Analysis of Safety and Durability in Municipal Bridge Design

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Abstract: This paper, based on the central role of municipal bridges in urban traffic, systematically analyzes the importance of safety and durability to traffic safety, people's livelihood and quality of life, urban transportation system stability. It provides a novel perspective to improve the safety of the play equipment from three dimensions: optimization of structural stress, upgrades of protection facilities, and improvements in evacuation ent up to October 2023. It also creates the triad of a durability-reinforcing system, starting with corrosion-resistant material selection and design, including drainage and waterproofing designs, while making room for maintenance. Research results are expected to prove closely that only through targeted design strategies, the bridge building safety risk can reduce significantly and service life can be extended effectively, thus proposed a practical and professional reference framework for municipal bridge design, which will help to promote the entire life span of bridges.

1. Introduction

Being the key links of urban transportation networks, the operational state of municipal bridges is closely related to citizen travel security, public resource utilization efficiency and urban economic activities smoothness. At present, part of some bridges, owing to not fully considering the safety redundancy and unsatisfactory durability protection measures in the design stage gradually appear structural cracking and geological environment long-term load performance decline problem. This not only raises maintenance expenses but also threatens traffic operation and public safety. In this background, in-depth exploration of municipal bridge design safety and longevity construction key points and effective operation strategies has become one of the important means to alleviate bridge system power pain point issues and guarantee urban transit sustainably.

2. Importance of Safety and Durability in Municipal Bridge Design

2.1 Ensuring Traffic Safety and Public Interest

From a safety point of view, there is diverse traffic load on municipal bridges every day, which significantly alters dynamic impact effects induced by heavy trucks or concentrated loads during peak pedestrian flow. Structural design failure to consider enough safety redundancy, the main girder bending strength is insufficient and the bearing seismic performance is not good enough, so that easily lead to dangerous situations such as girdle cracking, bearing displacement risks of structural collapse or even casualties. The safety design must be comprehensive and meticulous; weak anti-slip performance of the deck or inadequate anti-collision capability of guardrails both raise the likelihood of accidents such as vehicle skidding and pedestrian falls, posing a direct threat to user safety [1]. But from the standpoint of durability, if bridges are affected by poor corrosion resistance of materials or defectiveness in impermeability design resulting in accelerated steel condensation and carbonation phenomenon, it can greatly shorten service life. Such a bridge was at least meant to last 50 years, but could demand major repairs after just two decades. Inadequate maintenance of this asset for citizens led to road failures that are frequent and costly, not only drain considerable public funds, but also prepare temporary traffic controls during repair interfering with citizens' everyday travel which hinders the efficiency of obtaining public services. If not maintain in a timely manner, bridges with insufficient durability may become dangerous bridges due to

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structural performance degradation and can lead to long-term transport restrictions or closure, implying require public invest in new bridges only during refurbishment of an old one that is still serviceable wasting resources and further damaging public interest.

2.2 Maintaining Stable Operation of the Urban Transportation System

As for the public transportation system where people will not be able to pass through a bridge whose design safety defects such as damaged piers from impact by heavy vehicles or fallen expansion joints may cause sudden failure. Moreover, due to the fact some bridges function as single passageway between urban transportation networks so that break off once it is likely to lead upstream and downstream traffic congestion, cause a chain reaction, paralyze surrounding road network intersection caused by economic and social activities of logistics and commuting. Unresolved safety hazards of bridges may also lead to safety accidents that are stimulated by extreme weather, adding transportation system emergency response pressure [2]. In general, the durability is a new dimension for improving the transportation system. Maintenance period usually requires load limiting, one-way traffic or an absolute closure. This change modifies the original traffic flow route which leads to an increase in traffic volume on the detour routes and decreases efficiency of the work. When durability problems are severe they may result in shutdown for a long time to make repairs; this creates so-called “breakpoints” on the urban transport network that sever regional transport connections. If the bridges in industrial parks or logistics hubs are interrupted, it will postpone the delivery of raw materials and products for enterprises, which has a direct impact on regional economic development.

