

Fundamentals of property and compositions management concrete mix and concrete

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Abstract. The choice of the concrete composition following the set research tasks must satisfy the following requirements: 1-the maximum achievable strength on the given starting materials; 2-the required formability, corresponding to the accepted vibration-impact-peristaltic pressing; 3-a given level of dehydration of the concrete mixture, providing a residual W/C , close to the normal density of the cement paste. The accepted conditions are necessary and sufficient when using the physical-analytical method of designing concrete composition. Distinctive features of the method are the use of a large amount of information and the absence of arbitrary coefficients, technological constants, or parameters. The necessary data for the assignment of concrete compositions are determined according to the data of preliminary laboratory experiments, the given technological parameters of mechanisms and equipment, and the design characteristics of concrete and the structure to be formed. For the experimental study, a total of six independent information streams of initial data are used: 1-physical and mechanical properties of the constituents of concrete ($R_c, \rho_c, \rho_c^\circ, [V/C], p_c, \gamma_p, \rho_{shch}, \gamma_{sh}, \gamma_{shch}^\circ$); 2-laboratory data of tests of raw materials in concrete mix and concrete (a, b, c, Ku, A, B); 3-design characteristics of concrete mix and concrete (R_b, F, W, OK, Z_h); 4-characteristics of the product to be concreted (V, h, l, μ); 5-technological characteristics of equipment, mechanisms, and devices ($th, tb, TO, t0$); 6-the cost per unit volume of raw materials (Sc, Cn, Ssh, Se, Sg). Obviously, the listed volume of initial information comprehensively characterizes the materials used and the conditions for forming the product. The previously developed technological conditions for forming concrete pipes, in addition to the above, require, when assigning the composition of concrete, to take into account the observance of the balance of masses in the concrete mixture and compacted, modified concrete. This should be manifested in checking the equation of absolute volumes for the original and compacted (dewatered) concrete.

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1 Introduction

The greatest difficulty is the choice of the initial water-cement ratio. It would seem that the V/C value should be taken equal to the $[V/C]$ value for the test of normal density [1-10]. This is the condition for obtaining the maximum strength of concrete [11-15]. However, the formability of such an inactive, semi-dry concrete mixture is significantly impaired. In addition, when water is squeezed out and possible under-compaction, a drop in strength is likely. Therefore, it is necessary to comply with the condition of the mutual consistency of two opposite requirements:

- decrease in V/C to ensure R_{max} ;
- increase in W/C at a given cement consumption to ensure the rheological properties of the compacted mixture and optimal conditions for the structure formation of concrete.

The relationship between the above two opposite conditions is shown in Figure 1. The water-cement ratio of concrete is determined based on the limiting water-holding capacity of the cement paste, investigated by I.N. Akhverdov [16-22], the interval of variation of the optimal water-cement ratio is in the range from $(V/C)_{min}$ to $(V/C)_{max}$. When the value $(V/C)_{min}$, determined according to [23], the value of the coefficient $C_{opt} = 0.876 \cdot [V/C]$. The ultimate water-holding capacity is measured from the point of the greatest strength of the cement stone, equal to $1.65 \cdot [V/C]$. Therefore, $(V/C)_{max}$ is equal to:

$$(V/C)_{max} = 1.65 \cdot C_{opt} = 1.65 \cdot 0.876 [V/C] = 1.44 \cdot [V/C]$$

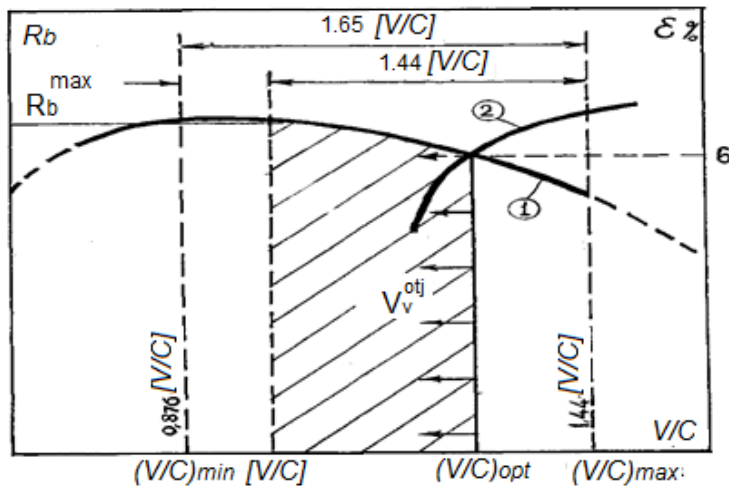
In the experiments, the portland cement of the Akhangaran plant M400 with $[V/C] = 0.24 \dots 0.25$ was used. Therefore, $(V/C)_{max}$ is equal to $0.34 \dots 0.36$.

