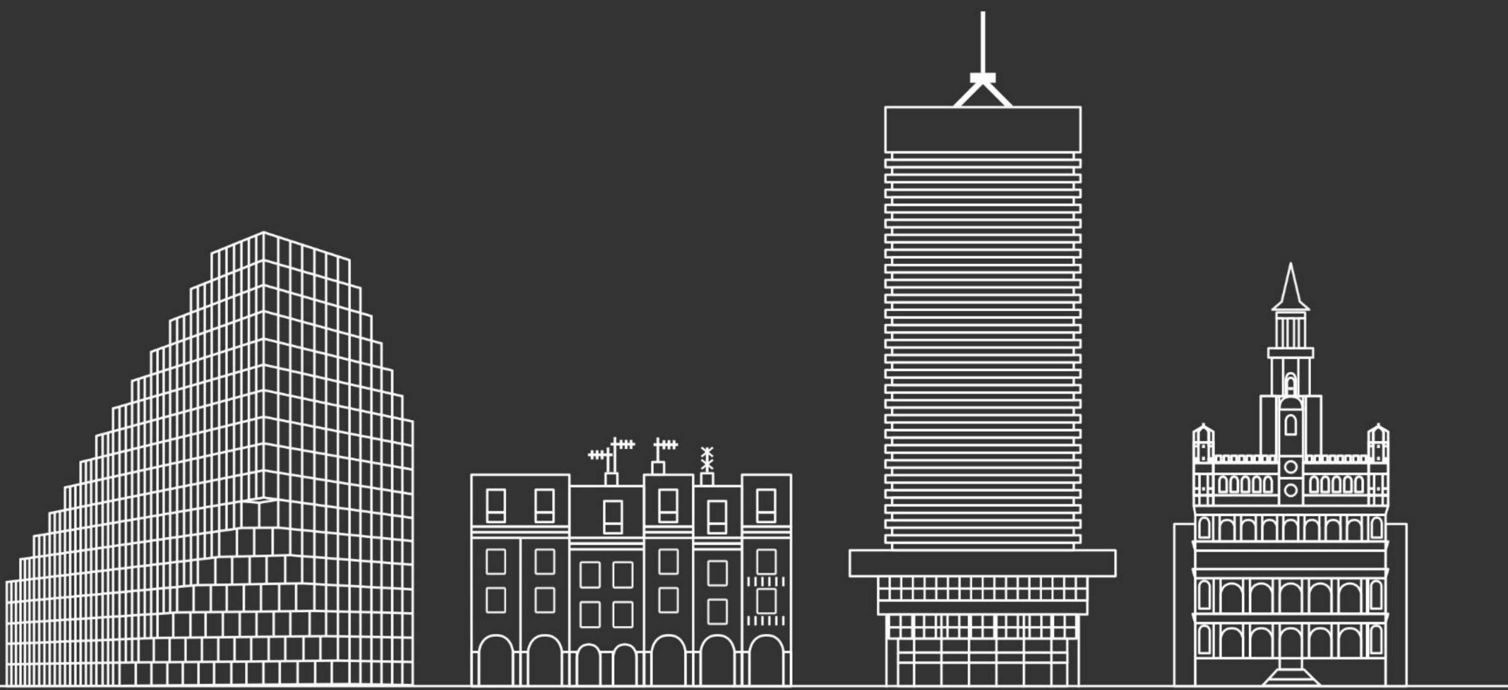
ICPS5

Design, Experiment and Analysis of Protective Structures

Proceedings of the 5th International Conference on Protective Structures | ICPS5
19-23 August 2018, Poznan, Poland



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Ministry of Science and Higher Education
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IAPS International Association of Protective Structures

Poznan, 2018

Design, Experiment and Analysis of Protective Structures
Proceedings of the 5th International Conference on Protective Structures (ICPS5)
Poznan, Poland, 19-23 August 2018.
Edited by Piotr W. Sielicki, T. Gajewski & M. Szymczyk.
Published by Agencja Reklamowa COMPRINT
ul. Nikodema Pajzderskiego 22
60-469 Poznań

ISBN: 978-83-89333-71-1 (e-version)

Preface

On behalf of the Organising Committee and International Association of Protective Structures (IAPS), welcome to the 5th International Conference on Protective Structures (ICPS5). This meeting is hosted by the Poznan University of Technology in the centre of Greater Poland area of Poland, city of Poznan, from 19th to 23rd August 2018.

