Research on durability of a concrete continuous rigid frame bridge

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Abstract: The research on the durability of concrete structures has also become one of the most important topics for discussion at international academic institutions and conferences. This paper summarizes and reviews the current research on the durability of bridge structure of the bridge at the index relationship between state lifetime and structure durability. According to the actual situation in this paper on a continuous rigid frame bridge China of Yunnan as an example, this bridge was completed and opened to traffic during the first half of the year. A series of tests are carried out for the durability problem. It is found that all the indicators are good within six months after the bridge opened to traffic, but durability issues should be further studied in future monitoring efforts.

1. Summary of research
Since 1960s, the use of concrete structures has entered a peak period. Meanwhile, the research on durability of concrete structures has also become an important topic discussed by international academic institutions or international academic conferences. In 1951, the former Soviet Union scholar AA Bekov and BM Moskow wrote <Corrosion of Concrete> and <Corrosion and protection methods of concrete and reinforced concrete> for the subsequent study on corrosion protection standards and durability of reinforced concrete structures basis. The concrete Committee of the Japan Society of Civil Engineers established the "durability design criteria for concrete structures" in 1989. The ACI437 Committee of the United States put forward the latest report of “Resistance assessment of existing concrete buildings” in 1991, and provided detailed methods and steps for testing experiments.

Since 1960s, the durability of concrete structure has been studied in China, mainly on the carbonization of concrete and corrosion of steel bars. The Civil Engineering Society of China held a national conference on durability in 1982 and 1983. In December 1991, the "national concrete durability team" was established in Tianjin, so that the research on the durability of concrete structure in China has taken a step in the direction of systematization and standardization.

Southwest Jiao Tong University has developed an expert system for evaluation of bridge bearing capacity (RBCAI), including establishing bridge database, database management system and building bridge damage grade evaluation. Ministry of Communications Highway Science Institute and the Beijing Highway Bureau jointly developed the Beijing Highway Bridge Database and completed the evaluation method of highway and bridge service function. China in the "code for durability design of concrete structure" (GB/T50476-2008) provides an important or large-scale project should be aimed at...
and the role of environmental category specific grade, and the durability index of frost resistance, diffusion coefficient of chloride ion in concrete and so on are put forward respectively.

2. Factors affecting the durability of the structure

Through a large number of studies found that the bridge durability damage is mainly related to the destruction of reinforced concrete. The damage of reinforced concrete structure is mainly due to the following reasons:

**Electrochemical corrosion of steel bar:** The corrosion of steel in concrete after the rust is 2-4 times larger than the corresponding reinforcement volume, if there is sufficient moisture, rust volume can reach 7 times the volume of the volume expansion of steel, the circumferential tensile stress of reinforced concrete outer concrete itself tensile force, can't limit the expansion of the poor and there will be radial cracks, the reinforced protective layer cracking leakage increased corrosion speed[2]

**Carbonization of concrete:** Because concrete is a porous and uneven material which coexists with gas, liquid and solid three-phase, there is a lot of void in the cement slurry. The acid gas contained in the air around the structure, such as CO2 and SO2, invades the concrete through the void, and reacts with the alkaline material to cause the carbonization of concrete. Carbonization reduces the alkalinity of concrete, weakens the protection of steel bars, and causes the loss of alkaline environment around the steel to become acid environment, which leads to corrosion.

**Destruction of chlorine ions:** Mainly from the concrete itself with chlorine ions or chloride from the outside into the concrete. Studies have shown that the corrosion of the steel when the chloride is infiltrated into the concrete reaches 0.1% - 0.2% of the weight of the concrete. In most parts of China, in order to prevent freezing of bridge deck in winter, salt is used to remove freezing. When salt is removed, \( \text{Cl}^- \) will infiltrate into concrete structure, which will cause corrosion of steel bar and accelerate[3]. According to the related research abroad, the bridge structures using deicing salts usually start corrosion damage in 5 to 10 years, resulting in steel corrosion and concrete expansion.

**Cracks:** When the crack is wider and deeper, it will affect the impervious performance of the structure, resulting in the continuous invasion of water and harmful substances, inducing the corrosion of steel bar or accelerating the natural aging of concrete, thus damaging the bearing capacity, service performance and durability of the engineering structure.

**Freezing thawing damage:** There will always be some water in the concrete that remains in the concrete pores during the mixing process, and the cycle of "freeze-thaw-freeze" will occur when the water alternates between positive and negative temperature. During the cyclic process, the concrete produces fatigue pressure under the dual action of water frost heave pressure and seepage pressure, and finally causes the concrete to take out and destroy from outside to inside. The damage forms mainly include frost heave cracking and surface spalling.

