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THE ANALYSIS OF TWO-WAY REINFORCED CONCRETE SLABS ON RIGID AND YIELDING SUPPORTS AT SHORT-TERM DYNAMIC LOADING

The paper presents the results of experimental research conducted into two-way reinforced concrete slabs subject to short-time dynamic loading. Properties of structural dynamic resistance have been shown in different phases of yielding support behavior.

Key words: dynamic loading; concrete structure; two-way slabs; yielding support.

In practice of civil and industrial engineering occasionally applied loads occur, mainly, due to impact and explosive loadings (dropping, blast, etc.). The use of yielding supports is one of the methods of raising explosion resistance of reinforced concrete structures. The analysis of reinforced concrete slabs (RCS) resting over yielding supports was conducted at the Department of Reinforced Concrete Structures, TSUAB, which has shown a high efficiency of their application [1, 2, 3, 5].

The experimental research focuses on the analysis of strength and deformability of RCS subject to the dynamic loading under various conditions of support structures.

As previous investigations have shown, the yielding support behaves in three fashions [4]: elastic, elastoplastic, and induration (Fig. 1).

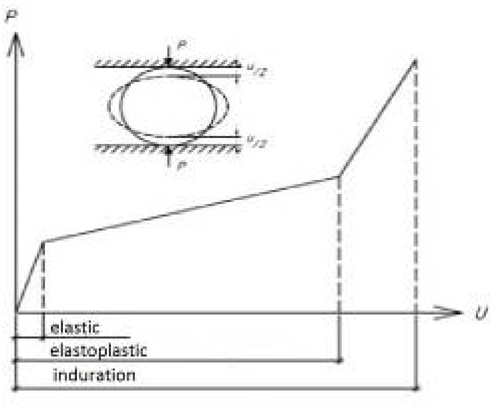

Fig. 1. Three phases of yielding support behavior

At that, the most positive effect was achieved at the elastoplastic phase. Taking this fact into account, 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 the similar rigidity. Further, the rigidity of yielding supports distributed around perimeter was computed in conformity with change of the support pressure.

Table 1

RCS pilot study program

Support conditions	Rigid	Yielding		
Rigidity	Side length constant	Side length constant	Changes according to the support pressure distribution diagram	
Prototype code	П-*i**	ПУ-*i**	ПУП-*i**	ПО-*i**
Количество	2	2	2	2
Number of prototypes	Rigid point support	Elastic	Elastoplastic	Elastoplastic with induration

**i* is a serial number of slab

RCS prototypes had dimensions of 1100×1600 mm and thickness of 40 mm. Prototype П-1 is a rigid point support (П); prototype ПУП-2 is yielding support (П) behaving in an elastoplastic fashion. Tied mesh reinforcement Ø4, type Bp500 with mesh size of 100 mm was used for these prototypes.

Experimental research has been carried out on the especially designed test bench (Fig. 2).

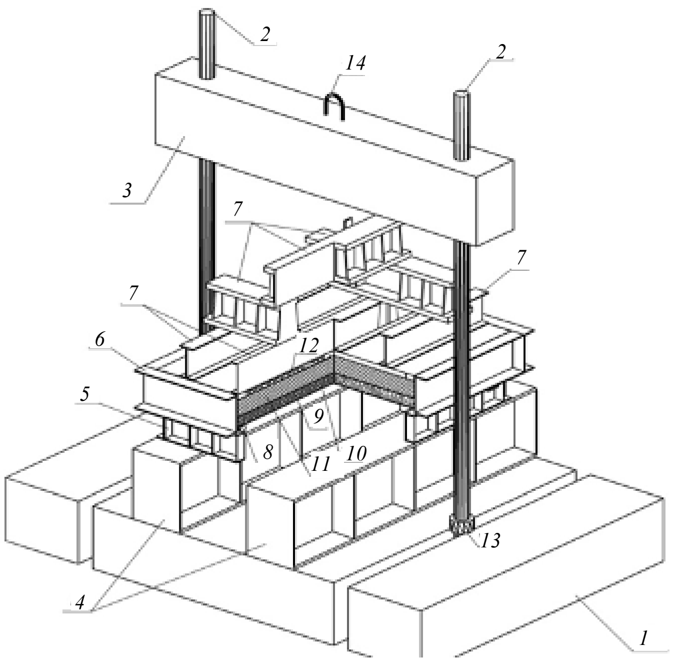

Fig. 2. General view of the test bench

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 supported by traverse 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 devises *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 instrumentation is given in Fig. 3.

