory sample, for modelling numerical samples of reinforced concrete beam in Abaqus software, eight-node continuous element with reduced integral (C3D8R) and truss element (T3D2) were used for modelling concrete and rebar, respectively, and nonlinear dynamic analysis was used for modelling impact load. To define the properties of concrete, the properties of plastically damaged concrete (CDP), which is a generalized failure criterion of Dragger-Prager, were used. Therefore, as previously stated, the model proposed by Niall and Rashed was used to consider the tensile stress-strain diagram and the model proposed by Hasso and Hasso was used to consider the compressive stress-strain diagram of concrete. Also, the modulus of elasticity of concrete was calculated according to Equation 7 and the Poisson's ratio of concrete was considered to be 0.2.

$$E_c = 5000\sqrt{f_c'} \quad (7)$$

For concrete, Rayleigh damping was used, and frequency analysis was used to calculate its coefficients. In this study, a simplified two-line diagram was used for the stress-strain curve of steel. Also, Table 1 gives the initial parameters and mechanical properties of A3 steel.

RESULTS

In this section, the effect of various parameters such as concrete beam support conditions, beam span length, concrete characteristic strength and steel reinforcement amount on the nonlinear dynamic behavior of reinforced concrete beams has been evaluated.

Effect of support conditions and beam length

In order to investigate the effect of support conditions, a concrete beam with a cross-section of 30 × 40 cm and lengths of 3, 4 and 5 m with a characteristic strength of 30 MPa and a conventional reinforcement amount (6Φ20) and with two fixed and simple boundary conditions was modelled and analyzed under an impact load resulting from the fall of a 50 kg weight from a height of 1 m. Figure 4 shows the maximum displacement of the mid-span of the numerical specimens of the concrete beam.

According to Figure 4, for lengths of 3, 4 and 5 m, changing the boundary conditions from simple to fixed causes a decrease in the displacement of the middle of the beam by 46.91, 45.55 and 39.46%, respectively. This indicates that the displacement of the middle of the beam in beams with fixed support conditions is less than that of beams with simple support. Also, under the same impact, the displacement of the middle of the beam will be reduced by increasing the length of the beam.

According to Figure 5, with increasing the length of the beam, the amount of force applied to the beam due to the bullet impact decreases, and for lengths of 3, 4 and 5 m, changing the support conditions from fixed to simple, the force applied to the beam decreases by 53, 52 and 55%, respectively. In Figure 6, the cracking behavior for numerical samples with different lengths

Table 1. Initial parameters and mechanical properties of A3 steel

E (GPa)	υ	ρ (kg/m³)	σ_y (MPa)	σ_u (MPa)	ε_u
210	0.3	7850	400	600	0.17

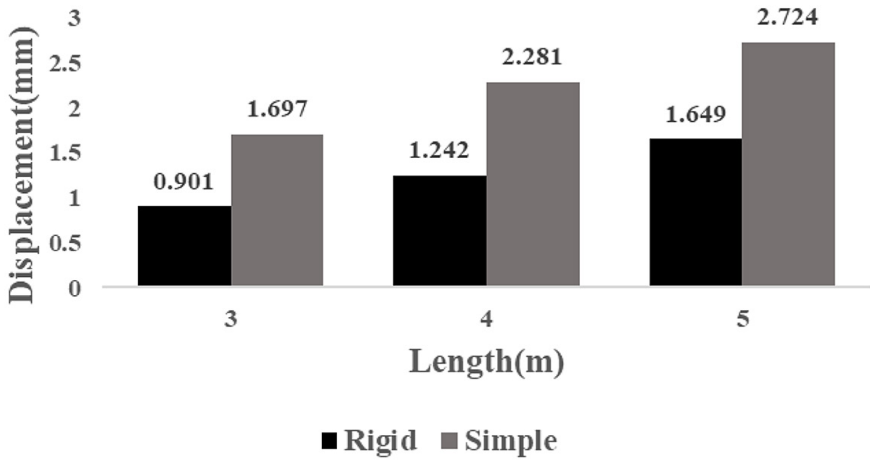

Figure 4. Comparison of maximum displacement of the middle of the span with different boundary conditions and lengths

