World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

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Reinforced concrete bridges deterioration processes: A review

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World Journal of Advanced Engineering Technology and Sciences, 2024, 13(02), 001–012

Publication history: Received on 13 September 2024; revised on 28 October 2024; accepted on 30 October 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.2.0525

Abstract

During their service life, reinforced concrete bridges are repeatedly subjected to an aggressive environment, which adversely affects the structural members. In order to prevent any serious damage from occurring, it is important to understand the factors and processes that have a negative effect on reinforced concrete bridges and might worsen the bridge's performance. The purpose of this paper is to review and identify the most common causes of reinforced concrete bridge deterioration. Initially, an in-depth review of a large amount of literature is conducted to identify the most relevant forms of degradation processes in reinforced concrete bridges. Then a detailed description of each process is provided in order to understand how it affects the bridge structural members. Finally, an analysis of the possible consequences regarding the bridge's normal function, serviceability, and safety is conducted. The findings in this paper show that there are a lot of negative processes occurring in reinforced concrete bridges that may cause damage to the structure. Moreover, different processes may have the same undesirable effect on the bridge and thus increase the severity of the damage. The comprehensive study and understanding of reinforced concrete bridge deterioration processes play a key role in preventing structural failures and ensuring the bridge's reliability during its service life.

Keywords: Damage; Degradation Processes; Deterioration; Reinforced concrete bridges; Safety; Serviceability

1. Introduction

The transportation system of every country plays a key role in the normal functioning of the economy. A substantial amount of money is required for establishing an effective and reliable transportation system, so it is essential to take good care of it in order to justify and protect this investment. Bridges are a main component in the transportation infrastructure and their safety and serviceability are crucial for ensuring economic growth and increasing people’s standard of living. Therefore, it is important to monitor bridges’ condition and take immediate and appropriate measures so that no significant damage would occur.

Bridges are exposed to more unfavorable conditions than other structures – aggressive environment, dynamic loading, climate exposure etc. This leads to different damage occurring in the structural members which adversely affects the bridge behavior and serviceability and could eventually endanger its safety. Hence, bridges are more susceptible to deterioration and thus to shorter lifespan. Therefore, in order to guarantee bridges reliability during their service life, higher requirements regarding bridge maintenance are imposed.

There are various processes common for reinforced concrete bridges that can lead to disruption of normal functioning or decrease in the bearing capacity. Sometimes these undesirable processes begin in the materials microstructures and cause damage in the inside of the structural member. In the beginning, there is no visible damage to the surface although a problem exists. So, in order to recognize the signs indicating a harmful process has begun in the structure, a substantial

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and detailed knowledge of the different deterioration processes in reinforced concrete bridges is necessary. It is also essential to know what factors contribute to bridge deterioration and to understand how each process works and affects the structural members so that appropriate measures can be taken for preventing or stopping these negative processes. On the other hand, the knowledge of the damage that may occur to the structure as a result of the different deterioration processes is crucial for choosing the right method for repairing any damaged element if necessary.

The purpose of this paper is to provide a detailed review of the most common processes which can cause reinforced concrete bridges deterioration. Furthermore, the paper focuses on the effect these processes have on the bridge safety and serviceability and the possible types of damage that may occur as a result. To accomplish the formulated goals, extensive research of the existing literature is carried out resulting in the identification of the types of degradation processes that are most commonly found in reinforced concrete bridges. Then a detailed description of each process is provided in order to understand how it affects the bridge structural members. Finally, an analysis of the possible consequences regarding the bridge normal function, serviceability and safety is conducted.

2. Literature Review

The problem with the different deterioration processes causing damage to reinforced concrete bridges is studied by a lot of authors around the world. Although there are some specific problems in given regions, the overall conclusion is that the negative factors affecting the reinforced concrete bridges condition and the effect they have on the structural members are similar regardless of the location. Moreover, there are a few processes and damage that are found in almost every bridge and they are identified as the most commonly occurring problems related to reinforced concrete bridges in general. Thus, these types of deterioration are the main subject of research in literature.

