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Recent hydraulic bridge failures in China: review and discussion

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Abstract: This paper studies 123 hydraulic bridge failures in China from 1998 to 2018. The geographic distribution, age distribution, bridge type distribution, time distribution and the hydraulic bridge failure causes are analyzed. Six typical failure cases of hydraulic bridges are analyzed in detail. 100 hydraulic bridge failures occurred in southern China so hydraulic bridge failures are much more common in this area. The average service life of these bridges is 28.9 years. The beam bridge accounts for the largest proportion of hydraulic bridge failure because 71 (57.7%) beam bridges were destroyed by flood. Hydraulic bridge failure mainly occurred between 2009 and 2014, which was related to the impact of the Wenchuan earthquake. The incidents major causes include unexpected flood, earthquake, old bridge, over sand exploitation, low awareness of hydraulic bridge damage, extreme morphology of the river, etc. There are both natural factors and man-made factors. These results show that three aspects should be paid attention to: (1) unexpected flood; (2) appropriate bridge type; and (3) extreme morphology of the river.

Keywords: Bridge, hydraulic failure, cause, China.

1. Introduction

There are many bridge failures in the world. Bridge failure is the most concerned problem of the engineers (Wesley Cook, Bar, & Halling, 2015; Harik, Shaaban, Gesund, Valli, & Wang, 1990; Rodrigo, Olària, Fernández-Ordoñez, & Gómez, 2015). The consequences of bridge failure can range from unexpected maintenance needs, to the loss of life and economic prosperity. Failure types include hydraulic, collision, overload, deterioration, fire, construction, fatigue, and miscellaneous (Duntemann & Subrizi, 2000; Moroni, Sarrazin, Venegas, & Villarroel, 2015; Wardhana & Hadipriono, 2003).

The damage caused by foundation scour and settlement from soil erosion is a great threat to bridge structure. Scour is the main cause of bridge failure (Duntemann & Subrizi, 2000; Harik et al., 1990). Wadhana found that flooding or scouring was the main cause of bridge failure in the United States (Wardhana & Hadipriono, 2003). Cook estimated an annual hydraulic bridge failure frequency of approximately 1/8500 (W. Cook, Barr, & Halling, 2014). Montalvo reported that in the United States, 55% of collapsed bridges were caused by hydraulic collapse (Montalvo, Cook, & Keeney, 2020). Flint indicated that bridge failures may increase due to more frequent or intense flooding (Madeleine M. Flint, Oliver Fringe, Sarah L. Billington, David Freyberg, & Diffenbaugh, 2017). Lin selected 45 bridges as a case study to evaluate scour performance using the developed integrated analysis technique (Lin, Bennett, Han, & Parsons, 2012). Hung examined the influence of scour on the behavior of bridge piers subjected to flood-induced loading(Hung & Yau, 2014). Hager investigated the end scour depth due to a single peaked flood wave in an essentially plane rectangular sediment bed containing a single pier for clear-water conditions(Hager & Unger, 2010).

Foundation settlement is caused by erosion and weak soil conditions. When the pier tilts, there is potential for the bridge to collapse without warning. After the construction of piers and abutments, the cross-section area of flood decreases and the velocity of flow increases, which causes local scour around the piers and makes the foundation empty. In recent years, global climate change has led to the gradual concentration of rainwater and the frequent occurrence of floods. Once the foundation without sufficient depth is submerged, it is easy to collapse. Today, climate change and associated extreme weather events are causing more flood-related damage to bridges(Choudhury & Hasnat, 2015; Wardhana & Hadipriono, 2003). Most of the damage are not just caused by water. During the flood period, sediment and other tiny floating objects are easy to deposit in the river channel, which affects the flood discharge and makes the bridge easy to be washed away by water. Large floating objects, such as trees, will directly impact the bridge foundation and damage the pier and river channel.

