A Comparison Between Chinese and British Standards For Concrete Exposed Environment In Durability Design Of Concrete Structures

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Abstract. With the development of China's economy, construction enterprises' overseas projects are increasing day by day. The first principle of overseas construction is to understand the local specifications. In this paper, the British standards BS EN 206-2013 and BS 8500-2015 and Chinese standard GB/T 50476-2008 are selected as the research objects, and the concrete exposure environment in the durability design of concrete structures is compared, so as to help Chinese enterprises understand the overseas codes, promote the cooperation between Chinese and British enterprises and the construction of Chinese enterprises in the United Kingdom.

1. Introduction

With the development of the "one belt and one road" construction and international capacity investment cooperation, China's foreign investment will increase significantly. Britain, with its transparent business environment, capital-hungry infrastructure investment market and close political ties with China, is welcomed by Chinese investors. At present, China and Britain have made a series of cooperation in the field of infrastructure construction and have achieved some results. For example, Beijing Construction Group, as a major investor, participated in the construction of the Manchester Airport City Park infrastructure, which cost 800 million pounds.

Concrete, as the main material for construction, has a large amount of consumption. With the development of concrete technology, the concrete used in infrastructure construction is no longer only pursuing high strength, but also turning to high performance. One of the criteria for evaluating high performance concrete is high durability. The durability of concrete is not only related to the selection of raw materials and mix design of concrete itself, but also closely related to the exposed environment. This is precisely the durability design principle of concrete structures in China and Britain at present. However, a large number of concrete structures deteriorate in advance. The reason is that the durability design cannot meet the environmental requirements. Therefore, durability of concrete structures and environmental exposure classification will become the focus of infrastructure construction.

Therefore, this paper selected British standards BS EN 206-2013 and BS 8500-2015 and Chinese standard GB/T 50476-2008 to make a comparative study involving exposure levels to avoid the failure of concrete structure durability design caused by experience errors. In addition, this comparative report...
also can deepen the understanding of the similarities and differences between the Chinese and British standards of concrete structure durability design to promote the exchanges and cooperation between Chinese and British concrete industry.

2. Exposure classes
First, the environmental effects of the two standards were analyzed. The classification of environmental exposure classes between Chinese and English codes is similar, which are both to divide the environmental categories according to the form of adverse effects of the environment on concrete structures at first, and then graded according to the degree of influence in different categories. However, there are differences in the levels of exposure classes corresponding to the same environmental categories in the Chinese and British standards as listed in Table 1.

| British standards | Chinese standards |
|-------------------|------------------|
| **Environmental categories** | **Exposure classes** | **Environmental categories** | **Exposure classes** |
| No risk of corrosion or attack | X0 | / | / |
| Corrosion induced by carbonation | XC1, XC2, XC3, XC4 | General environment | I-A, I-B, I-C |
| Freeze-thaw attack | XF1, XF2, XF3, XF4 | Freeze-thaw attack | II-C, II-D, II-E |
| Corrosion induced by chlorides from sea water | XS1, XS2, XS3 | Corrosion induced by chlorides from sea water | III-C, III-D, III-E, III-F |
| Corrosion induced by chlorides other than from sea water | XD1, XD2, XD3 | Corrosion induced by chlorides other than from sea water | IV-C, IV-D, IV-E |
| Chemical attack | XA1, XA2, XA3 | Chemical attack | V-C, V-D, V-E |

The environmental categories of British standards are divided into six categories, which are "No risk of corrosion or attack", "carbonation corrosion", "freeze-thaw corrosion", "corrosion caused by chloride in seawater", "corrosion caused by chloride except seawater and chemical erosion"; while in Chinese standards the environmental categories are divided into five classes, in which "No risk of corrosion or attack" is not included. Other environmental categories are the same as the British standards, in which "General environment" corresponds to "carbonation corrosion" in the British standards.

In terms of exposure classes, there are difference between Chinese and British standards about grades of corrosion caused by carbonation, freeze-thaw cycle and seawater chloride. Carbonation and Freeze-thaw erosion are classified into four grades in British standard, but into three grades in Chinese standards. “Corrosion induced by chlorides from sea water” are classified into three grades in British standard, but into four grades in Chinese standards.

By comparison, it is found that the classification of environmental effects of British standards on carbonation erosion and freeze-thaw erosion is more detailed, where the classification of the grade of corrosion caused by chloride in seawater is more detailed than that in the British standards. In addition, the method of expressing the severity of different environmental exposure classes in Chinese standards is more intuitive, in which A, B, C, D, E, F stands for mild, moderate, severe, very serious and extremely serious, respectively. However, the British standards cannot directly see the environmental action level from the representation method.

