Development of damage in concrete plates under impact loads

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Abstract

The results of numerical analyses carried out on concrete elements produced from waste aggregate (ceramic rubble) and steel fibres have been presented in this study. The elements taken into consideration were circular plates of 1 m diameter, thickness 0.1 m, with various percentage of steel fibres. Main study has been performed for plates without steel fibres and for three variants of reinforcement. Three types of fibres have been considered. Impact loads have been realized by the free fall of 40 kg mass from the height of 1 m. After each impact the permanent deflections of the plate were measured in several selected points, as well as localization of cracks, their configuration and dimensions. Nonlinear Finite Element Method computer code ABAQUS was applied, and the continuous plastic damage model for concrete was used, where the damage is defined by two scalar parameters.

Keywords: fibre reinforced concrete, impact loads, finite element method.

1. Introduction

The main goal of this study was to investigate the development of damage in circular plates made of fibre reinforced concrete produced from the waste material (sorted brick rubble) loaded by the series of impacts. In order to study the influence of energy quantity delivered to the system during each impact, various weight of impactors has been assumed in numerical analyses performed using ABAQUS/Explicit computer code. Adequate verification of assumed parameters and data for numerical computation was based on experimental results described in details in [2].

2. Numerical analysis

In this study the numerical analysis has a fundamental importance, due to the limited number of experimental tests possible to realize. The number of combinations between fibre percentage, fractions of rubble aggregate, water and sand volume in the mixture is very large – it is not possible to check experimentally the whole matrix of combinations.

Because of this, the discrete models of tested plates were elaborated in the ABAQUS/Explicit environment. The eight node brick finite elements with one point of Gauss integration have been applied in entire discrete model. In order to simplify the numerical discrete model, the uniform distribution of fibres (modelled as steel elements embedded [2] in the concrete volume) in the plate volume has been assumed. To describe adequately the entire phenomenon of impact of the weight dropped from a certain height on the surface of the plate the contact algorithm available in ABAQUS/Explicit has been applied. General view of numerical model is presented in Fig. 1 (left), and the assumed mesh for reinforcement is also shown (right).

The crucial factor in this analysis is the assumed material model for the concrete (Łodygowski and Rusinek [4]). On the basis of former studies [1,3] the CDP (Concrete Damaged Plasticity) model has been assumed also in this case with necessary calibration of parameters, allowing to capture the specific features of this kind of concrete. Details and description of assumed constitutive material model are given in [2],

The example of results for plate is shown in Fig. 2, where the final configuration of a damaged plate is presented (bottom view). Analysis of damage obtained for various configuration of plates (material and impact load intensity) shows the reduction of large crack zones for higher amount of fibres, the damage is distributed in large zones between supports. Also in this case the permanent deflections measured in the centre of the plate are smaller than for the plates without fibres or with low amount of fibres.

In the case of multiple loads exerted on the plate (i.e. many impacts with relatively low level of kinetic energy), also numerical analysis were performed in many steps with repeated impacts and accumulated damage.

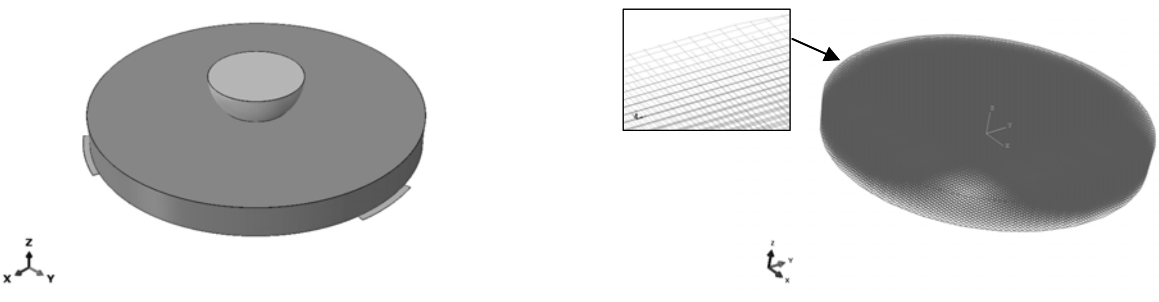

Fig. 1. General view of the model (left), reinforcement with zoom (right)

The damage patterns obtained for the all plates subjected to impact loading are very similar, the main difference occurs in process of cracks initialization and development. For lower values of reinforcement percentage, cracks are formed almost immediately, and subsequent impacts have influence only on growing width of cracks. In highly reinforced plates the final configuration of cracks develops during many impacts, cracks are closing, re-opening and changing their shape. Also the volume of totally damaged material in this case is much smaller than for low reinforced plates.