Based on Manuel d'Inspection Des Structure [1] and Ontario Structure Inspection Manual (OSIM) [2] the eight most common defects occurring in reinforced concrete bridges in Canada are identified – cracking, concrete disintegration, scaling and erosion, reinforcement steel corrosion, delamination, deposits, expansion joints problems and pop-outs [3]. Furthermore, the deterioration processes are classified into three general groups – chemical (alkali–silica reaction, carbonation, corrosion, crystallization, leaching, salt, and acid action), physical (temperature gradient, overloading, shrinkage, fatigue, freeze-thaw cycles) and biological [3].

Similar classification is given in EN 1504-9 [4]. There are two groups of processes causing damage – processes causing concrete damage (chemical, mechanical and biological) and processes causing steel corrosion.

The same classification – chemical, physical, and biological, is adopted by other authors as well [5-7].

Cracking, concrete spalling and efflorescence are used as subjects of studies [8].

Other authors describe the following deterioration types – reinforcement steel corrosion, concrete carbonation, alkali-silica reaction, crystallization, leaching, oil and fat influence, creep and shrinkage, salt and acid actions, temperature influence, fatigue, water penetration and overloading [5,9]. In addition, the reinforcement steel corrosion, concrete delamination and spalling, concrete carbonation and alkali-silica reaction are identified as the most common deterioration processes [9].

According to other authors there are five main damage types to reinforced concrete bridges – cracking, spallation, efflorescence, exposed reinforcement bars and reinforcement steel corrosion [10,11].

The three most common damage to reinforced concrete bridges in Ukraine are identified as cracking, spalling and pop-outs [12].

The following problems occurring in bridges in Germany are described – carbonation, alkali-silica reaction, concrete scaling, exposed reinforcement bars, reinforcement steel corrosion, water, and chlorides penetration [13].

Based on a study of guidelines for bridge inspection in five different countries (USA, Australia, Canada, Israel, and The United Kingdom) a comparison between the defects mentioned in them is made – structural and non-structural cracks, delamination, spalling, exposed rebars corrosion, efflorescence, freeze-thaw cycles, scaling [14].

In subsequent research the following four defects are studied – cracks, efflorescence, scaling and spalling [15].

The common damage described in Ontario Structure Inspection Manual [2] are adopted in another study – scaling, cracking, spalling, pop-outs, steel corrosion, delamination [16].

Based on the literature review the most common reinforced concrete bridge deterioration types and the causes for their occurrence are identified. A more detailed description and analysis of the effect they have on the bridge condition is given in the following section.

3. Reinforced Concrete Bridge Deterioration Processes and Damage

3.1. Concrete Carbonation

In general, concrete protects the reinforcement steel from the aggressive environment. On the one hand, it provides a physical barrier between the reinforcement bars and the outside environment and prevents the penetration of aggressive agents. On the other hand, concrete provides chemical protection for the reinforcement steel. When cement is mixed with water a process known as cement hydration begins. As a result of the reaction between the cement minerals and the water calcium hydroxide ($Ca(OH)_2$) is produced. This strong alkali determines a highly alkaline environment (pH 12,5-13,5), in which a passive oxide layer is formed over the rebars surface. It protects the reinforcement steel from aggressive ions and prevents corrosion processes from beginning [17].

However, as time passes the concrete protective features are diminished. As a result, favorable conditions for steel corrosion are established. The decrease in concrete ability to protect the reinforcement steel is due to degradation process in concrete known as concrete carbonation.

In general, concrete carbonation can be defined as the chemical reaction between the carbon dioxide (CO_2) in the air and the calcium hydroxide ($Ca(OH)_2$) in the cement. As a result, calcium carbonate ($CaCO_3$) is produced. A simplified representation of the process is given by Equation 1 [18-21]:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \text{ .... (1)}$$

A more detailed look on the process reveals the following four main stages of concrete carbonation [21]:

- It begins with diffusion of carbon dioxide into concrete pores.
- Provided that enough water is present, the calcium hydroxide in its solid form dissolves and diffuses in the water solution in the concrete pores:

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2(OH)^- \text{ .... (2)}$$

- The carbon dioxide also dissolves into the water solution and reacts with the already dissolved $Ca(OH)_2$:

$$Ca^{2+} + 2(OH)^- + CO_2 \rightarrow CaCO_3 + H_2O \text{ .... (3)}$$

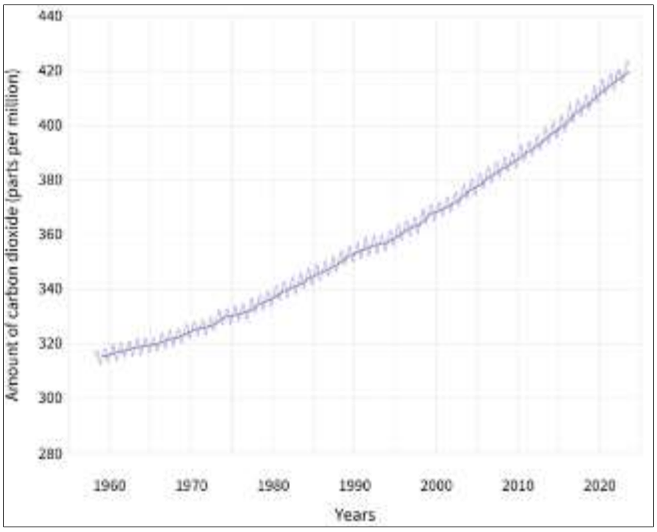
- It is possible that the CO_2 would react with other cement components to form more $CaCO_3$ and hydrated silica.

As a result of the concrete carbonation the amount of $Ca(OH)_2$ in concrete is reduced which leads to a decrease in the alkalinity (pH<9) [22,23]. Thus, concrete no longer protects the reinforcement steel from corrosion. The surface concrete layers change their microstructure and composition (Figure 1) and favorable conditions for steel corrosion are established.

Figure 1 Concrete carbonation and steel corrosion on a bridge deck

Concrete carbonation is a complicated physicochemical process that takes place over a long period of time. However, there are some factors that can speed up the process. A lot of these factors are present in the case of bridges. Therefore, concrete carbonation progresses at a faster rate and more intensely in bridge components.

The first factor that affects concrete carbonation is the carbon dioxide concentration. Carbon dioxide penetration in the concrete pores is a diffusion process i.e. the molecules flow from areas with higher concentration (the atmosphere) to areas with lower concentration (the concrete pores). Therefore, the increased carbon dioxide concentration contributes to a more rapid diffusion process and concrete carbonation respectively [21,24]. Based on data from the National Oceanic and Atmospheric Administration's Global Monitoring Lab in the last sixty years there has been a significant increase (about 30%) in the CO_2 amount in the atmosphere (Figure 2) and the global average atmospheric carbon dioxide in 2023 set a new record high.



(https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide, Last accessed on 05/10/2024)

Figure 2 Atmospheric carbon dioxide amount from 1958 to 2023

Reinforced concrete bridges rarely have any protective coating, especially the older ones and as an outside structure their surface is in direct contact with the atmospheric carbon dioxide. In addition, the amount of carbon dioxide around bridges is even higher because of the vehicles passing through and under the bridge. The problem is further intensified by the continuously increasing amount of traffic globally [19]. Therefore, concrete carbonation takes place faster and progresses more intensely in the case of bridges compared to buildings for example.

Another factor that helps the concrete carbonation progression is the presence of water. It is an important part of the carbonation process as it provides the environment in which the agents are dissolved and in which the chemical reactions take place. Water exposure is usually due to malfunctioning of the bridge draining system (Figure 3a) or damaged or overall missing waterproofing of the bridge expansion joints (Figure 3b) [19].

