Diagrams of concrete behavior over time

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Abstract. The article presents a new vision of building diagrams of the work of materials in time. The main starting point is the law of conservation of energy of a closed system. The material is represented by an initial graph of the energy acceleration distribution. The external influence is represented as a rectangular form of energy acceleration distribution. At every moment of time, the external acceleration of energy exceeds the acceleration of the material's energy. The obtained dependence of the material diagram is analyzed. Graphs of various forms of energy acceleration are obtained. Their summation shows the true diagram of the work of the material. Defining the characteristic points of the concrete behavior diagram, a true diagram of concrete behavior over time is constructed. By changing these characteristic points, we track the changing behavior of concrete over time.

1. Introduction

Let’s highlight the theoretical foundations of the relationship between time and energy. According to the law of conservation of energy of an isolated system - the sum of all energies in an isolated system is preserved. To evaluate the behavior of the material as a gradual kinetic, thermal activation process is necessary to consider the process in time [1-5]. The material itself is a set of particles bound in a single system and the binding energy of the system is equal to the difference between the total energy of the particles in the free state (when the particles do not interact) and the energy of the coupled system under consideration of the same particles [6-9].

We write the condition of failure of the binding energy of the sample over time: \( \frac{dA}{dt} \leq \frac{dU}{dt} \) - at a time the beginning of the interaction the external energy (power) must be greater than the internal energy of the (power) of the sample [10-15].

If the power to take the form of external influence to press the studied object in the form of a rectangle \( B^*t_x \), the condition of fracture energy connection at each sample time is written

\[
B^* \cdot t_x = \int_{t_x}^{t_f} B(t) \, dt .
\]  

(1)

The value
\[ B^* = \left[ \int_{t_x}^{t_L} B(t) dt \right] / t_x, \]  

(2)

will be given an energy acceleration of the sample at the current time \( t_x \). The obtained value of \( B^* \) predicts the behavior of the binding energy of the sample over time. In the future, the value of \( B^* \) will be called the "energy potential" to which it corresponds in substance and behavior - always decreases with time. The value of \( B^* dt \) is the elemental power of resistance of the binding energy of the sample. Then the distribution of its own power of the sample in time from the onset of exposure \( t_a \) to the current time \( t_x \) written:

\[ P(t) = \int_{t_a}^{t_x} \int \frac{B(t) dt}{t_x} dt. \]  

(3)

In relation (3) is considered the time from \( t_a = 0 \) to \( t_L \), subject \( t_a = 0 < t_a < t_x < t_L \). The condition \( 0 < t_a \) appears because \( t_a \) cannot accept the value 0. In the proposed dependence of (2): \( B^* \) - energy potential, the characteristics of the material, \( B(t) \) - a function that characterizes the distribution of the acceleration energy of the material over time; \( t_x \) and \( t_L \) - value of the current time and life span of the material.

2. Methods

Assume that the function \( B(t) \), which describes the acceleration of the energy distribution in time and continuous in the selected time interval and can be approximately described by Taylor’s formula. Taylor’s formula we take as a polynomial:

\[ B = b_0 + b_1 x + b_2 x^2 + b_3 x^3 + b_4 x^4 + \ldots. \]  

(4)

The coefficients \( b_i \) in this formula depend on the value of an argument to the point where we describe the function and the derivatives of the function at that point. We write down the value of the potential in line with the views of the distribution of speed:

\[ B^* = \frac{\int_{t_x}^{t_L} B(t) dt}{t_x} = \left( b_0 t_x + b_1 \frac{t_x^2}{2} + b_2 \frac{t_x^3}{3} + b_3 \frac{t_x^4}{4} + \ldots \right) / t_x \]  

(5)

We rewrite the last equation in relative units \( t_L = 1; 0 < t_x = x \leq 1 \):

\[ B^* = \frac{b_0}{1} \left( \frac{1}{x} - 1 \right) + \frac{b_1}{2} \left( \frac{1}{x} - x \right) + \frac{b_2}{3} \left( \frac{1}{x} - x^2 \right) + \frac{b_3}{4} \left( \frac{1}{x} - x^3 \right) + \ldots \]  

(6)

