УДК 691.88: 624.012.2: 691.327.33

V. Verba
Lviv Polytechnic National University,
Department of building constructions and bridges

RESULTS OF EXPERIMENTAL RESEARCH OF BEARING CAPACITY OF PLASTIC SLEEVE ANCHORS IN THIN AERATED CONCRETE MASONRY UNDER AXIAL LOAD

This article is devoted to a problem of anchoring strength of anchors (wall plugs) in thin aerated concrete blockwork. The question of bearing capacity of anchor fastenings in aerated concrete walls is slightly unveiled in modern design codes. As it is said in DSTU B V.2.6-195:2013 minimal design value of bearing capacity of plastic anchors used for fastening of insulating materials should not be less then 0,25 kN. In our research we used KPR-12x100N nylon plug with Ø8 woodscrew with an O-shape hook. For experiments we prepared 2 masonry fragments with up to 15 anchors' positions in each. Two specimens differ by diameter of drill bit (Ø11 and Ø12 mm). Two failure modes were obtained: 1) most anchors were pulled-away; 2) a few caused splitting of the specimen. It was observed an increase in bearing capacity by an average of 41.1 % due to decrease of diameter of used drill bit from 12 mm to 11 mm. Comparison of obtained results with the performance of reinforcement bars cast in cellular concrete found that the bearing capacity of cast reinforcing rod Ø 10 mm A500 is 50 % higher.

Key words: anchors in masonry, aerated concrete blockwork, frame anchors, anchors with plastic sleeve, anchors under tension.

В. Б. Верба
Національний університет "Львівська політехніка",
кафедра будівельних конструкцій та мостів

РЕЗУЛЬТАТИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ НЕСУЧОЇ ЗДАТНОСТІ АНКЕРІВ З ПЛАСТИКОВОЮ ВТУЛКОЮ В ТОНКІЙ КЛАДЦІ З ГАЗОБЕТОННИХ БЛОКІВ ЗА ДІЇ ОСЬОВОГО НАВАНТАЖЕННЯ

Розглянуто міцність анкерування дюбелів у тонкій кладці із блоків з автовлавного газобетону. Питання несучої здатності анкерів у газобетонній кладці слабо висвітлене у чинних нормах проектування. Стандарт ДСТУ Б В.2.6-195:2013 встановлює мінімальне значення несучої здатності анкерів з пластиковою втулкою, які використовують для кріплення ізоляційних матеріалів на рівні, не нижчому за 0,25 кН. У нашому дослідженні використано анкери KPR-12x100N з нейлоновою втулкою діаметром 12 мм та довжиною 100 мм виробництва Wkret-met (Польща) з шурупом із замкнутою петлею діаметром Ø 5,7 мм. Для випробувань виготовлено 2 зразки кладки, в кожному з яких було 15 місць монтажу анкерів. Отвори для анкерів висвердлено електродрилем без "удару" свердлами з номінальним діаметром 12 мм для першого зразка кладки та 11 мм у другому зразку. Внаслідок випробувань дюбелів KPR-12×100N при центрально прикладеному осьовому навантаженні у тонких стінах з газобетонної кладки завтовшки 100 мм отримано дві схеми руйнування: 1) більшість анкерів під час руйнування проковзували у місці контакту пластикової втулки з бетоном; 2) декілька анкерів

спричиняли розколювання самих зразків кладки (за мінімальної відстані від місця монтажу анкера до краю чи сусіднього анкера s = 100 мм). Спостерігалося в середньому на 41,1 % збільшення несучої здатності анкерів KPR-12×100N у разі переходу на менший діаметр свердла, використаного для монтажу, а саме – 11 мм, порівняно зі свердлом Ø 12мм. Порівнянням результатів дослідження анкерів KPR-12×100N з роботою замонолічених у ніздрюватому бетоні арматурних стрижнів встановлено, що несуча здатність замоноліченого стрижня Ø 10 мм А500 є на 50 % вищою.

Ключові слова: анкери в кладці, кладка з газобетонних блоків, рамні анкери, анкери з пластиковою втулкою, анкери за дії розтягуючих зусиль.

