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# Current Status of FRP Concrete Research

Zehua Cui [1], Hongwei Ren [2, *]

[1] School of Architectural Engineering, North China University of Science and Technology, Tangshan 063000, China

[2] School of Architectural Engineering, North China University of Science and Technology, Tangshan 063000, China

## Abstract

**This article introduces the broad application prospects of fiber-reinforced composite materials (FRP) in civil engineering reinforcement and new structures due to their excellent properties such as lightweight, high strength, corrosion resistance, and convenient construction. This article systematically introduces the material properties of FRP, summarizes the research progress of FRP concrete structures in stress-strain relationship, mechanical properties of pure bending and compression bending members, long-term load performance, and seismic performance. It summarizes the application status of FRP concrete technology in the United States, Europe, and China, and explores its application advantages in special fields such as complex environmental substructures, FRP reinforcement bars, FRP concrete composite structures, full FRP large structures, and bridge decks. Finally, it is pointed out that the current FRP concrete technology still faces challenges such as incomplete theoretical models, interface bonding, and long-term durability. Future research directions and application prospects are also discussed.**

## Keywords

**FRP concrete; Mechanical properties; Application status; Reinforcement technology; Material Properties.**

## 1. Introduction

Since the mid-19th century, reinforced concrete structures have been widely used in various fields of civil engineering due to their outstanding advantages such as good moldability, easy availability of raw materials, and high safety factor. However, in the actual production and use process, due to material aging, increased load, structural damage, changes in functional use, design and construction defects, as well as earthquakes, wars, and other reasons, the bearing capacity of the original structure cannot meet the requirements. Therefore, reinforcement and repair are necessary. As a result, there is an increasing amount of huge reinforcement and maintenance costs. According to statistics, the United States spends $22 billion annually on repairing and reinforcing bridges that have safety issues caused by steel corrosion. There is an urgent need for an economical and practical method to solve the above problems. At this point, engineers naturally think that if a corrosion-resistant material is used instead of steel bars in concrete, the problem can be fundamentally solved. The emergence of Fiber Reinforced Polymer (FRP) provides engineering and technical personnel with an attractive and more economical research solution to solve this problem. This article provides a brief introduction to the characteristics of FRP materials, the current research status of mechanical properties of FRP concrete structures, the current application status of FRP concrete structures at home and abroad, and their application in several special fields of engineering, and looks forward to their development trends.

## 2. Characteristics of FRP material

Fiber Reinforced Polymer (FRP) is a high-performance structural material, which is a new type of high-performance material formed by mixing fiber materials and matrix materials in a certain proportion and compounding them through a certain process. The commonly used FRP matrix includes resin, metal, carbon, ceramics, etc. The fiber types include glass fiber, boron fiber, carbon fiber, aramid fiber, ceramic fiber, basalt fiber, polyolefin fiber, PBO (poly (p-phenylene benzoxazole) fiber, and metal fiber. With its significant advantages: ① strong corrosion resistance, i.e. good durability; ② Small self weight and high material tensile strength, i.e. high mass to strength ratio; ③ Strong elastic deformation ability and fatigue resistance; ④ Higher resistance and lower magnetic induction. It has been widely applied in the field of civil engineering. The reinforcing fibers of FRP mainly include carbon fiber (CFRP), glass fiber (GFRP), aramid fiber (AFRP), and high modulus carbon fiber (HFRP), which have excellent mechanical properties and can significantly improve the bearing capacity and durability of concrete structures.

In recent years, especially after the Northridge earthquake in the United States and the Great Hanshin earthquake in Japan, the technology of using FRP materials (mainly sheets) to strengthen and reinforce concrete structures has been well applied in engineering. With the promotion and development of this technology around the world, the superior properties of FRP materials such as lightweight, high strength, corrosion resistance, and good construction performance have gradually been recognized by the engineering community, and have begun to be applied in various forms in civil and building structural engineering. At present, the application and research of FRP materials in engineering structures are very active, and have gradually formed a new research hotspot in the discipline.

## 3. Current Status of Research on Mechanical Properties of FRP Concrete Structures

The mechanical properties of FRP concrete mainly include stress-strain relationship, mechanical properties of pure bending and compression bending members, long-term load performance, and seismic performance.

