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STRESS-STRAIN BEHAVIOR, CRACKING AND BEARING STRENGTH OF FOAM CONCRETE SLABS PUNCHED THROUGH RIGID STAMPS

The article is devoted to the stress-strain behavior, cracking and bearing strength of plain and reinforced non-autoclaved foam concrete slab spunched through rigid stamp. Experimental researches were held on slabs freely supported along the contour. Authors made an effort to determine the level of loading that corresponded the start of cracking and it was set at the level of 0,6 N_{cr} . There was also evaluated the ultimate tensility of foam concrete.

Key words: foam concrete, punching, ultimate tensility, bearing strength, cracking.

Досліджено несучу здатність, тріщиноутворення та деформативність армованих та неармованих плит, виготовлених із безавтоклавного пінобетону, які випробовувалися на продавлювання жорстким штампом. Експериментальні дослідження проводилися на вільно опертих по контуру плитах. Автори зробили спробу встановити навантаження початку тріщиноутворення у пінобетонних плитах, які продавлюються, що становило ≈ 0,6 від N_{cr}, та граничну розтягуваність пінобетону.

Ключові слова: пінобетон, продавлювання, гранична розтягуваність, міцність на зминання, тріщиноутворення.

Introduction

Literature reviews of plain and reinforced non-autoclaved foam concrete construction design showed the lack of experimental data about stress-strain behavior, cracking and bearing strength of foam concrete. The known researches were few and fragmented, existent methodologies and statements of design standards do not spread to the construction with usage of porous concretes, especially foam concrete slabs punched through rigid stamps. It confirmed a necessity to learn the punching of foam concrete slabs by experimental and theoretical way and to determine theirs stress-strain behavior, the level of loading that corresponds the start of cracking and to evaluate the ultimate tensility of foam concrete in punched plain and reinforced slabs.

Research specimens: mechanical characteristics and methodology of experiments

In accordance with the research tasks for the study of stress-strain behavior, cracking and bearing strength of foam concrete slabs during punching there were prepared four slabs. Specimens were made of two types that differed in sizes and presence of reinforcement. The accepted sizes of slabs and type of reinforcement mesh as also the methodology of experiments were described in previous articles [1].

In short, test specimens were made of non-autoclaved foam concrete in the range of D600..D1000 density grades. Slabs were freely supported on square rigid table with inner hole 400×400 mm and then they were punched by one square stamp size 100×100 mm, that was set on the center of specimen.Loading of all specimens took place in 0,1..0,15 steps of the expected value of the destructive load.

Description of specimens' mechanical characteristics and the values of critical load that were determined by punching tests (see results of parallel researches [1]) are given in Table 1.

Table1.

Mechanical characteristics of foam concrete and slabs

Slab mark	Density of foam concrete, kg/m³	Critical load [1], kN	Foam concrete grade	Prism strength, MPa	Modulus of elasticity, MPa	Poisson's ratio
1	2	3	4	5	6	7
S-1	774	12,00		0,914	1599,51	
S-2	810	14,00	LC0,75	1,011	1752,3	0,173
S-3	805	11,00		0,995	1729,15	
S-4	781	10,95		0,924	1618,03	

Results and discussions

The results of experimental determination of bearing capacity of foam concrete during punching tests of slabs is comfortably to present on “P - Δ_{st}” diagrams. At Fig. 1 it is shown the growth of stamp settlement during loading of reinforced slabs S-1 and S-2.

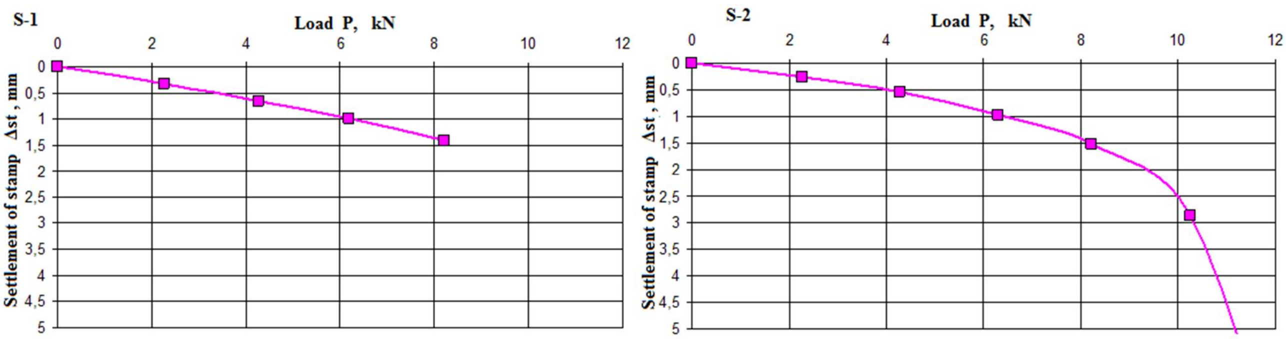


Fig 1. “P - Δ_{st}” diagrams of slab S-1 and S-2.