By the end of 2017, more than 830000 bridges had been built in China (Zhou & Zhang, 2019). Bridge failures often occur in China (Hong, Chiew, Lu, Lai, & Lin, 2012; Ji & Fu, 2010; D. Xu, 2003; H. T. Xu, Guo, Pu, & Yuan, 2007; Zhuang, Xiao, Jia, & Sun, 2020). In this paper, the diseases of hydraulic bridge in China from 1998 to 2018 are analyzed retrospectively. The investigation constitutes the types and causes of hydraulic bridge failure in China.

2. Case study of hydraulic bridge failure

This paper discusses the hydraulic bridge failure in China from 1998 to 2018.

2.1. *Taiwan Gaoping Bridge*

Taiwan Gaoping Bridge was a continuous beam bridge and about 1990 meters long. On August 27, 2000, severe tropical storm Bilis destroyed some piers of Gaoping Bridge. The bridge deck collapsed about 100 meters, a total of 17 vehicles collided on the road, and 22 people were seriously injured, as shown in Figure 1 (Sina, 2000).

Figure 1. Collapse of Gaoping Bridge.

2.2. *Sichuan Second Qujiang Bridge*

The Second Qujiang Bridge was an arch bridge, located in Dazhou City, Sichuan Province. It was 573 meters long and 15.5 meters wide. The construction began in 2008 and had expected to be completed in 2011. But in July 2010, after two-thirds of the total construction were completed, the project was destroyed by floods, as shown in Figure 2 (Xinhuashe, 2010). The bridge was under construction, so it was an unintegrated structural system. The instability of the bridge and the erosion caused by the over expectation flood leaded to the destruction of the bridge. Pearson—III theoretic frequency curves are widely used to calculate flood rate in China. The design flood rate prediction is based on historical measurements. More historical measurements can improve prediction precision.

Figure 2. Collapse of Second Qujiang Bridge.

2.3. *Tangying Bridge*

On July 24, 2010, Tangying Bridge in Luoyang City, Henan Province collapsed due to rainstorm, resulting in 53 deaths and 13 missing, as shown in Figure 3 (Zhaoting, 2010) .

Tangying Bridge was a continuous beam bridge with 233.7 meters long and 8 meters wide. The bridge, built in the 1980s, was a 5-span continuous arch bridge with a net span of 40 meters. It was made of stone and mortar without any reinforcement. This type of bridge structure is sensitive to foundation settlement. Any skewback foundation settlement will produce enormous secondary internal force. The flood scoured a skewback of the bridge and caused foundation settlement. Then the bridge collapsed under the action of a huge secondary internal force.

Figure 3. Collapse of Tangying Bridge.

2.4. *Shiting Bridge*

On August 19, 2010, Shiting Bridge of Baocheng railway was destroyed by flood, resulting in two sections of K165 train falling into the river, as shown in Figure 4 (Mengqi, 2010). Fortunately, there were no casualties.

Figure 4. Failure of Shiting River Bridge.

This bridge was constructed in the 1950s. It was a continuous beam with a net span of 16m. The piers were made of stone and the piles were made of wood. The pile cover was only 5 meters deep. Due to the weak discharge capacity of small span bridges, shallow foundations are particularly prone to erosion. Then two piers of the bridge were inclined due to the flood. When the train passed the bridge, two piers of the bridge collapsed.

2.5. *Mianzu Bridge*

Mianzu Bridge, a continuous concrete beam, was located in Mianzu City across the Shiting River. It was 366.5 meters long and 10.75 meters wide. On August 18, 2012, two piles disappeared due to flood scour, as shown in Figure 5 (Guang, 2012). The dashed lines represent the disappeared piles in Figure 5.

Figure 5. Failure of Mianzu Bridge.

The 2008 Wenchuan earthquake caused a large number of gravel and finger stones to fall into the Shiting River, which resulted in narrow water way increasing the flow velocity downstream of blocked part of the river. This enhanced the scouring effect. In addition, the excessive exploitation of river sediment aggravated the decline of river stage. Therefore, the piles were washed away by the flood.

