ON INDUSTRIAL SAFETY IN BRIDGE CONSTRUCTION

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ABSTRACT

Industrial safety system evolved on the railways for decades. In new economic conditions, many of its basic principles remain, but also those factors have arisen that require scientific analysis, experimental verification, modern technical and technological means. At the example of construction and maintenance of bridgeworks, the authors examine and evaluate the situation with safety, injury rate, fire hazard in railway transport.

Keywords: *transport, safety, bridge construction, cartogram of working conditions, injury rate, fire hazard, environmental factors.*

Background. *At every stage of railway reform and the establishment of JSC «Russian Railways» a special attention is paid to the preservation of all relations and principles for operation of industry as a single, continuously operating mechanism. These principles include maintenance of a high level of fire and industrial safety.*

Railway industry employs more than 1,2 million people, so it is a task on a national scale to ensure their safety and create favorable conditions for the activity [1].

In the post-reform conditions it was managed to keep the experience and industry organizational and material base. Thus, the total injury frequency rate (number of cases per 1000 employees) in the JSC «Russian Railways» in comparison with other sectors of economy is minimal and amounts to 0,75, while, for example, in agriculture it reaches a value of 7,2. The frequency rate of occupational injuries with fatalities on the railways is also minimal: it is 0,08, and on air transport, or, for example, in industrial construction it reaches values of 0,31 and 0,32.

Objective. *The objective of the authors is to examine and evaluate labor safety, injury rate, fire hazard in railway transport.*

Methods. *The authors use analysis, mathematical method, comparison, statistical method.*

Results.

Objective laws of fires

Fires are a particular danger on railways, because they not only cause direct damage, but also disrupt schedule of trains, threaten to destroy nearby buildings and structures and people in them. The total number of fires and property damage data are presented in Pic. 1. The number of people who died in fire, is shown in Pic. 2, and Pic. 3 shows a number of injured people.

The dynamics of indicators of fire, property damage and loss of life on stationary railway facilities, which include bridgeworks, is illustrated in Pic. 4.

The analysis of data shows a decline in the total number of fires, but material damage and number of dead people remain significant. In this regard, we believe it is advisable to build a mathematical model of the dynamics of fires F (t) on stationary objects, which will predict a possible number of fires in the coming period, to take decisions, which are appropriate for this expected situation.

To assess statistical data we use least-square method and take an exponential dependence. The resulting expression is:

$F^{cal} = 179 + 113\mathbf{e}^{-0,7\,(t-2003)}$ at $t > 2003$. (1)

The values calculated by years are shown in Pic. 5. The adequacy of the model (1) is estimated by Fisher test with a confidence level of 95%. The model can be used for short-term prediction of fires on stationary objects, which include bridgeworks of railways.

Every year a lot of funds are allocated for fire prevention measures, which largely determines decrease in the number of emergency. Investments over five years were analyzed. Incurred costs were approximated by linear regression equation:

$F^{cal} = 194 - 0,025 \cdot S.$ (2)

The adequacy of the model (2) was evaluated by Fisher test with a confidence level of 95%. The model gave acceptable results.

According to available statistics, it is possible to evaluate the effect of days of the week and months of the year on fire frequency on infrastructure facilities of JSC «Russian Railways».

Graphically, the dynamics of fires by month of the year is shown in Pic. 6, and Pic. 7 shows a similar dependence on the given day of the week.

Since the dynamics of the number of fires is marked random, it is advisable to find the distribution laws of fire frequency.

Processing of statistical data on fires (see. Pic. 8) revealed that Poisson and Pascal distribution laws provide the best approximation indicators and have a form:

for Poisson law –

$p_i = 1,452^i\, e^{-(1,452/i!)}$ (3)

for Pascal law –

$p_i = C^i_{i+2} \cdot 0,632^3 \cdot 0,368^i = (i+1) \cdot (i+2) \cdot 0,1262 \cdot 0,368^i.$ (4)

Injury rate of bridge-builders

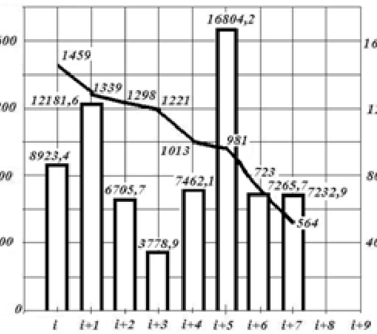
Track facilities is the largest department in the JSC «Russian Railways' and includes 395 divisions.

