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Experimental results of concrete under dynamic exposure preceded by long-term static load

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Abstract. Experimental study aimed at evaluation of static preload impact on concrete strength and deformation characteristics had been carried out in 2014–2017 in laboratory of Strength of Materials Department of Moscow State Institute of Civil Engineering. The paper briefly presents the research technique, outcome and suggests its interpretation. Authors' feature of the methodology is an absence of unloading when applying the dynamic load with stress growth rate of 450 MPa/sec and destruction time of approximately 0.8 sec after static preload with value of 0.3, 0.7 and 0.8 of prism strength. The use of portable dynamic module which was has been designed and built by Igor Bezgodov, engineer of Moscow State University of Civil Engineering, made it possible to complete the experiment. Investigation of samples under short- term static load of the same level and reference samples under static and dynamic load without preloading was carried out concurrently. The data obtained include strength values and stress-strain diagrams which allowed estimating the coefficients of longitudinal and transverse deformation and ultimate deformation. The authors suggest that long-term static preload does not affect the dynamic strengthening factor, which remained between 1.17 and 1.30 regardless of preload level. At the same time preloading changes stress-strain diagram significantly. Diagrams for various loading modes are combined on single figure to demonstrate their features. The coefficients of longitudinal and transverse deformation related to significant fragments of diagrams are presented in tables and compared to each other. Loading rate considerably lowers ultimate deformations under dynamic impact. Relatively low-level preloading does not modify longitudinal deformations perceptibly, however, at preloading level of 0.8 longitudinal deformations increase significantly and almost match the ones under static loading. The authors conclude that comparison of diagrams points out on necessity of taking deformation rate growth and static preload level into consideration in practical calculations of concrete and reinforced concrete constructions. Thus, the research contributes to the development of computational models of concrete and reinforced concrete.

1. Introduction

Concrete construction techniques are often based on empirical dependencies [1] due to insufficient knowledge of concrete limit state. It is reasonable to further explore idealized concrete state diagrams and their application in design techniques. Concrete under operating load corresponds to long-term diagram $\sigma - \varepsilon$ [2]. Assume that concrete is subjected to dynamic exposure on reaching certain value of σ / R_b. This model agrees with intense dynamic exposure on real structure (preload is caused by operating load). There is an uncertainty about correct selection of diagram to be used as estimation.

The impact of long-term preload followed by dynamic load on concrete strength and deformation properties is studied insufficiently [3, 4]. Experimental results are presented in the paper, and the authors suggest options of dynamic deformation diagram selection.

2. Experiment Technique

Concrete samples of identical composition and same age were divided by four groups. Specimens in groups 1 and 2 had not been preloaded and were examined under dynamic and long-term static load respectively ($\sigma_{preload}$ = 0, reference samples). Specimens in groups 3 and 4 were tested on short-term static and dynamic exposure respectively after preloading $\sigma_{preload}$ / R_b values of: 0.3 R_b, 0.7 R_b and 0.8 R_b. Preloading and subsequent loading of specimens, that were tested on prism strength, had been carried out gradually with stress growth step 0.1 R_b. Afterwards specimens were cured under design load for 360 days. A constant loading was maintained and controlled; the load change did not exceed 3%. The second stage of the experiment followed without unloading. Group 3 samples were brought to the failure with static load, group 4 – by dynamic load with average stress rate $\dot{\sigma}$ = 470 MPa/sec, destruction time 0.08 sec. Additional static loading was applied gradually with five minutes intervals until destruction. Reference samples had been cured for 14 days on each step of loading. At the end of this interval creep deformations growth ceased almost completely. More detailed information on experiment technique, equipment, loading and deformation measurement, alongside analysis of preload influence on concrete dynamic strength are enumerated in [5].

3. Experiment Results

It was also noticed in [2] that enhancement of concrete strength under dynamic load occurred with identical dynamic strengthening factor for different stress values caused by long-term preloading. Experiment results are outlined in figure 1.

