Magazine of Civil Engineering

ISSN
2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.104.13

Elasticity modulus of cement composites predicting using layer structure model

A.S. Korolev*[a], N.I. Vatin[b]
[a] South Ural State University, Chelyabinsk, Russia
[b] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
**E-mail: korolev@sc74.ru*

Keywords: modulus of elasticity of concrete, deformability of concrete, relative elastic deformations, relative residual deformations, layered calculation model

Abstract. The deformability of concrete along with the compressive strength is the determining factor in the calculation of concrete and reinforced concrete structures. In practice, with the same strength, the deformative properties of concrete, especially monolithic, can vary in a significant range, which affects the actual deflection of span structures and their reinforcement coefficient. However, the modulus of elasticity/deformation of concrete in production is not normed, and the introduction of the norm requires obtaining available bases for calculating the deformability of concrete under load from the composition of the concrete mix. The use of a layer calculation model allows you to quickly and accurately predict the elastic modulus and deformation of concrete. On the base of this model elasticity modulus depending on concrete mix components characteristics and proportions calculation method received and tested.

1. *Introduction*

Currently, the issues of estimating and predicting the composite materials elastic modulus, including cement composites, remain relevant. The purpose of such research is to develop methods for ensuring the specified elastic and plastic deformability of concrete while maintaining the strength class. This makes it possible to increase the technical and economic efficiency of various building structures, especially slab and beam constructions.

In practice, compressive strength norm and control are implemented everywhere, while the main indicator of concrete deformability, the modulus of elasticity (deformation), is not controlled in any way. Therefore, designers and technologists have nothing in service except its relations with the strength of the normative documentation. However, with the modern expansion of monolithic concreting, their values vary in a fairly wide range. The concrete modulus of elasticity and plastic deformations norming would greatly facilitate the task of providing calculated deflections of slab and beam constructions. To do this, it's necessary to create a model that combines simple technological techniques and trends in managing the elasticity of concrete. This makes possible to think about the concrete elastic modulus or deformation norm implementation, both instantaneous and long-term. However, when setting standards for the modulus of elasticity (deformation) of concrete, it is necessary to provide manufacturers with recommendations for managing the module when calculating and selecting the composition of concrete mixtures, as well as materials for their manufacture. Among the mentioned techniques and trends for improving elastic properties, we can distinguish:

1) increasing the compressive strength of concrete by increasing the compressive strength/modulus of elasticity of hydrating cement paste in the composite [1–10]

2) increasing the compressive strength/modulus of elasticity of the aggregate [11–13]

3) increasing the volume content of a more elastic component-aggregate (heavy) or hydrating cement paste (with light aggregates) [14–16]

Korolev, A.S., Vatin, N.I. Elasticity modulus of cement composites predicting using layer structure model. Magazine of Civil Engineering. 2021. 104(4). Article No. 10413. DOI: 10.34910/MCE.104.13

4) increasing the largest aggregate size and reducing the relative surface area of the aggregate [17–20]

A careful examination of the concrete elasticity modulus research results using the above techniques shows the absence of either a direct proportion or a direct connection between the module and each of the factors – strength concrete, modulus of elasticity of the aggregate, its maximum size and the content. It tells about the interaction of factors and the need to account for this interaction.

The greatest development of the theory of elasticity of composites was in the middle of the last century. Itskovich, Sheikin, Gansen, and others proposed computational models of the elasticity modulus from the main factors: the modulus of elasticity of components, the volume contents of components. Some models are based on the equal deformability of elements, others on their equal strength. I.N. Akhverdov [21] proposed a model that takes into account both the different deformations and different stresses of components.

$$E_c = \frac{1}{\frac{V_{agg}}{E_{agg}} k_{agg} + \frac{V_{c\,max}}{E_{cem}} k_{c\,max} + \frac{V_{c\,min}}{E_{cem}} k_{c\,min}} \quad (1)$$

where V_{agg} is the relative content of aggregate;

$V_{c\,max}$ is the relative content of the part of the hydrating cement paste with the maximum stress;

$V_{c\,min}$ is the relative content of the part of the hydrating cement paste with the maximum stress;

E_{agg} is the elastic modulus of the aggregate;

E_{cem} is the modulus of elasticity of hydrating cement paste;

k_{agg}, $k_{c\,max}$, $k_{c\,min}$ are the coefficients that take into account the proportion of tangent stresses during loading.

The given model takes into account different levels of tension of the composite elements during loading, and does not take into account the influence of the contact zone of the hydrated cement paste with the aggregate (ITZ).

