Detection and Repair Reinforcement of Reinforced Concrete Structures After Fire

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ABSTRACT: Fire seriously damages and destroys the buildings. Considering from the safety and economy, there is no need to dismantle and rebuild the building structure after fire, which can continue to be used after proper repair. This paper uses the method combined with the theory and engineering projects to research the detection and identification of buildings after fire and the theory of repair reinforcement of fire structure, lists some detection schemes, and proposes effective repair schemes, obtaining satisfactory results.

Keywords: fire; damaged reinforced concrete; detection; reinforcement

1 RESEARCH BACKGROUND

Without fire, there is no civilization and prosperity of human society. However, once the fire is out of control, it will form fire disaster, which brought us huge disasters and losses [1]. In 2001, the world-shaking “9.11” event destroyed the World Trade Center, and caused major casualties; in 2010, in the fire accident in Commercial Building in Jilin City, 19 people died and 24 people were injured, which was an fire disaster with the largest number of deaths and the largest losses in five years in Jilin Province; in 2015, in the fire explosion accident in Tianjin Ruihai Company, 165 people died, 8 people were missing and 798 people were injured, with direct economic losses of 7 billion. According to the research of World Fire Statistics Center, if the direct economic loss of fire accounts for 0.2% of the value of national economy, the total fire loss will account for 1% of the total value of national economy [2].

With the rapid development of the national economy and increasing concentration of urban population, people’s material standard of living improves gradually, population density gradually increase, high-rise buildings become more and more, decoration (flammable materials) are more and more high-end, thus increasing the fire load density, and increasing the probability and risk of fire. Based on this realistic situation, we should take measures: 1. To improve awareness of fire prevention, strengthen fire control, and improve fire-fighting facilities; 2. To prevent the spread of fire and prevent damage to the building structure through improving the fire resistance of housing; 3. To comprehensively identify the damaged structures and determine reasonable repair reinforcement schemes. Whether the damaged buildings can be used is mainly subject to experience and subjective judgment, or repair or reconstruction. When there is a bias in the subjective judgment, or reinforcement measures are improper, it will leave a security risk to the damaged structures.
In view of the above analysis, the detection and reinforcement of the main structure of the post-disaster building is a major concern. For the damaged reinforced concrete structures after fire, there is a need to correctly evaluate its safety, applicability and durability according to systematic and scientific detection and identification method, and it is very necessary to select the reasonably optimized repair reinforcement scheme on this basis.

2 OVERVIEW OF RELEVANT RESEARCH

The concrete materials and high-temperature performance of their structures were researched abroad earlier. In recent decades, foreign scholars have conducted a large number of researches on the temperature-rise process in the fire area, temperature distribution in the component, mechanical properties of reinforced concrete in a high temperature and after high temperature, thermal performance and so on, and have achieved some research findings.[3-6] In the early 20th century, the United States has carried out fire prevention research on the reinforced concrete structures, and determined the fire test methods for floors, walls and other components. In the 1950s, the former Soviet Union first issued a temporary design instruction on the heat-resistant reinforced concrete (y-151-56/MC IIIMxII). Later, the American Fire Protection Association (1962), FIP/CEB (1979), Sweden (1983) and France (1984) successively issued the fire-resistance design criteria for reinforced concrete.

The building fire and fire resistance of concrete structure were researched late in China. In the 1970s, the architectural scientific research institute and other units prepared Heat-resistance Design Specifications on Reinforced Concrete Structures in Metallurgical Industrial Plant. The Specifications give out the design calculation method in the range of 60℃ to 200℃, design measures, material index and relevant regulations. This is China’s first fire-resistance design specifications on the reinforced concrete structures. Since the 1980s, Tsinghua University, Southwest Jiaotong University and other universities have also researched the constitutive models of steel and concrete in a high temperature and after high temperature, reaction of components and structures in a high temperature and post-disaster assessment and repair and other issues, and have achieved some test results.

