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СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ

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Original Empirical Research

Methods for Strengthening Reinforced Concrete Columns Using Carbon Fiber in China

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Abstract

Introduction. China's construction industry developed in three phases: the first peak occurred in the 1950s, and the second one in the 1980s and 1990s. Generally, buildings constructed during the construction boom were characterized by relatively low design and construction standards resulting in poor quality. Currently, buildings constructed during the first and second phases are entering a phase of "aging" due to some factors such as low construction standards and outdated construction methods. Both the buildings themselves and their structures are flawed. Over time, most buildings exhibit varying degrees of deterioration and serious damage requiring urgent inspection, repair, and reinforcement. To meet the needs of social development, proper repair, reinforcement, and reconstruction of existing buildings is essential. The aim of this study is to identify the possibilities of reinforcing defective building structures with modern composite materials manufactured in China.

Materials and Methods. The object of the research are methods of strengthening reinforced concrete pillars. The author suggests using a systematic approach that accounts for the adjacent functional areas, their mutual influence and an expert assessment of their significance.

Research Results. The analysis showed that the strengthening mechanism for reinforced concrete columns subjected to axial compression and strengthened with carbon fiber sheets is a combination of carbon fiber sheets and concrete influenced by a host of factors. The strengthening method is strictly regulated, and the lateral restraint provided by the carbon fiber sheets under loading is capable of improving the compressive strength, structural stability, and durability of the columns.

Discussion and Conclusion. The strengthening methods for existing buildings vary widely, each with its own unique advantages and limitations. For example, bonded steel is fast to construct but requires a high quality; section enlargement is cost-effective but reduces space; carbon fiber strengthening offers numerous advantages but has limitations in investigating nodes and calculating load-bearing capacity. Although extensive research has been conducted on strengthening reinforced concrete axial compressed columns, the effectiveness depends on a host of factors. The discussion demonstrates that the choice of a strengthening method should be tailored to actual conditions. Carbon fiber strengthening requires further research, while strengthening axial compressed columns requires technological optimization. Furthermore, existing standards and regulations should be revised to reflect new advances and best practices.

Keywords: building structures, carbon fiber strengthening method, strengthening of reinforced concrete structures

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Оригинальное эмпирическое исследование

Методы усиления железобетонных колонн с помощью углеродного волокна в Китае

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Аннотация

Введение. Строительная отрасль Китая в настоящее время стремительно развивается. Первый пик пришёлся на 1950-е годы, а второй — на 1980-е и 1990-е годы. В целом, здания, построенные в период строительного бума, характеризовались относительно низкими стандартами проектирования и строительства, что приводило к низкому качеству. В настоящее время здания, построенные в течение первого и второго этапов, вступают в фазу «старения» из-за таких факторов, как низкие стандарты строительства и устаревшие методы строительства. Как сами здания, так и их конструкции являются несовершенными. Со временем большинство зданий демонстрируют различную степень старения и серьёзные повреждения, требующие срочной диагностики, ремонта и укрепления. Для удовлетворения потребностей социального развития необходимо проводить надлежащий ремонт, укрепление и реконструкцию существующих зданий. Цель настоящего исследования: выявление возможностей усиления дефектных строительных конструкций современными композитными материалами, производимыми в Китае.

Материалы и методы. Объектом исследования являются методы усиления железобетонных столбов. Автор предлагает использовать системный подход, учитывающий прилегающие функциональные зоны, их взаимовлияние и экспертную оценку значимости.

Результаты исследования. Анализ показал, что механизм армирования железобетонных колонн, подвергающихся осевому сжатию и армируемых листами из углеродного волокна, представляет собой комбинацию листов из углеродного волокна и бетона, на которую влияют множество факторов. Метод армирования строго регламентирован, а боковое ограничение, обеспечиваемое листами из углеродного волокна при нагружении, может повысить прочность на сжатие, структурную устойчивость и долговечность колонн.

