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A Case Study on the Restoration and Strengthening of a Historic Stadium in China

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ABSTRACT: The Jiangwan Stadium, which is a Municipal Level Cultural Relic Preservation Site in Shanghai, was built up in 1935. The structure members were deteriorating with aging although they were repaired for several times. For reserving the original features of the Cultural Relic Preservation Site as far as possible, the principle of the repairing work is eliminating all the unsafe factors in the structure members according to relative laws of Cultural Relic Preservation. There are some defects in the structure members, such as: severe carbonation of concrete; corrosion of steel rebar and breakdown of concrete coverage. In order to eliminate these defects and resume the safe state of the structure, the relative solutions are adopted.

1 INTROUCTION

Jiangwan Stadium is approximately 28000 square meters in area, and it was the biggest and most well-found stadium in Far East area when it was built up. Jiangwan Stadium comprises three fields: Playing field, Gymnasium and Natatorium, the photographs of which are shown in Figures 1~3. The Playing field is the main part of Jiangwan Stadium. A one-kilometer-long annular stand forms the body of the playing field.

Figure 1 : Full view of Playing field

Similar to the playing field, the Natatorium is also a annular architecture, in the middle of which is a 50×20m swimming poor. The main body of the playing field and the gymnasium are both reinforced concrete framing structures.

Gymnasium's stand is also reinforced concrete framing structure, and it has steel truss structure as roof system, which is separated from the stand's concrete framing structure.

Figure 2 : Full view of Natatorium

Figure 3 : Full view of Gymnasium

In 1930's, Jiangwan Stadium has suffered from severe derogation by the war. Although it was repaired for several times, but the structure members were still deteriorating with aging and weathering during the last 70 years. Furthermore, Jiangwan Stadium was left unused in recent, which has made things worse off. For the refurbishment and upgrading of existing Jiangwan Stadium and its surrounding sporting facilities, a plan named Jiangwan sports park was put forward and some relative departments has set about the repairing work on it. In this background, we accepted the consignation to design the repairing work.

As soon as the repairing work started, we were always puzzled by the contradiction between restoration and strengthening. It took a long time to get a balance point between them finally. For reserving the original features of the Cultural Relic Preservation Site as far as possible, the principle of the repairing work was set to eliminate unsafe factors in the structure members according to relative laws of Cultural Relic Preservation. By way of exception, aseismatic calculating was not accounted during the structural repair designing.

2 STRUCTURAL APPRAISAL

As stated in the inspection report, three fields of Jiangwan Stadium were constructed on timber-pile-supported footing, which restricted the nonnuiform settlement between different sectors effectively. Therefore the settlement of three fields remains stable and incline of structure member is not severe Although 70 years has past.

During the last 70 years, the concrete structure members have deteriorated with aging. Strength grading of concrete is very low in general . In several concrete members, Strength grade of concrete is even lower than C15. The process of carbonation has developed out of concrete coverage depth in almost all of beams and columns, which directly led to the accelerative development of steel rebar's rusting. It seems that concrete carbonation and the side effect caused by it occurred more popular in the hypaethral stand of the playing field. An inspection of the building itself revealed that there were some steel rebar exposed in the air with breakdown of concrete coverage and obvious vertical cracks were investigated in some beams' side surface, as figs. 4~5 shown .

Generally, as concrete carbonation has developed for a certain extent, the alkalescent circumstance in the concrete coverage which help to prevent steel rebar from corrosion would be destroyed. As a result, corrosion of steel rebar would develop more adequately. As steel corrodes the iron turns into iron oxide or rust. The rust takes up to four times the volume as the steel. This puts pressure on the concrete and causes cracking and spalling. Then cracks would come into being and even concrete coverage breakdown would occur somewhere, which would lead to farther steel rebar's corrosion. Such-and-such, a vicious circle would go on and on, and the concrete members would deteriorate gradually. From the above all, a conclusion could be drawn that concrete carbonation was the primary cause of concrete member's deterioration. So carbonation rehabilitation should be regarded as the first step and also the most important step of the concrete member's repairing work.

