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Experimental assessment of some factors affecting concrete strength in a single dynamic exposure

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Abstract. The paper presents experiment results of testing the concrete under dynamic exposure aimed at evaluating the influence of static pre-loading on the dynamic strengthening coefficient.

1 Introduction

Concrete strength dependence on construction type, environment conditions, construction features and loading duration is considered in present Russian building codes [1] as coefficient of working conditions γ_b. Although [1] does not define the value of γ_b that takes into consideration the influence of dynamic exposure on concrete, it states that the coefficient has to be specified in special technical conditions. The development of special technical specifications is specified in [2] and is time-consuming and liable process. While deciding developers rely on the best practices in domestic and foreign science as well as experimental confirmation of suggested solutions. The authors suggest that the data presented in the paper might be used during the development of special technical conditions to determine the coefficient of working conditions for concrete under dynamic exposure.

It is known that strength of concrete under dynamic exposure is more than prism strength. This strength change is generally characterized by dynamic hardening coefficient [3, 4]. Influence of exposure speed (time) on the dynamic hardening coefficient is thoroughly investigated in [5, 6, 7], and these references contain dependencies mentioned above.

Although the techniques reported in the majority of the studies on definition of the dynamic hardening coefficient considered the dynamic exposure of unloaded samples. However, in real operational conditions of construction the dynamic exposure is generally an emergency load (e.g. seismic) and is applied in the addition to the operational load.

The authors attempt to specify the influence of preload on the dynamic hardening coefficient. The research was taken in two stages.

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2 Assessment of the impact of long-term static preloading degree on the dynamic hardening coefficient under axial compression

For the experiment the specimens of 1 cement : 2.8 aggregate : 4.44 sand ratio by mass on Portland cement M450 in the amount of 270 kg per cm3 with water-cement ratio of 0.67. The crushed granite fractions of 5–10 and 10–20 mm and silica sand were used as an aggregate. The hardening of the specimens had taken place in wet sawdust for 28 days, and they were stored in normal conditions for two years afterwards until the experiment was held.

The samples were divided by four groups depending on assumed level of preliminary static loading: without static loading ($\sigma_{preload} = 0$, reference samples), with static loading of $\sigma_{preload} = 0.3R_b$, $\sigma_{preload} = 0.7R_b$ and $\sigma_{preload} = 0.8R_b$.

Preloading and loading of reference samples tested for prism strength determination was held incrementally to secure the growth of stress on the value close to $0.1R_b$. The specimens were endured under design load for 360 days. A constant load was maintained and controlled, the load change did not exceed 3%.

The second stage of the experiment followed without unloading. Some of the samples from each group were brought to the failure with static load, and others – by dynamic load. Static additional load was applied incrementally with five minute interval until destruction.

Mobile dynamic module compatible with common press machines was built to perform additional loading of all the specimens at once. The testing of the specimens could be performed promptly by connecting the dynamic module and applying dynamic load to every specimen alternately, while the exposure time is almost identical. Portable dynamic module, designed and built by Igor Bezgodov, is presented on Figure 1.