### 3.1. Stress strain relationship

The determination of the stress-strain relationship is a prerequisite for studying the overall performance of FRP concrete structures, and scholars at home and abroad have conducted extensive experimental research on this. The relevant test results indicate that FRP material is a linear elastic material, and there is basically no plastic deformation before reaching the ultimate tensile strength. Under axial compression, the stress on the core concrete increases linearly with strain, causing significant lateral deformation and yielding, forming a fixed lateral constraint force. At this point, the concrete will enter a state of triaxial compression. If FRP material can constrain the concrete in the core area to prevent compressive failure, the stress-strain relationship curve of concrete will be positively correlated with deformation; On the contrary, if the compressive strength of concrete cannot be further improved, the stress-strain relationship of concrete will stop when it reaches a certain ultimate strain value. However, how to determine the stress-strain relationship calculation model has become the key issue to be faced next. For this reason, scholars at home and abroad have also proposed different calculation models. As they are all based on the constitutive relationship of materials, they can only be used for initial data analysis, but it is difficult to accurately reflect their later changes. Therefore, the research on the stress-strain relationship of FRP concrete structures is still in the stage of continuous exploration and development.

### 3.2. Mechanical properties of pure bending and compression bending members

The main stress states of components in concrete structures are pure bending and compression bending. When FRP materials are applied to concrete structures, the changes in mechanical properties of these components will directly constrain the overall performance of the structure. When studying the load deformation relationship of pure bending members in FRP concrete structures, Yu Qing and others in China used numerical analysis methods to simulate the structure and derived the calculation formula for the bearing capacity of pure bending members in FRP concrete structures under different load conditions, providing a reference for the theoretical calculation of compression bending members. The relevant experimental results indicate that the axial force moment relationship of compression bending members in FRP concrete structures is mainly influenced by factors such as the proportion composition of FRP concrete materials themselves and the slenderness ratio of structural members. Its ductility increases with the decrease of load eccentricity, and its bearing capacity increases with the decrease of member slenderness ratio.

### 3.3. Performance under Long term Load

Through research, it has been found that the working performance of FRP concrete structures under long-term loads is inevitably constrained by the shrinkage and creep of the concrete itself. Tao Zhong and others in China have pioneered a computational analysis model for FRP concrete structures under the influence of concrete creep, providing the possibility for studying their long-term performance under load. In addition, an analysis of the factors affecting the deformation of eccentrically compressed members in FRP concrete structures under long-term loading was conducted. The results indicate that the deformation of FRP concrete components under long-term loads is mainly caused by load eccentricity and long-term load ratio, while the influence of FRP ratio and concrete strength is not significant.

### 3.4. Seismic performance

At present, domestic and foreign scholars have mainly conducted a large number of experimental studies on the seismic performance of FRP confined concrete structures and components using columns as the research object. The research results indicate that after adding FRP material to concrete, it exhibits good ductility and outstanding energy dissipation ability in resisting earthquakes. In addition, Fan Wei, Yu Liu and others analyzed after conducting experiments on FRP reinforced concrete components and pointed out that the failure mode of FRP reinforced reinforced reinforced concrete columns changed from brittle shear failure to ductile bending, which greatly improved the ductility of the columns. Moreover, its effect was more effective than that of stirrups, demonstrating the superiority of FRP materials in the field of structural seismic resistance. In addition, FRP materials have also been widely used in high-rise structure reinforcement projects and can achieve the purpose of resisting earthquakes.

## 4. The current application status of FRP concrete structures at home and abroad

### 4.1. Current Application Status of FRP Concrete in the United States

The American Concrete Institute began to conduct detailed discussions on the mechanical properties, design methods, experimental applications, and other research directions of FRP bars as early as 1996. Design criteria and construction regulations for FRP concrete structures have also been introduced successively. In 1960, FRP materials were first used in the reinforcement of concrete structures in military test stations, but their performance was limited by the lower modulus of glass fibers and did not show superiority. In the following 20 years, the worsening problem of steel corrosion around the world attracted the attention of engineers and prompted a re examination and deeper research on the application of FRP materials in concrete structures. With the gradual maturity of theoretical experiments, FRP materials have been widely used in various residential structures and bridge and tunnel engineering.

