ANALYSIS OF REINFORCEMENT STRUCTURES IMPROVEMENT AND ITS STABLIZATION

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Abstract

The topic of sustainability of reinforced concrete structures is strictly related with their durability in aggressive environments. In particular, at equal environmental impact, the higher the durability of construction materials, the higher the sustainability. The present review deals with the possible strategies aimed at producing sustainable and durable reinforced concrete structures in different environments. It focuses on the design methodologies as well as the use of unconventional corrosion-resistant reinforcements, alternative binders to Portland cement, and innovative or traditional solutions for reinforced concrete protection and prevention against rebars corrosion such as corrosion inhibitors, coatings, self-healing techniques, and waterproofing aggregates.

***Keywords**: concrete durability; rebars corrosion.*

Introduction

Production of the reinforced concrete floors of civilian buildings, when compared to other main elements of the supporting frame, using any known technology and work organization (factory prefabricated, monolithic, concreted in formwork or prefabricated monolithic) is characterized by significantly higher unit costs of the resources and, consequently, by their devices cost. This is due to their design work on bending, which requires the use of high-strength concrete, as well as sufficient reinforcement for the perception of the design loads. Moreover, the design loads for the precast prefabricated floor structures should also include technological, storage, installation and transport loads. And in case of a monolithic version, a large set of formwork is required, which is determined by the substantially large terms of the floors demolding start due to the need to perceive design loads immediately after stripping. That determines the relevance of further scientific research and pre-project developments aimed at reducing the overall resource consumption of the production and use of innovative structures of the reinforced concrete floors.

The possibility of improving the manufacturability of the design solutions of monolithic and precast monolithic structures of buildings and structures by studying and reducing resource costs throughout the life cycle is shown in our work. The studies of the manufacturability of the disassembled adjustable formwork systems also develop this idea. The work shows the reserves for reducing the duration, laboriousness and cost of the reinforced concrete structures producing of high-rise civilian buildings through the selection and use of a more rational set of small-panel board folding formwork. But they do not stand out separately and do not focus on improving manufacturability and the floor structures themselves as the most resource-intensive and, therefore, have large reserves to reduce the unit costs.

In the field of construction materials, it is increasingly evident that traditional environmental parameters (such as global warming potential (GWP), and gross energy requirement (GER)) as well as life cycles analyses are needed but not sufficient to define the sustainability of a building material. Simple parameters based on concrete composition, CO2 emissions, and compressive strength is no longer adequate for a holistic treatment of the issue. It is essential to combine information regarding the material performances and durability with the evaluation of its environmental impact. In other words, it is not possible to define a construction material as "green" without a deep investigation of its property evolution in different environments over time. The phenomena of early degradation, primarily those promoted by carbon dioxide or chlorides, can greatly reduce the sustainability of cementitious materials, both traditional and innovative. Therefore, this review aims to collect the main strategies currently available for obtaining durable and sustainable reinforced concrete structures, using both traditional and innovative materials.

Literature review

Sifatullah Bahij (2020) In the last few decades, premature deterioration of reinforced concrete (RC) structures has become a serious problem because of severe environmental actions, overloading, design faults, and materials deficiencies. Therefore, repair and strengthening of RC elements in existing structures are very important to extend their service life. There are numerous methods for retrofitting and strengthening of RC structural components such as; steel plate bonding, external pre-stressing, section enlargement, fiber-reinforced polymer (FRP) wrapping, and so on. Although these modifications can successfully improve the load-bearing capacity of the beams, but they are still prone to corrosion damage resulting in failure of the strengthened elements. Therefore, many researchers used cementitious materials due to their low-cost, corrosion resistance, and resulted in the improvement of the tensile and fatigue behaviors.

A V Andronov (2019) This study shows the feasibility of improving the manufacturability of the prefabricated monolithic floors reinforced concrete structures production by reducing their own weight. In the works of the authors, the reduction of the sole weight and the cost is achieved by using the light materials filling the inter-gully space. It is proposed to use gas-concrete, polystyrene foam concrete blocks or limestone-limestone blocks as a local building material in the Crimea with such materials for the advanced system MARCO. Due to that, the cost of the interfloor overlap device has been reduced by approximately 10%. In addition, there is an additional cost reduction also due to the improved ergonomic work performance, increasing the productivity of workers by 6%.

