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Analysis of the Decline of Concrete Structure Durability of a Seaside Gymnasium

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Abstract. To investigate the causes of the decline of concrete structure durability of a seaside gymnasium, we conducted durability tests at representative areas of the building based on the inspection of its appearance. The tests included the examination of rebar position, thickness of the concrete protection layer and concrete neutrality. The test data is analyzed based on both the original structure design and the construction report. Results show that the main causes of the decline of concrete structure durability include neutralization of concrete and shifting, lack of thickness and water seepage of the protection layer due to construction defect. The durability problems of seaside concrete structure are not necessarily caused by chloride ion invasion.

1. Introduction

The gymnasium is located in Ningbo, Zhejiang, and was completed ten years ago in 2007.The northeast of the building is about 8km distance from the nearest coastline. There is no mountain or tall buildings blocking, therefore the building suffers the sea breeze and fog directly. The major structure of building is round single layer grid structure, the diameter is 70.4m and the covering area is 3900 m^2.

The structure system of the gymnasium is reinforced concrete frame, the roof is made of steel truss, the foundation uses jacked prestressed concrete pipe piles. The design working life of structure is 50 years, the safety grade of architecture is II, the design grade of foundation is B, the safety grade of pile is II. The material of rebar mainly is HRB235 and HRB335. The concrete strength of beam, plate and column of the structure is C30. The wall above ±0.000 uses MU10 porous clay brick and M5 composite mortar. The wall below ±0.000 uses MU10 fly-ash solid brick and M7.5 waterproofing cement grout (with 5% water-repellent admixture).

Being used less than a decade, this gymnasium appeared some obvious problems and showed decline of durability of concrete structure. In order to offer guide for durability design, construction and maintenance for the buildings in this area, as well as provide a basis for structure rehabilitation and strengthening for buildings of this kind, we explored the factor causing the decline of durability of concrete structure. Based on the result of appearance investigation, the location of rebar was detected, thickness of concrete cover and depth of concrete neutralization was measured. Chloride ion content could be tested in some representative area if necessary. Some testing data was compared with architectural design drawings to analyze and conclude the factors causing the decline of durability of concrete structure.

2. Existing Durability Problem

After the appearance investigating, we found many problems: water seepage, rebar corrosion, cracking, concrete spalling and coming off of facing brick (Figure 1). Most of these problems appeared on the periphery of top slab of 1st floor, around the support columns and the drain pipe. Water seepage also appeared at the bottom of expansion joints and these areas usually were accompanied by corrosion of rebar. There were several area, in which rebar was almost exposed and could be taken down by hand (Figure 2). Preliminary measurement showed that the corrosion part had taken over 1/3 of the diameter of the rebar

Even though the top slab of 1st floor had drain channel and pipe, along the edge of the top slab rainwater still collected. In addition, expansion joints were damaged and this caused water seepage.

Figure 1. Water seepage, rebar corrosion.

Figure 2. Exposed rebar.

3. Principle of Corrosion of Rebar in Concrete

The structure of concrete is the most widely used structure in construction. For various reasons, concrete structure appears rebar corrosion, cracking and spalling of concrete, resulting in the decline of durability of concrete structure. Factors that cause decline of durability of concrete structure exist in every link of structure design, construction and maintenance[1].

The major ingredient of cement stone is $2Cao•SiO_2•nH_2O$, $Ca(OH)_2$, $3Cao•Al_2O_3•6H_2O$, $4CaO•Al_2O_3•Fe_2O_3•nH_2O$, etc. The existing of $Ca(OH)_2$ causes the pH value of solution in pore over 12.5 [1]in general, which is alkaline. In this condition, on the surface of the rebar a compact passive film will be formed, and this film will stop the ionization of anode, equivalent to anode polarization blocks oxidizing reaction.