2.6. *Huaiyuan Bridge*

Huaiyuan Bridge was a multi-span simply supported beam bridge with a total length of 135 meters. On August 19, 2010, the bridge collapsed due to flood, as shown in Figure 6 (Mingkang, 2010). More than 60 meters of the bridge fell into the river. Two people died.

Figure 6. Collapse of Chongzhou Huaiyuan Bridge.

The bridge was built in the 1960s and was identified as an unsafe bridge with limited bearing capacity in 2008. After the 2008 Wenchuan earthquake, the river became narrow due to the deposition of finger stones. As a result, the flow velocity was accelerated and the scour was intensified. This undermined the bridge foundation. Then the bridge was destroyed by the flood.

2.7. *Other cases of hydraulic bridge failure*

Some typical cases of hydraulic bridge failure are listed in Table 1.

Table 1. Cases of hydraulic bridge failure.

No.	Name	Local	Type	Summary	Time
1	High Screen Bridge	Taiwan Province	cable-stayed bridge	The flood washed over the pontoon and six cars crashed into the river.	2000.08.27
2	Sandu Bridge	Sichuan Province	arch bridge	Excessive sand mining, flood erosion, pier and bridge collapse.	2004.09.07
3	Nanzamu Bridge	Liaoning Province	multi-span beam	The flood destroyed the bridge, three cars and many people crashed into the river.	2005.08.13
4	Cold Water River Bridge	Shanxi Province	cable-stayed bridge	The 80m bridge collapsed after the flood.	2006.11.25
5	Changyuan Bridge	Zhejiang Province	multi-span beam	Flood impact pier, bridge deck longitudinal cracking, crack width 27cm.	2007.11.04
6	Silver Carp Bridge	Sichuan Province	suspension bridge	The flood cut the bridge into three parts and fell into the river	2009.07.13
7	Sichuan Wenchuan Chediguan Bridge	Sichuan Province	Continuous beam bridge	The heavy rain caused 200t boulders to roll down, resulting in the collapse of the bridge pier and the collapse of the 100m bridge.	2009.07.25
8	Sichuan G318 Line River Second Bridge	Sichuan Province	Concrete-filled steel tube arch bridge	After completion of the 2/3 project, the bridge was destroyed by the flood.	2010.07.20
9	Henan Luanchuan Yi River Bridge	Henan Province	Stone arch bridge	The trees blocked the river channel, causing collapse of all the upper structures.	2010.07.24
10	Baocheng railway Shiting River Bridge	Sichuan Province	Continuous beam bridge	The pier collapsed by the flood.	2010.08.19
11	Hai Xianlin Bridge, Anxian county,Sichuan Province	Sichuan Province	Continuous beam bridge	The superstructure was washed down by the flood.	2010.08.09

12	Chengdu Congzhou Old Ding Jiang Bridge	Sichuan Province	Continuous beam bridge	The mountain torrent scoured the bridge, causing the bridge to collapse.	2010.08.09
13	The Keelung Highway Bridge	Taiwan Province	Continuous beam bridge	The bridge was badly damaged by the massive flood.	2010
14	Chongzhou Huaiyuan Bridge	Sichuan Province	Simple support T-shaped	The bridge was badly damaged by the massive flood.	2010
15	Chongqing Fuling Red Mud Bridge	Sichuan Province	Arch bridge	The bridge was collapsed by the flood.	2010
16	Sichuan-Tibet Highway Bridge	Sichuan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2010
17	Dozens of bridges in Tonggu County, Jiangxi Province collapsed	Jiangxi Province	Continuous beam bridge	The bridge was collapsed by the flood.	2010
18	The Sun River Bridge of Liji Town, Wanning City	Hainan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2010
19	Guizhou Wangmo County Jiefang Bridge	Guizhou Province	Hyperbolic arch bridge	The bridge was badly damaged by the massive flood.	2011.06.06
20	Guizhou Wangmo County Ningbo Bridge	Guizhou Province	Stone arch bridge	The bridge was badly damaged by the massive flood.	2011.06.06
21	Guizhou Wangmo County Wangmu Bridge	Guizhou Province	Arch bridge	The bridge was badly damaged by the massive flood.	2011.06.06
22	Shiting River on the 1st Bridge	Sichuan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2012
23	Fuxin Long River Bridge	Sichuan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2012
24	106 Provincial Road De Shi Shiting River Bridge	Sichuan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2013
25	Panjiang Bridge	Sichuan Province	Arch bridge	The bridge was collapsed by the flood.	2013
26	Shiting River Guangluo Bridge	Sichuan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2013
27	Qingdao Trestle	Shandong Province	Continuous beam bridge	Storm surge caused the bridge to collapse	2013
28	Hunan Pingjiang Lufan Bridge	Hunan Province	Continuous beam bridge	The bridge was collapsed by the flood.	2013

