Effect of Corrosion on Seismic Performance and Safety of Reinforced Concrete Frame Structures

—Take the office building of the Tobacco Company (Hefei) as an example

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Abstract. This paper presents a comprehensive analysis of the seismic performance and safety of the building after the corrosion of the reinforced concrete structure. The office building of Tobacco Company (Hefei) is employed as an example, with metrics including concrete strength, cross-sectional dimensions of beam and column members, reinforcement and protective layer thickness of beam and column reinforcement, diameter detection of reinforcement, etc. Meanwhile, the analysis model is established by PKPM software with the testing data, and improvement suggestions are made for the analysis results. The findings of this paper can be used in engineering practice.

Keywords: Rebar corrosion; Seismic performance; Security.

1. Introduction

In recent years, the construction industry in China has continued to develop, and reinforced concrete structures are still the main form of the building structure. With the increase in the service life of buildings, the corrosion of reinforcing steel has become the primary problem affecting the safety and seismic performance of reinforced concrete structures. Therefore, it is particularly important to carry out engineering performance tests on reinforced concrete structures with corrosion problems and to analyse them according to the tested structures.

To analyse the effects of reinforcement corrosion on the seismic performance of reinforced concrete columns, Luo et al. [1] collected the damage modes, hysteresis curves, skeleton curves, stiffness degradation, ductility, and energy dissipation capacity of the specimens under different corrosion rates. The results showed that compared with uncorroded columns, the fullness of the hysteresis curves gradually decreased, and hoop bars increased as the corrosion rates of longitudinal bars. The energy dissipation capacity, stiffness, and deformation of the specimens also showed obvious changes. The effect of the hoop corrosion rate was more significant. Based on effective working practices, Zhang et al. [2] have effectively analysed the effect of corrosion on the seismic performance of reinforced concrete frame structures and proposed specific assurance measures, such as reinforcement mesh composite cement mortar reinforcement method and reinforced concrete slab wall reinforcement method.

Based on a large number of site inspection data, this paper combines the specific case using the bearing capacity calculation method to analyse and calculate the reinforced concrete frame structure. And the PKPM software is employed for modelling and analysis. The results show that the seismic performance of the building has been somewhat reduced, the safety part does not meet the requirements, and the rusted reinforced concrete frame structure fails to reach the designed bearing capacity of the building.

2. Architectural Overview

The building consists of four building monoliths, which are Office Building B, East Auxiliary Building, East Corridor, and West Corridor. Office Building B is a six-story frame structure with an independent foundation; the East Auxiliary Building is a four-story frame structure; the East and

West corridors are both two-story frame structures. The construction area of the project is about 3600 m2. The plan of the first floor is shown in Figure 1.