3. Strategies for Enhancing Safety in Municipal Bridge Design

3.1 Optimizing Structural Stress Design

Perform advanced load calculation: Break the boundaries of usefulness from static load analysis. Create a dynamic load database for the bridge from traffic flow information from its site, geological hazard occurrence patterns, and temperature stress distribution pattern data. Application of finite element analysis software to conduct 3D stress simulation of key components such as main girders, bearings, piers and other areas with possible stress concentration (mid-span, supports), etc., the cross-sectional dimensions and material strength of each component need to match the relevant settings at that location in terms of stress requirements [3]. Reinforce redundancy design of structural system: Shear Keys, Energy Dissipation Devices at main girder-pier connectors. A redundancy can rapidly redistribute constructive stress when the nominal local load-bearing capacity of one of its elements is surpassed, thereby preventing catastrophic collapse. And for long-span bridges, using the continuous girder combined with a rigid frame system under collection of bearings stiffness to spread deck bending moment and reduce stress burden in larger span section [4]. Whole-life-cycle stress monitoring reserved design: Pre-embedded layout of optical fiber sensors and strain gauges in key components. To monitor the transformation of structural stress change during operation in real time, the locations for sensor installations, data transmission paths and the protective measures should be clear during the design stage. The frequency of monitoring data exceeding the early warning value can be used as the basis for timely implementation of maintenance and reinforcement plans, preventing stress damage from accumulating into safety accidents.

3.2 Improving Protective Facility Design

Optimize on-deck traffic protection facilities: Use wave-shaped anti-collision guardrails higher than 1.2 meters for separating motorized and non-motorized lanes, and add concrete bases at the bottom of the guard rails to improve impact resistance. Use mortise-and-tenon joints where the guardrail crosspieces meet to prevent sharp fragments from breaking off in a collision. Install protective railings no less than 0.8m at an edge of a pedestrian walkway, while ensuring the space between each railing can prevent children from climbing and falling when set within 11cm. Attach anti-slip rubber strips on the inner side of railings to avoid direct collision with hard railings in case pedestrians slip. The outlets should be grated with a maximum opening size not greater than 2cm to prevent blockage from debris that could cause stagnant water on the surface. Install 2m-wide anti-slip asphalt around drainage outlets to minimize vehicle sliding risk in wet conditions [5]. Reinforcing protection outside the bridge structure: wrap type fender for bridge pier Fender material select high-elasticity polyurethane, and its thickness shall not be less than 50cm. Add internal steel structural skeletons to the fenders for increased impact stiffness. The pier is protected from external force impacts under the surface of water, when ships or floating objects touch the pier, fender through deformation to absorb impact energy, reduce damage to piers. For the backside of the girders inside the superstructure, perform protective and anticorrosive coating and fitting metal protection shields. The cover should be provided not touching directly with rainwater and the corrosive gases, but keep a 5cm ventilation gap between them. Make frequent checks on the condition of safety covers and replace them whenever needed.

3.3 Strengthening Emergency Evacuation Design

Create scenario-based emergency evacuation schemes: Perform evacuation simulation analysis for various kinds of accidents. For example, in fire accidents analysis smoke spread speed and temperature distribution. Interval setting of deck fire partition, effective every 50m, please use flame-retardant materials: Partition width ⩾3m; Fire hydrant and extinguisher are set near each fire partition; The interval of hydrants should not exceed 120m. Collapse accidents should predict the possible collapse area to arrange emergency evacuation channels on both sides of the bridge (channel width is not less than 2.5 m), which is used for the construction of high-strength concrete structure stability. Provide gentle slopes at the interface between the channel and the deck to facilitate egress for those with limited mobility [6]. Make sure sign and alarm systems in case of emergency work optimally: Each 20m on the deck place an emergency evacuation sign Make sure the signs are self-luminous material so they can be clearly seen during power outages. There must be clear indications on the sign that is currently at location and distance from the nearest exit as well as the evacuation route map. Extend the coverage of both ends of the bridge with emergency broadcasting presentations. In the event of an accident, real-time information and instructions for evacuating can be disseminated. In addition, install emergency call buttons on the deck at intervals of no more than 100m to allow people to press for help directly during emergencies.

4. Strategies for Enhancing Durability in Municipal Bridge Design

4.1 Selecting Optimal Corrosion-Resistant Materials

Develop a material corrosion risk evaluation: Identify the corrosion risk level (also high, medium or low) for each component in terms of climatic characteristics and environmental media state to which components are subjected and stress state process. Put high corrosion risk on pier columns in coastal areas and medium to low for decks in inland dry areas [7]. Component-wise material selection: For highly corrosion-susceptible underground or underwater components like piers and foundations, weather-resistance steel with a second coat of epoxy coal tar pitch (coating thickness 0.3-0.5mm controlled) should be used. In addition, do hot-dip galvanizing on the surface of steel with the thickness of zinc layer ≥ 85μm to improve resistance to salt spray corrosion. For pavement layers for decks, Select modified asphalt concrete and control the penetrating value of New Zealand asphalt between 40-60, do not less than 60℃ of softening point. Add 3%-5% anti-aging agents to improve UV resistance and high temperature agin Joining with sliding of the components, such as bearingslide, which wear-resisting polytetrafluoroethylene(PTFE) and stainless steel plate combinations. The surface roughnessof slidingplates Ra ≤ 0.8μm to chemical corrosionwear reduce and friction pieces.

