

# Statistical features of concrete destruction at background intensity of seismic impacts

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**Abstract.** The results of analytical studies of the effect of statistical asymmetry on the controlled parameters of concrete under the seismic effect of background intensity.

## 1 Introduction

The State Standard R ISO 2394-2016 provides for compulsory calculation and analytical procedures associated with the assessment at the stage of accepting the design decisions of the reliability of building structures within the specified period of operation. In essence, they are reduced to the analysis of dynamic models with. In such a formulation, the reliability of the construction does not appear to be its property and can be analyzed by methods of mathematical statistics in conjunction with the determining parameters of the equivalence of the external environment. The expected wear of the element is considered as a temporary fatigue process with various cumulative effects (transformation of the structure, accumulation of deformations, microcracks, etc.) until the appearance of signs of one of the calculated limiting states. In this case, the diagnosis of cumulative failure is identified with the achievement of one or more parameters of the material quality of the pre-admissible values. Analysis and statistical justification of the factors characterizing the dynamics of the decreasing reliability of concrete and reinforced concrete structures in the background manifestations of seismic impacts constitute the goal of this paper.

## 2 Materials and methods

Statistical patterns of changes in a number of strength and deformation properties are analyzed on the basis of experimental studies performed in the Irkutsk National Research State University [6], in which the influence of background seismic influences is modeled by repeated loads of prismatic B25 concrete samples in the age of two months. The number of cycles ( $N$ ), the loading level ( $\eta$ ) of equation (1), and the cycle characteristic ( $\rho$ ) of equation (2) are considered as variable parameters of impacts.

$$\eta = \sigma_b / R_b \quad (1)$$

$$\rho = \sigma_{min} / \sigma_{max} \quad (2)$$

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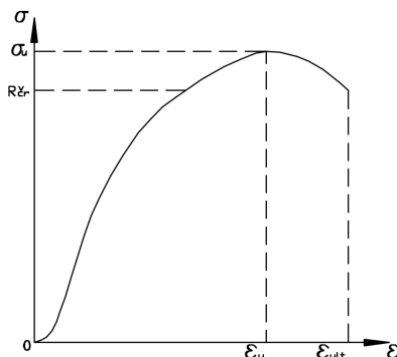
Full results of static tests after completion of the adopted cycles of exposure are given in the above-mentioned paper [6]. Below we analyze their convergence with different types of theoretical models in order to choose an approximation variant that allows us to predict the characteristic (normative) values of the parameters of the properties with the smallest error. In this case, symmetric (Gauss) and asymmetric (positive and negative) distribution functions are considered, taking into account the physical regularities of fatigue failure of concrete characterized by extreme changes in the process of cyclic influences, allowing to minimize the error from the uncertainty of their recovery from the experimental samples of limited volume. Convergence of empirical and hypothetical distributions was estimated by Kolmogorov's criterion [4], equation (3).

$$D_n = D_n(X) = \sup_{-\infty < x < \infty} |\hat{F}_n(x) - F(x)| \quad (3)$$

The hypothesis is considered acceptable if it does not exceed the critical level for the established security (significance). With comparative values of the criterion for several types of distributions, the hypothesis with the minimum deviation estimated by the coefficient of correspondence ( $k_c$ ) was taken as the approximating one (4).

$$k_c = \frac{\lambda_p - D_n}{\lambda_p} \cdot 100\% \quad (4)$$

The higher the value ( $k_c$ ) is, the greater the probability of validity of the hypothesis in question. If the value of ( $k_c$ ) is negative, the hypothesis is rejected. Based on the objectives of this study and taking into account the physical patterns of fatigue failure of concrete [1, 2, 3, 5, 7], the parameters of strength ( $\sigma_{max}$ ) of cracking ( $R_{cr}^v$ ), maxima ( $\epsilon_u$ ) and limiting ( $\epsilon_{ult}$ ) of deformations were considered as controlled parameters of their quality (Fig. 1). Their choice is due to high sensitivity to the low-cycle impacts under consideration, the use in functional normative functional models of the performance of reinforced concrete structures, the possibility of system control, standardization.



**Fig. 1.** Diagram of concrete deformation, conventional notation of strength and deformation parameters of concrete.

### 3 Results and discussion

The generalized results of the probabilistic statistical analysis are given in Table 1. They show a clear regularity in the transformation of the distribution of practically all parameters being controlled (with the exception of limiting deformations) in the direction of asymmetric approximations. The maximum value of the asymmetry coefficients is in the range of -0.94 - 1.42. The Kolmogorov's coefficient of compliance for asymmetric samples is 70 percent or more in most cases and indicates an acceptable level of convergence of the hypotheses under

consideration, as well as the reliable data of probabilistic forecasts based on them. Moreover, the latter refers to the estimation of quantiles of the established level of security with a priori conservation of the median (average) value of the experimental sample. Tables 2 and 3 show the probabilistic values of the controlled parameters of the 95% confidence limits under the assumption of a normal and asymmetric approximation of the distribution. Significant differences, especially in assessments of the strength and the boundary of microfractures, allow us to assert that it is necessary to take into account the transformation of the nature of distributions in the process of background seismic influences. Moreover, the nonidentity of the kinetics of changes in the strength and deformation parameters confirms gradual changes in the structure in the direction of development of pseudoplastic deformations (microfractures). This is confirmed by an increase in specific deformations on the descending section of the deformation diagram of the concrete. As to the degree of influence of individual parameters of cyclic background influences, the experimental base used does not allow to give an accurate quantitative estimate. The previously established [6] positive effect of limited ( $\eta$ ) and moderate ( $\rho \geq 0.3$ ) cycles on the formation of more ordered structures with increased resistance parameters is confirmed. This predetermines the extreme nature of the kinetics of their changes in the temporal aspect.

