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REHABILITATION OF RESIDENTIAL BUILDING WITH CORROSION DAMAGE: CASE STUDY IN AMMAN (MARJ - ALHAMAM), JORDAN

REPARACIJA STAMBENE ZGRADE OŠTEĆENE KOROZIJOM: STUDIJA SLUČAJA U AMANU (MARDŽ - ALHAMAM), JORDAN

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Keywords
- corrosion
- damp walls
- steel reinforcement, rebars, reinforced concrete
- carbonation of concrete
- rehabilitation of buildings

Abstract

Reinforced concrete structures and especially their reinforcing steel is usually suffering from corrosion and damp and they are a worldwide problem that results in economic and utilization issues. Many problems as corrosion and damp can be prevented in the design phase. This can be achieved by isolation of the structures from these sources. The study focuses on the rehabilitation of existing structures damaged by corrosion and damp. A case study is considered for a residential building located in Amman, Jordan. The chosen building is 10 years old, damaged by corrosion and damp which can be seen on the interior and exterior walls, as the corroded steel reinforcement bars are seen after the removal of the concrete cover. This study aims to find an innovative technique that can rehabilitate the building and prevent previously mentioned damage in the future. For this reason, a channel is constructed along the damaged side of the building with two retaining walls to prevent water dissipation into structural elements. The innovative technique is tested by pumping a massive amount of water, and no leaking or seepage is noticed. It is concluded that the technique shows a very effective way to prevent corrosion and damp damage.

Ključne reči
- korozija
- vlažni zidovi
- čelično ojačanje, armatura, armirani beton
- karbonizacija betona
- reparacija zgrade

Izvod

Armirane betonske konstrukcije, posebno čelična armatura, obično bivaju oštećeni korozijom i vlagom, i zato predstavljaju problem u svetu, sa ekonomskim i eksploatacionim posledicama. Mnogi problemi, kao što su korozija i vlaga, se mogu izbeći u fazi projektovanja. Ovo se može postići izolacijom ovih konstrukcija. U radu se fokusira na reparaciji postojećih konstrukcija, oštećenih korozijom i vlagom. Razmatra se studija slučaja stambene zgrade u Amanu, Jordan. Izabrana zgrada je stara 10 godina, oštećena je korozijom i vlagom, što se može videti na unutrašnjim i spoljnjim zidovima zgrade, gde su korodirane šipke čelične armature uočene posle uklanjanja betonskog sloja. Cilj rada je u iznalaženju inovativne metode za reparaciju zgrade i u budućem sprečavanju oštećenja spomenutog tipa. Stoga je konstruisan kanal duž oštećene strane zgrade sa dva potporna zida, radi sprečavanja prodiranja vode u strukturne elemente. Inovativna metoda je ispitana upumpavanjem veće količine vode, gde nije primećeno procurivanje. Zaključuje se da je ova metoda vrlo efikasan način za sprečavanje oštećenja od korozije i vlage.

INTRODUCTION

Aggressive environmental conditions can affect the durability of structures and it is one of the highest threats affecting the performance of reinforced concrete structures. On both concrete and steel regards, corrosion changes mechanical properties of materials such as the reduction of strength in structural elements /1/.

Inland environment with carbon dioxide (CO_2) plays a major role in the corrosion process. Two main ideas are linked to carbon dioxide. Firstly, the carbonation of concrete cover of structural and non-structural elements. Secondly, the reduction of pH (power of hydrogen) values from 12.5 (alkaline) to 7.0 (neutral), or even to 4.0 (acid). This can result in a loss of protective function, that reinforcement and steel rebars become exposed to the external environment, /1/.

Concrete is a porous material with some voids filled by entrained and entrapped water. As the surface of concrete structures has cracks under their self-weight, ions of CO_2 and Cl^- penetrate the concrete cover from its surface, /2/.

Structural deterioration can occur by two mechanisms. The first mechanism is represented by carbon dioxide (CO_2) and carbonation of concrete. It begins with a stage where CO_2 penetrates the concrete cover. When CO_2 penetrates the concrete cover, the carbonation of concrete occurs followed by acidification of concrete. The second mechanism is represented by chloride (Cl^-). As the amount of chloride in the concrete increases due to additional amounts, it reaches the critical amount. Both mechanisms lead to loss of the protection of steel rebars in the concrete, and as a result, corrosion occurs, /2/, (Fig. 1).

