HISTORICAL RAILWAY BRIDGES OF RUSSIA AS OBJECTS OF ARCHITECTURAL HERITAGE

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Abstract. Historical stages in the development of world bridge construction are considered. The problem is noted in the preservation of historical railway bridges in Russia. These bridges are objects of architectural heritage and elements of the state transport system so the growth of cargo turnover, increasing loads on structures, increasing requirements for transport safety is observed. Historical and logical research methods are used in the paper. They include the justification of truth and analysis in the evolutionary development of bridge construction. The analysis of evolutionary changes in regulatory requirements for the construction of bridges in Russia is carried out in the paper. The reasons of defects formation of supports of the operated railway bridges are opened. The target state program should be created. The methodology should be developed to protect historic railway bridges.

Key words: railway historical bridges, objects of architectural heritage, defects, bridge construction materials, architecture.

1. Introduction

Humanity does not think about what surrounds us and thinks that this environment will be eternal and does not consider it important – because it exists and works and therefore there is no problem. The time goes by. Part of the information is filtered out, goes away. Then there comes a time when something of this environment remains in a single copy: one house of the XIX century or one bridge of the XIX century. The moment comes suddenly and we have no information about the layer of culture. Then we need to ask the question: what has each of us done to preserve the historically valuable objects of each country, each culture.

The nineteenth century gave the world Railways and with them railway bridges.

Transport plays an important role in the economy of the state and is an integral part of it. The development and normal functioning of industry, agriculture, supply and trade depends on transport. The importance of transport is great in foreign economic relations, in defence of country, in development of new economic territories. It satisfies one of the human needs - the need for displacement, "ensuring the function of the state, whose activities are aimed at creating conditions that ensure a decent life and free development of man" (Kraskovsky and Uzdin, 1994).

The totality of means and ways of communication are activities provided by various technical devices and structures for the safe passage of people and goods through various obstacles-watercourses, roads, mountain ranges, etc. artificial structures include bridges, tunnels, pipes, retaining walls, regulatory structures, duckers, galleries, etc. Bridges remain relevant in ensuring the passage of rolling stock today.

The purpose of the paper is to draw attention to the problem of preservation of historical railway bridges as an element of the transport system of the state against the background of the growth of cargo turnover, increasing loads, increasing requirements for transport safety. The following tasks are distinguished from the formulated goal:

- attention should be paid to the possibility of loss of information about unique objects-historical railway bridges;
- existing problems need to be identified in maintaining this unique monument of architecture;
- methods, technologies and ways to preserve bridges need to be defined.
- Research of methods of scientific knowledge of this topic is based on the objectivity and progressiveness of historical processes.

The authors used historical and logical research methods including the justification of truth, analysis in the process of evolutionary development of bridge construction.

2. Historical aspects of world bridge construction

The art of building bridges was known in ancient times. Bridges represent one of the most ancient human inventions of engineering art. They appeared at the dawn of human development and in the initial period had a very primitive appearance.

The history of bridges can be divided into two periods - the first one, in which there was no movement of inorganic forces (automobile, steam) and the second one - the following time of technology which continues to present time.

The first period is prehistoric times lasting about 6,000 years. The second period does not reach 200 years but man conquered the power of steam in this period:

- George Stephenson invented the first train in 1825 between Stockton and Darlington.
- Karl Benz invented the first automobile in the world and received a patent for the invention of the automobile on January 29, 1886.

In the first period bridges were built entirely of wood and stone.

Wooden bridges. The first wooden bridges consisted of logs thrown over riverbeds that were sometimes covered with brushwood or earth. Next, the logs were hewn on one or two arrises in order to increase the plane touch the deck with the beams and to facilitate the connection of the individual parts among themselves.

Fabulous Semiramis (1100-1200 BC) built bridges, too. The bridge over the Euphrates river in Babylon is the most significant. It connects both halves of the city. The Greek historian Diodorus described this bridge, which consisted of hewn cedar and cypress beams and had a deck of palm beams. The length of the bridge exceeded 1,000 feet, the width was 20 feet and the distance between the supports was 12 feet. Movement occurred only during the day, the flooring was sorted out in two or three bays at night. Homer mentions bridges in his songs. This means that bridges in Greece and Asia Minor were not uncommon (around 820 BC).