4.2 Optimizing Drainage and Impermeability Design

Focus on designing deck drainage: Set cross slope of deck at 2%-3% and longitudinal slope no less than 0.3%, allowing rainwater to collect rapidly towards the sides. Place drainage outlets at every 10-15m along the deck edge with a lateral layout to avoid direct impact of water on girders. Implement filters inside outlet stores to have blockage with garbage. UPVC material is used for connected drainage pipes, with a diameter not smaller than 150mm pipe slope, must not less than 5% to ensure smooth drainage. To make deck expansion joint impermeable, use rubber waterstops and stainless steel cover plates. The width of waterstop should be at least 30cm, and the interface agent shall be used for contact surface with concrete to enhance bonding and prevent rainwater from flowing into girder joints [8]. Raising measures to prevent moisture from infiltrating components: In the bridge box girder inside, at the junction between top slab and web set longitudinal drainage grooves, that is, at a width of not less than 10cm and depth of not less than 5cm. Install vertical drainage pipes in intervals of 20m to remove condensation and seeping water from the interior of the box girder. For the pier/foundation transition (where piers are connected to the foundation/base), we use water-expanding sealant strips to encircle these transitions. To GIC- With sealant strips, it is possible to prevent the joint from being permeable for ground water or rainwater seeping into the pier by embedding the sealant strips with grooves in concrete which shall at least be 1.5 times deeper than strip diameter. On the surface of concrete components, apply penetrating crystalline waterproofing coatings with a thickness not less than 1.5mm and penetration depth not less than 5mm to enhance the impermeability of concrete itself.

4.3 Designing Reasonable Maintenance Space

Establish design standards for maintenance space: Define unique spatial requirements for individual components. The clear height of the interior between top and bottom slabs of bridge box girders should not be less than 1.8m; the clear width of webs shall not be less than 1.2m, setting inspection holes every 30m, and the inspection hole must set protective railings. The maintenance of piers should be configured between the piers and the ring-shaped maintenance platforms should be set up, the width of platform is not less than 1.5m, steel structure repair platform is used to build, bearing capacity of not less than 2.5 kN/m². Fit ladders connecting the platform to the ground, with safety cages on the outsides of the ladders. For the maintenance of bearings, reserve inspection channels above the bearings with channel width not less than 1m and set protective railings on both sides. In addition, arrange holes for hoisting adjacent to the bearings in order to remove the bearings with hoisting equipment when replacing [9]. Establish longitudinal inspection walkway on both sides: The maintenance access and the interface with electric machine equipment are designed as follows: Set up longitudinal inspection walkways on both sides of the bridge (walkway width shall not be less than 1m, paved with anti-slip steel plates). Vehicle intrusion prevention separator installation: 0.3m high separation barriers must be installed between the edge of walkway and the deck. Close to the key components, reserve power and lighting interfaces, the interface spacing should not exceed 50m, convenient for inspection equipment to be connected during maintenance. Provide inspection basket tracks under the main girders for long span bridges, along the entire length of the girder arrangement. To allow full convenience for inspection and maintenance of girder bottom, the basket preferably has a load capacity not less than 2kN and can be moved along the track.

5. Conclusion

Through systematic organization of municipal bridge design, this study elucidates that safety and durability are the fundamental support for the whole life cycle service of a bridge. At the safety level, structural stress digital optimization design can provide early warning on damage risk through dynamic load simulation and redundancy design; advanced protective facilities can build multi-level physical barriers to reduce accidental injuries; strengthening emergency evacuation priority policy optimization plan can upgrade back-end response efficiency. All this sits within a safety assurance system that relies on these three aspects synergistically. On the durability level, choosing optimal corrosion-resistant materials can decrease environmental erosion at the source; optimizing drainage system and impermeable design can block paths of water to produce damage; reasonable maintenance space design is more convenient for later management, all of which extend bridge service life. The research confirms that safety and durability design needs to be well integrated with the bridge's usage environment and functional requirements. They are interrelated and mutually restrictive. Only through overall planning can bridge traffic safety, public interest and urban transportation stability be better safeguarded.

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