

# Influence of Extreme Weather and Its Secondary Disasters on Bridges

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**Abstract.** Global climate change causes more and more extreme weather happened frequently. It poses a new challenge to the structural safety of civil engineering. Nowadays, bridge engineering designs must consider the possibility of extreme climates and the social, economic, and environmental damage they cause. In this paper, the influence of three kinds of extreme weather on bridges is summarized by the method of comprehensive narration, and the influence of secondary disasters is described. Results show that both extreme weather and secondary disasters can significantly impact bridges. Extreme weather includes rainstorms, typhoons and earthquakes and affects the structure and materials of the bridge. Heavy rain erodes the bridge's structure and material and causes flood and debris flow to harm the bridge. Flood water would continue to impact the pier and cause damage to the understructure of the bridge. Meanwhile, they could also induce secondary disasters such as aftershocks and debris flow, impacting the bridges and disrupting the function of the city.

**Keywords:** Extreme Weather; Bridge; Structure Damage; Material Damage.

## 1. Introduction

As global climate changes, extreme weather events become more frequent. Extreme weather, such as rainstorms, snowstorms, and floods, affects every aspect of people's lives and endangers the cities, states, and people's health. On February 15, heavy rains caused landslides in the Brazilian city of Petropolis, killing 193 people and leaving 69 missing. On February 21, California residents voluntarily reduced their water use by 15 percent due to an ongoing drought that has caused the land to crack. On February 18, the Atlantic storm Eunice hit Britain, Germany and the Netherlands, killing some people and causing flight cancellations. Since the middle of the 20th century, people have realized the significance of severe weather in construction. Extreme weather also has disastrous effects on our transport network, causing critical tunnels or bridges to close and, in the worst circumstances, leading to injuries and fatalities.

Nowadays, bridge engineering designs must consider the possibility of extreme climates and the social, economic, and environmental damage they cause. The measures for bridge maintenance mainly adopt different materials or structures, considering the extreme weather's impact or using methods to strengthen bridges. While the bridge was being built, a construction defense system was built to deal with the extreme weather.

The current research focuses on single extremes events, or single species bridge research. This study comprehensively discusses the influence of extreme weather like rainstorms, typhoons, and earthquakes on bridges and puts forward some measures before and after the bridge construction.

## 2. Extreme weather

Extreme weather events refer to the occurrence of unusual phenomena in the weather and climate of a place, or the occurrence of extreme weather when the local weather and climate deviate seriously from the average state. But extreme weather cannot be generalized, and its definition varies from different places. Later, the extreme threshold method is commonly used worldwide to define whether an extreme climate event occurs in a certain area. The World Meteorological Organization (WMO) put forward a set of extreme weather indices from 1998 to 2001. There are 27 core indices mainly

used internationally, including 11 precipitation and 16 temperature indices. Now, these indices are also widely used at home and abroad.

The extreme temperature index could be divided into four categories: the first category is the index with relative Min value, including the number of cold nights, warm nights, cold days and warm days; The second category is the index with fixed net value, including the number of frost days, summer days, freezing days and summer nights, The third category is the extreme value index, including the minimum value of the daily minimum temperature, the maximum value of the daily minimum temperature, the minimum value of the daily maximum temperature and the maximum value of the mesh maximum temperature. The fourth category is duration index and range index, among which cold period and warm period belong to duration index and daily temperature range belongs to range index.

Extreme precipitation indicators can be divided into four categories. The first is relative indicators, including extreme rainfall and extreme heavy rainfall. The second is absolute index includes two days with low intensity, two days with moderate intensity and three days with high intensity. The third is extreme value index is the maximum one-day rainfall and the maximum decrease of five consecutive days. The fourth duration index includes the longest continuous dry days and the longest continuous wet days.

As for the classification of extreme weather events, some definitions about severe and extreme events exist. Severe weather events cause large losses in measures such as the number of lives, financial capital, or environmental quality. Long-term observational projections can estimate measures of severity, and this measure yields a concept as risk. The risk depends on the event product of the probability of the event (the hazard), the vulnerability (e.g., how much damage ensues when the event hits someone), and the exposure to the hazards (e.g., how many people are exposed). Rare events are means that occur with low probability. Because these events are rare, human societies (and other ecosystems) often do not adapt to them so well when suffering large amounts of damage.

