

Study on the Causes and Countermeasures of Bridge Collapse in China

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Abstract. Under complex operating environment and natural disasters, bridges may face the risk of collapse. Aiming at bridges in China, this paper explores the causes of bridge collapse and the corresponding countermeasures. In this paper, firstly, the basic situation of bridge collapse in China in recent years and the serious losses caused by it are analyzed. Then, taking the Wenchuan earthquake and the flood in 2010 as examples, the paper analyzes the bridge collapse accidents caused by natural disasters and the serious impact on the health of bridges. Finally, in view of earthquake and flood, the countermeasures and solutions to prevent bridge collapse are put forward. The results show that the safety of bridge structure is very important, and its ability to resist human factors and natural disasters should be considered during the whole life cycle including design, construction and operation periods. This paper can provide some theoretical reference for bridge collapse resistance research.

Keywords: Bridge collapse; Natural disaster; Bridge structure.

1. Introduction

A bridge is a large structure used to cross obstacles, allowing transportation routes or other facilities to cross natural or artificial obstacles, such as rivers, straits, highways, rail lines. The role of Bridges is to allow people, vehicles, trains or ships to cross barriers, providing safer access to traffic and separating the flow of traffic. Bridges are indispensable to modern traffic system.

Unfortunately, cases of bridge collapsed are countless all over the world. Bridges collapsed happened in both rural and urban area with all kinds of reasons, during the construction, service phases and even the demolition phases. There are two reasons for the most common bridge collapse accidents in China, personnel management and natural disasters. These incidents have resulted in significant loss of life and property damage. As a consequence, the prevention and resolution of bridge collapse accidents have attracted significant attention from professionals, research institutions, and government departments, becoming a prominent area of research.

2. General Situation of Bridge Collapse

2.1. Classification of Accidents

Fig. 1 shows the statistical diagram of 584 cases of bridge accident in the world from 1913~2018 based on Peng's research [1]. It is evident that primary factors contributing to these occurrences encompass construction-related issues, natural disasters, design flaws, accidental loading events and durability concerns [1]. Notably, construction accounts for a significant majority at 42.12%. The proportion of bridges that have collapsed due to natural disasters is the second highest, with 29.97%. Furthermore, inadequate maintenance during initial bridge constructions and backward design has also been linked with certain instances of structural failure. Bridges collapsed because of extra load have increase after 2010.

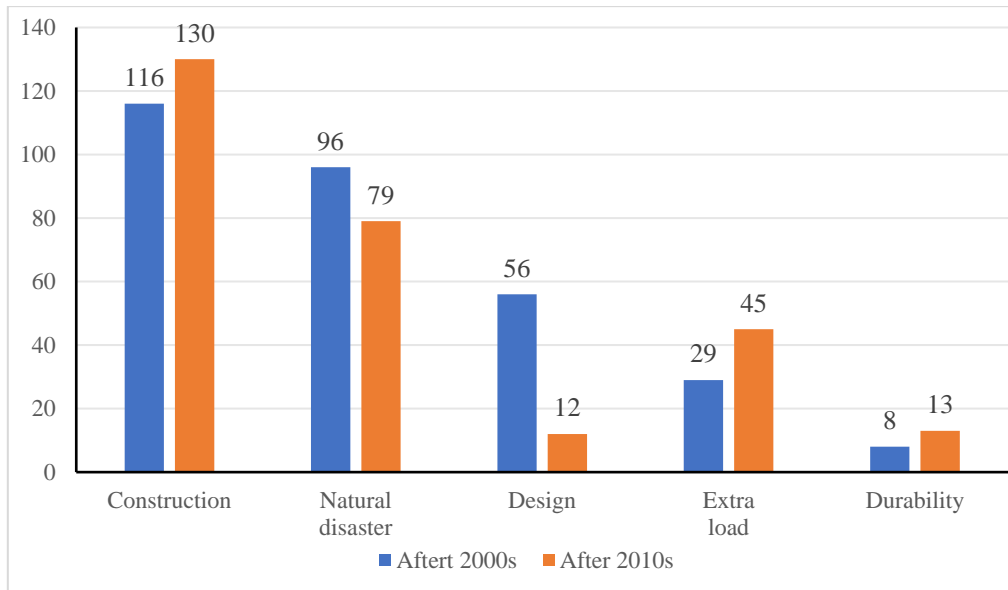


Figure 1. Statistical Diagram of 584 Cases of Bridge Accident in the World from 1913 to 2018 [1]

