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Stay-in-Place Formworks Applied in Civil Engineering – Requirements and Scope of the Control

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Abstract. Formworks are an inseparable element of the building and engineering structures shaping, which are implemented in technology of the monolithic concrete. This article attempts to collect information related to construction and material, as well as utility conditions which formworks should meet. Particular attention was paid to issues related to the use of SIP (stay-in-place) formwork systems. General requirements and functions that should be met by formworks (especially SIP formworks) are discussed, with an indication of loads acting on those formworks. In addition, the scope of control carried out as part of the execution supervision of formworks was analyzed and necessary actions to be taken in the event of a detected non-compliance were presented.

Introduction

It is estimated that 60-70% of all currently constructed building and engineering structures are made in concrete structure technology, in both prefabricated and monolithic constructions [1]. The undeniable advantages of this technology include, among others, the following [2, 3]: freedom of architectural forming, the possibility of using convenient static systems of individual structural elements, the possibility of recycling of selected elements after the end of the construction period, increased durability and resistance of the structure exposed to seismic movements or impact of the dynamics.

The shaping of almost every structural element made in monolithic technology takes place on the building site. This creates the necessity of using special forming devices, the so-called formworks [4], tasked with giving the right shape to a concrete mix and supporting a formed element before it reaches adequate strength. The stay-in-place (SIP) formwork is a separate category because it is an element that cannot be removed. This type of formwork is permanently installed and after the concrete work is an indispensable part of the object. During implementation, the SIP formwork acts as a forming and supporting element, while during operation – a construction, insulation (including insulation against corrosion) or construction-insulation element [5-8].

General requirements

According to the norm [9], structural formwork is used to give a concrete mixture the right form, consistent with the assumed architectural and construction design. Its task is to ensure proper support of a reinforcement during concreting and also to a concrete mixture until the concrete hardening process is completed and the desired strength is obtained. One of the most important requirements for a formwork is the possibility of its execution in accordance with the design model and applicable standards [10-13]. Formworks are a very special type of a temporary construction, where the pressure coming from the concrete mix is the leading parameter associated with the structural design [10, 14].

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In addition, a SIP formwork after the curing process of the concrete, during operation of the structure can act as an additional external reinforcement, integrated with the entire structure, transferring other external loads associated with the work of this structure. SIP formworks can also give a construction structure other special features, such as thermal or damp insulation [2, 3]. Basic conditions that should be met by SIP formworks are to ensure proper connection of the formwork with the monolithic part of the structure and allow a correct execution of reinforcement work. Moreover, at the moment of commencement of concrete works, formwork bearing elements should have proper strength and stiffness to enable a safe transfer of loads from the weight or pressure of the concrete mix [15, 16].

There are three main functions that building formwork should fulfill [15, 17]:

- ensuring the safety of the structure - it is necessary that a formwork meets all load capacity conditions, while maintaining appropriate safety factors,
- maintaining appropriate technical quality - designing and execution of a formwork should ensure proper stiffness, positioning and geometry of a formwork construction,
- economy - minimizing the time and costs associated with the implementation of a construction structure is directly related to the effective execution of a formwork.

The last factor is as important as the other two because the cost of a formwork can reach 35% to 60% of the total cost of constructing concrete [17]. The economics of formwork structures is also associated with the type of material from which the formwork is made. It is advisable to use materials with high strength and resistance [2].

Quality Control of formworks

Supervision and control are carried out in order to check the compliance of construction works with the design and technical specification. It refers not only to the verification of works, but also to the properties of the used products and materials [18, 19]. This control may concern both the whole structure and its individual elements or some technologies used in the structures. The requirement regarding the scope of control is determined in relation to the selected control class (Table 1). The expected control class should be specified in the design specification [3].

Depending on the control class, the scope of contracting supervision includes the following [3]:

- 1st class of control – a visual inspection and testing of randomly selected elements,
- 2nd class of control – a visual inspection and systematic inspection of a large formwork carried out before concreting,
- 3rd class of control – a visual inspection and detailed inspection of all works related to the formwork, affecting the achievement of adequate load-bearing capacity and durability of the formed structure (also made before the start of concrete works).

According to the recommendations in the standard [10], the control of a formwork should be done not only before concreting, but also after laying the concrete mix. The purpose of a control performed after concreting is to check strength parameters of the concrete, while the following things are subject to a control before concreting [15]:

- geometry of a formwork,
- leak tightness of a formwork,
- stability of a formwork and props (including the substructure of props),
- elimination of pollution such as dust, ice, snow etc.,
- elimination of water from the formwork surface,
- proper preparation of the formwork surface.