Determination of the optimal water-cement ratio in hypersolid concrete ($\varepsilon_{opr} = 6.0 \%$)

Explanation by the picture:

Left side: concrete strength scale.

Right side: scale of deformability of cement paste



1 is the curve of changes in the strength of concrete; 2 is the compression curve of the cement paste.

2 Methods

Following the methodology for designing concrete compositions [24, 25], three characteristics of the consistency of the concrete mixture are calculated:

1. Indicator of hardness of concrete mix:

$$G = 1 - OK/OK_{pr} \text{ or } G = lg Zh/Zh_0 \tag{1}$$

where OK_{pr}, Zh_0 are the limiting values of the cone settlement and the conditional stiffness of the concrete mixture of the highest mobility ($OK_{pr} = 20 \text{ cm}, Zh_0 = 0.62 \text{ s}$).

1. The limiting index of stiffness, equal to

$$[G] = G + c \cdot Z \tag{2}$$

where c is the cement qualimeter

1. Coefficient of concrete mix mobility:

$$m = 1/(1 + G) \tag{3}$$

The methodology for designing concrete compositions, adopted in [24, 25], involves the use of three dependencies: the Bolomey equations ($R_b = f(C/V)$), the equations of absolute volumes ($V_b = \Sigma V_k$) and the equations of workability of the concrete mixture ($G = f(X, Y, Z)$).

In our case, at $V/C = \text{const}$, two equations remain for determining the four unknown concrete compositions ($C, V, P, Shch$). Therefore, the following method of appointment and optimization of the initial composition of concrete is adopted.

1. We set the sand-cement ratio

$$x = P/C \tag{4}$$

taking it, for example, equal to $x = 0.6$.

2. The saturation of concrete with sand is calculated

$$X = \frac{x}{1/\rho_u^0 + V/C} \tag{5}$$

where ρ_c^0 is the density of the hydrated cement particles.

3. Determined the saturation of concrete with crushed stone

$$Y = \frac{[G] - a \cdot X}{B} \tag{6}$$

where a is the sand qualimeter; c - crushed stone qualimeter.

4. Calculate the maximum bulk volume of crushed stone in concrete

$$V_0 = \frac{Y}{m+Y} \tag{7}$$

where m is the mobility coefficient of the concrete mixture.

5. Determine the volume of the solution in concrete, assuming the limiting value of the compaction of the concrete mixture ($V_b = 1000l$)

$$V_p = 1000 - V_0 \cdot \frac{\gamma_{shch}^0}{\rho_{shch}} \tag{8}$$

where γ_{shch}^0 is bulk density of crushed stone in a compacted state; ρ_{shch} is the density of crushed stone.

6. The output of cement-sand mortar from one kg of cement is found by the formula:

$$\varphi_p = \frac{1}{\rho_c^\circ} + \frac{V}{C} + \frac{x}{\rho_c} \quad (9)$$

where ρ_c° is the density of hydrated cement particles; ρ_p is the density of sand particles.

7. We calculate the consumption of materials for 1m^3 of concrete

$$C = V_p / \varphi_p \quad (10)$$

$$V = C \cdot V/C \quad (11)$$

$$P = C \cdot x \quad (12)$$

$$Shch = V_0 \cdot \gamma shch^\circ \quad (13)$$

8. Let's calculate the calculated average concrete density

$$\gamma_b = C + V + P + Shch \quad (14)$$

The above calculations were performed in tabular form (Table 1), taking variable values of x with a step of 0.1.

3 Results and Discussion

Considering the curve of the change in the strength of concrete (Figure 1) in combination with the compression curve of the deformation of the cement paste as a function of the V/C values, we find that the optimal value $(V/C)_{opt}$ should be 9...12% less $(V/C)_{max}$, composing for used cements:

$$\begin{aligned} (V/C)_{opt} &= 0.31...0.32 \\ (V/C)_{opt} &= 0.32 = \text{const} = 1.28 \cdot [V/C] \end{aligned}$$

It should be noted that the presented curve R_b is built for concrete without chemical additives. This is caused by a decrease in their efficiency when squeezing water. The value $(V/C)_{opt}$ was chosen in such a way that, as a result of removing 15...18% of mixing water, the value of V/C in the pressed concrete was created, close to the water-cement factor of the test of normal density. In this case, sufficient deformability of concrete and its maximum possible strength is ensured.

