

Study Progress of FRP Rebars in Concrete Structures

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Fiber reinforced plastics (i. e. FRP) rebars are one kind of high-performance composite materials used in concrete structures of civil engineering. Compared with ordinary steel rebars, FRP rebars have the characteristics of high tensile strength, antisepsis, light weight, low elastics modulus and low shear strength, et al. At present time, FRP rebars have been studied and applied in Europe, America and Japan. Since 2000, in the Fund of NS-FC, we systematically carried out experimental and theoretical studies on FRP rebars. The progress of our research is briefly introduced in this paper.

Key words FRP rebar, Bond strength, Concrete beam, Prestressing, FRP grid rebar

Introduction

As the most widely used kind of structures in civil engineering, concrete structures, with proper design, reasonable construction and reliable quality, could have better durability in normal conditions. When the above three factors are not satisfied, serviceability, durability and security of concrete structures will be influenced by steel corrosion, which leads to large hidden danger.

It is said that, in America, the economic loss caused by steel corrosion is more than 70 billion dollars every year, and nearly 100 thousand bridges are badly corroded. More than one third of the reinforced concrete structures in Britain, which are built near the sea, need to be rebuilt or to replace the corroded rebars, because of steel corrosion. In Japan, sea sand is occasionally used as fine aggregate in concrete, which could make steel corrosion become a serious problem. Investigations on 177 concrete bridges and 672 concrete buildings in Okinawa (near the sea) show that, the damage rate of bridges is beyond 90%, and the damage rate of buildings, such as

schoolhouses and apartments, also is higher than 40%. According to a survey on 18 concrete docks in South China in 1981, with the service time of only 7 to 15 years, steel rebars of 16 docks were badly corroded. Another Investigation on 22 middle or small size marine structures in Zhenhai, Zhejiang Province, showed that longitudinal cracks, caused by steel corrosion, occurred in 538 members, 56% of the total 967 members. Coming into the 21st century, with the rapid development of fundamental construction in China, the problem of steel corrosion will be more serious.

To solve the problem of steel corrosion and longitudinal surface cracking in concrete structures, since 1960, foreign experts have studied the measures, the main of which are: to smear waterproof paint on the surface of concrete, to prevent concrete from corrosive agent; to improve antisepsis behaviors of rebars, and to develop corrosion-resisting rebars (such as stainless rebars), to apply Fiber Reinforced Plastics (i. e. FRP), to develop coated rebars (such as galvanized rebars, aluminium-coated rebars and epoxy-coated rebars), to use electric anti-corrosion method, to admix anti-corrosion agent in concrete, et al.

Based on thirty years' research and analysis, experts considered that applying FRP rebars in concrete structures is an effective way to prevent the corrosion of steel rebars^[1], while the antisepsis behaviors, economy, feasibility of construction and production of FRP rebars have all reached practical phase. FRP rebars are made up of continuous fibers, such as Glass-fibers, Carbon-fibers and Aramid fibers, which are bond with polyamide resin, polyethylene resin or epoxy resin. Compared with ordinary steel rebars, the main characters of FRP rebars are high tensile strength (almost same with high-strength steel), excellent antisepsis behaviors, light weight (only 25% as that of steel), similar expansion-rate with concrete, low elastics modulus (about 25% ~ 70% as

that of steel), low shear strength and low extrusion strength (no more than 10% of their tensile strength), et al.

FRP rebars are one kind of new-type artificial fiber material, has been used to replace steel rebars. A lot of studies have been carried out on material characters and structural performance of concrete structures reinforced with FRP rebars in Europe, America and Japan since 1980^[2]. In 1998, on the FIP conference hold in Amsterdam, Holland, FRP rebars were considered as one of the most important building materials, and got wide attentions. In 2000, production value of FRP rebars only in America, have exceeded 100 million dollars. In recent years, there are more and more FRP rebars produced in the world.

Research on FRP rebars are started late in China. In 1995, we firstly carried out the explorative studies of FRP rebars in concrete structures in China^[3]. In 2000, in the fund of National Natural Scientific Foundation of China (NSFC), we went on with the studies, and obtained important conclusions, which are briefly introduced in the following.

1 Bond and Anchorage behaviors of FRP rebars

Based on test results of 33 pull-out test specimens and 27 beam specimens, bond and anchorage behaviors between FRP rebars and different environments (including concrete C30, concrete C50, concrete C50 blended with polypropylene fibers, cement grout R42.5 and epoxy resin, et al), were studied and analyzed systematically. And studies show that:

(1) At failure stage, due to winding ribs of FRP rebars breaking off from the central FRP, FRP rebars produce a smaller slip against the surrounding concrete, in the meantime, the bond strength quickly decreased to a very small value, without obvious omen. In contrast, bond failure of steel rebars is caused by crush of the concrete between the ribs of steel rebars, with obvious omen.

