International Journal of Engineering & Technology, 7 (4.8) (2018) 168-173

International Journal of Engineering & Technology

Website:www.sciencepubco.com/index.php/IJET

Research paper

Investigation of the Resistance of Protective Plates of High-Strength Concrete with Dynamic Impact

Yevgenij Babych[1]*, Sergij Filipchuk[2], Yevgen Babich[3], Roman Pahomov[4],

[1] National University of Water and Environmental Engineering, Ukraine
[2] National University of Water and Environmental Engineering, Ukraine
[3] National University of Water and Environmental Engineering, Ukraine
[4]Poltava National Technical Yuri Kondratyuk University, Ukraine
**Corresponding author E-mail: e.m.babich@nuwm.edu.ua*

Abstract

In the article are given the results of the test of dynamic action of protective steel-reinforced concrete slabs. The results have been confirmed, and proved the feasibility and expediency of application for their manufacture of high-strength fast-hardening concretes. Using external damper blades for supporting the slabs allows to absorb the energy of the impact of the weapon up to 30% , which increases their overall resistance to dynamic influences. The use of high-strength concrete will reduce the thickness of the plates in 2 ... 3 times compared with the concrete of conventional classes.

Keywords: *strength, steel, concrete, dynamic impact.*

1. Introduction

Concrete protective fortifications are widely distributed in the general defense system of many states. First and foremost, thanks to the high strength and durability of such structures. In such structures there is a certain specific work of concrete in conditions of high-speed impact. This prize leads to the need to consider issues related to constructs and materials for the construction of fortifications. The use of reinforced concrete in fortifications is becoming more relevant with the emergence of new high-strength fast-acting concrete [1 - 6]. The negative experience of using concrete is typical only for fortification structures made of low-strength non-reinforced concrete, without obligatory elements of protection.

The most protected protective structures always have some main bearing elements made of reinforced concrete. This is the underground walls of various shapes and configurations, beams, crossbars, runways, shells and overlays. However using of reinforced concrete in modern fortifications, as a protective cover is virtually absent, or has very limited protection. Basically, these are not large checkpoints, checkpoints, which give light protection against splinting coating. The thickness of concrete in such buildings is not much more than 300 mm. They have a powerful triple reinforcement, which is carried out with the displacement of reinforcing nets and high pro-cent reinforcement [7, 8, 9].

The purpose of the research is:

- to establish the conformity of the theoretical provisions with regard to the expediency of the use of high-strength fast-hardening concrete for the manufacture of protective structures under the action of dynamic loads;
- to investigate the resistance of the test boards and the nature of their damage during dynamic action;
- compare the theoretical calculations with experimental data.

2. Research methods

In the laboratories of the department of industrial, civil engineering and engineering buildings, and the department of technology of building materials and material science, two series of slabs of high-strength, fast-hardening concrete were designed and manufactured. In each of the series, two plates were made. Plates of the first series (P1 and P2) had a size of 1000 × 1000 mm and a thickness of 300 and 400 mm, and the second (PSH-1 and PSH-2) - 2200 × 2200 mm and a thickness of 400 mm (Table 1).

Plate P1 was designed with a solid section with the thickness of 300 mm. The reinforcement consisted of three flat grids, forming a spatial frame of rods ∅16A500C (A_s = 2.011 cm^2) in a 150 mm step. As a transverse armature, curved rods ∅6 A240C (A_s = 0.283 cm^2) were used. with a step of 50 mm. From the outer and inner sides of the slab, fence grids with an angle of 20 × 20 mm were installed to prevent the possible removal of fragments of destroyed concrete (fig. 1).

Fig. 1: Formwork with an enclosed frame, prepared for concreting plates P1 and P2

Plate P2 was designed as three-layer with a damping layer, which served a mineral wool slab with a thickness of 98 mm. The plate itself has a thickness of 400 mm. The reinforcement consisted of four flat nets, forming a spatial frame of rods ∅12A500S (A_s = 1,131 cm^2) with a step of 150 mm. The bars of ∅6 A240C (A_s = 0.283 cm^2) were used as a transverse reinforcement with a step of 150 mm (fig. 2).

