# TYPICAL DISEASES OF THE STONE ARCH BRIDGES IN THE MOUNTAINOUS AREAS OF CHINA AND THEIR REMEDIES

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## SUMMARY

In the mountainous areas of western China, more than 70 percent of the bridges are stone arch bridges. The longest bridge is Danhe Bridge in Shanxi with the span of 146 meters. After decades of service, some of them have been damaged in varying degrees. A few have been damaged seriously and some even collapsed, especially those who bear overload traffic and suffer from lack of maintenance.

The typical diseases, detected by detailed investigations of the stone arch bridges in the mountainous areas of China, are summarized.. These diseases include longitudinal cracks in the main arch ring, transverse cracks in the spandrel arch ring, the side wall leaning outwards and released from the arch ring, the abutment cracking and leaning outwards, the waterproof layer of bridge deck pavement failing and the stones seriously weathered and eroded.

Remedial retrofit and strengthening methods for these diseases are described. Cracks were grouted and closed by epoxy resin adhesive, the cross section of arch ring was thickened or hooped with reinforcement concrete, the front wall and side wall of abutments were hooped by a frame beam with bolt grouting, the side wall of abutment was fixed by transverse steel bars and the bridge deck pavement was replaced with a new one including an effective waterproof layer. A large number of conducted successful stone arch bridge repairs corroborates the effectiveness of applied retrofit and strengthening methods. The durability and load-carrying capacity of these stone arch bridges have been largely increased by retrofit and strengthening procedures.

**Keywords:** *Diseases, mountainous areas, strengthening, stone arch bridges.*

## 1. TYPICAL DISEASES AND CAUSES OF THE STONE ARCH BRIDGES

The stone arch bridges are one of the basic bridge which appeared early in China, when it appeared, it had been a tremendous development. A large number of the arch stone bridge stand on the river or between the mountains, the Zhaozhou bridge shown in Fig. 1 is one of the most representative, which is more than 1400 years old. With a lot of construction in the Stone Arch bridge, some of them have been damaged in varying degrees. This paper summarizes the typical disease of stone arch bridge, and analysed the reasons by the actual investigation and literature collection.

***Fig. 1.*** *The ZhaoZhou Bridge.*

### 1.1. Longitudinal cracks in the main arch ring

The main arch ring of longitudinal cracks shown in Fig. 2 is one of the most common cracks in the stone arch Bridges. The cause of the disease, detected by detailed investigations and analysis, are summarized. These reasons include the poor quality of construction, the imperfection of the arch ring, the asymmetry of the padding on the arch ring, earth pressure and eccentric live loads.

***Fig. 2.*** *Longitudinal cracks in the main arch ring.*

### 1.2. Transverse cracks in the spandrel arch ring

Transverse cracks in the spandrel arch ring shown in Fig.3 is one of the most common cracks in the stone arch bridges. The main causes of cracks include:

1) The inadequate aggregated rock strength lead to partial deteriorated strength in the arch ring. The section of the arch bridge can`t provide the sufficient resistance in the load transfer, which finally leads to the transverse cracks in the spandrel arch ring.
2) The displacement of the pier and the basic results in transverse cracks. The most widely known Stone Arch Bridges are the redundant structure. If the pier and the basic generate displacement, the internal force redistribution will emerge in the bridge, and then ,some section in the spandrel arch ring can`t bear the action from the superstructure, which results in the transverse cracks.
3) Asymmetrical loading on the arch ring. The cracking which is caused by this kind of situation occurs mainly on the ramp bridge. Some bridge`s slope is sharply, however, the arch ring is horizontal in the design, as a result, spandrel construction is not symmetrical. The arch ring get the stress from the spandrel construction, and then the transverse cracks are appearing in the spandrel arch ring.
4) The longitudinal slip or rotation of pier and abutment is also one of the reasons for resulting in transverse cracks in the spandrel arch ring.
5) Poor construction quality have an effect on it, such as imperfect mortar between the stones and non-standard masonry techniques.