Numbers of impacts necessary to damage the plates, obtained in numerical analyses, correspond to the values achieved during the experimental tests. The only problem is to find out the criterion which allows to decide whether the plate is damaged or not.

To study the influence of impactor's mass on the number of impacts necessary to damage a plate, the adequate numerical analyses have been performed and studied. Four impactors were assumed: 40-60-80-100 kg, and a free fall from 1m height was considered. Six types of plates were studied: two types of fibres (E1 and D1) and three reinforcement percentages: 0.5-1.0-1.5% (related to the volume of the plate). Table 1 shows the values of total energy necessary to damage a plate for various plates and impactors. As one can see, the values of energy are rather similar, i.e. they do not depend much on the impactor's mass.

This tendency is preserved only for impactors within certain limits: assuming non-realistic values of impactor's energy also the damage is non-realistic due to secondary effects: impactor's dimensions, shape, etc.

Table 1: Total energies necessary to damage a plate

	Energy delivered by a single impact [J]			
Plate	400	600	800	1000
E1-05	2800	2400	2400	2000
E1-10	5600	5400	4800	4000
E1-15	8400	7200	6800	6400
D1-05	2400	2400	2400	2000
D1-10	9200	9000	8800	9000
D1-15	28000	27000	26400	26000

Analysing the development of damage in plates for various impactors (40-60-80-100 kg) during the entire process (i.e. until the total failure of the plate) it is easy to notice that final patterns (mechanisms) of damage are created earlier for higher mass of impactor. Due to this, the total energies necessary to damage a plate are diminishing for higher impactor's mass.

3. Conclusions

Three main goals were the object of this study:

- experimental and numerical investigation on dynamic response of plates subjected to repetitive impact loading up to total damage of material;
- description of damage mechanisms occurred in various types of plates differing in fibre types and reinforcement percentage, expressed in terms of total energy of impacts.
- study on relationship between the impactor's mass and the total energy necessary to damage the plate, for various types of fibres and reinforcement percentage.

Experiments allowed to describe the development of damage patterns in a function of number of impacts. Additionally the secondary effects revealed during the entire phenomena have been registered and documented.

This study shows the necessity of experimental verification for numerical analysis performed with the use of advanced nonlinear finite element algorithms. Among many important factors for such analysis the assumption of adequate material model for concrete describing the entire dynamic response: from initial pure elastic behaviour until the total material damage is the most important factor for the adequacy of numerical results. Another important factor for numerical analysis is the assumption concerning the spatial distribution of fibres in a volume of the plate. Simplified approach presented in this paper is adequate for this specific case, but in general the random (or pseudo-random) distribution should be applied.

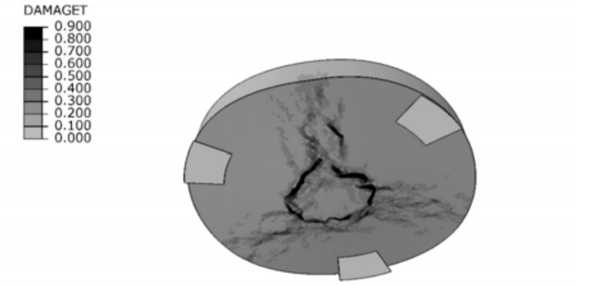

Figure 2. Final distribution of damage [2]

For lower values of fibre percentage in the material, the development of large cracks (i.e. large volume of damaged material) has been observed. Plates with higher fibre percentage are much more resistant to impacts, due to larger amount of energy dissipated by plastic effects in steel fibres. This allows to avoid development of large cracks in concrete matrix and consequently separation of the plate into several non-connected parts.

The expected results of this investigation are not only limited to prepared recipes for the concrete, but also concern the elaborated and calibrated material models, applicable in nonlinear finite element computer codes.

Special attention has been paid to study the relationship between the energy delivered to the system by impacts, and the development of damage in various types of plates (type of fibre and the reinforcement percentage). Although the values of damage energy changes for various types of impactors, certain regularity is observed. For higher mass of impactor, total failure of the plate occurs for lower values of total impact energy.

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