The average headcount of the complex is shown in Table 1, the farm employs 201 thousand. 907 people or 15,4% of all workers in JSC «Russian Railways». And although among them repairers of man-made facilities represent less than 1/40, their injury rate is the highest, that makes us look for opportunities to reduce it and create effective ways and means of ensuring safety, preservation of health of workers [2].

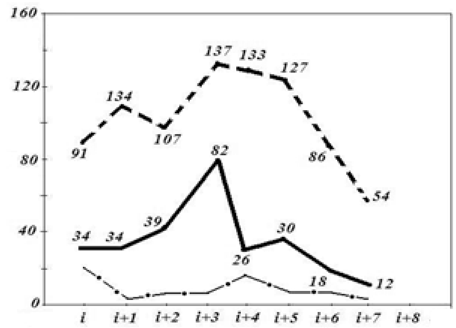
Let's analyze in detail injuries that occurred during the construction of railway bridges, overpass bridges, traffic intersections of different systems and complexity.

According to the criteria of reliability bridge constructions belong to the first group, i. e. they are structures that do not have a reserve, damage to them tend to lead to a disturbance (cessation or limitation) of movement. Time allocation of train delays due to the fault of employees, serving bridge constructions is shown in Pic. 9, which demonstrates that they are mainly characteristic of the most high-density sections.

Table 2 presents data on occupational injuries, which suggests that most of the accidents falls on mounters of concrete and metal structures.



Pic. 1. The number of fires (curve) and distribution of material damage caused by them (vertical columns) on railways of Russia.

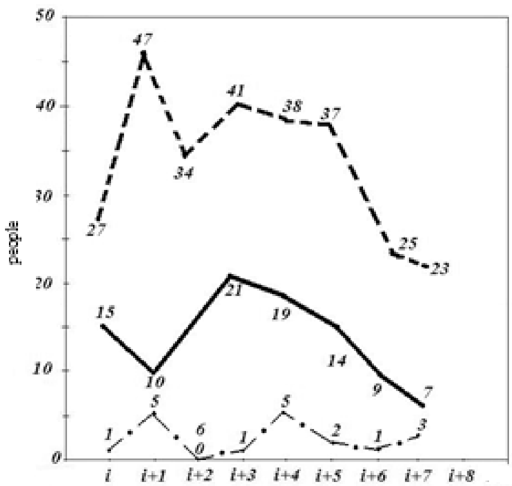


Pic. 2. Number of people, died in fires:

total number of people;

railway employees;

children.

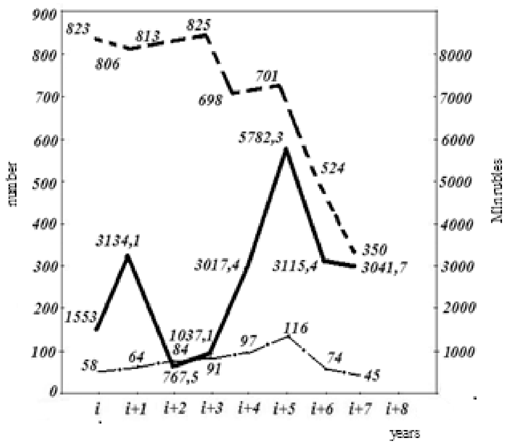


Pic. 3. Number of people, injured in fires:

total number of people;

railway employees;

employees of fire protection service.

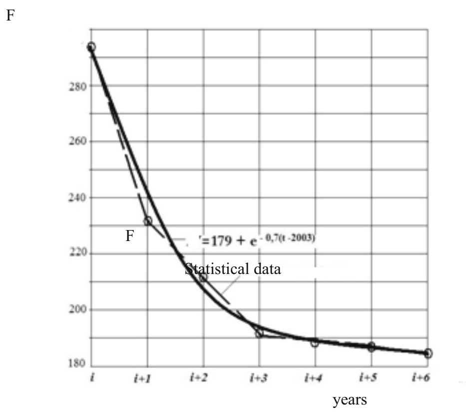


Pic. 4. Distribution of fires, material damage and death of people on stationary objects of railway transport:

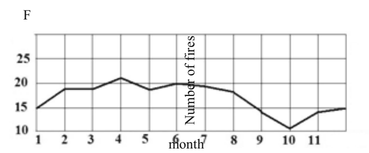
number of fires;

material damage;

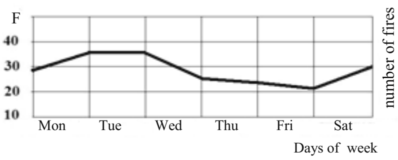
number of killed people.