3. Environmental classification
The specific environmental classification in the Chinese and British standards is shown in Table 2-6.

**Freeze-thaw cycle environment.** It can be seen from Table 3 that the classification of freeze-thaw environmental exposure classes in Chinese and British standards is not the same. The British standards classify it into 4 grades according to the environment in which the concrete is located, while Chinese
standard classifies it into 3 grades according to the extent to which it is likely to be damaged. Among them, British standards classify the horizontal surface of the frozen or cold areas with a high degree of water or salt free environment as XF3 grade, while Chinese standards classify the similar salt free environment or environment with a high degree of water as II-C grade, and the frozen or cold areas with a high degree of water or salt free environment as II-D grade. British standards classify the horizontal surface of the frozen or cold areas with a high degree of water environment or salt or seawater environment as XF4 grade, while Chinese standards classify the similar environment with a high degree of water or salt or seawater environment as II-D grade, and the frozen or cold areas with a high degree of water or salt free environment as II-E grade. The classification of medium saturated environment, no salt environment, high saturated cold area and salt environment is the same.

Environment with chlorides from sea water or with other chlorides. Under the condition of chloride erosion from seawater, Chinese standards classify the light salt fog area and the heavy salt fog area as III-D and III-E grade respectively, but in British standards, the two categories are both classified as XS1 grade. Chinese standard classifies the tide, the splash zone and the tide in the hot or non-hot area into grades III-E and III-F, respectively, but British standards classify this two categories both as XS3. Under the conditions of chloride corrosion other than from sea water, the exposure grades of the Chinese and British standards are basically the same, but the concentration of chlorine ions of different grades is stipulated in Chinese standard, and the classification is more detailed. See Tab.4 and Tab.5 for details.

Chemical corrosion environment. It can be seen from Tab.6 that under the condition of chemical corrosion environment, the exposure classification of the Chinese and British standards is basically the same. But British standards have a smaller limit on \( \text{SO}_4^{2-} \) in groundwater and soil, and the concentration of NH4- in water is required.
| Exposure classes | Type | Corrosion mechanism | Class description | Informative examples |
|------------------|------|---------------------|-------------------|----------------------|
| Chinese standard | I    | General environment | Corrosion of steel bar caused by carbonation of protective layer concrete | I—A (Dry indoor environment; Permanent still water immersion environment) ①Indoor components in perennial dry, low humidity environments; ②Components whose surfaces are permanently in still water |
| British standard | XC   | Where concrete containing reinforcement or other embedded metal is exposed to air and moisture | Corrosion induced by carbonation | XC1 (Dry or permanently wet) ①Reinforced and prestressed concrete surfaces inside enclosed structures except areas of structures with high humidity; ②Reinforced and prestressed concrete surfaces permanently submerged in non-aggressive water |
|                  |      |                     |                   | XC2 (Wet or rarely dry) Reinforced and prestressed concrete completely buried in soil classed as AC-1 and with a hydraulic gradient not greater than the specification associated with the designation |
|                  |      |                     |                   | XC3 | Moderate humidity or cyclic wet and dry |
|                  |      |                     |                   | XC4 | ①External reinforced and prestressed concrete surfaces sheltered from, or exposed to, direct rain; ②Reinforced and prestressed concrete surfaces subject to high humidity (e.g. poorly ventilated bathrooms, kitchens); ③Reinforced and prestressed concrete surfaces exposed to alternate wetting and drying; ④Interior concrete surfaces of pedestrian subways not subject to de-icing salts, voided superstructures or cellular abutments; ⑤Reinforced or prestressed concrete beneath waterproofing |
## Tab.3 Classification of exposure classes in freeze-thaw cycle environment