Обсуждение и заключение. Методы укрепления существующих зданий разнообразны, с уникальными преимуществами и ограничениями, например: метод приклеивания стали быстр в строительстве, но требует высокого качества; метод увеличения сечения экономичен, но сокращает пространство; метод укрепления углеродным волокном обладает множеством преимуществ, но имеет недостатки в исследовании узлов и расчете несущей способности, хотя исследование укрепления арматурно-бетонных осевых сжатых столбов достаточно глубокое и эффект зависит от многих факторов. Обсуждение показывает: выбор метода укрепления должен учитывать реальные условия; метод укрепления углеродным волокном требует дальнейших исследований, а укрепление осевых сжатых столбов — оптимизации технологии, при этом существующие стандарты и нормативы нужно пересмотреть с учетом новых достижений и практики.

Ключевые слова: строительные конструкции, метод усиления углеродной тканью, армирование железобетонных конструкций

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Introduction. Strengthening buildings entails reinforcing worn out and damaged structural materials and building structures in order to restore their functionality. Compared to the new construction, projects to repair and strengthen existing building structures offer the advantage of shorter construction time, lower investment costs, and higher payback. The building reinforcement and renovation sector in China is set to experience a considerable growth [1–2]. Thus research and practical use of the theory and technologies of building reinforcement and reconstruction are of a great theoretical and engineering value.

Materials and Methods. Of late China has made a major progress in both theoretical research and engineering development in renovation and reinforcement of existing buildings. There is a growing number of methods of reinforcing existing buildings and structures, particularly in the commonly used concrete structures. Lots of basic reinforcement methods have emerged. Let us take a look at some.

1. Bonding of steel elements. This method consists of attaching steel plates to the outer surface of concrete elements in order to increase their bending and shear strength, thereby their safety. It is commonly suitable for environments with a humidity of 20% and is used in order to reinforce bent elements exposed to conventional static forces [3]. Compared to large-scale construction, it is characterized by a short construction period, minimal amount of onsite work, and minimal impact on the physical appearance of existing building elements and the space above it. However, the method calls for high-quality construction, and the choice of adhesive material and the builders' professionalism are crucial to its efficiency. On top of that, if there are voids following bonding of the steel elements, they are extremely difficult to remove.

2. Increasing the cross-section. This method consists of increasing the cross-sectional area of concrete elements in order to enhance their load-bearing capacity and comply with the operational requirements. It is characterized by a relatively low construction cost and a wide range of applications, including reinforcement and modernization of various structural elements (beams, slabs, columns and walls) [4]. However, its major disadvantages are a long onsite construction time, significant environmental impact as well as reduction in usable area due to the increased cross-sectional area, which causes some limitations.

3. External steel reinforcement. This method consists of wrapping the surface of the concrete element with electro-welded steel profiles (available for both dry and wet methods) in order to increase the load-bearing capacity of the element. The method considerably increases the load-bearing capacity and rigidity of the element, is relatively easy to manufacture and calls for a short construction time making it commonly used to strengthen building elements [5]. However, external steel reinforcement also has a few disadvantages, such as high steel consumption, high cost and complexity of processing the joints of the elements.