Some progress has been made in the research of fire resistance of the concrete structures, but due to various reasons, the current researches are free of a complete system. In addition, the domestic and foreign research on the fire resistance of concrete structures and components is still relatively limited, and comprehensive identification and assessment of the damaged structures after fire are also in the exploratory stage. There are not clear rules to follow, and many problems need to be solved in a timely manner.

3 DETECTION AND REPAIR OF REINFORCED CONCRETE STRUCTURE AFTER FIRE

3.1 Detection of reinforced concrete structure after fire

The performance of building materials after fire will change, and then reduce the bearing capacity of the component and the entire structure[7]. Therefore, it is extremely important to detect the performance of materials and structures after fire. This is a complex work. A reasonable test result can be obtained only through detection and comprehensive analysis by using a variety of methods and means.

3.1.1 Determination of concrete strength

(1) Hammering method

Hammering method is actually a spectral analysis method by relying on the component sound, which mainly evaluates the concrete strength according to the sound sent by a hammer knocking on the concrete, moulage left on the concrete surface, degree of edge slump and depth of chisel into the concrete. The evaluation criteria are shown in Table 1[8].

(2) Ultrasonic method

Ultrasonic method is a method of reflecting the quality of concrete by the difference of propagation velocity of ultrasonic wave in the concrete. A lot of empirical formulas on the relationship between ultrasonic velocity and concrete strength have been established through many experimental researches, with a very good correlation. However, this method requires that the concrete surface should have a better flatness, and the ultrasonic transmission and acceptance probes are

| Concrete compressive strength (MPa) | Knock on by a hammer | Knock on vertically by a chisel |
|-----------------------------------|----------------------|-------------------------------|
| <7                                | Send a muffled sound after knocking on concrete, leave moulage after knocking on, and no slump in moulage edge | Be easier to chisel into the concrete, with the depth of 10 to 15mm |
| 7~10                              | Send a muffled sound after knocking on concrete, concrete smash and slump after knocking on, and leave moulage | Fall into about 5mm of concrete |
| 10~20                             | Leave obvious moulage and thin debris on the concrete surface after knocking on | Chisel out thin debris from the concrete surface |
| >20                               | Send a distinct sound after knocking on concrete, and leave unobvious moulage on the concrete surface | Leave shallow moulage, surface undamaged, and leave unobvious fringe beside moulage |
preferably arranged on opposite sides of the components (reducing the error caused by the change in the propagation path length), and it is difficult to ensure in the actual operation. In addition, in the detection by the ultrasonic method, “temperature difference effect”, water content and ranging will affect its accuracy. However, the current influence rules of these factors have been basically determined, and these influences can be eliminated by appropriate amendments. In addition, the ultrasonic wave is very sensitive to the mechanical property of concrete after different temperature effects, so that the ultrasonic detection method is still an important detection means to identify the damaged concrete structure after fire.

(3) Pull-out method
Pull-out method is a relatively reliable method used to detect the concrete strength on site. Test steps: first use high-strength construction glue to glue the steel plate on the concrete surface, and then record the force of pulling out the steel plate by the jack when the glue reach at a certain strength, and then convert the concrete strength within the thickness of 2.5cm. This strength value is just the strength of the cross-section damaged layer. This method only has a slight damage to the concrete surface, and has a very small impact on the mechanical performance of the entire structure, so it can be used for fully testing the reinforced concrete members after fire.

3.1.2 Measurement of reinforcement strength
The residual strength of reinforcement in the reinforced concrete members after fire can be obtained according to the relevant curve of the fire temperature of the reinforcement in fire; it can also be sampled from the components on site and measured by sending to the laboratory for material performance test. The sampling part is generally exposed burnt reinforce ment of the concrete members on site or standard specimen cut from the seriously damaged components. As the reinforcement cut from the components affects the bearing capacity of the structure, there is a need to support the components prior to sampling, and then dismantle the support after completion of the structure reinforcement [9, 10].