Beside concreting plates were concreted concrete cubes and prisms. As a result of testing the corresponding concrete cubes and prisms at the age of 28 days, the following results were obtained: the cube strength was $f_{cm,\ cube}$ = 85.3 MPa, prism strength $f_{cm\ prism}$ = 68.27 MPa.

For reinforcement of the test boards was used armature class A500S with diameters of 12 and 16 mm. The mechanical characteristics of the valves were determined experimentally by standard techniques. Three 40 cm long stems were tested in the UIM 50 (measuring scale 100-500 kN) bursting machine. Stretching efforts were applied in steps, with the expiry for removing the counters on the devices. During tests, the deflection of the reinforcement on the loading stages was measured by two strains of the Hugenberger with a price of 0,001 mm divisions at the base of 20 mm, which were located on the diametrically opposite sides of the rod. The beginning of the yield strength was recorded with the help of the strain gauge, as evidenced by the growth of deformations of rod at the same time as the index arrow on the scale of the press was known to be in a stable position. The strength limit was determined directly at the time of breaking of the sample [10, 11, 12].

According to the results of tests, the following characteristics for the fittings with diameters of 12 and 16 mm, respectively, were set: respectively, the limit of the tensity f_y = 538,2 and 556,9 MPa; tensile strength f_u = 658.7 and 676.3 MPa; maximal deformations corresponding to the yield point ε_{s0} = 240.2 × 10-5 and 272.2 × 10-5.

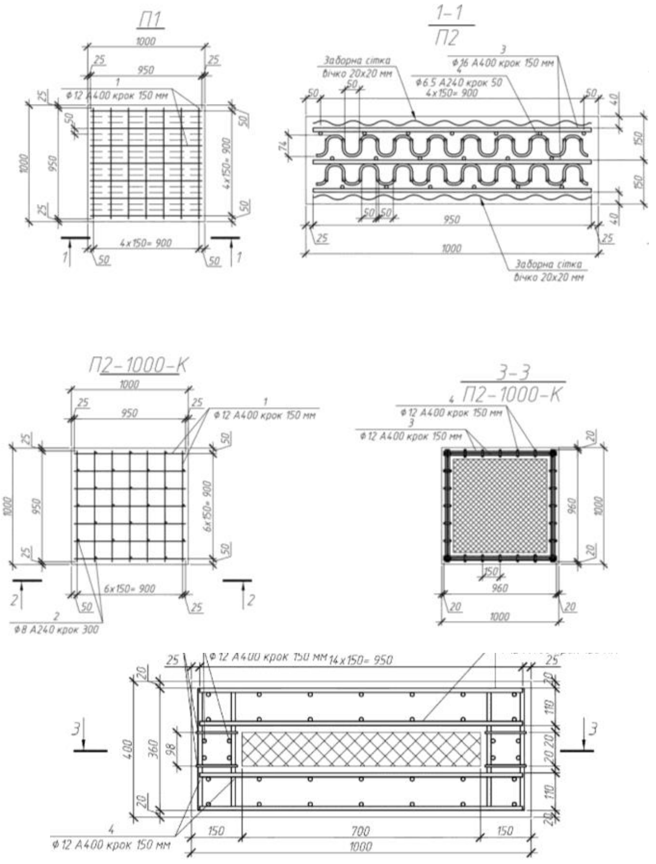

Fig. 2: Constructive scheme of test slabs P1 and P2 with high-strength fast-hardening concrete

Table 1: Program and volume of experimental research

№ Of series	Types of samples	Size of samples, cm	Number of samples	Subject of research
1	P1 P2	L = 100 B = 100	2	Hitting the plates with small guns of 7.2 mm and 12.7 mm caliber.
	Cubes	15×15×15	6	Cube concrete strength at the age of 28 days.
	Prisms	15×15×60	3	The prism strength of concrete, a module of elastic plasticity.
2	PSH-1 PSH-2	L = 220 B = 220	2	Hitting the plates with BMP-2 caliber 30 mm
	Cubes	15×15×15	6	Cube concrete strength at the age of 28 days.
	Prisms	15×15×60	3	The prism strength of concrete, a module of elastic plasticity.

In the second part of the field trials, was moduled fully - sized block of fortification structures. It consisted of a support block (fig. 3) and a three-layer board that was mounted in front of the block.