There are three levels of extreme weather. The first level is rare weather divided by the rarity of the extreme weather. The second level includes two parts. The first part is rare and severe weather and the second part is rare and non-severe weather, which two parts are divided by the severity of the extreme weather. The third level depends on the rapidity of the extreme weather. The rare and severe weather is divided into two parts, which are rare, severe, acute events (e.g., hurricane in New England) and rare, severe, chronic events (e.g., drought in India). The rare and non-severe weather is divided into two parts, which are rare, on-severe, acute events (e.g., hurricane over the south Atlantic Ocean) and rare, on-severe, chronic events (e.g., cold spell in Sahara).

### **3. Influence of rainstormS on bridge structure and material**

#### **3.1 The Concept Of Rainstorm And Its Subsequent Effects**

A rainstorm is very heavy rain, usually formed in cumulonimbus clouds. The frequency and intensity of extreme precipitation in China are increasing, and the heavy rainfall is concentrated with high intensity and can cause floods. China is affected by the monsoon climate, with extreme events such as heavy rain all year round. In 1998, the Yangtze river, Nenjiang River and Songhua River basins in China suffered large-scale floods, with a direct loss of 1,660 billion yuan. The Beijing-Tianjin-Hebei region, the southwest to the middle and lower reaches of the Yangtze River, and north China have all experienced floods caused by heavy rains.

The occurrence of heavy rain in mountainous areas usually leads to debris flow disaster. Debris flow in China is mainly affected by heavy rain, and continuous rain will make some mountainous areas too much water storage and debris flow. It primarily occurs in the season of frequent rainfall, so the debris flow shows a certain periodicity and seasonal characteristics. The occurrence of debris flow could also affect people's transportation, blocking the road, affecting travel, causing certain economic losses, destroying residents' houses and crops, and even threatening the lives of residents. After the debris flow occurs, the mountain is likely to fall again due to landslides.

### 3.2 The Impact Of Rainstorm On The Structure Of Bridges

The rainstorm has an impact on the structure and materials of bridges.

Firstly, the influence of heavy rain on the bridge structure is mainly on the deck and pier and other parts of the scour, affecting the beauty of the bridge structure. Heavy rain could also cause the loss of calcium ions in the bridge concrete pore solution in a short time. Thus, the deterioration of the mechanical properties of the concrete structure.

In addition, rainstorms could cause debris flow disaster, damaging bridge structures. The impact of debris flow on bridges varies; the most destructive are percussive action, souring action, and buried action. The percussive action can be divided into two parts: the impact of debris flow and large stones on bridge piers. Debris flow slurry moves fast and the capacity is heavy, carrying many stones, which could cause damage to the bridge pier. Secondly, debris flows in the impact process are caused by the climbing phenomenon and the ultra-high phenomenon of the curve. When gravel mud flows down from the mountain to meet obstacles, due to its strong impact, it impacts the bend. The bend is in the concave and convex surface, the flow of debris flow will make the speed difference on both sides, the flow of the concave bank will increase sharply, and the pier there will also bear the severe effect of debris flow.

The scouring effect of debris flow could be divided into three parts. The first is debris flow gully has three stages: upstream, middle and downstream. Upstream for erosion and shear damage, upstream is the area of debris flow formation, slope water constantly erosion. The original narrow channel width continues to increase, which results in landslides. The second middle reach of debris flow is scoured by side erosion. Because the slope in the middle reaches is gentle, the debris flow impact has both impact and buried effect. Many debris flows have formed a certain scale when they reach the middle reaches, and the scale of more debris flows increases with the cutting effect, and the impact on the river channel and bridge pier is more intense. The third is debris flow downstream accumulation and local erosion damage. In downstream of the gully, the slope becomes slower, and the speed of debris flow is easier to slow down, leading to debris accumulation downstream.

