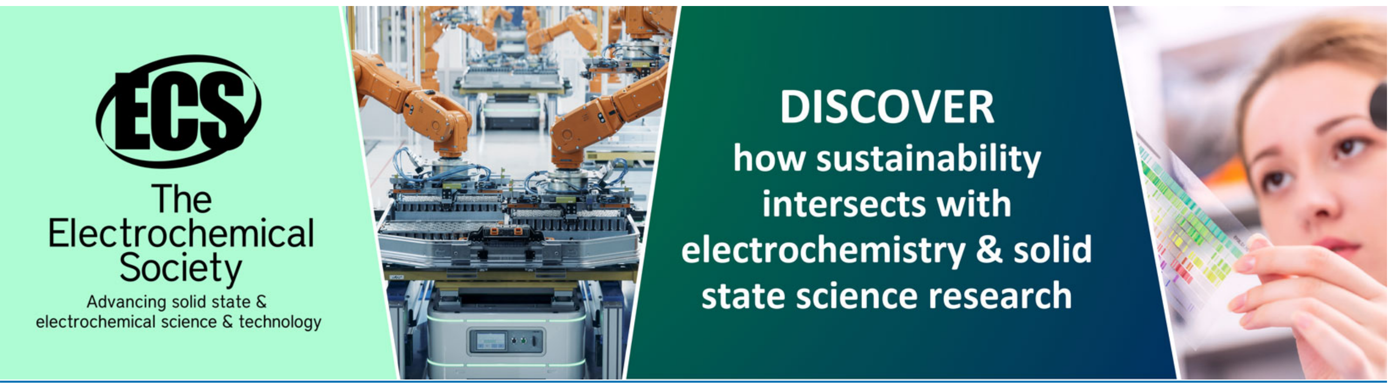
Modeling of Criteria of Reliability of Vibrating Platforms for Compaction of Construction Mixtures



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Modeling of Criteria of Reliability of Vibrating Platforms for Compaction of Construction Mixtures

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Abstract. The main criteria of vibration reliability of vibration sites of the construction industry are considered. It is proposed that the simplest and most important measure of vibration stress is the maximum value of acceleration *a(t)*, which was measured in absolute values, or in the dimensionless form of its attribution to the acceleration of gravity. One of the quality requirements is the maximum vibration acceleration, which at the points of the system does not exceed the maximum allowable values *a(t)*. As the vibration stress is 10^{-3} m in the form of a vibration displacement of 20 m/s^2, depending on the purpose of the elements of the vibrating machines, restrictions can be imposed on both absolute and relative displacements. Evaluate the magnitude of vibration stresses that occur in its elements, the strength of the system. The quality condition requires that the corresponding maximum stresses (in the case of a complex stress state – some maximum equivalent stresses) do not exceed the permissible values. Taken into account in the number of parameters of the quality of forces and moments occurring in the elements of the system, allows to calculate the bearing capacity of the elements. In any case, the vibration load over time leads to the failure of system elements, this is usually accompanied by the accumulation of relevant damage, so the most accurate approach to assessing the vibration reliability is based on consideration of the process of accumulation of damage.