Twelve three-layer twin plates (PNH-1 and PNH-2) of 2200 × 2200 mm and 400 mm in thickness were made (fig. 4). So, as in the plate P2 was used as a damping layer a mineral wool slab with a thickness of 98 mm and width 1900 mm.

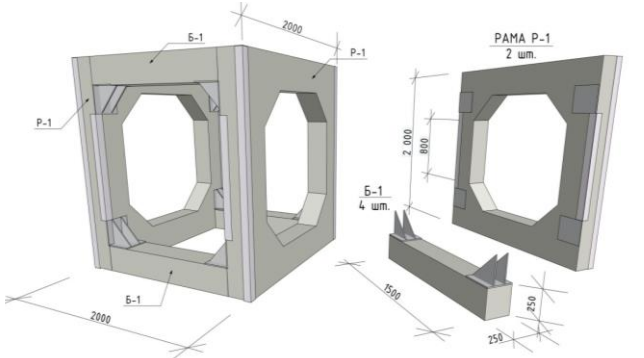

Fig. 3: General view of the main frame

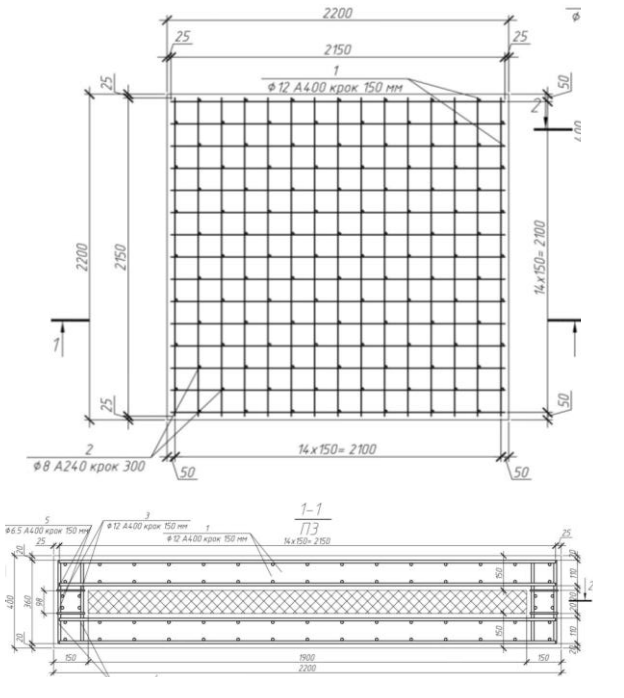

Fig. 4: Constructive scheme of experimental boards PSH-1 and PNN-2 which was made of high-precision fast-hardening concrete

The difference compared to the first-stage plate was that the outer layers were made of high-strength fast-hardening concrete class

C70, and the inner layer of 110 mm thick concrete from the class C45.

The reinforcement consisted of four flat nets, which formed a spatial frame from the rods ∅12A500C (A_s = 1,131 cm^2) in a step of 150 mm. As a transverse reinforcement, the rod ∅6 A240C (A_s = 0.283 cm^2) was used in increments of 150 mm (fig. 5).

Also, concreting plates and concreting frames [13, 14, 15] took place during the concreting cubes and prisms. As a result of the testing concrete cubes and prisms at the age of 28 days, the following results were obtained: for cubic strength plates, the strength was $f_{cm, cube}$ = 73.3 MPa, prism strength $f_{cm\ prism}$ = 55.1 MPa; for reference frame $f_{cm, cube}$ = 45,5 MPa, prism strength $f_{cm\ prism}$ = 34,4 MPa. The characteristics of the reinforcement for the designs of the second series were the same as for the first one (fig. 6).

