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The Research on the Rust of Reinforced Bar and the Strengthening Measures to the Existed R.C. Frame nearby the Sea

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Abstract The netlike cracks along the rebars at the bottom of concrete slabs as well as the circular cracks around the columns and beams were found in an underground park, which is a cast-in-site concrete frame. The building was about 300 m away from the sea.

The influencial factors which can cause rust of the rebars, such as concrete carbonization, chloride ion (Cl^{-1}) content, and design & construction measures, were analyzed respectively. The in-site inspections and *X*-spectrum analysis of concrete specimens drilled from the R.C. members were conducted. The concrete carbonization depth and the concrete protection layer were also collected.

In order to find out the main influence factor, steps were carried out as following: at first, according to comparison with the data of calculation and inspection results, the formula for the partial carbonization depth was modified to be used at high humidity environment. Then, the weight ratio of Cl^{-1} in the drilled R.C. members was 0.02%~0.07% and was lower than the required index 0.1% set by department of construction of Shandong province (DBJ14-S6-2005). The thickness of the concrete protection layer was measured and found to be thinner than the standard set by DBJ14-S6-2005, so as the main reason was identified at last.

To ensure the safety and durability of the building, strengthening measures were brought forward with consideration of the results from both the theoretical calculation and the inspections. The rusted concrete protectionion layer was removed and the anti-rust reagent was brushed when the rusted rebar was cleansed by special machine which can meet the durability requirements. The carbonic fibres reinforcement polymers were stuck on the new concrete protection layer which can provided the bearing capacity. The measures can be a good reference for the same project.

Keywords: R.C. Frame, Rebar Rust, Durability, Strengthening

Introduction

Rust of rebars is always of concern since it affects the reliability of concrete structures, especially in the high temperature, high humidity and salt spray environment in which the rust of reinforcing rebars becomes more serious.

In this paper, according to the rebar corrosion mechanism and its basic condition, theoretical and inspective analysis of an existing *R.C.* frame structure with underground garage nearby the sea were carried out. The main reason causing the rebar corrosion was determined with the consideration of the structural design, construction quality and structural environment, based on which measurements for the building strengthening were brought forward.

Overview of Engineering Survey

An existing residential building with a underground garage was studied in this paper. The construction area was about 40000 m^2.The structural type was of cast-in-site concrete frame, and was about 300 meters away from the high tide coastline. The rebars in the slabs and columns were found to have seriously rusted. Inspection survey on work site was conducted as following:

Concrete Slab Cracked Seriously: More than 70% of the slabs were found with longitudinal cracks, as shown in Figure2.1-2.2. Some were found with concrete flake-off. It was also found that the thickness of concrete protection layers was smaller than 6 mm when diged up. The weight lost ratio of the rusted rebars was between 10% and 20%. The rusted rebars in the members with higher concrete protectionion layer thickness were found with lower weight lost ratio. Rebars in good condition with concrete protectionion layer more than 15 mm were almost intact except a few slight rust spots.


Figure 2: *(a) Phenomenon of slab crack-up* *(b) Rustedrebar status after the concrete chiselled*

Stirrups Severely Rusted and Longitudinal Rebar with Rust Spots in Beam: Stirrups at the bottom of beam members almost had no concrete protection layers and the carbonization depth was up to 3 mm. As shown in Figure2.3~2.4, the weight lost ratio of the rusted rebar was more than 40%. Longitudinal cracks along the rebars were found at the bottom of the beams. Concrete protection layers on both sides of the beams were all beyond 40 mm. The inspection to the samples drilled from the beam indicated that both the awkward had few rust spots. The drilled samples from the beams selected at random were found in good condition and was tested for the alkaline by using phenolphthalein indictor. The test results showed that the concrete protection layers were just partly carbonized as the concrete color was red in the distance of 8 to 12 mm to the surface of the rebar, but the rust spot and tiny radical cracks were found around the rebars, which indicated that the rebars were rusted being placed into the beam.


Figure 2:*(c) seriously rusted stirrups at the bottom of beams* *(d) tiny rusted longitudinal rebars at the bottom of beams*

Stirrups of Frame Column were Severely Rusted While the Longitudinal Rebars were Almost in Good Condition: Part of concrete protection layers of stirrups in frame columns were less than 5 mm and the weight lost ratio of the rusted rebar was more than 20%. The longitudinal rebars of the other members were in good condition because the concrete protection layer's depth was more than 50 mm.

Analysis of the Reason of the Rust

Influential factors on the rusted rebars such as concrete carbonization, Cl^- content, the working environment, structural design, material and even construction were analyzed respectively.