The design of wooden bridges was significantly improved in the XVI century by the famous Italian engineer Andrea di Palladio (1508-1580). He worked as an apprentice at the famous sculptors in Vicenza - Giovani di Giacoma from Perlica and Girolami Pittoni from Lumignano. Andrea di Palladio was admitted to the Guild of masons. The types of structures he developed bear a great resemblance to the present parallel straight and arch trusses, the belts of which are joined together by vertical beams and diagonals in such a way that the verticals stretch out and the diagonals contract. The construction of Palladio trusses belongs to inverted triangular trusses and suspension systems. Such structures are similar in principle to the current Gerber or Cantilever beams (Dai *et al.*, 2017; Aïtcin *et al.*, 2016; Natário *et al.*, 2015; Calvi *et al.*, 2019; Siekierski, 2019).

Mingerou made research in France on the resistance of curved logs at the end of the eighteenth century. He built a bridge with a hole of 19.5 m for the experiment near Bordeaux. The canvas of the bridge was suspended from arches made of curved logs. The arch had 3 rows of bars in the vertical direction, two rows of bars in the horizontal direction.

Stone bridges. The art of building stone bridges was developed in Greece and Egypt in ancient times. The design of the arch covers was unknown. The openings were covered with stone beams so the bays of these bridges were small.

Ancient information about bridges with arches was preserved in China. Such bridges were built by Chin-Nong, fu-Hee's heir.

The Romans attached great state importance to roads and bridges. They built bridges in Rome and the provinces. The Romans did not know how to device bases in the water by excavating the upper weak soil. They built piers of bridge on huge stone slabs located directly at the bottom of the river.

Stone bridges with large openings and light construction were built in France. Bridge "Espalon" across the river Lot is the oldest one.

Metal bridges. England is the country where the cast iron bridge was built for the first time in 1779 thanks to the famous inventor Abraham Derby Sr.

The XIX century was a period of rapid development of scientific and technological progress, new economies, industries and technologies. This period is characterized by the growth of light industry, metallurgy, coal industry in Europe, especially in England, France. The question was ripe in increasing the volume of transportation for the delivery of raw materials to enterprises and shipment of finished products to consumers. Traditional horse-drawn transport could not cope with the task of time.

The first large beam metal railway bridge "Britannia" was built by Robert Stephenson in 1850. It consisted of two continuous beams spans of bays of 140.0 and 170.0 m.

The process of formation of the modern system of metal bridges was completed by the beginning of the XX century. Transition was defined to simple schemes in laced decks, welding iron was replaced by cast, bolted connections gave way to rivet and then to high-strength connections.

The use of span steel and reinforced concrete structures begins in the 40s of the XX century. They are the most common today (Colajanni *et al.*, 2016; Lantsoght *et al.*, 2017; Tong *et al.*, 2016; Diachenko *et al.*, 2018). Bridges are divided into beam and arch on the system of the supporting structure (Appleton, 2019; Mosleh and Varum, 2015).

"No rules for the calculation of bridges in the early period of bridges construction existed in all states without exception. The choice of norm depended on draftsman of project" (Gerstner, 1836*)*. Carpenters, masons, architects, builders, monks were engaged in the construction of bridges until 1716. They didn't have the right training.

France is the first country where for the first time constructors came to the belief that bridges and roads require specially trained engineers and their construction should not be provided to persons who do not have experience in the construction of engineering structures. The decree establishing the "Corpus of bridges and roads" was issued on 1 March 1716 to improve the ways of transport communication in France. The Paris school of bridges and roads was established under the Corpus. Jean Rodolphe Perone is the organizer and first principal of the school.

Admiral Mariano de Urquico created the Spanish Corpus of roads and canals in 1799. Augustine Betancourt created and directed the "Madrid school of roads, canals and bridges" in 1802. The first graduation of engineers took place in 1804 (Bogdanov and Arachno, 2009*)*.

XIX gave railways to the world and with them artificial structures designed to pass rolling stock through various obstacles. The development of metallurgy has given new metal structural elements, types and approaches of their connection that are most clearly manifested in the designs of bridges.

Railways with constant exploitation were opened: England – 1825, Germany – 1828, United States – 1830, Belgium – 1833, Russia-1837, Czech Republic – 1837, Poland – 1842, Spain – 1848, Sweden – 1862, Finland – 1862 (Sotnikov, 1994).

Professor of the University of Vienna Franz Anton von Gerstner and Russian civil servants contributed to the emergence of the first railway in Russia. They saw the prospect of the development of the Russian state in the development of railways (Zolotnitsky, 1882).