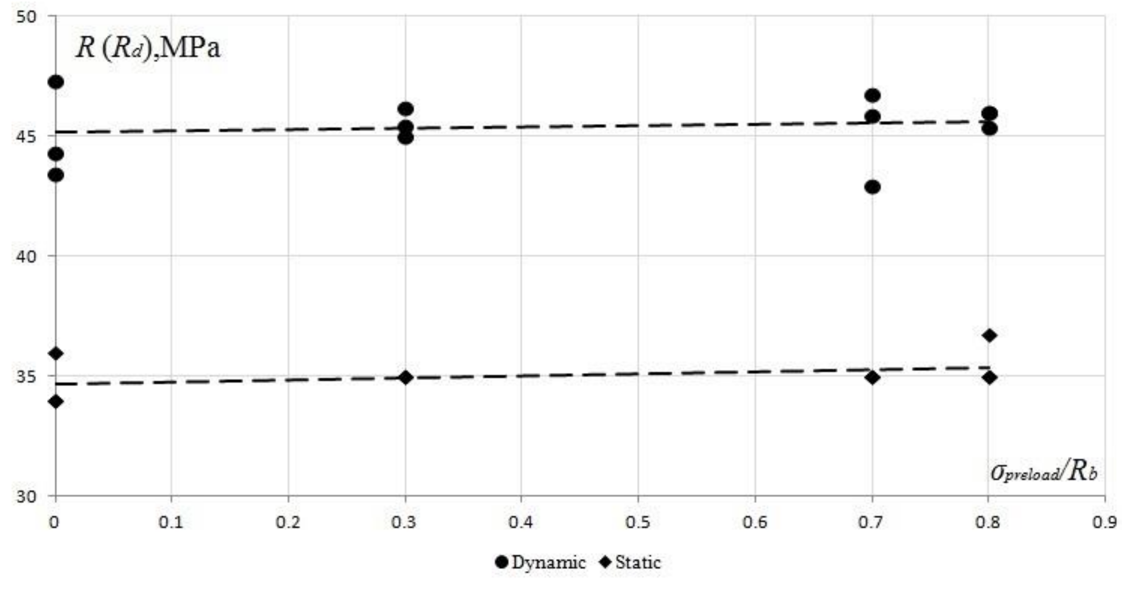

Figure 1. Influence of long-term static preloading on the dynamic strengthening factor under axial compression

Preloading affects both subsequent static loading and dynamic deformation diagrams appearance significantly as longitudinal deformation coefficient grows (table 1). In the latter case this influence is more substantial. Longitudinal deformations coefficient calculated on deformation growth of 3.5 MPa compared to preliminary stress (represents one step of loading application) for short-term loading exceeded the one calculated for reference samples (long term static) by 20–40% depending on preloading level. Dynamic longitudinal deformations coefficient exceeds several times the static one. Longitudinal deformations coefficient value is even higher than initial dynamic modulus $E_{d,0}$ (e.g. on preloading of σ / R_b = 0.7 E_d / $E_{d,0}$ ratio reaches 2.86).

Data on concrete deformations for every step of loading were also obtained during the experiment, deformation diagrams in σ / R – ε axes are depicted on figure 2.

