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INVESTIGATION OF DEFLECTIONS IN REINFORCED CONCRETE ARCHES OF HIGH-STRENGTH CONCRETE UNDER SHORT-TERM STATIC LOW-CYCLE REPEATED LOADS

ДОСЛІДЖЕННЯ ПРОГИНІВ В ЗАЛІЗОБЕТОННИХ АРКАХ З ВИСОКОМІЦНОГО БЕТОНУ НА ДІЮ КОРОТКОЧАСНИХ СТАТИЧНИХ МАЛОЦИКЛОВИХ ПОВТОРНИХ НАВАНТАЖЕНЬ

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The issue of improving Ukraine's defense capabilities in this difficult time is now an urgent one. There is an urgent need to build new and restore destroyed defense and civil defense facilities. In order to achieve the fastest possible pace of construction of defense facilities, it is proposed to use high-strength quick-setting concrete. The use of high-strength concrete can significantly reduce the volume of concrete, and thus the dead weight of structures, and reduce the consumption of reinforcing steel in reinforced concrete structures. This type of heavy concrete can significantly reduce the time required to construct structures, increase the strength and reliability of structures and the building as a whole. One of the effective structural schemes of a civil defense protective building (shelter) is a combination of structural elements made of monolithic reinforced concrete and prefabricated elements in the form of two-hinged arches made of high-strength concrete.

Наразі гостро стоїть питання підвищення обороноздатності України в цей тяжкий час. Нагальною є проблема зведення нових та відновлення зруйнованих споруд оборонного призначення та цивільного захисту населення. Щоб досягти максимально швидких темпів зведення оборонних споруд пропонується використовувати високоміцні швидкотверднучі бетони. Однією з ефективних конструктивних схем захисної будівлі цивільного захисту (сховища) є сполучення конструктивних елементів, зведених з монолітного залізобетону та збірних елементів у вигляді двохшарнірних арок, виготовлених з високоміцного бетону. Існує необхідність вивчення напружено-

деформованого стану залізобетонних арок з високоміцного бетону на дію статичних одноразових і повторних навантажень різного рівня та поглибленого визначення фізико-механічних і деформативних характеристик високоміцних бетонів. Це дозволить більш точно оцінювати напружено-деформований стан елементів залізобетонних конструкцій з таких бетонів, підвищити надійність проєктування і одержати істотний економічний ефект при зведенні будівель і споруд, що є актуальною задачею сьогодення.

Keywords:
Reinforced concrete, arch, load, fracture, reinforcement, cracks, graph, diagram, dependence, crack resistance.
Залізобетон, арка, навантаження, руйнування, арматура, тріщини, графік, діаграма, залежність, тріщиностійкість.

Introduction. The issue of improving Ukraine's defense capabilities in this difficult time is now an urgent one. There is an urgent need to build new and restore destroyed defense and civil defense facilities. In order to achieve the fastest possible pace of construction of defense facilities, it is proposed to use high-strength quick-setting concrete. The use of high-strength concrete can significantly reduce the volume of concrete, and thus the dead weight of structures, and reduce the consumption of reinforcing steel in reinforced concrete structures. This type of heavy concrete can significantly reduce the time required to construct structures, increase the strength and reliability of structures and the building as a whole. One of the effective structural schemes of a civil defense protective building (shelter) is a combination of structural elements made of monolithic reinforced concrete and prefabricated elements in the form of two-hinged arches made of high-strength concrete. There is a need to study the stress-strain state of reinforced concrete arches made of high-strength concrete under the action of static single and repeated loads of different levels and to determine in-depth the physical, mechanical, and deformation characteristics of high-strength concrete. This will make it possible to more accurately assess the stress-strain state of elements of reinforced concrete structures made of such concrete, improve design reliability, and obtain a significant economic effect in the construction of buildings and structures, which is an urgent task today.

Materials and methods. The geometric parameters of the experimental arches and their reinforcement schemes are given in the authors' works [1, 2, 3, 4]. The arches A1 and A2 were tested according to the scheme shown in Fig. 1 for short-term static low-cycle repeated loading (see Fig. 2, Fig. 3). The prototypes were manufactured and tested in accordance with current regulations [5].