Acidic materials (COx, SOx, NOx) in air permeated into concrete will cause the neutralization of concrete and pH value of solution in pore will reduce. Take carbon dioxide which is the commonest in air as an example, the reaction mechanism [2]can be expressed as:

$$CO_2+H_2O \rightarrow H_2CO_3 \qquad (1)$$

$$Ca(OH)_2+H_2CO_3 \rightarrow CaCO_3+2H_2O \qquad (2)$$

$$3CaO•2SiO_2•3H_2O+3H_2CO_3 \rightarrow 3CaCO_3+2SiO_3+2SiO_2+6H_2O \qquad (3)$$

$$2CaO \cdot SiO_2 \cdot 4H_2O + 2H_2CO_3 \rightarrow 2CaCO_3 + SiO_2 + 6H_2O \tag{4}$$

$$3CaO \cdot Al2O_3 \cdot 3CaO_4 \cdot 32H_2O + 3CO_2 \rightarrow 3CaCO_3 + 3CaSO_4 + Al2O_3 \cdot XH_2O + (32-x)H_2O \tag{5}$$

Lost the condition of alkaline, the passive film is difficult to keep and the weak spot will occur oxidation reactions as anode, and the reactions electrochemistry of cathode will react fast. The product and electrochemistry reaction process[3] is expressed in Figure 3.

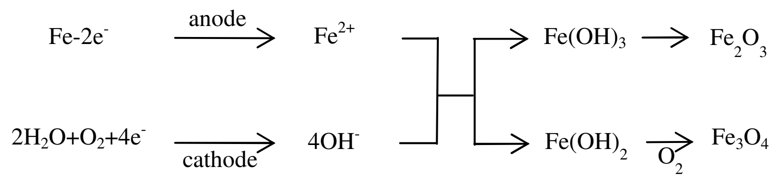

Fig. 3 Product and electrochemistry reaction process on the surface of rebar

In dampness condition, the reaction product (mFe3O4• nFe2O3• rH2O) [3] is loose, and the reaction product will form a rust layer. The volume of rust layer will be several times bigger than before, so it will press the circumambient concrete, result in concrete crack along rebar, concrete cover drop out and rebar exposure. In this condition, the rate of corrosion reaction will be accelerated.

Draw a conclusion, the destruction of passive film and the contact of water and oxygen are the immediate cause of corrosion. In order to prevent rebar from corrosion, contact of water and oxygen should be avoided, destruction of passive film should be prevented.

4. Test and Analysis of Result

4.1 Method of Test

After the appearance investigation of the gymnasium, in different directions of the building we selected 5 testing zones and 1 zone to take samples of exposed rebar (Figure 4). special testing for durability would be conducted in each of the zones. The size of testing zones of plate was about 80cm×80cm, the length of testing zones of beam was about 80cm and the width was the same with the beam. In 4 of the testing zones, the rebar was rusted and exposed, measurement of thickness of concrete cover would be easier. In 1 of the testing zone, iron mold was obvious, but the rebar was not exposed.

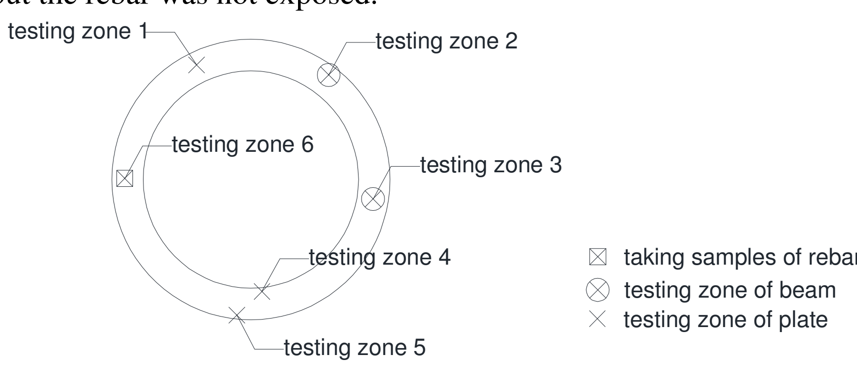

Figure 4. Sketch of testing zones.

Before the test, surface of the concrete should be cleaned. At first, we used the instrument (Elecometer331) to detect the location of rebar, and drew the location of rebar, then measured the distance between each rebar as well as the thickness of concrete cover. Based on the half-cell potential method, we used Elecometer331 to measure the potential on the surface of concrete of the test zones. We used concrete bouncing back instrument in test zones. It should be noted that the bouncing back instrument must avoid the rebar. By listening the echo, we could judge the existing of hollow. At last, we selected the side surface of beam, used a churn drill to bore a hole and measured the depth of concrete neutralization. During the process of drilling, we collected the chippings of concrete in different deepness to measure the distribution of chloride ion as occasion requires.

4.2 Testing Result

4.2.1 Test of Rebar Location and Thickness of Concrete Cover

According to the testing results, draw figure to show thickness of concrete cover in some of the testing zones(Figure 5, Figure 6) and analyze the test result of all the testing zones(Table 1).

