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Intervention Methodology for the Rehabilitation of Damaged Reinforced Concrete Structures

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Abstract. The quantity of aging concrete infrastructure deteriorating rapidly is increasing, as are the costs of repairing these structures. The management of interventions on reinforced concrete structures is not always optimal. This is due to the absence of a comprehensive protocol capable of uniformly guiding engineers in their choices regarding the priority and types of work to be carried out on their structures. This lack of decision-making assistance results in interventions that are not always optimal in terms of costs and durability. It is therefore important to establish a diagnostic methodology in order to properly specify the origin of the damage. This will improve the interpretation of defect symptoms and therefore facilitate the subsequent choice of actions and materials required during the intervention on the structure.
This study presents a methodology developed with the aim of standardizing, rationalizing, and integrating the different stages required to achieve optimal and quality interventions into a management tool. Three activities are essential in order to systematize the approach to refurbishment or maintenance of concrete structures: the diagnosis of deterioration, the evaluation of the relevance of interventions, and the selection of appropriate methods and products for refurbishment.

Key words: Degradations, Damage, Diagnosis, Intervention, Durability.

1. Introduction

Over the past ten years, the concrete repair industry has experienced significant growth. Indeed, a significant number of civil engineering structures require regular repairs to maintain their serviceability and extend their service life. However, the estimated costs for restoring concrete structures and refurbishing infrastructure are very high. This situation highlights the importance of developing sustainable and cost-effective solutions for maintaining concrete structures.

The nature and origin of defects in a concrete structure are numerous (Figure 1). Errors can occur during the design or construction phase of the structure. Other damages may appear during the life of the structure due to accidental loads such as earthquakes(Lu *et al.*, 2022; Usta, Onat and Bozdağ, 2023), accidental overload, usage loads, weather conditions(Ahmad, Pan and Chen, 2021; Khan and Santha Kumar, 2021), and industrial (Okeniyi *et al.*, 2015) and chemical environment. Concrete diseases can also cause serious deterioration in structures such as alkali-aggregate reaction (Ghiasvand *et al.*, 2023; Sirivivatnanon *et al.*, 2023), sulfate attack (Esselami, Wilson and Tagnit-Hamou, 2022; Liu *et al.*, 2022), and corrosion (Anterrieu *et al.*, 2019; Benítez *et al.*, 2019). In structures that need repairing, damage can range from local defects (cracks, chips, etc.) to significant delamination and deep chemical attacks. Other damages can be caused by thermomechanical loading (Bouabdallah, 2022). The structure may no longer perform its function: waterproofing, load-bearing capacity, aesthetics, etc. Therefore, intervention is necessary to restore and/or improve the initial function of the structure.

Despite the evident importance of repairs in the construction market, it is surprising to note the relative lack of standards, regulations or management tools in the field of refurbishment, evaluation and maintenance compared to that of the design and construction of new concrete structures. This is partly understandable because many structure managers are facing the end of the lifecycle of their structures for the first time and realize the problem too late to effectively and economically remedy it. In fact, some authors explain with a certain cynicism that facing the deterioration of their assets, these managers often lack adequate decision-making assistance and will, in despair, adopt opportunistic techniques that will only postpone the appearance of the same problem in time, while further increasing the final bill (Molez, 2003).

However, a working methodology can prove valuable for the design of a tool to assist in the management and maintenance of reinforced concrete structures. This study aims to understand the needs in the design of a tool to assist in the management and maintenance of concrete structures, in order to effectively guide engineers in the repair of their infrastructures and standardize work methodologies within an organization.

The concrete repair industry has been steadily expanding over the last decade. Many civil engineering works require repairs to ensure their safety and durability. This trend highlights the increased importance of performing effective and durable repairs, in order to optimize available resources and minimize long-term costs. Therefore, a clear and comprehensive diagnostic methodology is essential to ensure that repairs are carried out effectively and optimally.

Standardizing work methodologies within an organization is also an important goal of this study. When engineers have uniform work methodologies, it facilitates collaboration and allows for more efficient work. This can also help reduce the management and maintenance costs of concrete structures, as standardized work methods allow for maximizing efficiency and avoiding unnecessary redundancies.