The assigned W/C value allows you to calculate the dilution of the cement paste in the concrete mixture using the formula

$$Z = 1/[V/C] = 1/V/C$$

where $[V/C]$ is the water-cement ratio of the cement paste of normal density.

Obviously, the dilution of the cement paste is proportional to the difference between the cement-water ratios of the normal density paste and the concrete mixture.

For the production conditions of the Kuylyuk plant MZhbK, the calculation of equivalent concrete compositions was made. The initial data for the design of concrete compositions were obtained by testing the initial materials and experimental studies of the concrete mixture and concrete.

We accept the composition of concrete № 7 (Table 1) with the minimum consumption of cement and the highest density ($\gamma_b = 2427 \text{ kg/m}^3$). The nominal composition of the accepted concrete mixture is 1: 0.85: 2.89 at $W/C = 0.32$. We check the accepted composition of the concrete mixture for density (mass balance) after squeezing 15 ... 18% of the amount of mixing water ($V_{ost} = 131...126 \text{ l/m}^3$).

We check the balance of masses from the equation of absolute volumes, taking into

account 6% of the crimping of the cement paste in molded concrete ($\varepsilon = \frac{\Delta C}{C + \Delta C}$) with a pipe wall thickness of 150mm:

$$V_c^{oct} + V_v^{oct} \approx V_T^{opr} \tag{15}$$

Table 1. Calculation table of equivalent concrete compositions

№ of formulations	x	X	Y	V_0	V_p	φ_p	C	V	P	Shch	γ_b
				m ³	m ³	dm ³ /kg	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³
1	0.6	0.88	3.48	0.88	450	0.91	485	158	297	1469	241
2	0.7	1.02	3.0	0.87	460	0.95	484	155	339	1442	242
3	0.8	1.17	2.52	0.85	473	0.98	483	154	386	1407	243
4	0.9	1.31	2.04	0.82	491	1.02	481	154	433	1358	242
5	1.0	1.46	1.56	0.78	518	1.06	489	156	489	1287	242
6	1.1	1.61	1.08	0.71	561	1.10	510	163	561	1171	240
Optimal concrete composition											
per	0.85	1.24	2.28	0.83	481	1.0	480	154	408	1385	242

Substituting the calculated data from Table 1, we find, taking the smallest percentage of water extraction 15%

$$480 (1-0.02) / 2.74 + 154 (1-0.15) = 480 / 2.74 + 154 (1-0.18) \text{ or } 301 / = 301 /$$

As can be seen from the test, the condition for maintaining the density of the concrete structure is met.

It should be noted that a certain amount of the gas phase still remains in the pressurized volume. According to petrographic studies of the structure of pressed concrete, its amount is less than 0.6% of the volume. In ordinary vibro-compacted concrete, the residual volume of the gas phase, according to L.A. Malinina [26], is 2 ... 4%, which is 4 ... 7 times higher than the residual gas phase in concrete pipes. We observed the same volume of the gas phase in comparative petrographic studies of conventional concretes.

Frost's resistance of concrete in the appointment of its composition is produced using GOST 10060-87.

The compositions of concrete of a given frost resistance were determined using the value of the "compensation factor Φ_k ", which is equal to the ratio of the sum of volumes of air and contraction pores to the volume of free water content of concrete (volume of ice content of concrete).

The structural characteristic of concrete frost resistance is calculated by the formula

$$\Phi = (V_B + V_K) / V_L \tag{16}$$

where V_B is the volume of air or gas in the compacted mixture, %; V_K is volume of contraction pores in concrete, %; V_L is the volume of free water in concrete that freezes at -20 °C.

According to the normative data given in GOST 10060-87, the value of the compensation factor can be expressed as a function of the frost resistance of concrete, with an error of <4%

$$\Phi_k^{norm} = \Phi_0 \cdot [1 - \exp(-5F/100)] \tag{17}$$

where $\Phi_0 = 1.4$ is the limiting compensation factor of concrete without additives; F is design grade of concrete for frost resistance in cycles (from F50 to F500).

The calculation results are given in table. 2.