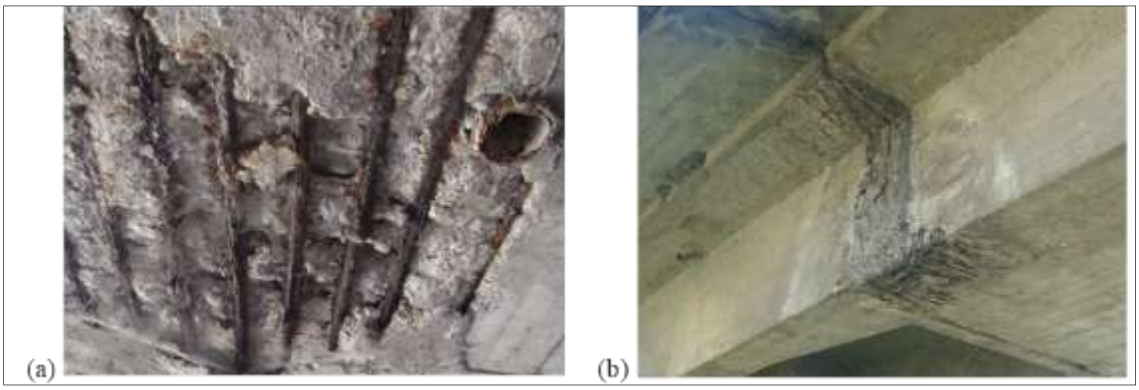


Figure 3 Concrete carbonation in a bridge deck due to water exposure caused by malfunctioning of the drainage system (a) and insufficient waterproofing of expansion joint (b)

Concrete permeability determines the external agents' ability to pass through concrete microstructure [21]. The more permeable the concrete is, the easier it is for CO_2 to penetrate concrete pores and the faster the carbonation is. Concrete permeability is dependent mainly on the amount, size, and distribution of pores in concrete [20,21] and is affected by the following three factors:

- Water/cement ratio – an increase in the water/cement ratio leads to a higher concrete porosity and permeability [20,21];
- Concrete compaction – if the concrete is well compacted, the number and size of air bubbles in the concrete mix is reduced which leads to a less permeable concrete [21];
- Concrete curing – it ensures that the cement hydration process is not ended prematurely. Otherwise, it is impossible to decrease the capillary pores volume which results in a higher concrete permeability [20,21].

Another factor that creates favorable conditions for concrete carbonation is the presence of cracks in concrete. If the concrete is cracked, it is easier for water and carbon dioxide to penetrate inside the concrete. As a result, the carbonation process speeds up.

The type of cement used in concrete is also a factor affecting concrete carbonation. In general, Pozzolanic and Slag concretes are believed to have higher carbonation rates than Portland cement concrete because they use up more $Ca(OH)_2$ during cement hydration. Thus, the available amount of $Ca(OH)_2$ is decreased which determines an accelerated carbonation process [21].

Apart from the type of cement, its quantity is also a contributing factor. The amount of $Ca(OH)_2$ is proportional to the amount of cement. The more cement is used, the more $Ca(OH)_2$ is available for carbonation and hence the more time is necessary for the reaction to take place. Therefore, the carbonation process is slowed down with the increase of cement content [20,21].

Finally, atmospheric conditions play a more significant role in the carbonation process in bridges as they are situated outside. First, there is the temperature influence. As a chemical reaction, carbonation is speeded up by heat. However, continuous exposure to high temperatures may cause water evaporation from the concrete pores resulting in carbonation slowing down. Second, there is also humidity. It is established that the carbonation process is most rapid and intense when the humidity is in the range of 50%-75%. The higher rates lead to concrete pore saturation which significantly slows carbonation as carbon dioxide penetration is almost impossible. On the other hand, if the humidity is too low, then the water content in the concrete pores is insufficient for the CO_2 and $Ca(OH)_2$ dissolution which also slows down the carbonation process [21].

3.2. Reinforcement steel corrosion

Reinforcement steel corrosion is an electrochemical process which can happen only if electrolyte and oxygen are present. The surface of the reinforcement bar comprises of electric cells forming anodes and cathodes connected by the bar. The corrosion process causes oxidation of iron at the anode and oxygen reduction at the cathode. As a result, destruction of the steel surface occurs [19,21]. The process of steel corrosion is shown in Figure 4.