| Exposur e classes | Type | Mechanism of corrosion | Class description | Informative examples |
|-------------------|------|------------------------|-------------------|---------------------|
| Chines e standard  | II   | Freeze-thaw environment | Concrete damage caused by repeated freezing and thawing | II—C (Non-salt environment in micro-frozen area, high water saturation of concrete; Salt free environment in cold and cold regions, moderate saturated concrete)  \[1\] The horizontal surface of the components in water level variation zone and the components frequently affected by rain in the micro-frozen area;  \[2\] Vertical surfaces of rain-affected components in severe cold and cold regions. |
| British standard  | XF   | Freeze-thaw attack     | where concrete is exposed to significant attack from freeze-thaw cycles whilst wet | XF1 (Moderate water saturation without deicing agent)  \[1\] Vertical concrete surfaces such as facades and columns exposed to rain and freezing;  \[2\] Non-vertical concrete surfaces and not highly saturated, but exposed to freezing and to rain or water. |
|                   |      |                        |                   | XF2 (Moderate water saturation with deicing agent) | Concrete surfaces such as parts of bridges, which would otherwise be classified as XF1, but which are exposed to deicing agent either directly or as spray or run-off. |
|                   |      |                        |                   | XF3 (High water saturation without deicing agent) | \[1\] Horizontal concrete surfaces such as parts of buildings, where water accumulates and which are exposed to freezing;  \[2\] Concrete surfaces subjected to frequent splashing with water and exposed to freezing. |
|                   |      |                        |                   | XF4 (High water saturation with deicing agent or sea water) | \[1\] Horizontal concrete surfaces, such as roads and pavements, exposed to freezing and to deicing agent either directly or as spray or run-off; \[2\] Concrete surfaces subjected to frequent splashing with water containing deicing agent and exposed to freezing. |
| Chinese standard | British standard | Exposu re classes | Type | Mechanism of corrosion | Class description | Informative examples |
|------------------|-------------------|-------------------|------|------------------------|-------------------|----------------------|
| III              | XS                | III               | III—C (①Underwater and middle soil areas; The surrounding areas permanently immersed in seawater or buried in soil) | Pier and foundation |                     |
|                  |                   |                   | III—D (①Atmospheric area (mild salt fog); ②Air area above 15m from the average water level; ③Outdoor Land Environment within 100m off the coast line of high tide) | ①Pier; ② Components of the superstructure of a bridge; ③ External walls and outdoor components of land buildings near the sea |                     |
|                  |                   |                   | III—E (①Atmospheric area (heavy salt mist); ②Air area above 15m from the average water level; ③Outdoor Land Environment within 100m off the coast line of high tide; ④Tidal zone and splash zone, not at hot area) | ①Components of the superstructure of a bridge; ② The outer walls and outdoor elements of a land building near the sea; ③Piers; ④ Docks; ⑤ etc. |                     |
|                  |                   |                   | III—F (Tidal zone and splash zone, at hot area) | Piers and Docks; |                     |
|                  |                   | XS                | XS1 (Exposed to salt mist but not in direct contact with sea water) | External reinforced and prestressed concrete surfaces in coastal areas |                     |
|                  |                   |                   | XS2 (Permanently submerged) | Reinforced and prestressed concrete surfaces completely submerged and remaining saturated, e.g. concrete below mid-tide level |                     |
|                  |                   |                   | XS3 (Tidal, splash and spray zones) | Reinforced and prestressed concrete surfaces in the uppertidal zones and the splash and spray zones |                     |
| Chinese standard | Exposure classes | Type | Mechanism of corrosion | Class description | Informative examples |
|------------------|------------------|------|------------------------|------------------|---------------------|
| IV               | Deicing salt and other chlorides environments | Corrosion of reinforcement caused by other chlorides | IV—C (①Mild action by deicing salt spray; ②Immersed in chlorinated water around; ③Contact with lower concentration chloride ion water (100-500mg/L), with a dry and wet alternation) | ① The components that contact salt mist 10 m away from the carriageway; ② Components in groundwater; ③ Components those are in the water level variation zone or partially exposed to the atmosphere and partly in the soil and water of the ground. |
| British standard | XD               | Corrosion induced by chlorides other than from sea water | IV—D (①Mild sputtering by deicing salt solution;②Contact with higher concentration chloride ion water (500-5000mg/L)), with a dry and wet alternation) | ① Bridge wall, bridge pier of overpass; ② Seawater swimming pool wall; ③ Components that are in the water level variation zone or partially exposed to the atmosphere and partly in the soil and water of the ground. |
| XD               |                  |      |                        | XD1 (Moderate humidity) | ① Pavement, bridge deck, bridge cap beam with salt permeable water, top of pier column; ② Bridge guardrail, parapet and overpass pier; ③ Components within 10 m of the carriageway.; ④ Components that are in the water level variation zone or partially exposed to the atmosphere and partly in the soil and water of the ground. |