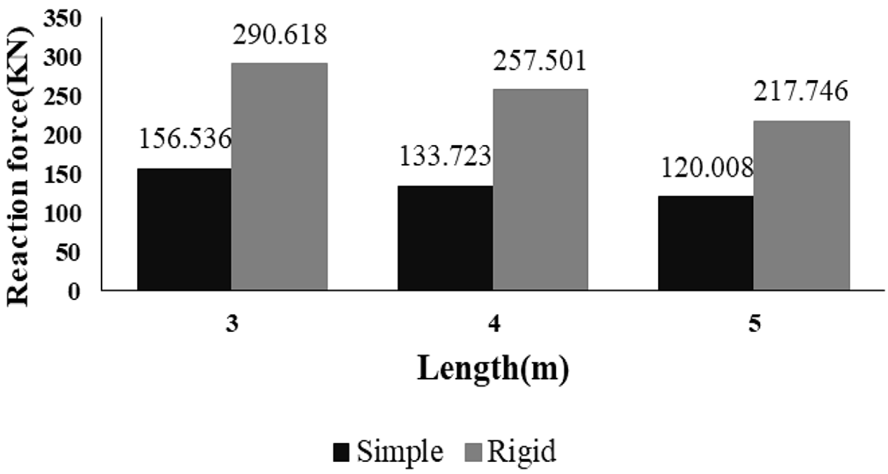

Figure 5. Comparison of maximum force on the beam with different boundary conditions and lengths

and supports is compared, where red lines indicate deep cracks and blue lines indicate hairline cracks. According to Fig. 6, in beams with fixed supports, with increasing beam length from 3 to 5 m, the maximum cracking value has decreased from 0.89 to 0.84. Also, in beams with fixed supports, cracking starts to grow and spread from the upper fibers next to the support, then from the lower fibers in the middle of the beam, and the highest cracking rate is observed in the upper fibers near the support. In beams with hinged supports, increasing the beam length has a greater effect on the maximum cracking. In these beams, increasing the beam length from 3 to 5 m has reduced the maximum cracking from 0.89 to 0.51. In beams with hinged supports, cracking spreads from the middle of the beam towards the support, and the highest cracking rate has occurred in the middle of the beam.

Effect of concrete characteristic strength

To investigate the effect of concrete characteristic strength on the behavior of reinforced concrete beam against impact loads, specimens with a cross section of 30 cm wide and 40 cm high and 5 m long, with a normal longitudinal reinforcement amount (6Φ20), with simple and fixed support conditions and with characteristic strengths of 25, 30 and 35 MPa have been considered. In Figure 7, the maximum displacement of the middle span of the concrete beam has been compared with respect to the characteristic strength of concrete and different boundary conditions of the beam. As can be seen in the figure, with the increase in the characteristic strength of the concrete, the maximum displacement value of the mid-span has decreased linearly for both boundary condition cases. For example, with the

