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Corrosion of Rebar by Chlorides and Concrete Durability

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Throughout the world, corrosion of rebar in concrete is a main form for concrete building destruction. The chloride is prime criminal. This paper presents the harm of chloride corrosion in China, the effect of chloride corrosion on the durability of concrete buildings and protection strategies for rebar corrosion.

Keywords : *chloride, rebar, concrete, corrosion durability*

1. Introduction

The problem of chloride-based premature corrosion of steel bars in reinforced concrete structures constitutes currently a major global problem for the construction industry. The corrosion of reinforcements has resulted to be one of the most frequent causes of their premature failures. A serious problem of concrete infrastructure deterioration, as a result of reinforced steel corrosion, goes along with great economical consequences. In order of decreasing importance, the major causes of concrete deterioration today are: corrosion of reinforcing steel, frost action in cold climates, and physical-chemical effects in aggressive environment (Mehta, P. K.1991). The costs associated with the effects of corrosion due to chloride have been estimated to run as high as '4% of GDP' (Parker 1, 1997) in countries such as the US. In the US alone, there are close to 600,000 bridges, it is reported that 43% of the bridges have been identified as being structurally deficient or functionally obsolete due to corrosion. That could cost as much as $200 billion annually. That cost is four times more than the price of their original construction. In the United States, the overall cost of reinforcing steel corrosion has been estimated at more than $150 billion per year.

Corrosion of reinforced concrete structures is also a major corrosion problem in North America, Europe, Middle East and other parts of the world.

Chloride induced rebar corrosion damage results mainly from the use of de-icing salts in cold climates and/or exposure to marine environments, which is the main impact on the durability of concrete building.

In China, the chloride corrosion damage and impact for the durability of concrete building are a prominent problem.

2. Chloride environment and corrosion instance in china

2.1 Marine environments

In China, the coastline has excess 10000 km. It has high temperature and humidity in the South, and has frozen and thaws in the north. The chlorides in seawater, sea breeze, sea fog may produce corrosion of concrete building. The rebar corrosion products have bigger volume than steel; the result is cracking of concrete, where penetration of chlorides increased, which further increases corrosion.

Table 1 lists survey information on corrosion of part of harbor buildings.

The forepart survey information in table 1 indicates that the corrosion of marine environments in China is heavy. A major problem of the construction deterioration is corroded rebar by chlorides. Premature deterioration of construction, repair and rehabilitation required high cost.

2.2 Chloride's thaw snow deice agent

In winter, a number of products that chemically melt ice is used to ensure public safety and provide convenient public access. The chloride is major deicing compound in China. The chlorides use for deicing roadways in the early years were sodium chloride (table salt), lately calcium chloride magnesium chloride are used also. The deicing salts are corrosive and accelerate rusting of metal railings, drains, and rebar in concrete, and underground utility lines if they are not properly protected. Salt solutions may enter in void concrete and expand by 10 to 20% in volume when they freeze that may also cause flaking of surface layers from concrete.

There is over 50% land that is snowy in China. In the year 2002, there was over 10000T deicing salt that was

Table 1. Corrosion part of harbor buildings

Name	Years of use	Corrosion instance	Source
27 harbors in east & south China	10-20	74% - components of rebar corrosion	Wu Shaozhang 1965
18 harbors in South China	7-25	89% - components of rebar corrosion	Hong Dinghai 1981
22 floodgates	7-15	56% - components of rebar corrosion	Tong Baoquan 1984
61 floodgates	15-23	87% - components of rebar corrosion	Xu Guanhau 1985
Harbor of Lian Yungang	4-20	84% - components of rebar corrosion	Shan Guoliang 1989
Harbor of Zhan Jiang	6	Repair	Hong Dinghai 1988
	23	21% - components of rebar corrosion	
	32	91% - components of rebar corrosion (removed)	
Harbor of Beilun(Ningbo)	6	69 - components of rebar corrosion	Hong Dinghai 1995

used in Beijing. Deterioration of deicing salt has many examples.

XI ZHIMEN bridge of Beijing (built in 1979 and removed in 1999 with a service life of 20 years), corrosion of rebar in concrete was very severe. Chloride concentration in concrete is greatly exceeded "critical concentration". There was over 50% column that was cracking and flaking. This instance was considered alkali-silica reaction (ASR) in early years, lately it was confirmed the deterioration of deicing salt. Beijing has a number of same bridges that are exposed in deicing salt and suffered deterioration. Same instance is occurred in Tianjin.

The chloride deicers may accelerate highway concrete deterioration. Such deterioration also occurs in the north of China.

Anticorrosion measures must be taken for highway bridges, city crossroads in the salt environment. The main measures involve reduction concrete permeability, use of concrete admixture (corrosion inhibitor, air-entraining, water-reducing), waterproof. These measures are only initial.

