Research of Deformative Properties of Concrete Taking into Account the Descending Branch of Deformation

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Abstract. In recent years due to the introduction of computer technology in the process of calculating and conducting experiments the ability of researchers in the knowledge of various, accurate processes, including the nature of the work of concrete on the downstream branch of deformation significantly expanded. Modern methods of measurement allow to fix, for example, deformation, to an accuracy of 0.0001 mm, which allows deeper penetration into the essence of the phenomenon of destruction. Widespread are so-called ‘hard’ test machines in which the change in load is followed by a change in deformation in contrast to the traditional experiment when the load increases continuously up to a destructive value. Such machines allowed for the first time to show the exact type of the curve of ‘stress – deformation’ with the construction of a descending branch (plot of the diagram, going after the point of maximum load). An experiment was conducted to study the deformation of concrete simultaneously on two different presses with a hard loading mode and by increasing the loading. The analysis of the deformation of concrete prisms on these presses is carried out. A complete diagram of deformation of concrete has been constructed taking into account the descending area of concrete deformation. Comparing of the received data with the normative confirms the adequacy of the data received.

1. Introduction

In recent years due to the introduction of computer technology in the process of calculating and conducting experiments the ability of researchers in the knowledge of various, accurate processes, including the nature of the work of concrete on the downstream branch of deformation significantly expanded. Modern methods of measurement allow to fix, for example, deformation, to an accuracy of 0.0001 mm, which allows deeper penetration into the essence of the phenomenon of destruction. Widespread are so-called ‘hard’ test machines in which the change in load is followed by a change in deformation in contrast to the traditional experiment when the load increases continuously up to a destructive value. Such machines allowed for the first time to show the exact type of the curve of ‘stress – deformation’ with the construction of a descending branch (plot of the diagram, going after the point of maximum load).

Hundreds of experimental works have been known to determine the compressive strength limit, but they were all executed with incremental load increments. Our own experiment claims to be a novelty...
approach, namely, the use of a “hard” machine and load by means of a stepwise increase in the displacement of a press plate.

During the tests the loading and deformation values were passed from the press to the computer. In the tabular view the following parameters were saved. They are:

- serial number of the sample;
- load time;
- the magnitude of the load for each increase in the movement of the press;
- tensions for each increase in the movement of the press;
- moving the press;
- load speed.

During the experiment the loading speed was taken fairly low to eliminate dynamic effects (1.5 mm/min), and we did not set one of the tasks to determine the effect of load speed on the strength characteristics of the samples. However, it should be noted that the change in load speed in the range from 1 to 3 mm/min, does not have a significant impact on strength [1, 2, 3].

2. Body and methods of experimental studies

The first part of the research was conducted at the Warsaw University of Natural Sciences (SGGW, Warsaw, Poland). The tests were carried out in a universal machine INSTRON 8806 (figure 1). It consists of four-column hydraulics for static and dynamic tests with a load capacity of up to 25000 kN. These high-power machines are fitted with high-rigid frames that provide precise alignment, and hydraulic lifting and locking devices, as well as a drive on the upper traverse.

![Figure 1. General view of the INSTRON 8806 test machine](image)

Exact mechanical systems along with improved functions of the digital controller and load sensors enable INSTRON to provide fully integrated, ready-made solutions for labor-intensive tasks. On these systems, a wide range of static and dynamic tests on the destruction mechanics of materials and reinforcing rods can be performed. With regard to the computer interface, the software provides full control over the system, including the creation of waveforms, calibration, installation of constraints and status tracking.
The research was subjected to concrete obtained in the laboratories of the departments of technology of building materials and materials science and industrial, civil engineering and engineering structures NUVGP [4, 5]. For achievement of the set goal and realization of the tasks, 3 prisms of 10×10×40 cm and 3 cubes in size of 10×10×10 cm in size of 1050×10 cm from concrete of the class C50 were concreted, which made it possible to determine the strength and deformation characteristics of the concrete. Test specimens of each series were carried out at the age of 28 days.

