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Experimental analysis and modeling of two-way reinforced concrete slabs over different kinds of yielding supports under short-term dynamic loading

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A B S T R A C T

This paper presents the experimental and theoretical results of an investigation carried on reinforced concrete plates placed on yielding supports along their perimeter under short-term dynamic loading. The yielding supports are made of elements with annular cross-section. Their functionality allows operations in elastic and elasto-plastic stages with a further turning to hardening stage. This particular support scheme has been adopted in order to simulate the different boundary conditions that r.c. slabs subjected to impacts may encounter in practical applications of civil engineering (e.g. roofs, vertical panels, retaining walls, guardrails, etc.). The experimental results showed that influence of support deformability on the structural response under impact depends on their rigidity and on the deformation stage. The results of numerical simulations based on a simple mechanical model qualitatively agree with the experimental results. Therefore the model can be adopted for simulation and design of reinforced concrete panels under impact or high-strain loading situations.

1. Introduction

Increasing number of emergent explosion loads acting on buildings and structures leads to the necessity to provide sustainability of structures to those kinds of loads [27]. Increase of load-bearing capacity of structures under dynamic loadings is mainly performed by means of increasing the geometrical dimensions of sections and their reinforcement [17]. The other way to provide durability of structures under intensive dynamic loads is application of active protective means (see also Chiaia et al. [16]). This paper considers this last particular case, i.e. application of yielding supports. One of the engineering approaches to attenuate impact forces is the use of absorbing systems and this study has been undertaken in order to improve the knowledge for establishing a rational performance-based impact resistant design procedure for the RC type rock-sheds. The impact resistant behavior of reinforced concrete (RC) infrastructures has so far been investigated employing experimental approaches [21,22,23,24,25,26]. However, to establish a rational impact resistant design procedure for the structural members, numerical analysis methods should be employed to complement the experimental results [13,14].

The impact phenomenon can be modeled in two ways depending on the physical conditions that are to be considered, namely (i) impact oscillators, which assume an instantaneous contact with a coefficient of restitution model (hard-impact model), and (ii) piecewise systems, which model the contact as a linear or Hertzian spring, leading to separate equations of motion for in- and for out-of-contact cases (soft-impact model). In Andreaus et al. [8] (see also Andreaus et al. [9,11,10]) it is shown that in impacts between deformable bodies the prescription of the velocity after the impact has an intrinsic indeterminacy (hyperstaticity of hard-impact dynamics), which can be overcome by the use of soft-impact dynamics. A more comprehensive literature on this subject is included in the works of Andreaus and his co-workers [12,3,4,5,2,6,7,1] and references therein.

In short-term dynamic loading, damage due to contact interactions [19] must be considered. Damage and fractures in heterogeneous materials have been analyzed in the literature [15] even as an instability event for the strain localization [18]. In this paper the effect of damage [20,29] is analyzed from the point of view of its plastic effect and recent results of a well-posed plastic model have been used [28].

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To find out the performance of reinforced concrete slab deformation under short-term dynamic loading, experimental investigations were carried out on hinge-supported on four sides models. The experimental part has been presented in Section 2. Section 3 is devoted to the model presentation and Section 4 to the exposure and to the analysis of the numerical simulations.

2. Experimental

2.1. Experimental setup

The pilot study program included tests of eight RCS prototypes (see Table 1). At the first step, supports used for parallel sides of RCS were of similar rigidity. Further, the rigidity of yielding supports distributed around perimeter was evaluated in conformity with change of the support pressure. In other words, the supports were selected on the basis of support reactions of slab and of their rigidity. Slabs rigidity was varied by wall thickness and its length by considering physical and mechanical parameters of the material insertion. Then supports ware tested experimentally and their geometrical parameters were updated. RCS prototypes had dimensions of 1100 × 1600 mm and thickness of 40 mm. Such size was chosen because of the operating conditions of slabs in existing structures. Besides, the ratio of slabs sides is 2/3 and at this ratio the structure works like two-way slab. The thickness of the slab has been chosen so that the calculated value of working reinforcement diameter to be larger than the structural value of reinforcement, that is the minimum accepted reinforcement according to Russian national construction codes. Prototype S-1 is a rigid point support (S); prototype S.el.pl.-2 is yielding support (S) behaving in an elasto-plastic fashion.