The first railway was laid between St. Petersburg and Tsarskoye Selo, the section was extended to Pavlovsk station later. The railway was named "Tsarskoye Selo". The railway wooden bridges in quantity of 42 were built on its site. Tsarskoye Selo railway bridge is the largest. It was built through Obvodnyj channel with length of

24 meters. The construction of the Tsarskoye Selo railway was the impetus for the development of a new type of transport in Russia.

The Russian school of bridge construction was finally formed in 1883 when the Department "Bridges" appeared in the Institute of the Corpus of railway engineers (now Emperor Alexander I Petersburg State Transport University). Professor Leopold Nicolai became the first leader (Bogdanov, 2016).

Railway bridge construction in Russia emerged as an integral part of the domestic bridge-building school (Smirnov *et al.*, 2017; Indeykin *et al.*, 2017). The Russian bridge-building school differs in rationalism in a choice and an estimation of designs, refusal of far-fetched decisions in the name of external showiness, aspiration to fuller account of conditions of work of structures.

A wealth of experience in the construction of bridges on ordinary roads was accumulated by the beginning of the construction of the first bridges on the railways of the country. Proven types of structures were available in practice but railway bridges differ in many ways from bridges for an ordinary road. Railway bridges do not require a continuous roadway as well as their width is smaller. They carry a significantly greater load, which affects their design. The problem of design and construction of the first bridges under train load appeared due to increased requirements for railway bridges. Scientific methods of calculation were absent and properties of building materials were insufficiently studied.

The development of bridge construction in Russia took place thanks to the graduates of the current Emperor Alexander I Petersburg State Transport University namely Dmitry Ivanovich Zhuravsky (St. Petersburg Institute of the Corpus of railway engineers – 1842), Nikolai Apollonovich Bellyubsky (St. Petersburg Institute of railway engineers-1867) and many others.

Zhuravsky D. I. improved the system of the American scientist William Gau and proposed to make truss elements of different thickness depending on their location. The largest railway bridges were designed and built on the route of the Nikolaev railway under the leadership of Zhuravsky (Sobor and Belyj, 2018).

The historical period of bridge construction development is characterized by a long and progressive period of development from the simplest engineering structures to complex ones. Engineering structures acquired strength, utility and beauty with the growth of scientific knowledge.

3. The reasons for the formation defects of bridge pillars on operated railway bridges

The modern Oktyabrskaya railway stretches from North to South from Murmansk to Moscow (over 2000 km). More than 900 km is located above the Arctic circle. The railway has 75% of freight and 40% of passenger traffic in the transport system of the North-Western region of Russia. Over 10500 artificial structures including 2800 bridges and 6500 bridge pillars are located on the network of the Oktyabrskaya railway at the present time. Data on railway bridges are presented by year of construction in Table 1.

The condition of 650 bridge pillars has been reviewed. Supports had different terms of construction, operational conditions, climatic zones, material of production (Table 2).

Table 1. Structure of railway bridges of Oktyabrskaya railway by years of construction.

Year of construction	Quantity, pieces	Quantity, %
до 1917	1226	43.75
1918-1941	346	12.35
1942-1945	27	0.97
1946-1981	918	32.76
1982-2017	285	10.17

Table 2. Distribution of pillars of railway bridges of the Oktyabrskaya railway depending on a material of production.

Material	Quantity
concrete	847
reinforced concrete	1252
quarry stone	2866
stone	1300
wood	162
metal	5

Table 3. Types of defects in the pillars of Oktyabrskaya railway bridges.

Type of defects	Quantity of pillars
Vertical cracks	70
Horizontal cracks	23
Shrinkage cracks	210
Leaching	1121
Destruction of stone cladding	210
Peeling of the protective layer with bare reinforcement	234
Cracks in the seams of lining	397

Bridge pillars are exposed to various factors during operation. These are operating conditions, atmospheric and climatic influence, quality of maintenance of artificial structures, etc. (Kharitonov *et al.*, 2016; Ryabova *et al.*, 2017; Kazanskaya and Smirnova, 2018; Smirnova 2018a, 2018b). Structural damage occurs due to these factors (Heravi *et al.*, 2018; Smirnova 2018c, 2018d; Shaybadullina *et al.*, 2018). Cracks, leaching, peeling of the protective layer are the most characteristic defects in the considered concrete, reinforced concrete, stone and quarry stone pillars (Table 3).

