Ensuring the safety of the transshipment process in river ports

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Abstract. The paper considers the issues of ensuring the safety of the transshipment process in river ports. The authors propose an approach to integrated safety assessment of the transshipment process in river ports taking into account various types of risk. The article analyzes the accidents and injuries during transshipment works in river ports. The authors establish that injuries in river ports are mainly due to operational reasons i.e. due to the presence of a significant number of cranes that have completed their standard service life. The paper studies the influence of the operating time on the static and fatigue strength characteristics of the metal structure of gantry cranes after 30-40 years of operation. The research results show that long-term operation don’t cause significant changes in mechanical characteristics, with static and fatigue strength.

1. Introduction

The transshipment process in river ports is a set of technological operations for the movement of goods, using special equipment and ensuring the required safety.

Nowadays, during the transshipment process in the port, the most attention is paid to the control of the transshipment equipment, with special attention required for the steel structures - since they cannot be completely replaced under operating conditions in case of resource depletion. Bearing elements of metal structures are subject to static, dynamic and other types of loads and require evaluation of their performance according to the criteria of static and cyclic strength.

Evaluation of the metal constructions performance of the transshipment equipment allows to conduct a quantitative assessment of the technical risk of operation based on physical-mechanical analysis methods using the” load-strength” model. This is an integral part of a comprehensive assessment of the safety with various types of risk of the transshipment process in river ports.

2. The various impacts on the safety of the transshipment process

There are many hazardous things that could happen during the transshipment process: technical system or device failure, pollution or destruction of the ecological system, harm to health, death of a person or a group of people, material damage from the hazards that have occurred or an increase in safety costs.
We can identify the following sources of danger during the transshipment process: transshipment equipment, cargo, the technological process, weather conditions and the human factor (Figure 1).

![Block diagram of the sources and factors affecting the safety of the transshipment process.](image)

These factors are characterized by the undesirable events, each of which may occur in relation to a particular risk object. The relation of objects of risk and undesirable events allows us to distinguish individual, technical, environmental, social and economic risks. Each type of risk determines the typical sources and risk factors, classification and characterization.

In case of safety violation of the transshipment process in the river port, the objects of negative factors influence may be: a person or a group of people, the environment, technical facilities and equipment, and cargo. We made recommendations on the need to assess various types of risk for the listed objects of impact (Table 1).

| Object of impact                          | Individual | Technical | Ecological | Social | Economic |
|------------------------------------------|------------|-----------|------------|--------|----------|
| Person or group of people                | ++         |           |            | +      | +        |
| Environment                              |            | ++        |            |        | ++       |
| Technical buildings and equipment         | ++         |           |            |        | ++       |
| Cargo                                    | ++         |           |            |        |          |

Note:
++ - evaluation is required
+ - evaluation recommended
− - evaluation is not required

3. The analysis of accident rate during the transshipment works in ports
To assess the nature of the accidents in ports, we analyzed statistical data and generalized the causes of accidents and injuries that have occurred over a number of years during the operation of port transshipment equipment. The results of the analysis are shown in Figure 2.
Figure 2. The results of the analysis of accidents during transshipment works in ports:

a) Classification of operations of the transshipment process by injury rate
b) Classification of accidents by employee categories
c) Classification of equipment failure by its nature.

The diagrams show:

a) Types of transshipment operations do not have a major impact on injuries during the transshipment process (Figure 2a).

b) Unqualified actions of workers cause accidents and injuries 3 times more than actions of engineers and technicians (Figure 2b). At the same time, a big role is played by the reasons related to the unsatisfactory supervision of the technical condition of the equipment, often due to the presence of a significant amount of transshipment equipment that work despite the end of its service life in the river ports. This necessitates a study of the impact of the technical state of the equipment. In particular, on the carrying capacity of the steel structure.

c) Injuries are caused mainly by operational reasons, while the level of accidents for operational reasons significantly exceeds the level of accidents for technical reasons (Figure 2c). This also confirms the need to conduct research on the operated equipment, and also makes it possible not to take into account production and constructional reasons at this stage of risk assessment.

Studies show that the impact of operating time contributes to the mechanical and fatigue characteristics of the material in a non-obvious way [1]. In this regard, we carried out the studies and clarified its impact on:
- mechanical characteristics of the metal structures material samples of gantry cranes, which main indicators are are the values of tensile strength (Ϭ₆), yield strength (Ϭ₇), relative elongation (δ), relative narrowing (ψ), impact toughness (KCV);
- fatigue resistance characteristics, which main indicators are the endurance limit values (Ϭ₁), the fatigue curve slope (m);
- crack resistance characteristics, which main indicators are the values of crack growth rate (v), stress intensity factor (K), parameters of the Paris equation (C) and (n).

4. The impact of operating time on mechanical characteristics with static strength and toughness

The impact of operating time on the above characteristics was investigated for the steel St3 and St38b2 used for gantry cranes.

We took the samples from metal structures of gantry cranes “Albatros 10 / 20-32 / 16” and “Ganz 6 / 5-32 type N”, which have been operated in the ports of Russia for 30-40 years.

