Development of lining formwork for column expansion during reconstruction of building and structures

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Abstract. The paper highlights the relevance of the use of stay-in-place formwork systems in improving the load-bearing capacity of columns by way of their expansion during reconstruction of buildings and structures. The review of a number of scientific publications has revealed that the current phase of development of this topic is seeing increased popularity of lining formworks made of composite materials. Therefore, a new formwork system is proposed, which can be made of various materials, such as: steel fiber reinforced concrete, fiber reinforced foam concrete or the composite material PENACOM. A stay-in-place (lining) formwork consists of regular-course and edge assembly elements (sections) forming two open-ended three-dimensional U-type shapes (shop-fabricated), which, when coupled, make a square or rectangular configuration of the necessary size. Reliable coupling of the elements is achieved by puzzle connections linked both vertically (to form sections) and horizontally (to form semi-sections). The paper describes the assembling technology for lining formworks and compares it with a conventional small-panel wooden formwork, as well as pneumatic and universal formworks previously developed by the authors with the use of composite materials.

1. Introduction

Reconstruction of modern construction systems often requires improvement of the load-bearing capacity of their structural elements [1-4]. It is known that one method of reinforcing building structures is to expand the underlying structural elements (pier foundations, columns, beams etc.) by way of shaping a concrete column or jackets and so on [5, 6]. When work is performed by applying conventional methods, both removable and stay-in-place formwork systems prove suitable, often combined with concrete spraying [7-9]. At the same time, it is worth noting that active efforts have been ongoing toward the development of stay-in-place formwork using composite materials. For instance, the work [10] suggests shaping a stay-in-place formwork with highly moldable mortar reinforced with composite micronet. The scientific paper [11] discusses the creation of rugged “textile-reinforced concrete” structures with an excellent performance in terms of bending strength, which require minimum finishing and therefore, help reduce the overall work time.

2. Mein text

2.1. Goal, tasks, research methods
The terms of reference and goal of this research are associated with the development of a stay-in-place formwork system (lining formwork) that is designed to increase the efficiency of repair and construction works during reconstruction of buildings and structures.

The primary methods employed in the research are analysis, comparison and finding analogies with the existing stay-in-place formwork systems.

2.2. Structural and technological specifics of new lining formwork

When lining formwork is made using structural composite materials, this practically eliminates labor inputs normally involved in pouring the concrete slurry in the formwork system and curing the concrete layer. The analysis of a range of composite materials shows that the materials best suited for this purpose are steel fiber reinforced concrete, fiber reinforced foam concrete and structural composite foam (PENACOM). In view of this and aiming to reduce labor inputs and, as a result, the overall duration and cost of related works, it would be practicable to use a stay-in-place lining formwork.

The proposed stay-in-place lining formwork consists of regular-course and edge assembly elements (sections), which are shown in ‘figure 1’. The number of regular-course sections depends on the height of the column due for reconstruction and the height of the section itself.

![Figure 1. Structural design of a stay-in-place lining formwork: 1 – edge assembly elements; 2 – regular-course assembly element](image)

The assembly elements are two open-ended three-dimensional U-type shapes, which, when coupled, form a square or rectangular figure of the necessary size, as illustrated by ‘figure 2’.

![Figure 2. Structural design of a stay-in-place lining formwork: a – regular-course assembly element before coupling; b – external view of a regular-course assembly element after coupling](image)

For proper fastening of individual elements with each other, a puzzle type connection is considered both for vertical attachment (sections) and horizontal attachment (semi-sections interconnected) (see ‘figure 1’ and ‘figure 2’). Shapes can be shop fabricated using molding technology.
Another benefit afforded by the use of lining formwork is the elimination of “wet processes” on the construction site. The thickness of shapes depends on the number of centimeters by which the cross-section of the column under reconstruction is to be increased, and which is a calculated value obtained in consideration of the increased column load. Given the design thickness of expansion \( d \), the thickness of one semi-section of lining formwork is assumed equal to \( 0.5d \).

Lining formwork made of the above-mentioned materials can also be used to make additional floors as part of reconstruction of frame buildings [12,13]. These materials are relatively lightweight and their use has an added benefit of reducing the weight of such additional floors as well as the foundation load.

Before putting in pace a stay-in-place lining formwork, a set of preparatory works may be required. Namely, where bare main reinforcing bars are found during structural reinforcement of buildings, these must be handled by welding on additional reinforcing bars with the use of shaped short reinforcing bars, as shown in ‘figure 3’.

Table 1 below lists the main processes used to arrange a stay-in-place lining formwork, with related labor inputs, which were determined experimentally, i.e. by way of stopwatch study.