Mechanism and Calculation of the Rust Caused by Concrete Carbonization The rusting of rebar was an electrochemical reaction process. According to electrochemical principle for metal corrosion, three preconditions must be met simultaneously to destroy the passivating film, and then rust the rebar, that was, 1) The presence of potential difference constituted corrosion battery. 2) Passivating film was in an active state. 3) There were water and oxygen on the surface of the rebar. Among the three preconditions, precondition (1) was always satisfied. The concrete carbonization was the most improtant factor in causing the reduction of *PH* and destroying the passivating film under the ordinary atmospheric environment, sometimes, Cl^- penatration or exessive chloride in the water when casting the concrete can cause the Cl^- content much more higher than the critical limit, and can also destroy the passivating film and then rust the rebar as well.

Concrete carbonization was one of the necessary preconditions for rebar corrosion. However, the theory cannot explain the phenomenon described in Figure2.1 that concrete around the rebar was not carbonized but the rebar had been rusted.

As shown in ref.[4], the rate of carbonization reaction was slower than the rate of CO_2 diffusion in concrete, which leads to partial carbonization towards the rebar, when PH is less than 9, the rebar was impossible to be passivated, i.e. , the rebar was in an active state, when PH is higher than 11.5, the rebar was completely passivated, when PH is between 9 and 11.5, the rate of rust became faster with the decrease of PH, at the same time, the rebar began to be activated. By ignoring the other factors such as Cl^-, mathematical formulas of full carbonization depth and partial carbonization depth were given in ref.[4,5] which was shown in formula 3-1, 3-2.

The formula of full carbonization depth can be expressed as(Jiang et al. 1999):

$$X_c = 839(1-RH)^{1.1}\sqrt{\frac{\frac{W}{\gamma_c C}-0.34}{\gamma_{HD}\gamma_c c}C_0}\bullet\sqrt{t} \qquad (3\text{-}1)$$

The formula of partial carbonization depth can be expressed as(Jiang et al. 1999):

$$X_L = 1.017\times10^4(0.7-RH)^{1.82}\sqrt{\frac{\frac{W}{C}-0.31}{c}} \qquad (3\text{-}2)$$

in which RH, W/C , C, γ_{HD}, γ_c, t are the relative humidity, water-cement ratio, cement consumption, correction factor of hydration degree, correction factor of cement variety and carbonization time, respectively.

The procedure of calculating relavant parameters was shown in Table 3.1. Ignoring the influence of Cl^-, the theoretical values and inspection ones were shown in Figure3.2. (Sample size n was 10, single sample size was greater than 100). Because the water-cement ratio was small and concrete had a brushing layer of 2 mm, the inspection results of the full carbonization depth were less than the calculated values in Figure3-1. When the humidity increased, the partial carbonization depth reduced, so the formula was modified because the mathematical model in ref.[5] was applied only to the environment in which the relative humidity was less than 70%.

Table 3.1: Calculation of relevant parameters

parameters	values	parameters	values
RH(%)	80	W/C	0.4
c (kg/m^3)	455	volume concentration of CO_2 (%)	0.0325
γ_{HD}	1.0	γ_c	1.0
t (day)	1200	——	

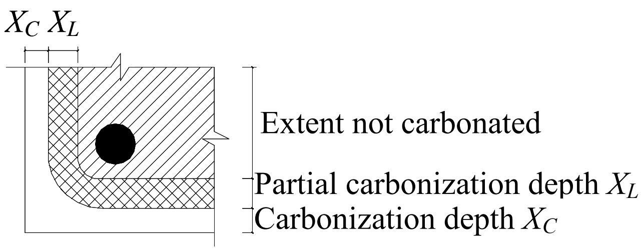

Figure 3. 1: Carbonization diagram of concrete members

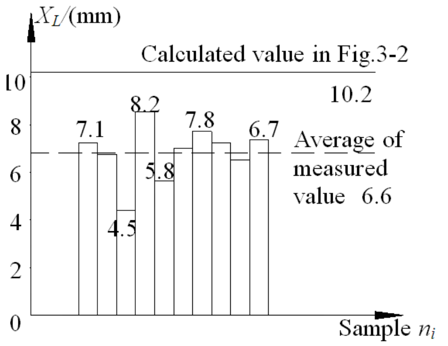

Figure 3. 2 *Measured values and calculated values of full carbonization depth*

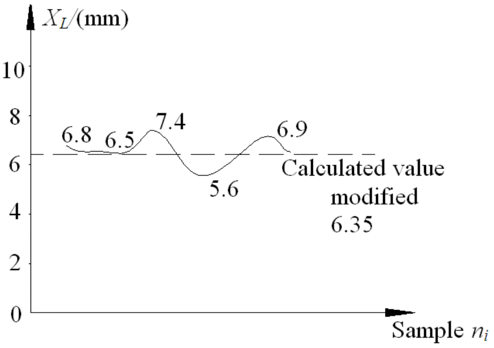

Figure 3. 3 *Fitting curve of measured values of the partial carbonization depth*

In Figure3-2,when revised parameters of the humidity was modified from 0.7 to 0.98, the average value of the carbonization depth was 6.35 mm and the partial carbonization depth decreased with the increase of the humidity, as shown in Figure3.3.