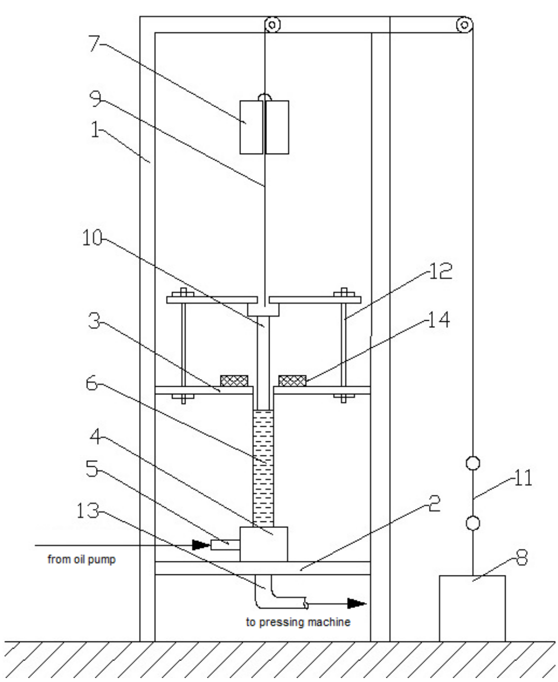

Fig. 1. Dynamic module for concrete samples testing: 1 – welded wire frame; 2, 3 – supporting table; 4 – distributor; 5 – choke; 6 – small cylinder; 7 – falling weight; 8 – counterweight; 9 – guide pin; 10 – small piston; 11 – wire; 12 – stop; 13 – power hose.

The dynamic module is a welded frame (1) that has posts with attached supporting tables (2, 3) inside. Oil is pumped into small cylinder (6) through the nozzle (5) located in the dispenser (4), which is installed on the lower table (2). Supporting table (3) limits the motion of drop weight (7), which is lifted up by counterweight (8). Drop weight (7) is directed by the guide rod (9) which is connected with the small piston (10).

Dynamic loading of specimens was carried out according by following technique. Weight (7) is lifted to certain level with counterweight (8) and is fixed by a thin wire (11). Oil is pumped into small cylinder (6) by pumping station. The piston of the small cylinder (10) comes to a specific level and is fixed by the limiter (12). The oil is supplied into small cylinder (6) and power hose (13) that is connected with press machine flat hydraulic lift jack (not shown on the figure). After turning on the recording devices, the wire (11) is cut and the falling weight (7) creates the load which is enough to destroy the specimen, and forces and deformations are measured. Porous rubber (14) laid on a supporting table (3) dampens impact load from a drop weight (7). The dynamic module could be used in facilities for axial compression testing.

The method of using a dynamic module for testing of samples that had been preloaded in conventional pressing machines with flat hydraulic jack lift has some features. Prior to dynamic loading, the power hose (13) has to be connected to the flat jack lift press. Pressure in the power hose (13) matches the pressure in the small cylinder (6) thanks to pumping station. After pressure levels equalize the flat jack lift incoming tap is opened. Shut-off valve connecting the dispenser with the pumping station is closed. Afterwards the weight (7) is discharged, and pressure enough to destroy the specimen is reached in the piston and lift jack.

Force sensor was installed between lift jack and the specimen to apply dynamic additional loading. Force sensors of all press machines were calibrated after test. Samples were tested consecutively by the dynamic module by the load of various intensity.

PC, multi-channel amplifier, analog-to-digital converter (ADC) and "ADCLab" software developed by CJSC “Rudnev-Shilyaev” (Moscow, Russia) was used to record the stress. Thanks to the use of modern amplifier, ADC and software, stresses were registered with an accuracy of 0.1 MPa. Test results are presented on Table1 and Figure 2.

Table 1.

Sample #	**Preload stress ratio $\sigma_{preload}/R_b$**	**Strength R or R_d, MPa**	**Strength R or R_d average, MPa**	**Coefficient of variation V, %**
Static tests				
15	0	34.00	34.67	3.3
18		36.00		
10		34.00		
21	0.3	35.00	35.00	0.0
3		35.00		
8		35.00		
7	0.7	35.00	35.00	0.0
13		35.00		
24		35.00		
15	0.8	36.75	35.58	2.8
19		35.00		
23		35.00		

Dynamic tests ($\dot{\sigma} \approx 500$ MPa/s, $\tau \approx 0.04$s)				
3	0	43.43	45.04	4.6
19		47.35		
23		44.33		
4	0.3	46.20	45.56	1.3
11		45.47		
22		45.00		
9	0.7	46.78	45.20	4.4
13		42.94		
16		45.88		
20	0.8	45.39	45.82	0.8
17		46.04		
5		46.04		

