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3D PRINTING TECHNOLOGY FOR MONOLITHIC BEAMS WITH THE POSSIBILITY OF REINFORCING BARS

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Demchyna B., Vozniuk L., Surmai M., Burak D., Shcherbakov S. 3d printing technology for monolithic beams with the possibility of installing reinforcing bars

The integration of 3D printing technology in construction has the potential to reduce costs and accelerate the construction and installation processes. While this technology is gaining global attention, Ukraine currently lacks regulations governing the design and construction of structures using 3D printing. Additionally, there is a limited experimental base regarding the bearing capacity and deformability of printed structures.

This publication proposes a methodology for the production of monolithic beams reinforced with single bars using a construction 3D printer. It outlines the entire process of manufacturing, from the design phase to product fabrication and readiness for experimental research.

To carry out the research, the design of the beams was first created using graphic software systems, which facilitated the formulation of tasks for a construction-grade 3D printer, considering the capabilities of this technology. Design and production drawings of the samples are included in this publication.

The reinforced monolithic beams were printed using a construction 3D printer by the Ukrainian company 3D TECHNOLOGY UTU LLC, following the developed work algorithm.

This methodology enabled the reinforcement of structures with single bars, in compliance with regulatory requirements, while allowing for future experiments.

As a result of this work, reinforced monolithic beams were successfully printed using the developed technology. To assess the physical and mechanical characteristics of the materials, samples of cubes and prisms were printed and cast into formwork. Additionally, reinforcement samples were created from the same batch used to reinforce the beams.

The proposed technology for producing beams with a 3D construction printer resulted in structures that adhered to previously established design solutions. The detailed sequence for printing beams allowed for effective reinforcement of monolithic beams with single bars.

Keywords: 3D printing, beam, manufacturing technology, design.

Демчина Б., Вознюк Л., Сурмай М., Бурак Д., Щербаков С. Технологія 3D друку монолітних балок із можливістю влаштування арматурних стрижнів

Зауважено, що використання технології 3D друку в будівництві дає змогу здешевити і пришвидшити будівельно-монтажні роботи. Сьогодні у світі приділяють неабияку увагу цій технології, проте в Україні наразі немає норм для проєктування і зведення конструкцій за допомогою технології 3D друку. Також немає значної експериментальної бази щодо несучої здатності q деформативності надрукованих конструкцій.

Запропоновано й описано методику виготовлення монолітних балок, армованих окремими стрижнями, за допомогою будівельного 3D принтера. Розроблено послідовність виготовлення конструкцій, від етапу проєктування до етапу виготовлення виробу для проведення експериментальних досліджень.

Для реалізації поставленого завдання балки спершу запроєктували у графічних програмних комплексах і змоделювали у вигляді завдання для будівельного 3D принтера з урахуванням можливостей заданої технології. Подано проєктні та виробничі креслення дослідних зразків.

Армовані монолітні балки надруковано на будівельному 3D принтері української компанії ТОВ «3D TECHNOLOGY UTU» за розробленою послідовністю виконання робіт.

Завдяки розробленій методиці виконано армування конструкцій окремими стрижнями, з урахуванням нормативних вимог і можливістю проведення подальших експериментів.

За розробленою технологією надруковано армовані монолітні балки. Для визначення фізико-механічних характеристик матеріалів надруковано й залито в опалубку зразки кубиків та призм, а також виготовлено зразки арматури з партії, яку використовували в армуванні балок.

Зазначено, що розроблена методика друку монолітних балок із використанням будівельного 3D принтера дала змогу отримати конструкції, які відповідають попередньо розробленим проєктним рішенням. Послідовність друку балок дала змогу армувати монолітні балки окремими стрижнями.

Ключові слова: 3D друк, балка, технологія виготовлення, конструювання.

Problem setting. In traditional construction, concrete work is one of the most expensive components of construction production. This work requires great precision and a large number of qualified workers.

The use of 3D printing technology in construction allows not only to replace fixed formwork but also to avoid its use. This is especially important in the construction of complex architectural structures.

As of the present day, the issue of reinforcing such structures during the printing process remains open, in particular with single bars.

Due to the constant growth of the construction industry, the shortage of skilled labour, and the significant carbon footprint of construction, much attention is being paid to 3D printing technology around the world today. This technology has already been used to build residential buildings, office centres, bridges, and entire blocks of similar buildings. However, Ukraine lacks regulations for the design and construction of structures using 3D printing technology. There is also no significant experimental base for the bearing capacity and deformability of printed structures.

Analysis of recent researches and publications. Due to the high cost of formwork and the ability of a 3D printer to print complex architectural forms, research is being conducted into the possibility and feasibility of printing fixed formwork using 3D printing technology [1].

A bicycle bridge made using 3D printing technology has been built and tested in the Netherlands. The span of the bridge is 6.5 m and the width are 3.5 m. The cross-sectional height of the bridge is 920 mm. The design load on the bridge is 5 kN/m^2 [2].