3.2 Repair reinforcement of reinforced concrete structures after fire
Speaking from the entire structure, fire can greatly change the structural deformation, internal force distribution and bearing capacity [11]. Reduction in bearing capacity of structure after fire and structural failure may result in the risk of collapse at any time. The calculation of the residual bearing capacity of the damaged reinforced concrete structure after fire is the main content of structural reliability identification after fire, and also the prerequisite for repair reinforcement.

3.2.1 Calculation of residual bearing capacity of reinforced concrete flexural members after fire
For the reinforced concrete members after fire, based on the calculation of the fire temperature field and the constitutive relations between the concrete and the reinforcement under the high temperature, the residual bearing capacity of the components can be analyzed and calculated.

3.2.1.1 Calculation of cross-section characteristic parameters of fire components
1. Reduced cross section of reinforcement
The reinforcement strength is reduced after fire. The equal strength substitution method can be used to calculate the bearing capacity of the reinforced concrete members after fire. The force of reinforcement at the yield strength is as follows:

\[ \sum A_{Si} f_{yT,i} = A_{yT} f_{y} \]  \hspace{1cm} (1)

\[ A_{yT} = \sum K_{Si} A_{Si} \]  \hspace{1cm} (2)

Where: \( A_{yT} \) is the reduced cross section of reinforcement; \( A_{Si} \) is the cross-sectional area of the i-th reinforcement; \( K_{Si} \) is the strength reduction factor of the i-th reinforcement.

2. Width reduction factor of rectangular section \( K(s) \)
The integral idea is used to divide the rectangular section of the concrete members into a grid based on \( \Delta x \times \Delta y \), and the central temperature of each small unit is taken as the temperature of the unit, then the axial pressure of the unit is:

\[ \Delta x \cdot \Delta y \cdot f_{cT} = \Delta v \cdot \Delta y \cdot K_{cT} f_{c} \]  \hspace{1cm} (3)

Where: \( f_{c} \) is the design value of concrete compressive strength under a normal temperature. To sum within the range of cross-section width \( b \), the resistant external force of the concrete strip with the height of \( \Delta y \) is:

\[ \sum_{b} \Delta y \cdot \Delta x \cdot K_{cT} f_{c} = K \cdot b \cdot \Delta y \cdot f_{c} \]  \hspace{1cm} (4)

\( K \) is called as the width reduction factor of rectangular section. The value of \( K \) changes with the vertical coordinate of concrete strip \( s \), so:

\[ K(s) = \frac{\sum K_{cT}(s) \Delta x}{b} \]  \hspace{1cm} (5)

3. Area factor of stepped cross section \( K_{s}(n) \)
When the rectangular section suffers from fire, the concrete strength will decrease, but the strength can be considered unchanged, and the width reduces, then the centroid and resultant force remain unchanged. As the value of \( K(s) \) changes with the vertical coordinate, \( K \) can be used to make the original rectangular section change to stepped cross section, as shown in Figure 1.
For each small strip, the height is $\Delta h$, and width is $K_i(s)b$. The total area of n-order stepped cross section (consisting of n concrete strips) is:

$$A_T = \sum_1^n K_i(s)b \cdot \Delta h = \Delta h \cdot b \sum_1^n K_i(s) = \Delta h \cdot bK_A(n)$$

(6)

Where, $K_A(n)$ is the sum of width reduction factors of the concrete strips in the shaded area in Figure 1.

4. Stepped area centroid moment

In the calculation of bearing capacity, it is necessary to know the centroid position of the stepped area. According to the resultant moment theorem, the stepped area centroid in fire edge $c$ can be expressed as:

$$c(n) = \frac{\sum_1^n K_i(s)c_i}{\sum_1^n K_i(s)}$$

(7)

Where, $c_i$ is the centroid moment of the i-th concrete strip to the edge of cross section. In the literature[12], the commonly used values are given out, such as width reduction coefficient of rectangular section $K(s)$, stepped area factor $K_A(n)$ and stepped area centroid moment $c(n)$, which can be directly referred in calculation.

