Effect of Acid Rain Pollution on Durability of Reinforced Concrete Structures

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Abstract. In order to solve the problem of insufficient accuracy and effectiveness of the current analysis model of the durability of reinforced concrete, the corrosion process of concrete by acid rain and the corrosion process of steel bars by acid rain are analyzed; based on the acid rain corrosion process, the structure of reinforced concrete composite beams under acid rain erosion Carbonization depth of medium concrete; Corrosion depth of reinforced concrete composite beam structure was obtained by carbonization depth; Durability index was calculated by carbonization depth and corrosion depth. It is suitable for analysis of the influence of acid rain pollution on the durability of reinforced concrete composite beam structures.

Keywords: reinforced concrete; durability; acid rain pollution.

1. Foreword
The rapid development of modern industry and the large-scale use of fossil fuel energy have made the environmental pollution problem more and more serious and caused damage to the ecological environment. Especially the pollution caused by acid rain. Acid rain is an acidic wet sediment, mainly caused by precipitation in the form of rain and snow with a pH value less than 5.65, caused by SO2 and NO2 in the air. In the environment, SO2 and NO2 do not exist naturally, but now the society is developing too fast, the consumption of various fuel energy sources, sulfur dioxide and nitrogen dioxide emitted during the process enter the atmosphere, and are chemically converted into secondary pollutants sulfuric acid and Nitric acid forms acid rain [1]. Reinforced concrete structural beams have a wide range of use, and are affected by acid rain pollution, which is prone to various degrees of corrosion of steel bars and damage to concrete. The durability problems of reinforced concrete composite beam structures used in engineering include freeze-thaw cycles, concrete corrosion, reinforcement corrosion, and alkali aggregate reflection, etc. [2]. If the corrosion time is too long, the reinforced concrete structure beams are corroded by acid rain and other reasons for a long time, and the durability is affected, which will reduce the reliability of the function of the reinforced concrete structure and cause potential safety problems.

2. Durability impact analysis
Under the condition of acid rain pollution, there are two main factors that affect the durability of reinforced concrete composite beam structures, including carbonization of concrete and corrosion of steel bars [3].
2.1. Analysis of the corrosion process of acid rain on concrete

Concrete is based on cement, and chemical admixtures and mineral admixtures are added if necessary. Carbonization of concrete is caused by chemical corrosion of concrete. Sulfur dioxide and nitrogen dioxide contained in acid rain are mixed into concrete, which reduces the alkalinity in concrete, which may cause concrete carbonization, and the pH value of concrete with severe carbonization. It is probably between 8.5 and 9.0. This situation easily causes corrosion of the reinforcing steel in the concrete. When the corrosion of the reinforcing steel is severe, the protective layer is damaged, thereby reducing its area and bearing capacity [4].

When the acid rain contacts the reinforced concrete composite beam structure, the corrosive substances in the acid rain react with Ca(OH)$_2$, the alkalinity of the medium in the concrete decreases, and calcium silicate and calcium aluminate in the reinforced concrete composite beam structure Hydrolysis, dissolution, and loss of stability have further affected the structural quality of the reinforced concrete composite beam, and its volume has continued to decrease.

$$\text{Ca(OH)}_2 + 2\text{H}^+ \rightarrow \text{Ca}^{2+} + 2\text{H}_2\text{O}$$
$$\text{nCaO} \cdot \text{mSiO}_2 \cdot 2\text{nH}^+ \rightarrow \text{nCa}^{2+} + \text{mSiO}_2 + \text{nH}_2\text{O}$$
$$\text{nCaO} \cdot \text{Al}_2\text{O}_3 + 2\text{nH}^+ \rightarrow \text{nCa}^{2+} + \text{mAl}_2\text{O}_3 + \text{nH}_2\text{O} \quad (1)$$

It can be seen from reaction formulas 1, 2, and 3 that the contact of acid rain with the structure of a reinforced concrete composite beam will corrode the inherent components in the concrete, turning it into a water-soluble medium, and accelerating the loss of its chemical components into ionic forms [3]. Harmful substances in the environment easily penetrate into the structure of the reinforced concrete composite beam, causing the passivation film on the surface of the internal reinforcement to rupture, leading to corrosion of the reinforcement. After that, the sulfate medium reacts with Ca(OH)$_2$ in the cement to form gypsum. The gypsum further reacts with the damaged calcium aluminate to generate calcium sulfoaluminate. The reaction formula is as follows:

$$(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) + \text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O} + 3\text{H}_2\text{O} \rightarrow \text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 10\text{H}_2\text{O} \quad (2)$$