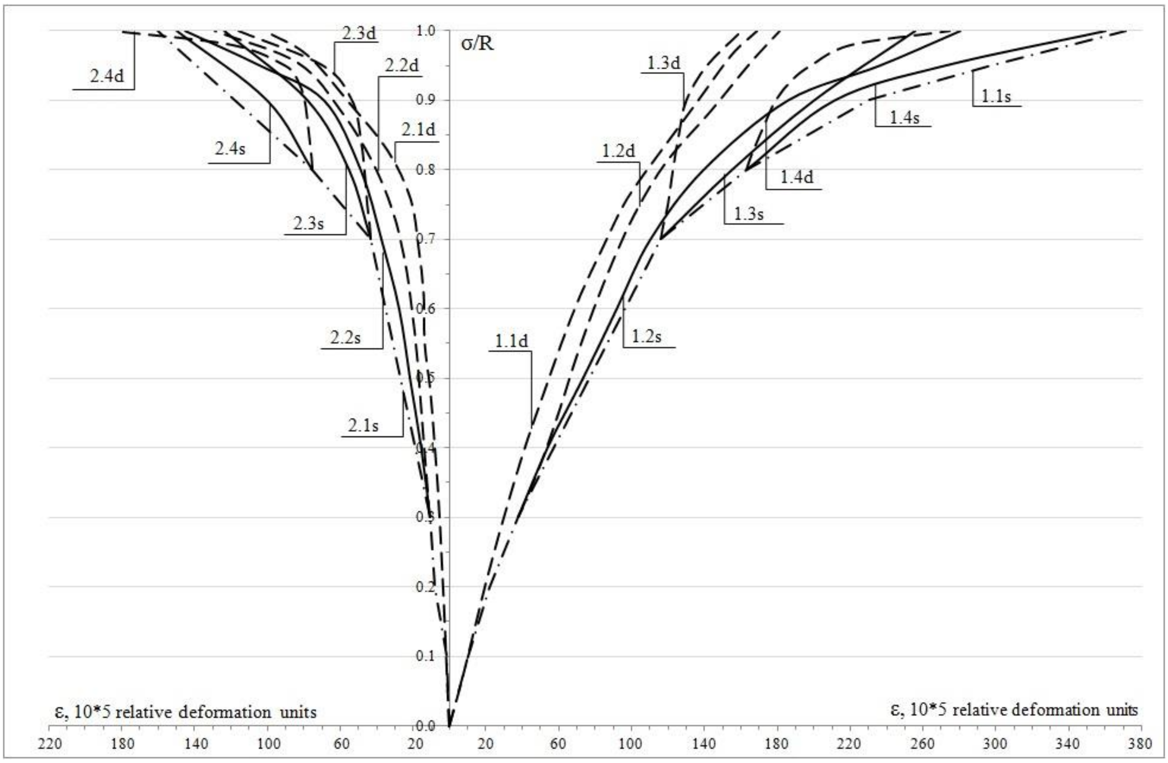

Figure 2. Experiment results. Longitudinal deformations: 1.1 d/s – dynamic / long-term static without preloading; 1.2d/s – dynamic/static with 0.3 R_b preloading; 1.3d/s – dynamic/static with 0.7 R_b preloading; 1.4d/s – dynamic/static with 0.8 R_b preloading; 2.1d/s – dynamic / long-term static without preloading; 2.2d/s – dynamic/static with 0.3 R_b preloading; 2.3d/s – dynamic/static with 0.7 R_b preloading; 2.4d/s – dynamic/static with 0.8 R_b preloading

Table 1. Influence of long-term static preloading on the dynamic strengthening factor under axial compression

	Transverse deformations coefficient, MPa[a]						
σ / R_b	Long-term static (reference), E_r	Static with preload, E_s	Dynamic with preload, E_d	E_s / E_r	E_d / E_s	E_s / $E_{s,0}$ [b]	E_d / $E_{d,0}$ [b]
0	31 500	-	40 900	-	1.3	1.0	1.0
0.3	17 800	21 600	52 600	1.21	2.44	0.69	1.29
0.7	7 800	9 200	117 000	1.18	12.7	0.29	2.86
0.8	5 200	7 200	48 000	1.38	9.2	0.22	1.17

[a] Longitudinal deformation coefficients were determined by deformation increment on stress increase by 3.5 MPa compared to preload (corresponds one step static load).

[b] Initial deformation modules were determined in (0.1-0.2) R range.

Ultimate deformations analysis confirms longitudinal deformation coefficient growth. Comparing deformations at the application of dynamical loads after preloading with the deformations of similar σ / R_b without preloading (tables 2 and 3), we conclude that ultimate deformations does not depend on preloading occurrence with the exception of highest preloading values. But it is should be mentioned that ultimate deformation increase is due to sharp reduction of longitudinal deformation coefficient on the value of 0.9 R_b, when microfractures, that emerged during preloading, presumably unite. Except the highest preloading level, the ultimate deformations were twice smaller than the ones during static exposure. Thus, preservation of strength and ultimate deformations in different preloading modes is possible due to considerable growth of longitudinal deformation coefficient, which indicated changes in the material structure and elasticity enhancement, as most of plastic deformations has already been implemented during long-term static exposure.

Table 2. Deformations at the start of dynamic exposure and their comparison to deformations of similar σ / R_b in dynamic exposure without preloading

σ / R_b	Longitudinal to transverse deformations ratio with preload ε_0, 10·5 relative deformations unit	Longitudinal to transverse deformations ratio without preload ε, 10·5 relative deformations unit	$\varepsilon_0 / \varepsilon$
0.3	37.34/10.5	21.2/4.75	1.76/2.21
0.7	117.1/43.6	52/16.9	2.25/2.58
0.8	162.73/75.57	81/33.8	2.0/2.24

Table 3. Ultimate deformation depending on the preloading level

σ / R_b	Ultimate longitudinal/transverse deformation		$\varepsilon_d / \varepsilon_s$
	static, ε_s, 10·5 relative deformations unit	dynamic, 10·5 relative deformations unit	
0	370/160.33	169/101.5	0.46/0.63
0.8	360/150	274/184.4	0.76/1.23
0.7	275/123.8	160.5/115.6	0.58/0.93
0.3	280/145	181/128.5	0.64/0.89

Transverse deformation coefficients, which is ratio of transverse deformations increments to longitudinal deformations increments per loading step, provide a notion on loading value influence on deformation diagram (figure 3).

