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Strategies for Establishing and Perfecting Long-Life Security Systems of Transportation Infrastructure

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Abstract: China's transportation infrastructure is facing severe challenges such as serious structural defects, short service life, aging, and unsafe operation with overextended lifespans. This paper, with reference to the advanced concepts of developed countries, proposes overall goals, strategic tasks, and recommendations for constructing a long-life safety system for China's transportation infrastructure. It also presents systematic research on construction of long-life safety systems for transportation infrastructure. This research is of strategic significance in ensuring the safe long-cycle service of transportation infrastructure, the safe and smooth operation of traffic arteries, and the sustainable development of the national economy, protecting people's lives in a stable and orderly manner, and contributing to national security and social stability.
Keywords: transportation infrastructures; long service life; safety

1 Introduction

Transportation infrastructure is the core of the transportation system of a society and is critical to people's welfare and livelihood, and the national security of a country. It is a public service that plays a driving role in the economy and a strategic role in national defense. Since it reformed and opened up, China has made remarkable achievements in its transportation infrastructure construction, and ranked first in the world in terms of buildings built. By the end of 2016, China had about 4.6×10^6 km of highways in use, including over 1.30×10^5 km of expressways that cover over 90% of cities and towns, and about 1.24×10^5 km of railway lines in use, including more than 2.2×10^4 km of high-speed rail lines [1]. However, due to degraded performance, overloading, natural disasters and other factors, some transportation infrastructure and large structures, including bridges, tunnels, roads, metro lines, and transportation hubs, are facing noticeable challenges such as increasing safety hazards, short service life, frequent accidents, severe damage caused by disasters, aging, and rising maintenance and management costs. There were 79 600 dilapidated bridges in the highway network in 2014, representing 10.5% of all bridges [2]; and according to preliminary statistics, around 1/3 of the 187 highway tunnels in Chongqing were subject to leakage, causing frequent accidents. Systematic research is urgently needed to comprehensively extend service life, improve safety performance and the capacity to handle transportation infrastructure emergencies, and guarantee the smooth operation of transportation arteries. Transport infrastructure is of strategic importance for maintaining the sustainable development of China's economy and improving the national security and social stability of China.

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2 Complex situations and critical challenges faced by China's transportation infrastructure

2.1 Severe structural defects, increasing safety hazards, and acute "short life" issues

Due to long-term natural processes (such as wind, rainfall, snow, vehicle load, and the ocean environment) and threats arising from multiple factors, such as natural and geological disasters or terrorist attacks, transportation infrastructure is experiencing growing structural defects, decreasing load-bearing capacity, loss of functionality, and even accidents like structural collapses. Improper structural design, improper construction organization and management, material performance defects, excessively overloaded vehicles, inadequate defect diagnosis methods, and unscheduled maintenance, have also contributed to increasing safety hazards, causing actual service life to be much shorter than the designed service life. How to innovate engineering construction management measures and techniques to enable transportation infrastructure to maintain safety performance for longer lives has become a burning question.

In China, over 1/4 of bridges suffer from safety hazards including structural defects, damage of various severity, and functional failure. 60% of bridges have a service life shorter than 25 years; over 40 major bridge collapse accidents have happened since 1999, causing huge property loss, personal injury and causalities, and extremely bad social impacts. With the increase in service time, the natural degradation of materials and structures, as well as the pressure of heavy-duty transportation, the operational safety and operating situations of bridge structures are still very grave (Fig. 1) [3,4].

By the end of 2015, China had a total of 12 683.9 km of highway tunnels in operation. As time goes on, many of them are experiencing defects such as leakage, cracked linings, and carbonation corrosion. Among the 58 highway tunnels in Ningbo, Zhejiang Province, the lengths subject to defects account for 36.5% of the total length. Approximately 11.6% of the 100-plus bridges on the railway lines between Beijing and Kowloon, Zhangping and Longchuan, and Beijing and Guangzhou are defect-affected [5]. By January 2016, 48.78% of railway tunnels in China had been defect-affected, and that figure was 37.46% for railways owned by joint ventures [6]

2.2 Rising aging problem posing multiple challenges for long-life safety

Transportation infrastructure usually has a designed service life ranging from 50 to 100 years. In addition to the "short-life" ones, a considerable amount of transportation infrastructure is approaching or has hit its designed service life and is now in the aging stage. We expect that China will run into peak aging transportation infrastructure and face huge operational risks in the next 20 to 30 years, and therefore it is necessary to develop scientific strategies as early as possible to address these challenges. Take the Wuhan Yangtze River Bridge [7], the Dayaoshan Tunnel [8], and the Beijing Metro Line 1 [9] for example; thanks to their good quality and proper management and maintenance, they still have a chance to maintain their function and extend their service life, even as they reach the end of their designed service life.