We carried out the tests to determine the mechanical characteristics in two stages: tensile tests and tests for impact bending.

Tests for tensile with operating time were carried out on a tensile testing machine IM-4R. The results of tensile test samples are presented in Table 2 [2].

Table 2. Mechanical characteristics of samples made of steel St38b2 and St3 with and without operating time.

| Crane, material       | Operating time, years | Metal construction element | Yield strength GB, MPa | Temporary resistance GT, MPa | Relative elongation δ% |
|-----------------------|-----------------------|----------------------------|------------------------|-----------------------------|------------------------|
| Albatros 10/20-32/16 (St38b2) | 40                    | Counterbalance             | 297                    | 562                         | 23,5                   |
|                       | 40                    | Jib                        | 300                    | 535                         | 25,0                   |
|                       | 40                    | Jib                        | 280                    | 441                         | 21,5                   |
|                       | 40                    | Jib                        | 286                    | 450                         | 22,0                   |
| Albatros 10/20-32/16 (St38b2) | 40                    | Jib                        | 261                    | 418                         | 22,5                   |
|                       | 40                    | Portal                     | 232                    | 412                         | 27,0                   |
|                       | 40                    | Portal                     | 253                    | 412                         | 34,0                   |
|                       | 40                    | Trunk                      | 255                    | 416                         | 34,0                   |
|                       | 40                    | Trunk                      | 259                    | 371                         | 33,0                   |
| Medium                | 40                    |                            | 267,8                  | 438,6                       | 27,45                  |
| Medium                | 40                    |                            | 220-240                | 380-470                     | 25                     |
| St38b2 [3]            | 30                    | Column                     | 244                    | 427                         | 33,0                   |
| Ganz 6/5-32 type N (St3) | 30                    | Column                     | 247                    | 429                         | 32,0                   |
|                       | 30                    | Jib                        | 287                    | 462                         | 31                     |
|                       | 30                    | Jib                        | 322                    | 477                         | 28,0                   |
| Medium                | 30                    |                            | 275                    | 448,75                      | 31                     |
| St3 [3]               | 30                    |                            | 250                    | 380-490                     | 26                     |

We compared the mechanical characteristics (samples with operating time and without operating time) using the methods of mathematical statistics. A check by the Fisher and Student criteria showed that the samples belong to the same general population [4]. The results of tensile tests show that the
operating time of 30–40 years do not cause changes in the values of the tensile strength $\sigma_B$, the yield strength $\sigma_T$, the relative elongation $\delta$ of the steel St3 and St38b2.

Tests for bending impact were carried out on a PSW-300 pendulum scraper in accordance with [4] on samples with a V-type concentrator. Figures and Tables 3 and 4 give the results of testing with and without operating time for impact toughness [2].

**Figure 3.** Change of impact toughness depending on the temperature for steel St3.

**Figure 4.** Change of impact toughness depending on the temperature for steel St38b2.
Table 3. Comparison of test results for the determination of impact toughness for St3.

| t, °C | Column (section 1) | Column (section 4) | Column (section 1) | Column (section 4) | Portal foot (section 1) | Portal foot (section 2) | Portal foot (section 3) | Samples of steel without operating time |
|------|-------------------|-------------------|-------------------|-------------------|------------------------|------------------------|------------------------|----------------------------------------|
| 25   | 160               | 162               | 170               | 172               | 176                    | 50                     |                        |                                        |
| 20   |                   |                   | 130               | 163               | 153                    | 30                     |                        |                                        |
| 0    | 140               | 137               | 81                | 97                | 93                     | 20                     |                        |                                        |
| -20  |                   |                   |                   |                   |                        |                        |                        |                                        |
| -30  |                   |                   |                   |                   |                        |                        |                        |                                        |

Table 4. Comparison of test results for the determination of impact toughness for St38b2.

| t, °C | Portal (section 3) | Jib (section 1) | Jib (section 5) | Counterbalance | Turntable (section 1) | Turntable (section 2) | Turntable (section 3) | Samples of steel without operating time |
|------|-------------------|----------------|----------------|-----------------|------------------------|------------------------|------------------------|----------------------------------------|
| 20   | 127               | 72             | 70             | 65              | 114                    | 115                    | 62                     | 50                                     |
| 0    |                   | 49             | 51             | 47              | 115                    | 121                    | 62                     | 30                                     |
| -20  | 20                | 49             | 51             | 47              | 62                     | 117                    | 57                     | 22                                     |
| -30  |                   |                |                |                 |                        |                        |                        |                                        |

Table 3 and 4 show that the impact toughness values of samples with an operating time of 30–40 years have a variation caused by the fact that samples were taken from metal structures with different levels of tension in operation. In this regard, it is possible to make a preliminary conclusion that the effect of the level of loading of the metal structure influences the measurements of impact toughness. To assess the impact of operation time on the values of impact toughness, we need an additional research.

