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CONCRETE DEFORMATION MODEL FOR RECONSTRUCTED REINFORCED CONCRETE

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Abstract: During the reconstruction, or upon expiration of the service life, as well as after external impact, reinforced concrete structures require examination and verification calculations. Existing diagrams of concrete deformation are focused on designing new structures and are not adapted to the concretes of the reconstructed structures. Using the world experience in describing alloy deformation, the concrete deformation model based on using the Arrhenius equation is proposed in this article. A technique for creating an individual deformations model during the reconstruction is demonstrated on a specific example. The physical meaning of the coefficients used in the proposed model is illustrated. Examples confirming the adequacy of the proposed concrete deformations model during the reconstruction are given.

Keywords: stress-strain diagram of concrete, reconstruction, reinforced concrete, compressive strain

МОДЕЛЬ ДЕФОРМИРОВАНИЯ БЕТОНА ДЛЯ РЕКОНСТРУИРУЕМОГО ЖЕЛЕЗОБЕТОНА

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Аннотация: При реконструкции во время эксплуатации сооружения, либо при необходимости продления срока его эксплуатации, железобетонные конструкции требуют обследования и проведения поверочных расчетов. Существующие диаграммы деформирования бетона ориентированы на проектирование новых конструкций и не адаптированы для бетонов реконструируемых сооружений. Используя мировой опыт описания деформирования металлических сплавов, предложена модель деформирования бетона на основе уравнения Аррениуса. Описана методика построения индивидуальной модели деформирования при реконструкции с использованием конкретного примера. Проиллюстрирован физический смыл коэффициентов, используемых в предлагаемой модели. Приведены примеры, подтверждающие адекватность предлагаемой модели деформирования бетона при реконструкции.

Ключевые слова: диаграмма деформирования бетона, реконструкция, железобетон, относительные деформации

INTRODUCTION

The number of structures that require inspection and verification calculations increases every year. One of the most modern and accurate calculation method is the diagram method. The basis of such method is a mathematically described dependence that relates strain to stress (σ–ε) [1]. There are a significant number of different proposals describing the dependence (σ–ε) [2], however all of them are focused on the design of new structures. This means that they are developed for a range of concrete characteristics that fall within the framework established by regulatory documents. During the long-term operation, concrete changes its deformation and strength characteristics, especially when it exposed to an aggressive environment or high temperatures. For such concretes, the ratio between strength and deformability goes beyond the standard one. Therefore, the existing relations (σ–ε) require adjustment, which is impossible without additional labor-intensive scientific and experimental studies.

METHOD

There are a number of analytical descriptions of the σ–ε curves for metals and alloys based on the well-known Arrhenius equation obtained to describe the kinetic processes occurring in gases:

$$k=A\cdot e^{-Ea/R\cdot T}, \qquad (1)$$

where k is the constant for chemical reaction rate; $A=(a\cdot T^{1/2})$ is the total number of molecular interactions; e is base of natural logarithm; Ea is the activation energy J/mol; R is the gas constant 8.31 J/mol·T; T is the temperature measured in K.

Based on the well-known Arrhenius equation, Zeger [3] proposed a logarithmic dependence of the relationship between stresses, temperature and metal strain rate. Davidenkov, using the Arrhenius equation, obtained the relationship between the yield strength of the metal and the strain rate [4]. A number of researchers noted that the logarithmic dependences of strains and stresses are in good agreement with experimental data for aluminum [5] at room temperatures.

Polukhin [5] proposed to use the Arrhenius equations in order to obtain the relationship between temperature, stresses and strains in metals. Besides, he applied a similar equation to determine the number of equilibria point defects in a metal, which allow consideration of microdefects in the material.

Let us focuses on the features of the application of the Arrhenius equation for concrete, which is a more complex multicomponent and inhomogeneous material that has many more structural defects compared to metals.

Taking into account the defects and microcracks in concrete, which close with increasing strains under load, and involve an increasing number of bonds, the coefficient A should obviously be a function of strains.

For concrete, it can be taken in the form

$$A=(a\cdot T^{1/2})=a\cdot \varepsilon^{b}, \qquad (2)$$

where a and b are the coefficients determined from boundary conditions; ε is the strain.