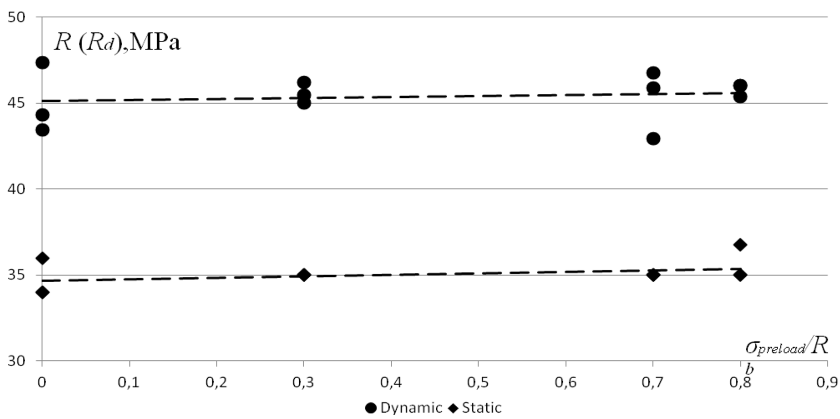

Fig. 2. Influence of long-term static preloading and its value on the dynamic strengthening factor under axial compression.

The impact of preliminary static load and its value on the dynamic strengthening factor is presented on Table 2. The dynamic strengthening factor is the ratio of dynamic strength for a particular value of static preloading to the corresponding strength under additional static loading.

Table 2.

Preload value $\sigma_{preload}/R_b$	**Average static strength, *R* (MPa)**	**Average dynamic strength, R_d (MPa)**	**Dynamic strengthening factor**
0	34.67	45.04	1.30
0.3	35.00	45.56	1.30
0.7	35.00	45.20	1.29
0.8	35.58	45.82	1.29

According to the tables and graphs the dynamic strengthening factor does not depend on static preload. Thus, it could be neglected when assigning concrete coefficient of the working conditions, and dynamic strengthening factor should be determined by axial compression tests of unloaded samples. The influence of long-term loading on concrete strength need to be considered with regard to the [1].

3 Evaluation of the static preloading value impact on the dynamic strengthening factor under biaxial compression

Concrete samples of 7x7x28 cm size, prism strength R_b = 20.41MPa and longitudinal deformations coefficient E = 28900 MPa were tested.

The equipment used allows a conventional dynamic loading with stress growth rate $\dot{\sigma}_1 = 470 - const$ MPa/s and destruction time: τ = 0.08 s.

Dynamic loading was carried out smoothly from zero up to destructive values. Preliminary static load in σ_2 direction was created by the of a membrane type devices, which provide constant stress σ_2 in the subsequent dynamic loading in the direction of σ_1. Biaxial compression testing technique was preloading the sample in the direction of σ_2 to a certain prism strength ($\sigma_2 = 0.2R_b$, $0.4R_b$ or $0.6R_b$), followed by destruction of the sample by static or dynamic load in the σ_1 direction. Static and dynamic tests under uniaxial compression were also conducted. Test results for different values of stress σ_2 under static and dynamic load are presented in table 3.

Table 3.

Specimen #	**Stress σ_2 (σ_2/R_b)**	**Strength $R_{ib}^{\sigma_2}$ ($R_{ib,d}^{\sigma_2}$), MPa**	**Strength average R^{σ_2} ($R_{b,d}^{\sigma_2}$), MPa**	**Coefficient of variation V, %**
Static tests				
2	0	20.24	20.41	1.8
4		20.06		
8		20.93		
9	0.2	26.98	26.57	1.2
19		26.24		
20		26.50		
12	0.4	26.50	27.34	3.1
29		28.17		
1	0.6	29.39	28.98	1.4
32		28.57		
Dynamic tests ($\dot{\sigma} \approx 470$ MPa/s. $\tau \approx 0.08$s)				
15	0	22.80	23.97	3.4
26		25.10		
33		24.00		
5	0.2	32.02	30.89	2.6
10		30.23		
28		30.42		
11	0.4	35.30	33.97	3.0
27		32.80		
30		33.80		
14	0.6	34.68	35.04	1.0
31		35,40		

Value of preload in σ_2 direction influence on the dynamic strengthening factor was evaluated, the results are in Table 4.

