Design Methods for Structural Reinforcement of Municipal Road Bridges

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Abstract: In the new era, with the rapid socio-economic development, the construction of municipal road bridges has become a crucial driving force for the sustainable development of the national economy. Only by ensuring the rationality of the structural design of municipal road bridges can a good city image be shaped and the safety of people's lives and property be guaranteed. This paper will elaborate in detail on the principles and specific methods of structural reinforcement design for municipal road bridges, aiming to significantly enhance bridge performance and ensure the smoothness of urban traffic.

1. Introduction

As a core component of the urban transportation network, municipal road bridges play a carrier role in ensuring the stable development of cities and enhancing regional economic levels. With the expansion of urban construction scale and the increase in traffic loads, road bridges built in the early stages are facing issues of structural performance degradation. Some of them have developed various diseases, affecting the safety of urban transportation. In this context, applying scientific structural reinforcement design methods can extend the service life of bridges and ensure the stable operation of the transportation system.

2. Necessity of Structural Reinforcement Design for Municipal Road Bridges

2.1 Improving Structural Load-Bearing Capacity

In the operation and maintenance of municipal road bridges, improving structural load-bearing capacity is one of the goals of reinforcement design, which can resolve the contradiction between traffic upgrades and the weakening of bridge performance. With the acceleration of urbanization, the volume of urban traffic has increased significantly, and the frequency of large passenger buses and heavy-duty trucks has continued to rise. The current traffic loads far exceed the load standards designed for early bridges. Due to factors such as vehicle model specifications in the early design, the upper limit of their load-bearing capacity is low. Long-term exposure to overloading pressures can easily lead to structural damage, such as bearing deformation. If reinforcement is not carried out in a timely manner, it will seriously threaten traffic safety. Structural reinforcement design for municipal road bridges can enhance load-bearing capacity, enabling bridges to meet current and future traffic demands, gradually restore structural strength, reduce the likelihood of environmental erosion, and provide necessary support for the stable operation of the urban transportation system while avoiding safety accidents caused by insufficient load-bearing capacity.

2.2 Enhancing Structural Disaster Resistance

As the lifeblood of urban transportation, the disaster resistance of municipal road bridges directly affects the smoothness of traffic and the quality of emergency rescue during disasters. Improving disaster resistance reflects the necessity of reinforcement design. Urban bridges are exposed to various natural disaster threats during use, such as earthquakes and floods, and may also suffer from accidental impacts like vehicle collisions. When a disaster occurs, if the bridge has poor disaster resistance, it will hinder the smooth transportation of relief supplies, delay disaster relief, and may

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even trigger secondary disasters, causing severe losses to urban development. Structural reinforcement design for municipal road bridges can fundamentally enhance their disaster resistance. Specific reinforcement efforts will optimize structural performance according to different disaster types, such as using fire-resistant and corrosion-resistant materials. This not only strengthens the structural stability of bridges during disasters but also reduces the probability of bridge damage, ensuring that bridges can quickly resume normal operation after a disaster.

2.3 Meeting Changing Traffic Demands

With the acceleration of urbanization, people' travel patterns have changed, and the traffic demands faced by municipal road bridges continue to evolve. Reinforcement design to meet these changing demands is highly necessary. On the one hand, the number of motor vehicles in cities continues to rise, and bridge traffic volumes increase during morning rush hours. Some bridges built in the early stages are prone to traffic congestion, affecting the quality of urban transportation[1]. On the other hand, the rapid development of urban transportation has given rise to emerging modes such as subways, and the growth of the logistics industry has increased the frequency of heavy-duty freight vehicle traffic, imposing higher requirements on load-bearing capacity and adaptability. Reinforcement design can effectively transform bridge decks and widen lanes, increasing bridge traffic capacity, alleviating urban traffic congestion, and meeting the traffic demands, here it means the demand for heavy-duty freight vehicles to pass through of heavy-duty freight vehicles. This ensures that bridges can play a traffic role and maintain the smooth operation of the urban transportation system amidst continuously changing traffic demands.

3. Principles of Structural Reinforcement Design for Municipal Road Bridges

3.1 Safety Principle

In the structural reinforcement design of municipal road bridges, the safety principle is the primary principle that should be followed throughout the entire reinforcement design process. Its essence is to avoid safety risks during and after bridge reinforcement through effective design, ensuring the stability and reliability of bridge structures and the safety of passing vehicles. The safety principle requires a comprehensive and detailed inspection and evaluation of bridges at the initial stage of reinforcement design to accurately identify types of bridge structural diseases and potential risk points, preventing a reduction in the targeted nature of the design scheme and leaving hidden safety hazards due to inspection loopholes. During the reinforcement design process, the safety principle is reflected in optimizing the structural stress system and formulating reliable reinforcement measures. At the same time, the durability and strength of the selected reinforcement materials should meet relevant requirements to avoid structural instability caused by poor material quality. After reinforcement is completed, the safety principle requires that bridge structures meet future disaster resistance demands and traffic load demands, enabling them to withstand sudden risks.