3. Discussion

3.1. *Geographic distribution of hydraulic bridge failure*

From 1998 to 2018, 123 bridge disasters by the flood have occurred in China, as shown in Table 2.

Table 2. Distribution of bridge disasters by flood in China.

Province	Number	Province	Number
Sichuan	60	Fujian	2
Guangdong	10	Gansu	2
Jiangxi	7	Shandong	2
Zhejiang	7	Taiwan	2
Hubei	6.	Anhui	1
Shanxi	5	Hainan	1
Guizhou	4	Hunan	1
Liaoning	4.	Jiangsu	1
Heilongjiang	3	Jilin	1
Henan	3	Tibet	1

The data is plotted on the map of China, as shown in Figure 7.

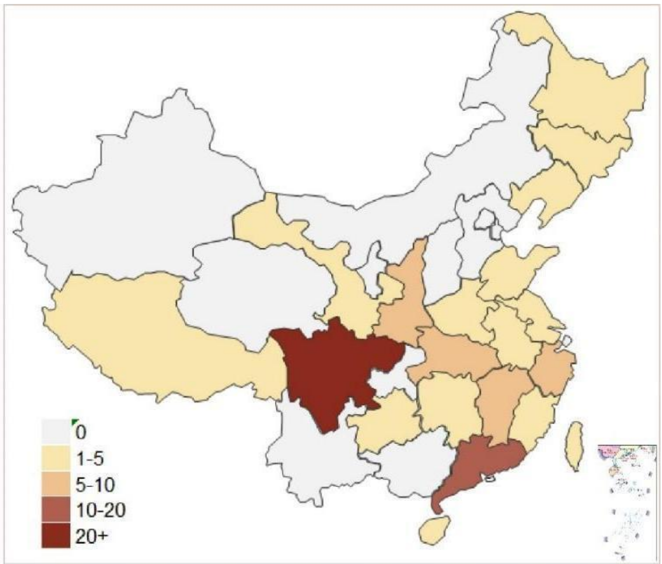

Figure 7. Distribution of damaged bridges across the country.

Sichuan Province has the highest number of hydraulic bridge failure, which is related to the impact of the Wenchuan earthquake. The 2008 Wenchuan earthquake led to a large number of sand and finger stones falling into the river, which resulted in narrow water way increasing the flow velocity downstream of blocked part of the river. Furthermore, the breached part of blocked water way caused rapid increase in velocity of sediment laden flow which had sufficient drag force and bed shear stress to further erode the bed than normal scour. (Ko, Chiou, Tsai, & Chen, 2014). In addition, some bridges have been damaged in varying degrees in the earthquake.

There were 100 hydraulic bridge failures in southern China and 23 hydraulic bridge failures in northern China, resulting in 67 deaths and 138 injuries. The results are listed in Table 3.

Table 3. Hydraulic bridge failures in southern China and northern China.

	southern China	northern China	Total
Number	100	23	123
Average annual probability	5.50	1.28	6.84
casualty	29 (dead)/48 (injured)	38/90	67/138

The average annual failure probability of hydraulic bridge in southern China is higher than that in northern China. This is due to the frequent heavy rain in southern China and the high probability of flood occurrence. However, the casualty rate of hydraulic bridge failure in southern China is lower than that in northern China. This is because the awareness of hydraulic bridge damage in northern China is relatively weak.

