

Strength and deformability of high strength concrete with superplasticizer S-3 under dynamic loading

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Abstract. The results of experimental studies of the strength and deformative properties of concretes with the addition of superplasticizer S-3 and without additives, of various compositions under dynamic loads, the rate of application of dynamic action averaged 700 MPa/sec are presented. The coefficient of dynamic strengthening of concrete is determined as the ratio of prismatic strength under static and dynamic loads for the studied concretes with and without the addition of S-3, the value of which varies from 1.14 to 1.28, the significant effect of the additive was not detected. Graphs of the dependence of the ratios of elastic modulus and ultimate deformations on the loading rate and the deformation rate are presented. According to the main deformative characteristics under dynamic loading, the studied concretes with and without additives differ little from each other.

1 Introduction

The use of superplasticizers (highly effective additives) significantly facilitates the solution of the problem of producing high—strength concrete, allows them to be obtained using traditional technology, on ordinary cement grades (M400-500): while maintaining sufficient workability of the concrete mixture. Given the great prospect of using high-strength concretes with the addition of superplasticizers in the production of precast and monolithic reinforced concrete, it is very relevant to conduct studies of the most important strength and deformative properties of concretes with the addition of superplasticizer S-3 under various load conditions (including dynamic).

2 Research methodology

In accordance with the main objectives of the study - to obtain new data on the strength and deformability of high-strength concrete with the addition of superplasticizer S-3, real experiments were carried out on five series of samples C, G, E, B and D for compression, under dynamic loading, made of non-steamed (series E, B and D) and steamed concrete (Series C and G). The adopted methodology was based on considerations to obtain comparable data with concrete without an additive, made on the same materials (cements,

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aggregates) as concrete with an additive, and having the same or increased strength due to some adjustment of the composition (group 1, each series – without an additive reference samples; group 2 – with an additive, liquefied concrete; group 3 - with an additive, equally mobile and equally strong with the initial concrete, but with reduced cement consumption. and water for 20%; group 4 -with an additive, equally mobile with the initial concrete, but with reduced water consumption for 20% and, accordingly, W/ C. Dynamic loading was carried out as a result of the sudden release of the energy of compressed oil stored in the battery of the installation, the rate of application of dynamic action averaged 700 MPa/sec.

The results on the strength of the studied concrete under dynamic loading (also for comparison with static) and the main characteristics of this loading are given in Table 1.

Table 1. Comparative data on the strength of high-strength concrete with and without superplasticizer under dynamic loading.

Series group	R _{st} , MPa	Average speed		The validity of the tests, sec	R _d , MPa		C _{ds}	$\frac{C_{ds}^{waa}}{C_{ds}^{wa}}$
		σ MPa* sec ⁻¹	ϵ 10 ⁻³ sec ⁻¹		Average	S _k (n)		
B-1	57.7	725	25.7	0.10	74.0	1.0(3)	1.28	1.00
B-2	57.4	691	25.1	0.10	69.1	1.01(3)	1.20	0.94
B-3	61.5	735	24.5	0.10	75.8	3.38(3)	1.23	0.96
B-4	69.8	715	22.3	0.11	80.7	3.71(4)	1.16	0.91
E-1	58.5	646	25.0	0.095	64.6	4.77(4)	1.14	1.00
E-2	48.0	606	26.7	0.09	54.6	2.39(4)	1.14	1.00
E-3	49.3	667	25.7	0.09	60.2	3.94(4)	1.22	1.07

Note. The age of the concrete at the time of the test was, for the B series-515 days, for the E series-505 days.

Table 1 shows that the coefficient of dynamic strengthening, defined as the ratio of strength indicators during dynamic and static test $C_{ds}=R_d/R_{st}$ of steamed concrete (series B) is higher than that of naturally hardened concrete (series E). Taking into account the available data spread, it can be seen from Table 1 that the introduction of an additive has relatively little effect on the dynamic strengthening coefficient (CDS) of naturally hardened concrete. Some observed decrease in its value for steamed concrete with the addition of C-3, of the order of 4-9% compared to concrete without an additive, is apparently due to some increased fragility of these concretes to dynamic influences, especially concrete of composition 4, for the manufacture of which a more rigid mixture with a low W / C factor is used. As indicated in [1], many factors that do not affect static loading can affect the CDS, in particular, the heterogeneity of the macrostructure of concrete, especially the contacts of a large aggregate. For example, with a decrease in the amount of cement dough, the relative volume of aggregates per unit volume of concrete increases, which can lead to an increase in the contacts of large aggregates, which are stress concentrators [2], as a result of which the CDS may decrease [1].