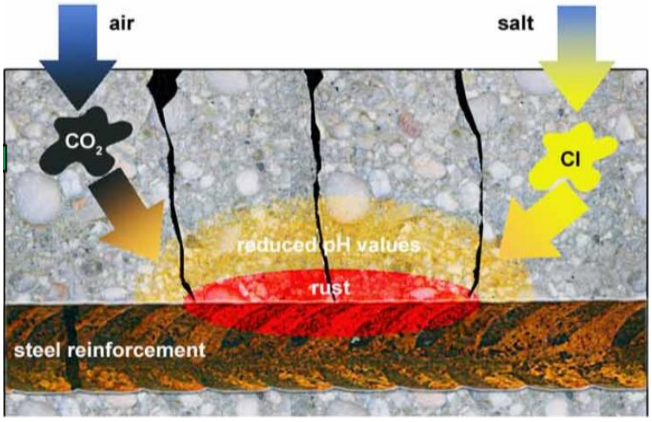

Figure 1. Rust formation on steel reinforcement.

Corrosion of the reinforcement can be defined as an electrochemical reaction. As shown below, the electrochemical reaction is a combined chemical reaction, called oxidation, and a current flow of free electrons. Simultaneously, a cathode and anode occur at the reinforcement surface, /3/, (Fig. 2).

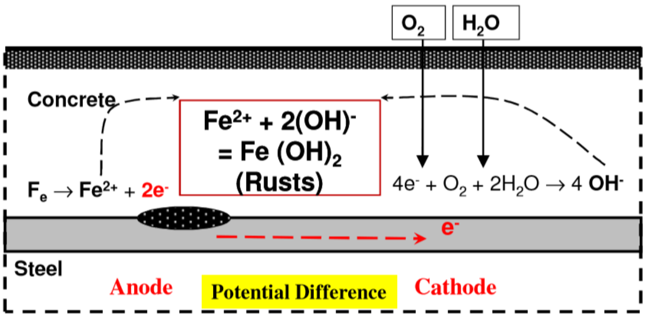

Figure 2. Anode and cathode formation on steel reinforcement bar.

A decomposition chemical reaction occurs at the anodes where the iron (Fe) is split into two substances. These are a free electron with negative sign (e^-) and ferrous ions Fe^{+2}. After that, the free electrons move to cathodes,

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^{2+} + 2e^- .$$

At cathodes, hydroxyl ions (OH^-) are produced when water (H_2O) reacts with the free electrons as,

$$2e^- + \mathrm{H_2O} + \frac{1}{2}\mathrm{O_2} \rightarrow 2\mathrm{OH}^- .$$

Then the negative hydroxyl ions (OH^-) react with positive ferrous ions Fe^{+2} to produce a ferrous hydroxide,

$$\mathrm{Fe}^{2+} + 2(\mathrm{OH})^- \rightarrow \mathrm{Fe(OH)_2} .$$

Finally, the hydrated ferric oxide which the rest is produced after converting from ferrous hydroxide as a result of a series of oxidation reactions.

When steel rebars corrode, they get coated by a layer of rust. As this layer is created, the volume of the steel rebars increase which leads to increased stress around the steel rebar and creates a crack surrounding them.

Carbonation of concrete

Simply, it can be defined as a chemical reaction between carbon dioxide as a gas with calcium hydroxide ($Ca(OH)_2$) which exists in cement, that produces a paste of calcium carbonate ($CaCO_3$), /4/.

i.e., $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$.

It is worth to mention that cement paste has over 12.5 pH and about 40 % calcium hydroxide ($Ca(OH)_2$). Generally, the pH of fully carbonated concrete is about 7, and the carbonation occurs when CO_2 enters the concrete from water or air through the cracks, /4/.

