
Technical Note

Concrete Mix Design Optimized Approach

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Catatan Redaksi:

Perencanaan campuran beton (*mix design*) adalah suatu langkah yang sangat penting dalam pengendalian mutu beton. Campuran yang salah akan mempengaruhi kemudahan pelaksanaan maupun performa beton dalam pemakaian. Makalah yang menarik ini mengungkapkan pengalaman dan praktek yang dilakukan di Romania dalam merencanakan campuran beton untuk berbagai kepentingan.

INTRODUCTION

In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. Within this process lies the key to a remarkable characteristic of concrete: it is plastic and malleable when freshly mixed, strong and durable when hardened. The key to achieving a strong, durable concrete rests in the careful selection and proportioning of its constituent ingredients.

DESIGNING THE CONCRETE MIX

The necessary first step to be taken to design a concrete mix is to establish clearly the requirements that the mix design must meet. These generally include one or more of the followings: mechanical strength, durability, characteristics of concrete member, and special requirements specified by the project design.

MIX DESIGN PROCEDURE

The mix design can not be resolved totally analytically, it requires, after the determination of job parameters (e.g. quantities of water, cement, aggregate, w/c ratio), calculation of weights, experimental adjutants (trial) tests on concrete for ensuring that it meets the design specifications.

Note: Discussion is expected before June, 1st 2004. The proper discussion will be published in "Dimensi Teknik Sipil" volume 6 number 2 September 2004

With this information and the aid of tables or simple calculations, the quantities (in kg) of cement, coarse aggregate, water, and entrained air required per cubic meter can be determined. The absolute volumes of the ingredients can be calculated and totaled. Based on a 1 m³ of mix, subtracting the total of the four ingredients from 1 will provide the absolute volume of the fine aggregate required. From the absolute volume, the mass of the fine aggregate can then be calculated.

Thus, the quantities of materials required for 1 m³ of concrete have been estimated and a trial batch based on these quantities can be made. If adjustments are necessary, further batches should be adjusted by keeping the water: cement ratio constant and adjusting the aggregates and entrained air to produce the desired slump and air content.

QUALITY REQUIREMENTS AND FACTORS AFFECTING DESIGNED CONCRETE

The physical characteristics, chemical composition, and the proportions of the ingredients from mix affect the properties of concrete, in its fresh and hardened state. When designing, we must consider the following quality requirements of concrete:

- **Fresh concrete:** air content, flow behavior (workability/consistency), bleeding, cement type, setting time, hydration heat limitation.
- **Hardened concrete:** strength at specified age - short term (e.g. initial pre stress force and long term), durability-environment/exposure (e.g. carbonation, chloride penetra-

tion, acid resistance, sulfate resistance), frost-thaw resistance, permeability (fluids, gas), resistance against early age cracking.

Factors to be considered regarding durability:

- Choice of slump.
- Environment conditions (dry, humid, humid with frost, marine and chemical aggressiveness).
- Exposure conditions (constructions protected against rain and humidity, frost-thaw saturated (no saturated) with water, exposure to water under pressure, exposed to marine or chemical environment etc.).
- Maximum size of aggregate.
- w/c ratio.
- Type of additive / admixture used.
- Minimum cement content:

Factors to be considered:

- **watertightness** (grades: P_4^{10} , P_8^{10} , P_{12}^{10} , P_4^{20} , P_8^{20} , P_{12}^{20})¹ it may be tested by measuring the flow through a saturated specimen, of 100 mm respectively 200 mm, subjected to pressure; a penetration test is more appropriate in cases where moisture is drawn in by capillary action.
- **freeze-thaw resistance** G50, G100, G150².

Proportioning relates to the following aspects:

- Workability (regarding fresh concrete).
- Durability, strength (regarding hardened concrete).
- Economy by:
 - Minimizing the amount of cement and w/c ratio.
 - Minimizing the amount of water, to reduce cement content, and to increase strength durability.
- Batch weights calculations.
- Adjustments.

¹ **Permeability**, according to Romanian specification STAS 3519-76 - Tests on concretes. Inspection of waterproofness and ISO 7031 - Tests on concrete watertightness, is defined as the flow property of concrete which quantitatively characterizes the ease by which a fluid or gas will pass through it, under the action of a pressure differential. It may be tested by measuring the flow, measured in Bar (1 Bar = 10 MPa), through a saturated specimen, of 100 mm respectively 200 mm height, subjected to pressure (4, 8 or 12 Bar); (Permeability grades: P_4^{10} , P_8^{10} , P_{12}^{10} , P_4^{20} , P_8^{20} , P_{12}^{20}).