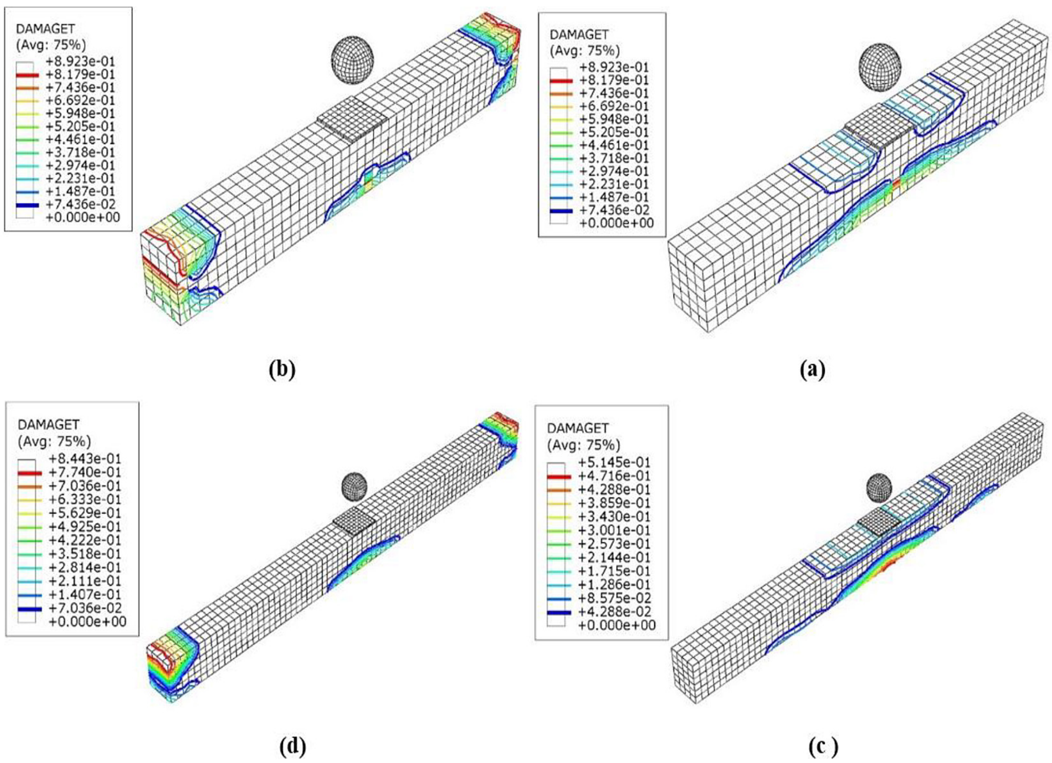

Figure 6. Comparison of cracking of reinforced concrete beam under impact load: (a) 3 m long specimen with simple support, (b) 3 m long specimen with fixed support, (c) 5 m long specimen with simple support and (d) 5 m long specimen with fixed support

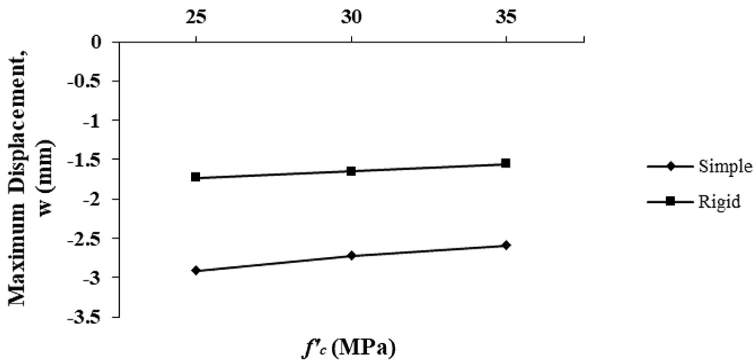

Figure 7. Comparison of maximum mid-span displacement according to concrete characteristic strength and different beam boundary conditions

change in the characteristic strength from 25 to 35 MPa, the maximum displacement value for the fixed and simple support has decreased by 10.17% and 10.90%, respectively.

In Figure 8, the maximum force applied to the concrete beam has been compared in terms of the characteristic strength of the concrete and the different boundary conditions of the beam. As can be seen in the figure, with the increase in the concrete strength, the maximum force applied to the beam has increased linearly for both boundary condition cases. For example, by changing the concrete strength from 25 to 35 MPa, the maximum force applied to the beam increased by 9.89% and 14.22% for fixed and simple supports, respectively.