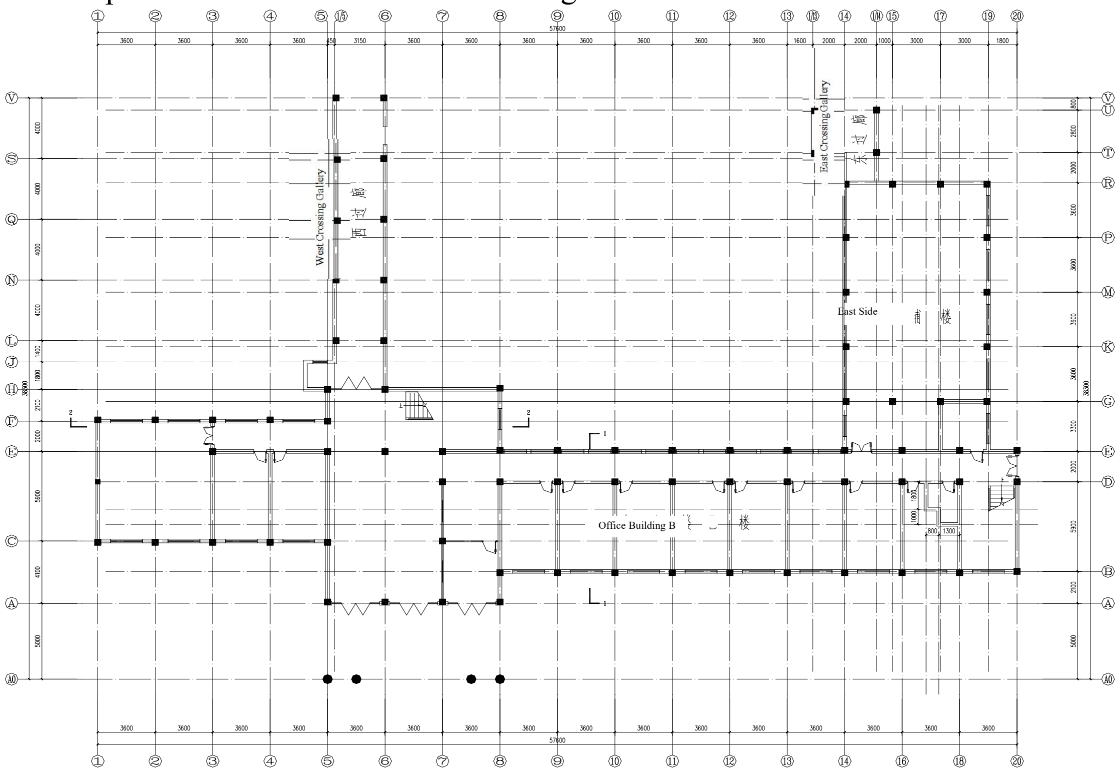


Figure 1. First-floor building layout

3. Field testing of samples

Site conditions and part of the sampling are shown in Figure 2, Figure 3, Figure 4, and Figure 5.

Figure 2. Corrosion of steel reinforcement of the top beam on the fifth floor of Building B

Figure 3. The roof beam on the second floor of the west corridor is badly corroded.

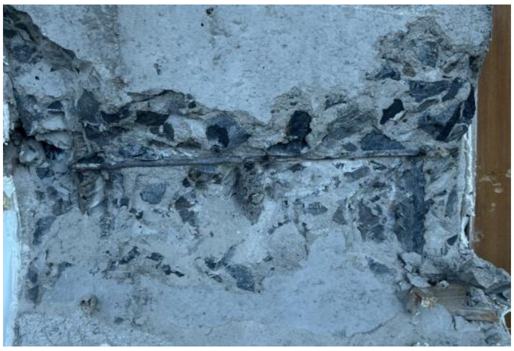


Figure 4. Building B hoops only use double-limb hoops.

Figure 5. Water seepage from the roof of the fifth floor of Building B.

4. Main testing instruments

(1) HT225-B All-in-one digital rebound meter (AJCS-JG-838);
(2) 5 m Steel tape measure (AJCS-JG-528(1));
(3) HT225-B All-in-one digital rebound meter (AJCS-JG-989);
(4) HC-GY71T All-in-one steel scanner (AJCS-JG-1213);
(5) Leica Flex line TS06 Total Station (AJCS-JG-479);
(6) 0-8 mm Concrete Carbonation Depth Gauge (AJCS-JG-462).

5. Basis of testing

(1) Rebound method of testing the compressive strength of concrete technical specifications JGJ/T 23-2011;
(2) Technical standards for testing reinforcing steel in concrete JGJ/T 152-2019;
(3) Technical standards for on-site inspection of concrete structures GB/T 50784-2013;
(4) Technical standards for building structure inspection GB/T 50344-2019;
(5) Building deformation measurement specification JGJ 8-2016

6. On-site test results

(1) The presumed values were corrected using the rebound method to test the members and the obtained concrete strength at the present age. According to the Appendix K of the Civil Building Reliability Appraisal Standard GB 50292-2015, the correction factor used was 0.92. The presumed values of the present-age concrete strength of the sampled components and the corrected presumed values of the present-age concrete strength are shown in Table 1.

Table 1. Concrete strength test results

Floor	Component name	Axis position	Design strength grade	Presumed compressive strength of concrete at the present age (MPa)	Corrected presumed compressive strength of concrete at present age (MPa)
First	Pillar	6/V	/	25.9	23.8
Second	Pillar	7/C	/	26.5	24.4
Third	Pillar	18/D	/	31.0	28.5
Fourth	Pillar	5/F	/	25.8	23.7
Fifth	Roof beam	5-7/C	/	28.7	26.4

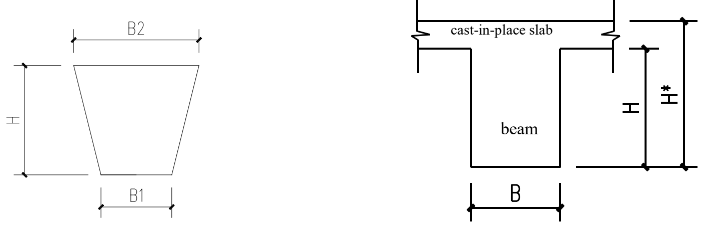
(2) Some concrete members were extracted on site, and a steel tape measure was used to detect the cross-sectional dimensions of over beams and columns (Table 2). The steel scanner was used to

detect the configuration and protective layer thickness of beam members (Table 3). Vernier calipers were used to detect the internal diameter of reinforcement (Table 4).

