Impacts of Extreme Environments on the Performance of the Bridges and the Countermeasures

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Abstract. Due to pollution and greenhouse gas emissions, global climate change has induced more and more extreme environmental conditions. This study introduces the effects of extreme temperatures, earthquakes, and storms, which a civil engineer cannot neglect, on the performance of bridges. Temperature change impacts the strength, deformation, and other properties of concrete, such as the cracks. Earthquakes could cause several cases of the beam falling due to the failure of the supporting connection and the substructure. The wind load could impact the dynamic stability of the bridge. Therefore, some countermeasures for designing, constructing, and maintaining bridges against these conditions are proposed. Set a temperature measuring tube and improve the quality of concrete could resist the extreme weather. The improvement of the bridge structure is necessary to resist earthquakes. Cantilever erection of steel truss beam, steel girder top falling beam closing, flexible arch laying erection, and flexible arch closure are effective measures to resist the storm.

Keywords: Extreme Temperatures; Earthquake; Storms; Bridges; Countermeasures.

1. Introduction

Bridge engineering is an essential part of infrastructure construction, with significant construction investment, usage for an extended period, durability and safety of the life property, the security of the vehicle traffic, and transactions in the bridge engineering design stage. Bridges would encounter extreme environmental conditions, like extreme temperatures, earthquakes, storms, and many other factors. To avoid and resist the above factors, structural design, materials selection, and the construction technology of the bridge are important elements. The designs need to meet the design requirements in the process of regular use, within reasonable use fixed number of years to meet the standard passage of vehicle traffic. Therefore, it needs to consider the security and durability of the bridge with an emphasis on design work, to complete a serviceable bridge construction. This study discusses the impacts of extreme environments on bridges and proposes countermeasures.

2. Impacts of extreme temperatures and countermeasures

Temperature change impacts the strength, deformation, and other properties of materials. Usually, the increase in temperature leads to a decrease in material strength, elastic modulus, and an increase in deformation. One of the most common building materials for bridges is concrete; thus, understanding how temperature can affect concrete is essential. Like other building materials, concrete is characteristic of thermal expansion and contraction. However, concrete engineering structures are usually subject to various constraints. Thus, when the temperature rises, the internal temperature compressive stress is produced because the temperature cannot expand freely. Furthermore, as the temperature goes down, temperature tensile stress could form due to the inability to shrink freely. Since concrete's strength is low, the temperature stress can easily lead to cracks.

2.1 Impacts of Extreme High Temperatures

Typically, the temperature on the surface of concrete can reach twice as high as the environmental temperature during high-temperature times. For example, if the temperature is 32, the surface temperature can be up to 60, leading to a temperature difference between the surface and interior of

the concrete, causing cracks. Under high temperatures, the concrete's performance varies mainly due to the water loss through evaporation, leading to a moisture difference between the surface and interior of the concrete, which is also a key reason for concrete cracks.

2.2 Impacts of Extreme Low Temperatures

Free water in the concrete poles is the main reason for concrete cracks in cold regions. When the water freeze, the volume could expand, destroying the concrete's internal structure. Especially if the saturated concrete is frozen, its capillary walls could be subject to both expansion and osmotic pressure, leading to cracks. After repeated freeze and thaw cycles, the tiny cracks could be connected, forming visible cracks. During these cycles, the strength of the concrete could diminish, causing internal damage to the concrete structure.

2.3 Countermeasures Of Extreme Temperatures

2.3.1. Set A Temperature Measuring tube

Some concrete cracks formed during or after construction due to temperature differences between the interior and surface of the concrete. Thus, in concrete construction, engineers should pay more attention to monitoring the temperature of the concrete, so engineers can take countermeasures as soon as possible to prevent cracks. Therefore, concrete components should be divided into the upper, middle, and lower layers based on the concrete pouring amount and area, and set temperature measurement pipes in these three layers, respectively. At the same time, the temperatures of these layers should be checked and recorded based on the construction requirement. Whenever the temperature difference between the surface and interior reaches 25 ℃, further countermeasures need to be taken immediately.

2.3.2. Improve The Quality Of Concrete

Concrete is one of the primary building materials in civil engineering, so its quality could directly affect the quality and safety of engineering structures. To improve concrete’s quality, some auxiliary materials can be added to increase the strength and compressive capacity to ensure the safety of construction. For example, cement usage can be reduced in the concrete raw materials collocation process, and some cement substitutes can be added to strengthen the integration of the raw materials. In terms of materials, it is advisable to use fly ash cement or low-heat cement with low content of C_3A and C_3S to minimize the amount of cement used and add a high-efficiency water-reducing agent with a slow setting. Also, the water-cement ratio needs to be significantly controlled. For instance, water-reducing agents can be added under necessary circumstances, reducing the gap between sand and stone to ensure the concrete's density and strength.