(2) The descending branch of bond stress-slip curves of beam specimens decreases more slowly after peak point than that of pull-out specimens. The bond strength of FRP rebars from pull-out tests is a little lower than that that from beam tests. For the stresses in winding ribs of pull-out specimens is more uniform than these of beam specimens, nearly all the winding

ribs fail at the same time. While the winding ribs in beam specimens fails in turn. Taking the bond strength between FRP rebars and concrete C30 as an example, comparisons between our test results^[4] with the tests abroad^[5] are illustrated in Table 1, showing the consistency of them.

Table 1 Comparisons between test results at home and abroad

Type of test	Our test results ^[4]	Test results abroad ^[5]
Pull-out test	11.8MPa	11.5MPa
Beam test	11.0MPa	11.3MPa

(3) Bond strength between FRP rebars and concrete is a little lower than that between steels and concrete, and the difference augments with increasing of concrete strength grade. Formulas of bond strength between FRP rebars and concrete are also derived.

(4) Bond strength between FRP rebars and cement grout is high, ensuring integration of the two materials, which affords the feasibility of FRP rebars applied in post-tensioned bonded prestressed concrete structures.

(5) Bond strength between FRP rebars and epoxy resin is very high, which is useful for developing anchorage of FRP rebars.

2 Behavior of Concrete Beams Reinforced with FRP Rebars

14 concrete beams reinforced with FRP rebars are tested under monotonic loads and analyzed by non-linear FEM. The following conclusions are drawn:

(1) Concrete beams reinforced with FRP rebars have two different failure modes, tension failure mode and compression failure mode. Theoretical formulas, for calculating flexural strength of normal sections of concrete beams reinforced with FRP rebars, are suggested respectively for the two failure modes.

(2) Crack spacing of concrete beams reinforced with FRP rebars is nearly 1.5 times as that of concrete beams reinforced with steel rebars. The crack width and deflections of concrete beams reinforced with FRP rebars can be correctly calculated by the formulas in Design Standard of Concrete Structures of China (GB 50010-2002).

(3) Owing to good antisepsis behaviors of FRP, the maximum allowable crack width of normal sections in concrete beams reinforced with FRP rebars

might be magnified. According to ACI 440 and Codes of Canada, the maximum allowable crack width is 0.5 mm for structures outdoor and 0.7 mm for structures indoor, but there are still no special regulations in present Chinese Codes.

3 Behavior of Concrete Beams Prestressed with FRP Rebars

Concrete beams prestressed with bonded or unbonded FRP rebars are tested under monotonic loads and analyzed by non-linear FEM. The main conclusions are:

(1) The failure of concrete beams prestressed with bonded FRP rebars is caused by crushing of concrete in compress zone, accompanied with the fracture of FRP rebars. By comparison, the failure causation of concrete beams prestressed with unbonded FRP rebars is the fracture of FRP rebars, while the concrete in compress zone presents plastic to a certain extent, but not crushed.

(2) Design and computation of effective prestressing of bonded FRP rebars, cracking resistance and flexural strength of normal sections of concrete beams prestressed with bonded FRP rebars could follow the Chinese Codes (GB 50010-2002), only to be care of the relative depth ξ_b of equivalent compression zone in concrete section.

(3) Effective prestressing of unbonded FRP rebars, cracking resistance of normal sections of concrete beams prestressed with unbonded FRP rebars can be calculated by the Chinese Codes (GB 50010-2002). But the calculation of flexural strength of normal sections needs further studies.

4 Behavior of Concrete Slabs Reinforced with FRP Grid Rebars

Behavior of concrete slabs reinforced with FRP grid rebars are tested. Test results of 4 slabs show

that, flexural strength of normal sections, maximum crack width and deflections of concrete slabs reinforced with FRP grid rebars can be computed by the present Chinese Codes (GB 50010-2002).

5 Conclusions

FRP rebars have high tensile strength and good antisepsis behaviors, but there are still lack of in-depth studies in China. In the fund of NSFC, studies on the application of FRP rebars in civil engineering have been carried out since 2000, and a series of research achievements are obtained. We hope that, the research and its applications can effectively solve the problem of steel corrosion in concrete structures, and can enhance security and durability of concrete structures in our country.

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