Fig 2. shows the growth of stamp settlement during loading of second subseries of specimens (plain foam concrete slabs S-3 and S-4).

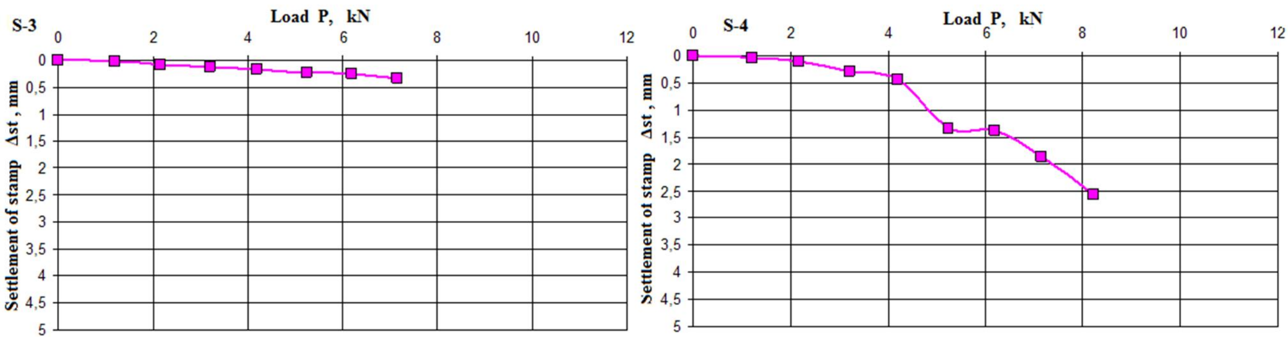


Fig 2. «P-Δ_{st}» diagrams of slabs S-3 and S-4.

Note: Inexplicaple decrease of test result of indentation of stamp in slab S-3 testing and sudden change on S-4 “P - Δ_{st}” diagram is explained by breakdown of one or both indicators.

Analysis of Fig 1. and Fig 2. diagrams led to conclusion that till the 0,6 N_{cr} load the foam concrete deformation growth under stamp showed linear dependence. At the 8-10 kN load the settlement of rigid stamp was in 1,2..2,5 mm ranges, wherein the lower values responded to reinforced specimens. These mentioned above values of stamp’s settlement met with the known ones from existent researches [4].

At the load level above 10 kN the settlements of stamp in foam concrete had suddenly grown up and they had been increasing until the slabs collapsed. Despite of slab’s type, the stamp settlement reached the depth of 1 cm. Then the destruction of slabs came according to two schemes: 1) by punching shear (with formation of punching pyramids in S-1, -2 and S-3 slabs); 2) by fracture (S-4 specimen). The depth of stamp settlement in foam concrete is depicted at Fig. 3.

Fig 3. Settlement of stamp in S-3 slab at the destruction stage.

The existent methods of evaluation of foam concrete bearing strength had been compared with the results of our investigations.

The results of comparison is in Table 2.

Table 2.

The comparison of experimental and theoretical critical stresses under stamp

Slab mark	Punching (stamp) area, cm^2	Experimental critical compressive stress, MPa	Theoretical critical stresses evaluated through methodology proposed by			
			Svidzinskyy Yu.V. [5], MPa	Demchyna Kh.B. [4] MPa	Desing codes	
					СНиП [2]	EN [3]
S-1	100	1,2	3,396	0,55..0,65	1,097	0,546..0,968
S-2		1,40	3,835		1,213	0,604..1,117
S-3		1,10	3,768		1,194	0,595..1,092
S-4		1,09	3,448		1,109	0,552..0,984

Notes:

СНиП design code [2] calculation formula: $R_{b,loc} = a\, j_b\, R_b$*; value of the coefficient* a *was taken equal to 1,0 (as for concrete grades below B25);* j_b *should be equal or less then 1,2 (as for cellular and lightweight concretes with compressive strength grades B2,5 or less); values for* R_b *were taken equal to prism strength (Table 1).*