3.2. *Age distribution analysis*

The service life distribution of 123 bridges investigated is shown in Figure 8. The average service life of these bridges is 28.9 years. Guigou Bridge in Henan Province survived only one day because of the flood. However, the life of Dongmen Bridge in Guangdong Province is 82 years, and that of Qingdao Trestle Bridge in Shandong Province is 121 years. The life of most bridges is less than 35 years and cannot reach the service life.

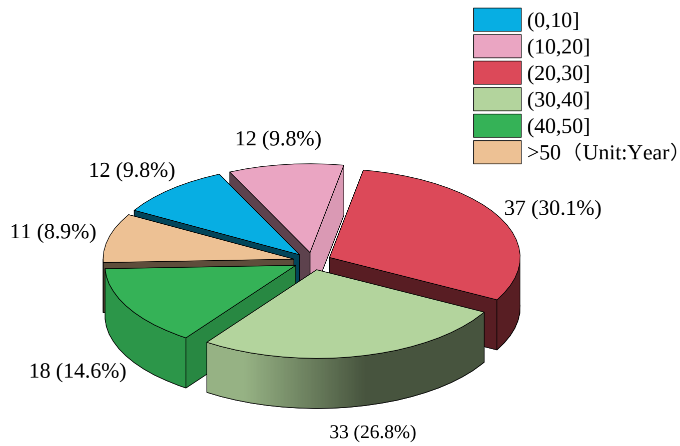

Figure 8. Age distribution of failed bridges.

3.3. *Time distribution of the hydraulic bridge failure*

The time of the hydraulic bridge failure is summarized, as shown in Figure 9. It mainly occurred between 2009 and 2014. During this period, the most hydraulic bridge failures happened in Sichuan Province, which was related to the impact of the Wenchuan earthquake. Some bridges were damaged in the Wenchuan earthquake and did not find or repair in time.

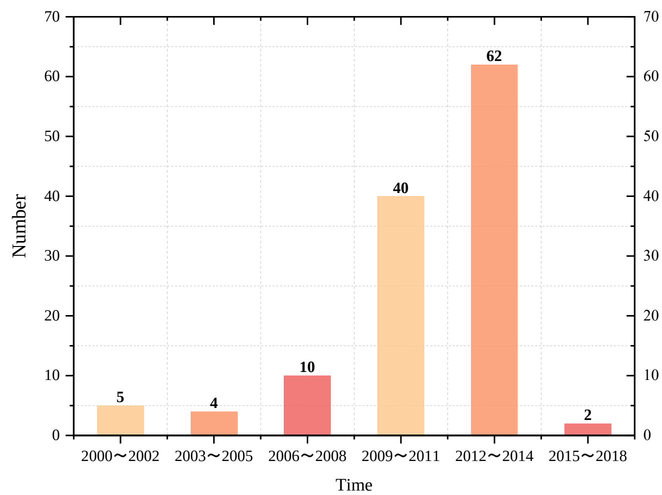

Figure 9. Time distribution of failed bridges.

3.4. *Bridge type distribution of the hydraulic bridge failure*

There are 71 beam bridges, 20 arch bridges, 2 suspension bridges and 1 cable-stayed bridge among the investigated bridges. The type of the other 29 bridges is unknown, as shown in Figure 10.

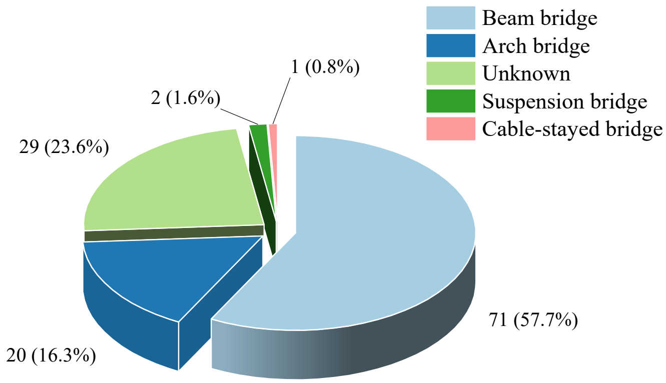

Figure 10. Bridge type distribution of failed bridges.