The second part of the research was conducted at the National University of Water and Environmental Engineering. There were tested 3 prisms in size 10×10×40 cm and 3 cubes in size 10×10×10 cm from the same concrete class C50. It should be noted that all the prisms and cubes were concreted simultaneously, and then tested in different places.

Mechanical characteristics of concrete (cubic and prism strength) with one-time short-term load were determined according to standard methods [6]. Tests of compression prism were performed in a hydraulic press PG-250 (with a cost of 2.5 kN). Their loads were carried out by degrees, the magnitude of which was assumed to be equal to 8÷10% of the expected destructive effort. For each load step, exposures were made for five minutes, to remove the counters and to stabilize the deformations. Before the main tests of prism, they were centered on the physical axis.

3. Testing results
During the testing of concrete cubes and prisms for compression at the age of 28 days for concrete class C50/60, the following results were obtained: \(f_{cm, \text{cube}} = 65.1\) MPa and \(f_{cm, \text{prism}} = 42.7\) MPa. Due to the rigid form of loading it was possible to observe and fix the complete picture of the work of concrete under compression [7, 8, 9]. The full diagram is presented in figure 2.

![Figure 2. Diagram of mechanical condition when tested in hard mode.](image)

The diagram shows three different areas. In the first section there is a silencing under the slabs of the press, when the growth of strains significantly outstrips the growth of the applied force. Approximately 5 MPa marks the beginning of the material, completing the process of local squeezing and aligning the ‘load-move’ dependency to the straight line. Most of the research material works under Hooke’s law and behaves elastically. A load of about 40 MPa the curve gradually deviates from the linear relationship between forces and deformations (the second section in the diagram). Then the angle of inclination of the tangent to the curve with the axis of ‘moving the press’ gradually increases, reaching the top of the graph to 90°, which is clearly visible in figure 2. Immediately after the peak of tension, the section of the descending branch ‘load - movement of the press’ begins. The load is decreasing and it can be seen that the downstream branch is not very long.

To check the correctness of the data received, in addition to the rigid loading regime, on the same samples, the effort was given in the traditional way - by increasing the load. This method of loading
provides much less information for analyzing the process of working concrete in compression. There is no descending branch in the ‘load-displacement’ diagram, and the sample itself collapses instantaneously at the maximum point of displacement (figure 3).

![Diagram of mechanical condition with gradual increase of load stages.](image)

**Figure 3.** Diagram of mechanical condition with gradual increase of load stages.

The maximum stress obtained by increasing the load is almost the same as the one obtained in the hard loading mode. In rigid mode $f_{cm, prism} = 42.7$ MPa, and usual $f_{cm, prism} = 45.0$ MPa.

In addition, on samples that were tested in National University of Water and Environmental Engineering laboratory. Additional indicators were installed to determine the movements between the press plates. Thus, the movements determined were similar to those identified in the INSTRON 8806 press. Considering figure 4 we can see the movement in both presses almost coincides. This allows us to talk about the homogeneity of concrete and adequacy, and the identity of the data obtained in two different presses with different modes of work. Also, the nature of the destruction of prisms is identical (figure 5).

![Moving in press](image)

**Figure 4.** Moving in press (a) INSTRON 8806; (b) PG-250.
Figure 5. The nature of the destruction of prisms (a) press INSTRON 8806; (b) press PG-250.

It is clear that it is extremely difficult to determine the true deformation of the sample due to the friction on the edges of the sample. Deformation is essentially overestimated. According to the most approximate estimates the displacement spent on clutter is about 60% of the total reduction in the distance between the press plates. Almost all of the first plot in the diagram consists of deformations of the friction on the edges of the sample. However, we will try to determine the real diagram of deformation of concrete, taking into account the diagram obtained on the press PG-250. The deformation of concrete in prisms tested in the press PG-250 under the usual load conditions were determined according to standard methods. On the basis of 200 mm in a prism were four indicators of clock type 1 MIG. At each loading stage, after the shutdown, device impressions were removed and entered in the test log. After data processing the voltage dependence - deformation was constructed. It is clear that this curve did not have a descending branch of deformation of concrete, but it ended at the maximum point of deformation of concrete. The deformation of the concrete in the prisms tested in the INSTRON 8806 press was by dividing the movements found between the press plates on the distance between the plates of the press. Since, as was noted above, the true deformation of the sample due to the stiffening at the edges of the sample differs from those obtained in this way.