Table 2. Beam and column section size test results

Floor	Component name	Axis position	Section parameters	Section size(mm)			
				Measured			Average
First Floor	Pillar	6/V	B×H	B×355	B×354	B×355	B×355
Second	Pillar	7/C	B×H	B×502	B×505	B×504	B×504
Third	Pillar	18/D	B×H	415×420	413×419	415×422	414×420
Fourth	roof beam	15/M-P	B×H	235×493	233×496	234×493	234×494
Sixth	roof beam	6/C-D	B×H	306×720	308×718	304×719	306×719

Schematic diagram of beam section size inspection, as follows:



The table with “B” or “H” instead of the cross-sectional parameters indicates that the site does not have testing conditions. The building has not collected design drawings, so there are no design parameters.

Table 3. Results of the beam, column reinforcement configuration and protective layer thickness test

Floor	Component name	Axis position	Column side or beam bottom row of reinforcing steel		Hoop reinforcement		Main tendons	
			Design Number	Actual Number	Spacing design value (mm)	Spacing measured average (mm)	Design value of protective layer thickness (mm)	Protection of measured layer range values (mm)
First	Pillar	6/V	/	West: 3	/	122	/	24~25
					/	208		
Second	Pillar	7/C	/	East: 3	/	106	/	12~25
					/	198		
Third	Pillar	18/D	/	East: 2	/	97	/	42~44
					/	217		
Fourth	roof beam	15/M-P	/	3	/	112	/	14~33
					/	202		
Fifth	roof beam	6/A-E	/	3	/	138	/	31~44
					/	213		

Table 4. Results of beam and column reinforcement diameter test

Floor	Component name	Axis position	Rebar type	Rebar location	Test results (mm)			
					First	Second	Third	Average
First	Pillar	(1/5)/V	Ribbed steel bars	Column side main reinforcement	15.1	15.3	15.2	15.2
					15.4	15.4	15.4	15.4
					15.5	16.4	16.3	16.1
			Smooth round steel bars	Hoop reinforcement	7.6	7.7	7.7	7.7
Third	Pillar	7/C	Ribbed steel bars	Column side main reinforcement	24.1	24.8	24.6	24.5
					24.7	24.7	24.0	24.4
					25.0	25.1	25.0	25.0
			Smooth round steel bars	Hoop reinforcement	8.1	7.7	7.9	7.9

7. Structural inspection calculations

7.1 Basic parameters and calculation information used for structural verification

(1) Load-taking values

Constant load (including plate self-weight): Floor (prefabricated panels): 3.5 kN/m2; Roofing (prefabricated panels): 4.5 kN/m2; Stairs:7.0 kN/m2

Live load: Floor: 1.5 kN/m2; Stairs: 3.5 kN/m2; No upper roof: 0.7 kN/m2; Upholstered roofs: 1.5 kN/m2; Large Conference Room: 2.5 kN/m2; Toilets: 2.0 kN/m2; Corridor: 2.0 kN/m2

Basic wind pressure: 0.35 kN/m2; Basic snow pressure: 0.60 kN/m2

(2) According to the structural test report and design information, the material strength is taken as:

Concrete strength grade: C20

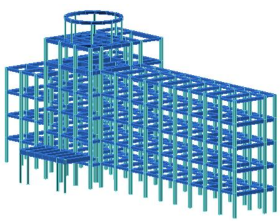
Design value of reinforcing steel strength: HPB235.

The design strength of reinforcing steel is taken as 210 N/mm2; The design strength of reinforcing steel is taken as 300 N/mm2.

(3) The seismic intensity of the building is 7 degrees; the design basic seismic acceleration is 0.10; the design seismic grouping is the first group; the frame seismic grade three; the safety grade of the building structure is grade two; and the structural importance factor γ0 is taken as 1.0.

7.2 Verification model

The structural design software of PKPM software (2010) version of the Chinese Academy of Building Sciences was used to carry out the load-bearing capacity verification analysis of the building, as shown in Figure 6, Figure 7, Figure 8, and Figure 9.