2.3.3. Maintenance After Construction

Similar to other works, maintenance of concrete construction can also extend the usage life. Later maintenance is the most effective way of preventing concrete cracks due to extreme temperatures. The reason for concrete cracks is the temperature difference, so the maintenance work should minimize this temperature gap. During construction, thermal insulation materials can be added to the structure. Also, engineers can place contraction joints in the concrete surface at predetermined locations to create weakened planes where the concrete can crack in a straight line.

In sum, the problems of temperature cracks affecting concrete construction have been an essential issue for decades. Higher-quality raw materials can prolong the service life, and reasonable adaptation parameters can be used as the reference. Scientific and rational process detection technology is also essential to ensure that each procedure is often carried out to protect the construction specifications fully.

3. Impacts of earthquake and countermeasures

An earthquake is a random process, and its occurrence time, place, and size are uncertain. When an earthquake occurs, the ground motion could affect the performance of a bridge. As civil engineers, it is essential to understand earthquakes and analyze further protection of the bridge against an earthquake.

3.1 Seismic Intensity Of Bridges

Seismic intensity is the degree of an earthquake in a specific area. It is related to the amount of energy the earthquake produced and the depth and distance from the engineering structures. The further the earthquake source away from the bridge, the less seismic intensity it could be. Typically, the maximum seismic intensity a bridge can withstand is called the essential seismic intensity, also known as the earthquake intensity.

3.2 Target Of Resisting Earthquakes

To find out the essential seismic intensity of a bridge, two stages need to be taken. The first stage is the ultimate bearing capacity calculation, and the second is checking the serviceability limit. Generally speaking, resisting earthquakes is to make sure small earthquakes cannot harm the bridges, the bridges can repair after moderate earthquakes, and bridges cannot fail after serious ones. Due to frequent small and medium earthquakes, the bridges' elastic range must withstand that damage.

3.3 Types Of Damages From Earthquakes

3.3.1. Upper Structure

Though it is not common to destroy the upper layout by an earthquake, several cases of the beam falling due to the failure of the supporting connection and the substructure in the early destructive earthquakes. The upper structure may fall in the direction of the bridge or torsion slip. According to the static research, most falling beams were in the direction of the beam. At the same time, when the beam falls in the order of the bridge, the beam end hits the side wall of the pier, which significantly damages the substructure.

3.3.2. Support Connection

The supporting connections such as beam supports and expansion joints have always been considered a weak link in the seismic performance of the bridge structure system. In previous destructive earthquakes, the seismic damage phenomenon of the supporting connections is more common.

3.3.3. Pier

Severe damage appears to include the collapse of the pier fault and extreme tilt. For the reinforced concrete abutment and pier, the damage phenomenon also consists of the small pier cracking of the protective layer of concrete peeling and longitudinal steel yield.

3.3.4. Pile Foundation

Sometimes subsidence slips would occur due to adverse geological conditions. Pile foundation of the pile caps is due to the enormous volume strength and stiffness, so rarely happen damage. Still, the phenomenon of pile foundation damage occurs frequently, especially for deep pile foundations is limited to the understanding of the early levels, the destruction of the pile foundation may appear in any position of the pile, and often or underground water, unfavorable to rapidly detect after the quake, repair difficulty is considerable.

3.4 Countermeasures Of Earthquakes

For a specific bridge vibration system, a detailed seismic acceleration time history is input, and the reaction time history of each mass point on the bridge can be calculated by the numerical

integration method. It is called the time-history analysis method, but it has practical significance to the seismic design of the structure. The maximum value of the structural response is mainly determined by the structure's natural vibration period and damping coefficient under site conditions.

The bridge structure should be simple; the pier should not be designed into the structure with holes; try to avoid mutation to reduce the ability's stress concentration.

Use the symmetrical structure to avoid the earthquake structure produced torque; It has been proved that the seismic performance of the gravity abutment is better in an earthquake, while the connection between the ear wall and the abutment body of the ear wall abutment is the easiest to destroy.

Bridge span structure and pier should be used lightweight gravity low stiffness structure; In the design, the structural stiffness can also be reduced to make the system have more extraordinary deformation performance, to reduce the seismic force and its influence.

The connection between various parts should be strengthened to improve the structure's integrity.

For the lower structure, a pile foundation is better than an open excavation foundation, a caisson foundation is better than an open excavation foundation, and a deep foundation is better than a shallow foundation.

The head subgrade and pier foundation pit backfilling should be layered and tamped.