If we try to summarize past and current research, we can highlight the following principles and postulates in the formation of elastic properties of cement composites:

1) cement composite is a three-phase structure, basic elements of which are hydrated cement paste, aggregate, and the contact area between them or interfacial transition zone (ITZ), these components have different elasticity and their different elasticity determines the overall deformation properties of the composite [15–20], spherulitic model is shown in Fig. 1, the contact area ITZ is more porous due to the water demand of the aggregate surface, so ITZ is more deformative in comparison to other elements;

2) the stress-strain state of the cement composite does not under the principle of additivity, each element in the overall structure has different stresses and deformations, so the elastic modules of elements, the volume content of elements, the degree of their involvement in the work, which depends on their geometric distribution and their differ-elasticity [3, 4, 10, 15, 20–21] are used as factors in creating mathematical models of elasticity or "stress-strain" dependencies.

Thus, when considering the operation of concrete under instantaneous loading without taking into account plastics, we can assume the validity of a layer design model with equal strength of elements, consisting of 3 consecutive continuous layers: cement paste, the contact zone with the aggregate ITZ and the aggregate. To simplify the calculation, consider a flat layer model in which there are no discrete elements, all elements are continuous within the surface area of the ITZ (Fig. 1).

In this paper, an attempt will be made to confirm the performance of this model and link it to the indicators of the composition of the concrete mix.

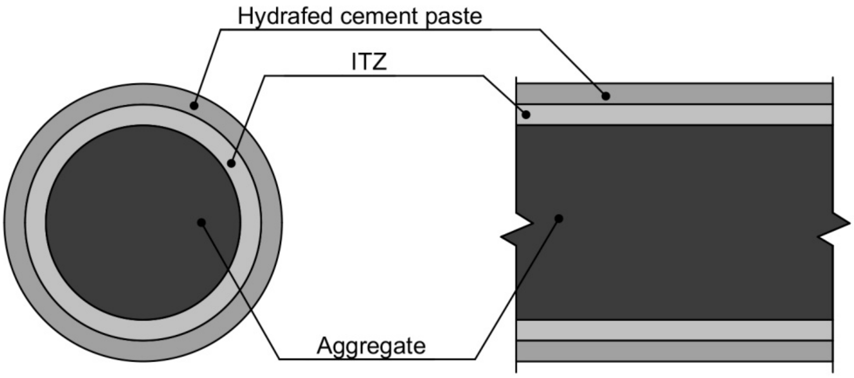

Figure 1. Spherical and layer calculation models of cement composite structure base element elastic and plastic properties.

2. *Materials and Methods*

The analytical method was used to select and evaluate the composites layer model calculation method.

Standard methods of Russian State Standards GOST 24452-80 “Concretes. Methods of prismatic, compressive strength, modulus of elasticity and Poisson's ratio determination” and GOST 22690-2015 “Concretes. Determination of strength by mechanical methods of nondestructive testing” were used to determine the modulus of elasticity and compressive strength of concrete of various classes. Each classes series of 3 samples were tested under compression on Matest press with determination of longitudinal elastic and plastic deformation using digital deformation sencors on every sides of sample. Compression was made by 10% of cracking stress stages to the 40% of cracking stress (Fig.2). Elasticity modulus has been determined as a relation of 30% cracking stress to the sum of elastic relative deformation except plastic on stages delay by standard. Compressive strength was determined on 6 samples series by standard.

Figure 2. Concrete sample modulus of elasticity under compression testing.

In our experiment to define fact concrete elasticity modulus, we used local producers materials: granite coarse aggregate and quartz sand with a strength of R_{agg} = 1000 MPa and an elastic modulus of E_{agg}=50*10^4 MPa, Portland cement B42.5 CEM I with a water requirement of normal density cement paste 25 % and the strength of cement paste with a with water/cement ratio (W/C) of normal density in the standard age R_{cem} = 100 MPa and an elastic modulus of E_{cem} = 50*10^4 MPa. Content of various classes mixture components presented in Table 1.