Pic. 5. Dynamics of fires on infrastructure facilities of JSC «Russian Railways».



Pic. 6. Dynamics of fires by months of the year.



Pic. 7. Dynamics of fires by days of week.

Table 1

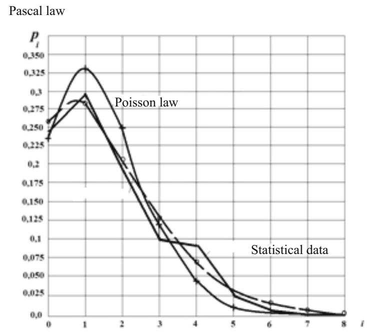
The average headcount of track complex

Position, profession	Payroll (number of people).
Track servicemen	81304
Foremen of track and man-made facilities	15455
Roadmasters	5314
Senior roadmasters	1385
Locomotive drivers and drivers of self-propelling special rolling stock	4569
Drivers of track- construction machines	3777
Operators of defect- detecting bogies	9712
Operators of track measurements	722
Repairers of man-made facilities	5406
Operators on duty on crossings	9718
Other professions	64545

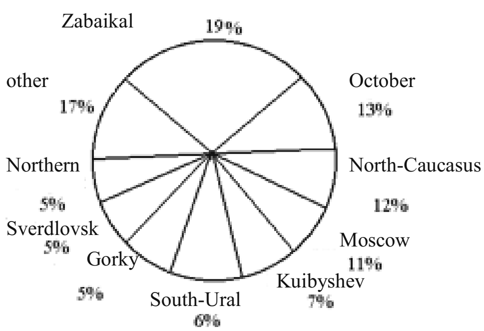
Table 2

Data on injuries by categories of workers

№	Position (profession) of an injured	As a percentage of total number of victims
1.	Mounter of concrete and metal structures	40
2.	Driver	9
3.	Electric welder	7
4.	Carpenter	10
5.	Locksmith	2
6.	Executive heads and specialists	6
7.	Crane driver	6
8.	Steelman	4
9.	General laborer	6
10.	Concretor	6
11.	Turner	2
12.	Strapper	2
	Total	100



Pic. 8. Assessment of statistical data on fires on infrastructure facilities of JSC «Russian Railways».



Pic. 9. Time distribution of train delays due to the fault of employees serving bridge construction.

Injury rate, taking into account length of service and age of employees, is illustrated in Table 3 and 4.

The analysis of general injuries shows (Pic. 10), that in recent years the severity of injuries continues to be at a high level, and this is due to the increasing complexity of technology of construction and installation work, a sharp increase in the rate of construction, reduction in the level of organization of production, lack of training of managers and executives.

A typical example is consequences of failures on bridge structures in the peak summer period (Pic. 11), when the aggravating causes of traumatic situations are precisely the circumstances of an organizational nature [3].

At this time, there has been a significant increase in the volume of work carried out, usually with a lack of staff. To cover the deficit of workers, less- trained people are attracted and it is necessary to conduct their training with a detailed analysis of typical accidents. It is necessary also to check more often procedure for issuing and processing orders, availability of safety certificates. In addition, training sessions, additional control of technology and labor discipline, as well as regulations and the comments made by superior organizations, public inspectors can provide additional benefit. It means that it is necessary to strive for timely elimination of injury preconditions.

As part of the study of relationship between the level of injury (I) and length (L) of artificial structures using the method of pair correlation assessment was performed regarding availability, closeness and communication direction of I and L. The significance of correlation coefficient was determined by Fisher transformation.

Calculations have shown absence of correlation between total injury rate and the length of railway lines on bridge structures. This gives grounds to conclude that in general on the railway network preventive measures allow to neutralize the effect of the increase in length of man-made structures on injury rate (Pic. 12). However, differences in the change in injury rate during maintenance of bridges of different types are quite characteristic.

