FORECAST OF WEAR OF METAL BRIDGE SPANS

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ABSTRACT

To get an objective assessment of the actual technical condition of a bridge, a mathematical model of the wear of artificial structures is designed. Weilbull law has appeared to be the best instrument between all studied laws of distribution that could be used to describe wear function. The model assesses the technical condition and its prediction in relation to the operating artificial structures on railways. The proposed design scheme, and graphs of wear function of bridge structures create conditions that will ensure maximum reliability of superstructures with a minimum of support costs.

ENGLISH SUMMARY

Background. *Frequency of repair or replacement of bridge elements is usually determined on the basis of average data. Normative terms are presented in «Technical conditions for carrying out preventative maintenance of engineering structures on the Russian railways» [1]. According to this document replacement of metal spans with support parts and supports should be scheduled every of 50–60 years, and the damaged items with their placement on high-strength bolts and components of support parts should be replaced with a periodicity of 25–30 years.*

However, the actual material parameters differ from the average, manufacturing defects, consequences of deviations from the technology can appear, operating conditions differ from those specified, etc. That is, the actual behavior of structures under external loading and environmental factors will not always coincide with the estimated model. The service life of a bridge span is projected with account of:

– state of the material of construction;

– wear level;

– intensity and nature of the load on the site of the railway and the changes in these data over time;

– intended level of load intensity in the long term;

– geographical location of the object (climatic region).

See this set of factors, it is advisable to from the control over technical condition of the bridge on the basis of standardized maintenance periods to the management on the actual state. This ensures sufficient prediction accuracy for each of the parameters of the bridge, and for all of its elements at any time after the start of operation. There is an opportunity to make the schedule of major works by keeping the bridge in good working condition, without relying on the average norm, and the actual characteristics of superstructures. This will result in enhanced reliability of the bridge, a significant reduction in the cost of its maintenance.

Objective. *The objective of the author is to construct a mathematical model of wear of artificial structures.*

Methods. *The author uses mathematical apparatus, analytical and descriptive methods.*

Results.

Model of structures' wear

To estimate the actual technical condition of the bridge we construct a mathematical model of its wear. In this case, we use the procedure set out in the regulatory document «Instruction on assessment and maintenance of artificial structures on the railways of the Russian Federation» [2]. Wear will be calculated in the form of set scores.

These scores of state $K_{пр}^{сост}$ *of artificial structures are determined by subtracting from the baseline assessments of the relevant changes, taking into account the category of defects and their number, according to the following formula:*

$$K_{пр}^{сост} = K_{баз}^{сост} - (n_I \alpha_I + n_{II} \alpha_{II} + n_{III} \alpha_{III}),$$

where $K_{баз}^{сост}$ *is base relative assessment of structures state, determined by a defect of the maximum category under the Appendix 1 [2] of those that were found during examination;*

n_I, n_{II}, n_{III} *is number of defects of respectively I, II, and III categories excluding a defect, produced during baseline assessment;*

α_I, α_{II}, α_{III} *are coefficients that take into account a category of defects according to Table П2.1 [2].*

All artificial structures are classified following presence of defects by four categories:

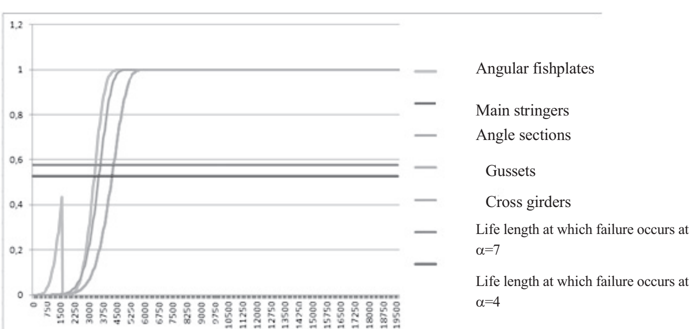
– The first – there are no defects;

– The second – there are minor defects that do not affect the security;

– The third – defects with potential security threat;

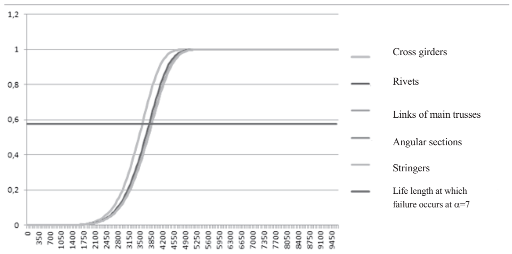
– The fourth – serious defects that affect the safety and require special conditions of operation of structures until the introduction of restrictions.

