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Mini Review

Eco-Resilient (ECORE) Concrete Constructions: A New Challenge and A New Concept

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Abstract

This paper presents a new concept concerning the development of eco-resilient concrete constructions, that is to say constructions with a reduced carbon footprint and which can withstand mechanical stress and physico-chemical attacks worsened by climate change. After a critical analysis of current research and development policies in the field of concrete construction, a new global approach is proposed which should allow this concrete construction profession to better respond to the challenges caused by global warming. This approach is based on two strong ideas

a) The use of fiber concretes in combination with passive or active reinforcements in all constructions susceptible to crack

b) The use of numerical models based on non-linear finite element calculations in order to optimize the design of eco-resilient concrete constructions.

Introduction

Climate change has different origins and consequences. Concrete constructions contribute to its origins and suffer from its consequences. Due to the high carbon footprint of cement, the main component of concrete, they are a significant contributor to global warming (not to mention the consumption of natural resources). As the most widely used material in the construction industry, concrete constructions fall victim to climate change. Indeed, climate change leads to exceptional and frequent natural risks. Among these risks, we can mention, non-exhaustively, floods, coastal flooding, earthquakes, and fires. All of these lead to severe mechanical and physical aggressions that these constructions must resist. The most significant aggressions include dynamic stresses (shocks and earthquakes), temperature variations (day/night, summer/winter), humidity variations (rain/drought), water penetration (floods), and very high temperatures (fires). Concrete constructions must therefore become increasingly resilient. The main aspect of this resilience is related to the design of these constructions, which must enable them to withstand with minimal damage. This is important, as rapid, cost-effective repairs that are resource-efficient are the best candidates for sustainable development. In conclusion, today's and tomorrow's concrete constructions must be ecological and resilient or eco-resilient (ECORE constructions). These two objectives are not so easy to achieve. The current research and development in the field of concrete constructions is an illustration of this.

This article aims to offer a critical analysis of current research and development in the field of concrete constructions and to propose a more relevant global approach to address the challenge posed by climate change: building with concrete in an ecological and resilient manner.

Critical Analysis of Current Research and Development in the Field of Concrete Constructions

Research at the material scale

Research and development, considered at the international scale, has mainly and strongly focused in recent years on the ecological aspects of concrete with the primary objective of reducing its carbon footprint. To achieve this, studies have focused on the development of concrete formulations containing less cement, by replacing this cement with powders that have lower carbon footprints than cement and/or come from recycled materials. They have thus focused on aspects related to rheology (workability), durability, and basic mechanical behaviors (compressive and tensile strengths) of these new "ecological" or alternative concretes.

However, it should not be forgotten that a construction material has no other purpose than to be used in the construction of a building (this is obvious). It is therefore the building itself that must be ecological, and concrete is only a means to achieve this. Concrete construction becomes "ecological" by reducing the amount of cement it contains while ensuring the functions it is required to perform.

As previously mentioned, due to climate change, concrete constructions are subjected to increased mechanical constraints and physico-chemical aggressions. Understanding the cracking process of these constructions is a major issue to consider in light of these aggressions, because:

a) The cracking process of concrete subjected to impulsive solicitations (such as shocks) or seismic type solicitations (which fall within the scope of plastic fatigue) is very different from that related to quasi-static solicitations.

b) So-called service cracking (crack openings not exceeding, normally, 300 μm) constitutes a very important accelerator for the penetration of aggressive liquids (water containing aggressive ions) for both concrete and reinforcements present in load-bearing structures, such as passive reinforcement of reinforced concrete or active reinforcement of prestressed concrete.

However, determining the tensile and compressive strengths of concrete does not provide relevant information on the static cracking process, let alone under seismic or dynamic (shock) solicitations of a construction made of this concrete. Only the use of fracture mechanics theory allows access to this relevant information.

Consequently, current research on alternative concretes are not enough relevant to meet the challenges of climate change.

Research at the structural scale

As mentioned previously, it is the concrete construction itself that must be ecological. In other words, this construction must minimize, for given functions, the amount of cement of which it is made. This minimization necessarily involves the choice of the design method chosen for the construction.