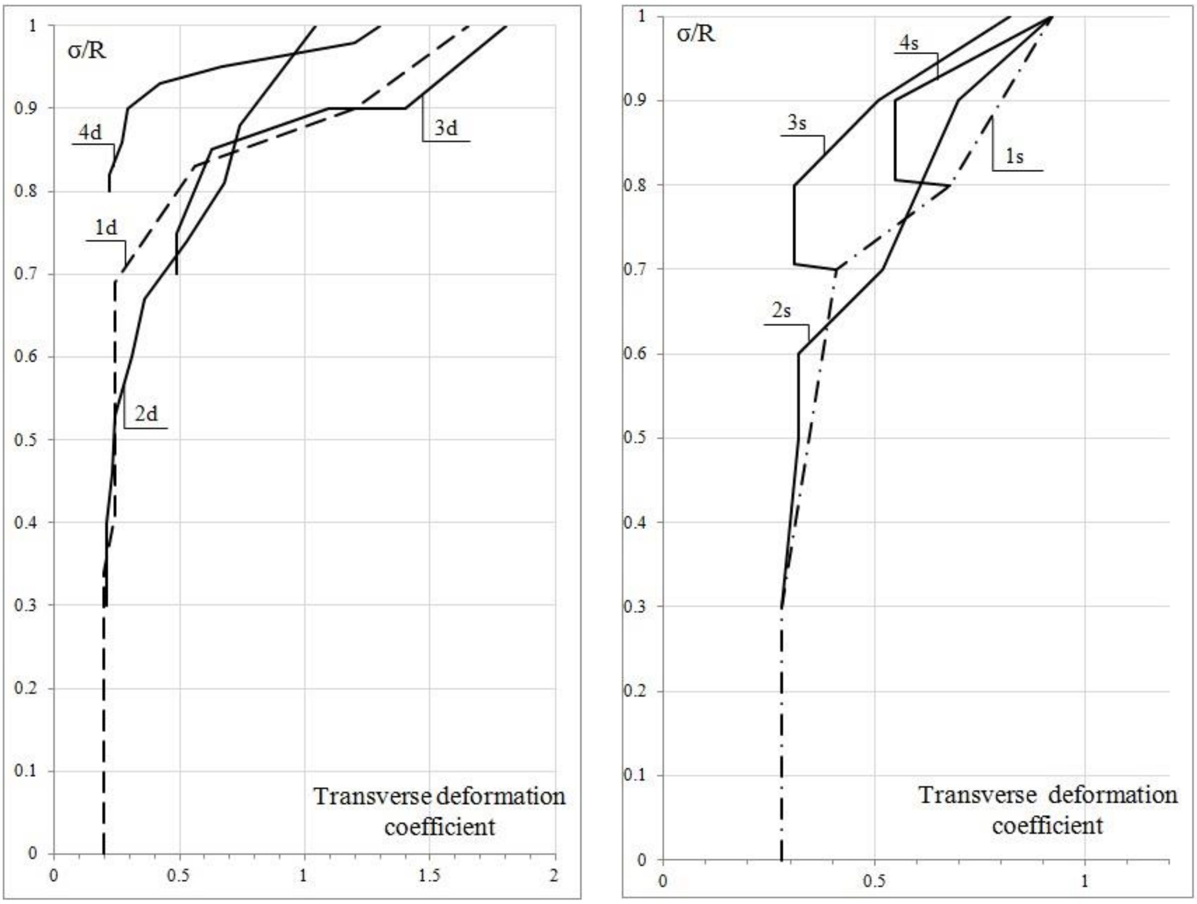

Figure 3. Experiment results. Transverse deformations coefficients: 1 d/s – dynamic / long-term static without preloading; 2d/s – dynamic/static with 0.3 R_b preloading; 3d/s – dynamic/static with 0.7 R_b preloading; 4d/s – dynamic/static with 0.8 R_b preloading

Unlike higher loading values, static load of 0.3 does not affect transverse deformation coefficient on transition from long-term to short-term mode. On the value of 0.7 the coefficient falls to initial value. Transverse deformation growth slowdown enables deformation to occur with lower values of transverse deformations coefficient and higher strains corresponding upper fracture limit (measured on coefficient of transverse deformations 0.5) on higher preloading levels. The data on transverse deformations coefficient during dynamic exposure of 0.7 require further investigation. For the rest the following patterns should be noted. Deformation under dynamic exposure occurs with lower coefficient. At the same time preloading does not affect transverse deformations coefficient which is measured at the dynamic load application to preloaded sample. Reducing the preload to 0.3 leads to reduction of stress values, which corresponds higher transverse deformation coefficient compared to base dynamic diagram and diagram on 0.7.

4. Conclusion

According to experiment results analysis the following suggestions on the choice of dynamic diagram on static load with preloading could be made.

Using dynamic diagram obtained without preloading is not correct and would cause distortion in stress-strain state evaluation. On relatively low or high preloading levels combining diagram without preloading with highest point of static diagram is appropriate. In 0.4–0.75 R_b range dynamic diagram with preloading is adequate. Combined analysis of transverse and longitudinal deformations indicates that preloading and its value along with dynamic loading represent a complex system of factors that affect deformation diagrams.

Acknowledgments
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