3.2.1.2 Calculation of bearing capacity of normal section of rectangular girder with single reinforcement

1. Calculation of flexural capacity of tensile zone in fire

The calculation of residual bearing capacity of the reinforced concrete flexural members after fire is different from that under a normal temperature: (1) the value of reinforcement strength is different, and the tensile reinforcement strength in the tensile zone after fire reduces; (2) the width in the compressive zone reduces from $b$ to $Kb$, but it is still rectangular. Therefore, the calculation of the residual flexural capacity of the cross section is the same as that under the normal temperature. Here, $K$ is the width reduction factor in the compressive zone. After the rectangular substitution, the cross-sectional stress pattern is shown in Figure 2:

$$Kb\alpha f_c = A_{cT}f_y$$

(8)

$$x \leq \xi_{bT}h_0 \quad M_{cT} = A_{cT}f_y(h_0 - 0.5x)$$

(9)

$$x > \xi_{bT}h_0 \quad M_{cT} = Kb\alpha f_c(h_0 - 0.5x_{max})$$

(10)

$$x_{max} = \xi_{bT}h_0 = \frac{\beta h_0}{1 + \frac{f_{yT}}{E_{yT}}\frac{0.003E}{}}$$

(11)

Where: $f_{yT}$ - design value of tensile strength of reinforcement; $E$ - elastic modulus; $K$, $E$ - strength and elastic modulus reduction factor determined by the reinforcement temperature at the corners.

2. Calculation of flexural capacity in the compressive zone in fire

For the component bearing section, in the compressive zone in fire, the effective cross section of the compressive zone is stepped cross section. It is equivalent to replace as rectangle, that is, within the range of compression height $x$, the concrete stress is $\alpha f_c$, while the compressive zone is comprised by a group of rectangular strips with the width of $K_i b$. Section stress pattern is shown in Figure 3:

$$\alpha f_c b \sum_1^x \Delta h K_i = A_{cT}f_y$$

(12)

$$M_{cT} = \alpha f_c b \sum_1^x \Delta h K_i(h_0 - c_i)$$

(13)
Where: \( f_c \) - design value of concrete axial compressive strength; \( \alpha_1 \) - take 1.0 when the coefficient does not exceed C50; take 0.94 when the coefficient is C80 (determined by linear interpolation method); \( b \) - width of girder section; \( \Delta h_i \) - height of the i-th concrete strip; \( K_i \) - width reduction factor of the i-th concrete strip; \( A_{sT} \) - reduced cross section of reinforcement; \( f_y \) - design value of tensile strength of reinforcement under a normal temperature; \( M_{uT} \) - resistance moment of girder section. In calculation of the residual flexural capacity according to the above formula, there is a need to calculate from the compressive edge, and sum each strip of concrete, until satisfying the Formula (12), and then the compression height \( x \) can be solved. Within the range of \( x \), the sum of moments of concrete on the tensile reinforcement centroid is the residual flexural capacity.

3.2.1.3 Calculation of bearing capacity of normal section of rectangular girder with double reinforcement

1. Calculation of flexural capacity of tensile zone in fire

In the tensile zone in fire, the concrete compressive zone is rectangular (Figure 4). Based on the balance relations:

\[
\alpha_1 f_c b h_0 x K_i A_{sT} f_y + \sum_i \Delta h_i K_i A_{sT} f_y = A_{sT} f_y
\]

(14)

\[
M_{uT} = \alpha_1 f_c A_{sT} (h_0 - 0.5 x) + A_{sT} f_y (h_0 - a'_s)
\]

(15)

According to Formula (14):

\[
x = \frac{A_{sT} f_y - A_{sT} f_y}{\alpha_1 f_c k_b}
\]

(16)

When \( x \leq \frac{\xi_{sT} h_0}{2} \), Formula (15) can be used to directly calculate the residual flexural capacity of the cross section.

When \( x > \frac{\xi_{sT} h_0}{2} \),

\[
M_{uT} = \alpha_1 f_c A_{sT} h_{\max} (h_0 - 0.5 x_{\max}) + A_{sT} f_y (h_0 - a'_s)
\]

(17)

When \( x < 2a'_s \),

\[
M_{uT} = A_{sT} f_y (h_0 - a'_s)
\]

(18)

Where: \( f_y' \) - Design value of compressive strength of compressive reinforcement under a normal temperature; \( A_{sT}' \) - Reduced cross section of compressive reinforcement; \( a_s' \) - Distance from compressive reinforcement centroid to compressive edge.