Buried action is divided into three parts. The first is Local accumulation and siltation of debris flow in the middle and upper reaches: the collection of debris flow in the middle and upper reaches increases the follow-up debris flow and forms a larger scale of debris flow. The second part is the accumulation of debris flow in the downstream stage. Because the downstream gully becomes gentler, debris flow speeds decrease, and the accumulation on both sides increases. This poses a threat to villages and Bridges downstream. The third is that the debris flow could block the river: when the debris flows more than the river and cannot be effectively discharged, large areas of accumulation in the river lead to the river blocked, so that more debris flow slurry accumulation forms barrier lake.

In addition to the above forms, debris flow destruction of bridges also includes erosion, vibration, smash and airwaves and other secondary disasters. Erosion is when debris flow contains a large amount of sand and stone, which continuously corrodes and destroys the surface of buildings. Vibration is that the flow rate of debris flow is very fast, which leads to huge vibration of the bridge pier at the moment of impact. Cracks develop in the bridge and structural strength decreases. Smash is when debris flow impacts the pier, a large number of slurries, sand and stone flying into the air, and then hits the bridge deck, resulting in varying degrees of damage to the bridge deck. Airwave is when paroxysmal debris flow produces undulating air flow under high-speed movement, which will lead to bridge damage in serious cases.

### 3.3 The Impact Of Rainstorm On The Materials Of Bridges

Concrete absorbs a lot of moisture in a short time, which could lead to changes in the internal humidity of concrete. Relative humidity will change the strength and material properties of concrete. When the relative humidity is more minor, the intensity would decrease more and the creep value would be larger. The sun exposure after heavy rain combines the two extreme climates, showing that the internal water absorption and evaporation are very large in a short time. Concrete is subjected to a severe wetting and drying cycle, and the internal relative humidity experiences a process from low

to high and then to low. This change in humidity has a much more significant impact on the material properties of concrete than single extreme weather, which leads to a drastic development of concrete damage.

In China, more bridges have been washed away by rainstorms or disasters in the south than in the north. The reasons are mainly as follows: there are many rivers in the south and the rainfall is heavy, so the probability of flood is high and the accident of bridge being washed away by flood is easy to happen. Secondly, the total number of bridges in the south is more than that in the north, resulting in many bridge destruction events. For example, the girder bridge in Front of Mogao Cave in Gansu Province was destroyed by floods caused by torrential rains in 2019. Floods damaged the mali-li Bridge in Fujian province. Lianghong Bridge, in Sichuan province, was destroyed by a mudslide triggered by heavy rain.

## **4. Influence of typhoon on bridge structure and material**

### **4.1 The Concept Of Typhoon And Its Subsequent Effects**

A typhoon is a kind of tropical cyclone, a low-pressure vortex occurring on the surface of the tropical and subtropical ocean. China divides the maximum average wind size near the bottom center of tropical cyclones in the South China Sea and the northwest Pacific Ocean into six grades. The six grades are tropical depression, tropical storm, severe tropical storm, typhoon, severe typhoon and super typhoon. The wind near the center is 12 or above, collectively referred to as typhoons.

China is located in the southeast of the Asian continent, the east of Pacific Ocean, with a coastline of more than 18,000 kilometers. The East Coast of China is easier to severe and frequent typhoon disasters. In 2021, Typhoon fireworks hit most areas along the southeast coast, and the southeast coastal provinces of Fujian and Zhejiang saw violent thunderstorms of 40 millimeters in one hour, accompanied by short thunderstorm winds and other fierce weather.

There are three main features of typhoon. The first is frequent landfall. From April to December every year, tropical cyclones make landfall in China, and they are most frequent from July to September. Second is that the scope of its influence is wide. The vast coastal areas of China, especially in the East China Sea, are directly affected by typhoon disasters. When the typhoon enters the inland, storm and floods could occur, which could also cause severe flooding in most areas of inland. The third is its destructive power. A typhoon brings high winds, high waves and storm surge. It has a serious threat to the safety of coastal and marine buildings, as well as ships. Shipwrecks and casualties are common in the path of typhoons. In addition, high waves could also affect coastal water conservancy projects and transportation infrastructure.

### **4.2 The Impact Of Typhoon On Bridges**

Typhoon has an impact on the structure and materials of bridges.