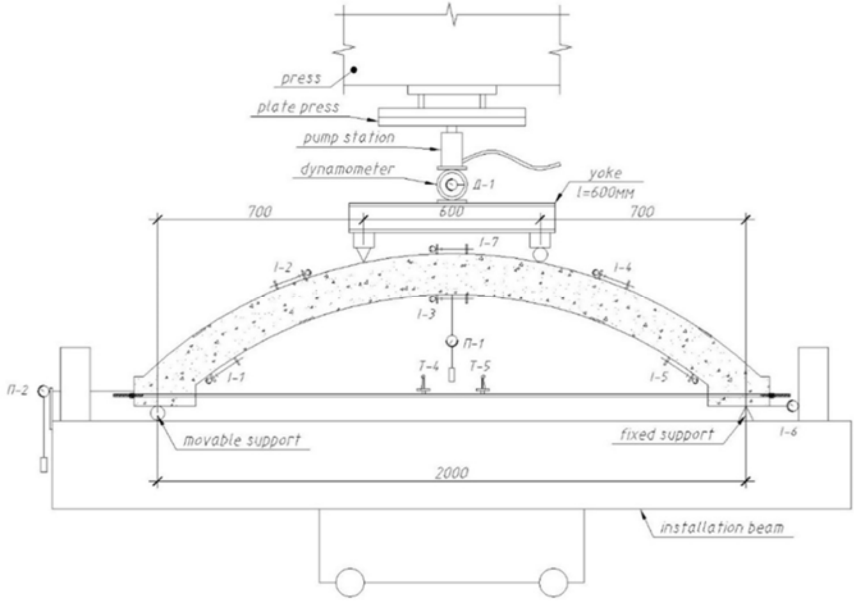

Figure 1. Scheme of testing of prototypes of arches A1 and A2 in the installation: T-4, T-5 – Hugenberger strain gauge; I-1, I-2, I-3, I-4, I-5, I-7 – clock type indicator 1(2) MIG; I-6 – indicator ICH-10m; П-1, П-2 – deflection gauge 6PAO; Д-1 is a dynamometer

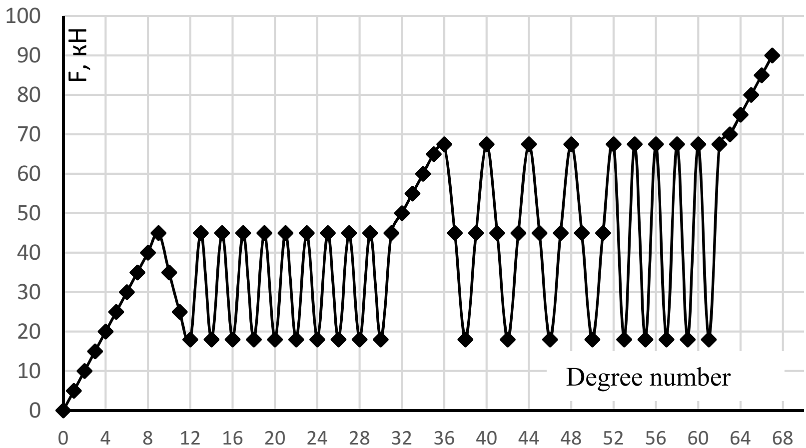

Figure 2. Method of testing the experimental arch A1 for repeated loads

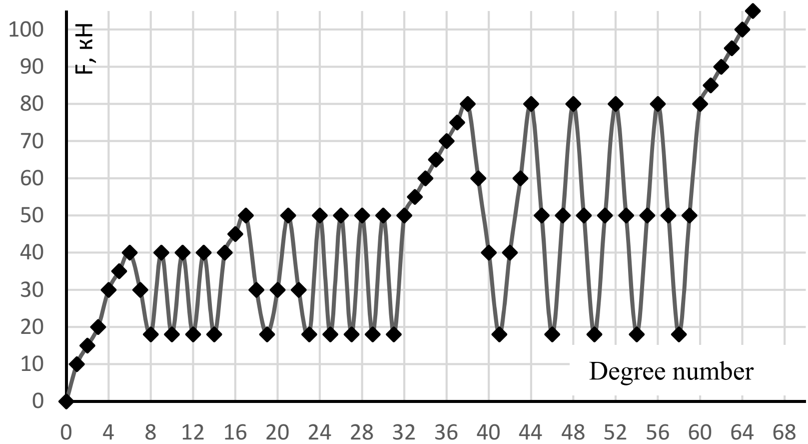

Figure 3. Method of testing the experimental arch A2 for repeated loads

The value of the levels of repeated loading on the experimental arches was: η = 0.2, 0.4, 0.5, 0.75, 0.8 of the destructive Fu. The number of cycles at a constant load level (η) was n ≤ 10.