In summary, a well-designed working methodology can be of great help for the management and maintenance of reinforced concrete structures. It allows for better understanding of the needs of engineers and effectively guides them in their repair work. It also promotes the standardization of work methodologies within an organization, which contributes to maximizing efficiency and reducing costs. By combining these elements, a clear and consistent working methodology can help engineers tackle the challenges of managing and maintaining reinforced concrete structures in a more effective and efficient manner.

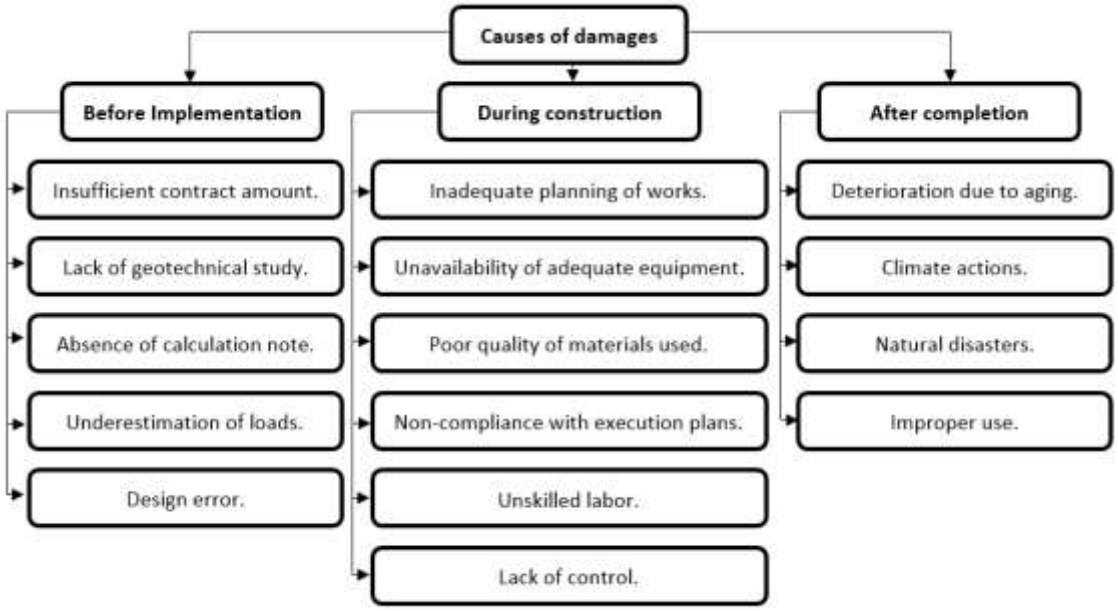

Fig 1. Probable causes of damage to reinforced concrete structures before, during, and after construction.

2. Methodology of Intervention

This study proposes a procedure that allows for the diagnosis of damage and the management of intervention on a reinforced concrete structure. The question we attempted to answer is the following: what makes an intervention on a reinforced concrete structure successful? The adoption of a systematic approach to repair seems to be an interesting and cost-effective means of achieving success. We present here a six-step process to be followed for repairing a concrete structure effectively (Figure 2):

- Identify defects and causes of damage.
- Evaluate the degree or extent of damage.
- Evaluate the necessity of intervention.
- Estimate the cost of the intervention.
- Choose the methods and products for repair.
- Periodically monitor the structure after intervention.