Typhoon destroys bridge structure mainly from three aspects: the first is about typhoon and wind wave load. In coastal areas, the foundation has a shallow depth and weak ability. When the bridge resists wind and waves, the bridge superstructure is prone to displacement under the action of typhoons and strong waves. Secondly, erosion damage is caused by typhoon. Under the typhoon, the water body scour the bridge's understructure with huge energy, accompanied by corrosion damage to the structure, which also increases the probability of bridge safety accidents. Thirdly, sand damage is caused by the typhoon. In areas where desertification is severe, large amounts of sediment can not only block drainage outlets and other facilities, but also create additional loads on Bridges as sand accumulates on bridge decks. The windward side of the bridge is also vulnerable to erosion by sand and gravel, which in severe cases can destroy the bridge.

In addition, typhoon also has certain damage to bridge material. For example, typhoon accelerates the carbonization of concrete. The concrete surface of the bridge is exposed, and strong wind erosion causes the thickness of the concrete protective layer to decrease and peel off, and the reinforcement inside the concrete could be rusted. The typhoon accelerates the carbonization of concrete, which in

turn causes the reinforcement near the concrete surface to rust in advance, the carbonation depth of the direct wind surface is higher than the carbonation depth of the moderate wind surface, about 1.5 times. Under the action of wind environment, the diffusion and infiltration of carbon dioxide occur simultaneously, that is to say, there is a certain correlation between the two processes.

Typhoons can damage bridges, and cause heavy rains and floods, and this secondary disaster is one of the main reasons for bridge damage. On August 27, 2000, under the influence of Typhoon Bilisi, part of Taiwan Gaoping Bridge was washed away by a stream, the foundation of the bridge was washed out, which resulted in serious exposure to the bridge structure. This damage caused the bridge's deck to collapse 100 meters. On August 14, 2012, The Jinyun Ship Bridge in Zhejiang Province was damaged due to the flood caused by typhoon Haikui, resulting in loose soil loss.

## **5. Influence of earthquake on bridge structure and material**

### **5.1 The Concept Of Earthquake And Its Subsequent Effects**

The earthquake is also called earth movement, or earth vibration. It is a natural phenomenon that seismic waves are generated during the rapid release of energy from the earth's crust. The leading cause of earthquakes is the collision between plates, which causes dislocation and rupture of plates' edges and inside plates.

The consequences of earthquake disasters are also incalculable, especially when they occur in urban areas. The hazards of urban earthquake disasters mainly include three parts: firstly, the direct losses caused by earthquake disasters are enormous. Urban space is densely populated and economically dense. Sudden building collapse would cause casualties, property losses and lifeline system destruction in a very short time. The city's transport and communications lifelines are intricate. It will take a long time to recover if the lifelines are damaged. Secondly, secondary disasters would intensify urban earthquake disasters. Earthquakes can cause a variety of secondary disasters, such as fires, floods, tsunamis, landslides, explosions and so on. They cause secondary threats to life and property. For example, in the San Francisco earthquake in the United States, the fire system was damaged, and more than 50 fires in the city caused three times more damage than the direct loss. Thirdly, earthquake disasters have a lasting impact on the economy and society of cities and the world. The most significant loss of earthquake damage in most areas is engineering disaster loss, but in developed cities, the proportion of engineering disaster is obviously decreased, and the subsequent proportion caused by economic interruption is significantly increased. For example, the 1995 Kobe earthquake paralyzed 90 percent of the port's berths, and it took about six months for the port to resume operations.

### **5.2 The Impact Of Earthquake On Bridges**

The occurrence of an earthquake greatly impacts the bridge, destroying the bridge's structure, and resulting in the failure of the bearing capacity of the bridge. A large number of earthquake damage analysis shows that there are four main causes of bridge earthquake damage. Firstly, the intensity of the earthquake exceeded the standard for seismic fortification. Secondly, foundation failure and foundation deformation caused by the earthquake. Thirdly, the bridge structure design and construction are unreasonable. Fourthly, the seismic capacity of the bridge structure itself is insufficient. According to the above four factors, it can be classified into two categories. The damage caused by seismic failure and the damage caused by strong structural vibration.