Table 1. Result of measurement of concrete cover thickness.

Type of rebar	Thickness of design /	Thickness of measurement/[mm]			
	[mm]	Average	Minimum	Standard deviation	Coefficient variation
Radial rebar of testing zone 1	15	<12	22	---	---
Tangential rebar of testing zone 1	25	22.5	<12	0.87	0.04
Stirrup of testing zone 2	25	13.25	13	0.43	0.03
Longitudinal rebar of testing zone 2	33	31	18	6.27	0.2
Stirrup of testing zone 3	25	<12	<12	---	---
Longitudinal rebar of testing zone 3	33	23.22	14	5.96	0.25
Radial rebar of testing zone 4	15	20.33	21	7.73	0.38
Tangential rebar of testing zone 4	25	26.63	<12	5.94	0.22
Radial rebar of testing zone 5	15	<12	<12	---	---
Longitudinal rebar of testing zone 5	25	18.25	<12	2.98	0.16

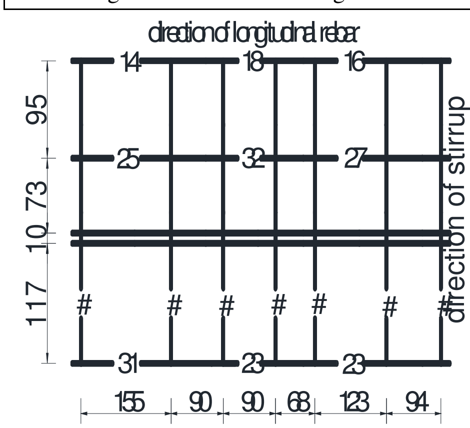

Figure 5. Rebar location and thickness of concrete cover in testing zone 3 [mm](“#” represent thickness of concrete cover less than 12).

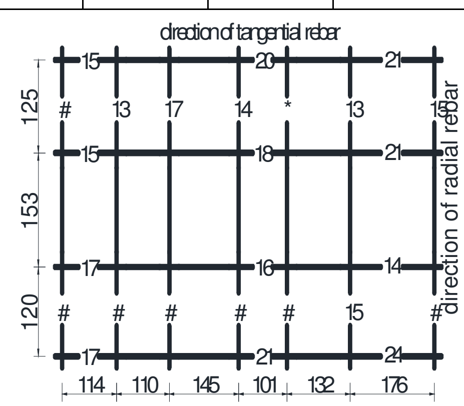

Figure 6. Rebar location and thickness of concrete cover in testing zone 5 [mm](“#” represent thickness of concrete cover less than 12, “*” represent the exposed rebar).

According to Table 1, in all zones, average of thickness of measurement is less than thickness of design, in some zones the rebar is even exposed. According to the measurement, location of rebar was irregular, the distance and angle of rebar of measurement was very different from the value of design. The coefficient variation and standard deviation is relatively small, indicating that the thickness of concrete cover is even.

4.2.2 Concrete Strength Test and Hollow of Concrete Detection

According to the build drawing, concrete strength in all the testing zones is C30. Based on the rebound value and equivalent value of all the testing zones(Table 2, Table 3), it is observed that the concrete strength is fine, meeting the requirement of design and the coefficient variation is small. But the concrete compressive strength in testing zone 4 is relatively low.

Table 2. Rebound value in each testing zone.

Testing zone	Rebound value (Ri)																
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	Rm
1	60	61	62	60	56	56	58	58	66	60	60	62	57	56	62	58	59.4
2	61	58	60	62	62	59	62	58	59	63	57	61	60	59	60	60	60.1
3	60	62	59	60	60	58	59	60	60	59	61	59	64	58	60	58	59.6
4	38	46	42	50	54	56	58	58	56	60	58	50	40	30	54	36	50.6
5	53	62	54	58	56	60	60	60	59	56	54	58	58	54	59	58	57.6

Table 3. Correction value and equivalent concrete strength.