China has a vast amount of large transportation infrastructure, which is a huge social asset. For transportation infrastructure that pasts its service life, but with good structural performance and functionality, its removal and reconstruction not only costs a lot and results in a huge waste of resources, but it is also impossible to carry out because of restraints like busy traffic, environmental conditions, or geographic space. If the infrastructure continues to function, there are many technical challenges, such as service life assessment and prediction, performance recovery and reinforcement, as well as safety protection, for longer service life. It is an important and pressing task for Chinese researchers to extend service life while maintaining the safety of transportation infrastructure in response to the aging problem.

2.3 No complete long-life safety system at national level

China has attached great importance to the safety of its

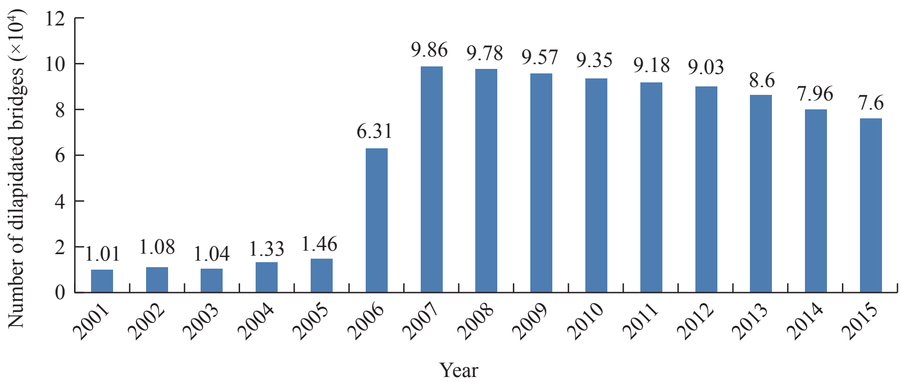

Fig. 1. Number of dilapidated bridges in China (2001–2015).

transportation infrastructure and developed many technologies, management approaches, and regulations to ensure safety, which have played an important role in maintaining the safe operation of its transportation infrastructure.

However, the design, construction, and management of transportation infrastructure vary by industry and region. Discrepancies between laws, regulations, and technical standards, no shared understandings, and an absence of top-level design and systematic planning, have all led to the absence of a complete long-life safety system. Compared with developed countries, China gives more priority to construction than to maintenance. Specifically, investigation, planning, design, construction, operation, and maintenance do not take long-life safety systems into consideration, and there is no adequate theoretical and technical support available to assess and predict safety performance and remaining service life. Deeper research on theories, technologies, and equipment that contributes to the performance, maintenance, enhancement, and recovery of large engineering structures is needed. Complete technical and management systems, laws and regulations concerning long-life safety of transportation infrastructure, and sophisticated standard systems concerning sustainable design, construction, and maintenance, are absent.

To sum up, China is facing daunting challenges in the long-life safety of transportation infrastructure, including many safety hazards, short service life, aging, and underdeveloped long-life safety technology. Therefore, China should plan to strengthen systematic research on the construction of theoretical and technical systems, ensure long-life safety of transportation infrastructure as early as possible, gradually develop a complete long-life safety system, and to secure the smooth operation of transportation arteries.

3 Practice of developed countries in long-life safety system and inspirations

Developed countries started mass construction of large structures earlier than China, and their aging problems are more acute. In order to make the best out of the functional potential of existing engineering structures and to reduce government investment, many developed countries have prepared national strategic plans or research programs aimed at enhancing the safety performance of transportation infrastructure while extending its service life. Those plans center on “economy, durability, green, and healthy,” to comprehensively secure the long-term safe operation of transportation arteries, and support the sustainable development of their national economies.

Entering the 21st century, the US, Japan, and European countries launched great efforts in scientific research and engineering practices concerning the extension of bridge life, including Sustainable Bridges [10] and Long Life Bridges [11] by the EU, Bridge Repair Plan for Longer Lives by Japan [12], and the Strategic Highway Research 2 (SHRP2) program and Long-Term Bridge Performance (LTBP) program [13] by the US.