Since one of the biggest limitations of 3D printing technology is the complexity of reinforcement, research is underway to develop reinforcement methods. For example, reinforcement of printed structures with steel meshes having a spacing of 6x6 mm and a bar diameter of 0.6 mm [3].

In Ukraine, Lviv Polytechnic National University is engaged in scientific research in the field of 3D printing. The dome structures, which were printed from polymers by 3D printing, were researched [4; 5].

Many researches are focused on the study of materials, or the ratio of materials in the mixture for printing. A promising area is the study of the possibility of printing with Ultra High-Performance Concrete (UHPC) [6].

In Ukraine, the 3D printer manufacturer 3D TECHNOLOGY UTU LLC is working on the implementation of 3D printing technology [7].

Task setting. The objective of this study is to develop a technology for manufacturing reinforced concrete beams using single reinforcing bars and 3D printing. This technology encompasses the design of reinforced concrete beams and the 3D printing process, which allows for the incorporation of individual reinforcing bars while considering the capabilities of a construction 3D printer. Additionally, the research aims to produce beam prototypes for further experimental studies based on the developed technology.

Main results. To complete the research task, the design of beams was first performed in graphic software systems to form a task for a construction-grade 3D printer.

The sequence of beam fabrication: beam design – determination of overall dimensions and reinforcement; preparation of a task for a 3D printer: setting the nozzle movement scheme of the printer, determining the number of passes (Fig. 1); first pass of the nozzle (Fig. 2); technological break of up to 5 minutes for concrete hardening; placement of reinforcing bars in the design position on the lower concrete layers (Fig. 3); technological break up to 5 minutes for concrete hardening; second, third, fourth pass of the nozzle with technological breaks of 3–5 min for concrete hardening, after each pass; placement of reinforcing bars in the design position along the fourth concrete pass (Fig. 5); a technological break of up to 5 minutes for concrete hardening; the fifth pass of the printer nozzle (Fig. 6); waiting 28 days until the concrete has reached the design strength (Fig. 8); transporting the structures to the laboratory.

The nozzle movement scheme of the 3D printer is shown in (Fig. 1). This figure schematically shows the direction of the nozzle in the second layer over the reinforcing bars. The beam was printed in 5 layers. Each layer consists of three passes in one level.

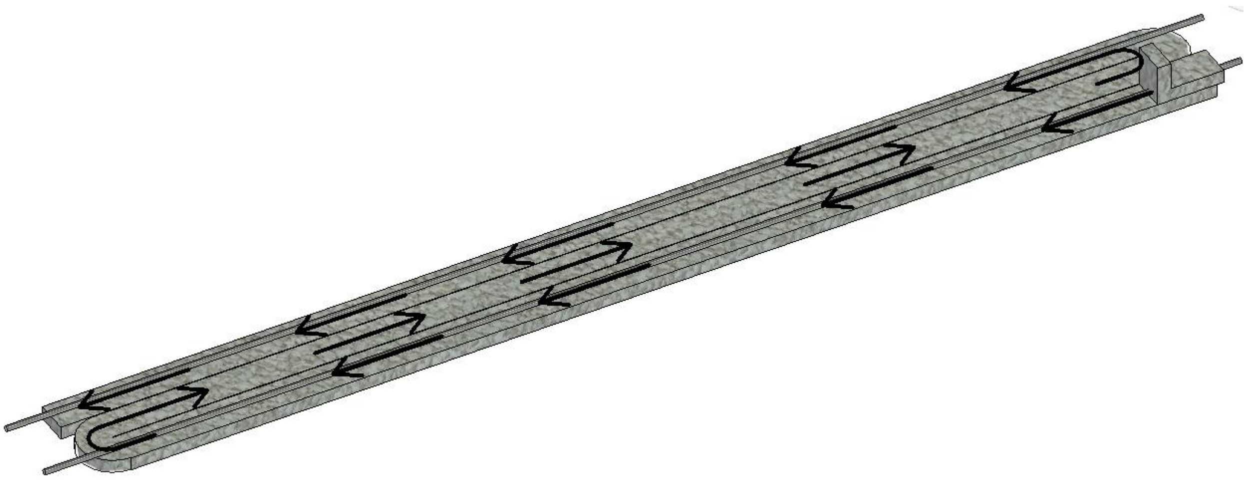

Fig. 1. Scheme of the printer nozzle movement

Fig. 2 shows the process of passing the nozzle of a construction 3D printer in the first layer.

Fig. 2. Printer nozzle passes in the first layer

Fig. 3 shows the placement of the reinforcing bars in the first concrete layer, which was performed 3–5 minutes after the layer was finished. The figure depicts the contours of the layers and the path of the printer nozzle.

Fig. 3. Reinforcement with individual reinforcing bars along the first layer of the printer

The upper and lower working reinforcement was of diameter 8, class A400C. In the zone of maximum bending moments, longer nuts were welded perpendicularly to the bar in the lower zone of the beam to allow for the attachment of reinforcement deformation measuring instruments during the test. The nuts are shown in detail in Fig. 4.

Fig. 4. Longer nut for attaching devices

Fig. 5 shows the placement of reinforcing bars on the fourth layer, which was performed 3–5 minutes after printing. After that, the fifth layer was placed.