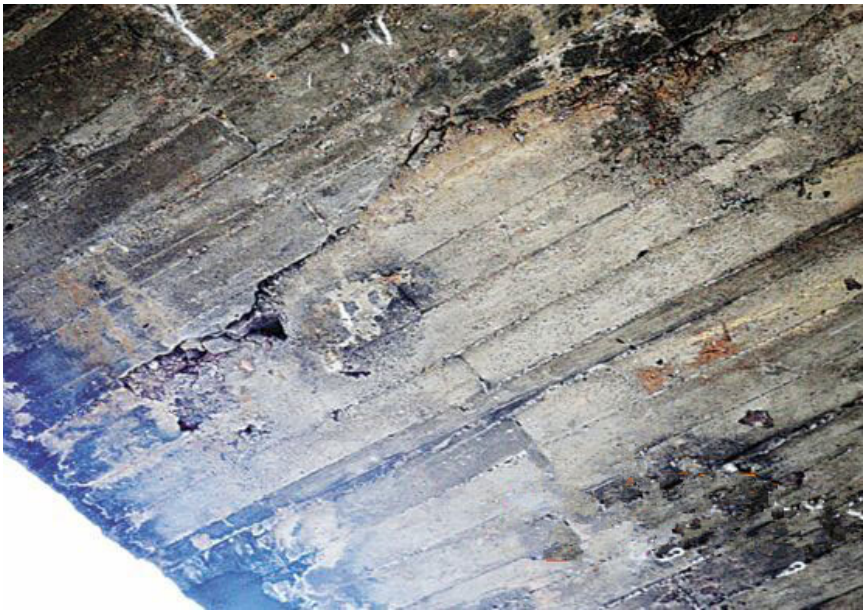

***Fig.3.*** *The transverse cracks in the spandrel arch ring.*

### 1.3. The side wall leaning outwards and released from the arch ring

This disease shown in Fig. 4 is often caused by serious side wall cracking or cracks under excessive, and the main factors causing these cracks include: The arch filler is insufficient or not dense, the load from the deck is too large, the strength of masonry is too low in the side wall, construction quality is poor and so on.

***Fig. 4.*** *The side wall leaning outwards.*

### 1.4. The abutment cracking and leaning outwards

The side wall or front wall often appear the transverse cracks and the longitudinal cracks shown in Fig. 5, cracks expand along the contact surface of mortar or stone. Some of the cracks run through the mortar or the stone, and their style of width can be the wide intermediate and the narrow ends. The cracks depth also are different, including deep cracks and surface crack. In short, because of the different diseases, the cracks are not the same.

It is noteworthy that the factors about the abutment cracking and leaning outwards are summarized.

1) The load above the abutment is too large or some vehicles act on the edge of the abutment, and all lead to too much earth pressure on the side wall so the cracks will be on it.
2) The filling is not dense in the abutment, and the drainage system is failing.
3) The strength of masonry is too low.
4) The abutment foundation have the uneven settlement and the slip.
5) Design defect and construction poor.

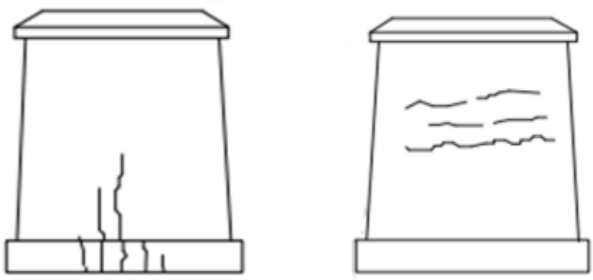

***Fig. 5.*** *The abutment cracking.*

### 1.5. The waterproof layer of bridge deck pavement failing

That the waterproof layer failing is one of the diseases of bridge deck pavement, this disease shown in Fig. 6 can result in the Water-Seepage, and influence the durability of bridge structures. there are some reasons about this diseases. The waterproof layer fracture in the construction loads. Due to the uneven deck pavement or the uneven waterproof layer, the thinner waterproof layer have the leakage on the loads. The waterproof layer maybe damage in the secondary circuit construction. The construction quality is too poor for the waterproof layer.