4. Impacts of storm and countermeasures

4.1 Influence Of Wind Static Force On A Bridge Structure

When the stiffness of the structure is significant, and there is almost no vibration or the structure has slight vibration but does not significantly affect the flow shape around the bridge, and therefore does not affect the force of the airflow on the bridge, the action of the wind on the bridge can be approximated as a kind of static load. It may lead to problems with strength, stiffness, and stability. As stipulated in the current bridge regulations, the stress and deformation of the bridge under lateral wind load are mainly considered. In addition, the effect of vertical lift on the structure should also be considered when the lift force is large. For larger flexible large span Bridges, the girder should be under lateral wind load of the whole lateral buckling. The mechanism is similar to the bridge lateral buckling of the whole, and the static torque under the action of the main girder turn caused additional corner pneumatic torque generated by the incremental over structure resisting moment of torsion instability.

4.2 Influence Of Wind Dynamic Force On A Bridge Structure

For long-span bridges, especially long-span suspension and cable-stayed bridges, which are sensitive to wind, it is necessary to consider not only the use of static wind load but also the dynamic force of the wind on the structure. The dynamic stability of bridges is essential. Flutter and chattering are two of bridges' most critical dynamic stability problems.

4.2.1. Flutter

Flutter is a kind of divergent vibration of bridge structure under the coupling cooperation of aerodynamic, elastic, and inertial forces. It is a kind of divergent vibration that could lead to structural damage when the vibration amplitude of the structure increases rapidly under a certain critical wind speed. Divergent vibration is a kind of aerodynamic force imbalance phenomenon. It is mainly because the movement of the structure (vibration) affects the flow around the bridge when the airflow, and thus affects the aerodynamic force, resulting in a so-called self-excited force. The system under the action of self-excited force amplitude gets more significant at the end of the induced force instability because this kind of vibration could lead to the whole body of the structure being broken, as the wind resistance design to find the critical wind speed of the main beam and leave a certain safety margin.

Flutter can be divided into two types. One is torsional flutter. This kind of divergent vibration damages the Tacoma suspension bridge in the United States because its main beam is a blunt body with poor flow linearity. The second is the bending-torsion coupling flutter, which is often seen in the case of a flat cross-sectional beam with a good flow line, and its generation mechanism is similar to the classical flutter of an airfoil.

The flutter of the bridge is closely related to the aerodynamic profile of the main beam section. The better the flow linearity of the main beam section, the better the aerodynamic stability. Therefore, in the preliminary design stage of long-span bridges, it is necessary to compare and select the main beam section or optimize the base section through a wind tunnel test to ensure the structure's safety against the wind.

4.2.2. Chattering

Chattering is mainly caused by turbulent elements in the atmosphere (namely, pulsating wind), a random forced vibration. Although it is a kind of limited amplitude vibration, due to the low wind speed and high frequency of chattering, it could lead to local fatigue of the structure and affect the safety of pedestrians and vehicles. Therefore, chattering phase analysis should be carried out in the wind resistance design of bridge beams. Recently, a new method of chattering response analysis has been proposed with a deep understanding of the chattering mechanism. In addition, the self-excited force of arbitrary motion is considered in the chattering phase analysis in the frequency domain. Furthermore, the nonlinear chattering response analysis method of bridge structure under large deformation can improve the credibility of chattering response analysis.

The chattering phase could also increase; with the increase of wind speed, the chattering phase (amplitude and internal structural force) increases exponentially. Therefore, for all kinds of bridges with high wind speed or large spans, especially cable-stayed Bridges and suspension bridges with large spans, chattering calculation must be carried out accordingly to wind resistance design.

4.3 Countermeasures Of Storms

4.3.1. Cantilever Erection Of Steel Truss Beam

Temporary piers with side spans are built between ports, 300T crawler cranes are used to install the first three internodes, and 75T bridge deck cranes are installed above the three internodes by crawler cranes. After the assembly and acceptance of the bridge deck cranes, the cantilever assembly is carried out in the middle of the span to the closing position. To meet the anti-overturn stability coefficient $K > 1.3$ in the steel beam cantilever erection process, the steel beam at the side end of the side span is anchored to the pier top. The steel beam is pre-raised to ensure that the cantilever erection of the steel beam is smooth at the upper pier and temporary pier.

4.3.2. Steel Girder Top Falling Beam Closing

In the construction of steel girder closing, the transverse deviation of the closing mouth is eliminated first. The vertical deviation and angle are eliminated, and finally, the longitudinal variation is eliminated. The vertical and horizontal divergence of the closure is adjusted by the pier top's vertical and horizontal deviation correction device. The side pier falling beam method changes the vertical deviation and turning angle of the closure. That is, large tonnage jacks are installed on the main port and temporary pier to adjust the height and angle of the steel truss girder by lifting and dropping beams (temporary pier raising and side pier lowering beams), and the steel truss girder closing is carried out with the vertical and horizontal movement adjustment system.