To correlate these deformations, use the true deformation diagram found in the PG-250 press. This can be done taking into account the identity of the results obtained on both presses. Parameters of the deformation diagram of a concrete with a one-time short-term load to fracture can be defined as prism strength $f_{cd}$ – on the basis of a certain average damaging load of three prisms; $E_{cm}$, $E_{cm0}$, $\varepsilon_i$ and $\lambda$ – were determined using the formula

$$E_{cm} = E_{cm0}(1 - \lambda \eta)$$

(1)
which was obtained on the basis of statistical processing of experimental data. Value $E_{cm0}$ were determined by the formula (1) at $\eta = 0$; $E_{cmu}$ – at $\eta = 1.0$; $\lambda$ – as a relation $(E_{cm0} - E_{cmu})/E_{cm0}$, $\varepsilon_c = f_{cd}/E_{cmu}$.

Taking into account the numerous studies of the deformability of concrete one can conclude that this formula works at load levels $\eta = 0.2-0.8$. After the load level $\eta = 0.8$ the dot module of deformation of the concrete will have a curvilinear character. We construct the lines to the complete deformation curves at the corresponding points for both load modes. For correlation we introduce the coefficients $K_i$.

$$K_i = \frac{E_{cm,i}^{8806}}{E_{cm,i}^{250}}$$

where $E_{cm,i}^{8806}$ - concrete deformation module is defined in i press load levels INSTRON 8806; $E_{cm,i}^{250}$ - the module of deformation of concrete is defined at the i level of the load in the press PG-250.

We think that at level of loading $\eta = 0.8$ there was a complete consolidation of the edges of the prism, and in the future these deformations will not increase. To construct a descending branch, we subtract from the rest of the test points the deformations defined in the press INSTRON 8806 from deformation of the seal. Get the diagram depicted in figure 6.

![Diagram of deformation of concrete](image)

**Figure 6.** Diagram of deformation of concrete: (a) - prism tested in press PG-250; (b) - prism tested in the press INSTRON 8806; (c) – according to DBN 2.6-98-2009; (d) – according to Eurocod-2.

### 4. Discussion

It can be seen that the obtained schedule quite well coincides with the schedule of deformation of concrete determined by DBN 2.6-98-2009 and a bit worse with the schedule defined by the function Eurocod-2. According to DBN 2.6-98-2009, the values of the deformation should have been made $\varepsilon_c = 202 \times 10^{-5}$ and $\varepsilon_{cu} = 240 \times 10^{-5}$. In scheme (a) they were $\varepsilon_c = 199 \times 10^{-5}$ and $\varepsilon_{cu} = 220 \times 10^{-5}$. As a result, the value of the relative boundary deformations of the concrete compression in the experiment turned out to be slightly less than the design standards. We can also verify the adequacy of the constructed equation using the norms of designing the Republic of Belarus SNB 5.03.01-02. According to these norms the subcritical area of concrete work on the downstream branch of the deformation diagram in the calculation is to be limited by the level of tension $\sigma_{cu} = k_u f_{ck}$. Coefficient $k_u$ for high-strength concrete
is taken 0.9. That is, at the extreme deformations of compression of concrete $\varepsilon_{cu}=220 \times 10^{-5}$ deformation value $\varepsilon_{c1}$ should be $\varepsilon_{c1} = 220 \times 10^{-5} \times 0.9 = 198 \times 10^{-5}$, which fully relates to the built-in scheme.

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