In normal conditions, porosity decreases with carbonation and this leads to an increase in the amount of strength. However, the passive film on reinforcement steel rebars gets destroyed by chloride ions, but this does not change the rate of carbonation, /5/.

Phenolphthalein is an effective method to identify and visualize the carbonation of concrete. Its colour changes to clear pink in the carbonated zone, from a deep pink in the uncarbonated zone, and it is an efficient and accurate way of carbonation identification, /5/, Fig. 3.

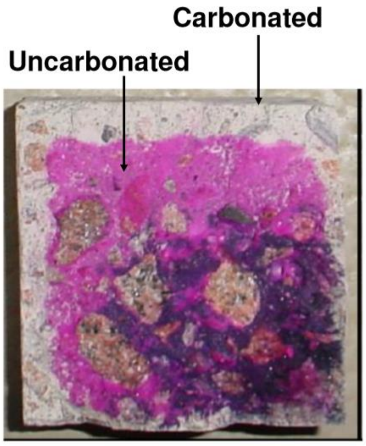

Figure 3. Carbonated and uncarbonated phenolphthalein.

There are many factors effecting the carbonation of concrete, /6/:

- water to cement ratio: porosity and permeability increase as a result of the increase in water to cement ratio. The higher the porosity and permeability, the higher is the rate of carbonation, as a carbonation agent (such as CO_2) has an easy way to penetrate the concrete cover;
- environmental condition: there is a specific range of relative humidity (RH) in which carbonation occurs. If the relative humidity is below 40 %, this means the concrete is dry and carbon dioxide (CO_2) cannot dissolve and so carbonation will not occur. Moreover, if the relative humidity (RH) is above 90 %, this means that carbon dioxide cannot penetrate the concrete and carbonation will not occur;
- depth of cover: as the cover of concrete increases, the carbonation effect decreases.

Diffusion of chloride in concrete

The main impact of the increased amount of chloride is that it breaks down the layer that protect the steel reinforcement bars, which results in corrosion of the bars, /7/.

The are two ways by which chloride ions can enter the concrete. The first way is during the mixing of the concrete, either as a contaminant, or as an admixture. The second way is from external sources, such as de-icing salt or sea water, /7/.

The protective oxide layer on the reinforcement can be damaged by a sufficient quantity of chloride reaching the reinforcement and causing localized corrosion, called pitting. The alkalinity controls the amount of chloride ions and their concentration that are necessary to initiate corrosion. The level of chloride and hydroxyl ion concentration has almost a linear relationship, /8/.

REHABILITATION OF BUILDINGS

Rehabilitation can be defined as the process of restoring the structure to the service level. There are many cases where rehabilitation is needed, for:
- faulty design of buildings;
- improper excavation and bad workmanship;
- extreme weathering and environmental conditions;
- high degree of chemical attack;
- ageing of the building.

Patch repair

The popularity of localized patch repair is achieved by its low cost and temporary relief. For a case where chloride-contaminated concrete may be surrounding the corroded zone, this technique is considered to be non-effective. This can be avoided by the removal of the concrete contaminated by the chloride. Hydro jetting, pneumatic hammer or milling machines are forms of mechanical equipment for concrete cover removal. The ideal condition for this repair technique is when there is a low and localized cover before a sufficient amount of chloride penetrates the cover.

Coating systems

Coating systems (or barrier systems) attempt to prevent oxygen from flowing onto the cathode. Practically, coating systems are not very effective systems, as cracks can been found in the coating system itself.

Migrating corrosion inhibitors

A corrosion inhibitor is defined as a chemical substance that reduces the corrosion of metals without a reduction in the concentration of corrosive agents. Corrosion inhibitors work by reducing the rate of anodic and/or cathodic reactions, thereby suppressing the overall corrosion rate. The effectiveness of migrating corrosion inhibitors is generally controlled by environmental, material, and structural factors, as shown in Table 1.

Table 1. Likely performance of migrating corrosion inhibitors in concrete.