2. Calculation of flexural capacity of compressive zone in fire

When the compressive zone suffers from fire, the calculation of the bearing capacity of girder with double reinforcement is the same as that of single reinforcement, so there is only need to consider the role of compressive reinforcement. The calculation diagram is shown in Figure 5. Based on the balance relations:

\[
\alpha_1 f_c b \sum_i \Delta h_i K_i A_{sT} f_y + A_{sT} f_y = A_{sT} f_y
\]

(19)

\[
M_{uT} = \alpha_1 f_c A_{sT} (h_0 - c_i) + A_{sT} f_y (h_0 - a'_s)
\]

(20)

Figure 5. Calculation diagram of girder with double reinforcement in compressive zone in fire.

3.2.2 Reinforcement methods for reinforced concrete structure after fire

Based on the detection and identification of the damaged building structure and calculation of residual bearing capacity, in accordance with the principle of reinforcement, the repair reinforcement is given to the damaged structure. The reinforcement technology of concrete structure can be divided into two categories: direct reinforcement method and indirect reinforcement method.

3.2.2.1 Commonly used reinforcement methods for concrete structure

1. Commonly used direct reinforcement methods

(1) A method of enlarging sections. This method can restore the bearing capacity to meet the normal use by enlarging the cross-sectional area of the fire components. (2) A method of replacing concrete. This method is similar to the method of enlarging sections. This method does not affect the building’s clearance after reinforcement, which is suitable for repair reinforcement of the seriously damaged concrete members in fire. (3) A method of bonding encased steel. This is a reinforcement method to enease the structural steel.
Table 2. Reinforcement methods for damaged concrete members after fire.

| Extent of damage | Structure classification | Optional reinforcement methods |
|------------------|--------------------------|--------------------------------|
| Seriously damaged components | Girder | Pre-stress reinforcement method, pre-stress reinforcement and bonded steel reinforcement method, method of enlarging sections, reinforcement method of bonding encased steel, method of changing force transferring path, method of increasing support system or load bearing wall |
| | Plate | Pre-stress reinforcement method, local replacement method, method of increasing support system |
| | Column | Pre-stress girder reinforcement method, method of enlarging sections, encased steel reinforcement method, reinforcement method of supplementing tensile reinforcement, sprayed concrete reinforcement method |
| | Girder | Pre-stress reinforcement method, method of enlarging sections, encased steel reinforcement method, reinforcement method of supplementing tensile reinforcement, sprayed concrete reinforcement method |
| | Column | Pre-stress girder reinforcement method, method of enlarging sections, encased steel reinforcement method, sprayed concrete reinforcement method |

2. Commonly used indirect reinforcement methods
(1) A pre-stress method. This method reinforces the structure by using additional pre-stressed steel tie rod (including horizontal tie rod, down-stayed tie rod and assembly tie rod) or brace rod. (2) A method of increasing support. This method is a reinforcement method, which improves its bearing capacity by reducing the calculated span and deformation of the structure.

3.2.2.2 Selection of repair reinforcement scheme
After detection of the structure after fire and identification of the extent of damage, it is necessary to propose a safe, applicable and economical repair reinforcement scheme. There are many methods to reinforce the reinforced concrete structure, but it is necessary to properly adopt different repair reinforcement schemes based on the characteristics of various types of structures, extent of damage after fire and parts to be reinforced.

At present, there are more methods to reinforce the concrete structure after fire. In the practical engineering application, the reasonable reinforcement scheme should be selected after analysis and research according to the specific situation of the damage to structure after fire. Table 2 is commonly used reinforcement methods for seriously damaged concrete members and moderately damaged concrete members after fire.

