Joint work of layers of different strengths in reinforced concrete multi-layered construction at compression

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Abstract. Currently, a lot of attention in the construction industry is given to the issues of ensuring the reliability of reinforced concrete structures at all stages, both manufacturing, design and operation. In this regard, this article conducted a study of the reliability and durability of multi-layered structures with a monolithic connection of layers in order to reduce the own weight of such elements and the cost of construction and repair. The method of determining the average strength in the section of the element is presented, which allows the forecast of the durability of multi-layered reinforced concrete structures and allows to determine the overall work of each component, regardless of their number and the moment connection time, as well as defects in the manufacture and damage caused during operation, various physical-mechanical and rheological characteristics of materials of layers of multi-layered structure, actual tense-deformed multi-layered parts as they work together. The presented method of calculation is based on the fundamental dependence of stresses and deformations in concrete, applied to a compressed multi-layered element.

1. Introduction
The current state of concrete strength theory accurately determines the relationship between stresses and deformations, taking into account the features of concrete work and types of tense condition, as well as power anisotropy and duration of pressure.

Today, extensive experimental data have developed criteria for long-term concrete strength for various tense states. Special attention deserves facilities that work in conditions of difficult tense state.

As it was stated in the works [1, 2], that with the pre-known characteristics of the strength of a particular concrete, the properties of its composite components, it is possible to predict the limit of short-term deformations, creep deformations and module the elasticity of the concrete, depending on its strength at the time of the download.

The mechanism of concrete hardening is accompanied by a complex set of factors that affect the long-term strength of concrete.

The studies of the various authors provide fairly accurate and algorithmically convenient methods of assessing the tense-deformed state of concretes [3, 4], the influence of power-pumping regimes. predicting the behavior of pre-stressed reinforced concrete elements [5], taking into account the non-linearity of force resistance, the effect of destructive processes on the long-term strength of concrete [7], and the downward branch of the deformation chart [8].

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2. Method
The properties of materials vary from point to point for various reasons in the body structure, including in the cross-section. The tensions in the cross-section of a multi-layered element with a monolithic bond of layers differ from evenly distributed even in central load. It is reasonable to assume that these properties can be described by probabilistic distribution laws, which will explain some of the phenomena obtained earlier in the experiments [9-15]. When compressed, the element has a homogeneous tense-deformed state of concrete in the cross-section of reinforced concrete multi-layered elements with a monolithic connection of layers. Modern theories of force resistance of materials operate in average strains. For example, when testing a concrete prism loaded with central force $P$, there are evenly distributed stresses $\sigma = \frac{P}{A}$, where $A$ - the area of the cross section of the prism.

By taking measurements of longitudinal deformations when force changes $P$, we get an experimentally known dependence «$\sigma - \varepsilon$» in time with instant in a static sense or mode change of power $P$.

Not to mention a specific distribution law, based on the fact that the experimental concrete diagram «$\sigma - \varepsilon$» with short-term loading is curvilinear at the load stage and linear when unloading, can be explained by the appearance of a downward branch by adopting the condition that the properties of the material on a single cross-section site are changed according to any distribution law $(\sigma)$. If you take a character of the strength of the material $\sigma$, appearing with frequency $P$, then

$$\int_{-\infty}^{\infty} P(\sigma) d\sigma = 1.$$  

3. Results
With the gradual load of the prototype, the stresses on the elementary sites increase and the weakest links are destroyed at the very beginning. Since their strength is small, their destruction will have little impact on the behavior of the prototype. The diagram «$\sigma - \varepsilon$» is almost linear at the beginning of the coordinates, which is due to linear deformation of fibers [16].

The number of links that fail increases with growth of a load and the remaining links are already less rigid. The curve «$\sigma - \varepsilon$» becomes nonlinear because the rigidity function $E(\sigma)$ is relatively nonlinear to $\sigma$.

Experimentally, it is established that when unloading deformations change almost linearly, because when unloading destroyed links do not work. The growth of strength does not compensate for the decrease of the whole (not destroyed) part of the cross section and there is appears a descending branch at the magnitude of the load, which leads the destroyed part beyond the extreme distribution function. Accepting that the strength by the area of the section of the compressed reinforced concrete element changes according to the law of normal distribution, then it is possible to record

$$P(\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\sigma - B_m)^2}{2\sigma^2}},$$

where the average quadratic deviation $\sigma = \nu B_m$, and $\nu$ - the factor of variation (variability) of the strength of concrete, then

$$P(\sigma_b) = \frac{1}{\sqrt{2\pi\nu B_m}} e^{-\frac{(\sigma_b - B_m)^2}{2\nu^2 B_m^2}}$$

There are known different dependence of the initial module deformations on the strength of the material. We will approximate this dependence in the form of Roche - Graf:
\[ E = \frac{aB}{(cB + b)}, \]  

(2)

Where \( B \) - the class of concrete (MPA), \( a=54752c \) and \( b=20.3c \) - coefficients, determined by the values of the initial elasticity module depending on the class of concrete.