3. *Results and Discussion*

Considering experimental data of cement concrete deformation under compression (Fig. 3) goes to following conclusions:

1) when compressive loading of samples according to the standard method in steps of 10 % with a delay at each stage, after reaching 10...20% of the destructive load, there are well-known incoming plastic deformations, which continue to develop at the next loading stages, when bending plastic deformations are not observed;

2) as the load increases, the increase in elastic deformations is expected to remain constant, the increase in plastic deformations with loading increases in an arithmetic progression over the load according to the proposed model (Eq.2), in this regard, the modulus of concrete deformation is not constant and depends on the load.

$$\varepsilon_s = \varepsilon_{0.3} \frac{\sigma_s}{\sigma_{0.3}}. \tag{2}$$

ε_s is the relative deformation of the composite at a given loading stage;

$\varepsilon_{0.3}$ is the relative deformation of the composite at a given loading stage;

σ_s is the compression stress of the composite at a given loading stage;

$\sigma_{0.3}$ is the compression stress of the composite at a given loading stage.

3) compression failure is classically gradual as micro- and macro-cracks form and accumulate, and bending failure is instantaneous after initial cracking.

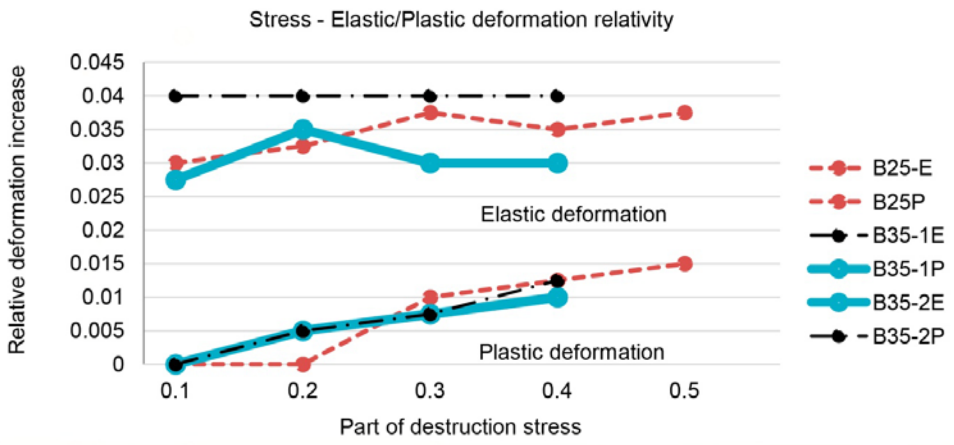

Figure 3. Concrete elastic and plastic deformations under compression by stages.

It is characteristic that concretes of the same strength class can differ significantly in elastic and plastic deformations. In this regard, we can offer the following model for the operation of cement composites under compressive loads. As the stress-strain state is loaded, it goes through the following stages:

1. 0 ... 10% of the destructive load is a zone of pure elasticity, joint elastic work of all components, only elastic deformations are observed. When stretching and bending, cement composites work only in this zone.

2. 10 ... 80% of the destructive load. Reaching the tensile strength of the cement paste shells, their primary fault in places of maximum tension (Fig. 4) and the development of microcracking, forming a zone of elastoplastic deformation. In this zone the cement paste and aggregate work is elastic, and highly porous contact zone, having the greatest deformation, is plastically squeezed due to transverse strains like compressible fluid. The total deformation includes instantaneous elastic and plastic deformations, because during instant loading, the contact area working elastically as the compressed fluid, which over time of transverse deformation coming to the accumulation of plastic deformations.

3. From 80% to destructive load is plastic zone, accumulated micro-cracking passes into macro-cracking, there are significant transverse cracks, visible cracks, and destruction.

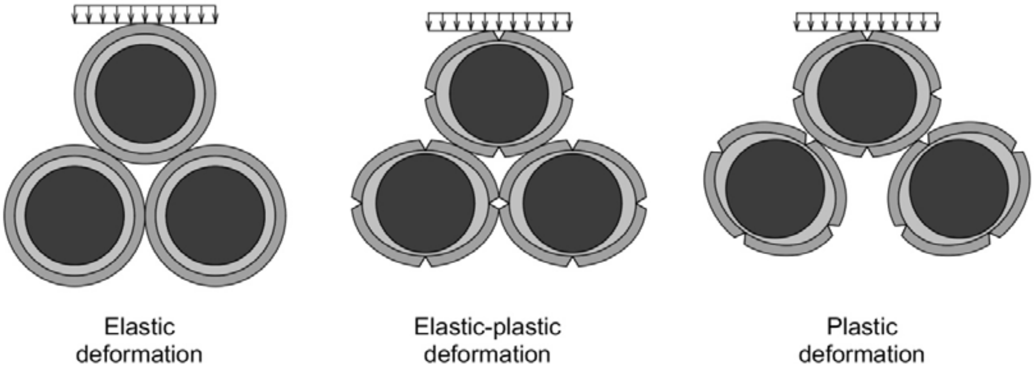

Figure 4. Three stages of deformation of concrete at failure.