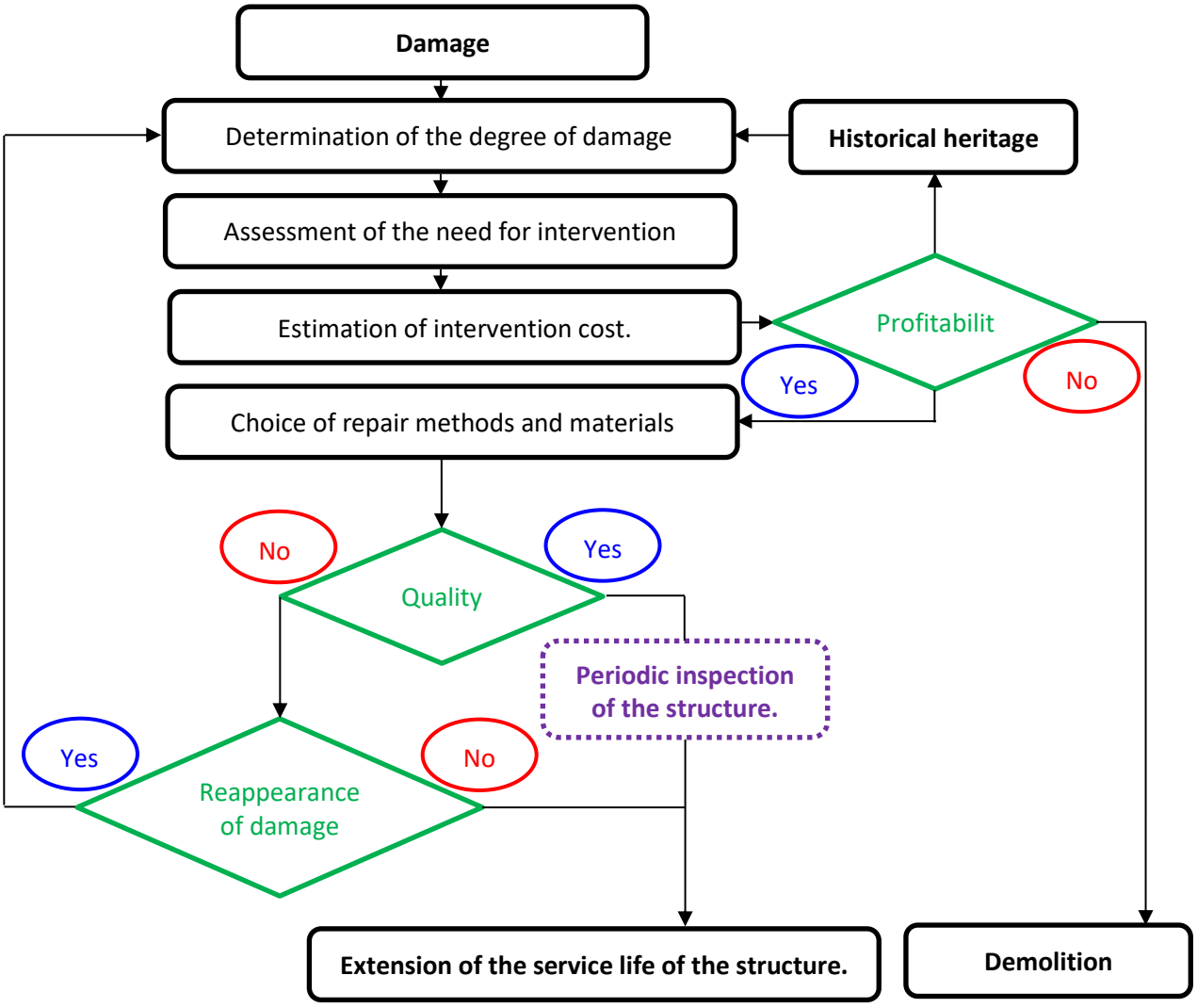

Fig 2. Intervention strategy for a reinforced concrete structure.

3. Diagnosis of concrete degradation

3.1. Determination of the origin of the damage

The first step to intervene effectively on a concrete structure is to determine the causes of existing damage. This step may also be the most important of the refurbishment or maintenance process. Indeed, if the phenomenon causing the deterioration of the base concrete is not controlled or if its diagnosis is incorrect, it is highly likely that this degradation mechanism will also affect the repair concrete (Kurt f, 2015). An incorrect identification of the problem source results in costly, ineffective, and recurrent interventions, which is certainly not desirable from the perspective of the durability of the work and the sometimes limited budgets of managers. Currently, there is no tool that performs the diagnosis of concrete degradation in structures. Therefore, it is important to first establish a diagnostic methodology to properly identify the origin of these damages. This will improve the interpretation of defect symptoms and, consequently, facilitate the subsequent selection of actions and materials required when intervening on the structure.

The precise determination of the causes of any deterioration in concrete is a complex subject. This is due to the lack of knowledge and complexity of the phenomena that affect this material.

3.2. Determination of the degree of damage

Assessing the extent of damage on a structure, which is usually left to the judgment of the responsible engineer, is not a simple task. Each degradation process occurs differently on concrete, and furthermore, its impact on the functionality, safety, and integrity of the structure depends on its evolution over time, its coexistence with other deteriorations, as well as the conditions to which the structure is subjected. Effective diagnosis of concrete deterioration requires a good interpretation of the pathology of the damage, as well as consideration of the conditions to which the structure is subjected.