4.3.3. Flexible Arch Laying Erection

The arch rib bracket is made of steel tube by lattice column structure, and the support column foot is provided with a cushioned seat. The steel beam chord for welding connection and the ear seat are arranged in the bottom plate of the arch rib segment, and the top of the arch rib bracket is connected. In the construction, the bracket system is hoisted with segmented stringers according to the height,

and the flange structure is used for connection at high altitudes. The flange connects the system with the bracket supervisor.

4.3.4. Flexible Arch Closure

The single-span flexible arch is closed twice. In the first closing construction, the overall elevation control of the lifting section is adjusted linearly, and the adjusting device is set at the closing mouth to fine-tune the position of the closing mouth. The second closing construction, through the bottom bracket on the bottom of the lifting section, by setting the support frame to adjust the vertical Angle and displacement of the arch rib, adjust in place for longitudinal locking, and then through the web on the push device to adjust the gap along the bridge, adjust in place after locking and closing weld welding, complete the closing.

After adjusting the relative elevation of the arch ribs assembled and lifted, the closing section is quickly installed. The closing matching parts are used for a quick temporary connection between the two sides of the arch ribs. Then the box structure of the arch ribs is welded to ensure that the box arch ribs can be closed smoothly and quickly, and the safety of vertical lifting of the arch ribs is ensured [9-10].

5. Conclusion and suggestions

This study discusses the effects of extreme temperatures, earthquakes, and storms on the performance of bridges.

Temperature change impacts the strength, deformation, and other properties of materials. As the temperature goes down, temperature tensile stress could form due to the inability to shrink freely. Since concrete's strength is low, the temperature stress can easily lead to cracks. Earthquake could cause several cases of the beam falling due to the failure of the supporting connection and the substructure in the early destructive earthquakes. As for storm, it is necessary to consider not only the use of static wind load but also the dynamic force of the wind on the structure. The dynamic stability of bridges is essential. Flutter and chattering are two of bridges' most critical dynamic stability problems.

Bridge engineering is an essential part of the infrastructure, related to economic development and people's life and property safety, so there are very formal requirements on safety and durability. Bridge designers should start with the scheme design, select reasonable design proposals according to the site environment and the owner's needs, and then control every part of the design process through careful calculation, analysis, research, and discussion to ensure the accuracy and completeness of the design drawings. The construction personnel should strictly follow the design to ensure that the geological prospecting corresponds to the site and the construction corresponds to the plan to ensure the construction quality. Supervisors should be residents at the site, carefully record every construction site section, strictly stop the construction not according to the requirements and report to the upper part of the door. In this case, the bridges can keep people away from some extreme environmental conditions. The bridge project is massive, with high investment and a long construction period. All parties involved should strictly comply with the requirements and make joint efforts to ensure the quality of the project and ensure the safety and durability of the bridge project.

References

[1] Yongqiang Zhang, Xing Qin. Consideration on safety and durability of bridge engineering. Building materials and decoration, 2018, no. 6, pp. 257-258.

[2] G. Wang, M. He, C. Zhou, Temperature and Temperature Stress Analysis in Mass Concrete under Cold Environments ofStrong Wind and Large Diurnal Temperature Range. Geofluids, 2022, pp. 1–16.

[3] Renbing Li. Brief introduction of construction temperature and crack prevention of highway and bridge concrete. Auto Weekly, 2012, No.5.

[4] Zhangping Fang. Causes and prevention measures of concrete cracks in civil construction. 2022, Vol.48, No.3.

[5] G. Kilic, Condition assessment of different historic bridges using Non-Destructive Techniques (NDT) with FTIR analysis in Izmir after the Samos Island earthquake. HERITAGE SCIENCE, 2022, vol. 10, no. 1. https://doi.org/10.1186/s40494-022-00746-x.

[6] Cuiru Li. Analysis of seismic effect on Bridges and Seismic Measures of Bridges. East China Highway, 2013, no. 3, pp. 34-35 Copy.

[7] A. Fenerci, O. Øiseth, Strong wind characteristics and dynamic response of a long-span suspension bridge during a storm. Journal of Wind Engineering & Industrial Aerodynamics, 2018, vol. 172, pp. 116–138. https://doi.org/10.1016/j.jweia.2017.10.030.

[8] Yanli Ren. Influence of Wind on Bridges and Further Research Measures. Management and Technology of Small and Medium Enterprises, 2011, no. 10, pp. 221-222.

[9] Shiyu Cheng. Construction Technology of Large-span Steel Truss Beam Flexible Arch Bridge in strong wind Area. China High and New Science and Technology, 2020, no. 9, pp. 93-94.

[10] S. Liu, Z. Yin, Study on temperature control and crack resistance of mass concrete anchorage in suspension bridge. Vibroengineering Procedia, 2021, pp. 38.