**Table 1.** Comparative data of convergence of normal and asymmetric distributions.

Parameters of cyclic influences	Controlled property indicators	Dimension of indicators	The preferred approximating distribution	$k_c, \%$	
				Normal distribution	Asymmetric distribution
1.	2.	3.	4.	5.	6.
$N = 100, \rho = 0, \eta = 0,6$	$R_b$	MPa	Reflected lognormal	57,9	60,3
	$R_{cr}^v/R_b$	-	-    -	80,7	81,5
	$\epsilon_u$	%	Logonormal	69,2	73,5
	$\epsilon_{ult}$	%	Gamma	36,2	42,2
$N = 100, \rho = 0, \eta = 0,8$	$R_b$	MPa	Reflected lognormal	33,9	44,1
	$R_{cr}^v/R_b$	-	Reflected Gamma	56,1	67,7
	$\epsilon_u$	%	Normal	80,0	-
	$\epsilon_{ult}$	%	The sum of the reflected lognormal and normal	81,4	88,1
$N = 100, \rho = 0,3, \eta = 0,8$	$R_b$	MPa	Logonormal	65,9	68,7
	$R_{cr}^v/R_b$	-	Reflected Gamma	70,1	71,1
	$\epsilon_u$	%	Normal	74,2	-
	$\epsilon_{ult}$	%	Gamma	83,2	83,9
$N = 50, \rho = 0, \eta = 0,8$	$R_b$	MPa	Logonormal	65,8	69,3
	$R_{cr}^v/R_b$	-	-    -	67,2	68,9
	$\epsilon_u$	%	-    -	60,3	71,8
	$\epsilon_{ult}$	%	-    -	56,3	69,3

**Table 2.** The influence of the number of cycles on the parameters of the security monitored parameters (95%).

Parameters of concrete properties	Dimension	The initial state		After the expiration of $N$ cycles, $c, \rho = 0, \eta = 0.8$			
		Under normal distrib.	When considering the asymmetry	50		100	
				Normal distrib.	Asym. distrib.	Normal distrib.	Asym. distrib.

$R_b$	MPa	34,7	-	37,3	37,4	31,6	19,1
$R_{Cr}^v/R_b$	-	0,86	-	0,87	0,88	0,84	0,72
$\varepsilon_u$	‰	2,5÷3,5	-	2,2÷3,1	2,2÷4,6	1,5÷3,3	1,4÷3,2
$\varepsilon_{ult}$	‰	2,9÷4,8	-	2,8÷4,1	2,9÷5,7	1,9÷4,4	1,8÷4,3
$\varepsilon_u/R_b$	‰ / MPa	0,07÷0,1 1	-	0,06÷0,0 81	0,06÷0,11	0,05÷0,1 1	0,07- 0,18
$\varepsilon_{ult}/R_b$	‰ / MPa	0,08÷0,1 4	-	0,075÷0, 11	0,08÷0,15	0,06÷0,1 4	0,09÷0,2 2

**Table 3.** Influence of parameters of the impact cycle on changes in the security controlled parameters (95%).

Parameters of concrete proper.	Dimension	After 100 cycles, $\rho = 0$ , when:				After the expiration of $N$ cycles, $\eta = 0,8$ , when:	
		$\eta = 0,6$		$\eta = 0,8$		$\rho = 0,3$	
		Normal distribution	Asym. distrib.	Normal distrib.	Asym. distrib.	Normal distrib.	Asym. distrib.
$R_b$	MPa	43,3	39,7	31,6	19,1	27,6	27,7
$R_{Cr}^v/R_b$	-	0,89	0,83	0,82	0,74	0,78	0,66
$\varepsilon_u$	‰	2,3÷3,8	2,4÷3,8	1,4÷3,3	1,4÷3,2	1,5÷2,6	1,6÷2,7
$\varepsilon_{ult}$	‰	3,3÷4,9	3,3÷5,0	1,8÷4,3	-	2,0÷3,2	2,0÷3,3
$\varepsilon_u/R_b$	‰ / MPa	0,05÷0, 09	0,06÷0,10	0,04÷0,1 0	0,07÷0,17	0,05÷00 9	0,06÷0,1 0
$\varepsilon_{ult}/R_b$	‰ / MPa	0,08÷0, 11	0,08÷0,13	0,06-0,14	-	0,07÷0,1 2	0,07÷0,1 2

## 4 Conclusion

1. Multiple cyclic effects, comparable in terms of the level of the stressed state of the elements with background seismic, contribute to the development of cumulative structural changes in concrete up to the appearance of parametric failures.

2. Taking into account the established statistical regularities, dynamic models of probable forecasts of cumulative failures should be taken as asymmetric distributions of indicators of the controlled parameters of strength and deformation properties.

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