Corrosion Mechanisms in Reinforced Concrete Structures

The protective capacity of reinforced concrete against carbon steel corrosion is one of the fundamental points that have made it the most used construction material for industrial and civil structures. Steel reinforcements give tensile strength to cementitious materials, and concrete offers protective conditions to preserve the steel from corrosion, thus making production of durable structures possible. The protective action is due to the formation of hydration products of Portland cement, which increases the alkalinity of the water inside the pores of the hardened concrete. In fact, the corrosion behavior of carbon steel is strongly influenced by the pH of the pore solution, and it is assumed that it is passive when it exceeds 11.5. In these conditions, the corrosion rate of carbon steel reinforcements becomes negligible due to the formation of a protective passive film, which slows down the anodic process of metal dissolution. Portland cement is composed by calcium silicates, which, reacting with water during the hardening process, lead to the formation of calcium hydroxide. This substance is a strong, slightly soluble hydroxide, which saturates the water of the pores. At room temperature, a simple saturated solution of this substance has a pH around 12.5. However, the pH of fresh cement paste is generally higher due to the presence of small amounts of sodium and potassium hydroxides, determining the increase in the pH up to 13.5. These alkalinity levels are reached immediately during the mixing, thus promoting a rapid passivation of the reinforcement. The free corrosion potential of rebars rapidly increases, during the setting and hardening phase, up to potentials typical of passive conditions. Fresh concrete is a suspension of water, solid particles of different granulometry, and cement dust, where water represents an amount of only about 20%. The solution in contact with steel reinforcements is limited to the adjacent water film, while the solid/liquid ratio increases as the degree of hydration increases. The alkali content of this water thin layer, responsible for the passivity of steel, does not depend only on the content of the above-mentioned hydroxides or on the possible presence of pozzolanic material, but also on the consumption of hydroxyl ions for the formation of the passive film itself. The protectiveness tends to increase over time and it becomes stable only after several months embedded in the cement matrix.

The protective action by Portland cement concrete, however, is not only due to high pH values, but it also depends on the presence of chlorides and on the ability of the cement matrix to decrease the chloride and carbonation penetration through the concrete cover.

The purpose of this scientific-applied work is to reduce the cost of the device for the interfloor reinforced concrete floors and coatings by reducing their own weight by choosing, justifying and developing the improved structural and technological systems for such floors.

The tasks of this work are determined as follows:

- The analysis of the status of the issue of improving the manufacturability of the device of the reinforced concrete floor structures with the identification of directions for their possible improvement by replacing a part of heavy concrete with hollow or solid liners of the lighter materials;
- The reasonable development of such ceilings improved designs, describing their essence and technological advantages; experimental and production studies of these structures;
- The assessment of the feasibility and effectiveness of the developments approbation to improve the technological level of the prefabricated monolithic civil engineering in the Crimea. The solution of the tasks determines the main content of this work.

Corrosion Inhibitors and Surface Treatments

Additional protection methods are necessary for reinforced concrete structures operating in severe field conditions or when very long service life is required: corrosion-resistant reinforcements, cathodic prevention, corrosion inhibitors, and surface treatments represent suitable "tools" to prevent corrosion in very aggressive environments. Surface treatments to apply on the surface of reinforced concrete elements are efficient protective methods at a relatively low cost. The European Standard EN 1504-2 identifies:

(a) Hydrophobic treatments, based on silanes, siloxanes and silicones;

(b) Treatments able to seal the capillary pores, based on sodium silicate or magnesium fluorosilicates;

(c) Organic coatings forming a continuous film, with a thickness between 0.1–0.3 mm, thermoplastic (acrylic, vinyl) or thermosetting (epoxy, polyurethane);

(d) Cementitious mortars containing acrylic or vinyl polymers with polymer/cement ratio in the range of 0.3–0.6 and thickness between 1 and 5 mm.