The IAPS has been formed for the purpose of promoting research and development associated with Protective Structures in Civil Engineering. Primary objectives are: bringing experts together working in the field of PS, being the umbrella for different actions, establishing an International Conference on Protective Structures (ICPS) to be held every two years, promotion of other professional activities, and support the publications of the International Journal of Protective Structures (IJPS). ICPS will address all relevant aspects of the subject of protective structures of the built environment, including structural mechanics, soil mechanics, traffic engineering, waterways as well as safety studies and risk analysis in both research and practice.

The purpose of this book is to bring together into one publication papers of issues that researchers, engineers and designers must clarify if they are to represent credible design.
Many of the authors in this book are working together to develop the standards and requirements for protective structures design. This handbook is organized into one consistent part, collecting all papers in the broad range of aspects of the incidental scenarios.

Piotr W. Sielicki
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Analysis of Impact Resistance and Protective Characteristics of Fibre Reinforced Concrete Plates

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1 Introduction

One of the goals of this study was to investigate the possibility to reuse the waste material (sorted brick rubble) as the aggregate in production of concrete elements. Application of steel fibers (unconventional reinforcement) increased considerably the resistance and durability of such elements for impact loads. Various factors and phenomena have been studied during experimental tests performed on series of circular plates, both qualitative and quantitative, as for example the mode of failure for various types of plates, the number and dimensions of cracks propagated through the material, development of damages, etc.

Experimental tests carried out during the research were the basis to create the discrete numerical model of the Finite Element Method in ABAQUS computer code environment. This allowed to calibrate the parameters of applied numerical material model for concrete, describe the nature and characteristics of impact loads, define the applied algorithms of contact between the impacting objects and concrete element under investigation, as well as other parameters of numerical analysis in order to obtain the adequate and reliable numerical discrete model.

Such verified numerical model may be applied in analyses of complex structures realized with investigated material without the necessity of carrying out the expensive and time consuming experimental tests. This allows also to study the mechanism of damage, both for entire element and for its components (concrete matrix and steel fibers).

2 Experimental tests

Special experimental stand has been realized in order to perform the impact tests. All tests have been carried out on circular plates of 1 m diameter, thickness 0.1 m, with various percentage of steel fibers. Three types of fibers have been applied: DRAMIX (one type) and EKOMET (two types), all well known and popular as an unconventional reinforcement. For each type of fiber, three values of percentage have been considered: 0.5, 1.0, 1.5% of total volume of the plate. Description of plates is given in Table 1.

The entire stand is shown in Fig. 1. Its detailed description is given in [5]

Impact loads were applied as a free fall of 40 kg mass from 1 m height. The falling mass of a spherical shape was precisely centred in regard to a circular plate.

In order to determine the material characteristics of concrete matrix and concrete with fibers, preliminary static tests have been carried out on series of samples. The results and detailed description of these tests were given by Domski and Katzer [1, 2]. For all tests the same concrete matrix has been used, with application of waste aggregate (sorted brick rubble). These characteristics were applied in order to determine the parameters of numerical material model for reinforced concrete (matrix with various percentage of fibers). Basic material characteristics achieved during static tests on material samples are described in details in [5].

Table 1: Description of entire set of plates

No.	Set of plates	Fibers	Dimension of fibers [mm]	Percentage of reinforcement (volumetric)
1	PEA05	EKOMET	50 x 0,8	0,50 %
2	PEA10	EKOMET	50 x 0,8	1,00 %
3	PEA15	EKOMET	50 x 0,8	1,50 %
4	PEB05	EKOMET	50 x 1,0	0,50 %
5	PEB10	EKOMET	50 x 1,0	1,00 %
6	PEB15	EKOMET	50 x 1,0	1,50 %
7	PDA05	DRAMIX	60 x 0,8	0,50 %
8	PDA10	DRAMIX	60 x 0,8	1,00 %
9	PDA15	DRAMIX	60 x 0,8	1,50 %
10	PM	-	-	without reinforcement