In constructing a mathematical model of wear of artificial structures it is necessary to specify the function of wear, consistent with the function of failure in reliability theory.



Pic. 1. The dependence of wear on the transmitted load for elements of metal riveted superstructure of the bridge over the river Snezhet, 375/4 km.

Pic. 2. The dependence of wear from the transmitted load for elements of metal riveted superstructure of the bridge over the river Wablya, 42 km PK4 of the section Unecha-Khutor.



Pic. 3. The dependence of wear from the transmitted load for elements of metal riveted superstructure of the bridge over the river Nerussa, 478 km of the second track of the portion of Bryansk-Suzemka-Bryansk.

To select a function of failure it is necessary to consider various laws of distribution and choose from them a model of wear which will be the most responsive to the real conditions of operation of such facilities.

Following typical distribution laws were taken [3]:

– normal

$$P(t)=\frac{1}{\sqrt{2\pi}}\int_{\frac{t-T_0}{\sigma}}^{\infty} e^{\frac{-x^2}{2}}dx\ ;$$

– gamma-distribution

$$P(t)=\int_{\lambda t}^{\infty}\frac{x^{\alpha-1}}{\Gamma(\alpha)}dx\ ;$$

– logarithmic-normal

$$P(t)=\frac{1}{\sqrt{2\pi}}\int_{\frac{\ln\frac{t}{T_0}}{\sigma}}^{\infty} e^{\frac{-x^2}{2}}dx\ ;$$

– Weibull distribution

$$P(t)=e^{-\frac{t}{\beta}t^{\alpha}}\ ;$$

– as well as exponential, which is a special case of Weibull distribution

$$P(t)=e^{-\lambda t}\ .$$

For an exponential law wear of an element at a predetermined interval depends only on the length of this interval and does not depend on the previous work time [3], while for elements of metal superstructure wear should depend on the duration of the previous operation. Therefore, for further consideration exponential law can be excluded.

Normal law simulates gradual failures that occur as a result of cumulative damage [3]. However, for it the asymmetry coefficient is equal to zero, so the law does not take into account a dramatic increase in the number of failures and thus the wear rate after the passage of the expectation, that is, the average time of operation of the element as compared with the period immediately preceding that moment. In addition, the normal law does not take into account the presence of sudden failures. And so, in the future, it makes no sense to consider it.

For gamma distribution and logarithmic-normal distribution asymmetry coefficient is positive and modeling of a sharp increase in the wear rate after passing average operating time of the element requires a negative asymmetry coefficient. Therefore, these laws are also excluded from further consideration.

The law of Weibull distribution uses negative asymmetry coefficient, which corresponds to the studied processes of aging elements of artificial structures, in particular to a sharp increase in the number of failures, the wear rate after the average period of operation of the element.

Weibull law in addition to the accumulated failures models sudden failures, and also takes into account the presence or absence of latent defects. [3]. For elements with frequent hidden defects, which for a long time do not age, the failure rate is high in the beginning of the operation, then it drops sharply. Here is a situation where Weibull law with parameter $\alpha<1$ is convenient. If hidden defects of elements are rare, but they are aging rapidly, the risk of failure increases monotonically. These items are best modeled by Weibull law with the parameter $\alpha>1$.

Thus, the analysis of all above distribution laws allowed Weibull law as the best optimal, as it is there that the curve of the distribution function most closely matches the curve of wear in artificial structures, including the fact that it grows faster after passing the point of the average operating time of the element than to this point.

