Indicators of Reliability of Artificial Structures with Elements Made of Polymer Composite Materials at all Stages of Their Life Cycle on the Basis of Risk Assessment

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Abstract

Year after year the traffic density on general-purpose highways increases. Thus, actions on repairs, capital repairs or reconstruction of artificial structures are required to ensure safe uninterrupted transportation process. Currently, the issue of improvement of reliability indicators with regard to artificial structures on highways upon their construction and maintenance, with account for cost optimization on the basis of application of polymer composite materials, is topical. Polymer composite materials are plastics reinforced by high-strength fibers. Studies of experience in application of polymer composite materials in various industries of the Russian Federation and abroad have shown that it is necessary to look for new effective construction solutions for more widespread introduction and expansion of the field of application of composite materials in the practice of transport construction on highways.

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Main text

The service life of many artificial structures on highways exceeds the statutory one. While in operation, artificial

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structures accumulate defects and damages which impede their operation or reduce the load-carrying capacity. According to the effective Industry-specific Road Guidance Document (ODM) 218.3.014-2011, when assessing a technical state of bridgeworks on highways, such reliability indicators as durability, safety, carrying capacity and maintainability, depending on which the general assessment of the technical state is determined, are defined. Available experimental and theoretical studies show that application of polymer composite materials in transport structures can have a positive impact on all reliability indicators with regard to artificial structures, contributing to extension of their statutory service life [Bokarev (2010), Smerdov (2014), Smerdov et al. (2014), Ivanov (2014), Ivanov and Yashnov (2014)].

Artificial structures located on highways constitute the object of the present study. Reliability indicators of artificial structures on highways, related to use of polymer composite materials, are the subject of the study. The work objective is in improvement of reliability of artificial structures with elements made of polymer composite materials, located on highways, at all stages of their life cycle on the basis of risk assessment.

By the end of 2015, the world market volume in the sector of polymer composite materials approximated to 65 billion euros, and the total volume of the world production of polymer composite materials amounted to 8 million tons. The consumption volume of polymer composite materials in Russia amounts to 0.5–2.0 % of the world consumption.

Polymer composite materials are plastics reinforced by high-strength fibers. Plastics are obtained as a result of hardening of polymer compounds which function as a matrix uniting reinforcing fibers. In most cases, composite materials are regarded as an alternative to traditional materials: metal, concrete, and reinforced concrete. In the practice of bridge construction, polymer composite materials became widely used both as materials of the basic bearing structures or their elements and in operational facilities of transport structures [Smerdov (2013), Ushakov (2009), Shilin et al. (2007)]. Due to the fact that high-strength fibers are used in polymer composite materials, constructions made of them become stronger in comparison with constructions which are similar in the form but made of traditional materials [Ushakov (2009)].

In modern conditions, polymer composite materials are widely used in the practice of road construction when reinforcing operated artificial structures [Shilin et al. (2007)]. Composite materials are most often applied when reinforcing spans and bridge footings. There is a rather wide variety of types of composite materials, used when reinforcing bridge elements, depending on their producers. For example, composite materials of FibArm trademark of JSC “Prepreg–Advanced Composite Materials (ACM)”, when reinforcing bridges, can be used in the form of:

1) carbon tapes FibArm Tape 230/300 (FibArm Tape 530/300) and carbon fabrics FibArm Tape/multiaxial (see Fig. 1, a);
2) nonwoven fabrics made of flattened fibers FibArm Spread Tape 230/250 (FibArm Spread Tape 500/250) (see Fig. 1, b);
3) composite carbon fiber lamels FibArm Lamel HS 14/50 (see Fig. 1, c);
4) carbon grids FibArm Grid 600/1000 (see Fig. 1, d);
5) carbon anchoring cables FibArm Anchor D12 (see Fig. 1, e).
Application of polymer composite materials when reinforcing road artificial structures contributes to their reliability improvement [Nerovnykh (2013)]. To a large extent, the traffic safety is defined by safe operation of artificial structures, in particular, bridges and overpasses, namely by their technical state. Currently, the Resource, Risk and Reliability Management methodology (URRAN) [O JSC “Russian Railways” (2012)] is being introduced into the practice of usage of artificial structures, according to which safety management with regard to transport facilities’ operation shall be exercised on the basis of risk management.