3.2.2.3 Construction sequence of repair
Under normal circumstances, the construction sequence of repair reinforcement of the damaged structure after fire is as follows: (1) According to the extent of damage, to set up the security support on the girder and at the bottom of plate according to the design requirements, in order to avoid further damage the component in the construction process of repair reinforcement, or even collapse; (2) to wipe out the original paint layer at the bottom of plate and chisel away the burning layer the bottom of plate, in order to deal with the burnt layer and restore the sections; (3) to wipe out the original paint layer of the girder and column, and chisel away its burning layer, in order to deal with the burnt layer and restore the sections; (4) to reinforce the structure of column; (5) to reinforce the structure of girder; (6) to reinforce the structure of girt; (7) to reinforce the structure of floor slab; (8) to paint the cement mortar on the undersurface of the girder, column and floor slab and the wall.

4. ANALYSIS OF PROJECT CASES
4.1 Overview of fire works
A building covers an area of 2,500m², with a gross building area of 8,600m², a reinforced concrete frame structure, standard floor height of 3.9m, basic column size of 6m×6m, structural plan view size of 64m×58m, and design layout of three functional zones, of which Zone A is four floors; Zone B is local six floors; Zone C is four floors, the plane is hexagon, and the top center is the ball node space grid structure with a three-dimensional space. From the first to the third floor is the business halls, the fourth floor is the wholesale, exhibition or office space, the local fifth to sixth floor is the office space. The structural plane layout and zoning of the typical floor of the building are shown in Figure 6. After closing down for fire that day, the second floor on the north side of the West Part of Building (Zone C) got fire at 22:00. Later, the relevant testing departments and design units conducted filed test, identification and reinforcement
design for the damaged structure of the commerce and trade building.

Figure 6. Structural plane layout and zoning diagram of the typical floor of a building.

4.2 Test and identification of damaged structure

4.2.1 Appearance inspection
Appearance inspection is conducted for all the concrete load-bearing components in directly affected fire zone through a large number of meticulous jobs, of which 200 components are inspected in Zone A, 388 components in Zone B, and 598 components in Zone C. Available tools: 0.5kg of hammer is used to distinguish flaking and hammering sound; for detection of cracks, there is a need to first use a wire brush to brush the component surface, and then inject into red ink with an injector for medical purpose, and use a filler gauge and other instruments to measure the depth and length of the crack, use 3 times or 10 times of amplifier to measure the width of the crack; use 225-type concrete resiliometer to measure the concrete strength; use a micrometer gauge and other instruments to measure the bending deflection. This paper selects a part to list in in Table 3.

4.2.2 Component strength detection
1. Ultrasonic test results
“CTS-25” type of non-metallic ultrasonic detector is used to test the extent and range of damage to the damaged concrete members. The sound velocity of the burnt limit is 3,800 m/s. If the value is greater than 3,800 m/s, the received signal is strong, head wave is obvious and amplitude is large, and then it has a very small impact on the component after fire. The conditions of different parts of damaged components in ultrasonic testing are shown in Table 4.

2. Test results of drilled core sampling
A variety of representative damaged components are

Table 3. Part of test results for damage conditions of component appearance in Zone A, B and C.

| No. | Component name | Visual inspection of appearance | Instrument measurement | Rebound test (MPa) |
|-----|----------------|---------------------------------|------------------------|-------------------|
|     |                | Plaster scaling off | Color | Crack | Hammering sound | Exposed reinforcement condition | Crack (mm) | Deformation (mm) |
| 1   | Floor East B9  | Normal       | Black | No    | Normal          | Length of exposed reinforcement of 100 | No       | No test | No test |
| 2   | Girder East L1 | Normal       | Black | Little | Slightly      | Muffled                           | Width of 0.1 | Deflection 10 | 22.4 |
| 3   | Girder Middle L1 | Normal | Black | No    | Normal         | No exposed                         | Width of 0.3 | Lateral bending 5 | No test |
| 4   | Girder East L1 | Normal       | Black | Few   | Slightly      | Muffled                           | Width of 0.3 | Deflection 21 | 18.2 |
| 5   | Column Middle Z1 | Normal | Black | No    | Normal         | No exposed                         | No        | Normal | 15.4 |
| 6   | Column Zb      | Scaling off  | Yellow | Big crack | Muffled | No exposed                         | Width of 0.6 | Depth of 60 | No test | <10.0 |