Table 4. The influence of stress state and stress value σ_2 on concrete strength under static and dynamic loading.

Preload $\sigma_{2,preload}/R_b$	Average static strength, R, MPa	Average dynamic strength, R_d, MPa	Dynamic strengthening factor
0	20.41	23.97	1.17
0.2	26.57	30.89	1.16
0.4	27.34	33.97	1.24
0.6	28.98	35.04	1.21

Test results suggest the following. Stress state type and value of the lateral compression affects the dynamic strengthening factor, but to a much lesser extent than the loading rate. Dynamic strengthening factor growth on biaxial stress compared to uniaxial stress was observed at lateral compression of $0.4R_b$ and $0.6R_b$.

However, the impact of stress σ_2 on the dynamic strengthening factor change is not significant, which that can be traced from the Figure 3. The graph depicts relation between σ_2 on static exposure and loading with rate of 470 MPa/s (curves in the top) in coordinates $\frac{\sigma_2}{R_b} - \frac{R_b^{\sigma_2}}{R_b}$ for static case and $\frac{\sigma_2}{R_b} - \frac{R_{b,d}^{\sigma_2}}{R_{b,d}}$ for dynamic. Static and dynamic curves almost match.

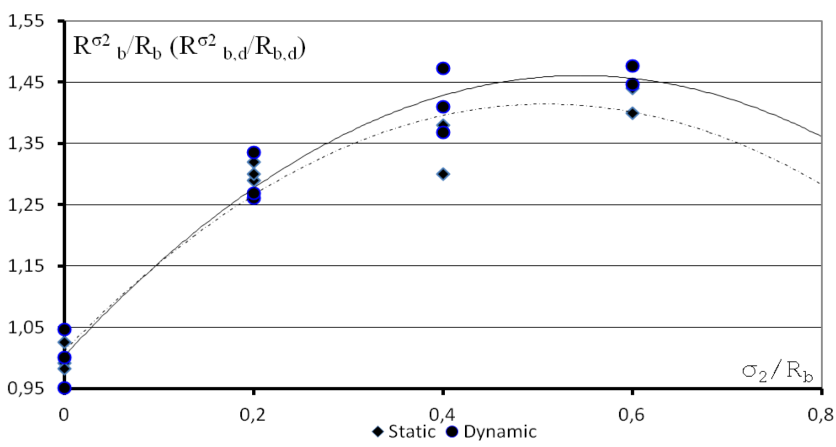

Fig. 3. Influence of static preloading on dynamic strengthening factor in biaxial compression.

At the same time it should be noted that under both static and dynamic loading, the type of stress state significantly affects concrete strength. The most significant increase in strength occurs upon the transition from uniaxial to biaxial compression, even with a small value of the second principal stress σ_2. At higher levels of lateral compression from $0.2R_b$ to $0.6R_b$ the trend of strength increase continues. Thus, when $\sigma_2 = 0.6R_b$ strength increase in both static and dynamic case increased by 40% compared to the strength un uniaxial testing with corresponding loading rate. Overall the static test results correspond to the data in [8, 9].

Thus, the evaluation of coefficient of working conditions of concrete under dynamic loading in biaxial compression can be based on data available regarding the concrete strength increase depending on the σ_2 value, by multiplying the short-term strength by dynamic strengthening factor obtained by testing the reference samples on axial compression.

4 Conclusion

Taking into account the results obtained in both directions of the study, it might be suggested that the coefficient of operating conditions of the concrete under dynamic exposure should be assumed equal to dynamic strengthening factor, obtained from the tests results on uniaxial compression, regardless of the preload duration, and stress level σ_2 under biaxial compression.

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