1. Introduction

The main purpose of the calculations of the vibration system for the appropriate mode and design of structural elements is to minimize [1] or to the permissible level of vibration and vibration in the elements of the vibration sites [2]. The calculation of random vibration requirements is formulated in terms of general terms of the theory of reliability by specifying the quality space [3], namely the set of vibration field parameters [4] and associated physical fields [5], and the range of permissible states in this quality space – constraints and parameters of these fields [6]. To calculate the reliability function according to the known characteristics of the process $v(t)$ [7], it is necessary to find the prediction of random processes in a given area over a given period of time [8], which is the problem of the theory of emissions of random processes [9].The emission of the process $v(t)$ from the region Ω [10] is the intersection of the process $v(t)$ of the boundary surface G[12] in the direction of the external normal to it [13]. The emission is a random event [14], and the number of emissions per segment $N(t)$ is a random variable $[0; t]$. Unfortunately [15], even for a homogeneous process $v(t)$ and a one-sided type constraint $v(t) \leq v_*$ [16], the problem of emission theory allows a complete solution only in some partial cases [17]. Accordingly, it is necessary to apply approximate methods for multidimensional random processes [18] and for acceptable areas of complex concentration [19], and especially functional quality devices [20]. A satisfactory and correct solution to the emission theory problem can be found for highly reliable systems in which the emission of a quality vector from the allowable limit is unlikely [21].Cumulative failure models [22] for convex areas $\Omega$of the reliability function $P(t)$can be written using a properly selected norm in space V:$P(t) = P\{\|v(\tau)\| \leq v_*, \tau \in [0; t]\}$, where v_*–the maximum allowable value of this rule. The process $v(t)$[23] is called cumulative (quasi-monotonic) on segment T by the norm $\|v\|$, if for any $t_1, t_2 \in T$ in a given area on given segments $\|v(t_1)\| \geq \|v(t_2)\|, t_2 > t_1$. A similar example of a cumulative process is a process whose components are equal to the extent of "incurable" damage [24]. The degree of fatigue damage is introduced as $v_{k+1} = v_k + f(v_k, s_k)$, where $f(v_k, s_k)$ – some integral function from the degree of damage and some characteristic (for example, maximum) stress of the k-th load cycle s_k [25]. It is assumed that, $v_0 = 0, v_* = 1$.The reliability function of the cumulative process is directly expressed through the one-dimensional probability density of the vector v at time t: $P(t) = \int_{\|v<1\|} P(v,t)dv$, $P(t) = \int_{\Omega^{\cdot}} p(v_1, \ldots, v_n)dv_1, \ldots, dv_n$. This expression completely coincides in form with the formula for the probability of stress $v \in \Omega$ in elementary calculations for reliability [26], when the quality of the system is described by a numerical vector v.The same applies to the Markov model of failures, the evolution of the vector $v(t)$in space V is a diffusion Markov process [27], so its transient probability density $p(v, t / v_0, t_0)$ satisfies Kolmogorov equation with corresponding point conditions: $\partial p/\partial t = \sum_{j=1}^{n} \partial(x_j p)/\partial v_j + 2^{-1} \sum_{j=1}^{n} \sum_{k=1}^{n} \partial^2(x_{jk}p)/(\partial v_j \partial v_k)$.

2. Purpose of research

The purpose of our research was formation of analytical provisions of the description modeling of criteria of reliability of vibrating platforms for compaction of construction mixtures.

3. Materials and methods

With initial type conditions $p(v, t/v_0, t_0)_{t=t_0} = \delta(v - v_0)$. The intensities are equal to:

$$x_j(v,t) = \lim_{\Delta t \to 0} \Delta t^{-1} \int_{-\infty}^{+\infty} (v_j - v_{j1}) p(v, t/v_1, t - \Delta t)\, dt,$$

$$x_{jk}(v,t) = \lim_{\Delta t \to 0} \Delta t^{-1} \int_{-\infty}^{+\infty} \int_{\Omega^{\cdot}} (v_j - v_{j1})(v_k - v_{k1}) p(v, t/v_1, t - \Delta t)\, dt,$$

where v_1 – the value of a random vector process $v(t)$ at a time$t - \Delta t$. Or Kolmogorov's inverse equation, which has the following form:

$$\partial p/\partial t = -\sum_{j=1}^{n} x_j\, \partial/\partial v_{0j} - 2^{-1} \sum_{j=1}^{n} \sum_{k=1}^{n} x_{jk} \partial^2(x_{jk}p)/(\partial v_{0j} \partial v_{0k}),$$

where v_{0j} – the vector component v_0.