3.2 Economy Principle

The core of the economy principle is to improve the efficiency of resource utilization and control costs within a reasonable range while meeting safety and functional requirements, preventing excessive resource waste and providing economic technical solutions for municipal engineering construction. Bridge reinforcement, as an important part of the operation and maintenance of municipal infrastructure, needs to balance economic costs and reinforcement effects and align with the financial budget planning of urban construction. Therefore, the economy principle should be integrated throughout the entire reinforcement design process[2]. At the initial stage of reinforcement design, this principle requires the preferential selection, meaning to give priority to selecting of low-cost and targeted reinforcement schemes based on bridge inspection results. In the middle stage of reinforcement design, this principle requires a comparison of the cost-effectiveness and availability of different materials while meeting performance requirements.

3.3 Feasibility Principle

The feasibility principle is a key principle that should be followed in the structural reinforcement design of municipal road bridges. Its core is to ensure that the reinforcement scheme can be effectively implemented in terms of environmental adaptability and technology. In actual bridge structural reinforcement, full consideration should be given to the actual situation. If a reinforcement scheme overly pursues technology while ignoring feasibility, it will be difficult to implement in an orderly manner, increasing engineering costs. Technical feasibility requires that the reinforcement scheme match existing technical levels, with the selection of mature and reliable construction processes and materials, ensuring that the construction team has certain construction capabilities. The feasibility of construction conditions should take into account actual traffic conditions and the on-site space of bridges. For example, when reinforcing bridge structures in urban core areas, a temporary traffic diversion scheme should be designed to prevent narrow construction areas from affecting the orderly progress of the project.

4. Design Methods for Structural Reinforcement of Municipal Road Bridges

4.1 Section Reinforcement Method

The section reinforcement method is a mature technology widely applied in the structural reinforcement of municipal road bridges. Its core principle is to enhance the load-bearing capacity and durability of major bridge components such as main beams and cover beams by increasing their structural dimensions and adding other materials, thereby resolving issues of structural performance degradation caused by material aging. This method is suitable for early-built reinforced concrete bridges or prestressed concrete bridges, which often suffer from problems such as steel bar corrosion after long-term use, leading to insufficient flexural load-bearing capacity of main beams. In specific reinforcement design, the section reinforcement method is divided into the enlarged section method and the concrete-encased method. The enlarged section method increases the cross-sectional area of components by pouring a new concrete layer in the compression zone and configuring corresponding stressed steel bars. The concrete-encased method is suitable for horizontal load-bearing components. It involves wrapping the original component with a steel bar mesh and pouring concrete to form a system where the original component, new concrete, and newly added steel bars bear loads together, fundamentally enhancing the ductility and compressive performance of components and effectively resolving bridge cracking issues. The section reinforcement method features mature construction technology and significant reinforcement effects[3]. In actual reinforcement design, emphasis should be placed on analyzing the connection and anchoring of newly added steel bars with the original ones and the treatment of the bonding surface between new and old concrete to prevent local stress concentration from damaging the new structure. Through reasonable section reinforcement design, not only can issues of component section defects in bridges be effectively resolved, but it can also be used in conjunction with other reinforcement methods to build a comprehensive reinforcement system, ensuring that bridge structures meet changing traffic demands and disaster resistance demands during long-term use and providing technical support for the safe operation of municipal road bridges.

4.2 Arch Rib Reinforcement Method

The arch rib reinforcement method is one of the reinforcement techniques for arch bridges in municipal roads, such as concrete arch bridges, mainly aimed at resolving issues such as reduced load-bearing capacity and section damage, providing necessary guarantees for the safe passage of arch bridges. Arch ribs are the main load-bearing components of arch bridges, responsible for bearing the vertical loads transmitted from the bridge deck and converting them into horizontal thrusts. If arch ribs are used for a long time, they are prone to diseases such as exposed steel bars and cracks, which significantly reduce the load-bearing capacity of arch bridges and may even lead to bridge collapse in severe cases. In the application of the arch rib reinforcement method, there are mainly three technical paths: First, adhesive reinforcement. Carbon fiber cloth or steel plates are pasted on the tension zone of arch ribs, enhancing their shear performance by leveraging the high strength of composite materials. This construction method has a minimal impact on the original structure and is convenient for construction, suitable for situations where the local strength of arch ribs is insufficient. Second, concrete encasement reinforcement. If the section damage of arch ribs is severe, steel sleeves can be used to wrap the arch ribs, expanding the cross-sectional area and effectively supplementing stressed steel bars, forming a collaborative load-bearing system between the original arch ribs and the new reinforcement layer, thereby enhancing the overall load-bearing capacity of arch ribs. Third, adding auxiliary components. By adding new arch ribs or support structures below the original arch ribs to share the loads of the original arch ribs, the stress system of the arch bridge can be improved. For example, adding reinforced concrete cross-braces between the arch ribs of stone arch bridges can reduce the probability of lateral deformation of arch ribs and enhance the overall structural integrity[4]. It should be noted that in the application of the arch rib reinforcement method, continuous attention should be paid to the bonding performance between the original arch ribs and the reinforcement materials and the coordination between the reinforced arch ribs and the bridge deck to prevent local stress concentration. Through the above arch rib reinforcement design, diseases of arch ribs can be effectively treated, the load-bearing capacity of arch bridges can be restored, and arch bridges can continue to function in municipal transportation.

