Imbalance in the hydrotechnical structure of seaspan lift-transition bridge in sea ferry crossing

E S Kligunov and K P Pozynich
Pacific National University, 136, Tikhoookeanskaya str., Khabarovsk, 680035, Russia
E-mail: 005196@pnu.edu.ru

Abstract. The article is devoted to the problem of reliability of functioning of onshore structures of transport systems using the example of railway ferry crossing. A brief assessment of the role ferry crossings at the current stage of the development railway and sea transport was given. The approach to the verification calculation of lifting mechanisms, suspension elements and counterweight devices of the sea span lift-transition road-railway bridge of stage I of the Vanino-Kholmsk ferry complex in the sea port of Kholmsk for the possibility of their use due to an increase in the weight of the span structure after repair was proposed and justified.

1. Introduction
In modern conditions, due to progress in bridge construction, marine (ocean) road-rail ferry lines become the main ones. These lines are a serious competition to lines using universal ships (dry cargo), due to the reduction, and in some cases, the complete elimination of transshipment operations. The effective realization of the maritime potential of our country in the transport component can be given by the synergy of the sea and the railway, which will create the prerequisites for serial, and therefore cheaper production of sea and river ships (ferries), locomotives, rolling stock, containers, digital support of production processes, the development of intermodal transport systems. The lines that provide ferries in the Russian Far East are both a mechanism for solving the problem of transport accessibility and the delivery of socially significant goods to Sakhalin, Kamchatka and Kuril Islands. The railway ferry crossing is a complex engineering structure. In its composition, it has complexes of coastal structures and specialized ships - ferries (Figure 1).

The Vanino-Kholmsk ferry complex (ferry crossing) was built in 1973 is the main transport corridor for the delivery of goods to Sakhalin from the mainland and needs today to carry out an urgent reconstruction of the coastal infrastructure. The global reconstruction of the infrastructure of the Vanino-Kholmsk railway ferry crossing was planned for 2019-2021 years. In accordance with the terms of reference in the sea harbours, berthing facilities are to be upgraded at both ports, and onshore facilities are to be repaired for the reception of new high-capacity sea ferries so that at the time of their reception the port infrastructure meets all the necessary requirements [1-7]. One of the main structural elements of the crossings is lift-transition bridges, which provide connection of sea ferries with the paths of approaches. The reconstruction project provides for the complete replacement of two lift-transition bridges, extension of piers, posts, concreting at a variable level, replacement of baffle frames, replacement of communications.
2. Methods

The lift-transition road-railway bridge (Figure 2) is a special hydraulic structure of the Vanino-Kholmsk marine ferry crossing.

Figure 1. General view of the ferry complex

Figure 2. Ferry loading at Kholmsk seaport

The bridge is constantly in contact with water, which is an aggressive medium in relation to the materials from which the bridge is built. Water has mechanical, physical, chemical and biological effects on them. All these types of impacts lead to premature destruction of hydraulic structures [1-7]. According to published data, at present, according to the results of the inventory, most of the hydraulic structures of Russia (more than 52%) are in a state that requires major repairs and are characterized by a low level of safety. A significant number of hydraulic structures need ongoing repair, or are in emergency and pre-emergency condition.

For more than 40 years of operation of the Vanino-Kholmsk ferry crossing, according to the regulations, technical inspections of the state of the structures and devices of the lift-transition bridge were carried out and technical services were carried out. One of the main tasks at the same time was to maintain the load value established by the project from the own weight of the sea span structure,
perceived by lifting mechanisms due to the adjustment of the weight of the main counterweights. At the same time, no preventive and overhaul repairs were carried out to eliminate critical defects in span structures and repairs of lifting mechanisms.

The Vanino-Kholmsk ferry crossing includes two identical two span road-railway bridges. Their design is identical and includes, among others, freely moving counterweights (Figure 3).

![Figure 3](image)

**Figure 3.** Lifting and transition bridge in the seaport of Kholmsk: longitudinal sections in non-working (a) and working (b) positions, transverse section along the axis of the lifting beam of the sea span (c) and plan (d): 1 - sea span; 2 - coastal span; 3 - counterweight of lifting mechanism; 4 - main counterweight; 5 - steam; 6 - bridge symmetry plane; 7 - coastal support; 8 - intermediate support; 9 - sea support; 10 - screw lifting mechanism on intermediate support; 11 - winch of sea support lifting mechanism

The main purpose of the bridges is to ensure the possibility of transferring railway trains from the shore tracks to the ferry tracks and/or back at a constantly changing depth of the ferry, which depends on the position of the sea level and the different intensity of mobile loads.