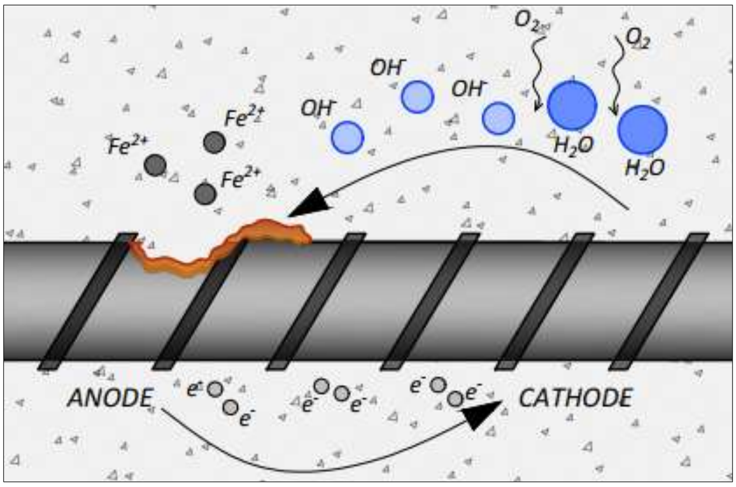


Figure 4 The mechanism of reinforcement steel corrosion [22,23]

The reinforcement steel corrosion can be divided into the following basic processes [23]:

- A depolarization reagent (usually oxygen or H^+) reaches the steel surface.
- The aforementioned electrochemical reactions occur at the anode and cathode.
- Corrosion products (rust) are accumulated on the steel surface or hydroxide and ferrous ions are separated from the steel surface and moved away into the water in the concrete pores.

The steel oxidation (anode reaction) causes a reduction of the cross-section area of the reinforcement bar. It can be described with Equation 4 [21-23,25]:

$$Fe \rightarrow Fe^{2+} + 2e^- \text{ …………… (4)}$$

The cathode reaction is represented by Equation 5 [21-23,25]:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \text{ ………….. (5)}$$

If the concrete carbonation is at a very high rate, respectively the pH value is very low, then the cathodic reaction may occur as a hydrogen evolution [23] expressed by Equation 6:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \text{ ………….. (6)}$$

The hydroxide ions, formed in the cathodic reactions, react with the ferrous ions, dissolved in the anodic reaction resulting in the formulation of corrosion product (rust) on the steel surface [19,21]. The process is described by Equation 7:

$$Fe^{2+} + 2(OH)^- \rightarrow Fe(OH)_2 \xrightarrow{O_2,\, H_2O} Fe_2O_3.n.H_2O \text{ ……………… (7)}$$

Rust increases in volume which creates internal stress on the concrete and may lead to cracking [21].

Reinforcement steel corrosion can be divided into two general types – corrosion caused by concrete carbonation and corrosion caused by chlorides [19,22,23]. The first type of corrosion occurs when the pH value drops under 9 and the protective oxide layer over the steel surface is compromised as described in 3.1. The second type of corrosion occurs when chloride ions penetrate the concrete structure, and their concentration becomes higher than a certain level [19,22,23]. Chloride accumulation in bridge structures is usually caused by salt concentration in the air in coastal areas, salt contamination of the aggregates or water used for the concrete mixture, or the application of salts for deicing the roads during the winter [22,23]. In the case of chloride-induced corrosion the anode and the cathode are separated, and the corrosion process is localized and more intense. Moreover, once the corrosion process has started, it is very difficult to be terminated and the damage to the reinforcement bar is almost impossible to fix [23].

The process of corrosion of reinforcement bars embedded in concrete is affected by various factors. As the steel corrosion is a direct result of concrete carbonation, the aforementioned factors in 3.1 which speed up carbonation, speed up the corrosion process as well. In addition, the higher concrete permeability and water content create favorable conditions for easier penetration of chloride ions resulting in speeded corrosion. The same applies to increased chloride concentration e.g. when the bridge is located near a body of salt water [21,23].

In addition to the already mentioned effects, moisture content also affects the corrosion process directly [23]. On the one hand, if the concrete pores are constantly saturated, corrosion may not occur because oxygen infiltration would be extremely slow. On the other hand, dried up pores also prevent corrosion from occurring as the necessary electrolyte for the reaction is missing [21]. Therefore, like carbonation, corrosion process intensifies only at certain moisture levels.

All the processes connected to steel corrosion are chemical reactions and as such they are influenced by temperature. In general, the increase of temperature leads to speeding up of the reinforcement steel corrosion [21].