Verification of EN 1992-1-1 methodology [3] consisted of two mentioned in it critical stresses evaluations: $s_{Rd,\max}$ *by formula* $s_{Rd,\max} = 0.6 \cdot v \cdot f_{cd}$ *and* s_{Rdu} *to be calculated as right part of the formula* $F_{Rdu} = A_{c0} \cdot f_{cd} \cdot (A_{c1} / A_{c0})^{D/4400} \le 3.0 \cdot f_{cd} \cdot A_{c0}$ *(* $\frac{D}{2200}$ *) divided by the punching area* A_{c0} *. The lower values obtained by first formula.*

Basing on results of comparing data in Table 2 the following conclusions could be made: proposed by СНиП [2], EN [3] and Demchyna Kh.B. [4] methodology of evaluation of critical compressive stresses under the stamp could be used to calculate bearing strength of foam concrete. СНиП's methodology gave slightly inflated results of bearing strength (up to 8,5 %), methodology by Demchyna Kh. B. provide the most considerable margin of safety, and EN's second formula for lightweight concretes showed the best convergence with experiment (divergence less then 19,3 %). Methodology of evaluation of critical compressive stresses under rigid stamp by Svidzinskyy Yu.V. [5] didn't work in case of punching non-autoclaved foam concrete slabs.

Metering of absolute deformation of foam concrete was conducted on upper and lower edge of slab, 25 mm from the stamp on 100 mm base. Measurements were conducted with a loading step of 2 kN, at reinforced slabs base of measurement was oriented once along and once across the anchored bars. The results of deformation measurement are represented graphically. At Fig. 4 plots of compressed and tensile deformation growths in S-1 and S-2 slabs are shown.