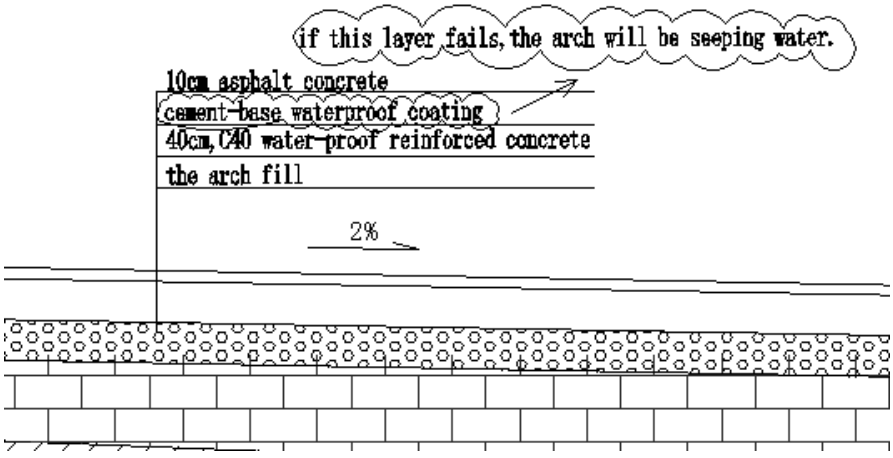


***Fig. 6.*** *The schematic diagram.*

### 1.6. The stones seriously weathered and eroded

Stone is exposed to the air, or soak in the sewage for a long time,which results in reducing their physical properties, and then, the ultimate bearing capacity is reduced in the Stone Arch Bridges. This disease is shown in Fig. 7.

***Fig. 7.*** *The stones seriously weathered and eroded.*

## 2. REMEDIAL RETROFIT AND STRENGTHENING METHODS

Remedial retrofit and strengthening methods for these diseases are described, Cracks were grouted and closed by epoxy resin adhesive, the cross section of arch ring was thickened or hooped with reinforcement concrete, the front wall and side wall of abutments were hooped by a frame beam with bolt grouting and the bridge deck pavement was replaced with a new one including an effective waterproof layer.

### 2.1. Pressure grouting method

Crack grouting is a method that grouter inject the Epoxy Resin Binder which is the proportion of configuration into the construction cracks in the certain pressure. It plays a certain function that close fracture and enhance the strength of construction. The main construction technology process about the pressure grouting are summarized. The process shown in Fig. 8 include: check and clean up the cracks→bore and embed the grout inlet→close fracture→test pressure→grout→inspect and treat the surface. Moreover, What calls for special attention is that the safety problem in the process of construction. The announcements include note the ventilation to prevent technical personnel poisoning at the construction site, grouting material should be sealed storage, construction personnel should wear mouth shad、rubber gloves and safety goggles, when physical contact to the Epoxy Resin Binder, don`t use the acetone cleaning, the correct way is erasing with sawdust or household cleanser firstly, and washing with the hot soapy water, the machinery of the construction should use the acetone、toluene or hot water cleaning. no open flame at the construction site, pay attention to recycle the instrument and the residual liquid to prevent pollution of the environment.

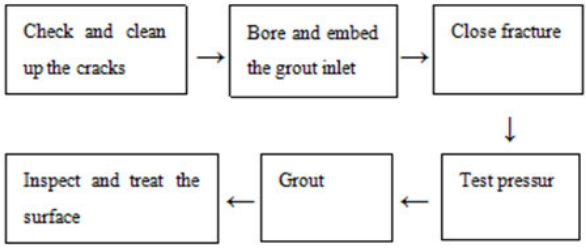


***Fig. 8.*** *The process of pressure grouting.*

## 2.2. Increased cross-section reinforcement method

In order to the load-bearing structure of stone arch bridge strengthened, we can use reinforced concrete to increase arch cross-section. this method is mainly used in case of the bearing capacity drops or some elements fails caused by the deformation of Arch Axis, cracks of the main arch and other diseases. The reinforcement technology shown in Fig.9 through the addition of the original owners arch soffit and sides of or vault a layer of reinforced concrete reinforcement layer so as to form a composite main arch, coordinated by composite main arch deformation, the main arch of old and new common force, to enhance the main arch, enhance the role of carrying capacity.