This method will allow to stop applying traditional approaches, main results of which are the reduction of a number of failures, losses, and fatalities, and apply safety management according to the criterion of the risk value with regard to a particular object [Nerovnykh (2013), O JSC “Russian Railways” (2012)].

The process of risk determination consists of the following main stages:
1) risk identification — determination of potential hazardous events occurrence of which will lead to certain negative consequences;
2) analysis of frequencies and consequences — determination of probability of occurrence of undesirable events and their seriousness;
3) risk assessment — determination of the risk level;
4) risk processing — monitoring or revision, or taking measures for its level reduction depending on the risk level [Nerovnykh (2013)].

One of the main stages when determining risks is the probability analysis [Smerdov (2010)]. While in operation, artificial structures are exposed to numerous temporary loads and environmental factors. Under such conditions, they have to maintain the necessary reliability level at any probable combination of external influences. The main indicator of reliability is probability of no-failure operation, i.e. likelihood that the failure of the construction will not occur during the specified service life. The condition of no-failure operation of the construction can be presented in the following general form:

\[ P(t) \leq Ps \]  

(1)
where $P(t)$ — failure probability at the point of time $t$; $P_s$ — standard failure probability proved by the existing design practice and operating experience.

During the service life of artificial structures, their reliability, ability to bear time-varying loads and influences do not remain constant. That is, artificial structures and their exposing loads compose a dynamic system, and behavior of its components can be described by some random processes. Random processes characterizing the resistance of constructions $\tilde{R}(t, r)$ and the load $\tilde{S}(t, s)$ develop in time [Smerdov (2010)]. And the failure probability at the moment $t_1$ equals to the probability that the random variable $\tilde{s} = \tilde{S}(t_1)$ will take a value exceeding the value $\tilde{r} = \tilde{R}(t_1)$ (Fig. 2):

$$P(t_1) = P\left(\tilde{s} > \tilde{r}\right)$$

(Fig. 2)

The formula (2) can be determined in another way, i.e. as random values of loads which do not depend on the value of durability. Therefore, to assess the reliability of constructions at the point of time $t_1$, it is possible to use the known formulas of two composed distributions of independent random variables and obtain an expression for probability density of safety margin $\tilde{f} = \tilde{r} - \tilde{s}$ (Fig. 3) [Smerdov (2010)]:

$$\varphi(f) = \int_{-\infty}^{+\infty} p_{S}(\tilde{s})p_{R}(\tilde{f} + \tilde{s})ds$$

(Fig. 3)

where $p_{S}(\tilde{s})$ and $p_{R}(\tilde{f} + \tilde{s})$ — probability densities of the external load and reliability of an artificial structure, respectively determined at the point of time $t$. 

![Failure area](image-url)
Fig. 3. Distribution density of the safety margin of an artificial structure $\tilde{f} = \tilde{r} - \tilde{s}$.

Thereby, the formula (3) will take the following form:

$$P(t_1) = \int_{-\infty}^{0} \phi(t) df$$

(4)

To solve a task of determination of no-failure operation probability with regard to artificial structures, it is necessary to establish a list of probable failures and corresponding conditions of limit states, know the distribution laws of all random factors and their correlations, i.e. cross-sections of $\tilde{R}(t, r)$ and $\tilde{S}(t, s)$ processes shall be determined at the point of time for which the calculation is performed [Smerdov (2010)].

The review presented above has shown that application of polymer composite materials as elements of reinforcement for transport structures contributes to improvement of their reliability indicators. The application field of polymer composite materials in the practice of transport construction shall extend. For this purpose, it is necessary to look for new effective construction solutions for their use in artificial structures, develop new methods of their application both upon new construction and operation. Efficiency of the existing and new methods of application of polymer composite materials shall be confirmed and controlled by URRAN methodology [Nerovnykh (2013), OJSC “Russian Railways” (2012)] which will ensure reliability of artificial structures with elements made of polymer composite materials, located on highways, at all stages of their life cycle.

References