4.3 Longitudinal Beam Reinforcement Method

In municipal road bridges, longitudinal beams are the main load-bearing components, responsible for bearing the vertical loads transmitted from the bridge deck pavement and transferring them to piers and bearings[5]. Their structural performance is an important factor affecting the overall load-bearing capacity of bridges. During long-term use, municipal road bridges may suffer from local crushing at bearings and other diseases due to the repeated action of traffic loads and material aging. If reinforcement intervention is not carried out in a timely manner, the load-bearing capacity of longitudinal beams will be reduced, leading to bridge deck settlement issues. In severe cases, there may be a safety hazard of longitudinal beam fracture. In reinforcement design, the implementation paths of the longitudinal beam reinforcement method are as follows: First, pasting reinforcing materials. Carbon fiber cloth is pasted in the tension zone of longitudinal beams, effectively supplementing their tensile performance by leveraging its high strength, suitable for situations where the flexural load-bearing capacity of bridges is insufficient. This reinforcement method has a short construction period and has a relatively small impact on traffic. Second, external prestressing reinforcement. Prestressed steel strands are arranged outside the longitudinal beams, and the tensile stress generated by loads is eliminated by prestressing to enhance the crack resistance of longitudinal beams, suitable for large-span bridges. Third, enlarged section reinforcement. Steel bars are added in the tension zone of longitudinal beams to expand their cross-sectional dimensions and enhance overall stiffness, suitable for situations with a large amount of steel bar corrosion. In addition, in the design of longitudinal beam reinforcement, full consideration should be given to traffic diversion schemes to minimize the impact of construction on traffic passage. At the same time, attention should be paid to the collaborative stress between reinforcement materials and the original longitudinal beams. In summary, through longitudinal beam reinforcement design, the load-bearing capacity of longitudinal beams can be enhanced, meeting current traffic load demands, extending the overall service life of bridges, and providing necessary support for the safe and smooth operation of municipal roads.

4.4 Adhesive Reinforcement Method

In the structural reinforcement of municipal road bridges, the adhesive reinforcement method is an efficient and convenient reinforcement method. Its core principle is to paste high-strength materials such as steel plates on the tension zones of bridge components using specialized adhesives, forming a collaborative stress system with the original components by leveraging the high strength of the reinforcement materials, effectively supplementing compressive and shear performance and enhancing the overall structural load-bearing capacity. This method is suitable for situations where the shear load-bearing capacity is insufficient, there is moderate cracking, but the degree of material aging is relatively light[6]. In actual reinforcement design, the application of the adhesive reinforcement method needs to follow a standardized process: First, the surface of the original component is treated to remove the weathered layer, laitance, etc. After pressure grouting and repairing cracks, the surface is ground to a rough state to ensure that the adhesive can fully adhere to it. Finally, the reinforcement material is pasted. If the pasted material is a steel plate, bolts are used to assist in fixation to ensure the tight bonding between the reinforcement material and the original component. After the adhesive cures, an overall stress structure is formed[7]. Compared with other reinforcement methods, the adhesive reinforcement method has a relatively small impact on bridge traffic and a short construction period, and can meet the requirements of different component shapes. In reinforcement design, staff should pay attention to the strength and durability of the adhesive and do a good job in the selection of reinforcement materials. Through reasonable adhesive reinforcement design, diseases of bridge components can be effectively treated, the overall structural performance can be enhanced, and an economic and safe technical solution can be provided for the safe operation of municipal road bridges.

5. Conclusion

In summary, in the context of modern social development, municipal road bridges play an important role. With the increase in the operating time of municipal road bridges, various types of diseases will appear, affecting their normal use. Therefore, it is necessary to carefully analyze structural reinforcement measures for municipal road bridges to effectively resolve diseases, enhance their service performance, and ensure the smoothness of roads.

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