Testing zone	1	2	3	4	5
Average	59.4	60.1	59.6	50.6	57.6
Angle of rebound	90°	90°	90°	90°	90°
Value of correction	-3.5	-3.5	-3.5	-3.5	-3.5
Corrected angle	55.9	56.6	56.1	47.1	54.1
Type of casting area	underside	underside	underside	underside	underside
Value of correction of casting area	0	0	0	-0.3	0
Value of corrected casting area	55.9	56.6	56.1	46.8	54.1
Standard deviation	2066	1.63	1.5	9.02	2.57
Coefficient variation	0.04	0.02	0.02	0.17	0.04
Carbonation depth [mm]	11	11	11	11	11
Equivalent value	48.9	50.1	49.3	34.2	45.8

According to the *Technical specification for inspecting of concrete compressive strength by rebound method* (JGJ/T 23-2011), the concrete compressive strength was 34.2MPa, met the requirement of design. By listening the echo, there was no hollow. In this testing zone, there was no rebar exposed, but the phenomenon of iron mold and water seepage was obvious, the concrete compressive strength was lower than other zones.

4.2.3 Concrete Neutralization Test

Nearby the iron mold, we carried out the minimally invasive detection. After the measurement of two holes for many times, we got the average depth of concrete neutralization which was 11mm. The extent of concrete neutralization was relatively serious, especially for the zones where concrete cover was thinner than 12mm. If the concrete cover was entirely neutralized, the protective effect to rebar will decrease.

4.2.4 Measurement of Potential on the Surface of Concrete

Using Elecometer331 and Cu-CuSO4 electrode, we measured the potential on surface of concrete by half-cell potential method. According to the figure, there was obvious minus value. According to *Technical standard for inspection of building structure* (GB 50344-2004), the absolute value of minus value is larger, the more likely that the rebar under the surface is rusted. Take testing zones 4 and 5 as example (Figure 5Figure 6), they confirmed that the potential of concrete in area of iron mold was lower than other area.

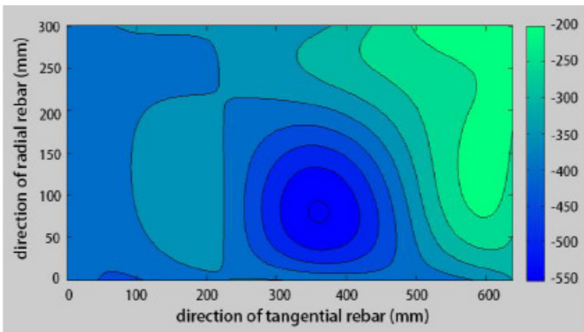

Figure 5. Potential on surface of concrete in testing zone 4 [mV].

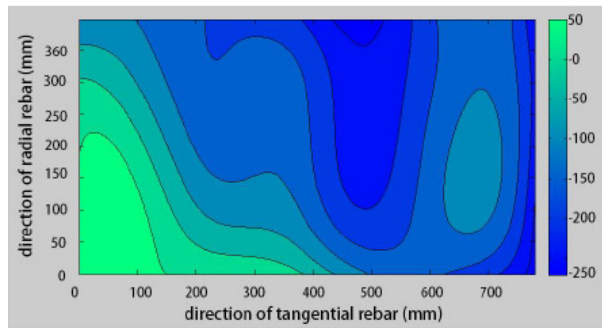

Figure 6. Potential on surface of concrete in testing zone 5 [mV].

4.3 Analysis of Testing Results

4.3.1 Concrete Cover is Too Thin

The concrete cover which is too thin could not provide enough chemical and physical protection. According to the principle of corrosion, if the concrete cover is not thick enough, the oxygen and moisture will contact with rebar earlier, what makes the probability of corrosion greater and the corrosion will become earlier, moreover the corrosion process will be faster [4, 5]. By means of using rebar detector, the thickness of concrete cover was measured, we found that concrete cover was too thin in all of the testing zones in which rebar was rusted. Reasons are as follows:

(1) The size of formwork was not the same with design value. In testing zone 2, the width of beam should be 250 mm, but the measurement width was 246 mm. In testing zone 3, the width of beam should be 400 mm, but the measurement width was 396 mm. The size of formwork was smaller than design, if the size of rebar cage was the same with design value, the thickness of concrete cover would be thin. Just like testing zone 2 (Figure 7), the concrete cover on the surface of stirrup was too thin, what caused the stirrup rusted seriously and even exposed.

(2) The rebar cage in formwork was slant, what caused the concrete cover too thin at one end and thick at other end. In the testing zone 5 (Figure 8), radial rebar was slant and this caused the concrete cover too thin at the end of some redial rebar. The tangential rebar was level, and the concrete cover was relatively uniform.