Depending on the prism strength of the concrete (2) will have a look:

\[ E_b = \frac{54752R_b}{R_b + 14.62}, \]  

(3)

where \( R_b = 0.72B \).

During the tests, except instant, partially manifested by strain creep.

Taking into account the deformation of concrete in short-term loaded prisms are recorded in a linear production

\[ \varepsilon_b(\sigma_b) = \frac{\sigma_b}{E_b} + C(t, t, \sigma_b)\sigma_b, \]  

(4)

where \( C(t, t, \sigma_b) = 0.2C(\infty, 28) \).

Characteristics of non-linearity of deformation:

\[ \varphi(\sigma_b) = E_bC(t, t, \sigma_b). \]  

(5)

Then (5) you can rewrite it

\[ \varepsilon_b(\sigma_b) = \frac{\sigma_b}{E_b} (1 + \varphi(\sigma_b)) \]  

(6)

After approximation of the dependence of the marginal measure of creep from the prism strength of concrete we get:

\[ C \ (28, \infty \times 10^6 = 189,2 - 4.2R_b, \]  

(7)

and

\[ \varphi(\sigma_b) = (37,84 - 0,84 \times \sigma_b) \times \frac{54752\sigma_b}{\sigma_b + 14,62}. \]  

(8)

Integrating efforts in the unbroken fibers of concrete at deformations, we get the values of average stresses in the cross section at the given deformations

\[ \sigma_b(\varepsilon_1) = \int_{R_b}^\infty \frac{1}{\sqrt{2 \times \pi \times \nu B_m}} \int_{R_b}^\infty e^{-\frac{(\theta-B_m)^2}{2\nu^2\theta_m^2}} \times \frac{E_b(R_b)}{1 + \varphi(R_b)} dR_b. \]  

(9)
If the variability of the average stresses in the multi-layered structure section is zero and the destruction of the structure is determined solely by the size and spread of its strength characteristics, we will come to one of the private cases of the reserve factor, the reverse the amount of which is called the homogeneity factor. The homogeneity ratio is expressed through the strength of the design and equals

\[ k_o = 1 - \sqrt{B_m}. \]  

(10)

### Table 1. The components of the calculation are reduced

| Concrete strength variation factor, \( \nu \) | Medium-square deviation, \( \sigma \) | Probability of destruction, \( P \) | Homogeneity ratio, \( k_o \) |
|-------------------------------------------|---------------------------------|---------------------------------|-----------------------------|
| 0.2841                                    | -0.8                            | 0.2119                          | 0.773                       |
| 0.2529                                    | 0.9                             | 0.1841                          | 0.772                       |
| 0.2234                                    | -1.1                            | 0.1587                          | 0.777                       |
| 0.1974                                    | -1.2                            | 0.1357                          | 0.783                       |
| 0.1737                                    | -1.3                            | 0.1151                          | 0.792                       |
| 0.1522                                    | -1.4                            | 0.0968                          | 0.802                       |
| 0.1326                                    | -1.5                            | 0.0808                          | 0.814                       |
| 0.1148                                    | -1.6                            | 0.0668                          | 0.828                       |
| 0.0988                                    | -1.7                            | 0.0548                          | 0.842                       |
| 0.085                                     | -1.8                            | 0.0446                          | 0.856                       |
| 0.0714                                    | -1.9                            | 0.0359                          | 0.871                       |
| 0.0598                                    | -2.0                            | 0.0287                          | 0.886                       |
| 0.0497                                    | -2.1                            | 0.0228                          | 0.901                       |
| 0.0409                                    | -2.2                            | 0.0179                          | 0.914                       |
| 0.0333                                    | -2.3                            | 0.0139                          | 0.927                       |
| 0.0268                                    | -2.4                            | 0.0107                          | 0.938                       |
| 0.0214                                    | -2.5                            | 0.0082                          | 0.949                       |
| 0.0169                                    | -2.6                            | 0.0062                          | 0.958                       |
| 0.0132                                    | -2.7                            | 0.0047                          | 0.966                       |
| 0.0102                                    | -2.8                            | 0.0035                          | 0.972                       |
| 0.0077                                    | -2.9                            | 0.0026                          | 0.978                       |
| 0.0059                                    | -3.0                            | 0.0019                          | 0.983                       |
| 0.0043                                    | -3.1                            | 0.00135                         | 0.987                       |