3. Durability related testing

There is an indicator relationship between the service life of the bridge and the durability of the structure. According to the actual situation, this paper takes a continuous rigid frame bridge located in Yunnan, China as an example (see Fig. 1). During the six months when the bridge is open to traffic, five indexes, such as the corrosion potential of steel bar, the depth of carbonation, the diffusion of chloride ions, the influence of cracks and freeze-thaw, are analyzed.

![Bridge facade map](image)

Figure 1. Bridge facade map
3.1. Corrosion detection of steel bar potential
In order to master the corrosion of the bridge, the project team tested the corrosion potential of the bridge. Inspection basis: <Technical standard for inspection of building structure>(GB/T 50344.1-2004); <Testing code of concrete for Port and Waterway Engineering >(JTJ 270-1998); <Specification for Inspection and Evaluation of Load-bearing Capacity of Highway Bridges>.

Half battery potential method was used for the potential detection. The steel bar in the concrete is regarded as a half battery pack and connected to a suitable reference electrode to form a full battery system. Concrete is electrolyte, and the potential value of reference electrode is relatively constant. The corrosion potential of steel bar in concrete is different due to different corrosion degree, which leads to the change of battery potential. The corrosion state of the steel bar is evaluated according to the potential of each point on the surface of the steel bar in the concrete.

Through the field investigation, it is found that the environment in each part is basically the same. In view of the appearance, there is no rust leakage or concrete expansion. Test results such as Figure 2, 3, 4:

3.2. Depth detection of carbonization
A representative site is selected and 1 to 3 holes are arranged as the depth of carbonization of the concrete structure of this section. Measuring the diameter of the hole is 12mm, after cleaning to the hole spraying 1% concentration of phenolphthalein charge and carbonation depth of concrete according to the determination of colour change. In addition, the drilling core concrete samples have better surface exposed for titration with phenolphthalein, using phenolphthalein charge to carbonation depth of concrete strength in titration before inspection. The field and core sample tests show that there is no obvious carbonization phenomenon in the concrete bridge.

3.3. Chlorine ion detection
According to the design requirements, chloride ion detection should include three contents: chloride ion permeability, chloride diffusion and chloride content.
Use of electrical flux method for detection: The test site was collected by electric drill, and the free chloride content in concrete was tested by RCT chloride rapid Analyzer in the laboratory. Its value represented by the percentage of the concrete quality. By measuring the amount of electricity passing through the concrete under the effect of applied voltage (60V), the permeability resistance of concrete can be reflected qualitatively. The detection results of water-solubility chloride content should be consistent with current national standard 《Standard for quality control of concrete》GB50164, <Premixed concrete> GB/T14902 and <Technical code for application of sea sand concrete> JGJ206.

Table 1. Chloride permeability of concrete

| Electric flux/C | Evaluation of chloride permeability of concrete |
|-----------------|-----------------------------------------------|
| >4000           | Higher                                        |
| 2000-4000       | Medium                                        |
| 1000-2000       | Low                                           |
| 100-1000        | Very Low                                      |
| <100            | Negligible                                    |

According to the experimental results and table 1, the surface chloride content and chloride diffusion coefficient are all small, and the thickness of reinforcement cover is within the prescribed range. Therefore, the corrosion of the steel bar caused by the intrusion of chloride ion has not been caused.

3.4. Freeze-thaw test
The bridge tested in this paper is in a low temperature area because of its geographical location, and it is often frozen in winter. The possibility of using ice to ensure traffic safety is more likely, and the effect of freezing and thawing will be more obvious. The experiment has been carried out, but it has not been damaged by freezing thawing due to the short traffic time of the bridge.

4. Conclusion
This paper first summarizes the research results of the durability of bridge structures. On this basis, taking a continuous rigid frame bridge as an example, the five indicators, such as the corrosion potential of steel bar, the depth of carbonation, the diffusion of chloride ions, the influence of cracks and freeze-thaw, are analyzed. The results show that:

1) The environment in each part of the bridge is basically the same. From the appearance of the bridge, there is no rust exudation or concrete expansion.

2) The carbonation depth of phenolphthalein titration concrete structure was measured by measuring three holes with a diameter of 12mm. It shows that there is no obvious concrete carbonization phenomenon.

3) Use electric drill to pick up powder on the test site, the use of RCT chloride rapid tester in the laboratory to test free chloride content in concrete. From the experimental results, it can be seen that both the surface chloride ion content and the chloride ion diffusion coefficient are small, and the thickness of the protective layer in the structure is within the prescribed range, no corrosion of the steel bar occurs due to intrusion of chloride ions.

Although the current inspection results are good, the bridge opened to traffic for only half a year. The monitoring of its durability should be continued for further study in subsequent bridge monitoring.

5. References
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