Figure 4 : Steel rebar corrosion

Figure 5 : Breakdown of concrete coverage

According to the inspection report and site investigation, Strength grade of sand mortar in the brick wall is very low. Moreover, the outer surface of external wall is fair-faced brick wall, and the sand mortar in the exposed joint was weathering more or less. Somewhere in the external wall of Playing field and Gymnasium, diagonal cracks caused by nonuniform settlement or temperature stress can be obviously seen (Fig.6). Fortunately, the cracks were almost stable according to site observation. The filler brick wall hasn't been connected to the reinforced concrete frame by tie bars when it was laid. It seems possible that the filler wall would collapse if earthquake occurs, especially for the external wall somewhere which has inclined outwards slightly.

Figure 6 : Diagonal cracks in the wall

The structure of Gymnasium's roof is steel truss of three-hinged arch (Fig. 7). Although it was designed and built up 70 years ago, the whole steel truss structure looks fairness all the same. The steel truss structure is still normal in work until now except that few steel members were deformed by accidental outside force and some members became corroded slightly.

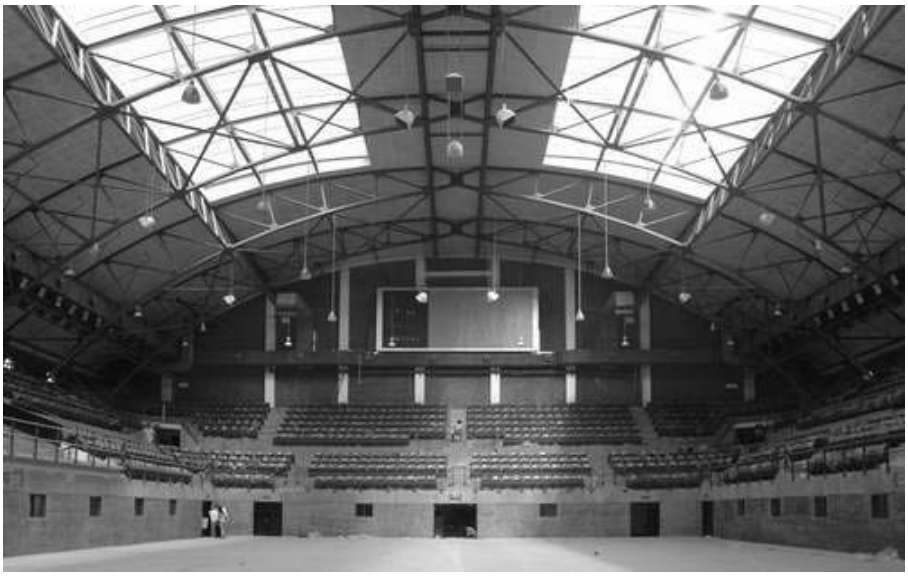

Figure 7 : Three-hinged arch roof of Gymnasium

3 STRUCTURAL REPAIRS

For reserving the original features of the Cultural Relic Preservation Site as far as possible, the principle of the repairing work is eliminating all the unsafe factors in the structure members according to relative laws of Cultural Relic Preservation.

3.1 Carbonation rehabilitation

In order to prevent development of concrete carbonation and corrosion of steel rebar, corrosion inhibitor is delivered in a liquid form and spray-applied over the surface of concrete members that are subject to corrosion. Corrosion inhibitor can help to resume the alkalescent circumstance in the concrete members and form a protective coating over the steel rebar's surface, in which steel rebar is prevent from corrosion and concrete carbonation is slowed down Obviously.

3.2 Surface repairs

In the surface area where concrete coverage breakdown was severe, unsound concrete were removed entirely. To the corroded steel rebar exposed in the air, abrasive method was taken to clean it, and spreaded corrosion inhibitor all over the surface. then high strength mortar was painted to mend it (Fig.8).

3.3 Cracks solution

A static load test was carried out in the site to find the reason why cracks occurred in some beam's side surface. No development tendency of cracks was found during the test. It can be implied that the cracks were brought out by the temperature stress or the construction joint due to the fact that waist steel was absent in the beams. Therefore the cracks can be considered stable. Cracks on the surface of concrete members were sealed by epoxy resin so that the steel rebar inside the structure would not corrode. To the cracks which were deep and wide (>0.3mm), grout-injector method was adopted and epoxy resin was poured deeply into the cracks by the use of grout pipe (Fig.9).