The average CDS value obtained in the experiment, equal to 1.19 for all groups of steamed concrete with an additive and 1.28- without an additive, as well as 1.14 for the first and second groups of naturally strengthening concrete, is not lower than it is observed for ordinary heavy concretes of medium grades. Therefore, there is no reason, based on the conducted studies, to reduce the value of the dynamic strengthening coefficient for the studied concretes when designing prefabricated and monolithic structures from them. Figure 1 shows graphs of the dependence of the CDS on the time of dynamic loading based on

research and literature data [3,4]. The regression line (dotted line) obtained by Yu.M.Bazhenov is also shown there:

$$C_{ds} = 1.58 - 0.35 \lg \tau + 0.07 (\lg \tau)^2 \tag{1}$$

where τ is the loading time in milliseconds (ms)

This formula, as the author notes, is valid for a time interval of 2-200 ms. As follows from Figure 1, in this time interval, the C_{ds} corresponding to formula (1) (dotted line) deviates slightly from the average values (solid line).

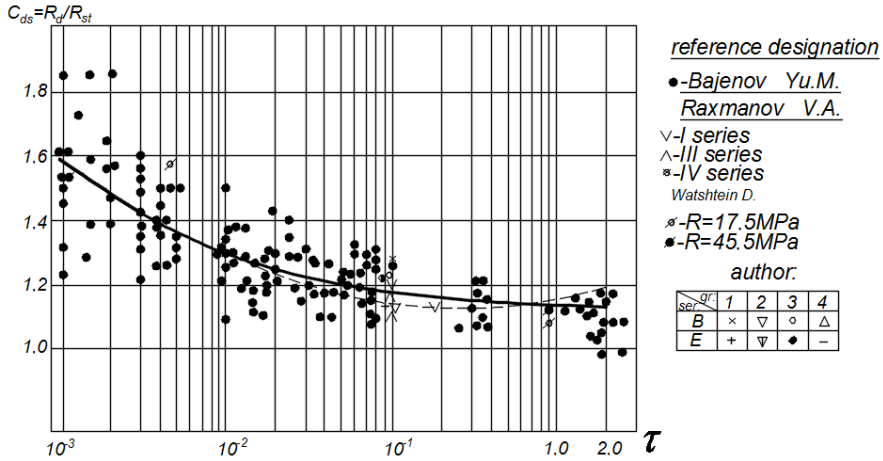


Fig. 1. Dependence of the CDS on the time of dynamic loading [1].

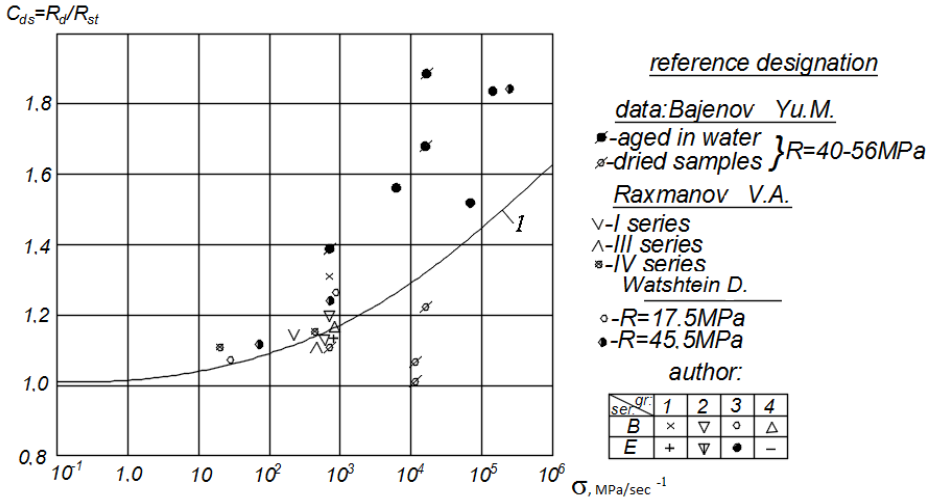


Fig. 2. Dependence of the CDS on the dynamic loading rate [5].