Experimental Analysis of Cl^- Penetration[6] For reinforced concrete structures, Cl^- was a very strong depassivator. Cl^- was absorbed by passivating film, which lead to the decrease of *PH* as low as 4, and causes passivating film destroyment. At the same time , Cl^- cannot be consumed during the corrosion process, and it played as a catalytic role in the generation of rusting the rebars.

In order to determinate the Cl^- content of structural member,concrete specimens from beams, slabs and columns were sampled respectively in different areas and depths according to different construction section. Concrete specimens were analyzed by *X*-spectrum. It was found that Cl^- content was between 0.02% and 0.07%, which is below the index 0.1% limited in the ref.[2] in alternating wet and dry environment of mild salt-fog area. So the excessive Cl^- content was not the reason for the rust of the rebars. Cl^- content of internal concrete was greater than that of the external concrete, which verified that Cl^- penatrated from salt-fog environment had an corrosion on the rebar with a thin concrete protection layer.

Other Pnfluencial Factors

Structural Designing Factor As described in ref.[2], concrete protection layers of slabs ,beams and columns must not be less than 30 mm and 40 mm， respectively， in mild salt-fog area,. But in this study, the concrete protection layer was set to be 20 mm and 25 mm， respectively， below the standard described in ref.[2]. In the mean time, only the waterproof concrete was prescibed in the structural documents, furthermore, other necessory measures such as anti-corrosion admixture were not introduced, which may be the most important “birth defect” causing the rusting of rebars.

Construction Factor Based on construction documents, the time the rebar moved to the working site was on mid-July and the concrete pouring time was on late September. It can then be concluded that the rebars were stored in the working site for more than two months. According to the climatological data, the humidity in the working site was 70%-90%, and it was often diffused by sea fog, so the conclusion was that the rebars had already been corroded by salt-fog before concrete was poured. The rust spots on the rebars drilled from deep concrete members confirmed the finding. As introduced in section 2, most of the concrete protection layers were significantly less than the required value. Passivating film on the rebars was actived because of the inadequate “carbonized residual”, the rusts developed rapidly and lead to cracks, which created the condition for the invaision of salt-fog and CO_2, thus the reinforced rebar was seriously eroded.

Environment Assessment of Structure Building There were no significant industrial pollution in the building environment and no other sources of pollution were found in the underground garage. During the spread of sea fog in the work site, the surface of members was dew and water film, as was known by the results of the experimental analysis in section 3.2 , the acceleration of salt-fog on the rust of rebar (especially for stirrups with very thin protect layers) could not be ignored.

The main reasons of the rebar corrosion were believed the initial rust spot caused by unsuitable storing protection and the thinner concrete protection layer accelerated the concrete carbonization, which in return caused the cracks along the rebar, at the same time, the cracks allowed the sea fog and CO_2 to penatrate the cracks and accelerated the rusting.

Retrofitting and Strengthening measurements

The retrofitting and strengthening measures were brought forward with the consideration of the principle to ensure structural reliability[2][7] , inducing the recovery of the strong alkaline environment for the rebar and the consideration of the structural working performance. The measurements were shown in Table 5.1, respectively.

Table 5.1: Retrofitting measures of members

Members and damage types	*Retrofitting measures of durability or bearing capacity*
C_{slab}≥30mm，$C_{beam,\ column}$≥40mm	Remove old decoration layers and brush two layers of anti-rust reagent
C_{slab}≥30mm，$C_{beam,\ column}$≥40mm ，W≤5%	Chisel the outside concrete and remove rusts on the rebar; Spray *C*35 concrete and plaster it smooth to conserve.
$W_{slab,\ beam,\ column}$≤5% (Figure5.1~5.3 were strengthening measures)	Chisel the outside concrete and remove rusts on the rebar. Spray *C*35 concrete and plaster it smooth to conserve. When the conservation of concrete was completed, *CFRP* was posted on the surface of members.