Another important factor affecting corrosion is the depth of the concrete cover. It determines the time it takes the aggressive agents to reach the reinforcement bar surface [23]. In some cases, the bridge service life could be considerably prolonged if a bigger concrete cover is applied. This understanding is adopted in contemporary design standards. For example, in EN 1992-2 [26] the required depth of the concrete cover may be up to 65 mm depending on the environment exposure class.

The presence of cracks in concrete influences the corrosion process as well. Cracked concrete creates easier access for the corrosion-inducing agents to the reinforcement steel. The process is further speeded up when the external cracks connect with the internal microcracks in the concrete structure. Moreover, the direction of the crack affects the corrosion differently. Cracks formed parallel to the reinforcement favor the corrosion process more than cracks, transverse to the bars because longitudinal cracks increase the cathodic areas and the areas with compromised protective oxide layer in addition to allowing aggressive agents an easier access to the reinforcement bars [21].

The main consequences of the reinforcement steel corrosion are cracking and subsequent spalling of concrete which in turn leads to reduction of the bearing capacity of the structural member. The products of corrosion (rust) may have an increase in volume up to 10 times the initial volume of the reinforcement steel [21]. Hence the forming of rust leads to creating considerable internal stress on concrete which results in cracking when the concrete tensile strength is surpassed. As the corrosion process continues, cracks widen, interlink with each other and eventually concrete spalling occurs (Figure 5).

Figure 5 Concrete spalling due to reinforcement steel corrosion

3.3. Cracking

Cracks occur in all concrete structures due to concrete low tensile strength. However, there are some factors that create favorable conditions for crack formation in bridges.

One of the main reasons for concrete cracking is overloading, which is especially relevant in the case of bridges. On a world scale, there is a constant increase in the traffic flow which is taken into account in the contemporary design codes. However, this might be a problem for the existing bridges as they are designed to withstand traffic loads corresponding to the traffic at the time of design [27]. Hence the increased traffic flow may lead to overloading of the bridge structure resulting in higher stress levels and more and wider cracks [7].

On the other hand, the increase of the number of vehicles and especially the portion of heavy goods vehicles contributes to faster development of material fatigue [27]. Material fatigue can be defined as a process of formation and propagation of cracks due to cyclic loading. Bridge structures are subjected daily to dynamic loading from the passing vehicles. The behavior of the materials in such conditions is different compared to static loading. When cyclic loading is applied over a period of time structural failure may occur suddenly at stress levels that are way lower than the design values. This is the result of material fatigue. In addition, in the case of bridges, usually traffic loads are higher than the dead loads. This creates bigger stress amplitudes which intensifies the problem with fatigue [28].

Another reason for concrete cracking is heat exposure. As an outside structure bridges are more susceptible to temperature changes. When the deformations of concrete are restrained the temperature gradient would generate internal stress leading to temperature cracks occurrence [29,30]. Apart from the daily and annual temperature change, sunshine is another common reason for cracking. If part of the bridge is exposed to the sun radiation for a longer time, its temperature is considerably higher than the parts that are in shadow. As a result, nonlinear temperature gradient is created. The parts of the bridge components with different temperatures restrain each other's deformations and hence high tensile stresses are generated locally causing cracks to occur. The same applies for a sudden drop in the temperature e.g. when the sun sets or when there is heavy rain or cold air flow. In this case the surface layer of the concrete cools down very fast while the temperature of the inside of the concrete is still relatively high which results in temperature gradient [30].

Exposure to freeze-thaw cycles is yet another negative consequence of the outside location of the bridge structure, which can cause cracks to occur. During wintertime when the temperature is below 0°C the water in the concrete pores freezes, increases its volume, and applies additional stress on the concrete leading to cracking. Cracks can occur in both cement and aggregates. As the frozen water expands, osmotic pressure occurs in the concrete pores which cause water migration to areas where it can freeze e.g. pores, cracks etc. [30]. As a result, new cracks are formed, and the existing ones are widened. When these processes happen near the concrete surface, cracks cause the separation of thin cement layers (scaling) (Figure 6a) which eventually leads to aggregate exposure (Figure 6b). Scaling is further intensified when deicing salts are applied to the pavement.