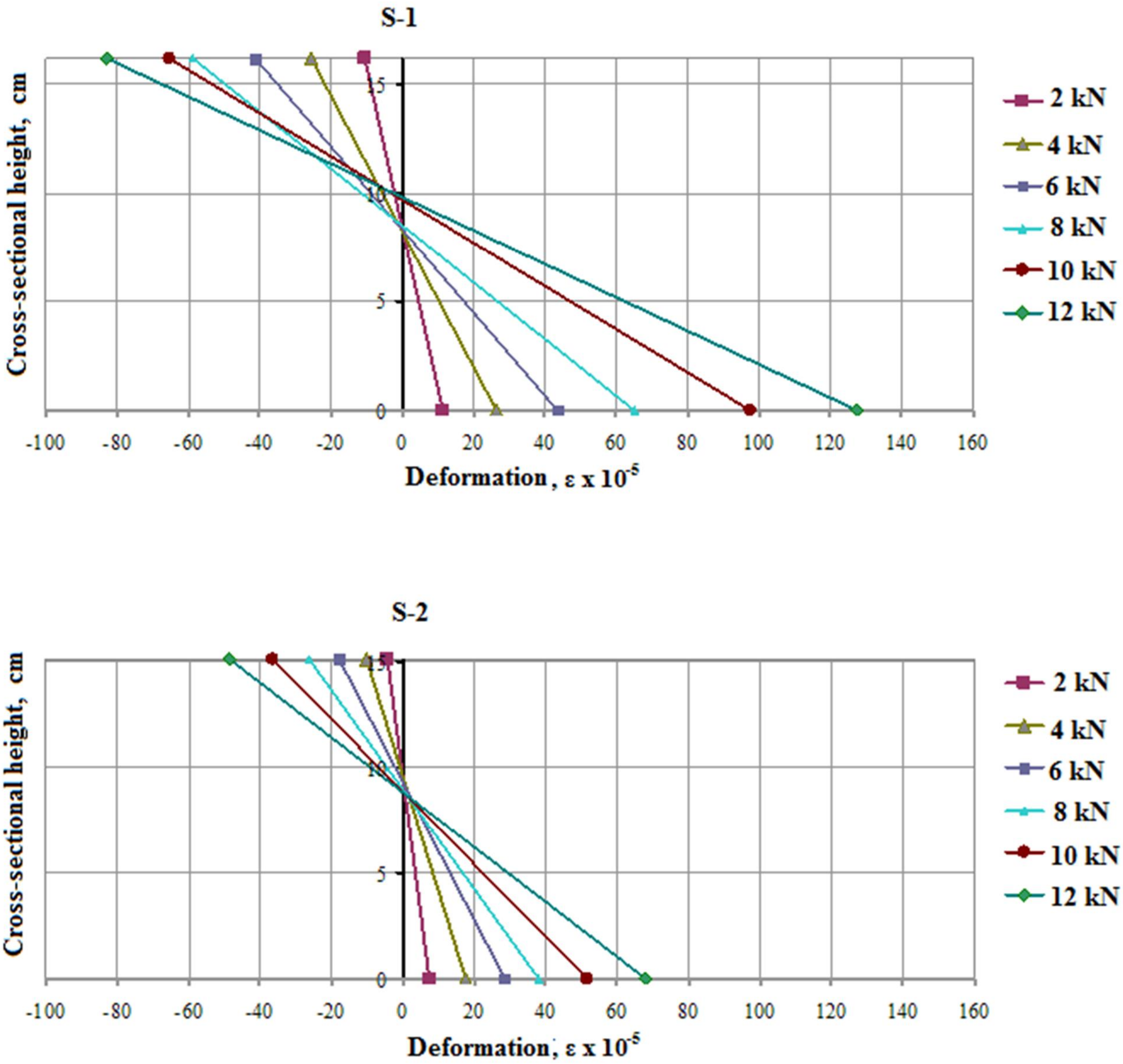
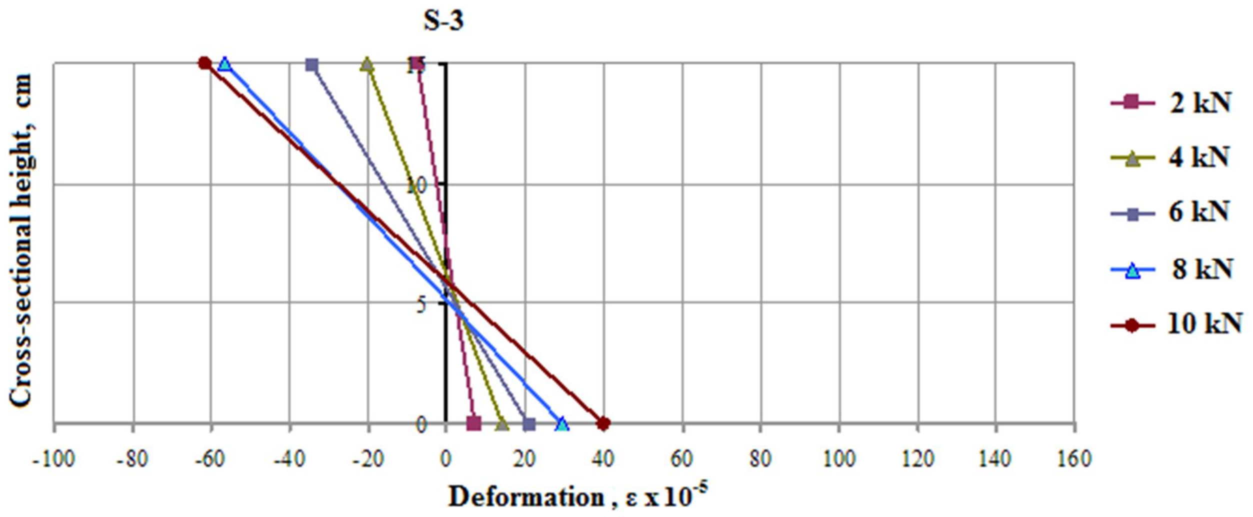


Fig 4. Foam concrete deformation (S-1 and S-2 specimens).

The analyzed diagrams of foam concrete deformations at lower stretched edge of slabs pointed that deformations along anchored reinforcement ($e = 68 \cdot 10^{-5}$ at 12 kN load level) were practically half as large as deformations along auxiliary crossbars ($e = 127{,}5 \cdot 10^{-5}$ at 12 kN load level). The deformations at upper edge of slab were considerably smaller. Step-by-step growth of deformations was noted by uniformity of indicator displays what was obliged to a presence of reinforcement that effectively dispense internal strains.

At Fig 5. given diagrams are similar to plots on Fig. 4 and relate to plain foam concrete slabs S-3 and S-4.