Taking into account the operation and stress-strain state of the experimental arch A1 under the action of low-cycle repeated loading, it was decided to assign levels (η) of repeated loading during the experiment, focusing on the processes of crack formation and crack development in the arch.

Results and discussion.

Arch A1. On the 1st loading cycle at F = 45 kN, the deflection of the arch girdle was f = 3.39 mm, and when unloaded to F = 18 kN, it was f = 2.06 mm, the residual deflection was Δf = 0.89 mm, which is 74% of the total residual deflection for the first 10 loading cycles and 43% of the total residual deflection for 19 loading cycles (Fig. 4). At the next 10 loading cycles at F = 45 kN, the deflection did not increase, the increase in residual deflection per cycle was Δf = 0.01...0.06 mm with its stabilization by the 11th loading cycle. On the 11th loading cycle at F = 67.5 kN, the deflection of the arch girdle increased and amounted to f = 4.75 mm, and when unloaded to F = 18 kN - f = 2.98 mm, the residual deflection was Δf = 0.61 mm, which is 70% of the total residual deflection for 9 loading cycles and 30% of the total residual deflection for 19 loading cycles. On subsequent loading cycles at F = 67.5 kN, the deflection increased until the 18th cycle, the deflection increase was: on the 12th cycle - Δf = 0.14 mm, on the 13th...17th cycles - on average Δf = 0.02 mm. The increase in residual deflection on the 12th...16th cycles when unloaded to F = 18 kN was Δf = 0.1...0.01 mm with its stabilization by the 17th loading cycle. At a load of F = 116 kN, the deflection of the arch girdle was f = 10.34 mm, which is less than the maximum permissible value of fu = 1/150l =

13.3 mm. The value of the deflection increase at the 20th cycle by load steps from F = 70 kN and before destruction increased with an increase in the load level and amounted to Δf = 0.16...0.63 mm, which is associated with an increase in plastic deformation in concrete and crack opening.

The dependence of the deflection of the arch belt on the loads during repeated loading cycles and before failure is linear. The nature of arch failure and crack formation is shown in Fig. 5.

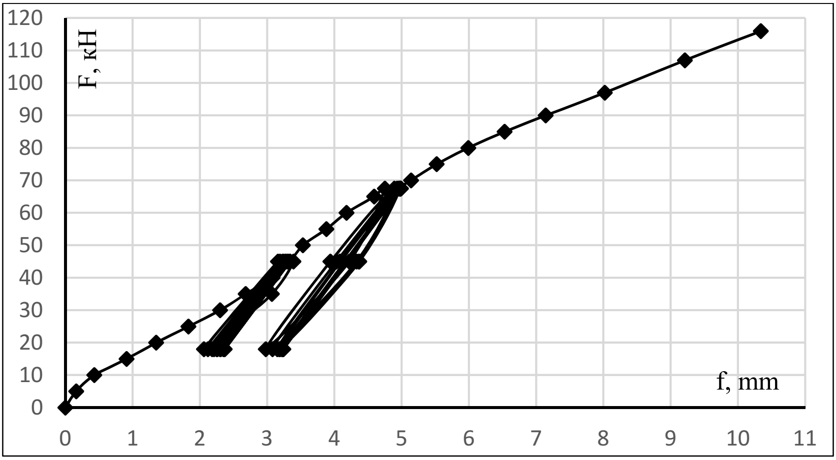

Figure 4. Changes in deflections of the A1 arch belt under repeated loading cycles

Figure 5. General view of the A1 arch after testing

Arch A2.

