Stabilization and stiffening of unique longspan bridge transport constructions

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Abstract. The article deals with the unique systems of longspans, gives examples of such constructions in Russia and abroad, as well as the main periods of their development history. Particular attention is paid to accidents and disasters that took place at various times. Based on the analysis of suspended and cable-stayed systems’ destruction, the main causes of damage are investigated and systematized, which is a very important element in ensuring the security of unique longspan systems. Recommendations are made on improving the stabilization and stiffness of bridge constructions.

Introduction
Suspension bridges include constructions in which the load-bearing elements work for tension. This allows applying high-strength materials with their mechanical properties, and a relatively small weight makes it possible to block structures with long spans. Suspension constructions are easy to install, have high operational reliability, you can achieve architectural expressiveness, interesting shaping with their use.

The disadvantages of such construction include a large deformability and the presence of thrust. The thrust is usually transmitted to anchor foundations or contour constructions. Deformability can be reduced by stabilization elements, stiffening beams, rope stay, braces, additional belts, and, if necessary, pre-stress can be created in structural elements.

Cable-stayed structures are stable systems with rectilinear elements, which are called guy cables. Such structures are widely used in the construction of bridges, which are respectively divided into cable-stayed and suspension.

Suspended bridges have a suspended roadway, and the main supporting structure consists of elements that work under tension.

The cable-stayed include such suspension bridges in which the roadway is suspended on a system of straight rope-forts and is a stable system.

There are three periods in the development of long-span suspended constructions: the first — XVIII century — is represented by small bridges with chain suspension; the second - XIX century - was marked by active development of modern materials from steel and cast iron, which caused a significant boost to the development of bridges; the third period - the XX - the beginning of the XXI century - is characterized by the rapid development of transport facilities based on the latest achievements in science and technology.
The most important direction of technological progress is the widespread application of high-strength steels in construction, their mechanical characteristics are much higher than conventional steels, and the cost difference is small.

However, the efficiency of using high-strength steels for compressed elements decreases from lateral bending thus is significant. Therefore, structures with the application of high-strength steels are preferable to use for tensile elements.

Features of the using such materials in suspended and cable-stayed structures include significant deformation from the movable loads’ action. The momentless nature of work for various combinations of loads has a significant impact on the rationality of the cable structure. Fully momentless construction’s work can be obtained only for certain cable-stayed systems under certain types of loading.

**Materials and methods**

There are examples of bridges, which were built abroad, and in Russia at various times that deserve in-depth study:

1. 1931 y., Hudson River, USA. The span of 1067 m. The bridge, which is the first in history that has surpassed the kilometer span.
2. 1937 y., the Golden Gate Bridge USA, San Francisco, the Main span of 1280 m.
3. 1965 y., USA, New York Bridge Verrazano-Nerrose. The main span of 1298 m. remains a record in America.
4. 1981 y., United Kingdom. Bridge over the Humber Strait. The span of 1410 m.
5. 2012 y., Vladivostok, Russia. The “Russian” bridge is the largest span for cable-stayed bridges - 1104 m.
6. 2012 y., Vladivostok, Russia. Bridge ”Golden” with a length of 1400 m. With a span of 737m.

In the construction of cable-stayed and suspension bridges, a great experience has been gained in ensuring the safety of transport facilities, instructive disasters with in-depth analysis of their causes and measures to enhance operational reliability.

There are a few publications devoted to the accident rate of long-span structures in Russia. The works of the following authors Ponomarev V.P., Travusha V.I., Bondarenko V.M., Eremina K.I., Telichenko V.I. [1, 2] attract the most interest, they are distinguished by a systematic approach to the integrated safety and the prevention of emergency situations.

The studies performed by Moistrenko I.U., Ovchinnikov I.G., Kokodayev A.V., Ovchinnikov I.I. contain a deep analysis of the causes of bridge structures ‘accidents’ [3].

The author Dmitriev F.D. was the first who attempted to study the accidents of engineering structures with the analysis of the crashes ‘causes. All bridge accidents provide a unique opportunity to identify the ultimate strength as well as the sustainability limit [4]. The author divides all causes of destruction into three types:

The first is the insuperable forces of nature (hurricanes, floods, earthquakes).

The second is the inaccuracy of engineering solutions.

Third - the impact of socio-economic conditions, the pursuit of profit.

This study examined the analysis of the of 22 bridges’ collapse with examination of their causes.

The analysis of the destruction of bridge constructions abroad is given in the works of Passek V.V. [5].

The authors of the in-depth review [6] addressed issues related to the prevention of emergencies of bridges arising from the ship dash.

Platonov A.S. [7] compares the causes of bridge crashes and classifies them into groups of greatest influence. 60% of them are natural impacts, 30% are design errors and poor-quality construction work, and 10% are overloads and violations of the rules for operating bridges.