In this model, under instantaneous loading, all components of a cement composite, even in the elastic-plastic zone, are equally stressed, work together, and are elastic. Microplastic deformations can be considered as a sum of deformations along the contact zones, after complete compression beginning the stage of macro-cracking and destruction occurs.

Differently from another models that all are spherulitic [15–20], the layer model in case of deformativity presenting the composite structure as a structure where all components non-discrete and continuous so modelled like layers.

According to the principle of equal stress of elements, to determine the elastic modulus of the composite, it is necessary to determine the sum of partial deformations of each micro-volume, which includes all 3 elements/layers of the concrete structure.

$$\varepsilon_c = \frac{\sigma_c}{E_c} = \frac{\frac{\sigma}{E_{cem}}\delta_{cem} + \frac{\sigma}{E_{itz}}\delta_{itz} + \frac{\sigma}{E_{agg}}\delta_{agg}}{\delta_{mv}} \tag{3}$$

σ_c is the stress in the composite structure;

E_c is the elastic modulus of the composite;

E_{cem} is the elastic modulus of the layer of the contact zone of hydrating cement paste and aggregate;

E_{itz} is the elastic modulus of the layer of the contact zone of hydrating cement paste and aggregate;

E_{agg} is the modulus of elasticity of the filler layer;

δ_{mv} is the thickness of the selected micro-volume that combines all the structural layers;

δ_{cem} is the thickness of the hydrating cement paste layer;

δ_{itz} is the layer thickness of the contact zone of hydrating cement paste and aggregate;

δ_{agg} is the thickness of the aggregate layer.

Converting the equation, we get the elastic modulus of the composite

$$E_c = \frac{\delta_{mv}}{\frac{\delta_{cem}}{E_{cem}} + \frac{\delta_{itz}}{E_{itz}} + \frac{\delta_{agg}}{E_{agg}}} \tag{4}$$

In its final form, the expression takes the form

$$E_c = \frac{E_{cem}E_{itz}E_{agg}}{cemE_{itz}E_{agg} + itzE_{cem}E_{agg} + aggE_{itz}E_{cem}}, \quad (5)$$

where $cem = \frac{\delta_{cem}}{\delta_{mv}}$; $itz = \frac{\delta_{itz}}{\delta_{mv}}$; $agg = \frac{\delta_{agg}}{\delta_{mv}}$.

In the resulting equation, the assumption is made that the elastic modulus of the aggregate particles (both large and small) is equal. if there is a significant difference, this expression should be used to determine the elastic modulus of the mortar and calculate the elasticity of the structure with a large aggregate using a 2-layer model [22].

If the elastic modulus of hydrating cement paste and aggregate can be quantified, then the elastic modulus of the contact zone, as well as the relative thicknesses of all layers, require approaches in determining.

The relative thicknesses of the "hydrating cement paste+contact zone" and "aggregate" layers can be calculated based on the composite layer model, in which the weighted average particle size is replaced by the weighted average size of the layers with a conditional specific surface area of the components. Accordingly, the relative thickness of "hydrating cement paste+contact zone" is determined

$$cem_0 = \frac{\delta_{cem0}}{\delta_{mv}} = \frac{S_{itz}\delta_{cem0}}{S_{itz}(\delta_{cem0} + \delta_{agg})} = \frac{V_{cem0}}{V_{cem0} + V_{agg}} \quad (6)$$

and the relative thickness of a layer of “aggregate“

$$agg = \frac{\delta_{agg}}{\delta_{mv}} = \frac{S_{itz}\delta_{agg}}{S_{itz}(\delta_{cem0} + \delta_{agg})} = \frac{V_{agg}}{V_{cem0} + V_{agg}}, \quad (7)$$

where δ_{cem0} is the absolute thickness of a layer of "hydrating cement paste+contact zone”;

S_{itz} is the related surface area of the contact zone;

V_{cem0} is the volume concentration of the "hydrating cement paste+contact zone" layer;

V_{agg} is the volume concentration of the “aggregate” layer.

$$V_{agg} = \frac{A}{\rho_{agg}} = \frac{\rho_{con} - C - W}{\rho_{agg}}, \quad (8)$$

where A is the aggregate consumption per cubic meter of the mix;

C is the cement consumption per cubic meter of the mix;

ρ_{con} is the average density of the mixture;

ρ_{agg} is the true density of the aggregate;

total water consumption

$W=C*W/C$

W/C is the water-cement ratio.