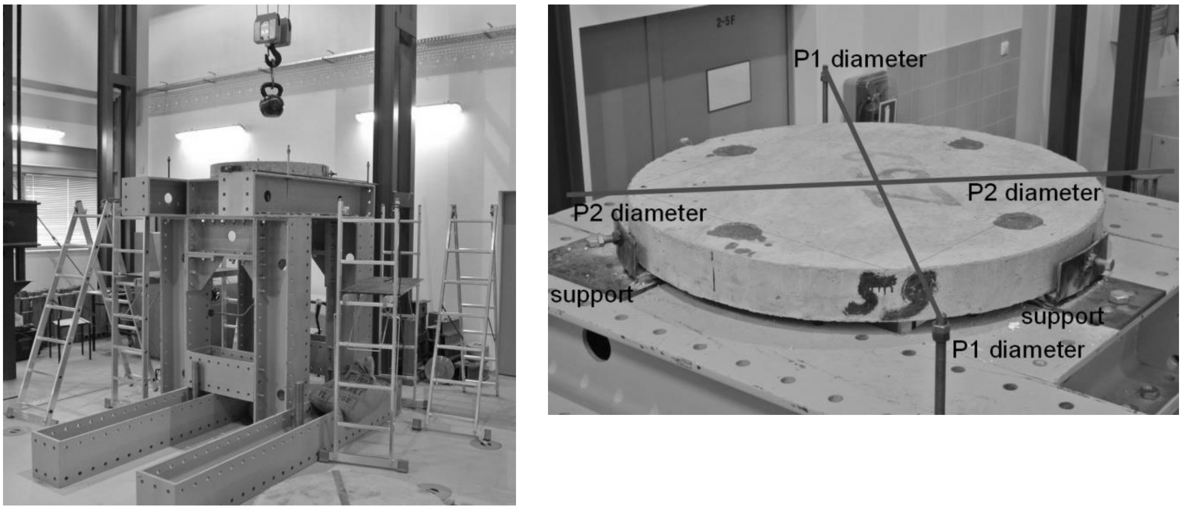

Figure 1: Experimental stand. Left – overall view of the stand. Right – plate before first impact

An example of final configuration of damaged plate is presented in Fig. 2. Due to random distribution of fibers, distribution of main cracks vary for each tested plate, but the general behaviour (i.e. formation of main cracks between the supports and development of minor secondary cracks of various forms and extend) is sustained for all plates [3].

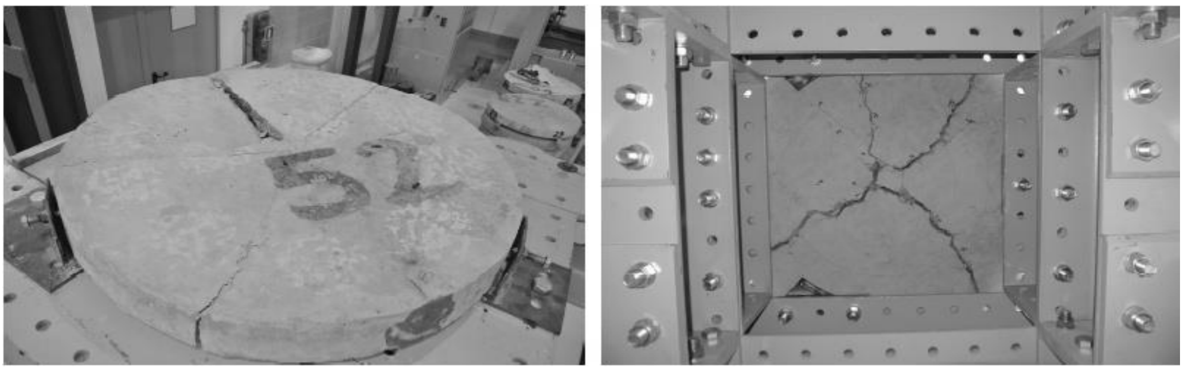

Figure 2: Upper and bottom view of a damaged plate

The following procedure was applied for each test: after an impact the permanent displacements of a plate have been measured in two perpendicular directions, the distribution of cracks and their opening have been also documented. In this way it was possible to observe the development of damages in a function of number of impacts, i.e. energy delivered to the plate and dissipated by the damage in the material. The average numbers of impacts necessary to completely destroy the plate are presented in Tab. 2, for each type of plate.

Table 2: Average number of impacts necessary to damage the plates

No.	Set of plates	Number of impacts
1	PEA05	7
2	PEA10	14
3	PEA15	21
4	PEB05	8
5	PEB10	11
6	PEB15	19
7	PDA05	6
8	PDA10	23
9	PDA15	60
10	PM	1

Very important observation concerns the initiation and development of cracks as a function of number of impacts. For plates without or with low percentage of reinforcement (0.5 %) main cracks are formed just after the initial impacts, and their pattern is generally maintained until the final total damage of the plate. In plates with higher percentage of reinforcement main cracks form themselves after several initial impacts, and develop almost to the final damage. This behaviour has been observed for all tested plates.