Table 1
RCS pilot study program.

Rigidity	Support conditions			
	Rigid	Yielding		
	Side length constant	Side length constant	Changes according to the support pressure distribution diagram	
Prototype code	S-i[a]	S.el.-i[a]	S.el.pl.-i[a]	S.in.-i[a]
Number of prototypes	2	2	2	2
	Phases of yielding support behavior			
	Rigid point support	Elastic	Elastoplastic	Elastoplastic with hardening

[a] i is a serial number of slab.

Tied mesh reinforcement Ø4, type Bp500 with mesh size of 100 mm was used for these prototypes. Mesh reinforcement was designed by considering the thickness of the slab. The following physical parameters of concrete and reinforcement have been considered on the basis of the Russian National Construction Codes (СП 52-101-2003): (1) The reinforcement percentage for slabs should be at least 0.05% and (2) The relative height of compressive zone of concrete ($\xi = x/h_0$) must be less or equal to boundary value $\xi R = 0.502$, so that cracks go along tensile zone and where x is the height of compressive zone of concrete and h_0 is the operational height of slab.

Experimental research has been carried out on the especially designed test bench (Fig. 1). In the following the authors make explicit the meaning of the numbers in Fig. 1. Prototype "9" was placed on a two-way slab resting over rigid or yielding supports "8" situated on frame support "5" which, in its turn, was placed on supporting beams "4". Dynamic loading was enabled by energy of hammer "3" that slides along column "2" rigidly fixed in reinforced floor "1". A dropping mechanism was used to hold the hammer at a fixed height by lifting loop "14". An even load distribution was provided by load-distribution devices "7", "12", water bag "11", and limiting frame "6" which prevented the water bag from horizontal deformation. To eliminate a friction force, canvas "10" was doubled between the water bag and the test structure.

The evaluation of the stress and strain state of structures was carried out using the instrumentation indications. Thus, for measurements of reinforcement and concrete strains, resistance strain gauges were used. A dynamometer, served as a force measure device; displacement of isolated points of the structure was registered by four sensors. Then, all these values were registered using 64-channel measuring and computing complex MIC-400D. Six accelerometers were installed to record accelerations using 16-channel digital recorder MIC-300M. All strain-measuring devices had been preliminarily calibrated.

A configuration diagram for the location of measuring sensors and facilities is given in Fig. 2.

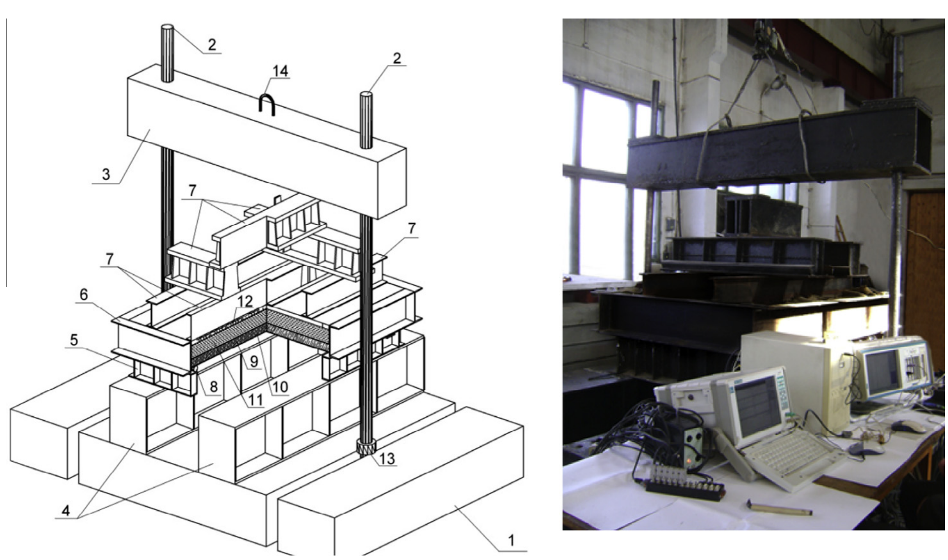

Fig. 1. General view of the test bench. The meaning of the numbers in the figure is explicated in the text. A picture of actual test setup is also provided.