4. Reinforcement by changing the design scheme. This method changes the transmission of forces in the structure by adding support points, beams (braces) or converting multi-span beams with simple supports into continuous ones. This considerably reduces the calculated bending moment, increases the load-bearing capacity of the structural element, and achieves the goal of reinforcing the original structure. Depending on the method of adding support points, the joint can be classified as a "wet" or a "dry" one. While using a wet joint, the contact surfaces between the beam and the support, as well as the concrete cast following pouring, at the support points call for roughening, scale removal and wetting. Micro-expanding concrete is commonly used for pouring. While using dry joints of steel clamps, cement mortar is poured between the steel clamp and the beam surface. After the steel clamp has been securely welded to the support, all of the gaps between the contacts are sealed and filled with a dry, durable solution. The method includes both additional reinforcement of the support and reinforcement used in combination. Additional reinforcement of the support strengthens the structure by adding load-bearing support elements. Despite the simple principle and the reliability of the transfer of effort, it is labour-intensive and might affect the aesthetics and functionality of a building, particularly spatial displacement. It is more suitable for strengthening structures with limited gaps and large spans. The complex reinforcement method can be divided into partial reinforcement, full reinforcement and foundation reinforcement. Strengthening is achieved by changing the transmission path of forces and increasing the load-bearing capacity and deformation capacity of the structure. The method also includes such methods as removal of girder (truss) walls, removal of girder columns, replacement of girder columns and modification of the load-bearing system [6]. It includes strengthening the structure, lifting with jacks and correcting the alignment of the superstructure, as well as removing rejected components. The method is characterized by a short construction time, low cost and minimal impact on production and daily life. It is suitable for strengthening tasks such as increasing usable area and ensuring structural safety in both new and existing buildings.

5. Prestressed fittings. Prestressed reinforcement can be divided into two types depending on the purpose of strengthening. One of them is prestressed reinforcement with screeds which is mostly used to strengthen beam-plate structures, frame structures, trusses and elements subject to significant non-central compression. Depending on the purpose of strenthening and the load requirements of the reinforced structure, the location of the ties can be divided into horizontal (or linear), reinforcing (or broken) and mixed. Another method is prestressed reinforcement which is mostly used for frame columns subject to axial compression and slight off-center compression. Double reinforcement reinforcement is suitable for reinforcing elements compressed axially and columns subject to small non-central compression, whereas single reinforcement is suitable for reinforcing columns subject to large non-central compression, with insufficient compressed reinforcement or low strength. The method makes use of prestressed steel rods (horizontal rods supporting transverse elements, retaining rods, and combined rods) in order to strengthen the load-bearing capacity of the structure. This method makes it possible to reduce the stress level in reinforced elements leading to a considerable increase in reinforcement efficiency and an increase in the overall load-bearing capacity of the structure. The method might also affect the appearance of reinforced elements. It is more suitable for reinforcing medium- and large-span structures, and is also effective for strengthening highly stressed and deformable concrete elements [7]. However, it should not be used in structures subject to increased shrinkage and creep of concrete, while corrosion of prestressed reinforcing rods should be paid a great deal of attention to.

6. Reinforcement method by gluing carbon fiber sheets. This method makes use of a special adhesive to glue carbon fiber sheets to the surface of the component, forming a composite material. This composite material interacts with the original structure or component, strengthening and improving its load-bearing capacity. This method has some advantages such as low weight, reduced thickness, availability of materials according to specifications, and resistance to alkalis, corrosion, and acids. The low weight and simplicity of the technological process enable it to be used in a limited space. On top of that, the reinforcement does not affect the normal use of the building making it simple, fast and widely applicable.

As early as in the late 19th century, the technology of gluing reinforcing carbon fiber fabric was widely used in developed countries such as the USA and Japan. Since it got introduced in China in the late 1990s, it has grabbed engineers' attention and has become a center for research and application of new materials for building reinforcement. A considerable number of previously constructed buildings currently fail to comply with the new operational requirements, have low design standards, low functionality and is in need of urgent strengthening. Gluing carbon fiber materials in order to reinforce concrete structures is the most convenient and effective reinforcement method that does not require the production to stop. It is particularly suitable in situations where the cross-sectional area of existing structural elements cannot be increased, space on the construction site is limited, and construction time is tight. On top of that, the method is suitable for reinforcing bridges, culverts and various other concrete structures. However, in the theoretical research and engineering application of the modern carbon fiber adhesive reinforcement method, there are still a number of issues to be solved. When it comes to the material properties, carbon fiber sheets used for reinforcement are typically less than 0.2 mm thick, but have a high tensile strength of over 3000–4000 MPa, which is about 10 times that of structural steel. They are thus particularly suitable for strengthening reinforced concrete elements subject to both bending and stretching. However, in order to reinforce a wide range of compressive elements, more research is needed on reinforcement mechanisms and methods of using carbon fiber sheets. Thus, in order to comply with the requirements for reinforcement and modernization of a large number of existing buildings, studies of the stress-strain state and methods of reinforcing compressive elements with carbon fiber sheets have a great theoretical and applied significance [8].