Introduction. Cellular concrete masonry is widely used in civil and industrial buildings. Its history counts more than 80 years, and geography of usage of aerated concrete masonry blocks covers all climatic zones and continents. It is rarely used more then 20–40 % of bearing capacity of aerated concrete masonry in low-rise building. The most widely used blocks with density 400–500 kg/m³ and strength grade C2–2.5 form masonry with design characteristics that are only one and a half times less than in masonry made of full-bodied silicate bricks. Aerated concrete blocks might be used as fillings of bearing walls in frame construction. In this case most part of load, especially vertical, takes the frame. However, these masonry structures have to be somehow fastened to reinforced concrete or metal frames. So, in both cases, either in one- or two-storey buildings or multi-storied frame buildings, a suitable fastening for aerated concrete blockwork should be guaranteed. For such a reason different types of anchors are used.

Review of scientific sources and publications. Masonry belongs to heterogeneous base materials. The hole prepared for an anchor can be drilled in mortar joints or even cavities. Due to relatively low strength of masonry, local loads cannot be high. Furthermore, aerated concrete made of cement and/or lime as binding agent, fine-grained aggregate, water and aluminium as the gas-forming agent with the density range 0.4–0.8 kg/dm³ and compressive strength range 2–6 N/mm² forms masonry with even lower strength of anchoring [1].

Most anchors gain their holding power out of a combination of three working principles: friction, keying, bonding. The weakest point in an anchor fastening determines the cause and the mode of failure [1]. There are distinguished four main modes of failure which are as follows: 1) break-out; 2) anchor pull-away; 3) failure of anchor parts and 4) edge breaking.

In cases of break-out, edge breaking and splitting the tensile strength of aerated concrete masonry is exceeded. The same mode of failure takes place under a combined load. The mode of failure 1. break-out, becomes more rare as the angle between direction of applied load and anchor axis increases.

The properties of base material play a crucial role in selecting of suitable anchor and estimation its bearing capacity. Another factor that influence much is the length of anchoring. Thus the aim of current research is an estimation of bearing capacity of anchors with plastic sleeves in thin aerated concrete masonry under tension load [5].

The question of bearing capacity of anchor fastenings in aerated concrete walls is slightly unveiled in modern design codes [3]. As it is said in DSTU B V.2.6-195:2013 minimal design value of bearing capacity of plastic anchors used for fastening of soft and hard, self-supporting insulating materials should not be less then 0,25 kN. Another statement says that only screw anchors are applicable. All other cases of anchor fastening with aerated concrete walls are not covered by design codes.

Research tasks. Exceptional attention should be paid for problem of fastening in thin aerated concrete walls in which are obvious limitations caused by depth of anchors setting. In order to reach our aims of research there are several tasks to be solved, namely: performance of scientific resources' review; evaluation of physical properties of aerated concrete by checking its grade; preparing of laboratory specimens of thin masonry and mounting anchors in it; experimental determination of failure mode and bearing capacity of anchors in thin blockwork specimens subjected to loading which is parallel to the anchor axis; comparison of obtained results with other researches [5, 6]; preparation of some recommendations or amendments to current design code for aerated concrete masonry [3].

Following program and methodology of experiments were proposed.

Materials and methods. Frame plastic anchors with steel screws are commonly used for securing support frames, timber frames, facade panels etc. In our research we used KPR-12x100N nylon plug with Ø8 woodscrew with an O-shape hook. Both nylon plug and screw were manufactured by Wkret-met (Poland) (see Fig. 1). Length of anchors' sleeve was 100 mm.

Fig. 1. Shape of KPR-12x100N anchor used in research

We made 2 masonry fragments for experiments. The shape of test specimens is shown on Fig. 2, ***a***). Each specimen consisted of two masonry rows with 1.5 blocks in a row. Specimens consist of prefabricated autoclaved aerated concrete blocks AEROC Classic (D500 density grade) with declared compressive strength grade C2.5. Blocks were 600×200×100 mm. Blockwork was made with thin mortar layers (3 mm or less). Pre-mixed cement-based mortar manufactured by local firm (TERMIT™ TK-16) was applied to bed joints and perpends. Location of anchors on specimens are shown on Fig. 2 as black dots. Since in each specimen up to 15 holes were prepared for testing, therefore for each position of the holes there were assigned serial numbers from 1 to 15. Holes drilling order is marked by numbers on Fig. 2, ***b***). Holes were drilled with drill bit Ø12 mm in first specimen and Ø11 mm in second, both were drilled without hammering.