(3) The distance between rebar was different from design value. In some testing zone, we found that the rebar cage was rough, some rebar distance of measurement was only 10 mm (Figure 9), however, the design value was 150 m. Even though the rebar cage was level, incorrect positioning of rebar made concrete cover of some rebar too thin. Taking testing zone 3 as an example, some rebar nearly adjoined each other, and the location of some rebar was very

different from design. In this testing zone, some rebar was exposed and some concrete cover was too thin.

Figure 7. Measurement of formwork size in testing zone 2.

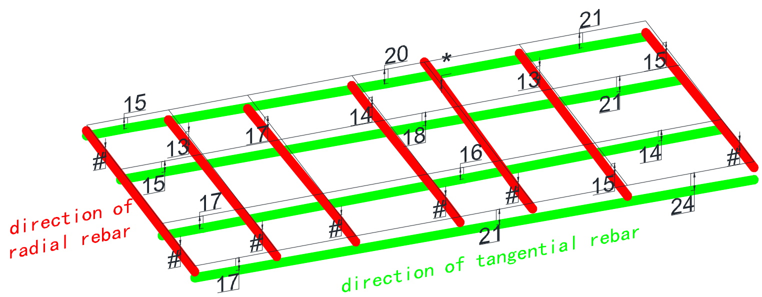

Figure 8. 3D diagram of concrete cover in testing zone 5 [mm].

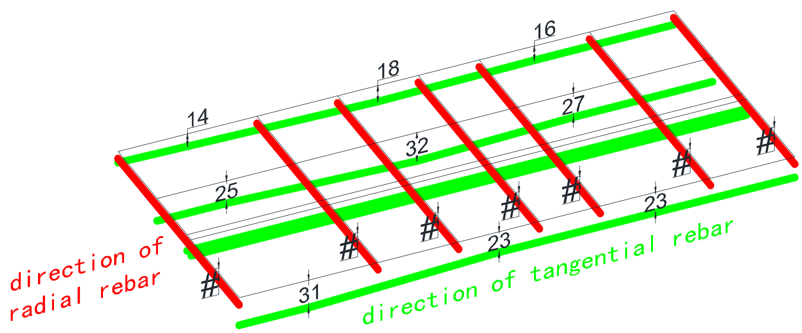

Figure 9. 3D diagram of concrete cover in testing zone 3 (mm).

4.3.2 Gap between Concrete and Column

Moist concrete will increase the rate of corrosion reaction [6], and moisture is necessary for corrosion reaction. Water seepage will increase the entering rate of harmful ions, even cause the destruction of passive film, eventually lead to the corrosion of rebar.

The column of this gymnasium was composite structure. In each column, there were two concrete columns which were the chief bearing components, and there were stainless steel plates outside to decorate. The stainless steel plates could not combine closely with concrete and there was gap between the two materials. At last, the gap caused water seepage and corrosion.

4.3.3 Concrete Neutralization

The concrete neutralization will make the pH value of solution in porosity lower, and the passive film is difficult to keep, so the rebar is easy to be rusted. By measurement, we found that the average depth of concrete neutralization was 11 mm. For some rebar whose concrete cover was too thin, the concrete cover couldn't provide alkaline condition for the rebar and the passive film was difficult to keep, the rebar was more likely to be rusted.

4.3.4 Ventage Caused by Construction Deficiency

There was no hollow in concrete, but there was some formwork not dismantled. There was obvious gap between formwork and concrete. The gap may increase the entering rate of moisture, oxygen and other harmful ions. The crack whose width is large enough will make corrosion coming earlier [7, 8]. There is no final conclusion on whether crack will increase the rate of corrosion reaction, but in order to control corrosion, many countries have restriction on crack width [9]. On the other hand, rust marks had significant influence on concrete appearance. We suggest that gap or crack should be strictly controlled in construction.

5. Conclusion

Result of testing and analysis show that, the durability of concrete structure of the gymnasium decline seriously. The following conclusions can be drawn from the results of this research:

(1) Too thin concrete cover, water seepage, concrete neutralization, crack and ventage are the factors that cause the decline of durability of concrete structure of the gymnasium.

(2) For the present construction level, the thickness of concrete cover which is designed according to the minimum requirement of specification is not enough to meet the requirement of working life.

(3) As a means of increasing level of durability, the size of formwork should be controlled accurately. The strength and stiffness of formwork should be increased and the size of reinforcement cage should be controlled accurately. What calls for special attention is that the thickness of concrete cover should be controlled accurately.

(4) Chloride ion may not be the main factor that causes the decline of durability of concrete structure of buildings in littoral environment.

Acknowledgements

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