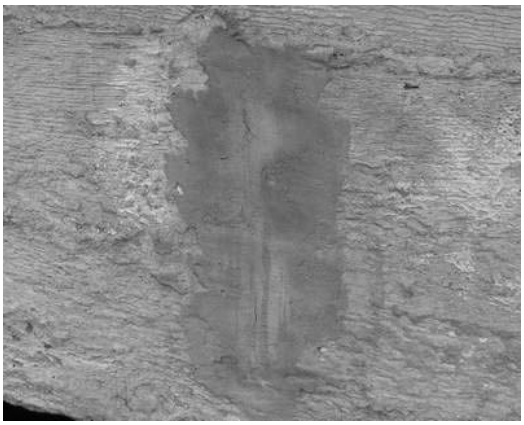

Figure 8 : mend with high strength mortar

Figure 9 : Cracks treated with grout pipe

3.4 Filler wall strengthening

In order to solve the steady problem of external filler wall, strengthening method of bar-mat and cement mortar was applied. Cement mortar surface with steel bar-mat, which was about 35mm in thickness, was attached on the wall's inner side to strengthen it. Steel bar-mat was connected tightly with both the filler wall and the concrete columns and beams (Fig.10). On the four-side boundary between Steel bar-mat and the frame members, steel bar-mat was welded with the bonded rebars which were post-installed into the concrete columns and beams. "L" shape tie-bars, which were post-installed in the wall at one side and welded with steel bar-mat at the other side were applied to attached the filler brick wall to steel bar-mat.

Figure 10 : strengthening method of bar-mat and cement mortar

3.5 Steel truss repairs

In the steel truss roof of the Gymnasium, all corroded steel members were cleaned by abrasive methods, then corrosion-proof paint were painted all over the surface. Few steel member which was deformed severely by accidental outside force was taken placed by new section. Static analysis of steel truss was carried out and the results showed that some lower chords of the steel truss are lack of strength in buckling out of plane. In order to strengthen it, two pieces of longitudinal bracing truss were added at the relative segment. The longitudinal bracing truss was connected to upper and lower chord of steel roof truss with high strength bolt .

3.6 Reinforced concrete flexural members strengthening

During the structural repair designing, Static analysis of integral structure without the consideration of seismic was carried out, and the corrosion of main structural members was also taken into account. The calculating results revealed that some beams and slabs are underreinforced under the service load according to the existing specification. To the beams and slabs which

were lack of strength or were deteriorared by the corrosion of reinforcing steel rebar, carbon fiber reinforced polymer (CFRP) wrap system is applied to strengthen them (Fig.11, Fig.12).

There were two kinds of carbon fiber reinforced polymer (CFRP) in use : carbon fiber sheet and carbon fiber plate, which was 0.11mm and 1.2mm in thickness respectively. In general, Carbon fiber plate (50mm in width) was externally and longitudinally bounded at the bottom of beam sections over the entire span for flexural strengthening. In stead of carbon fiber plate, Carbon fiber sheet was externally and longitudinally bounded at the upper of beam end sections for flexural strengthening for that carbon fiber sheet was free to bending anchorage at beam end. Carbon fiber sheet was also externally and longitudinally bounded at the upper and bottom of slab sections for flexural strengthening or wrapped over beam section as 'U' shape hoop for shearing strengthening. The clear spacing of carbon fiber sheet hoop is 200mm in general and the width of the hoop is varied from 100mm to 300mm.

Figure 11: CFRP strengthening in slab

Figure 12 : CFRP strengthening in stand beam

3.7 Reinforced concrete columns strengthening

As the calculating results shown, there were some concrete columns overreinforced and some other columns underreinforced. To these columns, the structural solution adopted was the strengthening method of enlarging the member size. The columns which are lack of strength are coated with reinforced concrete to be strengthened. As it was cultural relic preservation site, many architectural elevation and joint were preserved. So the relative columns had to be strengthened by enlarging the section size at three sides or at one side in order to maintain the original architectural features, as Fig.13 and Fig.14 shown.

Figure 13 : one-side Enlarging section size

Figure 14 : Three-side Enlarging section size

4 CONCLUSIONS

The restoration and strengthening of Jiangwan Stadium brought the old architecture an entirely new look and improved the safety degree of the whole structure.

The strengthening method of enlarging the member size can not only improve the bearing capacity of columns which were overreinforced or underreinforced, but also prevent the development of carbonation. The application of CFRP system improved the bearing capacity of flexural members which are lack of strength. Corrosion inhibitor's application can help to resume the alkalescent circumstance in the concrete members and restrict the development of steel rebar's corrosion. By the application of the above structural solutions, the safe state of the structure has been improved remarkably.

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