As is known, the coefficient of dynamic strengthening (other things being equal) depends on the loading rate and the deformation rate. The dependence of the C_{ds} on the loading rate is illustrated in Figure 2. Based on the processing of a large number of their own data and the data of other researchers, Popov N.N. and Rastorguev B.S. [4], a dependence (solid line in the Figure) was obtained, characterizing the change in CDS from the dynamic loading rate in a large range of changes in the latter from 10-1 to 10-6 MPa/sec. The data of our tests, as well as the data of Rakhmanov V.A. and Watstein D. were plotted on this graph. It can be seen that the results obtained by us for steamed concrete are close to the general pattern and

even lie higher than the average curve (solid line in Figure 2). Lower absolute values of the dynamic strengthening coefficient were obtained for natural strengthening concrete (Series E) both with and without additives compared with steamed concrete (Series B). However, according to [1], the coefficient of dynamic strengthening should be higher for naturally hardened concrete than for steamed concrete. Samples of the concrete studied by us were stored in air-dry conditions ($t = 20 \pm 2 \text{ }^\circ\text{C}$, $W = 65\%$), at which they dried out. This remark also applies to naturally hardened concrete stored immediately after stripping in air-dry conditions. The consequence of this was the observed strength drops at various times, which can, apparently, explain the lower values of the CDS of naturally hardened concretes obtained in experiments in relation to steamed concretes, which were less affected by the strengthening conditions. For samples of natural strengthening stored after 2 weeks in air-dry conditions by V.A. Raxmanov[3], lower values of CDS were also obtained.

According to the averaged readings of all longitudinal and transverse sensors of the three tested samples, diagrams " σ - ε " were constructed for each group of samples, the characteristic ones of which are shown in Figure 3.

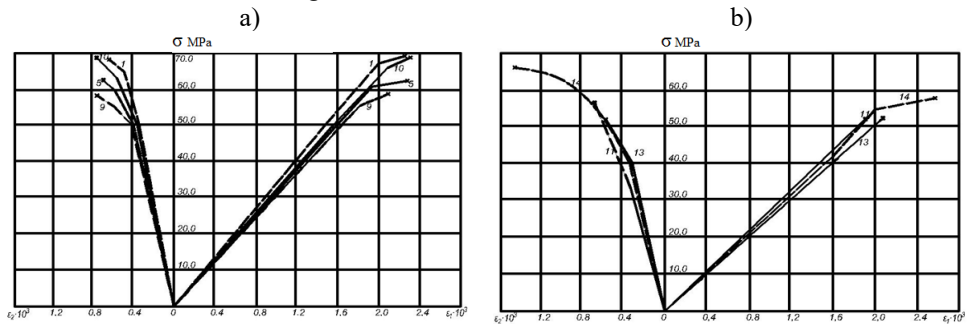


Fig. 3. Compression diagram of E-series concrete under dynamic loading of the first (a) and second (b) groups of samples. The numbers in the figure indicate the sample numbers.

Figure 4 shows typical diagrams of the dependence of averaged longitudinal (ε_1), transverse (ε_2) and volumetric (θ) relative deformations and the coefficient of transverse deformations ν on the level of tension n during compression for concrete series E of three groups of samples (1,2,3) and series B of three groups of samples (1,2,4) under dynamic (solid lines) and static (dotted lines) loading. From these diagrams, the general patterns of changes in the concrete characteristics listed above are visible. They are mostly close to the general patterns for high-strength concrete. The destruction of samples occurs with relatively small volumetric expansion deformations; the level of elastic work of deformations is much higher than that of medium-low strength concrete; the limiting coefficient of transverse deformations is close in magnitude to 0.3-0.4 and rarely reaches 0.45. In comparison with static loading, dynamic loading is characterized by a weaker manifestation of the expansion effect of concrete towards the end of destruction due to a significant acceleration of the process of its destruction and, as a consequence, this destruction is characterized by a slow development of transverse deformations compared to longitudinal ones, hence lower values of the coefficient of transverse deformations are obtained, rarely reaching 0.45.