For develop further approaches to calculating layer thicknesses, we suggest the following assumption: under the condition of not exceeding the water consumption sum water demand components of the mixture water content in the central layer of cement paste corresponds to the standard normal density W/C_{cem} = 0.22…0.28, the volume of the layer, the contact area is formed by water adsorbed by the aggregate and the corresponding water demand aggregate, which is calculated as the residual water after deduction of water requirement of cement

$$V_{itz} = W_{itz} = C\left(\frac{W}{C} - \frac{W}{C_{cem}}\right) = 0.15...0.7 \tag{9}$$

$$V_{cem0} = \frac{C(1 + W / C_{cem})}{\rho_{cp}} + W_{itz} \tag{10}$$

Then the volume of the hydrating cement paste layer is

$$V_{cem} = \frac{C(1 + W / C_{cem})}{\rho_{cp}}, \tag{11}$$

where ρ_{cp} is the density of cement paste with normal density

The relative thickness of the "hydrating cement paste" layer

$$cem = cem_0 \frac{V_{cem}}{V_{cem0}} = \frac{1}{1 + \dfrac{W_{itz}\rho_{cp}}{C(1 + W / C_{cem})}} \tag{12}$$

at the relative thickness of the layer "hydrating cement paste + aggregate”

$$cem_0 = \frac{1}{1 + \dfrac{(\rho_{con} - C - W)\rho_{cp}}{C\left(1 + \dfrac{W}{C_{cem}}\right) + W_{itz}\rho_{cp}}} \tag{13}$$

The relative thickness of a layer of "aggregate”

$$agg = \frac{1}{1 + \dfrac{C\left(1 + \dfrac{W}{C_{cem}}\right) + W_{itz}\,\rho_{cp}}{(\rho_{con} - C - W)\rho_{cp}}} \tag{14}$$

The relative thickness of a layer of "contact zone”

$$itz = \frac{\delta_{itz}}{\delta_{mv}} = \frac{S_{itz}\delta_{itz}}{S_{itz}(\delta_{cem} + \delta_{itz} + \delta_{agg})} = \frac{V_{itz}}{V_{cem} + V_{itz} + V_{agg}} = 1 - cem - agg \tag{15}$$

For further testing in the experiment with cement concretes, we will use the basic equation of module (5) using the equation (13), (14), (15). Working compositions of commercial concrete mixes of our own concrete mixing plant were used for testing. Thus, all data is available for calculation except the elastic modulus of the contact zone, which will be determined by the correlation method. Table 1 shows data for the sequential calculation of the elastic modulus of commercial concrete of classes B7.5…B60 for the layer model based on the parameters of the modulus of components and composition of the concrete mix: relative thicknesses cem, agg, itz. To assess the accuracy, the standard values of the elastic modulus for classes according to Russian Building Norms SNiP 2.03.01-84*(1996) “Concrete and reinforced concrete structures” were used.

As a result of correlation, the elastic modulus of the contact zone was determined as E_{itz} = 7*10^4 MPa. As can be seen from the data in table 1, the method, starting from class B20, gives a good convergence in the prediction of the elastic modulus, deviations do not exceed 5%. From class B15 and below, the calculation data is significantly overstated, obviously due to the large amount of free water and the hydration of the aggregate particles, the elastic modulus of the contact zone of low classes decreases, the convergence of the calculation at low classes reaches at E_{itz} = 4*10^4 MPa.

If we analyze the significance of the factors in the design model, we can conclude that a decrease or increase in the relative thickness and modulus of one of the layers leads to a disproportionate decrease or increase in the elastic modulus of concrete as a whole. Therefore, the increase in particle size of the aggregate is not accompanied by a reduction in water and cement can only lead to the increase in the ratio of the relative thickness of the flowable layer, the contact area and not only increase the modulus of the concrete, but lead to its reduction. To verify this proposal, the calculation model was tested by manufacturing concrete images from concrete of classes B25 (compositions 0, 3, 13) and B35 (compositions 1, 2, 4, 12, 14). In the compositions of class B25, the sand size modulus (MK) and cement consumption (C) varied: 0 – MK = 2.0, C = 360 kg/m^3; 3 – MK = 2.5, C = 340 kg/m^3; 13 – MK = 2.5, C = 290 kg/m^3. In the compositions of class B35, the largest aggregate size (NC), sand size modulus and cement consumption varied: 1 – MK = 2.0, NC = 20 mm, C = 350 kg/m^3; 2 – MK = 2.0, NC = 30 mm, C = 350 kg/m^3; 4 – MK = 2.5, NC = 30 mm, C = 350 kg /m^3 ; 12 – MK = 2.0, NC = 30 mm, C = 305 kg/m^3; 14 – MK = 2.5, NC = 30 mm, S = 300 kg/m^3.