Likely inhibition	Corrosive conditions	Concrete conditions	Severity of corrosion
good	mild corrosive, low chlorides or carbonation	dense concrete with good cover depth (> 50 mm)	limited corrosion with minor pitting of steel
moderate	moderate levels of chloride at rebar (i.e. < 1%)	moderate quality concrete, some cracking	moderate corrosion with some pitting
poor	high chloride levels at rebar	cracked, damaged concrete, low cover rebar	entrenched corrosion with deep pitting

Previous research

Singh (2013) rehabilitated 3 no. (G+8) multi-storied residential buildings at Ahmedabad, Gujrat, India, /9/. The first step was to remove the carbonated part of the concrete and remove the rust using appropriate chemicals. After that, an anti-corrosion and polymer bond coat, and anti-corrosion coating have been applied. For the cracks in the structure and beam-column connection, a low viscosity grout has been applied as a part of this rehabilitation process. After 9 years of using the buildings, some cracks and spalls due to repair were noticed that need to be rehabilitated.

Chen and Leung /10/ used high strength strain-hardening cementitious composites (SHCC) as a new rehabilitation method that needs less removing of surrounding concrete. First part of the study was a discussion regarding the design of the SHCC. Secondly, a direct tension method used to test the rebars with the reduced area embedded inside the SHCC blocks. Then a four-point bending method was used to test a beam with the reduced area rebars which patched with SHCC. The results showed that the proposed rehabilitation technique is efficient, reliable, and less expensive than other techniques.

Almassri and Halahla /11/ investigated the behaviour of corroded reinforced concrete beams using analytical techniques and finite element method. These beams were previously rehabilitated with carbon fiber polymer rods using near surface mounted technique. The finite element models showed the crack/failure pattern and moment-deflection behaviour. It was found that use of the external steel plate enhanced the strength and stiffness of the structures. In addition to this, it has changed the mode of failure of the corroded beams to a safer mode.

In our study, a residential building located in Amman, Jordan has been taken as a case study. An innovative technique has been developed to repair the corroded parts of the buildings. The following section shows the procedure applied for this repair.

REHABILITATION PROCESS OF AMMAN'S BUILDINGS

The innovative technique is developed in this study to repair the building and even make a long-term solution to prevent corrosion and damp damage. The following subsections show the step-by-step rehabilitation process.

Before rehabilitation

Aggressive damp attack can be seen in the following photos on the interior walls of the building in June 2019, (Fig. 4).

The following photos (see Fig. 5), illustrate the corroded steel reinforcement of foundation and structural parts. As can be noticed, the rebar is totally corroded.

Corrosion and damp damage resulted as a lack of drainage system surrounding the foundations, where water remains around them without being discharged using appropriate technique.

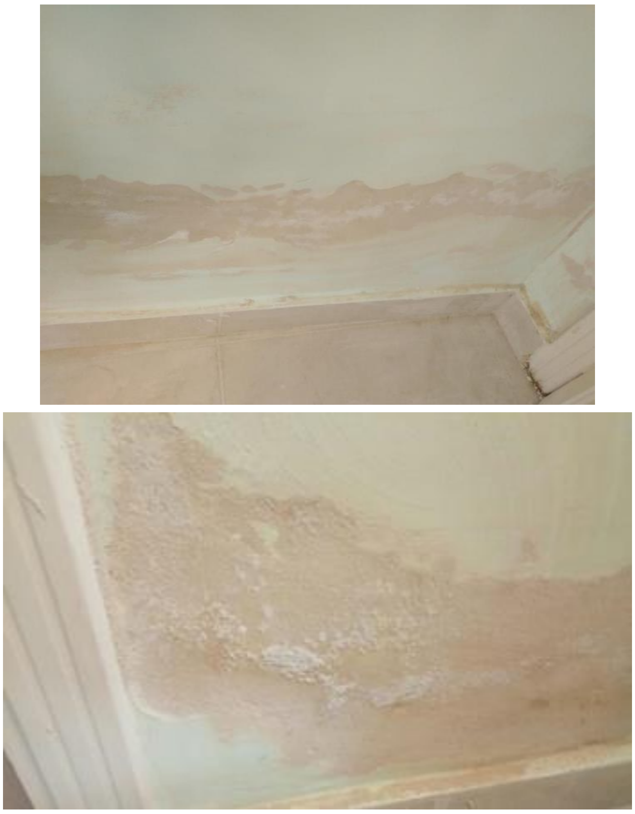

Figure 4. Damp on different locations of the internal walls.