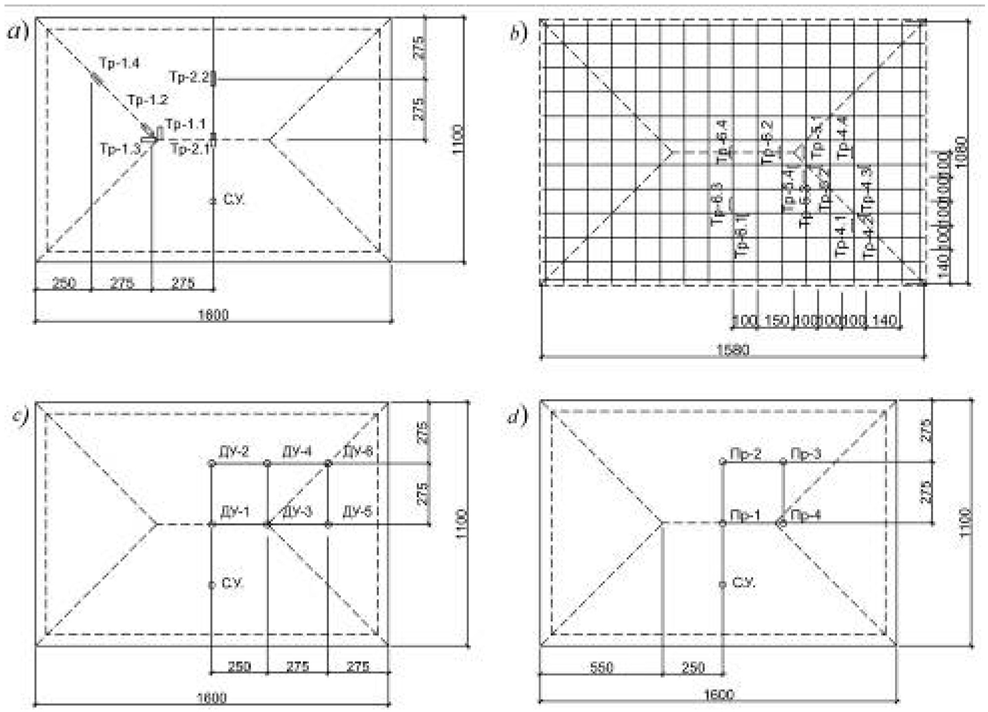

Fig. 3. Configuration diagram for location of: dynamometers on concrete compression area (*a*) and reinforcement (*b*); acceleration sensors (*c*), and deflectometers (*d*)

Figures 4–7 contain plots of the RCS response behavior, displacement of isolated points of the structure, deformations of the concrete compression area and reinforcement subject to the external action. The analysis of results obtained has shown that independently of the character of deformation of support structures, the time lag of the parameters relating to the system response behavior was observed at the initial stage of deformation. In achieving the peak values, the time lag of stress and strain state parameters was observed only in slabs resting over rigid and elastic yielding supports. Additionally, the time lag between displacement and real load at the beginning of loading was 8–10 ms for rigid support slabs (Figures 4, *a* and 6, *a*); and for slabs resting over yielding supports reacted in the elastic phase – 1 ms (Fig. 4, *b*); in the elastoplastic phase – 10–12 ms (Fig. 6, *b*); and in induration phase – 10–12 ms (Fig. 6, *c*). The time lag between displacement peak values and that of the load was equal to 8–15 ms, 13 ms, 1–3 ms and 1 ms, correspondingly (Figures 4 and 6). For deformations of the concrete compression area and the reinforcement, the starting time lag was changed within the limits of 6–15 ms and 9–15, correspondingly, and in reaching extreme values it was 1–15 ms and –2–4 ms, correspondingly.

In the meantime, it should be noted, that application of yielding supports leads to reduction of the system response and increases the load action time. For RCS on elastic yielding supports as compared to that on rigid ones, a change of the load action time is insignificant and amounts to ~ 5 ms; displacement of isolated points of the structure is also comparable (Fig. 4). Deformations of the concrete compression area and the reinforcement upon elastic yielding supports are also insignificant as compared to that of the rigid point supports. Reduction of the system response comes to 18% herein (Fig. 4).