| XD               |                  |      |                        | XD2 (Wet, rarely dry) | ① Reinforced and prestressed concrete surfaces totally immersed in water containing chlorides; ② Reinforced and prestressed concrete walls and structure supports more than 10 m horizontally from a carriageway; bridge deck soffits more than 5m vertically above the carriageway; ③ Parts of structures exposed to occasional or slight chloride conditions |
| XD               |                  |      |                        | XD3 (Cyclic wet and dry) | ① Reinforced and prestressed concrete walls and structure supports within 10 m of a carriageway; ② Bridge parapet edge beams; ③ Buried highway structures less than 1 m below carriageway level; ④ Reinforced pavements and car park slabs |
| Exposure classes | Type | Mechanism of corrosion | Class description | Informative examples |
|------------------|------|------------------------|-------------------|----------------------|
| Chinese standard | V    | Chemical corrosion environment | Corrosion of concrete by sulphate and other chemicals | Ⅴ—C (Sulfate ion concentration (mg/l) in water: 200-1000; Sulfate ion concentration (water solubility value) (mg/kg) in soil:300-1500; Magnesium ion concentration (mg/l) in water: 300-1000; PH in water: 6.5-5.5; Erosive carbon dioxide concentration in water (mg/L): 15-30; Exhaust gas from motor vehicles or locomotives) | ① Structural components directly exposed to exhaust gas, ② Garage or tunnel components in a confined space affected by exhaust gas, ③ Concrete structural components in salt-bearing atmosphere |
|                  |      |                        |                   | Ⅴ—D (Sulfate ion concentration (mg/l) in water: 1000-4000; Sulfate ion concentration (water solubility value) (mg/kg) in soil:1500-6000; Magnesium ion concentration (mg/l) in water: 1000-3000; PH in water: 5.5-4.5; Erosive carbon dioxide concentration in water (mg/L): 30-60; PH of acid rain (fog, dew) ≧ 4.5) | Components frequently affected by acid rain |
|                  |      |                        |                   | Ⅴ—E (Sulfate ion concentration (mg/l) in water: 4000-10000; Sulfate ion concentration (water solubility value) (mg/kg) in soil:6000-15000; Magnesium ion concentration (mg/l) in water: ≧ 3000; PH in water: <4.5; Erosive carbon dioxide concentration in water (mg/L): 60-100; PH of acid rain <4.5) | ① Components frequently affected by acid rain; ② Concrete structural components, such as sewers, stables, septic tanks, etc. exposed to hydrogen sulfide gas or other corrosive liquids |
| British standard | XA   | Chemical attack        | where concrete is exposed to chemical attack | XA1 (Slightly aggressive chemical environment; Sulfate ion concentration (mg/l) in water: 200-600; Sulfate ion concentration (water solubility value) (mg/kg) in soil:2000-3000; Magnesium ion concentration (mg/l) in water: 300-1000; PH in water: 6.5-5.5; Erosive carbon dioxide concentration in water (mg/L): 15-40; NH₄⁺ concentration (mg/l) in water: 15-30) | Concrete exposed to natural soil and groundwater shown at the left |
|                  |      |                        |                   | XA2 (Moderately aggressive chemical environment; Sulfate ion concentration (mg/l) in water: 600-3000; Sulfate ion concentration (water solubility value) (mg/kg) in soil:3000-12000; Magnesium ion concentration (mg/l) in water: 1000-3000; PH in water: 5.5-4.5; Erosive carbon dioxide concentration in water (mg/L): 40-100; NH₄⁺ concentration (mg/l) in water: 30-60; PH of acid rain (fog, dew) ≧ 4.5) | Concrete exposed to natural soil and groundwater shown at the left |
|                  |      |                        |                   | XA3 (Highly aggressive chemical environment; Moderately aggressive chemical environment; Sulfate ion concentration (mg/l) in water: 3000-6000; Sulfate ion concentration (water solubility value) (mg/kg) in soil:12000-24000; Magnesium ion concentration (mg/l) in water: >3000; PH in water: 4.5-4.0; Erosive carbon dioxide concentration in water (mg/L):>100; NH₄⁺ concentration (mg/l) in water:60-100) | Concrete exposed to natural soil and groundwater shown at the left |
4. Conclusions

The climate and environment of China and Britain are quite different because China has a large land span and many climate types, while Britain is in high latitude and belongs to temperate marine climate. However, due to the long coastline between China and Britain, there are many similar concrete exposure environments, such as chloride ion erosion, carbonation, and freeze-thaw and so on. Therefore, there are many similarities between the Chinese and British standards, such as the classification of environmental effects, the regulation of some ion content in chemical erosion environment. However, the Chinese national standard has a more direct way to express the severity of different environmental effects.

For the same environmental categories, there are differences in exposure levels between Chinese and English standards. The Chinese standard has a more detailed classification of chloride-induced corrosion in seawater than the British standard, while the British standard has a more detailed classification of the environmental effects of carbonation corrosion and freeze-thaw erosion. But the other environmental effects are basically the same.

Although the exposure environment of concrete in China and Britain is similar, durability design of concrete structures relies on raw materials and mix design. Due to the geographical limitation, the raw materials in China and Britain are different. Therefore, in practical engineering, it is not only necessary to recognize the similarities between the two specifications, but also to correctly treat their differences as China's experience cannot be applied in Britain in some aspects.

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