Augmented section of stone arch bridge strengthened is one of a more common approach, it has the advantages of uninterrupted traffic, this method is applied in practice, should pay attention to the following requirements: bridge clearance should be relatively large, after increasing the cross-section shall also meet the requirements for clearance under the bridge, but the bridge cannot be reduced spillway section; requirements bridge foundation is good enough to withstand the additional stress produced by live new sectional. piers size to meet the requirements of the new arch can withstand additional thrust.

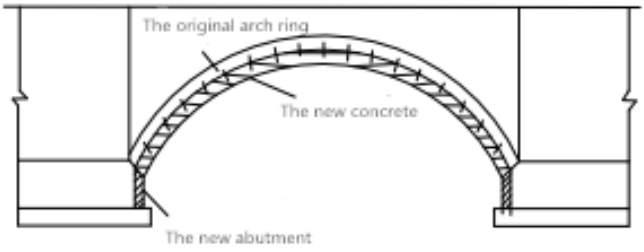


***Fig. 9.*** *The bridge is under construction.*

## 2.3. Hooped with reinforcement concrete

This method shown in Fig.10 include adding the hoop of the reinforced concrete floors to develop the composite arch ring. Use this theory that the composite arch ring can be consistent deformation and bear load together to increase the strength and stiffness of the main arch ring, and then, increase the bearing capacity.

This method has the advantages include:

1) Make full use of theory that the structural strength have a significantly increase from three-directional pressure.
2) Don't need to terminate the traffic at the construction site,
3) The hoop of the reinforced concrete floors can cast in place to achieve high strength of concrete, overcome the disadvantage of sprayed concrete, at the same time, increase the cross section and stiffness of the arch ring, and improve the ultimate bearing capacity and aseismic capacity.
4) That the new pouring concrete layer wrapped in old main arch ring increase the durability of the structure, enhance the capacity of water erosion prevention in the main arch ring and enhance the capacity of resistance to weather.


***Fig. 10.*** *Hooped with reinforcement concrete.*

### 2.4. Hooped by a frame beam with bolt grouting

Due to the depth of bridge pier embedment is not enough or construct poorly, the abutment cracks, and even the penetrating crack appears. At the same time, the front wall and side wall of abutments were hooped by a frame beam with bolt grouting, the side wall of abutment was fixed by transverse steel bars. In this way, we can improve the integrity of the structure and the bearing capacity. This method is shown in Fig.11.

***Fig. 11.*** *Hooped by a frame beam with bolt grouting.*

### 2.5. Replace the bridge deck pavement

Due to the vehicle overload and construction poor about the side of the waterproof layer, the arch ring have the water seepage problem, and the ridge deck pavement is failing. For the control of the disease, we can take the following actions :

1) The bridge deck pavement was replaced with a new one including an effective waterproof layer. The construction of the replacement should be carried out strictly in line with the construction technique to ensure the construction quality. This method is shown in Fig.12.
2) Using the waterproof concrete, it has good waterproof effect and durability. We should lay a waterproof screeding layer which is 5~10 cm to adjust the transverse slope of the bridge deck and possess the effect of waterproof. If we lay the asphalt on the screeding layer, the effect of waterproof will be better.
3) Deformation cracks and expansion joints should be focus on the side of the waterproof.

***Fig.12.*** *Replace the bridge deck pavement.*

## 3. CONCLUSION

This paper summarized the common diseases and causes for the Stone Arch Bridges, and Put forward the corresponding remedies. In addition to the already mentioned remedies, some new methods had been used at home and abroad, such as bonding steel plate, bonding CFRP, transforming the force system in the structure or using the high-performance concrete.

In summary, a large number of conducted successful stone arch bridge repairs corroborates the effectiveness of applied retrofit and strengthening methods. The durability and load-carrying capacity of these stone arch bridges have been largely increased by retrofit and strengthening procedures.

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