Fig. 5: Deck frame, prepared for concreting plates

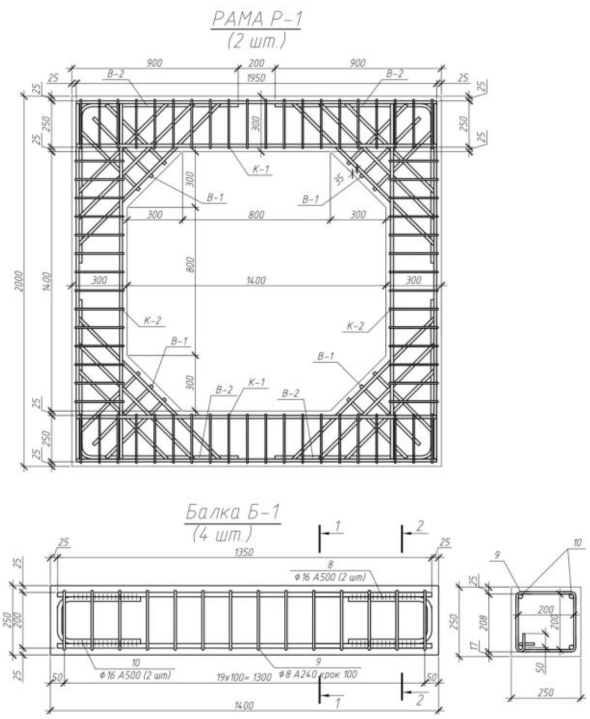

Fig. 6: Constructive scheme of the support unit

The support frame consisted of two monolithic frames of 2000x2000 mm in size and four 1400 mm long bolts. The cross sections of the elements of monolithic frames were 250 × 300 mm, and the bars were 250 × 250 mm. Four reinforcement bars ∅12A500S (A_s = 1,131 cm^2) were used as working valves in all elements of the support frame. As a transverse reinforcement, the rod ∅8 A240C (A_s = 0.503 cm^2) was used with a crown of 100 mm (fig. 7). To remove the concentration of stress in the nodes of monolithic frames were arranged twigs. For concreting monolithic frames and crossbars, mortar parts were constructed of plates in the thickness δ = 10 mm (fig. 6). The rails of the support frame were connected to the monolithic frames in the locations of these plates by welding (fig. 8).

The plate PSH-1 relied on a special spatial reinforced concrete frame system using mechanical damping devices (fig. 9). As mechanical damper devices served eight steel springs, which were located on two racks of the support cube of four on each rack. The springs were inserted into metal pipes which were pre-welded to the base parts of the support cube. The height of these pipes provides free spring movement, that is, the reliable operation of damper devices.

In order to prevent the plate from rolling over after the operation of mechanical damper devices, as a result of a shot from the weapon, special metal hooks were mounted, which fastened to the welded parts of the support block.

Fig. 7: Formwork with enclosed carcasses and mortar parts, prepared for concreting elements of the support unit

Fig. 8: Mounting bolts to monolithic frames with welding

Fig. 9: General view of the location of the mechanical damping devices

3. Results of the researches

Plates P1 and P2 were subjected to penetration of a firing pin thickness of 7.2 mm, 12.7 mm and a firing pin thickness of 120 mm. Firing pin had the characteristics and properties of weapons.
When exposed to plates with a firing pin thickness of 7.2 mm and 12.7 mm, there were prints in concrete of both plates with a depth of 3-5 mm and a diameter of 30-40 mm. Instead, in the foundation block made of concrete grade C15, the penetration depth was 13-15 mm. At the impact of plates with a firing pin thickness of 120 mm in a solid plate there was fragmentation of concrete at the site of the defeat (edge of the plate). In the three-layer plate, the destruction of the first layer of the plate occurred, and the second and third layers of the slab remained intact. The reinforcement in both plates suffered damage, but retained its integrity (fig. 10).

Fig. 10: Hitting the plate P-2 with a firing pin thickness of 120 mm

The PSH-1 plate was struck by five strokes of 30 mm firing pin, which caused the following local damage:
- the first strike (the numbering of strokes accepted conventional) hit the plate about 15 cm away from the upper face, destroyed not the entire thickness of the concrete edge of the plate without breaking its geometry;
- the second and third strokes of firing pin hit the middle part of the slab approximately at a distance of 50 and 70 cm from the left side and 60 and 35 cm from the bottom edge. Firing pin destroyed the concrete of the outer layer in an average diameter of 27 cm to the depth6 cm, the middle and internal faces have kept their integrity;
- the fourth strike hit the middle part of the slab (60 cm from the left side, 150 cm from the bottom edge) and penetrated the reinforcing net of the inner reinforced concrete layer, stopping after contact with the rod. On the outer surface of the plate, the destruction of concrete was formed at an average diameter of 26 cm, and on the inner surface of 34 cm;
- the fifth firing pin also hit the middle part of the plate (from the distance from the right side of 150 cm, from the bottom - 60 cm) and penetrating all the layers of the plate without encountering in its way any reinforcement rod.