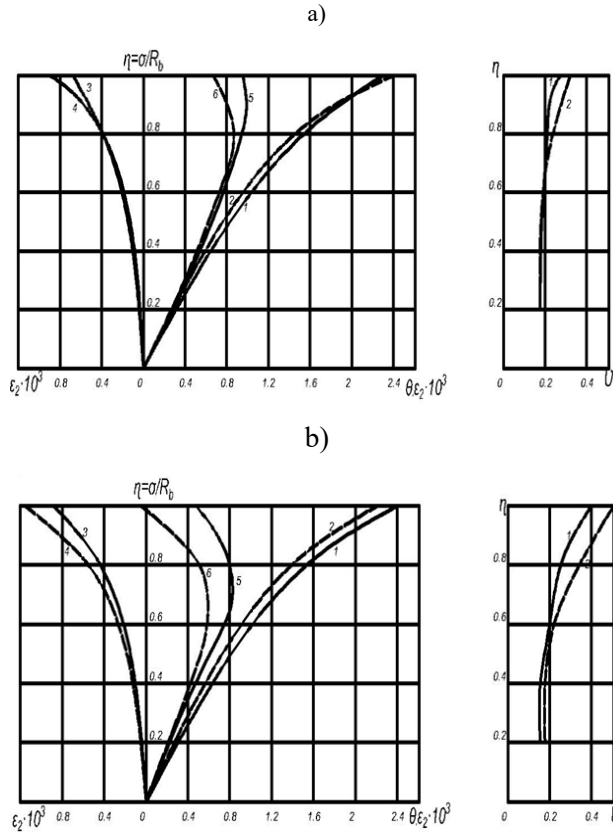


Fig. 4. A typical diagram of the dependence of deformations ε_1 , ε_2 , θ and the coefficient of transverse deformations ν on the level of compressive stresses η for concrete of the E series of two groups of samples 1 (a), 2 (b) under dynamic (solid lines) and static (dotted lines) loading.

Numerical values for the modulus of elasticity and ultimate deformations of tested concrete under dynamic loading and their standard deviations are given in Table.2. In the same place (for comparison), data on static loading are given for the same indicators.

Table 2. Comparative data on the deformability of concretes with superplasticizer S-3 under static and dynamic loads.

Series, group	Static loading		Dynamic loading				E_d / E_{st}	$\varepsilon_d / \varepsilon_{st}$
	$E_{st} \cdot 10^{-2}$ MPa	$\varepsilon_{st} \cdot 10^3$	$E_d \cdot 10^{-2}$ MPa		$\varepsilon_d \cdot 10^3$			
			average	S_k	average	S_k		
B-1	303	2.37	318	9.1	2.62	0.01	1.03	1.10
B-2	290	2.40	321	15.9	2.51	0.038	1.11	1.06
B-3	334	2.22	368	11.2	2.54	0.303	1.10	1.14
B-4	344	2.34	376	21.1	2.48	0.051	1.09	1.06
E-1	327	2.35	324	5.51	2.51	0.02	0.90	1.07
E-2	275	2.38	274	6.6	2.53	0.26	1.0	1.06
E-3	307	2.07	318,5	26.4	2.32	0.15	1.04	1.12

It can be seen from the presented data, the magnitude of the modulus of elasticity of the studied concretes increases slightly under dynamic loading. The exception was the first and second group of natural strengthening samples. The data obtained by D.Watstein [4] show an increase in the initial modulus of elasticity under dynamic loading by 11 and 24%, respectively, for concrete with a strength of 17.5 MPa and 45.5 MPa at loading speeds from 13.3 to 21.5 *10⁴ MPa/sec.

This is clearly seen from the graph of the dependence of the ratio of the elastic modulus of concrete on the duration of loading (Figure 5), constructed according to [3,4,6] and our experimental data. A similar pattern of changes in E_d/E_{st} is observed in Figure 6, constructed according to researchers [1,3,4, 6] depending on the rate of deformation: with an increase in the rate of deformation, the E_d/E_{st} ratio increases.

As follows from the presented in the Table 2 data, the value of the ultimate deformations of the studied concretes is somewhat greater under dynamic loading than under static loading. This increase in the ultimate deformations is mainly due to an increase in the proportion of elastic deformations in the total deformations of concrete due to its dynamic strengthening. Similar results were obtained by other researchers [3,6,7,10-12, etc.].

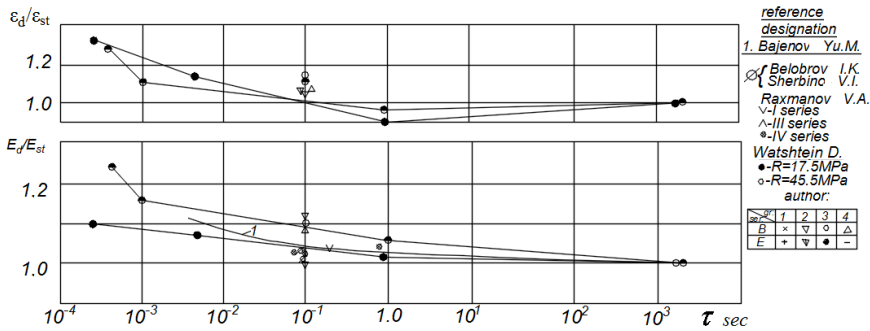


Fig. 5. Change of E_d / E_{st} and $\epsilon_d / \epsilon_{st}$ from the duration of loading.

