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Assessment of Crack Resistance of Reinforced Concrete Beam Fragments of Three-layer Floor Slabs

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Abstract. *The aim of the work is to study the crack resistance of reinforced concrete beam fragments of three-layer floor slabs. Experimental studies of samples-fragments of reinforced concrete three-layer slabs with an average layer of expanded polystyrene material without internal ribs. Experimental data on crack resistance, formation and development of cracks in fragments and recommendations for calculation are given. Based on the results of experiments, the methodology of the calculation normative standard for the formation of inclined cracks has been refined and supplemented. The coefficient of safety which is included in the formula of the normative standard, taking into account the working conditions of the concrete of the lower layer of fragments of floor slabs, based on the experiments carried out, is recommended to be taken equal to 0.4-0.5.*

Keywords: *samples, floor slabs, expanded polystyrene, concrete layer, mesh, reinforcement, frame.*

Introduction

Three-layer slabs above the technical underground and attic floors with an average layer of expanded polystyrene were developed until recently with intermediate through ribs made of heavy concrete, which are, as a rule, cold bridges, as well as complicating and weighing down their design.

To increase the efficiency of the construction of residential buildings, instead of these three-layer structures and solid reinforced concrete floor slabs, designs of flat three-layer floor slabs with an average layer of expanded polystyrene without internal ribs were proposed.

In order to unify the technological process, complex plates were designed with overall dimensions that completely repeat the dimensions of the floor-to-floor ceilings. The total thickness of the floor slabs is 150 mm.

The thickness of the middle heat-insulating layer of three-layer plates is determined by a thermal calculation according to regulatory documents. Calculated air temperatures in accordance with the projective practice are accepted: in residential premises t is 20°C, in the basement t is 5°C, in a warm attic t is 12°C. The thickness of the upper layer of concrete is 60 mm, with this in mind, the thickness of the lower layer of concrete is 70 mm [1].

Three-layer plates supported along the contour, due to the heterogeneity of their cross-sections from the span to the edge edges and work in two directions, it was impossible to equally study the nature of cracking and destruction of sections under sharply different stress conditions, especially in the places where the edges adjoin. Therefore, at the first stage of the study, beam samples – fragments were tested in order to identify the features and nature of cracking and destruction of the supporting sections of the plates. For floor slabs supported along the contour, they were like strips cut out of the middle part of a real slab, completely imitating the overall thickness, layer thicknesses, the width of the edge edges, the span length corresponding to the short span of the plates supported along the contour. The reinforcement of the fragments was close to real slabs.

According to the results of these calculations, strength and thermal characteristics are provided with a thickness of the contour edge for floor slabs is 100-160 mm. For floor slabs accepted 140-150 mm [2].

Research methods

The sample fragments were made in the experimental workshop of reinforced concrete in metal formwork. The prepared reinforcing grids were installed in a pre-lubricated form with an oil emulsion. Standard plastic and wire retainers were used to fix the reinforcement grids in the design position. To control the thickness of the lower concrete layer on the sides of the formwork, lines were applied with paint and controlled with a probe. The concrete mixture was placed in the mold up to the mark, followed by compaction by vibration without smoothing, then PSB foam plates were laid on the lower concrete layer and an upper distribution grid was installed, after which the concrete of the upper layer was laid with compaction and smoothing.

After holding the samples in the mold, under conditions of natural hardening at a positive air temperature in the room of the molding shop, they were stripped for 6-8 days, then they were stored in the same conditions before testing. Simultaneously with the concreting of samples, standard prisms with dimensions of 100x100x400 mm and cubes with dimensions of 100x100x100 mm were concreted. Cubes and prisms were kept under the same conditions as the samples. To identify the physical and mathematical properties of the working fittings, three rods with a length of 400 mm were prepared for each class. The characteristics of beam samples of fragments of three-layer slabs are given in Table 1 [3].

The fragments were supported on two sides, according to the beam scheme. The load was created by calibrated piece loads weighing 21 kg, evenly distributed over the surface of the plates. The fragments were loaded in steps of 0.05-0.07 of the theoretical destructive load. During the tests, the deflections of the upper and lower layer of fragments were measured with deflection meters with a division price of 0.01 mm, the draft of the supports using hour-type indicators with a division price of 0.01 mm. The crack opening width at various loading stages was measured using a portable microscope and a stencil with a division price of 0.05 mm. To measure concrete deformations at the most stressed points, resistance sensors of the PSB type with a base of 50 mm were used [4]. The general types of testing of fragments and the location of devices and cracks; the physical and mechanical characteristics of reinforcing steel, concrete and expanded polystyrene are given in Tables 1-3 [5].