Self-Healing Strategies for High Durability Concrete

Concrete is a low-tensile strength and fragile material that is very susceptible to cracking mainly due to shrinkage, tensile stress, and freezing and thawing cycles. Generally, microcracks do not significantly jeopardize the elastomechanical performance of concrete but promote an easier penetration of external matters such as water and other chemical agents (i.e., sulfates, chloride, and acids) resulting in cement matrix degradation followed by a corrosion of steel rebars. In other words, the microcrack formation is generally responsible for a reduction in a service life of concrete structures without affecting their strength. For this reason, the development of techniques aiming at increasing the lifespan or reducing the maintenance costs of buildings is essential, especially in a sustainable perspective of concrete structures. In the last years, starting from the autogenous self-healing phenomena, researchers investigated several self-healing approaches able to improve the natural capability of concrete to fill cracks.

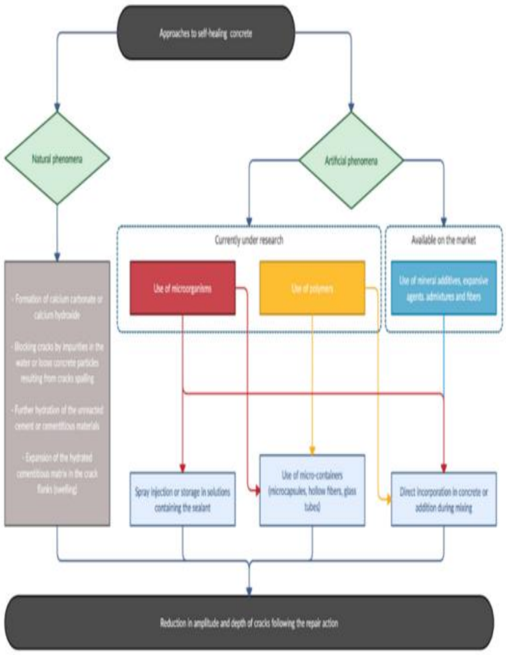

Figure: Different approaches to self-healing

A technique similar to the bacterial concreting involves the use of polymeric-based repairing agents (such as epoxy resin, methyl-methacrylate, ethyl-cyanoacrylate, or polyurethane) stored in hollow glass fibers, ceramic tubes, porous plastic fibers, or micro-/macrocapsules. The healing ability is related to the microcapsule damage around the cracks that releases the healing agent. Nevertheless, issues related to rheology, dispersion of microcapsules, and mechanical strength loss must be solved before a widespread use of these systems.

Corrosion Resistant Reinforcements

When the concrete cover is not able to provide the proper protection against corrosion of the traditional carbon steel reinforcement, e.g., in highly aggressive environmental conditions (especially in the presence of chlorides) or when a long service life is required, it is possible to use additional prevention/protection systems in order to guarantee the required durability. The use of corrosion resistant reinforcements is one of the main additional prevention/protection systems and can be a sound choice for new structures or in repair of existing ones. The corrosion resistance of reinforcements can be obtained with coatings, both metallic (galvanized steel) or organic (epoxy coated bars), modifying the chemical composition of the steel (mainly using stainless steels) or using composite materials.

The corrosion resistant reinforcement should fulfil the requirements settled for the traditional carbon steel bars, such as strength, ductility, weldability, and bond to concrete. These rebars are characterized by different corrosion behavior and costs. Their related benefits can be evaluated with performance-based approaches for the design of durability. As far as the costs are concerned, although their higher initial costs, their use can lead to significant costs savings during the service life of the structure, due to a reduction in maintenance costs (direct and indirect). Moreover, a selective use in the most critical parts can be considered, thus a reduction in the initial cost can be achieved.

Results

The use of the multi-hollow floor slabs of the high-rise civilian buildings should be considered ubiquitous in the USSR and certainly an effective technological solution to the past. Changing the hingemovable work scheme for pinching in the monolithic supporting zone with preserving the reverse bend, it is still possible to achieve some saving of resources. The new elaborations of the CSRIEE housing introduce the practice of high-rise civil construction of new generation houses, differing in the use of prefabricated multi-core reinforced concrete floor slabs of increased spans, thickness and carrying capacity. The constraining factor in the development and distribution of such innovative structural and technological systems is the lack of domestic equipment for factory manufacturing of hollow-core reinforced concrete slabs. The simple and time-tested flow aggregate production lines of the prestressed slabs, in most cases, were destroyed during the crisis, and the foreign-made stand-shape molding lines, although energy-efficient, require large up-front investments that can be recouped only with the mass construction of the mentioned houses new generation.