Due to the continuous development of carbon fiber reinforcement technologies in China, the "Technical Code for Reinforcing Concrete Structures with Carbon Fiber Sheets" CECS 146:2003 (the 2007 edition) has been officially published, and a corresponding set of drawings for reinforcing structures has been published. This code takes a full consideration of the latest research conducted by numerous domestic universities and research institutes over the recent years, integrating valuable practical experience gained by a range of organizations in using carbon fiber materials for structural reinforcement in design and construction. It also draws on extensive international literature in order to provide scientific and authoritative guidance on the theoretical research and engineering practice of carbon fiber reinforced concrete structures.

In general, the use of carbon fiber glued sheets for reinforcing concrete structures has led to numerous advances in both theoretical research and engineering applications. However, there are still lots of theoretical problems and technical difficulties to be addressed. For example, the mechanism of operation and specific methods of applying carbon fiber glued reinforcement at the joints of components have been insufficiently studied, and the system of analysis and calculation of load-bearing capacity is in need of improvement. In particular, in the field of reinforcement of compressed elements, although the current "Technical Code for Reinforced Concrete Structures with Carbon Fiber Sheets" CECS 146:2003 (the 2007 edition) clearly states that the use of carbon fiber sheets for reinforcing concrete columns might limit the deformation of concrete, thereby increasing compressive strength and reducing the axial coefficient with current research remaining insufficient and incomplete [10]. The regulations emphasize that the effect of reinforcement with carbon fiber sheets can be taken into account in the design only if there is reliable evidence [9]. Therefore, in order to further expand the scope of carbon fiber sheet reinforcement and increase the efficiency of its reinforcement, it is particularly essential to conduct more in-depth and systematic research on existing theoretical and technical issues.

Let us analyze the reinforcement mechanism and methods of constructing reinforced concrete columns operating on axial compression and reinforced with a carbon fiber sheet.

1. Theoretical analysis of elements operating on axial compression.

An element operating on axial compression perceives axial force along the axis of its center of gravity of the cross-section when the point of application of the external force acting on the element coincides with the center of gravity of the cross-section of the element, and the stress distribution over the cross-section of the element is uniform.

When an element operating on axial compression fails, the direction of force coincides with the axis of the element. As a rule, when a reinforced concrete column is subjected to axial compression, the clamps limit the lateral expansion and deformation of the concrete inside it, exerting lateral compression on the concrete core. The combined effect of various vertical axial pressures and a small initial eccentricity compresses the entire shaft of the column, causing compression and deformation of the steel rods, which results in the ultimate flow rate of the inner steel rods. Due to the protrusion of the steel reinforcement, there are cracks on the concrete surface of the column shaft that become more distinct as the load increases. After steel reinforcement has failed, the load-bearing capacity of the element is not sufficient, and cracks on the concrete surface eventually cause complete failure to occur.

2. Stress analysis during axial compression of elements reinforced with carbon fabric.

The characteristics of the elements under axial compression reinforced with carbon fabric differ significantly from those of non-reinforced elements.

After reinforcing the axial compressed element with carbon fabric, it becomes a structure subject to secondary stresses. Before the carbon fabric was applied, the axial compressed element had been under stress (primary stress), i.e., stresses and deformations in it. However, the newly glued carbon fabric is not stressed at this moment. It is only when a test load (secondary stress) is applied that the new part of the carbon fabric connected to the concrete starts being stressed. Therefore, the stress and deformation of the newly added carbon fiber part are always behind the accumulated stresses and deformations of the original component. When the load-bearing capacity of the original component has reached its limit, the newly added carbon fabric has not yet reached its limiting state of bearing capacity, and its tensile strength might continue playing its role.