Testing of the model showed that the thickness and elasticity of the weakest element disproportionately reduces the elasticity and increases the plastic properties of the cement composite as a whole. The contact zone ITZ is determined not only by the relative surface of the aggregate, but also by the water/cement and water/aggregate ratio subject to cement and aggregate water demand. So, increasing cement composite elastic properties requires complex solutions. The most effective of which, while maintaining the strength class of concrete, is simultaneously increasing the size of the aggregate and reducing cement consumption, provided by reducing the water demand of the aggregate and plasticizing the mixture through the use of additives. The elastic properties of the predominant aggregate element are also crucial, a 10% decrease in the elastic modulus of the aggregate can lead to a 15–20% decrease in the elastic modulus.

Reducing the relative surface of the aggregate without reducing the consumption of cement leads to an increase in the thickness of the layers of cement paste and the contact zone, which negates the effect of increasing the modulus of elasticity. Meanwhile, reducing the consumption of cement with strength maintaining, the modulus of elasticity can be increased by 10% or more.

It should also be noted the tendency (Table 2, last column) to significantly reduce (by 15–20%) plastic deformations when creating conditions for increasing the modulus of elasticity. According to the proposed model of concrete deformation, the main potential for the development of plastic deformations is the contact zone ITZ. An attempt was made to correlate the level of plastic deformation at 30% loading. As a result, a directly proportional relationship between the relative thickness of the contact zone and the relative plastic deformation of concrete is determined

$$\varepsilon_{pl0.3} = k_{pl0.3} itz \tag{16}$$

$k_{pl0.3}$=0.08 is the coefficient of plastic deformation.

Table 1 shows the calculated data of relative plastic deformation at 30% loading, and the equation 2 can be converted to other loading levels. In prospective it makes possible to determine the modulus of concrete deformations under prolonged load action. The modulus of deformations standard calculation (Russian Building Rules SP 63/13330/2018 “Concrete and reinforced concrete constructions”) is

$$E_{b,\tau} = \frac{E_b}{1+\varphi_{b,cr}} = \frac{1.1E_b}{1+0.8\varphi_{b,cr}} \tag{17}$$

$\varphi_{b,cr}$ is the coefficient of creep of concrete is taken on the recommendations.

Taking into account that modulus of elasticity increasing goes to plastic deformation decrease, the coefficient of creep of concrete $\varphi_{b,ct}$ could be corrected in correlation with $\varepsilon_{pl0.3}$.

Table 1. Calculated and standard characteristics of the concrete elasticity modulus.

B	C, kg/m^3	W/C	W, kg/m^3	W_{cp}, kg/m^3	W_{itz}, kg/m^3	V_{cem0}, m^3/m^3	ρ_{con}, kg/m^3	V_{agg}, m^3/m^3	cem	itz	agg	E_c, 10^3, MPa	E_{st}, 10^3, MPa	Δ, %	$\varepsilon_{el0.3}$, 10^{-2}
5	180	1.40	252	45.0	207.0	313.2	2200	631.4	0.112	0.219	0.668	21.3	13.0	-63.9	1.75
10	210	1.00	210	52.5	157.5	281.4	2250	653.6	0.133	0.168	0.699	24.6	18.0	-36.5	1.35
15	260	0.80	208	65.0	143.0	296.4	2330	665	0.160	0.149	0.692	26.1	23.0	-13.6	1.19
20	290	0.70	203	72.5	130.5	301.6	2350	663.2	0.177	0.135	0.687	27.3	27.0	-1.1	1.08
25	320	0.60	192	80.0	112.0	300.8	2450	692.1	0.190	0.113	0.697	29.5	30.0	1.5	0.09
30	360	0.54	194	90.0	104.4	316.8	2450	677	0.214	0.105	0.681	30.4	32.5	6.5	0.84
35	380	0.46	175	95.0	79.8	304.0	2450	676.9	0.229	0.081	0.69	33.3	34.5	3.4	0.65
40	410	0.42	172	103.0	69.7	311.6	2480	677.8	0.244	0.070	0.685	34.9	36.0	3.1	0.56
45	440	0.38	167	110.0	57.2	316.8	2480	668.9	0.263	0.058	0.679	36.9	37.5	1.7	0.46
50	470	0.35	165	118.0	47.0	324.3	2500	666.3	0.280	0.047	0.673	38.7	39.0	0.7	0.38
55	480	0.34	163	120.0	43.2	326.4	2450	645.3	0.291	0.044	0.664	39.3	39.5	0.6	0.36
60	520	0.32	166	130.0	36.4	343.2	2430	622.7	0.318	0.038	0.645	40.6	40.0	-1.5	0.30