If the control reveals some non-compliance, proper measures should be taken as soon as possible to ensure that the construction fulfills functions consistent with the project. It is recommended to carry out a corrective procedure, where the analysis should be made in the strictly specified order [3]. The repair procedure is presented in Fig. 1.

Table 1. Control classes to which structural elements and building structures are subject [10].

Type of item	1st class of control	2nd class of control	3rd class of control
Structural elements	single walls single columns single foundations as foundational footings RC (reinforced concrete) plates and beams with a span of *less than 10 m*	slender walls slender column pile caps arches with a span of *less than 10 m* RC (reinforced concrete) plates and beams with a span of *more than 10 m*	RC arches and vaults arches with a span of *more than 10 m* complex foundation structures elements that are affected by high values of compressive forces
Building structures	buildings with *less than two floors*	buildings with *more than two floors* (no more than 10 floors) typical bridge structures	high-rise buildings special bridge structures nuclear reactor buildings large dams and hydrotechnical structures other security housing

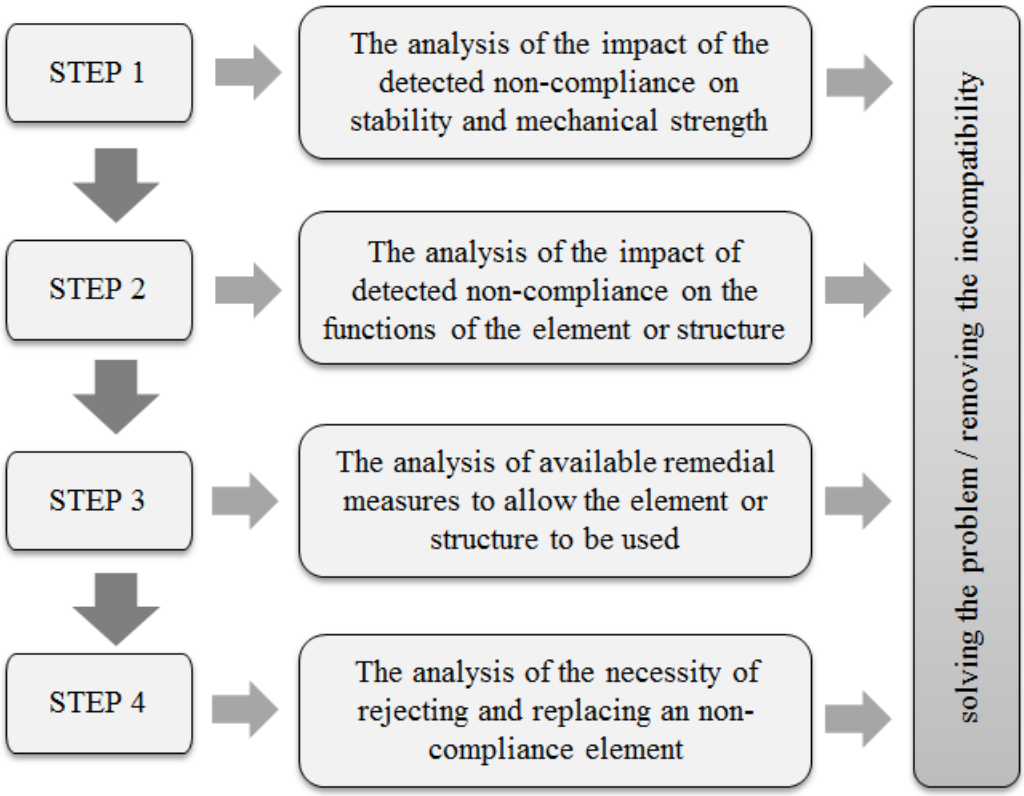

Fig. 1. The schema of the repair procedure [3].

Works related to the execution of the formwork of a structure are often at heights. Then it is extremely important to protect employees against a life-threatening fall. Ensuring a proper safety and health plan and compliance with applicable health and safety regulations is a superior responsibility of the safety and health plan [20]. One of the most common technical and organizational mistakes include downplaying the necessity of using safety equipment for a formwork [21]. If any violation is detected, all measures must be taken immediately to remedy the irregularity.

Summary

Most of the currently implemented construction projects are made in the monolithic concrete technology, which often requires the use of individually designed construction formworks. Due to their functions, such as ensuring the correct shape of a concrete element, transferring the accompanying impacts and establishing an integral part of the structure during operation, the SIP formworks must meet a number of specific requirements. Above all, they should ensure safety of people and constructions, maintain appropriate technical quality and be used as effectively as possible, which translates into the economy of the entire investment. In addition, each formwork (especially a SIP formwork) is subject to strict supervision and compliance control with the design and technical specification. In the case of a non-compliance and excessive intolerance, it is necessary to carry out an appropriate repair procedure, ensuring that the structure performs functions consistent with the project.

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