**Table 1. Structure of processes involved in arranging a stay-in-place lining formwork and labor inputs.**

| Process description                                    | Labor input, man/hour |
|--------------------------------------------------------|-----------------------|
|                                                        | Option 1 | Option 2 |
| Removal of fragile concrete areas                      | Applicable | Applicable |
| Cleaning the columns to be reinforced (dirt removal)   | Applicable | Applicable |
| Welding short bars to bare main reinforcing bars (where necessary) | Not applicable | Applicable |
| Degreasing the column surface and dust removal         | Applicable | Applicable |
| Applying adhesive to the column and the internal formwork surface | Applicable | Applicable |
| Assembly of lining formwork                            | Applicable | Applicable |
| Installation and dismantling of scaffolds              | Applicable | Applicable |
| TOTAL                                                  | 0.53      | 0.64      |

**Figure 3.** Arrangement of reinforced-concrete expansion [14].
Where an additional reinforcing cage is required, it is recommended that the lining be made of U-type sections made of steel fiber reinforced concrete.

The labor inputs were determined for lining a column with a cross-section of 400 × 400 mm and a height of 2,700 mm. The number of U-type sections is 6 each, the height of each section is 900 mm, the thickness of each section is 15 mm. This way, the contact area of the lining formwork and the column to be reinforced is determined as 0.432 mm².

Assuming the above, the labor inputs for making 1 m² of a stay-in-place formwork for option 1 is equal to 0.45 man/hour, for option 2 – 0.52 man/hour.

For the purpose of the experiment, the U-type sections were made of OSB T&G sheets. The adhesive was an epoxy glue.

The data provided in Table 1 fail to give an entirely true picture, because, when reinforcing a column with the cross-section as above, U-type sections made of steel fiber reinforced concrete, fiber reinforced foam concrete or the composite material PENACOM [15], despite the same size, may have different weights. Obviously, labor inputs will increase for certain operations, such as lifting and bringing semi-sections to the place where the lining is made. Practice shows that columns bearing high loads, which are to be expanded as part of reconstruction, may have their cross-section increased by 30 cm and more.

3. Conclusions
In order to assess the efficiency of the newly developed lining formwork, we will compare it with a conventional small-panel formwork system and some innovative formwork systems (pneumatic and universal transformer formworks) developed by the authors and presented in the papers [16, 17], which are used for reconstruction of buildings and structures.

‘Figure 4’ below provides the comparative labor inputs data for all formwork systems developed by the authors versus a conventional small-panel formwork used in rehabilitation and reconstruction works.

![Figure 4](image)

**Figure 4.** Labor inputs as man-h/m² involved in the installation and dismantling of conventional pneumatic, universal and stay-in-place formworks.

The newly developed removable formwork systems [16,17] allow reducing labor inputs involved in the installation and dismantling works. Although the labor inputs associated with the installation of the proposed stay-in-place formwork (lining formwork) were assumed as the maximum level, it should be noted that, compared to other methods shown in ‘figure 4’, they demonstrate the overall most efficient performance. Eliminating temporary forming equipment, this is not only an element improving the
load-bearing capacity of the columns under study, but also the put-in-place finishing material (decoration element), and it will suffices to apply a layer of the finishing painting required for design purposes to have the structure ready for use. At the same time, the use of other formwork systems necessitates the performance of works, such as filling in the concrete mixture and its curing followed by a range of finishing works.

The calculation of savings accomplished by reducing labor costs (table 2) was made in accordance with the current regulatory document [18] using the formula

\[ E = (T_p - T_{pred}) \cdot A; \]

where \( T_p \) – labor inputs involved in the installation and dismantling of a conventional formwork, \( T_{pred} = 0.065 \text{ man/day; } T_{pred} \) – labor inputs involved in the installation and dismantling of an innovative formwork, man/day; \( A \) – scope of actually performed work (conventionally assumed equal to 1,000 m²).

| Parameter                          | Pneumatic formwork | Universal transformer formwork | Stay-in-place lining formwork |
|-----------------------------------|--------------------|--------------------------------|-----------------------------|
| Labor inputs – installation and dismantling, man/day | 0.029 | 0.049 | 0.056 |
| Labor savings, man/day per 1,000 m² | 36     | 16    | 9    |

The labor savings accomplished through the use of the newly developed formwork systems are shown in ‘figure 5’.

![Figure 5. Labor savings (RUB) accomplished through the use of the new formwork systems in the current-year prices with an annual work scope assumed as 1,000m².](image)

To sum up, we would like to note once again that the new stay-in-place lining formwork is not only an element improving the load-bearing capacity of columns to be reinforced by way of expanding their cross-section, but also a finishing material. The efficiency ensured by the use of this formwork consists in the elimination of labor inputs involved in finishing works. Therefore, the practical value of this paper can be realized by utilizing its results in reinforcing structural elements as part of reconstruction of buildings and structures, with minimal labor inputs. The theoretical value of this paper is warranted by the fact that it can be used as the basis for developing new stay-in-place (lining) formwork systems made of composite materials, which are required to improve the load-bearing capacity of columns by way of expansion (eliminating “wet” onsite processes) during reconstruction of buildings and structures.
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