As in equation (1), coefficient *a* reflects the number of connections involved, i.e., actually reflects the strength properties of concrete. In the Arrhenius equation, the total number of bonds involved changes with temperature, which is typical for a gas. If there is no dependence of concrete strain on temperature, the variable T - was replaced by the variable ε similarly to the assumptions of Seger. Thus, the dependence of stresses on strain for concrete can be represented as:

$$\sigma(\varepsilon)=a\cdot\varepsilon^{b}\cdot e^{\frac{-b\cdot\varepsilon}{p}} \qquad (3)$$

The resulting expression (3) is recommended to be used to describe the dependence (σ–ε) of concrete during reconstruction. The values of the coefficients *a* and *b* are finded from the survey results.

RESULTS AND DISCUSSION

As an example, a diagram of a concrete specimen cut from a reinforced concrete girder of rectangular cross section of 400 x 200 mm have been constructed using the test results. Design reinforcement consisted of 3 bars of Ø28 placed in one row (Rs=400MPa, Es=200 103MPa). At the time of the survey, the structure had been under operation for over 30 years. The maximum compressive stress in concrete during testing was 32 MPa, the strain was 0.003. In addition, it was found that compressive stress in concrete of 6.4 MPa corresponded to strain of 0.0005. The expression (3) was written using the data established during the testing of the specimen:

$$32 \cdot 10^6 = a \cdot 0{,}003^b \cdot e^{\frac{-b \cdot 0{,}003}{p}} \qquad (4)$$

$$6{,}4 \cdot 10^6 = a \cdot 0{,}0005^b \cdot e^{\frac{-b \cdot 0{,}0005}{p}} \qquad (5)$$

Having solved equations (4) and (5) together, the values of the coefficients for expression (3) have been determined as follows: $a = 2.958 \cdot 10^{12}$ and $b = 1.679$. The curve σb(εb) has been developed for the reduced values of these coefficients as illustrated in fig. 1.

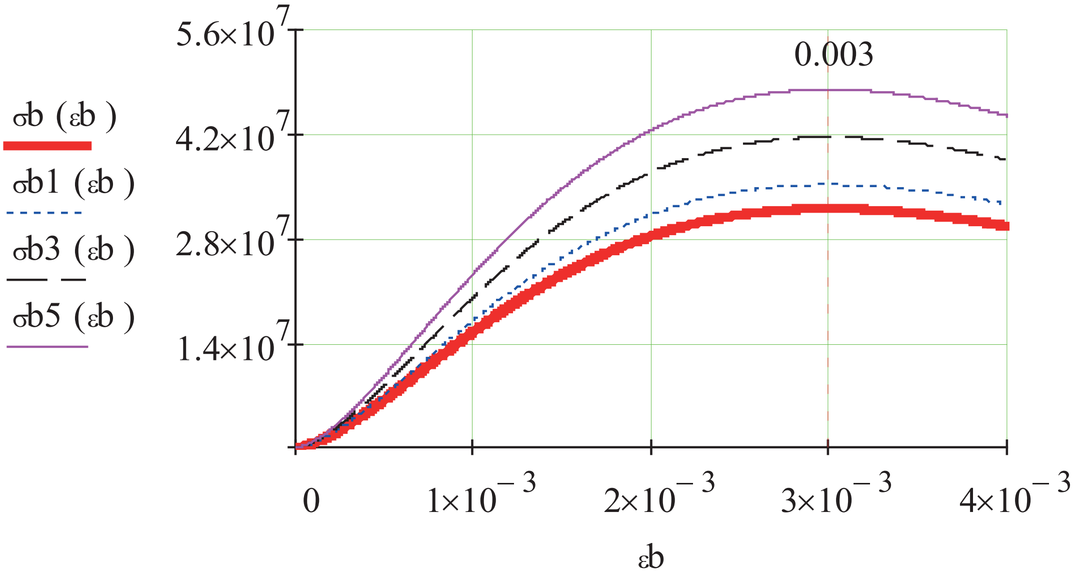

Figure 1. Concrete stress-strain diagrams for various values of the coefficient a

Analysis of equation (3) shows that an increase in the coefficient ***a*** lead to a proportional change in the maximum stresses in the diagram. The curves σ1(ε), σ3(ε), σ5(ε) are plotted for the coefficients ***a*** increased in 1.1; 1.3 and 1.5 times, respectively. As a result, the value of the maximum stresses in the diagram increased to 35.2 MPa, 41.6 MPa, and 48 MPa, respectively. The strain value at the maximum stress did not change.