Figure 9 shows the effect of concrete characteristic strength on the cracking behavior of reinforced concrete beams. In this figure, hairline cracks are marked in blue and deep cracks are marked in red. According to Figure 9, the maximum cracking in the specimen with fixed support conditions and a length of 5 m and characteristic strengths of 25, 30 and 35 MPa is 0.89, 0.84 and 0.79, respectively. Also, in samples with

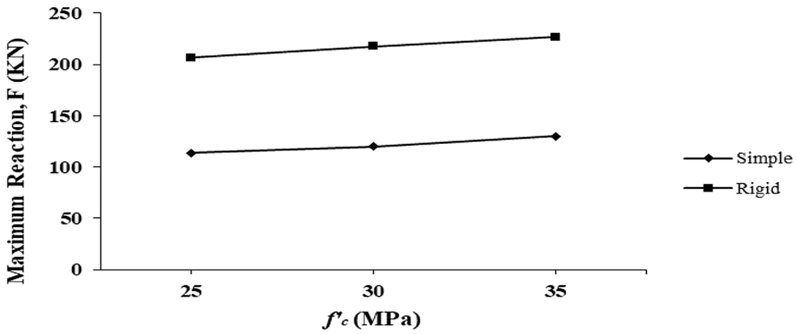

Figure 8. Comparison of maximum force applied to the beam according to concrete characteristic strength and different beam boundary conditions

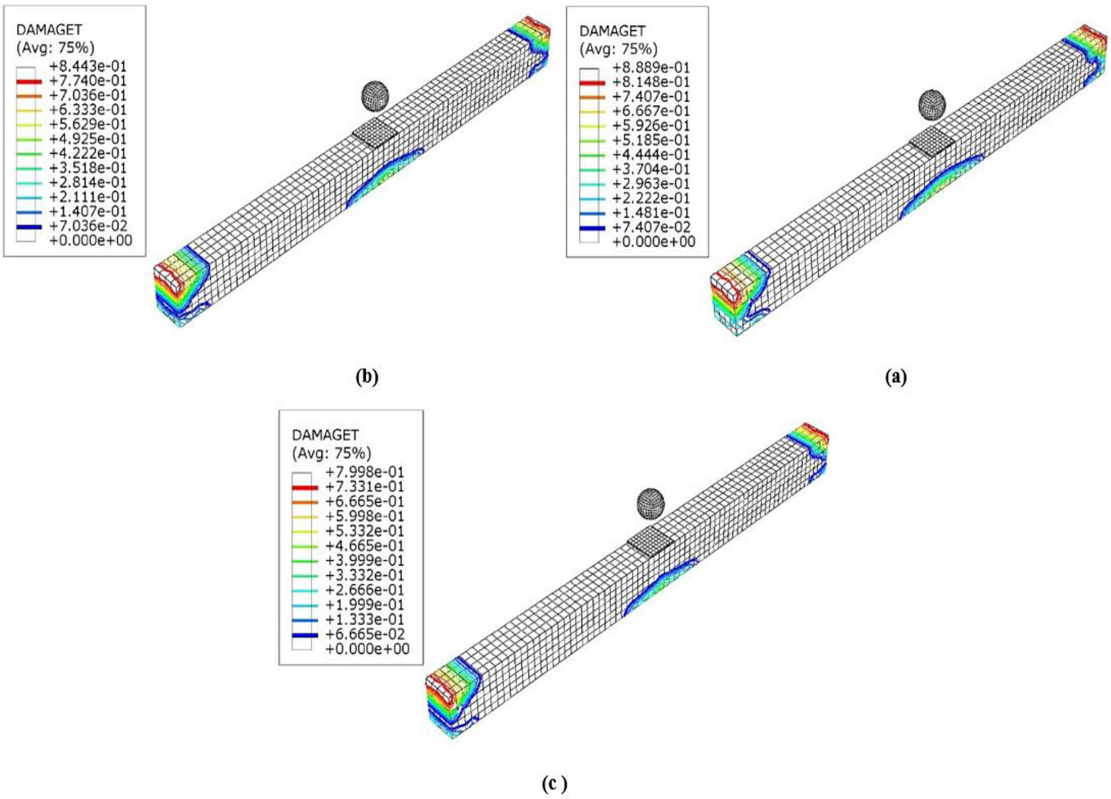

Figure 9. Comparison of reinforced concrete beam cracking under impact load for samples with fixed support and concrete with characteristic strength of (a) 25 MPa, (b) 30 MPa and (c) 35 MPa