From 2000 to 2018, beam bridges accounted for the biggest share of hydraulic bridge failure. Suspension bridge and cable-stayed bridge take up a small proportion. Beam bridges have more piers and are prone to water scouring, leading to collapse. Arch bridges are generally built in mountainous areas. They are prone to collapse during floods or mudslides. In suspension bridges and cable-stayed bridges, cable is the main load-bearing structure, they are larger than the beam bridge span, suitable for building in the water depth, not easy to be destroyed by water.

4. Summary and recommendations

This paper investigates 123 hydraulic bridge failures. The geographic distribution, age distribution, bridge type distribution and time distribution are analyzed. It is found that there are more hydraulic bridge failures in southern China. Sichuan Province has the highest number of hydraulic bridge failure. Most bridges have a life span of less than 35 years. The average service life of these bridges is 28.9 years. Hydraulic bridge failures mainly occurred between 2009 and 2014. The beam bridge accounts for the biggest share of hydraulic bridge failures. There are both natural factors and man-made factors, such as unexpected flood, earthquake, old bridge, over sand exploitation, low awareness of hydraulic bridge damage, extreme morphology of the river, etc. Finally, the findings of this study are as followings:

1. Most of the collapses occurred on old bridges. They cannot be assumed to meet modern design standards. Therefore, the bridge design engineer must adequately consider the expected flood;

2. The bridge type with fewer piers should be selected, such as cable-stayed bridge and suspension bridge, so as to avoid hydraulic damage. The estimated pier scour depth is not sufficient and doesn't consider all factors responsible for large scour;

3. Before construction of any bridge on river, possible changes in extreme morphology of the river should be examined, considering all the natural and anthropogenic factors.

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Huili Wang: data curation, conceptualization, methodology.
Zhikang Luo: writing – review & editing.

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References

Choudhury, J. R., & Hasnat, A. (2015). Bridge collapses around the world: Causes and mechanisms. Paper presented at the IABSE-JSCE Joint Conference on Advances in Bridge Engineering-III, Dhaka, Bangladesh.

Cook, W., Bar, P. J., & Halling, M. W. (2015). Bridge failure rate. Journal of Performance of Constructed Facilities, 29(3), 1-8. doi:https://doi.org/10.1061/(asce)cf.1943-5509.0000571

Cook, W., Barr, P. J., & Halling, M. W. (2014). Segregation of bridge failure causes and consequences. Paper presented at the TRB 2014, Washington, DC.

Duntemann, J. F., & Subrizi, C. D. (2000). Lessons learned from bridge construction failures. Paper presented at the Second Forensic Engineering Congress, Puerto.

Guang, L. (2012). https://www.cet.com.cn/dfpd/tsgd/594779.shtml.

Hager, W. H., & Unger, J. (2010). Bridge Pier Scour under Flood Waves. Journal of Hydraulic Engineering, 136(10), 842-847. doi:https://doi.org/10.1061/(ASCE)HY.1943-7900.0000281

Harik, I. E., Shaaban, A. M., Gesund, H., Valli, G. Y. S., & Wang, S. T. (1990). United States bridge failures, 1951–1988. Journal of Performance of Constructed Facilities, 4(4), 272–277.