The plate PSH-2 relied on the entire area on the plate PSH-1 after its test, that is, without mechanical damping devices.
The PSH-2 plate was struck by six strikes of 30 mm firing pin, which caused the following damage (fig. 11):
- the first firing pin hit the plate approximately 85 cm away from the lower edge and 21 cm from the left face, penetrating all layers of PSH-2 and was stopped by the plate PSH-1 (the depth of immersion in this plate was 1 cm);
- the second and third strokes of pin hit the middle part of the slab at a distance of 67 and 90 cm from the left side and 90 and 54 cm from the upper face. The pin also passed all layers of PSH-2 and were stopped by the PSH-1 plate (the depth of immersion in this plate was 1.5 cm). Firing pin destroyed the concrete of the outer layer in the middle in diameter of 29 cm;
- the fourth, fifth and sixth strikes hit the right side of the slab (21 cm, 50 cm and 44 cm from the right side, 115 cm from the bottom and 65 cm from the upper face), and as previous strikes passed all the layers of the slab and were stopped by a plate of PSH-1 (depth immersion in this plate was 1.5 cm). On the outer surface of the slab formed the destruction of concrete with an average diameter of 30 cm.

Fig. 11: Hitting PSH-2 plate with a 30 mm firing pin

Another 30 mm firing pin was released on a concrete block made of ordinary C15 grade concrete. As a result of hit, this unit was completely destroyed.
Also, a comparison was made of firing pin that were subjected to strikes with calculations in PC FORT [3]. To do this, in the corresponding window of the program we will enter the initial data with the size of the plate, the characteristics of the materials and the type of firing pin. According to the calculation of plates P1 and P2 their strength is ensured as in real conditions (fig. 12).
When performing a checking calculation for PSH-1 and PSH-2 plates exposed to a striking thickness of 30 mm (fig. 13), it was found that the strength of these plates is not provided. That is, both plates should be destroyed from the strike.
Plate PSH-2 in real field conditions was destroyed as a result of firing pin strike, which coincides with the program. Instead, the PSH-1 stood a strike of 30 mm firing pin. This can be explained by the use of mechanical damping devices (metal springs) that were installed at the ends of the plate.

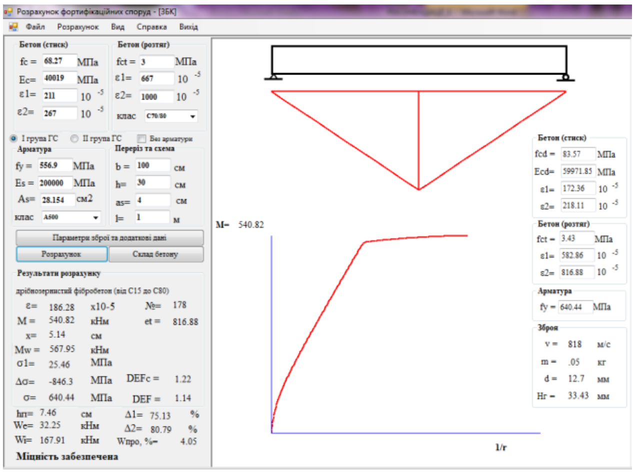

Fig. 12: To the automatic calculation of plate P1

As a result of the selection of the required thickness of the slab, it was found that to provide the required strength the thickness of the slab should be 43 cm (fig. 14). These results are confirmed by testing the PSH-2 plate. Firing pin, breaking the plate PSH-2 was detained by a plate of PNH-1 and dent in the stove was 1.5-2 cm. That is, if the thickness of the plate 43 cm fight would not break through this plate.