lower characteristic strength, more cracks were observed in the middle of the beam and near the support. In other words, the cracking rate decreased with increasing characteristic strength of concrete.

Effect of reinforcement amount

In this part of the study, samples of A beam with a cross section of 30 cm wide, 40 cm high and 5 m long, with simple and fixed support conditions, with a characteristic strength of 30 MPa and with minimum, maximum and special longitudinal reinforcement arrangement values has been considered. In investigating the effect of the amount of longitudinal reinforcement on the behavior of the reinforced concrete beam, a numerical sample with ordinary reinforcement with special shackles has been considered, that is, in addition to the common shackles in other numerical samples, hooks have also been considered throughout the beam. In Figure 10, the maximum displacement of the middle of the span of a concrete beam has been compared in terms of

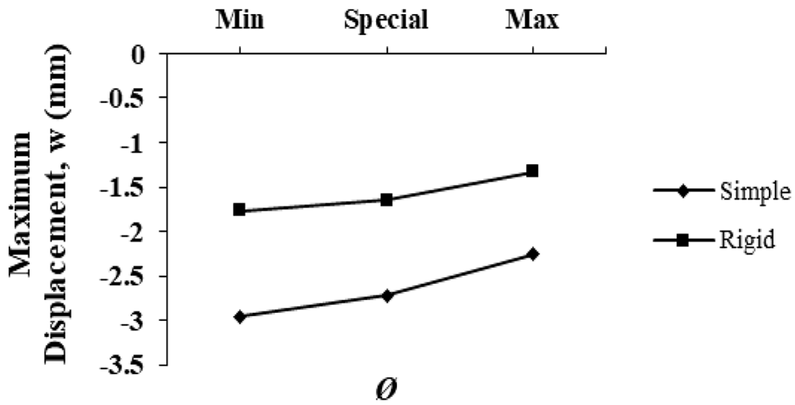

Figure 10. Comparison of maximum mid-span displacement according to the amount of steel reinforcement and different boundary conditions of the beam

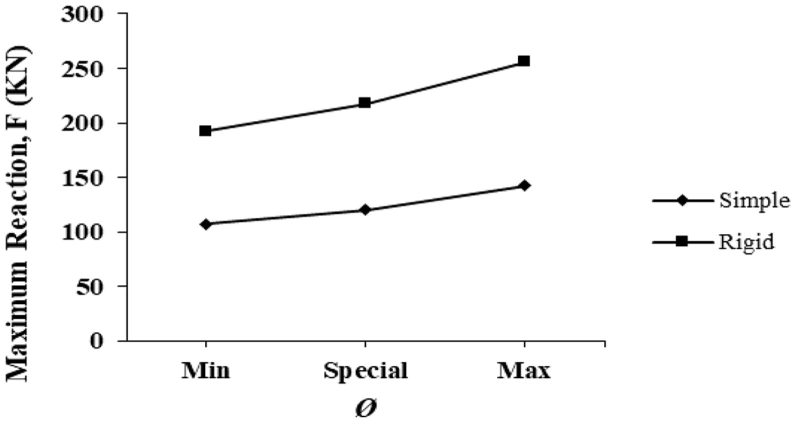

Figure 11. Comparison of maximum force applied to the beam according to the amount of steel reinforcement and different boundary conditions of the beam