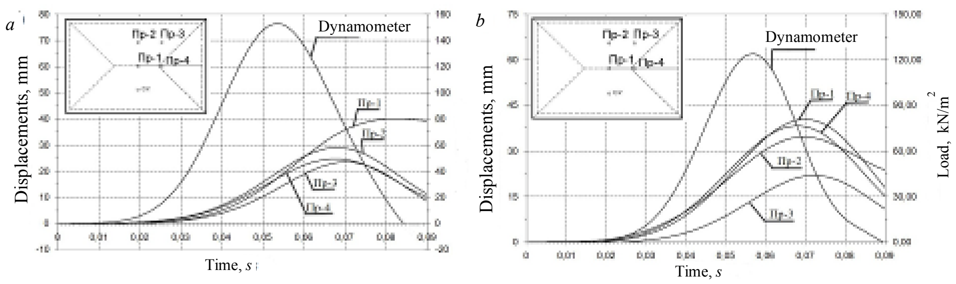

Fig. 4. Diagrams of response behavior and displacements for slabs resting over: rigid point supports (*a*) and elastic-phase yielding supports (*b*)

For RCS resting over elastoplastic-phase supports and induration-phase supports the load action time was increased 10,4 and 28 %, correspondingly, while the system response behavior was reduced 22,8 and 48 %, correspondingly (Figures 5 and 6). Also, deformations were reduced 10 % in slabs resting over elastoplastic-phase supports and 20 % in slabs resting over induration-phase supports (Fig. 6). RCS displacements having yielding supports are similar to those having rigid point supports. However, for yielding supports slabs, the displacement values are given allowing for yielding support deformations (Fig. 5). While comparing displacements of yielding support RCS except for support deformations (25–36,5 mm) with displacements of rigid support RCS, a considerable reduction of displacement is being observed: 33 % for elastoplasic-phase yielding support RCS and 50 % for induration-phase support RCS. The analysis of reinforcement deformation curves has shown that a number of resistance strain gauges located in more strained cross-section areas, were failed (Fig. 7) that, in its turn, indicates a dramatic growth of deformations in reinforcement. Reinforcement deformations of elastoplasic-phase support RCS were 35 % less than that of the rigid point support RCS (Fig. 7, *a, b*). RCS deformations having induration-phase yielding supports are 55–64 % lower than those of elastoplasic-phase supports (Fig. 7, *b, c*).

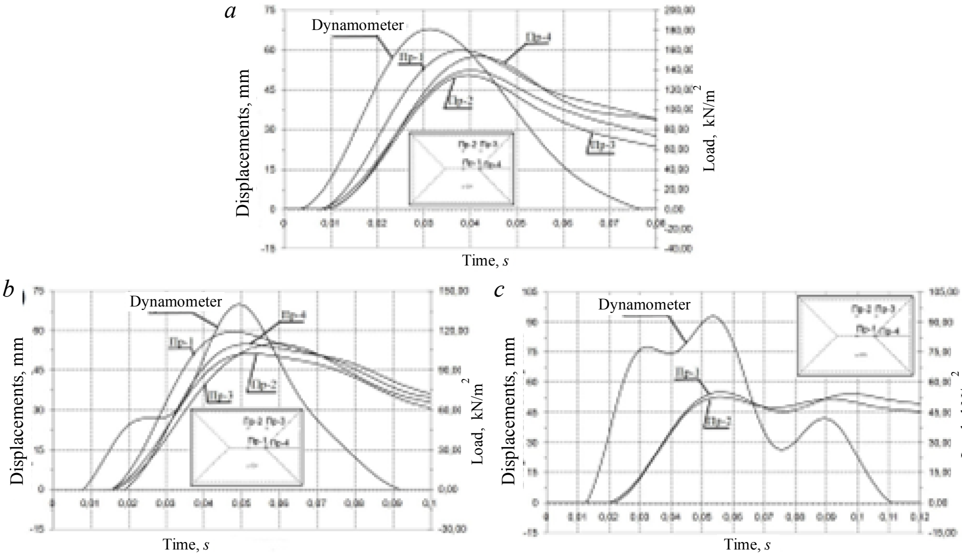

Fig. 5. Diagrams of response behavior and displacements for slabs resting over: rigid point supports (*a*), elastic-phase yielding supports (*b*) and induration-phase yielding supports (*c*)