2.2. Geographical Situation of China

China has a diverse geographical landscape. It is characterized by the higher terrain in the western region. The eastern region is low-lying and includes extensive mountain ranges, with plateaus interwoven with plains and basins. Building a bridge in mountainous terrain requires crossing deep valleys while addressing steep terrain constraints and ensuring that structural stability and safety measures are maintained throughout the development process. In addition, bridges crossing large rivers face great challenges brought about by fast flowing water and complex hydrodynamics, thus placing strict requirements on their carrying capacity and erosion resistance.

In addition, China's Bridges are dangerously vulnerable to severe weather events and natural disasters. This is exacerbated, in particular, by the four prominent seismic belts prevalent in its western and northern regions, as well as recurrent historical inundation events in the Yangtze and Yellow River basins. The occurrence of seasonal debris flows in mountainous areas further exacerbates these inherent challenges encountered during bridge construction.

2.3. Consequences of Bridge Collapse

Bridge collapse can bring huge cost from three aspect, economically, socially, and directly cost to human. For example, railroad bridge collapsed in Tianjing on 11th November 2020 killed 8 people, causing direct economic cost 4.82 billion RMB [2].

(1) Cost of human

When a bridge collapses, it results in immediate severe consequences, primarily manifested through casualties. This abrupt catastrophe inflicts irreversible physical harm upon its victims while simultaneously inducing profound psychological trauma within their families and communities.

(2) Economic losses

The resultant financial implications stemming from such occurrences must not be underestimated. Initially, as pivotal components within transportation infrastructures, bridges inherently entail substantial costs associated with both construction and maintenance. In instances where collapses transpire, a comprehensive cleanup along with extensive reconstruction efforts become imperative-undoubtedly entailing significant financial burdens. Furthermore, the aftermath might disrupt local traffic patterns thereby impacting logistical operations alongside impeding overall economic progress. For businesses or inhabitants reliant upon these bridges for daily commutes, such interruptions directly obstruct commercial activities consequently leading to subsequent indirect financial

repercussions. Additionally, the incident can result in vehicular damages, losses pertaining merchandise, and other forms property destruction further exacerbating overall monetary setbacks.

(3) Society losses

The societal ramifications ensuing from such events extend extensively. Other thoroughfares experience heightened vehicular pressures culminating in severe congestion phenomena. These developments adversely affect travel efficiencies whilst potentially precipitating various societal issues including increased frequency regarding vehicular incidents, escalated environmental contamination among others. Conversely, this catastrophic occurrence exerts discernible influences upon public psyche. Emerging apprehensions concerning potential reoccurrences elsewhere prompt inquiries into structural safety encompassing bridges. Such anxieties coupled with widespread panic propagate throughout societies ultimately exerting tangible impacts upon communal stability alongside harmony.

3. Natural Disaster in China

In Fig. 2, there are a great increase in number of bridges collapsed in China after 2010 is because Wenchuan earthquake happened in 2008 and the flood in 2010. After the earthquake, a lot of bridges were already damaged, and the flood just destroyed the last hope. Earthquake's damage can be classify into 4 different kinds, damage to superstructure, damage to support connector, damage to abutments and piers, and damage to foundation [3].