Among foreign authors, it is necessary to mention Professor Joachim Scheer: “Destruction of bridges: nature, examples, causes and effects” [8].
In domestic and foreign literature, there is extremely valuable material with an overview of serious accidents of bridges. Each bridge engineer should carefully study the selected examples, which are the bearers of the richest experience in the construction of longspan bridge constructions.

The classic examples of bridge failure include:

The first example: the collapse of the Tacoma-Nerrows bridge in November 1940, which occurred because of aerodynamic fluctuations.

The second example: the bridge over the River Tay, on the east coast of Scotland. In this case, errors in the design and construction led to the collapse.

The third example: the destruction of a bridge in the province of Quebec in Canada in 1907 and 1916. The main reason is the loss of stability of rods working in compression with weak lattice bonds. The destruction of the bridge in 1916 was due to the supporting of the transverse beam on cylindrical supports. Sliding was one of the reasons for the bridge collapse.

The study of classical examples of suspended and cable-stayed bridges catastrophes leads to the following generalizations and conclusions.

As a rule, the destruction of bridges can occur for several reasons. Errors at the design stage, violations during construction works, violations of the rules of operation and others.

One of the main reasons for the bridges collapse is a wrong constructive solution. This reason became the main cause of the destruction of the bridge over the Firth of Tay in Scotland in 1879.

Bridges accidents can occur due to insufficient consideration of wind load. An example would be the destruction of the Tacoma-Nerrose bridge in the United States. During the construction of this bridge, solid beams were used, on which the roadway was laid. It was enough to replace them with ordinary ones - through and the wind would not create such a tension, passing through the beams.

The destruction of the bridge may occur due to resonance phenomena. For example, if the natural oscillations of the bridge coincide with the rotation of the wagon wheels at a certain speed.

An emergency may arise from exceeding the permissible load. A famous example of such a phenomenon is the Ohio River Bridge, USA. On the pre-holiday days, the traffic flow exceeded the allowable values, which led to congestion and bridge collapse.

Natural disasters are considered the most common cause of bridge collapse. These include floods with a sudden rise in water levels, earthquakes, landslides, tornadoes. Therefore, the tornado caused the catastrophe in 2003 of the River Bridge, Kinza in the USA. When the elements struck, 11 supports of 20 were immediately knocked over.

The crash of Tacoma Bridge in the USA gave impetus to the development of the theory of cable-stayed and suspension bridges and drew attention to the aerodynamic stability of bridges - one of the directions of the dynamics of structures.

It should be noted that in case of catastrophes of metal bridges, the stability of individual elements of the structure occurs most often.

For reinforced concrete bridges, which constitute the bulk of bridges in the world, the variability in time of the mechanical properties of materials, the scatter of material characteristics and the geometry of the dimensions of structural elements are very important.

Summary

Based on the analysis of the stabilization and stiffening of longspan and cable-stayed systems, we can draw the following conclusions.

To reduce the number of accidents of suspended and cable-stayed bridges, their systematization is first necessary, as well as the study of the causes. This information should be the property of experts who are engaged in design, construction work and operation of bridge structures.

Particular attention should be paid to the mathematical models’ formation of probable critical situations of longspan structures of various structures. A deeper study of the stresses and strains of structures and buildings on the various possible effects on them is needed.
The improvement of the operational reliability of transport facilities requires a thorough study of such techniques as:
• monitoring and diagnostics of transport facilities;
• safety assessment of bridge construction;
• restoration and increase of operational reliability of objects.

Of course, it is necessary to conduct research and scientific and methodological developments to prevent emergencies of unique transport facilities, their design, construction and operation.

Suspended and cable-stayed bridges are characterized by amazing beauty and elegance. However, the world history of the collapse of bridge structures requires a combination of not only beauty, but also reliability, therefore, it is necessary to choose the most rational option that satisfies all requirements.

An obligatory component of any project of a unique structure should be the accumulation and preliminary study of foreign and domestic experience in the construction of similar structures.

References
[1] Pononarev V P, Travush V I, Bondarenko V M, Eremin K I 2012 On the Need for Systematic Approach to Research in the Field of Integrated Safety and the Prevention of Accidents of Buildings and Structures (Prevention of buildings and constructions’ accidents).
[2] Telichenko V I, Eremina K I 2011 The Safety of Operated Buildings and Constructions (Moscow).
[3] Maystrenko I U, Ovchinnikov I I, Ovchinnikov I G, Kokodeev A V 2017 Accidents and Bridge Construction’s Collision, the Analysis of their Causes (Transport construction).
[4] Dmitryev F D 1953 Collapse of the Engineering Structures. Historical Technical Essays (State publishing house of literature on construction and architecture, Moscow).
[5] Pasek V V 1970 Bridge Construction’s Collapse Abroad (Moscow).
[6] Perevozchikov B F, Seliverstov V A 2000 Bridge Support Protection from the Ship Dash.
[7] Platonov A S 2009 Lessons from Metal Bridge Accidents (Transport construction) pp.6-9.
[8] Joachim S 2010 Failed Bridges: Case Studies, Causes and Consequences (Berlin) p. 321.