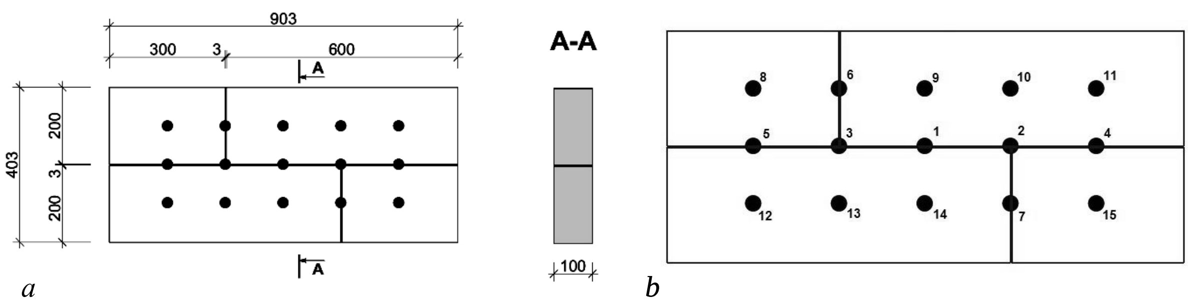

Fig. 2. Shape of test masonry specimens (a) and drilling order (b)

After mounting of the anchors specimens were tested. Investigation was held in such way that specimens lay in horizontal position. Two massive metal supports were placed on specimen to create with their help vertical tension load on anchor's hook. The loading was developed by talrep M12 with hooks and measured by ring dynamometer. Measuring and loading devices were connected with anchor and support by metal chain. Loadings were applied until anchor displacement reached 10 mm. The prototype chart and common view of experimental stand are shown on Fig. 3. When testing under tension, the load should be applied centrally. To achieve this, the role of hinges between the load device and the anchor played chain links.

Installation of plastic anchors was carried out in accordance with the manufacturer's instructions. A load was applied not less than 10 minutes after the installation. The rate of load increase was such that its maximum occurred after 1-3 minutes after the start of the test.

After main experiments on anchors' bearing capacity four cubes of 100 mm edge were sawn from blocks that were not damaged to obtain aerated concrete compressive strength. They were precisely measured and weighed to check declared density grade of blocks and compressed on laboratory press P-125 with 62.5 kN measuring scale. Aerated concrete moisture was measured by electronic testo™ 606-1 moisture meter by taking data from more then 10 points of several different blocks [5].

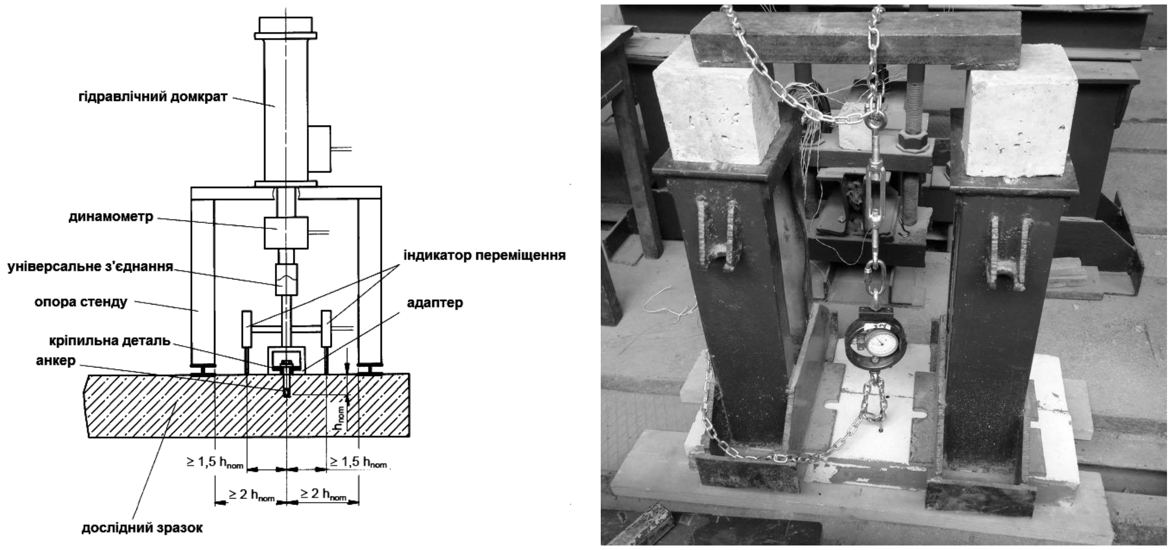

Fig. 3. Prototype chart and side view of experimental stand for tension loading

Results and Discussion. The Tables 1 and 2 show the results of tests. The order of the lines in the table indicates the sequence with which the tests were conducted. For the ease of analysis of the test results, results obtained in masonry joints are highlighted by a bold font. The dash marks unavailable data due to prior splitting of specimen. In this particular case of first specimen, the splitting of the sample was observed in the tests carried in positions 2 and 3.
The destructive load is estimated from the difference in the dynamometer displays, taking that one division was 2.22 kg or 0.022 kN.