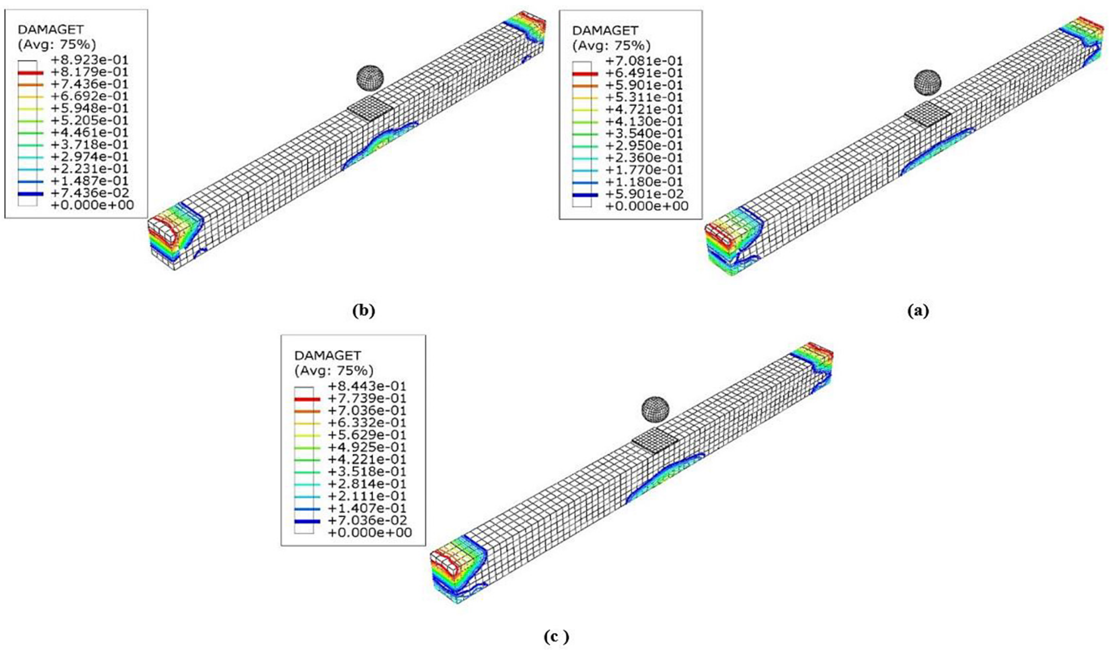

Figure 12. Comparison of reinforced concrete beam cracking under impact load for specimens with fixed support and longitudinal reinforcement: (a) maximum, (b) minimum and (c) special

the amount of steel reinforcement and different boundary conditions of the beam. As can be seen in the figure, by increasing the amount of reinforcement and also by adding shackles near the support, the maximum displacement value has decreased for both boundary condition cases. For example, by using special bracing and minimum reinforcement, the maximum displacement for fixed and simple supports has been reduced by 6.78 and 7.88%, respectively.

In Fig. 11, the maximum force on a concrete beam has been compared according to the amount of steel reinforcement and different boundary conditions of the beam. As can be seen in the figure, by increasing the amount of reinforcement and adding bracing near the supports, the maximum force on the beam (maximum load-bearing force of the beam) has increased for both boundary conditions. For example, by adding bracing near the supports, the maximum force on the beam has increased by 13.11 and 11.80% for fixed and simple supports, respectively.

Fig. 12 shows the effect of the amount of reinforcement on cracking on the samples. According to this figure, the maximum cracking in the sample with maximum and minimum longitudinal reinforcement is 0.7 and 0.89, respectively, and in the sample with special reinforcement is 0.84. As can be seen in Figure 12, increasing the percentage of reinforcement and also adding hooks to the stirrups will reduce the maximum cracking of the beam, but the effect of increasing the percentage of reinforcement in reducing the cracking of the beam is more noticeable.