The degree of unloading of the original component and the treatment of new and old joint surfaces are two important factors impacting the joint operation of the reinforced component.

In order to reduce the problem of the stresses and deformations of the newly added carbon fiber part, the component must be unloaded prior to reinforcement. When the reinforced component fails, the reinforced part can reduce accumulated stresses and deformations that lag behind the original component. At the initial stage of the load-bearing capacity, unloading has a greater impact on the reinforcement efficiency of the component. There are two specific unloading methods: direct unloading and indirect unloading. Direct unloading implies the complete or partial removal of the load from the component, while indirect unloading implies the application of a counteracting force to the existing structure in order to relieve accumulated stresses and deformations at the initial stage of the load.

3. Processing the interface between new and old reinforced components.

Processing of the interface and the quality of the bond between the carbon fiber sheet and the source component have a direct impact on the final reinforcement effect. Compressive and shear stresses between the new and old structures are transmitted across the boundary, so the interface must be smooth and even. In order to investigate the bond strength between the carbon fiber sheet and the original structure, the carbon fiber sheet is first glued to a concrete sample, and then a shear test is performed. This enables an analysis of the influence of the factors such as surface treatment, bonding material, and concrete strength on bond strength. Carbon fabric has an extremely high tensile strength. The transverse carbon fiber fabric in axially compressed elements not only coordinates the deformation with the clamps in axially compressed elements, but also works in conjunction with the longitudinal carbon fiber fabric acting as a hoop that increases the load-bearing capacity of axially compressed elements.

4. Stress mechanism in axially compressed elements reinforced with carbon fiber sheets.

When concrete in an axially compressed column is subjected to compressive forces in a few directions, its volume changes. This is due to a gradual change in stresses and deformations in the concrete resulting in small cracks. Applying lateral pressure to the concrete surface at this point might limit the rate of change of these small cracks thus causing an increase in the load-bearing capacity of the concrete. If the concrete surface is wrapped with a steel tube or other hoop-shaped shell, the expansion of the concrete volume is limited by the lateral force applied by the shell, thereby reducing or slowing down the rate of change of stresses and deformations in the concrete, which ultimately results in an increase in the axial compressive strength of the concrete and improves its ductility. This principle is commonly used in practical applications in engineering reinforcement, e.g., in pipe concrete. This type of material, which optimizes mechanical properties of concrete and increases its axial compressive strength by applying lateral forces to the concrete surface, is called space-limited concrete. If the prefabricated shell, which transmits lateral forces to the concrete surface, is made of carbon fabric, it is regarded as concrete with a limited space.

There has been some research into the methods of strengthening reinforced concrete columns operating on axial compression with carbon fabric. While using carbon fabric to reinforce concrete structures, there are three common reinforcement methods: wet bonding, continuous fiber winding, and prefabricated sheaths. The specific construction process using carbon fabric is the following:

1) preparation of the concrete column mounting surface to increase the contact area;

2) applying metal mesh in order to increase the strength of the concrete column;

3) pouring concrete into the gaps between the metal mesh to strengthen the structure;

4) wrapping with a plastic wrap in order to preserve moisture and prevent cracking;

5) cutting a carbon fiber sheet;

6) preparation and application of glue, sheet sticker (after the fastening is completed, it is necessary to wait till the adhesive joint has hardened);

7) inspection and additional reinforcement of all of the areas weakened with glue;

8) maintenance services.

Having studied multiple materials and relevant literature as well as having conducted numerous theoretical studies and engineering developments based on the characteristics of carbon fiber reinforcement, and in order to ensure effective reinforcement in combination with reinforcement methods for columns subjected to axial compression, carbon fiber sheets and static load tests, factors affecting the optimal construction method must be considered.

Researchers in China and abroad have achieved considerable results by means of the experimental research and analysis of factors affecting concrete reinforcement with carbon fiber sheets. The factors affecting the load-bearing capacity of reinforced concrete columns subjected to axial compression and carbon fiber reinforcement can be summarized as follows:

– Smoothness of the surface to be bonded.