Nowadays, concrete constructions are predominantly dimensioned through the use of design standards (in Europe, the Eurocodes). They were established at the beginning of the 20th century to allow numerous design offices around the world to quickly and as safely as possible design concrete constructions. These design standards are based on fairly rudimentary simplified approaches compared to the real mechanical and physico-chemical behaviors of concrete constructions. This is one of the main reasons why they involve numerous so-called safety factors, which aim to compensate for the shortcomings present.

The problem, in light of current challenges, is that these safety factors generally lead to significantly oversizing concrete constructions, without always oversizing them for safety. In other words, the design standards lead to an overconsumption of concrete and therefore cement. Today, a large majority of national and international working groups concerning the design of concrete constructions are working on improving the design standards. Improving a conceptually inadequate tool will not lead to an adapted tool, but can only reduce its inadequacy.

Proposal of a global approach to the design of ECORE concrete constructions

In order for concrete constructions to improve their resistance to mechanical and physico- chemical aggressions related to climate change, they must improve their resistance to cracking in the face of these aggressions.

It is now known and accepted that fibers, especially steel fibers, contribute significantly to controlling this cracking (research on this subject is completely clear and mature). Thus:

a) They are more effective than reinforced concrete reinforcements in controlling service cracks. For the same service solicitation, the cracks are less open, more tortuous in their path, and often discontinuous in the presence of fibers. Concrete constructions thus resist the penetration of liquids much better.

b) Fibers associated with reinforced concrete reinforcements significantly improve the behavior of concrete constructions under shock and seismic loads.

These positive contributions of fibers are linked to the fact that they act on a different scale than the cracking process of concrete and are complementary to considered classical reinforcements (passive and active reinforcements). Fibers must be considered as indispensable as these classical reinforcements today. Fibers must be used in all concrete constructions for which their functions are penalized by cracking. The addition of fibers thus leads to an improvement in the resilience of concrete constructions, but does not necessarily meet the objective of improving the ecological performance of these constructions. To achieve this, their design must result in a significant reduction in the quantity of cement used, as well as in the quantity of reinforcements and fibers.

Constructions with hyperstatic mechanical behavior are those that lead to greater safety when they are subject to cracking. This fact is linked to a much less localized cracking process (due to stress redistribution) than that related to statically isostatic constructions, especially when it comes to service cracking. As previously mentioned, design standards for concrete structures are too rudimentary to realistically consider the multiple cracking mechanisms of hyperstatic structures, whether they are reinforced concrete structures or fiber reinforced concrete structures, and even less so when it comes to a mixed reinforcement composed of rebars and fibers. They cannot lead to an optimized design of these structures. The solution can only come through the use of nonlinear finite element analysis, i.e., considering the cracking processes of concrete constructions.

There are a number of numerical models in the literature that have this objective. The main problem in using these models for an optimized design (in terms of shape, geometry, and dimensions) is that they are currently insufficiently validated at the scale of real structures. In the past, numerous experimental studies were carried out internationally on structures or structural elements at the full scale. The main objective of these studies was to show that the design standards were relevant with regard to their ultimate state resistance. Today, similar test campaigns must be carried out. However, this time, their objective must be to convincingly validate these numerical models with regard to their ability to qualitatively and quantitatively consider the cracking processes at the service and ultimate limit states of structures. If this objective is not considered a priority in the field of concrete constructions, it is unlikely that the concept of eco-resilient (ECORE) constructions will develop.

Conclusion

This paper addresses the response of the concrete construction industry to the challenge posed by climate change and the resulting disruption. It is indicated that to meet this challenge, a relevant, effective, and accessible approach consists of developing the concept of eco-resilient (ECORE) constructions. This concept is based on two strong ideas:

a) Using fiber concrete in combination with passive or active reinforcements in all constructions likely to crack when subjected to solicitations aggravated by climate disruption.

b) Using numerical models based on nonlinear finite element analysis to optimize the design of these eco-resilient concrete constructions.

The implementation and success of this new concept are strongly linked to the realization of numerous experimental campaigns on structural elements at the full scale. These campaigns aim to convincingly validate these numerical models.