Failures of bridge structures can lead to an accident - an unexpected failure of the structure due to its partial or complete destruction (Krejza *et al.*, 2016).

Ensuring reliability and safety guarantees trouble-free bridges (Kazanskaya and Belentsov, 2019). This is the main task in the construction and operation of engineering structures (Belentsov and Smirnova, 2018; Smirnova *et al.*, 2019; Kharitonov *et al.*, 2015; Kharitonov *et al.*, 2017). Bridge accidents cause significant economic and environmental damage and can result in loss of life.

The optimal decision should be made in a timely manner for planning, organization, inspection of bridge structures, repair work (Steenbeerg *et al*, 2015). This will allow having complete and objective information about the technical condition.

The analysis shows that the defects of the pillars of the operated bridges of Oktyabrskaya railway are formed due to the following factors:

- service life;
- natural and climatic conditions;
- intensity of the movement of rolling stock;
- weight characteristics of rolling stock;
- quality of construction and installation works;
- insufficient maintenance of pillars.
- water pollution and changes of pH level.

Pillars of previous years and reinforced concrete pillars of the period 70-80-ies are most susceptible to damage.

The scientifically grounded technique is necessary for an assessment, forecasting of a technical condition and a complex of actions for safe operation of artificial constructions on railway transport. This will determine the causes of defects, durability and maintainability of bridge pillars.

4. The need to preserve the architecture of historical railway bridges in Russia

Two railway bridges built in the XIX - early XX centuries remain today on the former Tsarskoye Selo railway (now the section of the St. Petersburg-Vitebsk railway from Vitebsk station to Pavlovsk station).

The first one is the Tsarskoye Selo railway bridge. It is mixed bridge across the Obvodnyj canal (Fig. 1). The last reconstruction was carried out in 1900-1904.

The Tsarskoye Selo railway bridge was included in the list of identified objects of cultural heritage in May 2018 by the order of the Committee for state control, use and protection of historical and cultural monuments of the Government of St. Petersburg.

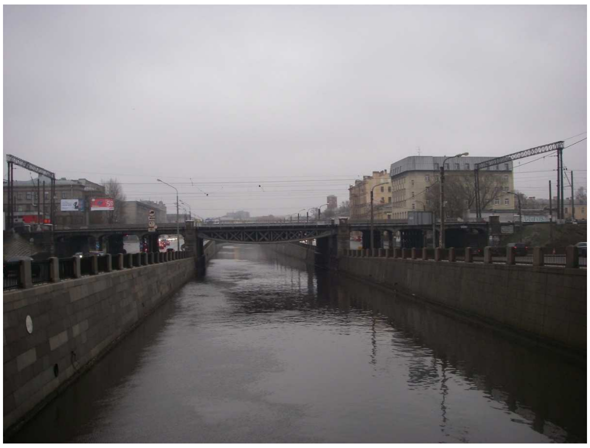

Fig. 1. Tsarskoye Selo railway bridge over the Obvodnyj canal (St. Petersburg).

The second one is the bridge on Borovaya street (Fig. 2). The construction of this bridge was carried out in 1900 -1904 years. The spans of these bridges are made of cast iron. Intermediate pillars contain elements of cast iron and steel structures.

These two metal bridges are built in the style of industrial modernism. They have unique metal pillars that are no longer in Russia. These bridges have not had any major or restoration repairs in period of more than 100 years of operation. The bridges are in operation and meet the requirements to date. There are no defects associated with deformation of structural elements from circulating loads. The main damages are metal corrosion and peeling of the protective paint layer.

For the preservation of these bridges one can consider methods such as conservation, repair restoration, restoration and use for other purposes.
The bridges are located on the operated section of the railway so one can consider two options: restoration repair and restoration itself with the preservation of operational properties.

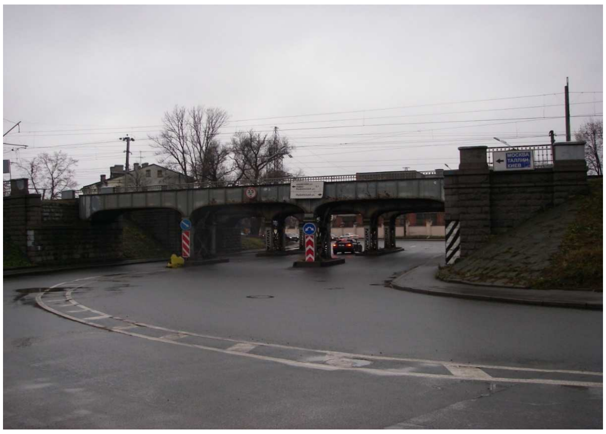

Fig. 2. Railway bridge on Borovaya street (St. Petersburg).