Conditional in relation to the vector of initial data v_0, the reliability function $P(t/v_0)$ is associated with a transient probability ratio at $t_0 = 0$:$P(t/v_0) = \int_{\Omega^{\cdot}} pv, t/v_0, t_0\, dv$. Based on the above, let the intensity x_j and x_{jk} process $v(t)$ do not depend on time. Then reliability satisfies Kolmogorov's inverse law $\partial p/\partial t = -\sum_{j=1}^{n} x_j\, \partial/\partial v_{0j} + 2^{-1}\sum_{j=1}^{n}\sum_{k=1}^{n} x_{jk}\partial^2/(\partial v_{0j}\partial v_{0k})$, according to the initial condition $P(t/v_0) = 1(t = 0, v_0 \in \Omega)$and the boundary condition$P(t/v_0) = 0, (\, v_0 \in \mathrm{G})$.

The corresponding solution of the equation can be obtained only in a few partial cases, which are not of great interest for vibration calculations. The type of boundary condition gives direction to a simple and effective way of finding approximate solutions: the reliability function is represented in the form of a series of coordinate functions that rotate (invert to zero by G), and the coefficients of the series and time functions are determined from ordinary fundamental equations of the method Bubnov-Galorkin. Approximate and two-sided reliability estimates can be determined in the process of considering probabilistic models in which failures form an ordinary flow, the probability of transforming a failure in a short period of time Δt is in order $0\Delta t$. For such models, effective reliability estimates are known, expressed in terms of emission counts. After a comparison, we can show that the function $\lambda(t)$ has the content of the failure rate. We obtain $\lambda = const$, respectively, the linear and exponential dependence of the function on time (figure 1a). In this regard, we talk about the linear and exponential evaluation of the reliability function. In this case, the right part of the formula should include the number of emissions, determined by the set of implementations that are in the region Ω at $t = 0$. So, we come to the need to consider conditional processes. However, the inequality $P(t) \geq P(0)[1 - \langle N(t)\rangle]$ is also valid if the number of emissions $N(t)$ of the unconditional process is understood (figure1b).

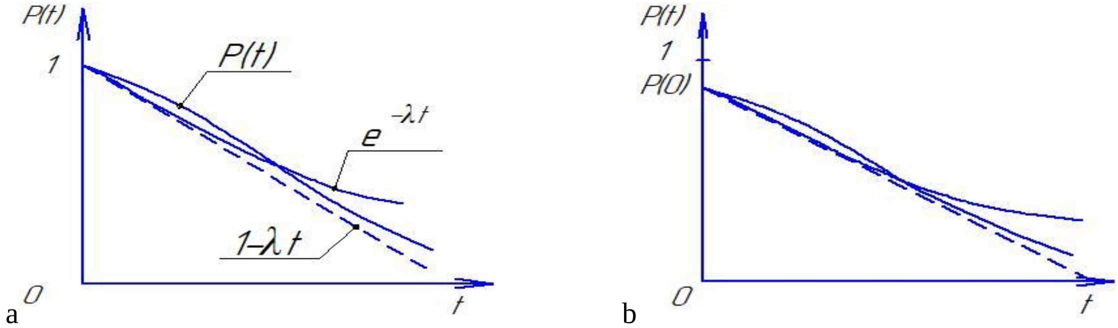

Figure 1. Reliability function and its evaluation (a) and reliability function taking into account the probability of failure at the initial time (b).

Approximate estimates of the reliability function are also valid if the number of emissions is interpreted in a certain way. If, $v(x,t)-$ scalar field, and the quality condition is given in the form $v(x,t) < v_* x \in \Omega$. Then $N(t)$ will be equal to the number $v(x,t)$ of emissions v_* by level in the space-time cylinder $\Omega_t = \Omega[0,t]$. In turn, the mathematical expectation of the number of emissions can be expressed through the mathematical expectation of the number of emissions of critical points in the field $v(x,t)$ at Ω_t. As a result, the estimation of the reliability function is reduced to the calculation of the average number of emissions from the region in a finite-dimensional space.