Table 4. Summary sheet of ultrasonic testing.

| No. | Distance to the bottom of girders (cm) | Item | Mean sound velocity V (m/s) | Number of measuring points n | Number of measured component |
|-----|---------------------------------------|------|-----------------------------|------------------------------|------------------------------|
|     |                                       |      | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| A II L | 2830 | 4053 | 3964 | 3976 | 44 | 6 |
| A III L | 3218 | 3487 | 3801 | 4054 | 39 | 5 |
| B II L | 3547 | 3715 | 3967 | 3978 | 147 | 21 |
| B III L | 3174 | 3315 | 3614 | 3775 | 157 | 18 |
| B IV L | 3333 | 3767 | 3859 | 3816 | 86 | 14 |
| C II L | 2378 | 3242 | 3434 | 3624 | 93 | 12 |
| C III L | 2297 | 3117 | 3239 | 3332 | 97 | 12 |
| C IV L | 2699 | 3255 | 3366 | 3524 | 3694 | 86 | 11 |
| A II Z | 4247 |           | 12 | 2 |
| A III Z | 4070 |           | 14 | 3 |
| B IV Z | 4231 |           | 61 | 7 |
| C II Z36 | 4078(weak received signal) |           | 3 | 1 |
| C II Z32 | 4193(weak received signal) |           | 2 | 1 |
| B III Z18 | 3789(weak received signal) |           | 5 | 1 |
selected according to zoning and grading by onsite appearance inspection, in order to use the “engineering diamond drill machine” for drilling core samples for the girder, plate and column respectively. After processing into standard parts, the residual strength of concrete is measured. A complete core sample can be taken out for lightly burnt components (Figure 7); for seriously burnt components, the core is generally incomplete (Figure 8). Especially for the seriously burnt girders, there are cracks inside, which may fall apart after taking out core sample. For the zone with seriously burnt plate, the terrazzo facing will change its color and become hollow; for the zone with seriously burnt bottom of the plate, it will be white or light red and reach a loose state. The test results of the compressive strength of concrete core sample are shown in Table 5. The strength of core sample shown in Table is relatively high, mainly because the particle size of concrete stone is relatively large (exceeding the provisions of 5cm of drill sampling. However, 10cm of drill sampling is impossible due to too thin plate).

### Table 5. Test results of compressive strength of concrete core samples.

| No. of core samples | Coring location | Strength of core samples (MPa) | Description of core sample appearance |
|---------------------|-----------------|--------------------------------|--------------------------------------|
| C IV Z13            | Away from 0.7m of floor | 17.3                          | Slight yellow core sample, which seems slight red; with cracks |
| A H L 1-5           | Elevation of 9.3m, away from 0.84m of 1 column in the third floor | 27.9                          | Complete core sample |
| A II L 5-6          | Elevation of 9.3m, away from 1.0m of 6 column | 24.1                          | Complete core sample |
| A III L 1-2         | Elevation of 13.2m, away from 1.20m of 1 column | 23.4                          | More cracks around girder |
| B II L IV-18        | Away from 3.5m of 13 column | 11.8                          | More cracks in core sample, cracks on the side of girder |
| B II L IV-13        | Away from 1.2m of 13 column | 18.0                          | Obvious cracks in core sample |
| B II L 16-20        | Away from 2.9m of 16 column | 30.7                          | Relatively complete core sample |
| B III L IV-18       | Away from 3.4m of 18 column | —                             | Core sample falling apart after taking out |
| B III L IV-14       | Away from 1.45m of 14 column | 16.8                          | Slight yellow core sample |
| B III L 10-11       | Away from 0.88 of 11 column | 16.0                          | Two long minute cracks in core sample |
| B III L 16-20       | Away from 2.1m of 20 column | 14.5                          | Serious core sample |