Fig. 5. Placement of individual reinforcing bars on the fourth layer

The optimal time for ensuring sufficient hardening of the concrete layers is approximately 5 minutes. This duration helps prevent the reinforcement from "sinking" into the concrete and ensures that the protective layer around the reinforcement is maintained. During a technological break, the 3D printer can continue to operate by printing other designs instead of remaining idle.

After the final fifth pass, the printing of the beams was completed. The finished beam samples from this series are shown in Fig. 6.

Fig. 6. Reinforced concrete beams printed by 3D printing with reinforcement by single bars

After 28 days, when the concrete reached the design strength, these samples were delivered to the laboratory of Lviv Polytechnic National University for further experimental research.

As a result of the work done, a technology for manufacturing beams reinforced with single bars was developed using 3D printing technology. Working designs of the beams were also achieved, as shown in Fig. 7.

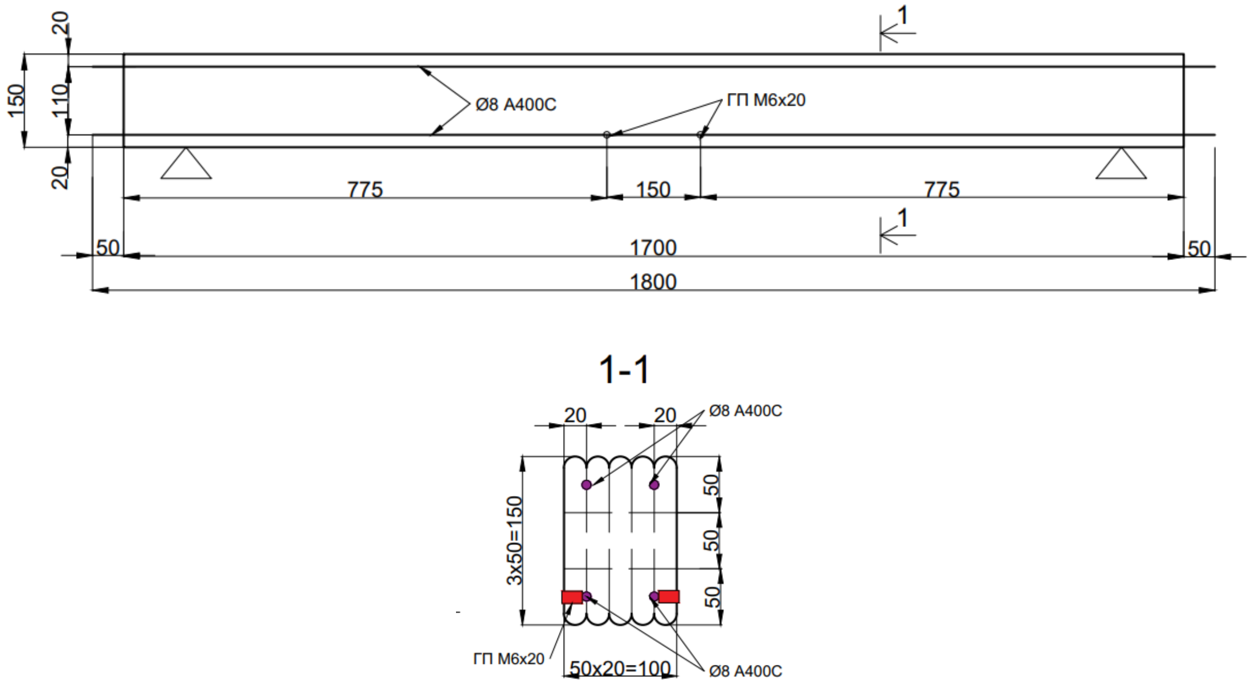

Fig. 7. Reinforced beam made by 3D printing with single bars reinforcement

The beam's overall dimensions are 1700 mm, with a cross-sectional width of 100 mm and a height of 150 mm. The beam was printed horizontally in 5 layers. Each layer consisted of three nozzle passes with a height of 20 mm and a width of 50 mm. To place the beam in the design position, it must be turned 90 degrees from the printing position.

To determine the possible slippage of the working reinforcement, it was released 50 mm beyond the surface of the concrete at the ends.

To determine the physical and mechanical characteristics of the materials, samples of cubes and prisms were printed and poured into the formwork. Reinforcement samples were also made from the batch used to reinforce the beams.

As a result of the developed methodology, beams were printed and ready for experimental research, shown in Fig. 8.

Fig. 8. Beams made by 3D printing with reinforcement with single bars after reaching the design strength

Further, it is planned to conduct experimental research of beams manufactured using 3D printing technology under load in the laboratory.

Conclusions. The technology developed for manufacturing beams with a 3D construction printer allows for the production of structures that fully align with previously established design solutions.

The proposed printing sequence enables the precise placement of individual reinforcing bars in areas subject to the highest bending moments.

This manufacturing method, particularly with the use of single reinforcing bars, can be effectively implemented in real construction practices.

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