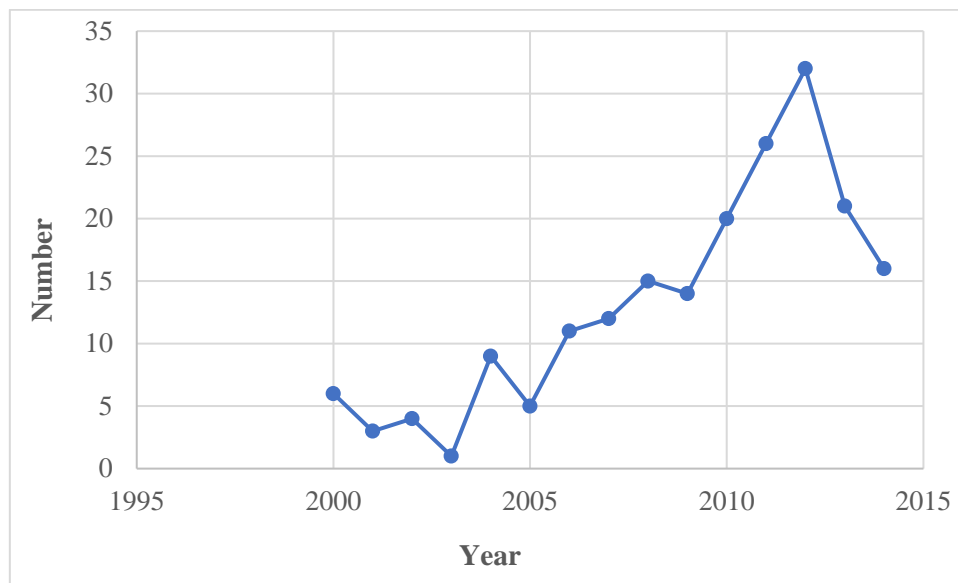


Figure 2. Statistics of Bridge Collapse in China from 2000 to 2014 [2]

3.1. The Wenchuan Earthquake

The Wenchuan earthquake, an exceptionally rare natural disaster, struck Wenchuan County in Sichuan Province on May 12, 2008. With a magnitude of 8 on the Richter scale and a maximum intensity of 11 degrees, the earthquake impacted an area exceeding 100,000 square kilometers. It resulted in the loss of 69,227 lives with an additional 17,923 individuals reported missing and caused direct economic losses estimated at no less than 845.1 billion yuan. The shallow earthquake released immense energy and was further compounded by frequent aftershocks that exacerbated the devastation. This seismic event was triggered by the extrusion of the Indian Ocean plate against the Eurasian plate within the Longmenshan fault zone [3].

3.1.1. Damage of superstructure.

During the earthquake, intense seismic waves exert significant forces on the superstructures of bridges and buildings, leading to substantial inertial forces and immediate deformation. These abrupt

forces often surpass design expectations, potentially resulting in cracking, fracturing, or even collapse of the superstructure. In particular for bridges, failure of supports may cause sections of the superstructure such as bridge decks and beams to fall, posing a grave threat to traffic and personnel safety below.

3.1.2. Damage of abutments and piers.

As the load-bearing components of a bridge, bridge piers and columns are subjected to significant vertical and horizontal forces during an earthquake. The propagation of seismic waves causes these components to undergo repeated stretching, compression, and bending, leading to stress concentration and fatigue damage. As the earthquake persists, the piers and columns may develop cracks, tilt, or even fail completely. These damages not only diminish the structural capacity of the bridge but also pose a risk for overall instability that could result in severe safety incidents.

3.1.3. Damage of support connector.

Support connector, such as bridge supports, expansion joints, and shear keys, are crucial components for ensuring the overall stability and safety of a structure. However, when subjected to strong seismic forces during an earthquake, these connectors often become the weakest link. They may experience displacement, fracture or detachment due to the impact of seismic waves, leading to a loss of connection between the superstructure and substructure. This failure not only compromises the overall structural performance but also has the potential to initiate a chain reaction that exacerbates damage throughout the entire structure.

3.1.4. Damage of foundation.

The foundation serves as the fundamental support for buildings and bridges, and its stability directly impacts the safety of the superstructure. However, during an earthquake, the physical and mechanical properties of the foundation soil may undergo significant changes, such as liquefaction, slippage, cracking, and collapse. These phenomena can compromise the bearing capacity and stability of the foundation, leading to settlement, tilting or collapse of the superstructure. Furthermore, foundation damage may also trigger secondary disasters like ground cracks, landslides and debris flows, exacerbating the severity of earthquake disasters. Therefore, in both design and construction processes it is imperative to fully consider the seismic performance of foundations while implementing effective reinforcement and protection measures.