Table 2. Dependence of the compensation factor on the concrete grade of the given frost resistance

Design grade of concrete for frost resistance, in cycles	Compensation factor Φ_k , not lower		
	according to GOST 10060-87	according to the formula (4.17)	deviation
50	0.35	0.31	+0.04
75	0.45	0.44	+0.01
100	0.55	0.55	-
150	0.70	0.74	-0.04
200	0.85	0.88	-0.03
300	1.05	1.09	-0.04
400	1.20	1.21	-0.01
500	1.30	1.29	+0.01

Based on the formulas given in GOST 10060-87, the condition for ensuring the specified frost resistance of concrete is observed if the actual compensation factor of concrete is greater than that required for the design value of frost resistance. The actual compensation factor of concrete is:

$$\Phi_k = (10v + 0.12 C/\rho_c)/C(V/C - 0.27) \quad (18)$$

The required value of the compensation factor of concrete of a given frost resistance depends on the consumption of cement C , a change in the value of the V/C factor, as well as a change in the air entrainment of concrete V_b due to the use of special chemical additives.

The design of the composition of concrete of given frost resistance is carried out in the following order:

If necessary, the conditions of frost resistance of concrete should consider the change in W/C as a result of water extraction.

1. The value of the V/C factor is determined from the condition of ensuring the design strength of concrete;
2. For a given frost resistance, the required compensation factor of concrete is calculated using the formula (17), table. 2.
3. The maximum permissible consumption of cement for concrete of a given frost resistance at the found value of W / C is calculated using the formula (18)

$$C_{max} = \frac{10V_b}{\Phi_k^{actions}(\frac{V}{C}-0.27)-0.12 \cdot C/\rho_c} \quad (19)$$

4. The resulting cement consumption C_{max} is compared with the minimum required cement consumption C_{min} based on the conditions for ensuring the density of hydraulic concrete ($C_{min} = 210 \text{ kg/m}^3$), or with the minimum cement consumption required to ensure the specified mobility of the concrete mixture.

5. A new value of W/C is calculated according to the given value of Φ_k and the accepted minimum required cement consumption C_{min} from the condition of ensuring the workability of concrete.

$$\frac{V}{C} = 0.27 + \frac{1}{\Phi_k} \left(\frac{10 \cdot V_b}{C_{min}} + \frac{0.12C}{\rho_c} \right) \quad (20)$$

This W/C value is compared with the residual W/C value of concrete.

$$\Phi_k^{action} = \frac{\frac{V_{vz}}{C} + 0.04}{\frac{V}{C} - \left[\frac{V}{C}\right]}$$

where V_{vz} is the volume of air or gas, l/m^3 ; C - cement consumption per $1 m^3$ of concrete, kg/m^3 ; $[W/C]$ - the water-cement factor of the test of normal density.

To ensure the design frost resistance of concrete, it is necessary that the actual compensation factor Φ_k^{action} be greater than or equal to the standard compensation factor: $\Phi_k^{action} \geq \Phi_k^{standart}$

It is written down the frost resistance conditions of the concrete or

$$\frac{\frac{V_{vz}}{C} + 0.04}{\frac{V}{C} - \left[\frac{V}{C}\right]} \geq \Phi_k^{normat}$$

The last value is determined by the formula (17) or from table 7 of GOST 10060-87. According to the research results, the integral porosity of hyper-compact concrete is 2.3%, i.e., the volume of air pores was $V_{vz} = 23 l/m^3$. Then the actual compensation factor of concrete with a cement consumption $C = 480 kg/m^3$, $(V/C)_{rest} = 0.29$ equal: $\Phi_k^{dev} = (23/480 + 0.04) / (0.29 - 0.26) = 1.36$

For concrete with a design frost resistance F300 ... 400 $f_{cnorm} = 1.2$, (Table 2).

Obviously, $\Phi_k^{effect} = 1.36 > \Phi_k^{normat} = 1.2$

The frost resistance grade of vibropressed concrete, taking into account $\Phi_k^{dev} = 1.36$, is more than 500 (F500).

4 Conclusions

1. Obtaining extra-strong concretes of class B100 and higher is possible based on control of the composition of the concrete mixture and concrete, using the developed physical-analytical method for designing concrete compositions and applying the peristaltic method of hyperextension and modification of the concrete mixture.

2. Experimental data have confirmed that the greatest concrete strength is provided at (W/C) close to the normal density of the cement paste and the use of concrete mixtures with a cement consumption of 10 ... 12% exceeding the minimum binder consumption, which provides optimal conditions for deformation, hypersolidation, and modification mixtures.

3. The choice of the optimal concrete compositions to be hypercompacted and modified is made from the table of equivalent concrete compositions, while the technological parameters of the compositions are obtained in the course of preliminary laboratory experiments.

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