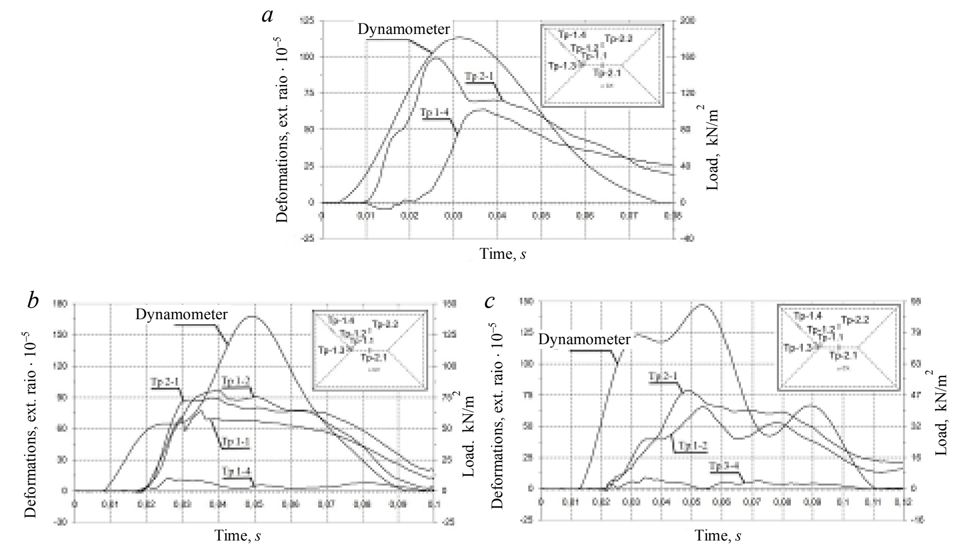

Fig. 6. Diagrams of response behavior deformations of the concrete compression area for slabs resting over: rigid point supports (*a*), elastic-phase yielding supports (*b*) and induration-phase yielding supports (*c*)

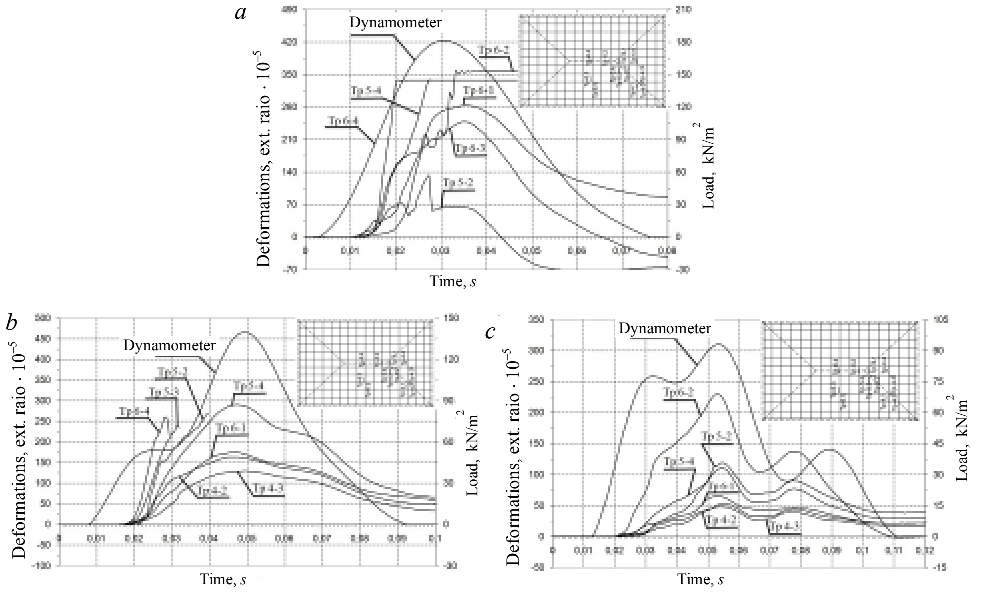

Fig. 7. Diagrams of response behavior deformations of the reinforcement for slabs resting over: rigid point supports (*a*), elastic-phase yielding supports (*b*) and induration-phase yielding supports (*c*)

In toto, it is worth noting that along with reduction of support rigidity, the response behavior, displacement, and stress have been reduced in the whole structure. The maximum effect has been achieved in slabs resting over elastoplastic-phase or induration-phase supports.

It is interesting to compare the response behavior for slabs resting over elastoplastic-phase and induration-phase supports. In the first case (Figures 5, 6 and 7, *b*), at RCS elastic-elastoplastic transition, an insignificant reduction of response behavior was observed following which it restarted to grow up to its maximum while the loading was being reduced down to zero. In the second case (Figures 5, 6 and 7, *c*), at the loading reduction stage, RCS transition into induration phase was observed that lead to a local growth of the system response and was accompanied by the growth of deformations and displacements. This fact can be explained by significant velocities and accelerations acquired by the structure under RCS deformation. Later, upon RCS transition into induration phase, accelerations create a loading additional to the actual one that results in an abrupt system reaction and other parameters of stress and strain state.

Implications: the use of yielding supports in two-way slab system allows raising the structural resistance to highly-intensity dynamic loadings. A positive effect of the support yield is increased with the reduction of support rigidity and is expressed in reduction of the system response behavior, displacements, and stress state of RCS.

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