3.2. The 2010 Flood in China

The 2010 flood in China constituted a significant natural disaster that impacted the Yangtze River basin, the Pearl River basin, and numerous provinces, primarily during the first half of the year, particularly between May and July. Certain regions experienced concurrent secondary disasters such as flash floods and mudslides. The flood notably affected the Yangtze River basin, with water levels surpassing alarm thresholds in many areas; here, the Three Gorges Reservoir played a pivotal role in regulation and storage. In addition to causing casualties and structural collapses, the flood resulted in substantial crop damage and direct economic losses. Flood's damage can be classify into 4 different kinds, scour and erosion, unbalanced water pressure, strike, destruction of balance [4].

3.2.1. Scour and erosion.

The substantial quantities of sand and rock transported by the flood exert a significant impact on the foundation and substructure of the bridge, including its piers and abutments, at high velocities. Prolonged erosion will result in the depletion of foundational soil, diminishing the load-bearing capacity and potentially causing tilting or subsidence of the bridge. Furthermore, debris carried by floodwaters may also collide with bridge structures, leading to localized damage.

3.2.2. Unbalanced water pressure.

When the water level of a flood rises, it exerts substantial hydrostatic pressure on the substructure of the bridge. This pressure is exerted on piers and abutments, potentially leading to structural cracks or

deformation. If the hydrostatic pressure surpasses the load-bearing capacity of the structure, it may result in structural collapse.

3.2.3. Strike.

In inundated areas, substantial floating objects in the current, such as trees, vehicles, and debris from buildings, may impact the bridge with the flow. These drifting objects possess significant kinetic energy and can inflict severe damage upon striking the bridge structure. This is particularly pertinent to the upper components of the bridge, including the bridge deck and beam structure, which may suffer fractures or displacement due to these impacts.

3.2.4. Destruction of balance.

The inundation-induced damage and erosion of bridge foundations can directly compromise the overall structural stability. The loss of foundation stability may lead to the collapse of the superstructure. Furthermore, flooding events may trigger secondary disasters such as landslides and mudslides, exacerbating the structural deterioration of the bridge.

Pengshan Minjiang Bridge is 16×30m prestressed reinforced concrete simply supported T beam, 494.7m long, 12.5m wide, is the main road connecting Pengshan City to the provincial scenic area Pengzu Mountain and Huanglongxi and the surrounding cities. As shown in Fig. 3, a total of 3 piers with a span of 120m collapsed. The flood's impact on the bridge primarily involves substructure erosion, leading to the washing away of the pier foundation and resulting in its suspension or even inclination, thereby compromising the bridge's stability.



Figure 3. Pengshan Minjiang River Bridge Collapse Site [1]

Due to persistent precipitation in the upstream area and ongoing erosion of the foundation of the Minjiang River Bridge caused by flooding, the bridge deck shifted. Subsequently, one pier collapsed initially, followed by the upper span structure of that pier. The adjacent pier also succumbed to lateral horizontal thrust and vertical compressive stress, resulting in progressive bridge collapse.

4. Protection

4.1. Classification of Bridge in China

Table 1 shows the classification of bridges by the Chinese government. It is directly related to the number of nearby residents which is reasonable. The more residents may use the bridge, the more important it is, the longer life span will be planned. With longer life span, the cost of the bridge increase. However, it also cause a problem which the small bridge may be lack of strength to resist natural disaster. In the long term, there may need lots of reconstruction which is not the best plan to design a bridge. Global warming cause the frequency of extreme weather have increased a lot than before, and the system of classify bridges did not considering it.