Figure 5. Corroded steel reinforcement bars.

Rehabilitation process

The aim of the innovative technique is to prevent the previously mentioned damages by preventing water from being stored around the structural and non-structural parts.

The first step is to uncover the damaged part of columns, foundations, walls, and their surroundings, as shown in Fig. 6.

Figure 6. Excavation works.

Secondly, A water drainage channel is created along the side of the building to provide a path for water to follow, as shown in Fig. 7.

Figure 7. Water channel.

Then, the two retaining walls are constructed on both sides to work as a barrier for the water seepage. The fourth step is to construct a sloped base that forces the water to flow towards the channel onto the other side of the foundation. As the isolation is an important part of the construction, columns and foundations are isolated by bitumen.

Apparently, the whole system is isolated by concrete covering it as shown in Fig. 8.

Figure 8. Casting of concrete before flooring.

Figure 9 illustrates the innovative technique used in this case study done by AutoCAD.

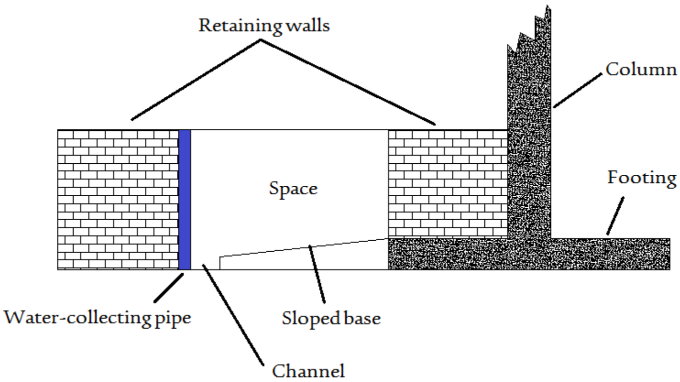

Figure 9. AutoCAD drawing of the whole system.

The collecting pipe is placed over the channel to force the water on the surface to flow towards the channel instead of being around the foundations. As what Fig. 9 illustrates, the sloped base forces the water to flow toward the channel.

The main aim of making the space is to provide a ventilation that prevents damp damage and provides an additional area for water in case of over-flow in the channel.

Figure 10 shows the top view of the system where the channel retaining walls and channel are along the side of the building.

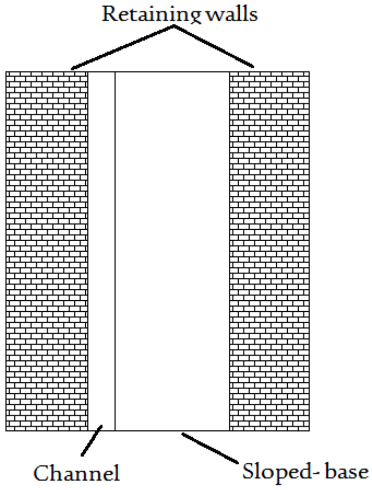

Figure 10. Top view of the system.

Seepage testing

To test the seepage and if there is any leaking in the system, a massive amount of water is pumped into the constructed system, where it was left for about two weeks, Fig. 11. No seepage, leacks or damp have been seen around the system which has proved it was a successful process of isolation.

Figure 11. Seepage testing technique.

CONCLUSION AND RECOMMENDATIONS

The aim of this study is to find an innovative technique to prevent corrosion and damp damage and find an effective solution to prevent such damages. A case study was taken in Amman, Jordan. The innovative techniques started by uncovering the damaged part of the building to identify the problem. A water channel has been constructed to provide a far-away path from the building for the water to follow and avoid damage. A sloped base was constructed to force the water to follow toward the channel, where two retaining walls have been constructed to prevent water seepage out of the channel. After the testing the techniques, no seepage or leakage has been noticed. As a result of the work, it is recommended to keep the structures isolated from the corrosion and damp sources, and by using of such technique, the corrosion and damp damage can be prevented, or at least kept to a minimum.

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