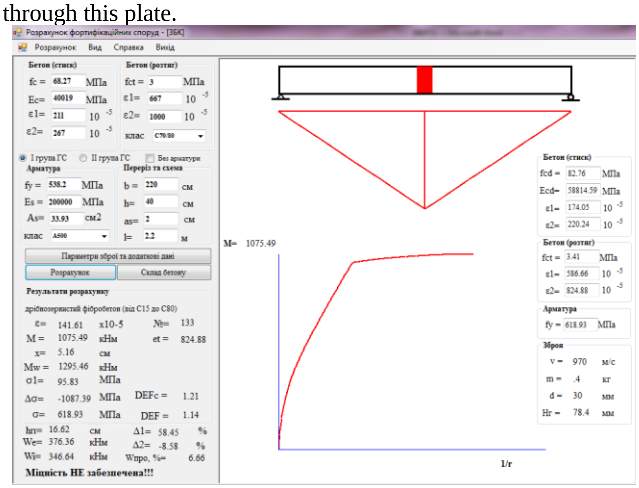

Fig. 13: Before the automated calculation of plates PSH-1 and PS-2

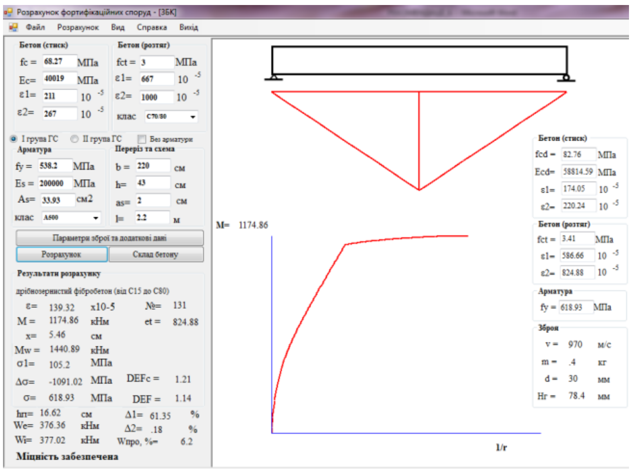

Fig. 14: Updated automated calculation of PSH-1 and PSH-2 plates

4. Conclusions

The results of the test with dynamic action with a firing pin of up to 30 mm of experimental protective steel-fiber reinforced concrete slabs supported the possibility and expediency of application for their production of high-strength fast-hardening concrete. The depth of propagation of firing pin in high-strength concrete compared with the usual class C15 was less than 3 times. That is, the use of high-strength concrete will reduce the thickness of the boards in 2 ... 3 times compared with the concrete of conventional classes.

The use of external dampers for flattening the plates at the rear allows up to 30% to absorb the energy of the impact of the weapon, which increases their overall resistance to dynamic influences.

The results of experiments confirmed the predictive prediction using the FORT developed complex for this topic.

The preliminary calculations show that solid plates of high-speed fast-hardening concrete having the appropriate reinforcement in the thickness of 700 ... 800 mm can make the necessary resistance to weapons with a caliber up to 130 mm.

References

[1] Bazhenov Yu.M. Beton pry dynamycheskom nahruzhenyy. M.: Stroiyzdat, 1970, 274 s.

[2] Belov N.N. Raschet zhelezobetonnykh konstruktsyi na vzryvnye y udarnye nahruzky. / Belov N.N., Kopanytsa D.H., Kumpliak O.H., Yuhov N.T. // Tomsk: STT, 2004. 466 s. ISBN 5-93629-183-9.

[3] Dvorkin L.J., Babich E.M., ZHitkovs'kij V.V., Bordyuzhenko O.M., Filipchuk S.V.,Kochkar'ov D.V., Kovalik I.V., Koval'chuk T.V., Skripnik M.M. Visokomicni shvidkotverdnuchi betoni ta fibro betoni – Rivne: NUVGP, 2017. 331 s.

[4] Kumpliak O.H. , Kopanytsa D.H. Prochnost y deformatyvnost zhelezobetonnыkh sooruzhenyi pry kratkovremennom dynamycheskom nahruzhenyy. Tomsk: STT, 2002. 336 s.

[5] Babych, E.M., Andriichuk, O.V. Strength of Elements with Annular Cross Sections Made of Steel-fiber-Reinforced Concrete Under One-Time Loads Materials Science vol. 52 (4), pp. 509-513, 2017

[6] Lyubchenko, I.G., Babich, E.M., Babich, V.I., Pershakov, V.N. Steel-Concrete Trusses for Rural Construction. | [STALEZHELEZOBETONNYE FERMY DLYA SEL'SKOGO STROITEL'STVA.] Beton i Zhelezobeton. vol. 7, pp. 5-7 1976.

