Analysis of arch bridge collapse based on finite element technology

Yu Niu and Qingshun Yang*
School of Civil Engineering, Qinghai University, Xining, China
*Corresponding author e-mail: yqss112@163.com

Abstract. Even in today's technologically advanced, engineering accidents are still unavoidable. How to numerically simulate the collapse process of bridges becomes a major problem, and the continuous development and maturity of finite element technology provides an effective way to solve this problem. This paper takes the Yilanao Bridge in Taiwan as the research object, and establishes multiple models based on the finite element analysis software MSC.MARC and MIDAS, and analyzes the causes of the damage. This paper has certain reference significance for the study of the failure form and failure process of arch bridges.

1. Introduction
An arch bridge refers to a bridge with an "arch" as the main load-bearing member in a vertical plane. It has an important position in the ancient and even modern bridge family with its beautiful shape, round curve and dynamic sense.

The arch bridge has a long history of development. Around 100 BC, ancient Rome was built on the trans-Tagus River and built the world's first existing stone arch bridge, the Alcantara Bridge. China's arch bridge was built in the middle and late Eastern Han Dynasty. It has a history of more than 1,800 years. The earliest and preserved Zhaozhou Bridge in China was built in 605. In the second half of the 19th century, the second industrial revolution, the development and application of steel has been greatly developed. Steel arch bridges have gradually replaced stone arch bridges. In 1874, the United States built the first steel arch bridge, that is, St. Louis across the Mississippi River. In the first half of the 20th century, the construction method of reinforced concrete arch bridges was changed from expensive floor-standing scaffolding arch ribs to more economical wooden or steel arch-shaped bracket cast-in-place arch ribs, saving construction costs. 50-70s Large-span reinforced concrete arch bridges have been further developed due to the successful construction of cantilever assembly and cantilever construction. For example, in 1964, Australia built a 304.8-meter-wide Gladesville bridge at Sydney Harbour; the United States was built in 1977. The highest highway bridge in the United States, namely the New River Gorge Bridge. In recent years, the development of arch bridges has been changing with each passing day. On April 29, 2009, China built the largest arch bridge in the world in Chongqing, namely the Chaotianmen Yangtze River Bridge. The support of the main bridge has a 145000kN ball-type anti-seismic support. The seat is the spherical bearing with the largest bearing capacity of the world. On November 19, 2015, China built the world's largest reinforced concrete arch bridge in the western part of Guizhou Province, namely the Beipanjiang River Bridge. The main span of the bridge is 290 meters of prestressed concrete hollow-necked rigid frame, which is the world's first. Fasting continuous rigid frame.
At present, the research on bridge collapse has gradually gained the attention of the industry. Many scholars have written the literature according to their own research, but there are few studies on finite element analysis based on specific engineering examples. In view of this, this paper combs the research status of the subject, and uses the finite element analysis software MSC.MARC and MIDAS to analyze the Taiwan Yilanao Bridge.

2. Research status
At present, regarding the research on the characteristics of the catenary arch bridge, many scholars have achieved certain results according to their own research ideas and different analysis methods and software. For example, X Zhang used computer-aided design software CAD and large-scale finite element analysis software ANSYS to establish a finite element model of a multi-arch bridge in his master's thesis, and made the force performance under different load conditions. analysis[1]. S Chen used the finite element analysis software Msc/Nastran to establish a finite element model in his master's thesis, not only analyzed its force characteristics, but also gave an optimization design and comparison of its force performance[3]. Even in today's technologically advanced, engineering accidents are still unavoidable. On October 1, 2019, the collapse of the Yilan Bridge in Taiwan Province of China was impressive. The X Lu team established a finite element model and conducted research. In addition, many scholars have published relevant research results on the collapse of arch bridges. Z Gui conducted a comprehensive analysis of the collapse and reconstruction of the steel truss arch bridge in Summanda, USA, and summarized its warning[4]. Based on NVivo, J Zhu analyzed the cause of the bridge collapse accident in Harbin on August 24, 2012 [5]. S Zhao and his partner counted the examples of bridge damage in recent years, studied its failure mechanism, and gave corresponding prevention measures [6]. Y Zheng used the principle of statistics to analyze the causes of bridge collapse and proposed related prevention measures [7]. R Yi and others have statistically analyzed the collapse of bridges in China in the past 15 years, and analyzed the causes of collapse in the four stages of construction, operation, maintenance and demolition, and reached relevant conclusions [8].