Despite the increase in the length of concrete bridges, there is a continuous decrease in the number of injuries during their servicing. This is evidenced by a significant negative correlation r = – 0,48. At the same time the presence of a weak positive correlation r = 0,2 points to a tendency for a certain growth in the number of injuries with the growth of work volume in the metal spans.

Environmental factors

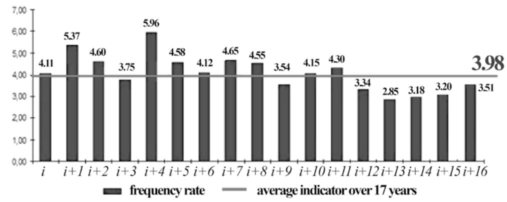
It is known that environmental conditions, in which this or that work is performed, may be optimal, acceptable, harmful or extreme [4]. Evaluation of production environment is based on basic laws and health documents.

Based on the analysis of requirements for the performance of work and the requirements of sanitary hygiene cartogram was composed regarding working conditions of repairmen of bridge structures (see. Pic. 13).

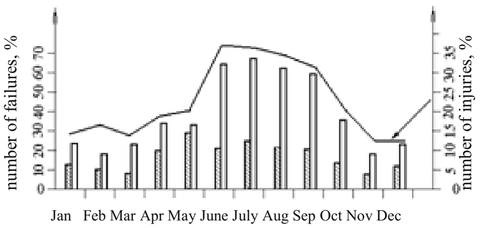
Table 3

Injuries and work experience of injured

№	Length of service (years)	Number of injured, %
1.	less than 1 year	11,9
2.	1	26,19
3.	2–5	14,2
4.	5–10	28,57
5.	More than 10 years	19,14
	Total	100



Pic. 10. Frequency rate of accidents.



Pic. 11. Dynamics of failures and injury rate on bridge structures depending on season:

– for large and middle bridges;

– for small bridges and pipes.

With distance from the center indicators are pointed, indicating deterioration of production environment, increasing severity and intensity of work of an employee. This characteristic makes it easy to identify to optimization of which factors attention should be paid first (improvement of working environment, reduction of severity, intensity of labor), or to create a comprehensive system of measures to ensure optimization of all sides of work of bridge workers.

Bridge construction is one of the most labor-intensive sides of construction. The share of «living» labor in costs for construction and installation work is much higher, and growth rate of labor productivity is less. This is due to the peculiarities of construction and especially the complexity of organization of production.

To obtain reliable information on the degree of dependence of productivity on internal and external factors it is worth using data of Mostotrest, which involve materials of 65 observations for ten years for 14 bridge construction crews. At the same time we introduce the variables:

1. The volume of work performed on their own by bridge-building organizations for the year.

2. Payroll fund.

3. Average number of employees in the organization.

4. Average annual value of assets.

5. Profit of the organization.

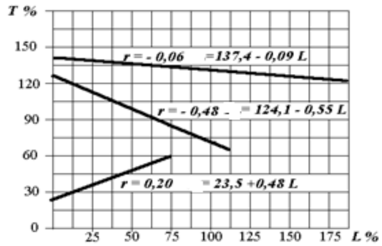
6. The volume of work carried out in the region during the year.

7. Average salary in the region, where there is a bridge-building organization.

Table 4

Injuries by age of suffered

№	Age (years)	The number of injured, %
1.	younger than 28	11,9
2.	28–35	16,66
3.	35–45	21,42
4.	45–50	21,42
5.	50–55	9,52
6.	55–60	11.9
7.	older than 60	7,18
	Total	100



Pic. 12. Field correlation between injuries and length of bridge structures.

8. The rates of foreign currencies.

9. The average annual salary of specialists in the field of bridge construction.

10. The size of living wage.

11. Average rate of unemployment.

The analytical dependence was obtained of productivity on parameters that characterize the performed work done:

$y_i = 104{,}89 + 0{,}523X_1 - 1{,}5057X_2 - 0{,}1764X_3 + 1{,}8429X_4 + 0{,}504X_5 - 0{,}017X_6 + 0{,}141X_7 + 4{,}84X_8 - 0{,}0285X_9 + 0{,}101X_{10} + 0{,}002X_{11}$.

Studies have shown that when planning the scope of work for the next period and the number of workers, it is possible to predict their level of performance. Similarly, accepting a certain level of performance of the previous period, and knowing the planned volume of work, it is possible to predict the number of workers.