While using carbon fabric for bonding and reinforcing concrete structures, the surface of the concrete component must be preliminarily polished. Mechanical methods or manual polishing can be used in order to remove loose and damaged areas of the concrete surface, as well as the dirt from the aggregate and mortar making the surface of the concrete component relatively smooth and even. This contributes to the carbon fabric adhering tighly to the surface of the concrete component, thereby improving the adhesion of the surface to be bonded.

– Selecting and cutting carbon fabric.

While choosing a carbon fabric, it is necessary to confirm the strength of the materials used by the manufacturer prior to the testing to ensure that they are in compliance with the specification and specify the strength class. The choice of strength class (1 or 2) must be taken into account while designing the concrete component to be tested.

Cutting carbon fiber fabric. Firstly, the formed carbon fiber fabric must be cut to a specified size according to the design requirements. Uneven or oblique cutting against the fibers is strictly prohibited in order to prevent the fibers from falling off. Secondly, after cutting, the bonding direction should correspond to the direction of the carbon fiber fibers. Thirdly, the cut carbon fiber tape must be dry, clean and unpolluted to avoid the sticking of sand, wax, oil, etc .

– Choosing the glue.

While choosing an adhesive, it should be taken into account whether the microstructure of bonding and the bond strength are in compliance with the requirements. There are lots of types of interface agents on the market with different compositions and binding properties. The selection must be carried out in compliance with the requirements of the carbon fiber fabric operating instructions.

– The method of gluing carbon fiber fabric.

According to the research and analysis of carbon fiber fabric at home and abroad, different bonding schemes have varying degrees of an increase in the load-bearing capacity of concrete components. This can be controlled by means of adjusting the size of the spacing, width of the location and shape of the circumference of the carbon fiber fabric ring. There are presently four types of bonding methods used:

– single-layer annular concrete column;
– double-layer annular concrete column;
– vertical and horizontal wrapping;
– full wrapping.

Research Results. A comprehensive and in-depth analysis and study of the reinforcement mechanism and methods of constructing reinforced concrete columns subjected to axial compression using carbon fiber sheets has been performed. From both a microscopic and macroscopic perspective, the reinforcement mechanism shows that due to their high strength and elasticity carbon fiber sheets are tightly bound to concrete. When exposed to columns undergoing axial compression, these stresses are impacted by complex and diverse factors. The concrete strength, degree of reinforcement, as well as the number and quality of carbon fiber sheet layers have a considerable effect on reinforcement.

When it comes to the construction methods, each stage from the preparation of the structure to the direct bonding is strictly regulated. Safety and precautions are of primary importance during construction. Employees must utilize personal protective equipment in order to prevent injury from flying fibers of carbon fiber sheets. On top of that, the construction conditions must be in compliance with the requirements, including appropriate temperature and humidity, in order to ensure reliable adhesion of carbon fiber sheets to concrete. According to the in-depth analysis of the stress mechanism, carbon fiber fabric glued to a concrete column undergoing axial compression will generate lateral constraints. Due to the ring effect created by the carbon fiber fabric, this passive restraint system can effectively limit the lateral deformation of concrete, thereby improving the compressive strength of the reinforced concrete column and the overall stability and durability of the structure.

Discussion and Conclusion. In the field of construction, strengthening existing buildings is essential to ensuring their structural safety and functionality. There are currently lots of strengthening methods with their own characteristics.

The method of reinforcement using steel plate bonding allows for quick work and shorter construction time, but puts a great deal of pressure on the quality of work: from choosing the materials to the bonding technology, each stage must be in compliance with the standards, otherwise it will affect strengthening and building safety. The method of reinforcement by increasing the cross-section has a low cost, but it takes up space inside the building, changes the internal layout and affects the functionality of the building. The carbon fiber reinforcement method is commonly used — the materials have high strength, lightness and corrosion resistance, and are capable of increasing load-bearing capacity and earthquake resistance without adding significant weight. However, it has limitations in the analysis of nodes and the calculation of load-bearing capacity calling for further research to be conducted. The effectiveness of strengthening centrally compressed reinforced concrete pillars depends on lots of factors, such as material properties, quality of work, etc.