Because the calcium sulfoaluminate has a large water content and a volume expansion, the cement stone is damaged. This phenomenon is the sulfate corrosion of concrete. The reaction is as follows:

$$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O} + \text{SO}_4^{2-} + 2\text{Ca} (\text{OH})_2 + 10\text{H}_2\text{O} \rightarrow \text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 10\text{H}_2\text{O} + \text{OH}-\text{Ca} (\text{OH})_2 + \text{SO}_4^{2-} + \text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot \text{H}_2\text{O} + \text{OH}^- \quad (3)$$

Hazardous pollutants in acid rain, SO$_4^{2-}$ ions can chemically corrode with cement sulfate in reinforced concrete composite beam structures, generate non-solid materials, and cause the volume expansion and cracking of reinforced concrete composite beam structures. Based on the above analysis, it can be known that acid rain corrodes concrete, which will cause the concrete volume to crack, exposing the steel bars inside and directly contacting the acid rain.

2.2. Analysis of acid rain on the corrosion process of steel bars

After the acid rain drops, a chemical reaction occurs with the material in the concrete, which causes the hardened cement on the surface of the concrete to dissolve, resulting in large-scale cracks, resulting in reduced strength, corrosion of the coating, and the steel bars inside are exposed to the outside and corroded by acid rain [5]. The harmful factor in acid rain, SO$_4^{2-}$ can quickly increase the rust rate of steel, and form a corrosion battery on the surface of the steel. In a strongly acidic environment, the dissolution and corrosion of Fe are enhanced, and the acidity of acid rain is enhanced, the chemical reaction is strong, and the corrosion is severe. Its reaction formula is as follows:

$$4\text{H}_2\text{SO}_4 + 4\text{Fe} + 2\text{O}_2 \rightarrow 4\text{FeSO}_4 + 4\text{H}_2\text{O}$$
$$4\text{H}_2\text{SO}_4 + 4\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{FeOOH} + 4\text{H}_2\text{SO}_4 \quad (4)$$

One of the factors that has a great influence on the structure of reinforced concrete composite beams is the corrosion of steel bars. When the surface corrosion rate of the steel bar is greater than 10%, the
elongation of the steel bar is significantly reduced, resulting in a reduction in the cross-sectional area of the steel bar and a reduction in the ultimate elongation [6]. When the corrosion degree of the reinforcing bar is greater than 5%, longitudinal cracks are liable to occur. When it is more than 10%, the protective layer of the concrete is peeled off, and the effectiveness of the section is reduced. The above shows that acid rain corrodes the steel bars, rusts the bars, and damages the concrete.

2.3. Calculating the carbonation depth of concrete under acid rain erosion

Reinforced concrete composite beams are often used in high-rise buildings and bridges. According to the corrosion process of reinforced concrete by acid rain, an analysis model of the durability of reinforced concrete composite beams under acid rain pollution conditions is constructed. The carbonization depth of the concrete structure in the reinforced concrete composite beam structure is an important indicator reflecting the degree of carbonization of the structure. The carbonization depth and time have a relationship in the formula, the formula is as follows:

$$H = P \sqrt{t}$$  (5)

In the formula, $H$ represents the carbonization depth of the concrete; $P$ represents the carbonization speed coefficient of the concrete; $t$ represents the carbonization time of the concrete structure in the reinforced concrete composite beam structure. The carbonization depth of concrete is formed based on a combination of a diffusion theory model and an empirical model. There is an empirical formula for calculating the carbonization depth of concrete. The formula is as follows:

$$H = P \sqrt{t} = e_1 e_2 e_3 (1.1 \frac{W}{S}) \sqrt{t}$$  (6)

In formula (6), $P$ is the carbonization rate coefficient of the concrete in the composite beam structure; $e_1$ is the coefficient of influence of meteorological conditions. The wet area is 0.4 to 0.7, the dry area is 1.1 to 1.3, and the general area is 1.0. $e_2$ indicates the coefficient of influence of cement types, and the coefficient is different for different types of cement; $e_3$ indicates the coefficient of influence of fly ash, which is taken as 1.3 when less than 13%. The carbonation depth of the concrete in the composite beam structure affects the degree of corrosion of the internal steel bars. The cross-sectional area of the steel bars is reduced by corrosion of the steel bars, and the corrosion is not uniform. And it may cause the concrete protective layer to crack, which further accelerates the corrosion of the reinforced concrete composite beam structure. These factors have an impact on the durability of reinforced concrete composite beam structures.