In 1988, the US launched the Long-Term Pavement Performance (LTPP) program [14–17] to trace the evolution of pavement performance of typical sections over 20 years, and 20-plus countries, including Canada, participated in this international cooperative project. In 2008, the US launched the LTBP program [18–20] with the intention of establishing a concrete and real-time bridge health database within 20 years to study basic structural performance theories and application technologies of bridges, and finally, to improve the safety, reliability, and service life of bridges. In 2015, Japan released a development plan centering on longer service life, better safety performance, and higher resistance to damage and destruction. The plan introduces monitoring measures and preventive maintenance concepts to boost the development of modern monitoring technology, and reduce major accidents arising from degraded performance to zero. South Korea proposed the Super Bridge 200 project, targeted at extending the designed service life of bridges to 200 years through comprehensive improvement in design, construction, maintenance, and management technologies. The UK launched the Road Asset Management System program, intending to invest 15 billion GBP into safety improvement and service life extension of over 100 trunk roads. Australia and New Zealand launched their own “asset maintenance and management” programs, which serve as a guideline for the overall development, management, and operation of highways [21].

As we can see, developed countries have designed their own strategic or research plans centering on “long-life safety” to provide comprehensive support for the safe operation of transportation infrastructure with a longer life, and sustainable development of the national economy. China should refer to the advanced concepts and practices of developed countries and gradually create technical, management, and standardized systems that fit its transportation infrastructure development in order to secure the safe operation, with an extended life span, of its transportation infrastructure, and to become one of the leading players in this field in the world.

4 Thoughts on building a long-life safety system of transportation infrastructure

To address the severe challenges, such as serious structural defects, short service life, aging, and safe operation during extended service life, faced by its transportation infrastructure, China should refer to developed countries’ practices and experiences to conduct systematic research and establish complete systems in this regard. For this purpose, this paper proposes the overall goals, strategic tasks, and recommendations concerning China’s efforts in building systems to ensure long-life safety of transportation infrastructure.

4.1 Overall goals

China's efforts in the construction of long-life safety systems should center on sustainable development, to create cost-effective, durable, green, energy-saving, safe, and reliable transportation infrastructure. Starting with IT-based, standard, professional, sophisticated, and intelligent systems, China should boost research on, and construction of, theoretical and technical systems to ensure the long-life safety of transportation infrastructure and comprehensively strengthen the monitoring, diagnosis, and emergency response capacities of major engineering structures through coordinated planning at a national level. China should plan to catch up with or surpass developed countries' maintenance levels and service life of engineering structures.

4.2 Strategic tasks

(1) Make a breakthrough in technical challenges, such as maintaining long-term service performance, significant improvement in service life, and rapid recovery of structural defects, based on modern information technology, inspection (monitoring) technology, assessment prediction, and advanced maintenance technology and achievements in tackling key sci-tech problems. Promote innovation in new design theories, construction and reconstruction of engineering structures in China, engineering sciences, and modern materials. Establish long-life safety systems for major large structures centering on health monitoring, safety assessment, life prediction, and advanced maintenance and emergency response. And finally, cultivate emerging industries and take the lead in NDT, diagnosis technology, and equipment for engineering structures.

(2) Break the "information isolated island" barrier with studies on new theories, new materials, new structures, new equipment, new technologies, new standards, and deep integration with Internet Plus, cloud computing, big data, AI, and virtual reality. Achieve life-cycle information coverage. Establish a life-cycle management and decision system based on investigation, design, construction, maintenance, and operation management to boost advanced preventive maintenance-based systems and reduce the incident rate of major structures.

(3) Establish long-life safety-related policies, regulations, and standard systems for major engineering structures that cover sustainable design, construction, operation, and management by sticking to the principles of technical innovation, circular economy, energy conservation, environmental protection, and sustainable development. Systematically organize existing laws and regulations, standards, and rules. Strengthen discipline development and talent cultivation in the field. Advance China's IT-based, automatic smart traffic system through scientific management, comprehensive monitoring, and efficient emergency response to transform China from a big player in the field of large engineering structure construction to a major power in the field of large engineering structure construction and maintenance.

4.3 Recommendations

(1) China should build its own long-life safety systems for major transportation infrastructure assemblies, prepare a mid- and long-term development plan in a coordinated manner, set strategic development goals, directions, and priorities for scientific research, and work out implementation plans and approaches to development.

(2) The Ministry of Science and Technology should incorporate the construction of "long-life safety systems for major structures of transportation infrastructure" into the national key scientific research and development plan, keep tackling any sci-tech problems raised, and gradually come up with a complete long-life safety system to comprehensively enhance long-life safety performance and emergency response capacities.

(3) The National Development and Reform Commission, and other government agencies concerned, should develop strategic emerging industry empowerment action plans centering on the long-life safety of transportation infrastructure to boost the rapid development of relevant industries and set up several national-level engineering labs.

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