The earthquake damage to bridges mainly occurs in the following aspects. Firstly, the seismic damage of the superstructure of a continuous bridge is especially displacement and collision. Displacement earthquake damage refers to the displacement and other destructive earthquake damage, usually occurring in the expansion joint and support position. Manifesting as the longitudinal and transverse dislocation and out-of-plane rotation of the bridge superstructure beam plate. Collision damage refers to the collision between adjacent superstructure beams and plates, and between side spans and slabs or abutments.

Secondly, for the substructure of the continuous bridge, the primary seismic damage is the bending damage of the pier and the seismic damage of the frame pier. Piers bending failure generally shows plastic damage, pier columns crack, failure of concrete, massive spalling, internal steel exposed and various damage forms. The reason is that the earthquake intensity destruction ability is strong, and the longitudinal reinforcement lap is not firm, stirrup reinforcement is unreasonable and construction technology defects and many other factors. The seismic damage to the frame pier mainly includes the failure of the cover beam, pier column and joint. The failure forms of cover beam include shear failure, bending failure and failure caused by insufficient shear strength and anchorage length of reinforcement. The joints mainly show shear failure. Abutment damage is also typical in past earthquakes. The abutment slip caused by the loss of bearing capacity of the foundation, the collision damage between the abutment and the superstructure, and the joint bridge tilt are the main manifestations of abutment damage.

Finally, continuous beam foundation earthquake damage is one of the phenomena of bridge damage caused by many earthquakes in our country. The reduction or failure of the bearing capacity of the foundation is the main factor in the failure of the bridge foundation. In general, the seismic failure of the enlarged foundation and gravity foundation is caused by the decrease in the bearing capacity of the foundation. For the damage of pile foundation, there are not only factors such as the decrease of foundation bearing capacity, but also the decrease of friction caused by sand liquefaction and the inertia of bridge superstructure.

Earthquake is one of the most serious disasters that cause casualties. In the 21st century, China's economy is developing rapidly and the population is gathering increasingly. Earthquake disasters often cause tragic damage. On January 15, 2021, the M6.2 earthquake struck Indonesia, causing strong tremors and triggering power outages and three landslides. More than 300 houses were damaged, many hotels and hospitals collapsed and many people were buried. The collapsed buildings caused a large number of casualties and blocked roads. On August 14 2021, the M7.2 earthquake struck Haiti. More than 900 aftershocks followed the main quake. Some towns were completely destroyed and the earthquake caused significant damage, with 53,815 houses destroyed and 83,770 damaged. The houses in rural areas were severely damaged. A total of 2248 people were killed, 12,763 injured and 329 missing. On November 28 2021, the M7.5 earthquake in Peru caused the collapse of about 2,592 buildings, the majority of mud and stone houses were damaged, and the earthquake caused power outages. In this earthquake, twelve people were killed and 136 injured.

## 6. Conclusion

The main contribution of this paper is to clarify the concept of three kinds of extreme weather, comprehensively describe their influence on bridge structure and material, and make a detailed explanation of the influence of secondary disasters. By studying the influence of rainstorms, typhoons and earthquakes on the bridge, this paper finds that not only the extreme weather impacts the bridge, but also the secondary disasters caused by it greatly damage the bridge.

Heavy rain erodes the bridge's structure and material and causes flood and debris flow to harm the bridge. Flood water would continue to impact the pier and cause damage to the understructure of the bridge. The impact force of debris flow could cause the displacement of bridge structure. Typhoon would cause wind erosion of the bridge deck, accelerate the corrosion of concrete and steel bars, and cause waves on the water surface, which would beat the bridge structure and cause the displacement of the bridge superstructure. The desert area would also damage sand, resulting in increased bridge load. For the earthquake, there is a very strong destructive force, in a short time, would destroy the weak structure of the bridge. However, the secondary disaster, including aftershocks, the impact on the city's traffic, the lifeline is also very huge. If these secondary disasters damage them, they would need a long time to recover. It is one of the factors that cause extreme weather to have a significant impact on humans.

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