### 4.2. Application Status of FRP Concrete in Europe

In the early 1990s, many universities and research societies in Europe carried out a series of collaborative projects on the use of FRP materials for strengthening practical structural engineering, with the theme of studying the overall mechanical performance indicators of FRP concrete structures, and specifically researching the development of FRP materials from structural characteristics, design methods, economic perspectives, etc. The University of Stuttgart in Germany first attempted to apply FRP to concrete buildings in the early 1970s, but was limited by the material properties of low elastic modulus and did not achieve significant breakthroughs. Until the mid-1970s, some German contractors collaborated to produce GFRP rods and anchorages for post tensioning, which were the prototypes of prestressed components later produced. In 1983, the Dutch developed pre-stressed components based on AFRP and began to apply them to soundproof walls on highways and corner ladders in hydroelectric power plants. In 1986, Germany built the world's first highway bridge using FRP post tensioned prestressed cables, marking its increasingly mature development in Europe.

### 4.3. Application Status of FRP Concrete in China

Compared with developed countries abroad, the research and application of FRP materials in the field of civil engineering in China started relatively late. However, with the active efforts of numerous researchers, it has developed rapidly and achieved gratifying research results. The use of FRP materials for repairing and reinforcing bridge piers and columns has been applied in China. In order to ensure the normal use of the Shuangchi Bridge located in Jiangsu Province, two reinforced concrete bridge piers and columns developed cracks during use. To repair and reinforce the cracks in the piers and columns, engineering personnel applied external CFRP. Compared to traditional reinforcement techniques, the advantage of FRP reinforcement technology is that it causes minimal damage to the original structure and does not require replacement of the cross-section. Therefore, it has a high degree of synergy with the original structure. Although the market price of FRP materials is higher than that of traditional steel and concrete, from the perspective of economic benefits engineering life cycle analysis, due to its use of less labor and ability to significantly shorten the construction period compared to traditional reinforcement methods, the overall economic benefits are significantly better. Therefore, the development and application of this technology have significant social, scientific, and engineering application value and significance.

## 5. Several special fields of FRP application in engineering

At present, FRP is applied in several special fields in civil engineering.

### 5.1. Application of FRP in Infrastructure in Complex Environments

In recent years, the defects of structural performance degradation and resistance attenuation in the underground foundation of waterfront docks due to environmental impact have received widespread attention. Due to the complex causes of this situation, a large number of civil engineers are increasingly aware of the advantages of FRP composite materials as a feasible material to solve some problems in complex environmental substructures. For example, increasing the number of layers of FRP material to strengthen an existing structure or replacing some steel bars with GFRP reinforcement bars. The use of these new materials will greatly improve the structural performance compared to the original structure.

### 5.2. FRP reinforcement bars

FRP reinforcement can replace ordinary steel bars to solve the problem of easy corrosion. In addition, FRP reinforcement is lightweight, non-magnetic, and has excellent fatigue resistance.

### 5.3. FRP concrete composite structure

Inspired by the successful application of steel-concrete composite structures, a new concept of combining concrete and FRP has become a promising and feasible solution when considering economic factors. The current research in this field focuses on using FRP to encapsulate concrete, similar to steel tube concrete. Seible studied this structural system by using GFRP shell filled concrete to replace the main beam support of the bridge with FRP made bridge deck panels. This FRP concrete composite beam column effectively utilizes the best performance of FRP and concrete. The high strength, light weight, high stiffness, and low price of FRP concrete composite structures will change the factors affecting the construction cost of FRP in its promotion and application.

### 5.4. Large scale structures made of full FRP composite materials

The multifunctionality and manufacturability of FRP composite materials provide engineers with many opportunities to develop and apply this unique FRP composite material in special building structures that require corrosion resistance or magneto electric shielding. For example, building structures used for electromagnetic testing operations or metal plate rooms for photosensitive circuits. The first fully GFRP building was the Electromagnetic Interference Laboratory of Apple Computer Company in the United States. Another engineering example is the 5-story upper structure of IBM Computer's circuit board workshop.