At the initial stages of loading, up to the formation of the first cracks, the deformation of the fragment samples occurred, as is usually observed in solid bent elements, according to dependencies close to elastic work. The first cracks formed in the middle of the span at a load of 0.55-0.8 on average 0.7 of the destructive one, followed by their development and the formation of new cracks in an average third of the span. The opening width of these cracks varied from 0.05 mm at the time of formation to 1-2 mm by the time of exhaustion of the bearing capacity [6].

The calculation for the formation of normal cracks in the span consisted in checking the condition: cracks in the sections do not form if the bending moment from external forces does not exceed the bending moment of the limiting internal forces before the formation of cracks.

With further increases in the load, cracks were formed in the supporting sections, where the concrete layers are adjacent to the end edge. The supporting sections work under conditions of a complex stress state: a large transverse force and a small bending moment act simultaneously near the rib.

At a load of 0.64-1.0 from the destructive one, upper normal pressure cracks formed at the junction of the upper concrete layer to the edge. The upper concrete layer in the composition of the slab as a compressed shelf of a box structure experiences compressive forces. In addition, as a beam pinched in the ribs, it is subjected to bending, while negative bending moments occur on the supporting sections. Table 3 is results of crack resistance of fragments of floor slabs.

The calculation was carried out as for a beam pinched in an edge, without taking into account the

Table 1 – Physical and mechanical characteristics of concrete

Designation of fragments	Cubic strength	Prismatic strength	Tensile strength	Initial modulus of elasticity 10^{-3}
	MPa			
FP1	22	13	1,6	22
FP2	15	9,5	1,1	20
FP3	16	11	1,1	20
FP4	14	11	1,9	19
FP5	22	16	1,9	22
FP6	18	10	1,1	19
FP7, 8	12	9	1,6	25

Table 2 – Physical and mechanical properties of expanded polystyrene

Brand of expanded polystyrene	Density kg/m³	Ultimate strength	Modulus of deformation	Compressibility
		MPa		
EPB-30	28,0	0,22	4,4	0,08

middle layer, in fact, the beam works as pinched in an edge on an elastic base and with malleable contacts between layers, the upper layer transmits a certain part of the load to the lower concrete layer through expanded polystyrene.

The analysis of formula [1] showed that the second term in the denominator is negligible compared to 1, which means that the effect of precipitation of the middle layer of expanded polystyrene is insignificant, obviously due to the relatively small thickness of its layer. In this case, the value M_o will be close to the value obtained for a beam supported on incompressible supports, and the plots of moments and deflections in the span do not correspond to the actual ones. Consequently, the classical method [5] of calculating the upper shelf of three-layer slabs as beams on an elastic base is impractical to apply due to the small thickness of the middle layer. Approximately the same result is obtained when analyzing the operation of the upper layer as a continuous multi-span beam on elastic supports [6].

Since, therefore, a purely theoretical result has not yet been achieved, some generalized experimental parameters have been used additionally. Therefore, when calculating this influence of the middle layer should be taken into account.

As can be seen from Table 4, after such an adjustment, the experimental and theoretical values converged and their ratio averaged 1, 2.

The formation of normal cracks in the area of the abutment of the upper concrete layer to the edge in three-layer fragments with a low-strength middle layer, although it has a significant effect on the achievement of the limiting state of the structure, is not a limiting factor in the exhaustion of the bearing capacity of the element, the strength of these sections is high enough.

The lower concrete layer in the composition of the slab as a stretched shelf of a box structure experiences tensile forces. The supporting sections, as noted above, work in conditions of a complex stress state. In addition, after the formation of the upper supporting crack, the supporting section weakens, as a result, the tensile stresses increase and the formation of inclined cracks follows in the area of the lower concrete layer adjacent to the edge. The width of their opening, with the exception of the FP2 sample, varied in the same interval as the cracks in the span. In the case of the FP2 sample, due to weak reinforcement in the span, the supporting cracks managed to open only up to 0.5 mm.

At present, the method of formation of inclined cracks, taking into account the actual stress-strain state of the elements, has not been sufficiently developed.

In three-layer beam fragments, the stress state before the formation of inclined cracks is influenced by the formation and development of normal pressure cracks, stretching work of the lower concrete layer.

The found coefficient γ_φ for the elements of the floor slabs under the load of the formation of inclined cracks varied from 0.37 to 0.49 on average 0.44 (Table 5). To ensure a margin for the formation of inclined cracks and for further convenience of calculation, the value of the coefficient $\gamma_\varphi = 0.4$ was selected.