3.3. Assessment of the relevance of intervention

Once the cause of the deterioration is known and the extent of the damage is evaluated during the inspection, it is necessary to make a decision regarding the need for work on the structure. Indeed, just because a structure is damaged does not necessarily mean it requires repair or maintenance work (Kurt f, 2015).

However, optimizing interventions requires analysis that remains complex even for experienced engineers responsible for assessing the condition of structures. In fact, these specialists currently do not have precise standards or criteria for decision-making regarding prioritization and improvement of repair work (Bouabdallah *et al.*, 2007).

It is therefore crucial to develop a methodology that guides the engineer in decision-making to eliminate subjectivity in determining structures that require priority interventions, to improve the distribution and planning of budgets and efforts devoted to maintaining the overall performance of a structure.

The implementation of such a decision-making support approach aims to achieve the following objectives (Bouabdallah *et al.*, 2007):

- Objectively evaluate the importance of the concrete deficiency or deficiencies;
- Plan repair campaigns in order of importance;
- Optimize the timing and number of interventions;
- Ensure the relevance of interventions;
- Monitor the temporal evolution of the evaluated structure's condition;

Using data from visual inspections conducted beforehand on the structure, it is possible to quantify the actual need for intervention. Three parameters must be considered in estimating the relevance of an intervention:

- The importance of the examined structure (type, dimensions and functionality);
- The pathology of the observed degradation (type and dimensions);
- The primary impact of the degradation on the behavior of the structure (stability, functionality, waterproofing, aesthetics);

3.4. Choice of repair methods and products

With the increasing importance of repair work, numerous repair materials and techniques have been developed by the industry. Unfortunately, the lack of specific scientific knowledge regarding concrete repair problems, or the absence of expertise in repair techniques and materials, often leads to a design based on manufacturer recommendations or personal experience. We can easily understand the economic and scientific stakes of research undertaken in this field to rationalize techniques and materials and reduce the costs involved.

To achieve a sustainable and profitable intervention, the decision concerning the choice of repair methods and products that best suit the degradation of a structure should be the last step in an organized repair approach. This is important to emphasize, as it is common to prematurely select repair or maintenance options during the repair process (Kurt f, 2015). Indeed, it is strongly recommended to make this decision downstream of the determination of the causes of the damage and the evaluation of the relevance of the intervention. By doing so, the engineer has the maximum information capable of guiding him/her on the exposure conditions to which the repair will be confronted and the best time to carry out this repair.

In order to optimize the performance of repairs and reduce their frequency, it is essential to establish a classification of repair materials and techniques according to the damages for which they are most effective and cost-effective, which will standardize the choice of repair methods and products made by the engineers responsible for repair work. The combination of this informational organization with the knowledge accumulated during the diagnosis of the degradation and the evaluation of the need for repair is a very interesting approach that allows the performance of interventions to be optimized.

3.5. Monitoring of the structure

Monitoring the condition of the structure after intervention allows us to intervene in a timely manner. Maintenance and monitoring defects in reinforced concrete structures can cause significant degradation, as defects in identifying damage to a structure in service can quickly become a catastrophe. The rapid intervention of repair or reinforcement can stop or prevent any worsening.

4. Conclusions

The objective of this study is to analyze the causes of degradation in concrete structures and propose an effective intervention method. The conclusions drawn from this study are as follows:

- Accurately determining the causes of deterioration will improve and facilitate the choice of intervention and the selection of appropriate materials during the intervention on the structure. This will reduce the risk of reoccurrence of deterioration in the future and lead to a successful intervention in terms of quality, durability, and cost-effectiveness.
- Classifying repair materials and techniques based on the damages for which they are most effective and cost-efficient will standardize the selection of repair methods and products made by engineers.

- Implementing a decision-support approach will guide the engineer in determining which structures require priority interventions and thus improve the distribution and planning of budgets and efforts devoted to maintaining the overall performance of a structure.
- Although the final decision regarding the timing and type of intervention is made by the engineer or manager responsible for managing the structures, the proposed method guides this choice in a consistent and coherent manner.

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