Concrete is a heterogeneous material with pores and structural defects, which lead to a decrease in the angle of inclination of the tangent to the axis of strain at the initial stage of loading. This fact was demonstrated in the studies of many authors, including Berg [6]. The coefficient b of the proposed deformation model accounts the effects of the physical and mechanical properties of an inhomogeneous material with pores and structural defects.

The effects of the coefficient b on the diagram are illustrated in fig. 2. The curves σ1(ε), σ3(ε), σ5(ε) were constructed for the coefficients ***b*** increased in 1.1, 1.3, and 1.5 times, respectively, with simultaneous proportional correction of the coefficient ***a*** to the initial level of maximum stresses on the diagram. Such correction is necessary due to the fact that the coefficient ***b*** is also included in the first part of equation (3). Respectively, one numerically affects the reflection of the strength characteristic. This does not contradict the meaning of the coefficient b, since pores and structural defects affect the strength of the material. In this case, the correction was aimed to demonstrate the effect of the coefficient ***b***.

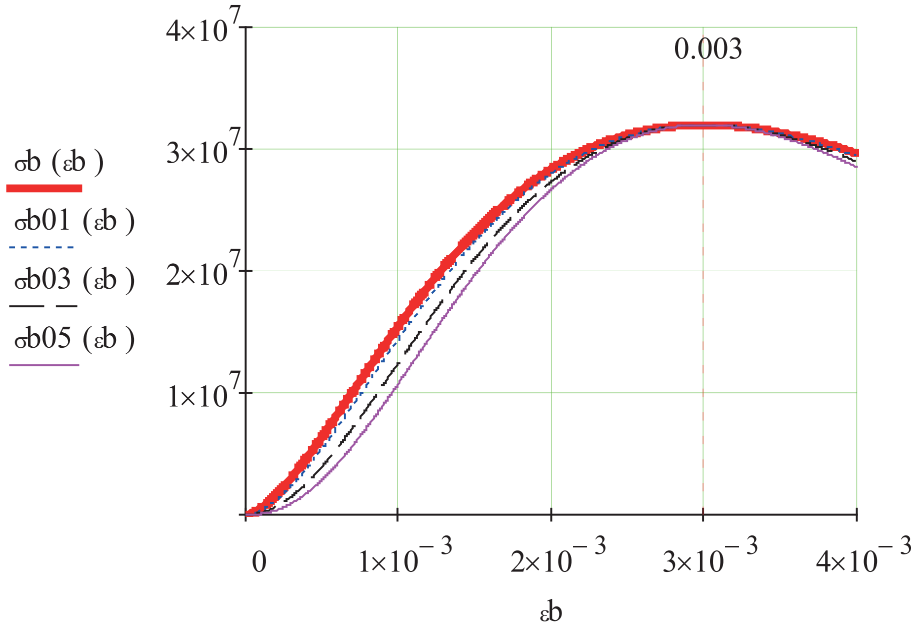

Figure 2. Concrete stress-strain diagrams obtained for variable coefficient b

The more structure defects in concrete, the faster destruction occurs under extreme loads. In such problems, it is often necessary to consider the descending branch. If there is a need to clarify the descending branch on the diagram, the coefficient ***c*** should be added to the analytical expression (3). Its physical meaning is similar to the coefficient ***b*** only on the outrageous section of the diagram. The coefficient c can be obtained from any point on the descending branch of the diagram when testing a specimen.

This ensures correctness of the deformation graph in the most difficult area of the fracture:

$$\sigma(\varepsilon) = a \cdot \varepsilon^{b} \cdot e^{\frac{-c \cdot \varepsilon}{p}}$$

The reliability of the expression (3) to relation (σ–ε) was confirmed by studies that were published in [7] and [8]. The work [7] presents experimental studies confirming the adequacy of using expression (3) for concrete with a strength of 32 MPa after 30 years of operation. The paper [8] provides an analysis of the application of equation (3) for construction of a stress-strain diagram of concrete exposured to fire at temperatures of 400° C and 600° C, according to experimental data obtained by VNIIPO [9] and polymer concrete tested at Mordovian State University [10].

CONCLUSION

Thus, the application of the proposed exponential relation in order to create a concrete deformation model allows approximation of a stress-strain curve (σ–ε) in a fairly simple expression with reflection of the main specific properties of concrete associated with an inhomogeneous structure, the presence of microcracks, pores and other microdefects. Besides, this is urgent in the case of reconstruction, when the strength and deformation properties of concrete are determined during the survey of structures. It allows construct a concrete deformation model based on a small number of test results directly for the reconstructed structure.

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