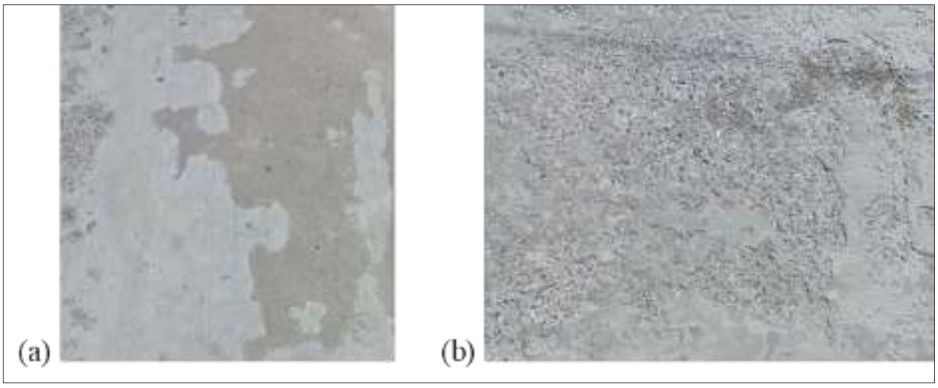


Figure 6 Concrete scaling (a) and aggregate exposure due to scaling (b)

Creep and shrinkage are two processes that are usually underestimated when designing buildings but with the conventional buildings their effect is negligeable. However, bridge structures are different and if these processes are not considered, the consequences may be more significant. The effects of creep and shrinkage must be taken into account when calculating bridge deformations, when pre-stressing or post-tensioning is applied, when bearings and expansion joints are designed etc. [31]. If creep and shrinkage are not considered in the design process, additional stress and strains occur which eventually leads to cracking. The problem is bigger for bridges constructed with high-strength concrete (compression strength over 50 MPa) as most of the design codes don't give guidelines for calculation of the coefficient of creep and shrinkage of high-strength concrete [32] or in the case of Eurocode 2 [33] the data is insufficient and controversial [34,35].

There are two main consequences of crack formation in concrete. First, the presence of cracks, especially if those cracks are wide, makes the penetration of aggressive agents and moisture easier which respectively promotes the development of negative processes as it was already covered. Second, cracks reduce the element stiffness and thus the deformations are increased which can adversely affect bridge serviceability.

3.4. Delamination and spalling

Delamination is the cracking at a plane parallel to the concrete surface situated near the outermost reinforcement bar which causes discontinuation of the concrete body (Figure 7a). It is a direct result of the additional stress created by the expanded products of steel corrosion. The additional stress leads to cracking causing separation of the concrete around the corroded reinforcement bars. Delamination could be either localized or spread over an extensive area, especially when the concrete cover depth is small. There are no external signs indicating delamination which makes it more dangerous. The easiest way to determine delamination is by hammer blow to the concrete surface. If the produced noise is hollow, then delamination is present. A more sophisticated method would be using infrared cameras [22].

If the corrosion process is not terminated and it continues to progress, the delaminated areas are combined with each other. Next, the cracks head out to the concrete surface and when they eventually reach it, spalling occurs (Figure 7b). It leaves conical indentations on the concrete surface and exposed reinforcement bars. Apart from steel corrosion, other possible causes for spalling include vehicle collision, water freezing in the delaminated area, rapidly reaching high temperatures (e.g. during fire), high local pressure etc. [22].