The figure shows the graph of the function from the set:

\[ \left( \frac{1}{x} - 1 \right); \frac{1}{2} \left( \frac{1}{x} - x \right); \frac{1}{3} \left( \frac{1}{x} - x^2 \right); \ldots; \frac{1}{11} \left( \frac{1}{x} - x^{10} \right); \frac{1}{21} \left( \frac{1}{x} - x^{20} \right). \]  

(7)
A number derived from the relation (4), excluding the coefficients $b_i$. The potential $B^*$ is obtained by summing the curves derived from a set of given coefficients $b_i$. Considering the curves shown in figure 1 shows that the series describing the potential $B^*$ convergent. The resulting curves have similar shapes. The curvature of the plot $(1/x-1)$ gradually decreases. In the following charts are bulging lines with changing curvature. The largest deviation from the smooth curvature of the decrease (buckling) for plotting the vertical of 0.025 for graphics with $x'$ (held in the figure below the reference line, showing a change of curvature of the graphs). The summation curves to the coefficients $b_i$ will produce curves similar to those shown in the chart with a possible wave-like view.

\[ \frac{1}{x} - 1; \frac{1}{2} \left( \frac{1}{x} - x \right); \frac{1}{3} \left( \frac{1}{x} - x^2 \right); \frac{1}{4} \left( \frac{1}{x} - x^3 \right); \ldots; \frac{1}{11} \left( \frac{1}{x} - x^{10} \right); \frac{1}{21} \left( \frac{1}{x} - x^{20} \right) \]

The tangent to the curve obtained can have a negative slope, or perhaps total intersection of the curve with the horizontal axis, which would mean the transfer point $t_L$.

The main conclusions of the analysis functions:

1. The potentials of most functions have similar shapes, that is, the behavior of the potential energy in time for many objects alike.
2. Subject to the waves on the line potential, i.e. acceleration or deceleration to reduce it. Waves on the change in potential energy can be caused by a view of the function of acceleration energy and the way approximation (polynomial).
3. The potential function (without external influence) continuously decreases with time (his property).
4. The growth potential of an object over time is only possible due to the influence of external energy.

Knowledge of the potential to get the current capacity of the facility which in this case is written as:

\[ P(t) = \int_{t_a}^{t_x} B^* \, dt = \int_{t_a}^{t_x} \left[ \frac{1}{x} \frac{G}{1} - \frac{b_0}{1} - x \left( \frac{b_1}{2} x + \frac{b_2}{3} x^2 + \ldots \right) \right] \, dt = \]

or

\[ P(t) = G \ln x - \frac{b_0}{1} x - \frac{b_1}{4} x^2 - \frac{b_2}{9} x^3 + \ldots - G \ln a + \frac{b_0}{1} a + \frac{b_1}{4} a^2 + \frac{b_2}{9} a^3 + \ldots \]
\[ P(t) = G \ln \frac{x}{a} + \frac{b_0}{1} (a - x) + \frac{b_1}{4} (a^2 - x^2) + \frac{b_2}{9} (a^3 - x^3) + \ldots \quad (8) \]

3. Building a chart

Suppose we know the modulus of elasticity of concrete \( E = 36 \times 10^3 \) MPa and two specific points: the 1st point (the end of the conditional elastic material)

\[ P_L = 29 \text{ MPa} \ , \ t_L = 220 \times 10^{-5} \]

Then, based on the last record, we find:

For the first point - \( t_a = 0.2 \times \frac{29}{36 \times 10^3} = 16 \times 10^{-5} \), \( t_x \approx \frac{16 \times 10^{-5}}{0.95} = 16.8 \times 10^{-5} \).

\[
\begin{align*}
(B_0+B_1/2) \cdot \ln \left( \frac{16.8 \times 10^{-5}}{16 \times 10^{-5}} \right) + B_0 \cdot (16 \times 10^{-5})^2 - (16.8 \times 10^{-5})^2 = 0.051B_0 \\
+ 0.026B_1 - 0.000008B_0 - 0.000000007B_1 = 0.050992B_0 + 0.026B_1 = 0.2 \cdot 29 \text{MPa} = 5.8 \text{ MPa}
\end{align*}
\]

For the second point we get - \( t_a = 29/(36 \times 10^3) = 80.5 \times 10^{-5} \), \( t_x = 220 \times 10^{-5} \).