Facilities may need to be replaced, for example, if bridges deteriorate or do not meet new standards. This will facilitate the use of the bridge for other purposes. It can be moved to another location while maintaining the transport function such as pedestrian. One can turn the object into a museum.

At present ten railway bridges are protected by the state in Russia. The bridge over the Chumysh river in the Altai territory (Telmensky district, built in 1916), the viaduct in the Krasnodar territory (Novorossiysk, 1943), the bridge over the Zhuravka river (Krasnodar territory, 1918), the bridge over the Iset river in the Sverdlovsk region (Kamensk-Uralsky, 1939), the Tsarsky bridge over the Yenisei river (Krasnoyarsk, the end of 1899), the Romanovsky bridge over the Volga river (Tatarstan, 1910-1910), the bridge through the Don river (Rostov-on-Don, 1873-1874), the bridge through the Medveditsa river (Saratov region, 1901), Finland bridge over the Neva river (St. Petersburg, 1910-1914), Tsarskoye Selo bridge over the Obvodnyj canal (St. Petersburg, 1837, reconstruction-1900-1904).

Many States care about the preservation of railway bridges as historical monuments. The Garabit viaduct designed by Gustave Eiffel (1880-1884) in France is a historical monument of the French Ministry of culture (Fig. 3).

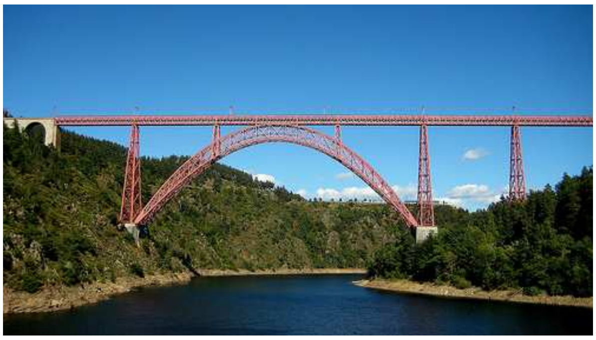

Fig. 3. Garabit Viaduct is a historic monument since 1965.

The British government nominated the Forth Bridge across the Firth of Forth in the east of Scotland for inclusion in the UNESCO world heritage list in 1999 (Fig. 4).

These examples show all countries how to treat the historical heritage in order to preserve for posterity all the best that humanity has.

Fig. 4. Forth Bridge.

5. Conclusions

Railway bridges are unique structures that have a number of factors that distinguish them from each other.

The study of the past of railways is an urgent task since it makes possible to understand the cause-and-effect relationships of the development of bridge construction, a natural stage of technical progress that has a serious impact on civilization.

Standards of design of railway bridges are regulated by the current state regulations and industry instructions. They must guarantee safe movement for the entire period of operation, be calculated taking into account the speed of freight and passenger trains, maintain the maximum permissible weight.

The use of bridge structures shows the need to find new and alternative ways of transporting goods in modern conditions. The technical condition for today and prospects of increase in volumes, weight of cargo transportation, loadings should be considered.

The target program and methodology for the protection of historical railway bridges in Russia is not available today. The following laws regulate activities for the preservation of cultural heritage: national standard of the Russian Federation "Composition and content of scientific and technical information for the preservation of cultural heritage. Historical and cultural monuments" as well as Federal law "On objects of cultural heritage (monuments of history and culture) of peoples of Russian Federation". This is clearly not enough.

We may lose the information that historic railway bridges preserve. This is the technology of production and installation, long-term trouble-free operation, conditions and reasons for the long life cycle of bridges.

Close cooperation of specialists from different countries is necessary in order not to lose historical objects and creatively use the experience gained in the world practice of bridge construction, architecture and restoration.

The preservation of those fragments of historical buildings that bear the memory of our cultural past is the greatest contribution to the perpetuation of the memory of our great architects and scientists. This can be done using the scientific and technical potential of Russian and world schools of bridge construction, restoration of historical heritage.

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