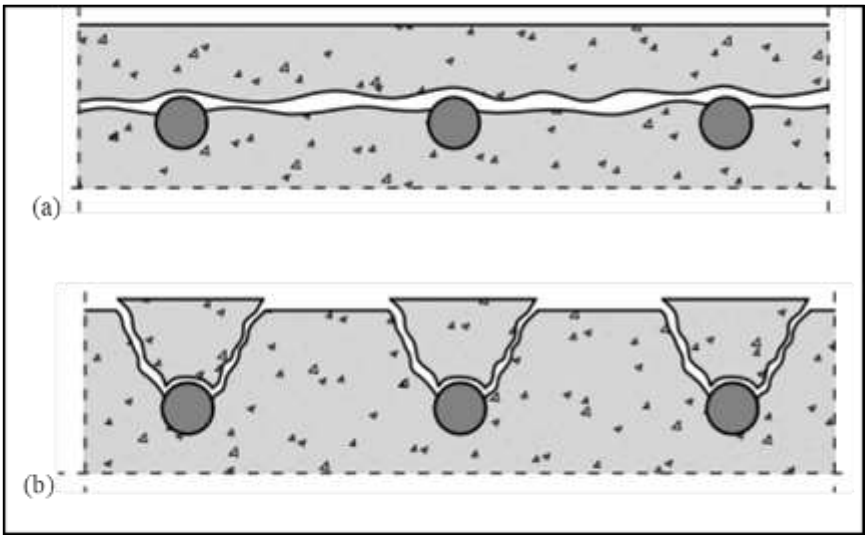


Figure 7 Concrete delamination (a) and spalling (b) [25]

3.5. Leaching and efflorescence

Leaching is the process of dissolution of the calcium hydroxide salts in the pore water and migration through the concrete structure. The dissolved salts then crystalize and deposit on the concrete surface and the water either evaporates or reacts with the carbon dioxide in the air. The deposits usually consist of sulfates and carbonates of sodium, potassium, or calcium with the main element being calcium carbonate [36].

The deposited salts on the concrete surface are known as efflorescence. Efflorescence may occur in the form of white, powdery deposits (Figure 8a) or stalactite-like formation (Figure 8b) when water dripping is present.

Figure 8 Efflorescence in the form of powdery deposits (a) and stalactite-like formations (b)

Leaching and efflorescence are no serious threat for the structure safety but rather an aesthetic problem. However, they are caused by water migration through the concrete structure and their occurrence is a sign of other undesirable processes related to water infiltration. Therefore, the presence of efflorescence needs to be monitored, and preventive measures must be taken in order to avoid future problems [36].

3.6. Alkali-aggregate reaction

The alkali-aggregate reaction is a type of concrete deterioration that is caused by the reaction between the alkali hydroxides in concrete and some types of aggregates. The most common form of alkali-aggregate reaction is the reaction with aggregates containing silica (alkali-silica reaction) which are widely used. Another less common form is the reaction with carbonates (alkali-carbonate reaction) found in some dolomitic limestones [38] (https://www.cement.org/learn/concrete-technology/durability/alkali-aggregate-reaction, Last accessed on 05/10/2024).

The alkali-silica reaction (also known as concrete cancer) may occur only if a sufficient amount of alkaline and water in the concrete pores and reactive aggregates are present. As a result of the alkali-silica reaction hydrophilic amorphous gel which can absorb a large amount of water is produced around the aggregate particles. The increased volume of the gel in the concrete structure generates stresses that lead to cracking with distinctive pattern (Figure 9) [14,37,38].

(https://en.wikipedia.org/wiki/Alkali%E2%80%93silica_reaction, Last accessed on 05/10/2024)

Figure 9 Cracks caused by alkali-silica reaction

4. Conclusion

The review conducted in the paper reveals that the negative processes occurring in reinforced concrete bridges which may cause damage to the structure are numerous. Moreover, several processes may have the same undesirable effect on the bridge and thus increase the severity of the damage. The problem with bridge deterioration and damage is complex and the different processes are connected to each other and cannot be studied separately. On the other hand, these connections mean that the same factors affect more than one deterioration process. Hence eliminating these factors if possible or taking appropriate measures for decreasing their influence can stop or slow down more than one undesirable process.

If the control organs responsible for bridge monitoring and maintenance are unfamiliar with the mechanisms by which degradation happens the problems may not be found in time which may result in severe damage. The timely discovery and repair of deteriorated structural members play a key role in securing the safety and reliability of the bridge. This way a lot of effort and money can be saved for costly and time-consuming repair works and rehabilitations. Therefore, extensive knowledge of the deterioration processes is required in order to be able to recognize the signs of deterioration in reinforced concrete bridges. Furthermore, it is important to know the causes that lead to degradation as well in order to choose the appropriate preventive measures or repair techniques and to execute them. Inappropriate or poorly executed repair works may have the opposite of the desired effect and lead to intensifying the problems. Therefore, the comprehensive study and understanding of reinforced concrete bridges deterioration processes is crucial for preventing structural failures and ensuring the bridge serviceability during its life span and thus creating and maintaining reliable and sustainable structures.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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