\[
\begin{align*}
(B_0+B_1/2) \cdot \ln \left( \frac{220 \times 10^{-5}}{80.5 \times 10^{-5}} \right) + B_0 \cdot (80.5 \times 10^{-5})^2 - (220 \times 10^{-5})^2 = 1.011B_0 + 0.5055B_1 - 0.0014B_0 - 0.0000011B_1 = 1.01086B_0 + 0.5055B_1 = 29 \text{ MPa}
\end{align*}
\]

From these equations we get \( B_0 = -2393 \), \( B_1 = 4845 \), and a chart of concrete –

\[ aE = 29.5 \cdot \ln(t/a) - 2393(a - t) + 1211(a^2 - t^2). \quad (9) \]

For comparison, we present a diagram linking the stresses \( \sigma \) and deformations \( \varepsilon \) of the same concrete, obtained using the degradation theory [13]:

\[ a = 8 \times 10^{-5} \quad \sigma_{B40} = 6.88 \ln \varepsilon - 0.000329 \varepsilon^2 + 0.11619 \varepsilon - 17.6. \quad (10) \]

The formula obtained from the simplified degradation theory has the following form

\[ \sigma_{B40} = 14.065 \ln \varepsilon - 6666 \varepsilon + 129.68744. \quad (11) \]

The elastic zone depending on (8) is equal to \( a = 8 \times 10^{-5} \), depending on (11)

\[ a = 10.4 \times 10^{-5}. \]

4. Conclusions

The influence of the series with a degree higher than the third has virtually no effect on the calculation. Therefore, the analysis is sufficient to use only the first three terms of the series. Great influence of the first two terms of the series to look at the acceleration energy of the object and allows the use of pure logarithmic dependence to analyze the behavior of concrete at the time.

References

[1] Erofeev V T, Bogatov A D, Smirnov V F, Rimshin V I and Kurbatov V L 2015 Biosciences Biotechnology Research Asia 12 1
[2] Erofeev V, Kalashnikov V, Karpushin S, Tretiakov I and Matviévskiy A 2016 Solid State Phenomena 871
[3] Varlamov A A, Gavrilov V B and Shapovalov E L 2017 IOP Conf. Series: Materials Science and Engineering 262 012051 DOI:10.1088/1757-899X/262/1/012051
[4] Varlamov A A, Rimshin V I and Tverskoi S Y 2018 IFAC-PapersOnLine 1 51-30 https://doi.org/10.1016/j.ifacol.2018.11.190
[5] Alexander M, Beushausen H 2019 Cement and Concrete Research 122.
[6] Telichenko V, Rimshin V and Kuzina E 2018 IOP Conference Series: Materials Science and Engineering 463(3) 032024
[7] Khamidulina D, Rimshin V, Varlamov A and Nekrasov S 2019 E3S Web of Conferences 135 3057 https://doi.org/10.1051/e3sconf/201913503057
[8] Varlamov A A, Rimshin V I, Tverskoi S Y 2018 IOP Conference Series: Materials Science and Engineering, 463 022029 Doi:10.1088/1757-899X/463/2/022029
[9] Varlamov A A, Rimshin V I and Tverskoi S Y 2018 IOP Conference Series: Materials Science and Engineering 463 022028 Doi:10.1088/1757-899X/463/2/022028
[10] Demis S, Vagelis G and Papadakis D 2019 Journal of Building Engineering 26 100876
[11] Nekrasov S, Varlamov A, Khamidulina D and Rimshin V 2019 E3S Web of Conferences 135 3058 https://doi.org/10.1051/e3sconf/201913503058
[12] Varlamov A A, Yakobchuk D L and Lozhkin I A 2019 IOP Conference Series: Materials Science and Engineering 661 012087 doi:10.1088/1757-899X/661/1/012087
[13] Varlamov A A 2014 Izvestia KGASU 3 29
[14] Varlamov A A, Rimshin V I 2019 Behaviors of concrete. General theory of degradation www.dx.doi.org/10.12737/monography5c8a716e3c4460.52838016.-A
[15] Antoshkin V D, Travush V I, Erofeev V T, Rimshin V I and Kurbatov V L 2015 Modern Applied Science 9 3
[16] Varlamov A A and Krutsilyak Y M 2003 Beton i Zhelezobeton 5
[17] Navarro-Rubio J, Pineda P and García-Martínez A 2019 Sustainable Cities and Society 44