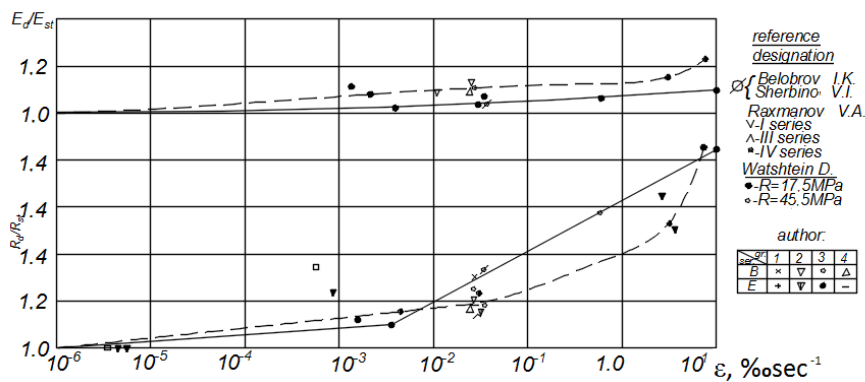


Fig. 6. Change of E_d / E_{st} and R_d / R_{st} depends on the rate of deformation.

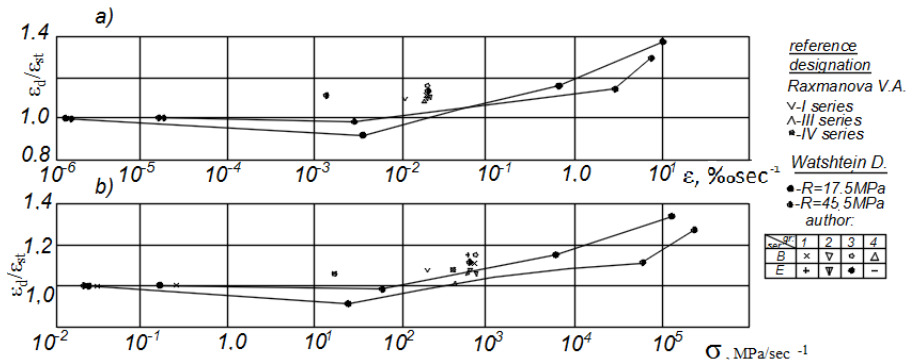


Fig.7. Change of ϵ_d/ϵ_{st} depends on the rate of deformation (a) and the rate of dynamic loading (b).

Figure 5 and Figure 7 show, according to the data of different authors and their own data, graphs of changes in the ratio of limit deformations of ϵ_d/ϵ_{st} depending on the duration and speed of loading (deformation). As follows from these graphs, with an increase in the rate of loading (deformation) the ratio of limit deformations decreases somewhat at first, and then begins to increase. A decrease in the limiting deformations with an increase in the loading rate (deformation) under static loads, as well as the relationship of the latter with the strength of concrete, is noted in the works of a number of authors, among which the works of A.V. Yashin [7] can be noted. From Figure 7, b it follows that the minimum of the curves is within $1 \div 10^2 \text{ MPa sec}^{-1}$.

As can be seen from the presented graphs and tables, according to the main deformative characteristics under dynamic loading, the studied concretes with and without additives differ little from each other.

3 Conclusions

As a result of the experiments conducted on dynamic effects with an average application rate of 700 MPa / sec , the coefficient dynamic strengthening (CDS) was determined for the studied high-strength concretes with and without the addition of S-3, the value of which varies from 1.14 to 1.28. Its lower values (pa 4-9%) were observed for steamed concrete with the addition of S-3 (especially for concrete with a reduced W/ C ratio). Taking into account that sufficiently high values of CDS were obtained in the experiment and its decrease in some cases was small, the available recommendations on the use of CDS can be maintained for the studied concretes with the addition of S-3.

As can be seen from the graphs and tables presented, according to the main deformative characteristics under dynamic loading, the studied concretes with and without additives differ little among themselves.

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