Hong, J.-H., Chiew, Y.-M., Lu, J.-Y., Lai, J.-S., & Lin, Y.-B. (2012). Houfeng bridge failure in Taiwan. Journal of Hydraulic Engineering, 138(2), 186-198. doi:https://doi.org/10.1061/(ASCE)HY.1943-7900.0000430

Hung, C.-C., & Yau, W.-G. (2014). Behavior of scoured bridge piers subjected to flood-induced loads. Engineering Structures, 80, 241–250. doi:https://doi.org/10.1016/j.engstruct.2014.09.009

Ji, B. H., & Fu, Z. Q. (2010). Analysis of Domestic Bridge Collapse Accidents In Recent Years. China Civil Engineering Journal, 43(S), 495-498. doi:https://doi.org/10.15951/j.tmgcxb.2010.s1.010 (in Chinese)

Ko, Y.-Y., Chiou, J.-S., Tsai, Y.-C., & Chen, C.-H. (2014). Evaluation of Flood-Resistant Capacity of Scoured Bridges. Journal of Performance of Constructed Facilities, 28 (1), 61-75 doi:https://doi.org/10.1061/(ASCE)CF.1943-5509.0000381

Lin, C., Bennett, C., Han, J., & Parsons, R. L. (2012). Integrated analysis of the performance of pile-supported bridges under scoured conditions. Engineering Structures, 36, 27–38. doi:https://doi.org/10.1016/j.engstruct.2011.11.015

Madeleine M. Flint, Oliver Fringe, Sarah L. Billington, David Freyberg, & Diffenbaugh, N. S. (2017). Historical Analysis of Hydraulic Bridge Collapses in the Continental United States. Journal of Infrastructure Systems, 23(3), 1-16. doi:https://doi.org/10.1061/(ASCE)IS.1943-555X.0000354

Mengqi, L. (2010). http://news.sohu.com/20100819/n274335662.shtml.

Mingkang, L. (2010). https://cd.qq.com/zt2010/chongzhou/.

Montalvo, C., Cook, W., & Keeney, T. (2020). Retrospective Analysis of Hydraulic Bridge Collapse. Journal of Performance of Constructed Facilities, 34(1), 1-8. doi:https://doi.org/10.1061/(ASCE)CF.1943-5509.0001378

Moroni, M. O., Sarrazin, M., Venegas, B., & Villarroel, J. (2015). Seismic behavior of chilean bridges with seismic protection devices. Revista de la Construcción Journal of Construction, 1(1).

Rodrigo, B. G., Olària, S. R. i., Fernández-Ordoñez, D., & Gómez, J. M. C.-S. (2015). Rehabilitation of Historic Masonry Bridges: Lessons Learned from a Medieval Bridge in Northeast Spain. Revista de la Construcción Journal of Construction, 14(2), 9-13.

Sina. (2000). https://news.sina.com.cn/china/2000-08-28/121178.html.

Wardhana, K., & Hadipriono, F. C. (2003). Analysis of Recent Bridge Failures in the United States. Journal of Performance of Constructed Facilities, 17(3), 144-150 doi:https://doi.org/10.1061/(ASCE)0887-3828(2003)17:3(144)

Xinhuashe. (2010). https://war.163.com/photoview/00AN0001/10072.html#p=6C3OLBSD00AN0001.

Xu, D. (2003). Accident Environmental Risk Assessment in Bridge Construction. China Safety Science Journal, 13(8), 46-49. doi:https://doi.org/10.16265/j.cnki.issn1003-3033.2003.08.012 (in Chinese)

Xu, H. T., Guo, G. Z., Pu, H. L., & Yuan, M. (2007). Causes and lessons of bridge accidents in China in recent years. China Safety Science Journal, 17(11), 90-96. doi:https://doi.org/10.16265/j.cnki.issn1003-3033.2007.11.018 (in Chinese)

Zhaoting. (2010). http://news.sohu.com/20100729/n273847112.shtml.

Zhou, X., & Zhang, X. (2019). Thoughts on the Development of Bridge Technology in China. Engineering, 5, 1120–1130. doi:https://doi.org/10.1016/j.eng.2019.10.001

Zhuang, D., Xiao, R., Jia, L., & Sun, B. (2020). Failure analysis for overall stability against sliding and overturning of a girder bridge. Engineering Failure Analysis, 109, 1-13. doi: https://doi.org/10.1016/j.engfailanal.2019.104271