Table 2. Calculated and experimental characteristics of the concrete elasticity modulus and plastic deformations.

No.	B	C, kg/m^3	W/C	W, kg/m^3	W_{cp}, kg/m^3	W_{itz}, kg/m^3	V_{cem0}, m^3/m^3	ρ_{con}, kg/m^3	V_{agg}, m^3/m^3	cem	itz	agg	E_c, 10^3, MPa	E_{exp}, 10^3, MPa	Δ, %	$\varepsilon_{el0.3}$, 10^{-2}	$\varepsilon_{el0.3exp}$, 10^{-2}
0	25	360	0.61	220	90	129.6	354.6	2430	755	0.20	0.12	0.68	29.1	29	-0.4	0.93	1.00
3	25	340	0.62	211	85	125.8	338.3	2470	783	0.19	0.11	0.70	29.6	33	10.3	0.90	0.80
13	25	290	0.63	183	72.5	110.2	291.5	2470	815	0.16	0.1	0.74	31.0	33	6.0	0.80	0.25
1	35	350	0.54	189	87.5	101.5	320.3	2500	800	0.20	0.09	0.71	32.1	35	8.2	0.72	0.80
2	35	350	0.54	189	87.5	101.5	320.3	2510	804	0.19	0.09	0.72	32.2	38	15.3	0.72	0.80
4	35	350	0.54	189	87.5	101.5	320.3	2500	800	0.20	0.09	0.71	32.1	34	5.5	0.72	0.80
12	35	305	0.53	162	76.3	85.4	276.0	2540	846	0.17	0.08	0.75	34.1	38	10.3	0.61	0.50
14	35	300	0.53	159	75.0	84.0	271.5	2490	829	0.17	0.08	0.75	34.0	36	5.4	0.61	1.00

4. *Conclusion*

As a result of analytical and experimental work, first the suitability of the layer model for evaluating the instant elastic modulus and deformative properties of cement composites was confirmed. It made in development of all basic and last researches in this area for available technological calculation support.

First the cement composite elasticity modulus calculation model based on the layer model operates on 6 factors: elastic modules and relative thicknesses of structural layers "aggregate", "contact zone of cement paste-aggregate", "hydrated cement paste". Cause the model is operating by easy definable factors in difference from other solutions first it made possible to receive the “step-by-step” method of cement composites elasticity modulus calculation depending on concrete mix components properties and proportions. Calculation is determining the relative thicknesses of layers with known separate elasticity modulus and finally defines whole composite structure elasticity modulus. So with components elasticity modulus data the calculation of composite elasticity modulus making of Eq. 5. The method allows to solve two basic technological problems: 1) to ensure the normative deformability of the given class concrete; 2) to identify ways to increase elastic properties within a given composition and raw materials.

Separately, it should be noted that method makes possible to norm the modulus of elasticity of commercial concrete because making available to predict elastic properties on the stage of the concrete mix composition design. The development of methods for simple and rapid control of the modulus of elasticity of concrete will make able to norm the deformative properties of concrete in projects and ensure compliance with these standards, which in turn will ensure minimum costs already at the design stage.

5. *Acknowledgment*

The work was performed within the framework of the state task of the Ministry of science and higher education of the Russian Federation FENU-2020-0019.