CONCLUSIONS

In this study, the ABAQUS finite element software was used to evaluate the nonlinear dynamic behavior of reinforced concrete beams under impact load. After ensuring the concrete beam modelling method, first, in order to achieve a suitable meshing for the beam, the element dimensions were changed so that the response converged to a certain value. Then, the effect of the beam support conditions, beam length, concrete characteristic strength value, and the amount of longitudinal and transverse steel reinforcement was investigated. For this purpose, the results of the comparison and evaluation of the dynamic behavior of the beams, which are presented in the form of a time history of the change in the mid-span displacement of the beams, and a time history of the force applied to the beams, are summarized below.

1. Regarding the support conditions of the beam, it was observed that the simple support condition causes a greater displacement than the fixed support condition. For example, for beam lengths of 3, 4 and 5 meters, by changing the boundary conditions from simple to fixed, the displacement of the centre of the span of the concrete beam has decreased by 46.91%, 45.55% and 39.46%, respectively.
2. In examining the forces applied to the concrete beam with different support conditions, it was observed that the fixed double-ended beam withstands a greater force than the simple double-ended beam. For example, for beam lengths of 3, 4 and 5 meters, by changing the boundary conditions from simple to fixed, the applied force has increased by 85.65%, 92.56% and 81.44%, respectively.
3. The length of the beam has played an important role in the response of the concrete beam under impact load. So that with a 66% increase in the length of the beam (from 3 to 5 meters), the maximum displacement of the middle of the span for fixed and simple supports has increased by about 83% and 60%, respectively.
4. In the evaluation of the forces applied to the beam by changing the length of the beam, it was observed that the applied force has decreased with increasing length. For example, for a 1.25-fold increase in the length of the beam (from 4 to 5 meters), the maximum applied force has experienced a decrease of 15.43% and 10.25% for the two fixed and simple boundary conditions, respectively.
5. In examining the effect of the characteristic strength of the concrete by keeping other parameters constant, it was seen that the displacement of the middle of the span has decreased linearly with increasing concrete strength. For example, with a 40% increase in concrete strength (from 25 to 35 MPa), the maximum displacement at the mid-span of the beam has decreased by 10.17% and 10.90% for fixed and simple supports, respectively.
6. Increasing the characteristic strength of concrete has led to a linear increase in the load-bearing capacity of the beam for both support conditions. For example, with a 40% increase in concrete strength (from 25 to 35 MPa), the maximum force applied to the beam has

increased by 89.9% and 22.14% for fixed and simple supports, respectively.

7. In examining the amount of steel reinforcement, the minimum and maximum amount of code reinforcement and special bracing near the support have been used. The results showed that with an increase in the amount of longitudinal reinforcement, the displacement at the mid-span has decreased. For example, by changing the amount of reinforcement from minimum to maximum reinforcement, for two fixed and simple boundary conditions, respectively, the maximum displacement of the centre of the T-span is the concrete resistance has decreased by 24.47% and 23.54%. Also, the use of special bracing near the support has reduced the displacement. For example, by using special bracing and minimum reinforcement amount, the maximum displacement amount for fixed and simple support has decreased by 6.78% and 7.88%, respectively.
8. Increasing the longitudinal reinforcement has increased the load-bearing capacity of the beam. For example, by increasing the amount of reinforcement from minimum to maximum reinforcement, the maximum force has increased by 33.01% and 32.66%, respectively, for fixed and simple supports. Also, the use of special bracing has led to a 13% increase in the load-bearing capacity of the beam.
9. In specimens with fixed support, the cracking rate decreases with increasing the beam length from three to five meters, with increasing the concrete strength from 25 to 35 MPa, and also with increasing the percentage of reinforcement from minimum to maximum. Of course, the effect of increasing the percentage of reinforcement is more noticeable, so that the lowest cracking rate in all specimens with fixed support is related to the beam with maximum longitudinal reinforcement and is 0.71.

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