The experimental tests and obtained results have been described with all details in [5].

3 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 in the plate volume has been assumed. Although in reality the distribution is random, this assumption gave acceptable results comparing with experimental data. 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. 3.

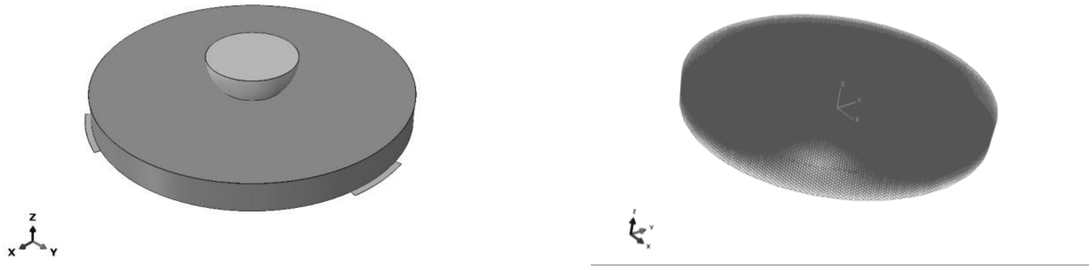

Figure 3: General view of the model (left), reinforcement (right)

The crucial factor in this analysis is the assumed material model for the concrete (Łodygowski and Rusinek [4]). On the basis of former studies [5-9] 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 (increased resistance in pure tension, etc.). The assumed material parameters for CDP in Abaqus/Explicit finite element program are described in [5].

The example of results for plate is shown in Fig. 4, where the final configuration of a damaged plate is presented (bottom view),

Analysis of damages obtained for various configuration of plates (material and impact load intensity) shows the reduction of large crack zones for higher amount of fibers, the damages are 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 fibers or with low amount of fibers.

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 damages.

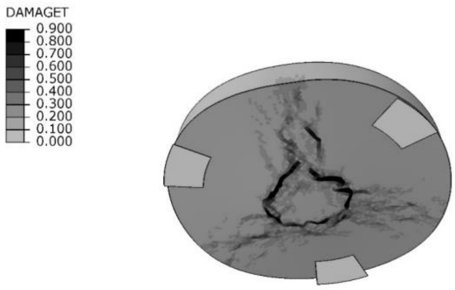

Figure 4: Final distribution of damages (plate PEB10) [5]

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 damage material in this case is much smaller than for low reinforced plates.

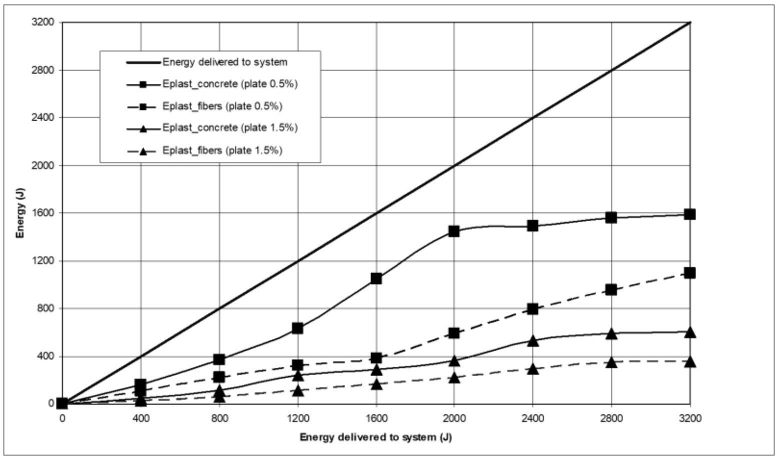

Figure 5: Energy delivered to the system, energies dissipated in concrete matrix and fibers (plates PDA05, and PDA15)

Numbers of impacts necessary to damage the plates, obtained in numerical analyses, correspond 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. In experimental tests this was quite obvious and visible – the plate has lost its integrity and get separated into few parts. In numerical analyses, this total separation was difficult to evaluate and needed the observation of whole energies of the system (i.e. increase of kinetic energy for a longer period of time).

4 Conclusions

Two 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 fiber types 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 fibers 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.

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 fibers. 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.

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