3. Introduction to the accident
At about 9:30 am on October 1, 2019, the Yilanao Cross-sea Bridge in Taiwan broke and collapsed. The tanker truck on the bridge and the bridge deck fell from an altitude of about 18 meters, and three boats stopped under the bridge. The fishing boat was crushed on the spot, and 10 people were injured and 5 people were missing [13]. While deeply deploring this accident, I used finite element analysis software to reproduce the bridge collapse process and made relevant analysis in stages.

4. statement
This study is a simulation based on publicly available information under the guidance of its instructor Yang Qingshun, an undergraduate student at Qinghai University. As the cause of the collapse of the bridge is under investigation, it is not enough to give a definitive conclusion. The analysis results in this paper are my exploratory research conducted during the holidays. The main purpose is to introduce the application of computer simulation in related fields and to train finite element analysis skills. This analysis is for scientific research use only, and the cause of the accident should be determined by the professional according to the actual situation.

5. Establishment of finite element model
5.1. Material parameters
The steel used for the main beam, the transverse beam, the inclined bracing, the arch rib and the boom is selected from the Grade 3 in the GB(S) database. The dummy beam is selected from the custom material Dummy, and its elastic modulus is $E = 1e - 10tonf/mm^3, I_{yy} = 1mm^4$. 
5.2. **Section setting**
1: B 3000 × 15000 × 1000/1000 main beam  
2: B 2000 × 4000 × 33/33 arch rib  
3: SR 130 boom  
4: SR 220 boom  
5: B 2000 × 2000 × 27/27  
6: Dummy Beam dummy beam

5.3. **Model comparison show**
Based on the public information, I used MSC.MARC and MIDAS to establish the finite element model of the Yilanao Bridge in Taiwan. The bridge span is 140m, 30m high and 15m wide. The arch axis is catenary and the material is steel. For the sake of comparison, the figure below shows the finite element model I built and the finite element model established by the Lu Xinzheng team.

![Figure 1. The finite element model I built](image1)

![Figure 2. The finite element model Lu built](image2)

6. **Analysis of calculation results**
Based on the public video material, we can know that the destruction of the Yilanao Bridge in Taiwan was completely collapsed after the sixth boom of the right was broken. Below we will analyze the cause of the damage in chronological order.
6.1. **Element stress analysis on the break of the boom at the beginning of the failure**

![Figure 3. Deformation displacement before failure](image)

![Figure 4. Deformation displacement after failure](image)

As can be seen from Figure 3, among all the 13 booms, the 6th, 7th and 8th booms on the right are most severely deformed, and the stress is about 375MPa. The steel used in our selection is Grade3 in the GB(S) database. The design values of tensile strength and compressive strength are both 435 MPa and the load reserve is 13.7%. Therefore, there is no problem in design. When the sixth boom of the right is broken, the two adjacent booms are right. The stress of the fifth and seventh booms suddenly increased to about 500 MPa, which exceeded our tensile strength.
6.2 Analysis of deformation displacement of the main beam

It can be seen from Figure 5 and Figure 6 that after the elastic support of the main beam of the arch bridge is lost, the deflection is significantly increased to cause instability, and a large deformation displacement is generated, causing it to fall off the bracket and cause collapse.

6.3. Element Stress Analysis of Brackets and Arch ribs
The bracket and the rib are only subjected to self-weight after losing the pull-down force of the boom, so the stress is small, as shown in Figure 7, but because of the momentary loss of the pull-down force of the boom, it causes a large upward movement. Because the arch ribs are connected to the bracket, the two brackets are brought closer to the center of the main beam while the arch ribs are rebounding upward, which exacerbates the deformation and displacement of the main beam, and the arch rib and the main beam are connected by the bracket, so the arch rib Due to the pull-down force of the main beam collapsing and collapsing with the main beam, the arch rib and the bracket still maintain relative integrity after the collapse. The entire destruction process in the numerical simulation is basically consistent with the destruction video.

7. Conclusion
1) The arch rib is the main force component of the arch bridge, so the arch axis has a great influence on the bearing capacity of the arch bridge.
2) The stress changes of each part of the catenary arch bridge are relatively stable, and there is no stress concentration phenomenon.
3) The distribution and variation trend of the internal force of the model is approximately about the central axisymmetry of the arch bridge. The results validate the basic characteristics of the arch bridge.
4) After the boom is broken, it will have a great influence on the stress of the adjacent boom. In this case, it increases by 33.3%.
5) The arch rib that instantly loses the pull-down force of the boom will rebound upwards, and at the same time, the bracket will be moved closer to the middle.
6) It is feasible and accurate to analyze steel arch bridge with finite element software MIDAS.

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