5. Impact of operation time on fatigue strength and durability

Fatigue tests were carried out on samples that were cut from the trunk of the gantry crane “Albatros 10 / 20-32 / 16” and the jib of the gantry crane “Ganz 6 / 5-32 type N”. The test results are summarized in table 6.
Table 5. The results of fatigue tests of samples of steel St38b2 and St3 with the operating time.

| Sample number | Tension, $\Sigma_a$, MPa | Steel St38b2, Operation time 40 years | Steel Cт3, Operation time 29 years |
|---------------|---------------------------|--------------------------------------|-----------------------------------|
| 1             | 316                       | $1,62 \times 10^5$                   | $1,7 \times 10^5$                 |
| 2             | 277                       | $3,12 \times 10^5$                   | $2,1 \times 10^5$                 |
| 3             | 238                       | $9,43 \times 10^5$                   | $5,1 \times 10^5$                 |
| 4             | 200                       | $2,63 \times 10^6$ passed the test base | $2 \times 10^6$ passed the test base |

View of the fatigue curve for samples taken from elements of a metal structure with operating time of 30 and 40 years, presented in figure 5 [4].

Figure 5. Fatigue curve for steel St38b2 with 40 years in operation.

As we can see from Table 6, the fatigue limit of steel St38b2 and St3 based on $2 \times 10^6$ is 200 MPa, i.e. the fatigue resistance characteristics of St38b2 steel with a life of 40 years and St3 steel with a life of 30 years in operation remained at the same level.

6. Impact of operation time on the characteristics of crack resistance

Tests on cyclic crack resistance of the samples were carried out on the “Amsler HFP” pulsator and on the “SCHENCK” PC-400S universal electrohydraulic machine. Figure 6 and 7 show the speed of fatigue fractures growth in the metals in operation [2].
According to the obtained experimental data of crack growth rates, corresponding to different values of $\Delta K$, we calculated the coefficients “C” and “n”, which are characteristics of the cyclic crack resistance of the material under given test conditions:

$$\frac{da}{dN} = C \Delta K^n$$  \hspace{1cm} (1)

### Table 6. Characteristics of the cyclic crack resistance of samples of steel St38b2 and St3.

| Crane            | Steel  | Object | Characteristics of cyclic crack resistance | Coefficient of determination |
|------------------|--------|--------|---------------------------------------------|-----------------------------|
| Albatros 10/20-32/16 | St38b2 | Portal | $1,66 \cdot 10^{-12}$                       | 0,989                       |
| Albatros 10/20-32/16 | St38b2 | Portal | $1,73 \cdot 10^{-12}$                       | 0,992                       |
| Albatros 10/20-32/16 | St38b2 | Jib    | $1,87 \cdot 10^{-12}$                       | 0,989                       |
| Ganz 6/5-32 type N | St3    | Jib    | $10^{14}$                                    | 0,989                       |
| Ganz 6/5-32 type N | St3    | Column | $2 \cdot 10^{-12}$                          | 0,988                       |

Comparison of the kinetic diagrams of fatigue destruction and characteristics of cyclic crack resistance of metal portal and jib of a gantry crane after 40 years of operation with the metal of a gantry crane after 30 years of operation showed that metal after 40 years of operation is characterized by higher...
values of fatigue cracks growth rate in the region of low values of the linear section of a diagram - from 14 to 25 MPa√m, - up to 1.5-2.5 times. With increasing ΔK, this difference weakens and the rates of crack growth become hardly distinguishable.

The results of tests on cyclic crack resistance showed that the kinetic diagrams of fatigue failure of the metal of all series on St38b2 steel are located close to each other. For samples of steel St3, we need to conduct additional research.

7. Conclusion
The paper provides a block diagram of the sources and factors affecting the safety of the transshipment process and recommendations on the assessment of various types of risk depending on the object of impact.

Moreover, this article analyzes the causes of accidents in the river ports during the transshipment process.

The study presents the results of research on the evaluation of the influence of operation time on the mechanical characteristics, characteristics of fatigue strength and durability of St3 and St38b2 steels with an operating time of 30 ... 40 years.

The materials obtained as a result of this research allow to conduct a quantitative assessment of the technical risk of the metal constructions of the transshipment equipment on the basis of physical and mechanical methods of analysis using the load-strength model [5-8].

8. Discussion
Research results show that operation for 30 ... 40 years don’t cause significant changes in the mechanical characteristics, characteristics of crack resistance and fatigue. This is mainly due to the fact that the metal structures of gantry cranes are designed with large safety margins.

However, it is necessary to pay special attention to the study of the influence of operation time on the mechanical characteristics, characteristics of crack resistance and fatigue of details and assemblies, depending on their loading during operation.

To improve the reliability of port transshipment equipment, it is necessary to ensure a high level of maintenance, repairs and compliance with the rules of safe operation.

For a comprehensive assessment of the safety of the transshipment process in river ports, in accordance with the recommendations of Table 1, it is also necessary to take into account the results of a quantitative assessment of the environmental risks, as well as the results of an individual risk assessment. The obtained results must be compared with an acceptable risk that combines technical and economic aspects.

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