Especially the space steel truss roof in Zone C collapses and smashes four layers of overhanging corridor, and damages three layers of floor slab. “Are the most parts demolished for reconstruction, or a small part is demolished for reconstruction, or repaired according to the original design?” After acquiring the detection and identification data, they are analyzed and researched, and comprehensively demonstrated by experts in the relevant professional technical group, and finally the overall repair reinforcement scheme is selected: repair reinforcement according to the original design, and appropriate local adjustments, demolition of a small part of for reconstruction. It is necessary to perfect and improve the existing problems in the construction and deficiencies in use.

2. Fire part
As the original design implemented the old norms, some provisions were not clear enough, and some supporting norms have not been promulgated, the original design failed to fully implement the design specifications of high-rise building structure. At this time of repair design, the new norms have been promulgated, so there is a need to newly set up fire partition, fire door, alarm, automatic fire extinguishing system and other fire protection facilities in strict accordance with the Fire Prevention Norm for High-rise Civil Architecture Design (GB 50045-95).

3. Structure part
Comprehensive analysis, review and checking calculation are implemented for all structural components. The repair reinforcement design scheme and construction measures are selected according to the detection, checking calculation and identification results. In order to maximize the use of the residual bearing capacity of structure after fire, except for newly manufacturing seriously damaged dangerous components, the decoration repair and structure repair reinforcement method are used for repair design of other components.

4. Repair scheme design

#### 4.3 Overall repair design scheme

1. Building part
Most parts of the whole building suffer from fire.

2. Fre part
As the original design implemented the old norms, some provisions were not clear enough, and some supporting norms have not been promulgated, the original design failed to fully implement the design specifications of high-rise building structure. At this time of repair design, the new norms have been promulgated, so there is a need to newly set up fire partition, fire door, alarm, automatic fire extinguishing system and other fire protection facilities in strict accordance with the Fire Prevention Norm for High-rise Civil Architecture Design (GB 50045-95).

3. Structure part
Comprehensive analysis, review and checking calculation are implemented for all structural components. The repair reinforcement design scheme and construction measures are selected according to the detection, checking calculation and identification results. In order to maximize the use of the residual bearing capacity of structure after fire, except for newly manufacturing seriously damaged dangerous components, the decoration repair and structure repair reinforcement method are used for repair design of other components.

4.3.2 Structure reinforcement design scheme
On the basis of site survey, after multi-research and demonstration, the repair reinforcement can be given to buildings. The principle of repair of the main frame
structure is to meet the requirements of the original seismic design code (GBJ11-89) and ensure the original bearing capacity of components; the repair reinforcement construction should be safe, convenient and fast, in order to strive for building as soon as possible. Epoxy resin pouring and decoration processing is used for the slightly damaged components after fire (RC-1 level); structure repair is used for the moderately damaged components (RC-2 level); structure reinforcement design is used for the seriously damaged components (RC-3 level); the dangerous components (RC-4 level) are demolished for newly manufacturing. For example, three layers of ball node steel truss and roof in Zone C fully collapse due to severe damage in fire, which require newly manufacturing; four layers of overhanging corridor are smashed in Zone C, which require re-pouring.

5 CONCLUSION

Based on the previous research achievements, this paper conducts a quantitative calculation and analysis of the detection and identification of building structure after fire, and puts forward the corresponding repair reinforcement scheme, and applies for the above research achievements in the specific engineering cases, which have achieved satisfactory results, thus providing some reference for further research of building fire engineering and repair reinforcement work.

How to implement detection, identification and repair reinforcement of the reinforced concrete structure after fire in a reasonable, economical and effective manner is a subject to be solved urgently. At present, in China, the research in this regard has not yet formed a scientific system. A lot of issues need to be further explored and researched: (1) to further improve the physical parameters of components; (2) to further improve the repair reinforcement theory and calculation methods for the structure after fire, and apply for the computer simulation analysis to make the research of fire-resistant performance more accurate, and the structure repair reinforcement design more convenient and practical.

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