In actual practice, while choosing a reinforcement method, it is necessary to conduct a comprehensive assessment of the condition of a building and flexibly adjust the approach. The carbon fiber reinforcement method calls for an in-depth study and improvement of the theoretical foundations of design; strengthening centrally compressed pillars calls for development of new materials and technologies, as well as increased quality control. On top of that, outdated standards and regulations are in need of a timely reviewe in order to ensure the scientific justification of reinforcement.

References

1. Xu Qingfu, Tang Xiangtan, Wang Yun Research of Design and Technology of Reinforcement of Structures of Residential Buildings. *Ceramics.* 2025;10:212–214. https://doi.org/10.19397/j.cnki.ceramics.2025.10.042

2. Xiang Bingquan, Li Ruilin, Xu Dan, et. A Study of Rapid Verification of Earthquake Resistance and Reinforcement Methods of Brick-and-Concrete Buildings in the area of Chuzhou. *Sichuan Cement.* 2025;(11):73–77. https://doi.org/10.20198/j.cnki.scsn.2025.11.026.

3. Zhao Weijie, Cheng Yangyang, Zhang Zhen Research of Methods of Inspection, Assessment and Reinforcement of Building Structures. *Metal Structures in Chinese Construction.* 2025;24(16):79–81. https://doi.org/10.20080/j.cnki.ISSN1671-3362.2025.16.027

4. Li Genmo, Luo Kaihai, Huang Shimin, et. Review of Research and Practical Application of Seismic Reinforcement Methods for Existing Stone Buildings. *Earthquake Resistance and Reinforcement of Building Structures.* 2025;47(03):139–147. https://doi.org/10.16226/j.issn.1002-8412.2025.03.016

5. Chen Incan *Investigation of Earthquake Resistance and Seismic Insulation Reinforcement of Historical Buildings with Brick and Wooden Structures in Lingnan District*. Guangzhou University, 2025. https://doi.org/10.27040/d.cnki.ggzdu.2025.000677

6. Yu Hongjun, Zhang Nan Research of Reinforcement Methods of Building Structures Based on Optimal Design and Application Examples. *Metal Structures in Chinese Construction.* 2025, 24(06): 130–132. https://doi.org/10.20080/j.cnki.ISSN1671-3362.2025.06.044

7. Gao Xing, Wang Weiyu Investigation of the Mechanism of Operation and Methods of Reinforcement of Residential Buildings of the "Xuanyao" Type (Vaulted Cave Dwellings). *Building Structures.* 2025;55(02):143–150. https://doi.org/10.19701/j.jzjg.20220914

8. Yang Shuaimin *Research of Technologies for Reinforcing Structures of Existing Buildings and their Economic Efficiency*. East China University of Technology, 2024. https://doi.org/10.27145/d.cnki.ghddc.2024.000872

9. Liu Liying, Ou Zhenfeng, Yang Chunshan, et. Numerical Modeling and Analysis of Full-Scale Measurements of Deformations of Coastal Structures Caused by the Development of a Foundation Pit for Lowering Sections. *Prevention and Elimination of Accidents in Tunnels and Underground Structures.* 2024;6(04):12–19. https://doi.org/10.19952/j.cnki.2096-5052.2024.04.02

10. Wang Yaohan A Brief Analysis of the Application of Reinforcement Technologies for Building Structures. *Metal Structures in Chinese Construction. Proceedings of the Forum on Intellectual Construction and Economic Development from the Perspective of New Qualitative Productive Forces (I).* Wuhan Institute of Municipal Construction Design, LLC. 2024:156–157. https://www.chndoi.org/Resolution/Handler?doi=10.26914/c.cnkihy.2024.036623

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