On the 1st loading cycle at F = 40 kN, the deflection of the arch girdle was f = 2.31 mm, and when unloaded to F = 18 kN - f = 1.82 mm, the residual deflection was Δf = 1.09 mm, which is 92% of the total residual deflection for the first 4 loading cycles and 32.5% of the total residual deflection for 15 loading cycles (Fig. 6). On the next 4 loading cycles at F = 40 kN, the increase in deflection values was

Δf = 0.09...0.01 mm, with a decrease in its value on each subsequent cycle, and the deflection value at F = 18 kN increased on unloading cycles by an average of Δf = 0.03 mm. On the 5th loading cycle at F = 50 kN, the deflection value increased to f = 3.28 mm, and when unloaded to F = 18 kN - to f = 2.24 mm, the residual deflection was Δf = 0.33 mm, which is 73.3% of the total residual deflection for the next 5 loading cycles and 9.8% of the total residual deflection for 15 loading cycles. At the next 6 loading cycles at F = 50 kN, the deflection value increased by a value: Δf = 0.11 mm - on the 6th cycle, Δf = 0.02 mm - on average on the 7th...11th cycles, and when unloaded to F = 18 kN, respectively, by Δf = 0.07...0.02 mm with stabilization on the 10th cycle. On the 11th loading cycle at F = 80 kN, the deflection of the arch increased and amounted to f = 7.23 mm, and when unloaded to F = 18 kN - f = 3.64 mm, the residual deflection was Δf = 1.28 mm, which is 74.4% of the total residual deflection on the 12th...15th loading cycles and 38.2% of the total residual deflection for 15 loading cycles. At the next 5 loading cycles at F = 80 kN, the deflection increase averaged Δf = 0.2 mm, and at unloading to F = 18 kN - Δf = 0.19...0.05 mm, with a decrease in the value of the residual deflection increase by the 16th loading cycle. At a load of F = 105 kN, the deflection of the arch girdle was f = 10.3 mm, which is less than the maximum permissible value of fu = 13.3 mm. The value of the deflection increase at the 16th cycle by load steps from F = 80 kN and before fracture increased with an increase in the load level and amounted to Δf = 0.22...1.66 mm, which is associated with an increase in plastic deformation in concrete and crack opening.

The deflections of the experimental arch A2 under repeated loading cycles correspond to those of the arch A1. The nature of arch fracture and crack formation is shown in Fig. 7.

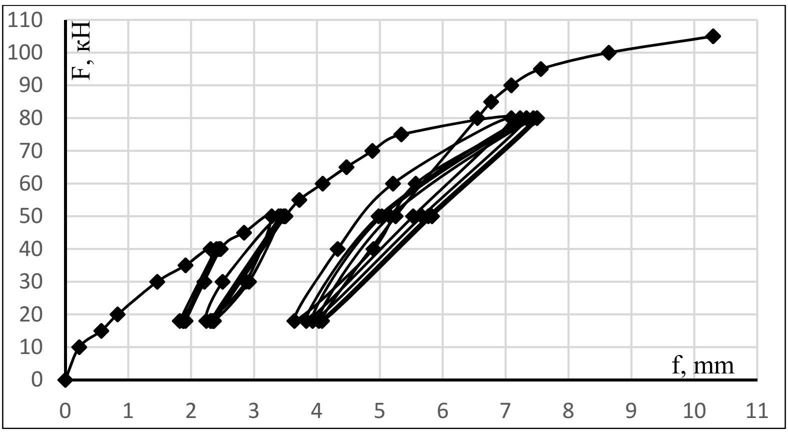

Figure 6. Changes in deflections of the A2 arch belt under repeated loading cycles

Figure 7. General view of the A2 arch after testing

Conclusions. For the first time, data on the operation of two-hinged reinforced concrete arches made of high-strength quick-setting concrete were obtained experimentally, which made it possible to identify the peculiarities of the stress-strain state of normal sections and the nature of deflection development under repeated (low-cycle) short-term static loads.

The residual deflection on the first cycle under the action of a repeated static load of $\eta = 0.4$ Fu was on average 40% of the total residual deflection for all cycles, and the deflection stabilized over eight subsequent loading cycles. When the arch was loaded at the level of $\eta = 0.5$ Fu, the residual deflection was 10% of the total deflection with stabilization over the next six cycles. When the arch was loaded to the level of $\eta = 0.6$ Fu, the residual deflection was 30% of the total with stabilization for the next six cycles. When the arch was loaded on reloading cycles to the level of $\eta = 0.8$ Fu, the residual deflection on the cycle was 38% of the total residual deflection, the deflections of the arch belt stabilized on four subsequent loading cycles.

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