2.3 Saline-soil

The soil with a salt exceeding 0.3% is called saline-soil. Saline-soil exists extensively in China. Chloride saline-soil exists on the coast; sub- chloride saline-soil exists on the west. Table 2 lists classification and distribution of saline-soil in China.

The corrosion of saline-soil is severe. There have a few examples:

* An electric power plant:
  It locates in chloride saline-soil on the coast, the rebar in concrete corroded severely. A repair expensed 300 million Yuan.
* A salt base on west:

Table 2. classification and distribution of saline-soil in China

Name	Cl^-/SO_4^{--}	$CO_3^{--}+HCO_3^-/Cl^-+SO_4^{--}$	Distribution
Chloride saline-soil	>2		border sea, Qinghai
Sub- chloride saline-soil	2 – 1		Qinghai, Xingiang, Gansu
Sub-sulfate saline-soil	1 – 0.3		Xingjiang, Inner Mongolia, Gansu
Sulfate saline-soil	<0.3		Xingjiang, Gansu
Alkali-sulfate saline-soil		>0.3	Xizang, Inner Mongolia

  It locates in an area of saline-soil and produced salts. After its running for 6 year , the workshops and buildings are corroded severely and resulted in shutdown. with a loss of more than100 million Yuan.
* A concrete pipe for an oil field on the west:
  It locates in an area of saline-soil and is a water pipe. The construction cost is 30 million Yuan. After its use for 2 years, concrete pipe corroded severely and rupture, it cannot be use but abandon.

2.4 Other example:

* "Sea sand buildings": Because of inadequate use of sea sand in concrete, premature rebar corrosion and concrete deterioration occurred in some building groups.
* "Buildings with interfused chlorides": Antifreeze admixtures or light materials containing chlorides were used for a small amount of building group, which resulted in heavy corrosion, whose repair fee was very great.
* Several bridges abruptly broke down that was associated

with corrosion.

2.5 Great economic loss due to chloride corrosion

"China Corrosion Investigation Report" published recently indicates (the author participated in the work) that the direct corrosion loss in China exceeds 200 billion Yuan annually, including100 billion Yuan for building corrosion loss (table 3). The main infrastructures are located in marine environments and snowy areas In China will surely be corroded by chloride.

This investigated information indicates that direct + indirect corrosion losses exceed 500 billion Yuan annually. It is about 6% of GDP. The chloride corrosion takes a lager proportion.

Table 3. the direct loss of several major industries in China

Industries section	Corrosion loss / billion Yuan
Chemistry	30
Power (electric, oil, coal)	17.21
Traffic (train, auto)	30.39
Building (bridge, highway, structure)	100
Machine	51.243
Total	228.843

3. Principle measure for preventing chloride corrosion

Corrosion in its broadest sense is the destruction of a substance or its properties because of a adverse reaction with its environment. The chloride can supply harsh service environments to which many buildings will be exposed to typically. Corrosion of steel reinforcement (rebar) in concrete is one of the highest cost forms of corrosion in China. It is extremely difficult - but not impossible - to build reinforced concrete buildings that would be free of corrosion. The achievement of this goal would require the adoption of a series of approaches. Proper attention to durability considerations in design can greatly extend the life of a structure. High quality concrete and adequate cover provide the first line of defense against corrosion. However, practical experience has shown that relying solely on concrete quality and cover as a corrosion-protection strategy cannot assure long-term durability and protection against corrosion particularly in severe chloride service environments. Secondly, affixation measures are also used for durability considerations. These are the protection methods that act to delay or offset the effects of chloride corrosion, including epoxy coated bars, corrosion inhibitors, coating for concrete, cathodes protection, additives, etc. The combination of the first and second measures is the best design consideration. Table 4 lists consequently numerous technologies that are being applied

Table 4. Morn technologies to combat chloride corrosion

Class	Object	Measures	Instance in China
First line (Basic measures)	concrete	High performance concrete: Reduce the permeability of the concrete Ensure at least two inches of concrete cover for rebar Use a pozzolan or, even better, a blended cement in the concrete Use a water-reducing agent; low-, mid-, or high-range Cure the concrete properly Fibrin concrete	At a stage of research, development and engineering use
Additional measures	Rebar	Coat rebar with epoxy. Galvanize rebar	Initial use
		Stainless rebar	Investigation
	Rebar	Corrosion inhibitor admixtures	Further use
	Surface of concrete	Coats	Further use
	Rebar & concrete	Cathode protection Electrochemical chloride extraction	Investigation

to combating this chloride corrosion problem. These technologies are being investigated and applied in China.

4. Conclusion

The problem of chloride-based premature corrosion of rebar in concrete structures constitutes currently a major global problem for the construction industry. In China, the chloride corrosion damage and impact on the durability of concrete buildings are also a prominent problem. It is extremely difficult - but not impossible - to build reinforced concrete buildings that would be free of corrosion. The combination of high quality concrete and the second measures is likely to best design consideration.

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