Table 1

Test results of the anchor KPR-12 × 100N at nominal diameter of a drill bit Ø 12 mm in thin aerated concrete masonry

Hole number (see Fig. 2, b)	Dynamometer displays		Maximum load, kN	Notes
	Start	End		
1	**188**	**240**	**1.156**	
9	188	208	0.444	
14	187	202	0.333	
10	188	220	0.711	
2	**132**	**180**	**1.067**	**splitting**
7	**132**	**166**	**0.756**	
4	**130**	**190**	**1.333**	
11	112	132	0.444	
15	154	190	0.800	
3	**138**	**194**	**1.244**	**splitting**
6	**–**	**–**	**–**	
13	–	–	–	
5	**137**	**168**	**0.689**	
8	124	170	1.022	
12	110	132	0.489	

With regard to the failure scheme, all anchor fastenings except positions 2 and 3 were destroyed due to a slip of plastic sleeves. Thus, the failure mode is “anchor pull-away”.

Testing of the second specimen took place similarly to the previous procedure, but the free placement of plastic sleeves and a relatively large spread of obtained data led to the idea of reducing the nominal diameter of used drill bit. Table 2 shows the results of tests of the second sample. The principle of filling the data remained unchanged.

Table 2

Test results of the anchor KPR-12 × 100N at nominal diameter of a drill bit Ø 11 mm in thin aerated concrete masonry

Hole number (see Fig. 2, *b*)	Dynamometer displays		Maximum load, kN	Notes
	Start	End		
1	**110**	**143**	**0.733**	
9	107	140	0.733	
14	110	148	0.844	
10	–	–	–	
2	**108**	**152**	**0.978**	**splitting**
7	–	–	–	
4	**106**	**190**	**1.867**	
11	105	145	0.889	
15	105	150	1.000	
3	**129**	**192**	**1.400**	
6	**129**	**184**	**1.222**	
13	129	155	0.578	
5	**129**	**210**	**1.800**	
8	129	204	1.667	
12	129	178	1.089	

In the second series of test anchors, the anchor on 2nd position caused splitting of the masonry sample. In all the rest of the tests there was observed pull-away failure mode.

If we compare the average strength of anchoring of the second series of anchors in comparison with the first one, then due to a better selection of the diameter of a drill bit, it was possible to achieve an increase in strength by an average of 41.1 %.

As for the moment of beginning of a slip, in both series of tests the beginning of slip came on average at loads exceeding 0,5 from the destructive. That results in conclusion that the received load-shift functions correspond to the admissible values and the value of the coefficient α_i will not be determined.

Let's proceed to analysis of the results based on the following assumptions. Since we tested two samples of masonry, the conditions for mounting of anchors differed, so we split the results into two series, finding the variation coefficient for each of these series separately (Table 3). In addition, we excluded one smallest result, and one or two results, which showed the highest value of the anchorage strength.

This statistical analysis was done in tabular form using MS Excel. We find the coefficient of variation as the result of dividing the result returned by the STDEVPA function (standard deviation – the measure of how widely the experiment data is scattered relative to the average) to the result of the function AVERAGE (the average of the given set).

Table 3

Finding coefficients of variation in series

Series No	Experimental data of maximum loads, selected for statistical analysis										v, %
1st	1.156	0.444	0.711	0.756	1.333	0.444	0.800	0.689	1.022	0.489	36.72
2nd	0.733	0.733	0.844	0.889	1.000	1.400	1.222	0.578	1.667	1.089	31.39

Having obtained the value of the coefficient of variation, we can calculate the coefficient α_V using value of v_{max} = 15 %.