References

1. Alsalman, A., Dang, C.N., Prinz, G.S., Hale, W.M. Evaluation of modulus of elasticity of ultra-high performance concrete. Construction and Building Materials. 2017. DOI: 10.1016/j.conbuildmat.2017.07.158
2. Fládr, J., Bílý, P., Trtík, T. Analysis of the influence of supplementary cementitious materials used in UHPC on modulus of elasticity. IOP Conference Series: Materials Science and Engineering. 2019. 522. Pp. 012010. DOI: 10.1088/1757-899X/522/1/012010.
3. Bahr, O., Schaumann, P., Bollen, B., Bracke, J. Young’s modulus and Poisson’s ratio of concrete at high temperatures: Experimental investigations. Materials and Design. 2013. DOI: 10.1016/j.matdes.2012.07.070
4. Brooks, J.J. Elasticity of Concrete. Concrete and Masonry Movements 2015.
5. Kurugöl, S., Tanaçan, L., Ersoy, H.Y. Young’s modulus of fiber-reinforced and polymer-modified lightweight concrete composites. Construction and Building Materials. 2008. DOI: 10.1016/j.conbuildmat.2007.03.017
6. Klyuev, S.V., Khezhev, T.A., Pukharenko, Y.V., Klyuev, A.V. Experimental study of fiber-reinforced concrete structures. Materials Science Forum. 2018. Pp. 115–119. DOI: 10.4028/MSF.945.115
7. Noguchi, T., Nemati, K.M. Relationship between compressive strength and modulus of elasticity of high-strength concrete. Proceedings of the 6th International Conference on Fracture Mechanics of Concrete and Concrete Structures. 2007.
8. Sideris, K.K., Manita, P., Sideris, K. Estimation of ultimate modulus of elasticity and Poisson ratio of normal concrete. Cement and Concrete Composites. 2004. 26(6). Pp. 623–631. DOI: 10.1016/S0958-9465(03)00084-2
9. Wongpa, J., Kiattikomol, K., Jaturapitakkul, C., Chindaprasirt, P. Compressive strength, modulus of elasticity, and water permeability of inorganic polymer concrete. Materials and Design. 2010. DOI: 10.1016/j.matdes.2010.05.012
10. Yildirim, H., Sengul, O. Modulus of elasticity of substandard and normal concretes. Construction and Building Materials. 2011. DOI: 10.1016/j.conbuildmat.2010.10.009
11. Odelson, J.B., Kerr, E.A., Vichit-Vadakan, W. Young’s modulus of cement paste at elevated temperatures. Cement and Concrete Research. 2007. DOI: 10.1016/j.cemconres.2006.11.006
12. Sprince, A., Pakrastins, L., Gailitis, R. Long-Term Parameters of New Cement Composites 2020. Pp. 85–94.
13. Sanahuja, J., Dormieux, L., Chanvillard, G. Modelling elasticity of a hydrating cement paste. Cement and Concrete Research. 2007. DOI: 10.1016/j.cemconres.2007.07.003
14. Silva, R.V., De Brito, J., Dhir, R.K. Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete 2016.
15. Topçu, I.B., Bilir, T., Boğa, A.R. Estimation of the modulus of elasticity of slag concrete by using composite material models. Construction and Building Materials. 2010. DOI: 10.1016/j.conbuildmat.2009.10.034
16. Usanova, K. Properties of Cold-Bonded Fly Ash Lightweight Aggregate Concretes. Lecture Notes in Civil Engineering. 2020. Pp. 507–516. DOI: 10.1007/978-3-030-42351-3_44
17. Jurowski, K., Grzeszczyk, S. The influence of concrete composition on Young’s modulus. Procedia Engineering. 2015. DOI: 10.1016/j.proeng.2015.06.181
18. Li, G., Zhao, Y., Pang, S.S. Four-phase sphere modeling of effective bulk modulus of concrete. Cement and Concrete Research. 1999. DOI: 10.1016/S0008-8846(99)00040-X
19. Zhu, X., Gao, Y., Dai, Z., Corr, D.J., Shah, S.P. Effect of interfacial transition zone on the Young’s modulus of carbon nanofiber reinforced cement concrete. Cement and Concrete Research. 2018. DOI: 10.1016/j.cemconres.2018.02.014

20. Varlamov, A.A., Rimshin, V.I., Tverskoi, S.Y. The modulus of elasticity in the theory of degradation. IOP Conference Series: Materials Science and Engineering. 2018. 463. Pp. 022029. DOI: 10.1088/1757-899X/463/2/022029. URL: https://iopscience.iop.org/article/10.1088/1757-899X/463/2/022029
21. Akhverdov, I.N. Osnovy fiziki betona. Moskva, Strojizdat, 1981.
22. Korolev, A.S., Zyrianov, F.A. Layer model of the cement composites deformation in the reinforced masonry structures. Construction of Unique Buildings and Structures. 2020. 92. DOI: 10.18720/CUBS.92.2

Contacts:

Alexander Korolev, korolev@sc74.ru
Nikolai Vatin, vatin@mail.ru