We have studied the probability of safe operation of the team of bridge-builders. If during the period of observation of their activities it was revealed that cases of injury occur in approximately equal intervals, the probability of safety within a specified period can be calculated using the formula:

$$P = (1 - T_s / NT)^n \qquad (6)$$

where P is a probability of safe operation;

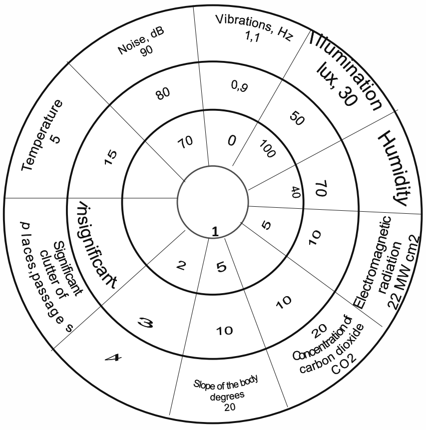
T_s *is a specified time interval during which the value P is determined;*

N is a number of teams or sections of bridge-construction crew;

n is a number of injury cases in N teams over time T.

Calculation results are considered reliable, providing the main condition – the safety during the period T_s*, in the case where the value of P corresponds to labor safety, i. e.* $P \geq 0{,}95$*. If the probability is less than the value of 0,95, there cannot be full assurance of safety for this category of workers in the period* T_s*.*

Probability indicators of safe operation of various teams of bridge-construction crews are shown in Table 5.



Pic. 13. Cartogram of working conditions of repairmen of bridge structures: 1- supreme comfort zone; 2 – comfort zone; 3 – uncomfortable zone; 4 – invalid zone.

These data allow us to conclude that the workers of various professions have unequal probability of safe work in a certain period of time. With these guidelines for a separate team, people, who are responsible for industrial safety in Mostotrest, receive timely opportunity to carry out targeted preventive measures.

In the absence of clearly defined intervals between cases of injury or occupational diseases it is necessary to increase the volume of studied cases through involvement of additional materials for related teams, however, the period with injuries should not be more than three years.

Data on cumulative risk of injury for a year, and knowledge of existing hazards allow more precise distribute funds for nomenclature health measures and carry them out in reasonable time.

Hazardous materials

As previously established, the most dangerous from the point of view of fire are reinforced concrete bridge structures, because many flammable building materials are used in their construction. Including all kinds of primer, paint, mastic, and most importantly – wood.

*In accordance with construction rules and regulations SNiP 21–01–97 * fire hazard of building materials is determined with fire characteristics. Domestic standards since their adoption were not altered or added. For example, GOST 12.1.044–89 has not been revised for nearly twenty years. At the same time knowledge about the processes of ignition and burning of construction materials under actual fire conditions were significantly deepened. Researchers constantly clarify the procedure of standard tests, which allow to use resulting data as input values for simulation of expected risks and countermeasures.*

During the construction of bridges, various wood products are used. Take for example, a pine tree, which is the most common material for bridge constructed facilities; it is recommended in NPB 251–98 as reference material when assessing the effectiveness of fire protection.

Dry pine wood contains 49,5% of carbon, 6,3% of hydrogen; 44,1% of oxygen, 0,1% of nitrogen. Its chemical components are cellulose and lignin. Other constituent elements are hemicellulose, pectin and mineral (mainly – calcium salt) substances [5].

Before the experiments with the means of fire protection we have experimentally determined the fire danger indices of pine wood: groups of combustibility, flammability, flame spread over the surface, smoke-forming ability, toxicity of combustion products.

The experimental results are used as a a baseline to assess the effect of flame retardants on the fire hazard of timber. When processing data, we calculated maximum flue gas temperature, duration of self- combustion, degree of damage on length, degree of damage on weight.

Flue gas temperature T (°C) and duration of the self-combustion T_{SC} (sec) were fixed as the average value of three tests.

The extent of damage on the length S_L (%) was determined by the percentage of the length of the damaged samples to their original length and was calculated as the arithmetic average value of this ratio according to each test.

The extent of damage on weight S_m (%) was determined by the percentage of the mass of the damaged part of the sample to the initial (according to results of one test) and was calculated as the arithmetic average value of this ratio according to each test.