For first series:

$$\alpha_v = \frac{1}{1+0{,}03(36{,}72-15)} = 0{,}605 \tag{1}$$

For the second

$$\alpha_v = \frac{1}{1+0{,}03(31{,}39-15)} = 0{,}670 \tag{2}$$

The characteristic value of the destructive load for single anchors in thin walls mounted in the holes drilled by a Ø 12 mm drill bit, according to the formula, will be:

$$N_{Rk} = N_{Rk,1,2,3,0} \cdot \min(\min\alpha_i) \cdot \min\alpha_v = 0{,}444 \cdot 0{,}605 = 0{,}269 \text{ kN.} \tag{3}$$

The characteristic value of the destructive load for single anchors in thin walls mounted in the holes drilled by a Ø 11 mm drill bit, according to the formula, will be:

$$N_{Rk} = N_{Rk,1,2,3,0} \cdot \min(\min\alpha_i) \cdot \min\alpha_v = 0{,}5778 \cdot 0{,}670 = 0{,}387 \text{ kN} \tag{4}$$

Since the experimental way failed to achieve the failure of the anchor's metal part, thus in determination of the characteristic bearing capacity of the anchor will be used the coefficient of reliability $\gamma_{M,AAC} = 2{,}0$ as for cellular concrete.

Consequently, the characteristic value of bearing capacity at tensile loads of single anchors KPR-12 × 100N in thin walls of autoclave aerated concrete blocks masonry mounted in holes drilled with a Ø 12 mm drill bit is:

$$F_{Rk} = 0{,}1 \text{ kN} \le N_{Rd} = 0{,}269/2{,}0 = 0{,}135 \tag{5}$$

The characteristic value of bearing capacity at tensile loads of single anchors KPR-12 × 100N in thin walls of autoclave aerated concrete blocks masonry mounted in holes drilled with a Ø 11 mm drill bit is:

$$F_{Rk} = 0{,}2 \text{ kN} \le N_{Rd} = 0{,}387/2{,}0 \approx 0{,}2 \tag{6}$$

It is also interesting to compare the strength of the anchorage of the plastic anchors we have tested with the strength of the anchorage of reinforcement rods in cellular concrete, which can also be used for fastening of structural elements / equipment. For comparison, we will use results of previous researches [6,7]. The nominal diameter of the reinforcement bar for comparison will be Ø 10 grade A500C. The slightly smaller diameter of the reinforcement than the diameter of the plastic sleeve of the anchor is explained by the fact that when the connection between the reinforcement Ø 10 and the concrete is broken due to the presence of ribs on reinforcement, a hole is formed that is proportional to the one we received when testing the anchor KPR-12 × 100N.

Estimation of stresses on the surface of bonding is calculated by the formula:

$$f_{bk}{}^{u} = (0{,}3312 - 0{,}0035\frac{l_b}{d})f_{cm,cube} = (0{,}3312 - 0{,}0035 \cdot \frac{100}{10}) \cdot 2{,}9 = 0{,}859 \text{ MPa} \tag{7}$$

The characteristic resistance of the bar pull-out from cellular concrete is:

$$N_{Rk} = f_{bk}{}^{u} \cdot 0{,}25 \cdot \pi \cdot d_{nom} \cdot l_{nom} = 0{,}859 \cdot 0{,}25 \cdot 3{,}14 \cdot 10 \cdot 100 \cdot (10^{-3}) = 0{,}67 \text{ kN} \tag{8}$$

Applying the reliability factor from ETAG 020 [4] for autoclaved aerated concrete, we obtain the following characteristic value of the bearing capacity of reinforcement bonding in aerated concrete:

$$F_{Rk} = 0{,}3 \text{ kN} \le N_{Rd} = 0{,}67/2{,}0 = 0{,}335 \tag{9}$$

Conclusions. Modern Ukrainian design code for cellular concrete blockwork construction [3] approves usage of anchors for fastening as common practice, the only limitations are that theirs bearing capacity under tension should exceed 0.25 kN and it should be screw anchors. Other parameters might be set by experiment. As for above statements these provisions were obtained for walls with minimum thickness of 250 mm. We suppose there is a lack of data about bearing capacity of anchors in thin aerated concrete masonry thus we focus on it in our research.

The given ultimate loads and characteristic values of bearing capacity in this article reflect actual test results and are thus valid only for the indicated test conditions, namely type of anchor and masonry. Due to variations in local base materials, on-site testing is required to determine performance at any specific case.

When testing an anchor KPR-12×100N under centrally applied tensile load in 100 mm thick walls of of autoclave aerated concrete blockwork, two failure modes were obtained: 1) most anchors were pulled-away; 2) a few caused splitting of the base (at a minimum distance from the installation of the anchor to the edge or next anchor s = 100 mm). It was observed an increase in bearing capacity by an average of 41.1 % for anchors KPR-12×100N in thin 100 mm thick aerated concrete blockwork due to decrease of diameter of used drill bit from 12 mm to 11, resulting in characteristic value of bearing capacity in first case $F_{Rk} = 0{,}1$ kN and $F_{Rk} = 0{,}2$ kN in second.