2.4. Calculate the corrosion depth and durability index of steel bars

Under the general atmospheric environment, acid rain drops and chemical reaction of the reinforced concrete composite beam structure, and calculate the corrosion time of the steel bar.

$$t_0 = \left( \frac{h - c_0}{P} \right)^2$$  (7)

In the formula, $h$ is the thickness of the protective layer of the reinforced concrete composite beam structure; $c_0$ is the carbonization parameter of the concrete in the reinforced concrete composite beam structure; $P$ is the carbonization speed coefficient of the concrete in the reinforced concrete composite beam structure. $t_0$ represents the corrosion time of the steel bar in the reinforced concrete composite beam structure; the formula for calculating the carbonization parameter $c_0$ is as follows:

$$c_0 = \frac{\left( -TH^2 + 1.3TH \right) (h - 5)}{Q} \left( t > t_0 \right)$$  (8)
In formulas (8) and (9), TH represents the relative humidity of the environment; h represents the thickness of the protective layer of the reinforced concrete composite beam structure, and Q represents the standard compressive strength value of the reinforced concrete composite beam structure. In the reinforced concrete composite beam structure, some corrosion products will be attached after the reinforcement is rusted, the volume will increase, and the concrete near the reinforcement will be subject to expansion pressure, which will cause the protective layer to rupture [7]. According to the cracking conditions of the protective layer of the reinforced concrete composite beam structure, the rust expansion cracking time of the concrete protective layer is calculated as follows:

\[
T = \frac{h_\sigma}{v_\sigma}
\]  

In formula 10, \(v_\sigma\) is the corrosion rate of the steel bar before the rust and cracking of the protective layer in the reinforced concrete composite beam structure; \(h_\sigma\) is the depth of the steel rust when the concrete cover is rusted and cracked in the composite beam structure; T represents the beginning of the steel rust to rust Cracking time. There are two kinds of rebars that are often used, namely round bars and deformed bars. The calculation formula for round bars is as follows:

\[
h_\sigma = k \left( 0.017 \frac{h}{d} + 0.004 p + 0.031 \right)
\]  

Deformed reinforcing bar calculation formula:

\[
h_\sigma = k \left( 0.013 \frac{h}{d} + 0.011 p + 0.031 \right)
\]  

In formulas (11) and (12), k represents the influence factor of the reinforcement position in the composite beam structure; h represents the thickness of the concrete protection layer in the composite beam structure; p represents the compressive strength of the concrete cube; Based on the above information, the structural durability index of the reinforced concrete composite beam is calculated as follows:

\[
R = \frac{h_\sigma t_2 + h_b (t_3 - t_2)}{Ht_1}
\]  

In the formula, R indicates the durability index; H indicates the carbonization depth; t1 indicates the time taken for the thickness of the protective layer in the reinforced concrete composite beam structure; t2 indicates the time for the corrosion of the steel bar in the reinforced concrete composite beam structure; t3 indicates the concrete protection in the reinforced concrete composite beam structure Layer swell time.

An analysis model of the durability effect of reinforced concrete under acid rain erosion is completed. By analyzing the corrosion process of concrete and steel bars by acid rain, a model is established, and the model is used to calculate the concrete carbonation depth, reinforcement corrosion depth, and durability index. The acid rain pollution conditions can be analyzed in detail Influence on the durability of reinforced concrete composite beam structures.

3. Conclusion
The effect of acid rain pollution on the durability of reinforced concrete composite beams was analyzed, and the corrosion process of concrete and steel bars was analyzed using acid rain. The deterioration of
the reinforced concrete composite beam structure caused by acid rain pollution is difficult to repair by current technology. Therefore, it is necessary to carry out research work on the durability of reinforced concrete composite beam structures under acid rain pollution, study the factors affecting durability and its damage law, take measures to improve durability, adapt to the current social development, ensure economic development and reduce Economic losses.

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