The sea end of the sea span during loading and unloading operations, being pre-imposed (with the help of lifting mechanisms) on the stern of the ferry, continuously follows its movements (oscillations) with a special "beak" entering when the bridge is lowered into the "nest" provided in the stern of the ferry.

A two-span lift-transition bridge from the shore to the "bed", formed by two sea lanes to keep the stern of the ship in the correct position, allows locomotive traction to roll up and roll out railway cars from the ferry, as well as load and unload rail-free transport, with the calculated amplitude of vertical movements of the ferry stern up to 4.0 m.
The lifting mechanisms available in the coastal structures are located on the abutments of the intermediate support (vertical drive screws) and on the abutments of the sea support (electric winches). Drawbridge mechanisms belong to the category of mechanisms of lifting machines.

Counterweights are used to balance span structures. Their mass is selected so that the system has a small initial imbalance from the own weight of the span (that is, towards the drawdown span) at any stage of the wiring.

To ensure tight adjoining of the span to the support parts, the value of unbalance in the induced position (initial unbalance) must be at least one percent of the total weight of the span with facilities (full moving mass) and at least 5 tons.

Chambers are arranged in the upper part of counterweights for laying of adjusting ballast from cast-iron or weighted concrete blocks with total weight up to 5% of weight of counterweight. By supplementing or removing the units from the chambers, the balancing of the span structure is adjusted during construction, and if necessary during the operational period. Counterweight devices almost completely balance the own weight of span structures.

Figure 4 shows the cable-unit suspension system of the lift-transition bridge and the location of lifting mechanisms.

Figure 4. Suspension system of span structures of lift-transition bridge: 1 - shore support No. 1; 2 – shore superstructure; 3 - counterweight intermediate support No. 2; 4 - balancing device of the counterweight; 5 - sea span; 6 - counterweight of the sea support No. 3; 7 - lifting ropes of a sea support No. 3; 8 - lifting beam No. 3; 9 - operative counterweight; 10 - shock absorber; 11 - lifting winch of a sea support No. 3; 12 - traverse beam of the sea support No. 3; 13 - screw lifting mechanism of the intermediate support No. 2; 14 - traverse beam of the intermediate support No. 2

3. Discussion
Under conditions of long-term operation, the steel structures of the bridge underwent significant corrosion wear, as a result of which the lifting capacity of the longitudinal and transverse beams decreased by 80% and 5-15%, respectively. This led to the fact that the carrying capacity of the span was insufficient to perceive mobile loads, that is, a reduction in the weight of the railway load was required.
The project organization developed proposals that made it possible to carry out work in the shortest time and without disrupting the supply of vital goods for residents of the island region in order to ensure the safe operation of the ferry crossing before the start of its global reconstruction. The purpose of repair and restoration works is reinforcement of span elements with preservation of design lifting capacity of the structure [8-12].

4. Results
The customer accepted the option of repairing span structures with the installation of additional linings and steel bonds. As a result, the mass of the span and the amount of imbalance increased.

Difference of masses of mounted and dismantled materials of bridge span was:
- metal rolling \( \Delta m_{M,PR} = 104.76 - 75.53 = 29.23 \) tons;
- timber \( \Delta V_{P, MAT} = 62.25 - 60.36 = 1.89 \) m³.

Considering the density of wood \( \rho \approx 0.66 \) tons/m³, we get a total increase in the mass of the sea span:
\[
\Delta m_{M, PR} = \Delta m_{M, PR} + \Delta V_{P, MAT} \cdot \rho = 29.23 + 1.89 \cdot 0.66 = 30.48 \text{ tons.}
\]

Accordingly, the change in weight of the sea span will be:
\[
\Delta P_{M,PR} = \Delta m_{M, PR} \cdot g = 30.48 \cdot 9.81 = 299.02 \text{ kN.}
\]

where \( g \) - acceleration of free fall, \( g = 9.81 \) m/s².

Difference of masses of mounted and dismantled steel structures of sea span lifting beam was:
\[
\Delta m_{P,B} = 3.13 - 1.08 = 2.05 \text{ tons;}
\]

The change in the weight of the lifting beam of the marine superstructure will be:
\[
\Delta P_{P,B} = \Delta m_{P,B} \cdot g = 2.05 \cdot 9.81 = 20.12 \text{ kN.}
\]

To determine the load \( \Delta P_{PR} \) change at the sea span suspension points, we will bring changes in the weight of the sea span and the sea span lifting beam to the sea supports of the lift-transition bridge. Let us accept the following assumptions:
- the weight of the sea span \( \Delta P_{M,PR} \) is applied in the middle of the span;
- weight of lifting beam \( \Delta P_{P,B} \) passes through axis of counterweights.