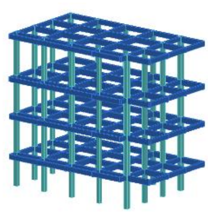


Figure 6. Monomer I (Building B)

Figure 7. Monomer II (East Auxiliary Building)

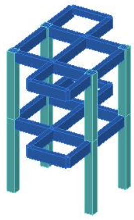


Figure 8. Monomer III (East corridor)

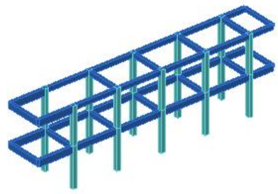


Figure 9. Monomer IV (West corridor)

7.3 Analysis of results

The data from the field tests combined with the structural verification model were calculated and analyzed. The following conclusions were made:

1. Monomer I (Building B): The beam and column bearing capacity do not meet the code requirements; Part of the column axial pressure ratio does not meet the code requirements.
2. Monomer II (East Auxiliary Building): The beam and column bearing capacity meet the code requirements; The floor and roof panel bearing capacity does not meet the code requirements; The column axial pressure ratio meets the code requirements.
3. Monomer III (East corridor) and Monomer IV (West corridor): The beam and column bearing capacity meet the code requirements; The floor and roof panel bearing capacity meet the code requirements; The column axial pressure ratio meets the code requirements.

8. Seismic resistance and safety

8.1 Seismic analysis

According to the Building Seismic Identification Standards GB 50023-2009 [3] and requirements of the seismic design (specifications) of the original construction, a verification model was established to verify the bearing capacity of the office building of Tobacco Company (Hefei). This building is a Class A multi-story reinforced concrete building with an intensity of 7 degrees. The following conclusions are drawn:

The site and foundation, exterior and interior quality of Building B, the East Auxiliary Building, and the East and West corridors meet the requirements of seismic appraisal. The seismic bearing capacity and measures of some superstructures do not meet the requirements of seismic appraisal.

The comprehensive assessment of the seismic performance of Building B, the East Auxiliary Building, and the East and West corridors does not meet the seismic requirements, and safety is not guaranteed.

8.2 Security Analysis

According to the Civil Building Reliability Appraisal Standard GB 50292-2015 [4], the safety level of the appraisal unit shall be assessed according to the safety level of its foundation, upper load-bearing structure, and load-bearing part of the enclosure system, as well as other safety issues related to the whole building. In general, the assessment results of the foundation and the upper load-bearing structure should be determined according to the lower grade. Through the above analysis, the structural safety level of the office building, Building B and East Auxiliary Building, are assessed as Csu (Table 5), and the East and West corridors is assessed as Bsu (Table 6)

Table 5. Comprehensive security appraisal rating results for Building B and East Auxiliary Building

Structure system name	Structural system safety level	Identification unit security level
Foundation	Bu	Csu
Upper load-bearing structure	Cu	
Envelope system	Cu	

Table 6. East-West over-corridor safety comprehensive identification rating results

Structure system name	Structural system safety level	Identification unit security level
Foundation	Bu	Bsu
Upper load-bearing structure	Bu	
Envelope system	Bu	

9. Conclusions

In the nodes of reinforced concrete frame structures near the beams and columns, the earthquake may cause a maximum shear and bending moment. The weak link of the seismic structure often becomes the main part of earthquake disasters. The design code requires calls for “nodes stronger than components”. The nucleus of the node is in a complex multi-axis stress state under the joint action of axial force, bending moment, and shear force at the beam and column ends. Before concrete cracking, the nodal stresses are close to the elastic distribution, and the stresses in the hoop are very low [5]. Reinforcement corrosion has a great adverse effect on the structural performance of reinforced concrete. After rusting, the reinforcement may produce a rather thin layer that is easy to peel off on the surface and simultaneously diffuse into the surrounding concrete pores. These products will accumulate over time and spread close to each other in the concrete, resulting in corrosion products after diffusion.

Therefore, compared with the unused reinforcement in this building, the volume of the corroded reinforcement will increase significantly, and the enlarged reinforcement will produce an outward expansion force on the concrete. The expansion force will prompt the cracking of the concrete inside. The bond between the reinforcement and the concrete will gradually decrease. Thus, the concrete and the reinforcement will not become a whole common force but form two structures that do not affect each other. Once the earthquake occurs, the concrete will crack rapidly with the cracks, and the reinforced concrete frame structure will not be able to reach the bearing capacity of the building. This may lead to the immediate collapse of the building, causing incalculable harm.

Acknowledgments

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