### 5.5. Advantages of FRP Bridge Panels

One of the root causes of the deterioration of bridge structural performance and resistance attenuation is erosion. In traditional design, the use of antifreeze in winter can deteriorate the steel bars in the structure. FRP is a feasible solution to this problem. Because FRP has excellent corrosion resistance. Due to the fact that most bridges with deteriorating structural performance and weakened resistance are located on important transportation routes, it is extremely important to quickly replace those bridges to avoid long-term traffic interruptions. Using FRP bridge panels to replace those with deteriorated structural performance and reduced resistance is a time-saving solution. Because these bridge decks can be produced in the factory and installed on-site in a very short time. In earthquake prone areas, FRP composite materials are lightweight and can reduce the effect of inertial forces during earthquakes. Using FRP bridge decks will reduce the damage caused by earthquakes. Due to the numerous advantages of FRP bridge decks compared to traditional bridge decks. In recent years, people have been committed to developing and researching high-performance, lightweight, and cost-effective bridge deck systems made of FRP.

## 6. Conclusion

In conclusion, FRP concrete technology plays an important role in the field of civil engineering due to its excellent mechanical properties and wide application prospects. However, there are still some challenges and problems in the current FRP confined concrete technology, and there is still a lack of research results on this material. Relevant experimental research still needs further improvement and exploration, such as the establishment of computational theoretical models, and the bonding performance and long-term durability of the interface between FRP and concrete, which greatly limit its application in more important engineering fields. I believe that with the continuous deepening of research and the constant innovation of technology. FRP concrete technology will be applied in more fields and contribute more to the development of civil engineering. In the future, we look forward to greater breakthroughs and progress in the application of FRP concrete technology in engineering.

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## References

[1] Cao Zheng, Zhang Junhai, Cao Xiaojing: Application Status and Development Trends of FRP in Civil Engineering, Journal of Nantong Vocational University (Comprehensive Edition), (2002) No. 02, p.36-38.

[2] Ye Lieping, Feng Peng: Application and Development of FRP in Engineering Structures, Journal of Civil Engineering, (2006)No.03,p.24-36.

[3] Yang Jianhua, Tang Yuling: Review of Research Progress on FRP Concrete, Heilongjiang Transportation Science and Technology, 43 (2020) No.03, p73-74.

[4] Wang Quanfeng, Yang Yongxin, Yue Qingrui: Research on FRP Composite Materials and Their Applications in Civil Engineering, Journal of Huaqiao University (Natural Science Edition), (2005)No.01,p1-6.

[5] Wu Gang, Lv Zhitao: Study on the Stress Strain Relationship of Fiber Reinforced Polymer (FRP) Constrained Concrete Rectangular Columns, Journal of Building Structures, (2004)No.03,p99-106.

[6] Yu Qing, Han Linhai, Tao Zhong: Study on the flexural bearing capacity of FRP restrained concrete components, Journal of Civil Engineering, (2004) No.11,p33-40.

[7] Yu Qing, Tao Zhong: Theoretical analysis of mechanical properties of FRP restrained concrete compression bending members, industrial construction, (2001)No.04,p9-11+22.

[8] Yu Qing, Han Linhai, Zhang Zheng: Research on the Calculation Method of Bearing Capacity of Carbon Fiber Constrained Concrete Compression Bending Members, Journal of Civil Engineering, (2004)No.10,p33-40.

[9] Tao Zhong, Yu Qing: Theoretical Analysis of Creep Characteristics of FRP Constrained Concrete Columns, Industrial Construction, (2001)No.04,p12-16.

[10] Sun Wenbin: Research Status and Prospects of Mechanical Properties of FRP Constrained Concrete, Chinese and Foreign Highways, 30 (2010) No.04, p265-271.

[11] Yu Qing, Tao Zhong, Zhang Zheng: Analysis of Factors Affecting the Deformation of FRP Constrained Concrete Eccentric Components under Long term Load, Industrial Buildings, (2005)No.09,p8-10+41.

[12] Fan Wei, Yu Liu, Wang Lijun, Bai Runshan, Wang Tiecheng: Seismic performance analysis of reinforced concrete columns, mining pressure and roof management, (2004)No.01,p112-114+117.

[13] Fan Yaoyuan: Research Progress on FRP Concrete Structures, Low Temperature Building Technology, 38 (2016) No.03, p.12-14.