Function of distribution and dependence of parameters

The dependence of wear on time will be described by Weibull distribution function

$$F(t)=1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}\ ,$$

where α is the shape parameter and β is scale parameter. Then we find a point of inflexion of the function. To do this, we differentiate it twice in t, equate the result to zero and obtain the abscissa of the point of inflection:

$$t=\beta\left(\frac{\alpha-1}{\alpha}\right)^{\frac{1}{\alpha}}\ .$$

Substituting the abscissa in wear function, we determine the value of the distribution function at the inflection point:

$$F(t)=1-e^{-\left(\frac{\alpha-1}{\alpha}\right)}\ .$$

We draw a line through the found inflection point of the graph of the function which is parallel to the x-axis. Its equation will have a form:

$$y=1-e^{-\left(\frac{\alpha-1}{\alpha}\right)}\ .$$

We calculate that at the obtained value of the wear

$$F(t)=1-e^{-\left(\frac{\alpha-1}{\alpha}\right)}$$

in the element of artificial structures a failure occurs. The obtained formulas allow us to calculate the time of failure with known coefficients α and β. These coefficients are found by the examination, i. e. the analysis of the actual technical condition.

Examination data of artificial structures were provided by road diagnostics centers with participation of bridge masters of track parts.

We give dependences of wear on the operating time for the elements of superstructures of three metal bridges:

1. Over river Snezhet, 375/4 km of Bryansk track distance. Spans are clenched on the project PSK made in 1946, established in 1947 under the design load H-7. Inspection was conducted on the 22nd of August, 2007.

2. Over river Wablya, 42 km of PK4 of the section Unecha- Khutor Mikhailovsky of Unecha track distance. Inspection was conducted on the 15th of April 2009.

3. Over river Nerussa, 478 km of the second track of the section Bryansk-Suzemka -Bryansk of Lgov track distance. Inspection was conducted on 19–21 May 2009.

Pic.1 shows the graphs of wear functions of elements of metal riveted superstructure of the bridge over the river Snezhet, which were found to be defective.

For the element angular fishplate life length at which failure occurs at α = 4 is equal to

$$F(t)=1-e^{-\left(\frac{4-1}{4}\right)}\approx 0{,}5276,$$

for the remaining elements life length, at which failure occurs at α = 7 is equal to

$$F(t)=1-e^{-\left(\frac{7-1}{7}\right)}\approx 0{,}5756.$$

For a given wear F* (t0) at a certain time moment t0 and at fixed α ratio β of Weibull function is determined from the equation

$$F^*(t_0)=1-e^{-\left(\frac{t}{\beta}\right)^{\alpha}}.$$

Chart analysis leads to the following conclusions. The design lifetime for overlays such as angular fishplate is T_n=30 years. The results obtained by the proposed prediction model of wear can extend the actual life of up to $T_ф$=31 years. Accordingly, for the main stringers of the span it is T_n=60 years and $T_ф$=81 years. The design lifetime for the main stringers is T_n=60 years, according to the proposed prediction model of wear the actual life will be $T_ф$=81 years. The design lifetime for the main stringers of the span is T_n=60 years, according to the proposed prediction model of wear the actual life will be $T_ф$=62 years.

Pic. 2 shows graphs of wear function for elements of metal riveted superstructure of the bridge over the river Wablya based on the detected defects therein.

For investigated elements life length, at which failure occurs at α=4 is equal to

$$F(t)=1-e^{-\left(\frac{2-1}{2}\right)}\approx 0{,}3935.$$

The design lifetime of web plates of a top chord is T_n=60 years, according to the proposed prediction model of wear the expected actual life is $T_ф$=63 years.

Pic. 3. shows graphs of wear functions for elements of metal riveted superstructure of the bridge over the river Nerussa in which the defects were found.

For investigated elements life length at which failure occurs at α=7 is equal to

$$F(t)=1-e^{-\left(\frac{2-1}{2}\right)}\approx 0{,}5756.$$

The design lifetime of cross girders is T_n=60 years, according to the proposed prediction model of wear the expected actual life is $T_ф$=63,4 years. The design lifetime of cross girders is T_n=60 years, according to the proposed prediction model of wear the actual life will be $T_ф$=69 years. The design lifetime of cross girders is T_n=60 years, according to the proposed prediction model of wear the actual life will be $T_ф$=57 years.

Conclusion. The proposed prediction model of wear enables to reasonably decide to extend the life of artificial structures, reduce maintenance costs while ensuring the set reliability. That is, it is possible to operate the bridge structures in terms of «reliability – costs».

Keywords: railway, bridge structure, wear function, Weibull distribution, time factor, reliability, prediction, mathematical model.

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Статья поступила в редакцию / article received 06.06.2014
Принята к публикации /article accepted 01.09.2014