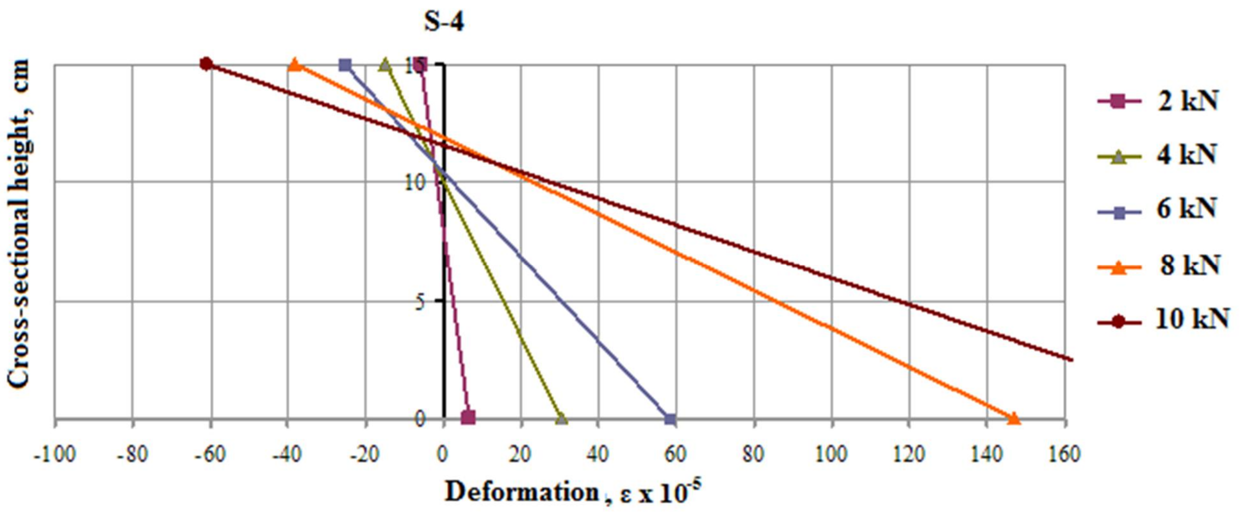


Fig 5. Foam concrete deformation (S-3 and S-4 specimens).

Analysis of Fig 5. diagram led to conclusion that deformations of compressed zone occurred regardless of reinforcement presence in lower zone. At 10 kN load level compressive strain around the stamp was at rate of $e = 56 \cdot 10^{-5}$. Distribution of tensile strains was non-uniform. Significant difference between Fig 4. and Fig 5. caused by the fact that instead of S-4 slab, the critical cracks in S-3 did not cross the base of deformation measurement.

There were few researches of fracture starting in foam concretes. It is considered that ultimate tensility of cellular concrete under stretching should be as 0.1-0.15 mm/m, but under other stress-strain state that value should be larger because of crack propagation stopping inside a foam concrete with less tensile stresses. Sazhnyev N.P. [6] suggested that ultimate tensility under bending should be equal to 0,66..0,88 mm/m. Design codes [3] stated that fracture could begin at compressive zone stresses about 0,6 of f_{ck}.

At reinforced specimens a presence of steel bars fatigue the cracks propagation in stretched zone thus it is hard to detect the moment of cracking start through experiment. But it is possible during plain slabs' test. At Fig 5. there was registered sudden change of deformations between the load levels at 6 kN (0,55 ofP_{cr}) and at 8 kN (0,73 ofP_{cr}). We bound this with a crack emergence and the deformations before leap were $e = 58 \cdot 10^{-5}$.

Conclusions

Bearing strength of foam concrete under the stamp in case of punching could be evaluated by the methods of design codes (СНиП [2], EN [3]) and Demchyna Kh.B. proposals [4]. СНиП's methodology gave slightly inflated results of bearing strength (up to 8,5 %), methodology by Demchyna Kh. B. provide the most considerable margin of safety, and EN's second formula for lightweight concretes showed the best convergence with experiment (divergence less then 19,3 %). Methodology of evaluation of critical compressive stresses under rigid stamp by Svidzinskyy Yu.V. [5] didn't work in case of punching non-autoclaved foam concrete slabs.

Deformations at lower stretched edge of slabs along anchored reinforcement ($e = 68 \cdot 10^{-5}$ at 12 kN load level) were practically half as large as deformations along auxiliary crossbars ($e = 127{,}5 \cdot 10^{-5}$ at 12 kN load level). The deformations at upper edge of slab were considerably smaller.

Presence of reinforcement ensured effective distribution of internal stresses that was confirmed by uniform step-by-step growth of tensile deformations. Distribution of tensile strains in non-reinforced stretched zone was non-uniform and depended on cracking.

Deformations of compressed zone occurred regardless of reinforcement presence in lower zone. At 10 kN load level compressive strain around the stamp was at rate of $e = 56 \cdot 10^{-5}$.

Fracture in punched foam concrete slabs started at load level about 0,6 of P_{cr}. Ultimate tensility of foam concrete then was not less then 0,58 mm/m.

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