Table 1. The Classification of Bridges by GB 50201-2014 Standard [5]

Level	Importance	Residents (10 thousand people)	Equivalent economic scale (10 thousand people)	Flood control standard [return period (year)]
I	Very important	≥ 150	≥ 300	≥ 200
II	Important	$\geq 50 \& < 150$	$\geq 100 \& < 300$	100~200
III	Relatively important	$\geq 20 \& < 50$	$\geq 40 \& < 100$	50~100
IV	general	< 20	< 40	20~50

4.2. Solutions of Earthquake

Designers should implement a series of comprehensive measures to enhance the seismic resilience of bridges and other structures in anticipation of potential earthquake damage. Primarily, it is imperative to fortify the earthquake-resistant design of the superstructure by bolstering structural strength and stiffness, employing seismic isolation technology to mitigate vibration amplitude, and enhancing structural redundancy to ensure overall stability in case of component failure. Simultaneously, optimizing the seismic performance of supporting connectors is equally indispensable. This involves selecting high-performance connectors, reinforcing the structural design of connection parts, and conducting regular inspections and maintenance to significantly improve connector stability and durability.

For piers and columns, their seismic resistance needs to be enhanced through the use of high-performance materials, the addition of lateral constraints and the optimization of structural forms. In addition, ensuring the stability of the foundation is the key to the overall seismic performance of the bridge. Some measures should be taken to improve the bearing capacity and stability of the foundation, such as foundation treatment, seismic foundation and foundation monitoring system.

In addition to these technical measures mentioned above, it is essential to develop a detailed earthquake emergency plan while intensifying public awareness campaigns on disaster prevention and mitigation. Regular earthquake drills should also be conducted. These comprehensive disaster prevention measures will strengthen our ability to respond effectively during earthquakes while minimizing their impact on bridges and other structures. Through these efforts, the safety of life and property can be better protected and social stability and economic development can be maintained [6].

4.3. Solutions of Flood

In light of the potential impact of flooding on bridge infrastructure, it is imperative to implement a comprehensive set of measures aimed at enhancing the flood resilience of bridges. Firstly, reinforcing the bridge's drainage system is essential to ensure unobstructed water flow during floods and minimize erosion on the foundation. This involves installing sufficient drainage outlets, clearing blockages, and enhancing maintenance protocols for drainage facilities.

Secondly, strengthening measures are required for the substructure of the bridge, particularly its piers and abutments, to enhance flood resistance. Enhancements may include increasing pier diameter, deepening foundation burial depth, and utilizing high-performance concrete to improve bearing capacity and stability. Additionally, protective structures such as slope protection and retaining walls can be installed around piers to mitigate direct impacts from floating debris and sediment during floods.

The superstructure also necessitates reinforcement and protection. Installation of protective railings along both sides of the bridge deck can prevent vehicles or debris in floodwaters from impacting the structure. Furthermore, vulnerable components like expansion joints and supports should be reinforced to ensure stability and longevity.

Furthermore, bolstering monitoring systems with early warning capabilities for bridges is crucial. Implementing water level monitoring equipment alongside flood warning signage enables timely understanding of flood dynamics—providing a robust safeguard for bridge safety. Simultaneously developing detailed emergency plans outlining response procedures ensures swift and effective rescue operations during flooding incidents.

Lastly but equally important is public education outreach efforts which cannot be overlooked. By disseminating knowledge about flood control while raising awareness about disaster prevention among communities will enable informed actions in protecting personal safety when faced with flooding threats [6].

5. Conclusion

This paper primarily examines the current status, underlying causes, and implications of bridge collapses in China, leading to the following conclusions:

(1) Natural disasters and operational violations account for the majority of bridge failures. While incidents attributed to design flaws have diminished over time, the increasing demand for vehicular traffic has resulted in a rise in collapses due to overloading. Given China's complex and diverse topography, bridge failures can lead to significant human, economic, and social losses.

(2) In the early 21st century, China faced two major natural disasters - the Wenchuan earthquake and floods in the Yangtze River basin - which inflicted varying degrees of damage on bridges within Sichuan and Chongqing as well as across the Yangtze River region. Earthquakes can cause irreversible harm to a bridge's superstructure, support connector, support connector, and foundation. Flooding leads to scour and erosion unbalanced water pressure, strike and destruction of balance, the four main reasons that cause a bridge collapse.

(3) Finally, during the design phase of bridges, government authorities typically estimate their intended lifespan based on regional economic capacity and population density. However, additional factors should be considered when determining both design specifications and investment strategies for these infrastructures.

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