4. Discussion

Today, the most important area in the progressive technologies of the construction industry is to obtain concrete of such quality as to ensure both reliability and durability, and to reduce the own weight of design elements and cost [17]. Multi-layered constructions are traditionally made of lightweight concrete and using the presented method of determining the average strength in the section of the element allows the forecast of the durability of multi-layered reinforced concrete constructions and allows to determine in general the work of each component, regardless of their number and the time of the connection, as well as defects in the manufacture and damage caused during operation, various physical-mechanical and reological
characteristics materials of layers of multi-layered design, the actual tense-deformed state of multi-layered constructions when they work together. From this method of calculation follows the commonality of physical meaning on the basis of a fundamental dependence of stresses and deformations in concrete, considered for a compressed multi-layered elements [18]. The principle of dependency, discussed in this article, allows you to almost solve the entire list of tasks that arise during calculations. The proposed technique allows take into account the process of redistribution of stresses between layers in multi-layered structures with a rigid connection between layers. In the case reviewed, the long and instantaneous average strength of the concrete in the cross-section would be nothing more than the maximum stress on the chart with prolonged or instant compression.

References
[1] Alexandrovsky S.V., Solomonov V.V. Dependence deformations the creep of aging concrete from entry-level stresses, inter-industry construction issues. Domestic experience. Reference collection, - 1972, Pp.6-12.
[2] Bazhenov Y.M. Concrete Technology. M.: ACB, 2002. 500 p.
[3] Bondarenko V.M. Some fundamental questions of the development of reinforced concrete theory. V Intercollegiate Conference, - MGAKHIS, Moscow, 2009.
[4] Berlinova M.N., Berlinov M.V., Tvorogov A.V. Entropy criterion of concrete strength in construction constructions / Scientific Review. 2015. No.22. Pp. 162-166.
[5] Zveryaev E.M., Berlinov M.V. and Berlinova M.N. The integral method of definition of basic tension condition of anisotropic shell. International Journal of Applied Engineering Research. 2016. T.11. №8. Pp. 5811-5816.
[6] Tvorogov A.V. Diagrams of concrete deformation. In the book: Construction - formation of living environment. Proceedings of the Eighteenth International interuniversity scientific-practical conference of students, undergraduates, graduate students and young scientists. Moscow. 2015. Pp.1005-1007.
[7] Tvorogova M.N. Resistance to the deformation and destruction of reinforced concrete structures, taking into account non-linear and unbalanced properties and modes of heating / Thesis on the Ph.D. degree. -Moscow, 2006.
[8] Nazarenko V.G., Tvorogov A.N., Lukantsov P.N. O to the construction of the functions of aging concrete / Concrete and reinforced concrete. -2010. No.1. Pp.6-10.
[9] Korol E.A., Berlinova M.N. Development of methods of calculating multi-layered fencing structures with monolithic connection of layers. - Moscow : MISI Publishing House - MOSCOW, 2018. (Library of Scientific Developments and Projects of the Moscow State University). Scientific electronic publication.
[10] Korol E.A. Three-layered reinforced concrete structures made of light concrete and features of their calculation. Monograph. ASV Publishing House. 2001.
[11] Berlinov M.V. 2017 Developing the phenomenological equations triaxial deformation of concrete under dynamic loads In MATEC Web of Conferences. V106. P 4008.
[12] Korol E.A, Berlinov M V and Berlinova M N 2017 The long term stability of multilayer walling structures In MATEC Web of Conferences V.106. P. 4006.
[13] Korol E., Kagan P., Barabanova T. Automation of the formation of organizational technological documentation. Applied Mechanics and Materials. 2015. T. 738-739. 444 p.
[14] Korol E.A., Berlinov M.V. Berlinova M.N. Kinetics of the strength of concrete in constructions. Procedia Engineering. 2016. Pp. 292-297.
[15] Recommendations for the calculation and design of frame structures using monolithic insulating concrete with high-poroused and plasticized matrix. Moscow. 2006.
[16] Russian State Standard SP 63_13330_2017.
[17] Chinenkov Yu.V. and Korol E.A. (1999) Bending three-layered enclosing structures made of lightweight concrete for the second stage of building heat protection Concrete and reinforced concrete. No 3. Pp 2-9.

[18] Korol E A 2004 Deformation model for calculating three-layer Ferro-concrete elements Proceedings of higher educational establishments. No 5. Pp 11-17.