Meanwhile, the analysis of the available publications and production experience allows us to trace another trend - the development and implementation of foreign elaborations in Russia, including the replacing part of heavy concrete in interfloor flat slabs with lighter inserts made of materials of artificial origin (lightweight concrete, expanded polystyrene, cardboard, plastic, etc.). So, such examples as the theoretical and experimental studies of specialists of the Siberian Federal University (SFU) are of interest with the purpose to create a precast-monolithic construction of an interfloor overlap in which its lower part is made in the factory using the same method of continuous formless molding, and the upper one is concreted later in the project position of lighter concrete. Certainly, the savings in materials and the reduction in its own weight of the structure cannot be noticeable because the lighter concrete should be replaced on the upper part of the slab and must necessarily be structural, perceiving compressive stresses in the span and tensile and tangential at the bearing sections. It is preferable to exclude or replace heavy concrete in the middle of the span and the thicker slab close to the neutral line of normal stresses. But, from the technological point of view, the possibility of simultaneously creating a heat-insulating screed immediately below the floor finish is also positive.

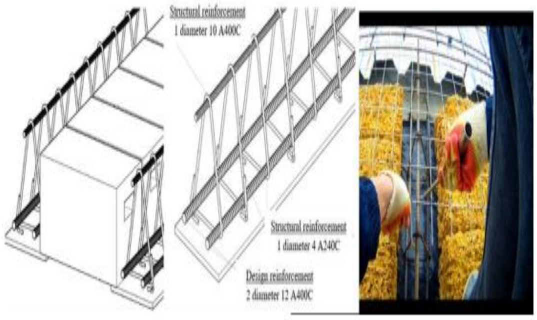

Figure: Elements of the prefabricated system and the obtained cross-sections of the spatial reinforcement frame of the monolithic supporting beam of the projected slab – the object of research and introduction

But in general we see the more promising structures for reinforced concrete floors with fixed formwork for bearing prefabricated monolithic beams, between which there are various inserts that replace reinforced concrete with a lighter building material, on the top of which a thin reinforced concrete slab is concreted. The substantial savings of heavy concrete are achieved by reducing the own weight of the slab, thereby reducing the design constant load on which the structure is designed. These systems include MARCO systems, manufactured and supplied to the Russian market, for example, by Columbus, GRAS and others. Analyzing the well-known foreign systems Porotherm, Teriva, Ytong, Rectolight, as well as the previously mentioned domestic precast monolithic system SMP MARKO (prefabricated monolithic floors - monolithic reinforced structures) created in their development, it was found that the latter is the most adapted (technologically advanced) for use in the Crimea. Its proposed modification consists in replacing the prefabricated reinforcing-shuttering block with two elements manufactured in construction conditions – the reinforcing spatial framework and the formwork board-foundation, on which a gap providing the required thickness of the protective layer of concrete, the reinforcement framework was mounted.

Such a modification makes it possible to completely eliminate transportation costs for the delivery of factory-made elements, which for the conditions of the Crimea are of great economic importance due to the range of factory production locations of such prefabricated elements and, until now, quite complex logistics. In the process of experimental implementation of the proposed technology, some time-keeping observations had been carried out, the video recording the process was carried out simultaneously by the two cameras from different points, and the physiological parameters of the state of the workers were recorded online. After processing the results of the experimental observations according to the selected methods of evaluating the ergonomics of labor, the severity category of labor from heavy (when setting up monolithic floors) to medium reduction was observed when performing the work on the proposed technology. This additionally gives also the substantial increase in the labor productivity of workers by 6% with a corresponding decrease in the production costs. Even more tangible will be the economic and social effect of replacing liners from local blocks of the Crimean shell rock to similarsized blocks of aerated concrete, polystyrene concrete or even polystyrene foam.

Conclusion

This paper highlights the possible strategies for obtaining sustainable and durable concretes. In particular, it is shown how it is possible to realize durable reinforced concrete structures in different aggressive environments through an appropriate design that starts from a proper concrete composition (binders type and dosage, water content, aggregates, admixtures), passes through the choice of reinforcements (traditional carbon steel, galvanized steel, stainless steel, composite materials or coated reinforcements), and ends with the selection of additional solutions such as inhibitors, coating, self-healing techniques or waterproofing aggregates.

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