4. Results and discussion

Calculation of vibration reliability of optimal vibration protection the vibration platform is considered as a system described by the equation of motion $\ddot{u} + 2\varepsilon\dot{u} + uw_0^2 = -a_0(t)$.Accordingly, the quality conditions are reflected in the form $|u(t)| \leq u_*, |a(t)| \leq a_*$, where $a = a_0 + \ddot{u}$ – absolute vibration acceleration. As a criterion for the optimality of the system for reliability, the condition is chosen that the reliability functions at the time $t = T_*$ take the maximum value:

$$P(t) = P\left\{ \sup_{\tau} \|a(x_j,\tau)\| \leq a_*,\ \sup_{\tau} \|a(x_j,\tau)\| \leq u_*,\ j = 1,2,\dots,\tau \in [0,t] \right\}.$$

Given for stationary oscillations of highly reliable systems, this condition $P(t) \approx 1 - \int_0^t \lambda(\tau) d\tau$ is equivalent to the condition $\lambda(G) = min, \varepsilon, w_0$, where the average number of emissions per unit time is calculated for the rectangular range of available states. It is proposed that the process $a_0(t)$ at the output of the system is narrow-line with the carrier frequency Θ. In figure 2a shows the results of the corresponding calculation data $\lambda(G)$ at $u_* = 10^{-3}$ m and $a_* = 20$ m/s^2. In figure 2b plotted according to the calculations $\lambda(G)$ for the case of exponentially correlated process at the input with the correlation $K_{a_0}(\tau) = \sigma_0^2 \exp(-a|\tau|)$. Based on the above calculations for the values of the parameters $\varepsilon / w_0 = 0.5$, $a_* = 2\sigma_0$, $U_* = (\sigma_0 \cdot a^{-2} \cdot 10^{-4})$. Curves 1 in figure 2a and figure 2b correspond to band emissions $|a| < a_*$, curve 2 to band emissions $|U| < U_*$, curves 3 are constructed for the total number of emissions.

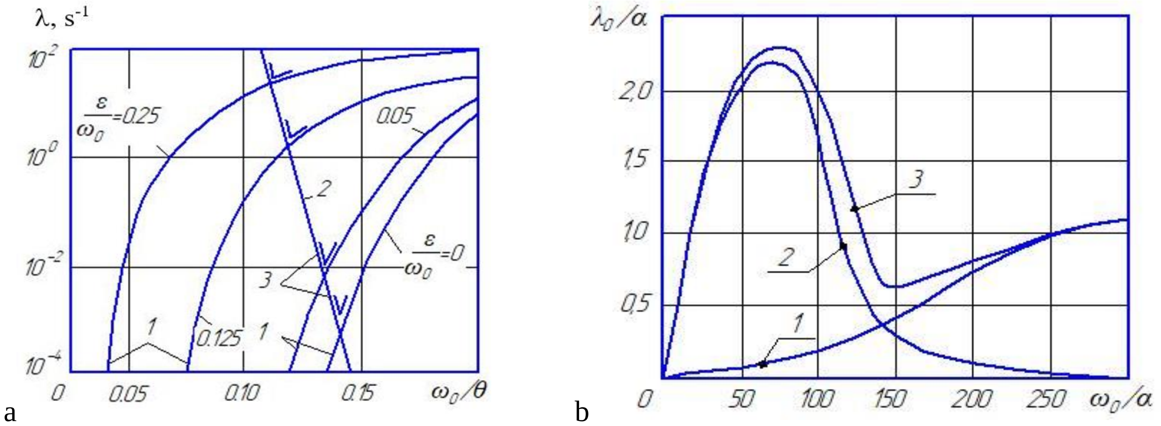

Figure 2. Reliability optimization for narrow line output (a) and exponentially correlated initial influence (b).