On the compiled design scheme (Figure 5) at point C, the span structure is supported on the stern of the ferry, while the span \( AC = 33.4 \) m. Point B on the scheme is the point of suspension of the span structure.

In such structures, imbalance is the weight of the span that falls on the stern of the ferry in working conditions.

The inherent imbalance of the span ensures the stability of the span during operation.

The introduction of initial imbalance prevents the possibility of spontaneous wiring under the influence of random factors, and also ensures a tight landing of the span on the support parts upon completion of aiming.

![Figure 5. Design diagram for determining the imbalance of the sea span structure](image-url)
When planning urgent repair and restoration work of the lift-transition bridge, the mass of the sea span was increased by 30.48 tons, a span lifting beam by 2.05 tons, which, naturally, led to the increase in imbalance on the sea support by 20.53 tons. At the same time, for each of the two suspension points of the sea span structure according to Figure 5, 10.26 tons will be additionally accounted for. Accordingly, this will necessitate an increase in the mass of the main counterweights on the sea support to maintain the design level of imbalance, which will require high material and time costs.

Obviously, it is not desirable to overstate the amount of imbalance compared to the project, since this will affect, among other things, the power characteristics of the drive of the lifting mechanism.

This circumstance led to the need to carry out a large volume of verification calculations of installed lifting mechanisms (electric winches), elements of cable-unit systems of the span structure, suspension elements of the main counterweights, etc.

It should be noted that in the process of movement of the span structure, the violation of the balance of the entire system causes an increase in the length of the supporting ropes both from the side of the span structure and from the side of the counterweight. With a small mass of span, this violation of balance is insignificant.

Verification calculations of the ropes of lifting mechanisms, as well as the ropes of counterweight devices, showed that the size of the ropes does not require changes.

5. Conclusion
The verification calculations of lifting mechanisms, span suspension and counterweight devices for the possibility of their use after the repair of the Vanino-Kholmsk ferry bridge in the Kholmsk seaport due to the increase in its mass showed that the operation of lifting mechanisms, span suspension elements and counterweight devices in the event of an increase in the mass of sea span after repair (increase) of weight of main counterweights and replacement of elements of lifting mechanisms and counterweight devices is possible.

It is advisable to increase the weight of the main counterweights on the offshore support in order to reduce the load on the lifting mechanism drive. In accordance with the breaking force of the ropes, according to our calculations, the mass of each counterweight of the sea support cannot exceed 82.35 tons. With the design weight of each of the main balances on the sea support 76 tons, in order to eliminate the problem of imbalance. It is enough to increase the weight of one counterweight on the sea support by 6.35 tons.

References
[1] Liu C, Jiang Zh and Yu H 2020 Measurement 151 107169
[2] Kodur V K R and Naser M Z 2019 J. of Constructional Steel Research 156 46-53
[3] Alencar G, de Jesus A, Guilherme J, da Silva S and Calçada R 2019 Engineering Failure Analysis 104 154-176
[4] Andersen S-N and Tørset T 2019 Case Studies on Transport Policy 7(3) 667-676
[5] Bogunovic-Jakobsen J 1997 J. of Wind Engineering and Industrial Aerodynamics 69–71 795-805
[6] Milne D, Le Pen L, Watson G, Thompson D, Powrie W, Hayward M and Morley S 2018 Transportation Geotechnics 17(A) 61-68
[7] Marques F, Moutinho C, Hu W, Cunha A and Caetan E 2016 Engineering Structures 123 15-29
[8] Ma H, Zhang Zh, Ding B and Tu X 2018 Construction and Building Materials 191 679-691
[9] Van Puymbroeck E, Nagy W and de Backer H 2018 Procedia Structural Integrity 13 920-925
[10] Dinas A, Nikolaidis Th N and Baniotopoulos C C 2017 Procedia Environmental Sciences 38 578-585
[11] Plachý T, Polák M P and Ryjáček P 2017 Procedia Engineering 199 3053-3058
[12] Leander J, Honfi D, Larsson-Ivanov O and Björnsson Í 2018 Engineering Failure Analysis 91 306-314