Notes:

1. Anti-rust reagent (whose weight was adviced to 2%) was mixed in the sprayed concrete.
2. Water to binder ratio of concrete was less than 0.45.
3. C means concrete protect layers and W was the weight lost ratio of the rusted rebar in members.

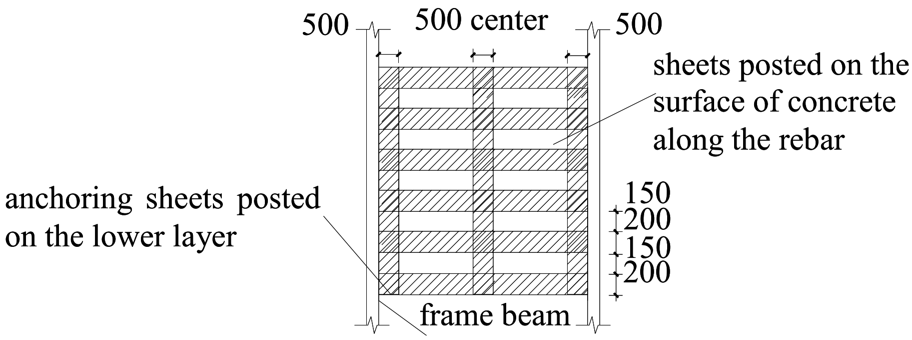

Figure 5.1: *Pasting diagram of CFRP on slabs* (mm)

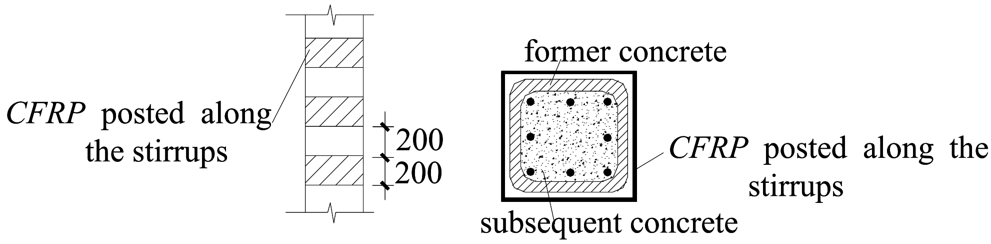

Figure 5.2*: Elevational and sectional drawings of CFRP on columns* (mm)

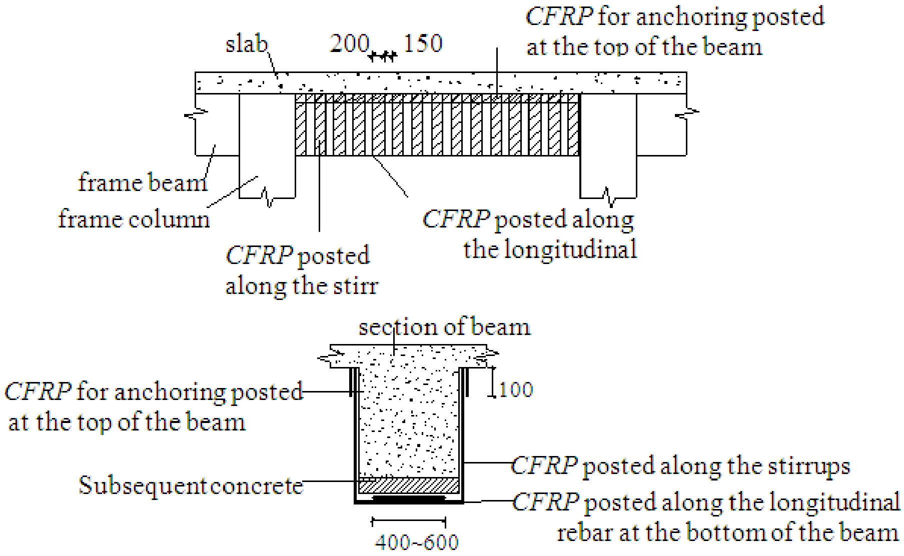

Figure 5.3: *Elevational and sectional drawings of CFRP on beams* (mm)

Conclusions

In this paper, the following conclusions were drawn from the mechanism of rust and durability of structure through theoretical analysis and experimental study:

1) During the construction process, the main reason for the rust of rebar was the poor control of the concrete protection layer. During the construction, the rust of rebar was aggravated by improper storing protection and the corrosion of Cl^-.

2) The applicability of the formula of "carbonization depth" was verified and application of the mathematical models was explored. It was found that the partial carbonization depth decreased with the increase of the humidity.

3) The durability of the concrete structure in salt-fog area inshore was to be designed. During the contruction, building materials and protect layers of members needed to be put under strict control.

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