[7] Hakan Hansson. Warhead penetration in concrete protective structures. Licentiate Thesis. – Stockholm, 2011. – 188 c.

[8] Kufuor K.G., Perry S.H. Hard impact of shallow reinforced concrete domes. Int. Conf. Structural Impact and Crashworthiness: Int. Conf. – V.2. – London, 1984. – P.675-686.

[9] Wang S., Zhang M., Quek T. Compressive behavior of plain and fiber-reinforced high-strength concrete subjected to high strain rate loading // Applied Mechanics and Materials Vol. 82 (2011). P. 57-62.

[10] GOST 10180-90. Betony. Metody opredelenyia prochnosty po kontrolnym obraztsam.– M. : NYYZhB Hosstroia SSSR, 1991. – 31 s.

[11] GOST 24452-80. Betony. Metody opredelenyia pryzmennoi prochnosty, modulia upruhosty y koeffytsyenta Puassona.– M. : NYYZhB Hosstroia SSSR, 1980. – 14 s.

[12] DSTU B V.2.7– 214:2009. Budivelni materialy. Betony. Metody vyznachennia mitsnosti za kontrolnymy zrazkamy. – K. Minrehionbud, 2010. – 31 s.

[13] Mekhanichni harakteristiki shvidkotverdnuchih visokomicnih betoniv. / Є.M. Babich, V.Є. Babich, S.V. Filipchuk, D.V. Kochkar'ov // Resursoekonomni materiali, konstrukcії, budivli ta sporudi: Zbirnik naukovih prac'. – Rivne: NUVGP, 2016. – Vipusk 32. – S. 114 –120.

[14] Babych, Y., Filipchuk, S., Fenko, O., “Mathematical modeling of the resistance of pulling out steel bars from high strength concrete,”International Journal of Engineering and Technology (UAE), vol. 7 (3.2), pp. 516-521, May 2018.

[15] Babych Ye.M., Kochkarov D.V., Filipchuk S.V.. Otsiniuvannia mitsnisnykh i deformatsiinykh kharakterystyk vysokomitsnykh betoniv pry dynamichnykh vplyvakh. ”Nauka ta budivnytstvo” Zhurnal – Kyiv: NDIBK, 2017. – № 4. – S. 15 –21.

[16] Piskunov, V. G., Goryk, A. V., & Cherednikov, V. N. (2000). Modeling of transverse shears of piecewise homogeneous composite bars using an iterative process with account of tangential loads. 1. construction of a model.Mechanics of Composite Materials, 36(4), 287-296. doi:10.1007/BF02262807

[17] Piskunov, V. G., Gorik, A. V., & Cherednikov, V. N. (2000). Modeling of transverse shears of piecewise homogeneous composite

bars using an iterative process with account of tangential loads 2. resolving equations and results. Mechanics of Composite Materials, 36(6), 445-452. https://doi.org/10.1023/A:1006798314569

[18] Kochkarev, D., Galinska, T., & Tkachuk, O. (2018). Normal sections calculation of bending reinforced concrete and fiber concrete element. *International Journal of Engineering and Technology(UAE), 7*(3), 176-182. http://dx.doi.org/10.14419/ijet.v7i3.2.14399

[19] Kochkarev, D., & Galinska, T. (2017). Calculation methodology of reinforced concrete elements based on calculated resistance of reinforced concrete. Paper presented at the *MATEC Web of Conferences, 116* https://doi.org/10.1051/matecconf/201711602020

[20] Kochkarev, D., Azizov T., & Galinska, T. (2018) Bending deflection reinforced concrete elements determination. Paper presented at the MATEC Web of Conferences, 230 https://doi.org/10.1051/matecconf/201823002012

[21] Kochkarev, D., & Galinska, T. (2018). Nonlinear Calculations of the Strength of Cross-sections of Bending Reinforced Concrete Elements and Their Practical Realization. Cement Based Materials, 13-30 http://dx.doi.org/10.5772/intechopen.75122