In order to assess the durability, use a value equal to the duration of the loadT_*, which is necessary to achieve the condition $v = v_* = 1$. Therefore, with a small scatter of durability, the value T_* is close to the mathematical expectation $\langle T \rangle$. The value T_* is called the expected durability. Accordingly, if we do not take into account the probability of instantaneous destruction due to the emission of the process $f(t)$ for the level $s_*(t)$ then the expression for the expected durability takes the form $T_* = T_e \left[\int_0^\infty p(s) \cdot ds \cdot \{N\langle s \rangle\}^{-1} \right]^{-1}$, where T_e – some effective period of the cycle, $p(s)$– distribution of the parameter s the load process $f(t)$. Accordingly, for broad-line load processes, there are different ways to select the load parameter s, which lead to different estimates of durability. To give an example of a cycle, consecutive maxima, maximum values, the half-difference of successive maxima and minima, maximum process values at some characteristic time interval, and the like are considered. To schematize a given process by loading by some equivalent narrow-line process, the following methods are proposed: emissions (number of cycles coincides with the average number of process zeros), maxima (number of cycles is taken as the average number of process maxima), scope (cycle is characterized by amplitude equal to half), complete cycles (a method that consists in the sequential removal from the process of intermediate cycles with increasing amplitudes) and so on. Considering the expression for the probability density $p(s)$ of the load parameter$s$ (t) in the case of a stationary normal process $f(t)$ in figure 3.

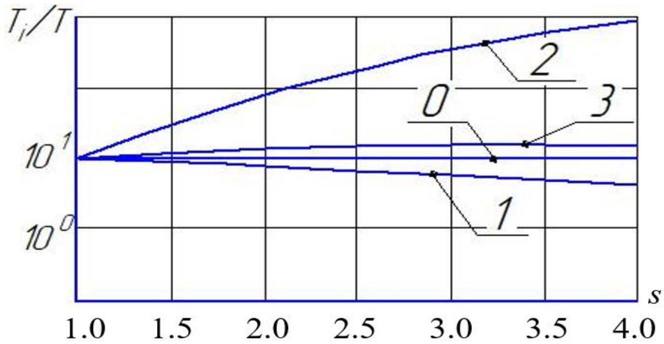

Figure 3. Comparison of estimates of expected durability in schematization by different methods: 0 – emission method; 1 –the method of maxima; 2 – the method of calculations; 3 –the method of full cycles.

The distribution of maxima is given by the formula according by: emission method $p_1(s) = s \cdot \sigma_s^{-2} \cdot \exp(-s^2 \cdot 2^{-1} \cdot \sigma_s^{-2})$, the method of calculations $p_2(s) = \beta^2 \cdot s \cdot \sigma_s^{-2} \cdot \exp(-\beta^2 \cdot s^2 \cdot 2^{-1} \cdot \sigma_s^{-2})$, the method of full cycle $sp_3(s) = c \cdot \beta^{-1} \cdot s \cdot \sigma_s^{-2} \cdot \exp(-s^2 \cdot 2^{-1} \cdot \sigma_s^{-2})$, where β– the coefficient of broadness of the process; a, c, s– some constants. The nature of the dependence of the expected durability on the nature of broadness is shown in figure 3. Accordingly, the expected durability T_i, which corresponds to the probability density. The calculations take into account thats_1, $m = 5$. The method of maxima gives a bottom estimate for the expected durability, the method of spans and full cycles – inflated values of this estimate. For narrow-line processes, all of the above methods lead to almost identical results.

5. Conclusions

1. It is proposed that the simplest and most important measure of vibration stress is the maximum value of acceleration *a(t),* which was measured in absolute values, or in the dimensionless form of its attribution to the acceleration of gravity.

2. One of the quality requirements is the maximum vibration acceleration, which at the points of the system does not exceed the maximum allowable values *a(t)*. As the vibration stress is 10^{-3} m in the form of a vibration displacement of 20 m/s^2, depending on the purpose of the elements of the vibrating machines, restrictions can be imposed on both absolute and relative displacements.

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