Assessment of flammability of wood materials was carried out by the method of GOST 30402–96, identical to the international standard ISO 5657. The technique helps to clarify investigated parameters for a given level of influence on the sample surface of the radiant heat flow and flames from the ignition source.

Test results showed that all flame retardant compositions, taken for the study, have an expected effect in decrease of heat release (as compared with unprotected wood samples). And in each case, the same pattern was repeated: flame spread occurred along the entire length of the samples.

Table 5

Probability of safe work of teams, depending on the period of time

№	Position (profession) of workers	Working hours T_s, months			
		24	12	6	3
1.	Mounter of concrete and metal structures	0,62	0,64	0,73	0,82
2.	Driver	0,83	0,86	0,88	0,905
3.	Electric welder	0,65	0,68	0,72	0,81
4.	Carpenter	0,75	0,77	0,887	0,93
5.	Locksmith	0.89	0,91	0,92	0,94
6.	Crane driver	0,9	0,93	0,95	0,96
7.	Earth mover driver	0,87	0,89	0,92	0,94
8.	Steelman	0,75	0,76	0,873	0,919
9.	Electrician	0,82	0,84	0,93	0,95
10.	Tractor driver	0,87	0,88	0,89	0,95

Table 6

The results of wood flammability determination

Name of coating	Value of critical incident heat flow, kW/m²							
	12,5	15,0	17,5	20,0	22,5	25,0	27,5	30,0
Unprotected wood	580*	220	145	90	85	70	50	45
MPVO	ni**	140	125	120	110	100	100	90
Asfor	ni	210	150	145	120	90	70	65
Ograks-V-SK	ni	ni	220	110	55	30	20	15
Negorin	ni	ni	370	60	55	50	50	45
Asfor-Extra	ni	ni	ni	730	230	150	125	110
SGK-1	ni	ni	ni	220	120	80	60	60
Ograks-PD-1	ni	ni	ni	450	320	240	175	125
OZK-45D	ni	ni	ni	660	300	140	85	60
Pirilaks	ni	ni	ni	780	255	200	130	80

Notes: * Figures show time (sec) to the ignition of samples. They are arithmetical mean value of three measurements.
** Samples did not ignite within 900 seconds of heat flow exposure.

In [7] it is noted that according to the criterion of their efficiency all flame retardants may be divided into three groups: classical means of fire protection, conditionally new agents, agents of new generation.

Relatively new agents provide flammability group G2 in the creation of saturated layer of flame retardants in surface layers of wood. They have a long-term preservation of flame retardant properties, but they also have negative characteristics: presence of odors, aggressiveness to the materials, which are part of building structures.

New generation agents have high levels of quality of fire protection, corresponding to flammability group G1. They are compatible with most weatherproof coatings.

Samples for the study were prepared in accordance with the recommendations of GOST 30244–94. Fire retardant compositions were applied with a brush in compliance with technology specified by the manufacturer [6, 7]. The experimental data obtained are presented in Table 6.

Experimental results indicate that unprotected timber ignites at value of incident heat flow of 12,5 kW / m². All flame retardant compositions (impregnating compounds, varnishes, paints) increase the limit value of incident heat flow that leads to the consequences of the same nature.

By increasing the density of heat flow to 15,0 kW / m² wood ignites, which was treated with compositions MPVO and sfor; at 17,5 kW / m² – with compositions Negorin and Ograks-V-SK; at 20,0 kW / m² with compositions SGK, Ograks-PD-1, OZK-45 Pirilaks, Asfor-Extra.

At a density of 20,0 kW / m² all tested samples ignited. Thus, depending on the type of coating it lasted from 90 to 780 seconds (exception – varnish Negorin). For large values of heat flow density time to the ignition of untreated and protected wood differs slightly.

During experiments preliminary conclusions were confirmed on the effect of fire protection on wood flammability: the expected effect, among other things, manifests itself in a more vigorous carbonization of the surface layer, creating a barrier to the heating of underlying layers, and reduction in concentration of combustible gaseous thermal decomposition products.

Conclusion. *Experiment results allow us to determine areas for improvement of flame retardant compositions, including through the use of additives, which maximize the degree of swelling (thermal expansion) of coatings. When using compositions, used in the industry, such as Pirilaks, OZK-45D and Asfor, it may be recommended to increase the rate of consumption on the protected surface.*

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