At the same time, as can be seen from Table 6, a satisfactory convergence of experimental and theoretical values of loads for the formation of inclined cracks in the area of the lower concrete layer abutting the edge was obtained.

Table 3 – Results of crack resistance of fragments of floor slabs in the span

Loads (kPa) and their ratios	Designation of plates				
	FP1	FP2	FP3	FP4	FP5
Crack formation load in the span					
Experienced q_{crc}^{exp}	9,1	8,1	7,0	9,1	8,12
Theoretical q_{crc}^{th}	6,0	4,2	4,1	7,1	7,8
q_{crc}^{exp} / q_{crc}^{th}	1,6	2,0	1,8	1,2	1,18

Table 4 – Loads of formation of normal cracks at the supports

Designation of fragments	q_{crc}^{exp}	q_{crc}^{th}	q_{crc}^{exp} / q_{crc}^{th}
	kN/m		
FP1	8,9	10	0,9
FP2	7,8	7	1,2
FP3	7,8	6,8	1,2
FP4	13,95	12,01	1,2
FP5	14	11,98	1,1
Average			1,2

Table 5 – The value of the coefficient γ_φ for fragments of slabs

Designation of fragments	σ_x	$\sigma_{mt} = \tau_{xy}$	γ_φ
	MPa		
FP3	0,059	0,61	0,4
FP4	0,048	0,49	0,47
FP6	0,049	0,43	0,47
FP15	0,082	0,79	0,45
FP16	0,064	0,71	0,41

Table 6 – Loads of formation of inclined cracks at the supports

Designation of fragments	σ_x	$\sigma_{mt} = \tau_{xy}$	γ_φ
	MPa		
FP1	9,91	10,25	0,95
FP2	7,79	6,7	1,2
FP3	8,5	6,7	1,3
FP4	13	11,9	1,1
FP5	11,5	12,4	0,95

Conclusion

Based on the experiments carried out, the methodology of normative standards for calculating the formation of inclined cracks has been clarified and supplemented. The coefficient γ_φ taking into account the working conditions of the concrete of the lower layer of fragments of floor slabs, based on the experiments carried out, is recommended to be taken equal to 0.4-0.5.

The calculation of fragments of three-layer slabs was carried out on the action of a transverse force to ensure strength along an inclined crack with a coefficient φ_n taking into account the influence of longitudinal tensile forces in the lower layer, and the working cross-section height for the lower concrete layer.

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Үш қабатты еден плиталарының темірбетон арқалықтары фрагменттерінің жарыққа төзімділігін бағалау

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***Аңдатпа.** Жұмыстың мақсаты – үш қабатты еден плиталарының темірбетон арқалықтары фрагменттерінің жарыққа төзімділігін зерттеу. Ішкі қаттылықсыз полистирол көбік материалының орташа қаба-*

ты бар темірбетон үш қабатты плиталардың сынықтарын тәжірибелік зерттеу. Фрагменттерде жарықтарға төзімділік, жарықтардың пайда болуы және дамуы туралы эксперименттік мәліметтер және есептеу бойынша ұсыныстар келтірілген. Эксперименттер нәтижелері бойынша көлбеу жарықтардың пайда болу нормативін есептеу әдістемесі нақтыланды және толықтырылды. Жүргізілген эксперименттерге сүйене отырып, еден плиталарының фрагменттерінің төменгі қабатының бетонын пайдалану шарттарын ескере отырып, нормативтік стандарттың формуласына кіретін сенімділік коэффициентін 0,4-0,5-ке тең қабылдау ұсынылады.

Кілт сөздер: *үлгілер, ара жабындар, полистирол көбігі, бетон қабаты, тор, арматура, қаңқа.*

Оценка на трещиностойкость железобетонных балочных фрагментов трехслойных плит перекрытий

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Аннотация. *Целью работы является изучение трещиностойкости фрагментов железобетонных балок трехслойных плит перекрытия. Экспериментальные исследования образцов-фрагментов железобетонных трехслойных плит со средним слоем пенополистирольного материала без внутренних ребер жесткости. Приведены экспериментальные данные по трещиностойкости, образованию и развитию трещин в фрагментах и рекомендации по расчету. По результатам экспериментов была уточнена и дополнена методика расчета норматива образования наклонных трещин. Коэффициент надежности, который входит в формулу нормативного стандарта, с учетом условий эксплуатации бетона нижнего слоя фрагментов плит перекрытия, исходя из проведенных экспериментов, рекомендуется принимать равным 0,4-0,5.*

Ключевые слова: *образцы, плиты перекрытия, пенополистирол, бетонный слой, сетка, арматура, каркас.*

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