Comparison of the results from current research with the performance of reinforcement bars cast in cellular concrete found that the bearing capacity of cast reinforcing rod Ø 10 mm A500 is 50 % higher.

The KPR-12×100N anchors we tested in thin aerated concrete blockwork walls on a thin layer of mortar under tensile loads can not be used alone for constructive application, since their bearing capacity found to be lower than the regulated minimum.

1. Anchor Fastening Technology Manual [Електронне видання] // HILTI, 2014 – Режим доступу: https://www. hilti. group [Accessed 29 Nov. 2017]. 2. European Techical Assessment, ETA-12/0272. [Електронне видання] – Warszawa: Instytut Techniki Budowlanej, 2016. – Режим доступу: https://www. wkret-met. com/aprobaty/ETA-12_0272_EN. pdf [Accessed 29 Nov. 2017]. 3. ДСТУ Б В.2.6-195:2013 Конструкції стін із блоків з ніздрюватого бетону автоклавного твердження. Загальні технічні умови. – К.: Мінрегіонбуд України, 2013. – 64 с. – (Національний стандарт України). 4. ETAG 020 Guideline for European Technical Approval of Plastic Anchors For Multiple Use In Concrete And Masonry For Non-Structural Applications. – Brussels: EOTA, 2011. 5. Verba V., Charaf Yo., Ouassim T. Bearing capacity of anchors in thin aerated concrete masonry under tension and shear loading// VII Міжнародний молодіжний науковий форум "Litteris et Artibus" // Матеріали. – Львів: Видавництво Львівської політехніки, 2017. – 1 електрон. опт. диск (CD-ROM). – С. 226–227. 6. Верба В. Б. Анкерування сталевої арматури в безавтоклавному пінобетоні за рахунок зчплення та пластинкових анкерів [Текст]: дис. канд. техн. наук: [спец.] 05.23.01 "Будівельні конструкції, будівлі та споруди" / Верба Володимир Богданович; М-во освіти і науки, молоді та спорту України, Нац. ун-т "Львівська політехніка". – Львів, 2012. – 195 с. 7. Верба В. Б. Розрахунок граничних напружень зчеплення арматури з пінобетоном [Текст] / В. Б. Верба // Вісник Національного університету "Львівська політехніка" № 755. Теорія і практика будівництва. – Львів: Видавництво Львівської політехніки, 2013. – С. 37–40.

References

1. Anchor Fastening Technology Manual. (2014). [ebook] HILTI. Available at: https://www. hilti. group [Accessed 29 Nov. 2017]. 2. European Techical Assessment, ETA-12/0272. (2016). [ebook] Warszawa: Instytut Techniki Budowlanej. Available at: https://www. wkret-met. com/aprobaty/ETA-12_0272_EN. pdf [Accessed 29 Nov. 2017]. 3. Konstruktsii stin iz blokiv z nizdriuvatoho betonu avtoklavnoho tverdnennia. Zahalni tekhnichni umovy [Autoclaved aerated concrete masonry structures. General technical conditions]. DSTU B V.2.6-195:2013. 4. EOTA (2011). ETAG 020 Guideline for European Technical Approval of Plastic Anchors For Multiple Use In Concrete And Masonry For Non-Structural Applications. Brussels: EOTA. 5. Verba, V., Charaf, Y. and Ouassim, T. (2017). Bearing capacity of anchors in thin aerated concrete masonry under tension and shear loading. In: 7th INTERNATIONAL YOUTH SCIENCE FORUM "LITTERIS ET ARTIBUS". Lviv: Lviv Polytechnic Publishing House, pp.226-227. 6. Verba, V. (2012). Ankeruvannia stalevoi armatury v bezavtoklavnomu pinobetoni za rakhunok zchplennia ta plastynkovykh ankeriv [Anchoring of steel reinforcement in nonautoclaved foam concrete by bonding and plate anchors]. Ph. D. Lviv Polytechnic National University. 7. Verba, V. (2013). Rozrakhunok hranychnykh napruzhen zcheplennia armatury z pinobetonom [Calculation of critical stresses of reinforcement bars' bonding in foam concrete]. Visnyk Natsionalnoho universytetu "Lvivska politekhnika". Teoriia i praktyka budivnytstva [Lviv Polytechnic National University Periodical. Theory and Practice of Civil Engineering], (755), pp.37–40.