² **Freeze -thaw strength**, according to STAS 3518-89 - Tests on concretes. Strength determination at frost-thawing, represents the maximum number of freeze-thaw successive cycles that the concrete specimens can go through without decreasing their strength by 25 % in comparison with the laboratory reference specimens. Freeze-thaw grades: G50, G100, G150 (approximately 50 cycles per year, average max. 150-200 cycles per year).

Factors to be considered when choosing aggregates:

- Economical consideration:
 - Minimize water and cement, stiffest possible mix;
 - Largest particle max size of aggregate, shape, surface texture;
 - Optimize ratio of fine to coarse;
 - Grading and its significance: consistency, strength, finisability.
- Size and shape of members: maximum size aggregate;
- Physical properties: strength;
- Exposure condition: Air entraining or not, sulfate attack;
- Maximum aggregate size: The largest maximum aggregate size that will conform to limitations given below:
 - Nominal maximum size aggregate should not be larger than:
 - $\Phi_{max} \leq 1/4$ of narrowest dimension of structural member;
 - $\leq 1/3$ thickness of slab
 - $\leq 1/6$ reservoir wall thickness
 - \leq spacing between re-bars – 5 mm
 - $\leq 1,3$ x concrete cover of re-bars
 - $\leq 1/3$ concrete pump piping

Factors to consider when choosing water to cement ratio:

- Compressive strength is inversely proportional to w/c:
- Economical consideration: Minimize water and cement, stiffest possible mix.

Table a. Characteristic strength of concrete (MPa)

Concrete grades	C 2,8	C 4	C 6	C 8	C 12	C 16	C 18	C 20	C 25	C 28	C 30	C 32	C 35	C 40	C 45	C 50
	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	3,5	5	7,5	10	15	20	22,5	25	30	35	37	40	45	50	55	60
Characteristic strength of concrete																
$f_{c,28}$ cylinder	2,8	4	6	8	12	16	18	20	25	28	30	32	35	40	45	50
$f_{c,28}$ cube	3,5	5	7,5	10	15	20	22,5	25	30	35	37	40	45	50	55	60

Source: NE 012-1999. Practice code for the execution of concrete, reinforced concrete and prestressed concrete works, Part 1 – Concrete and reinforced concrete.

DETERMINATION OF JOB PARAMETERS

Step 1: Durability conditioning of concrete

Environment conditions, obtained for table 2 \Rightarrow class of exposure
 Requirements of grade and durability, obtained from table 3 and 4.

1. W/C ratio:

Table 3 ⇒ suggested w/c ratio.

2. Cement content:

Table 4 ⇒ suggested minimum cement content C (kg/m³).

Step 2: Preliminary procedures for determining the quality mix proportions of concrete constituents

1. Slump:

Table 1 ⇒ suggested slump T (mm).

2. Minimum cement content:

Table 5 ⇒ suggested minimum cement content C (kg/m³).

3. Aggregates:

a) Selection of aggregates by type (table 14).

b) Nominal maximum size of aggregates:

Computed according to the following restrictions:

- $\phi_{max} \leq$ minimum dimension of bearing member/4;
- $\phi_{max} \leq$ thickness of slab/3;
- $\phi_{max} \leq$ thickness of reservoir wall/6;
- $\phi_{max} \leq$ minimum distance between re-bars - 5 mm;
- $\phi_{max} \leq 1,3 \times$ reinforcement concrete cover;
- $\phi_{max} \leq$ diameter of pump hose/3

4. Gradation of aggregate particles:

Table 6 ⇒ suggested grading curve ⇒ table 7 ⇒ upper and lower gradation limits.

5. Cement:

Table 10, 11, 12 ⇒ Recommended cement type and grade.

6. Water-cement maximum ratio:

Table 5 ⇒ recommended water-cement maximum ratio.

Step 3: Procedures for determining the batch weights for mix proportions of constituents

1. Estimate mixing water and air content:

Table 13 ⇒ W (kg/m³)

Correction of water quantity according to maximum nominal size aggregate ⇒ $W' = W \times c$ (kg/m³).

Table 11 ⇒ suggested volume of air-entrainment

2. Water-cement ratio:

Table 16 ⇒ suggested w/c ratio.

Final adopted value of w/c = minimum value between (step 2.6. and step 3.2)

3. Cement:

$$C' = \frac{A'}{A/C} \quad [\text{kg/m}^3]$$

Final adopted value of C = maximum value between (step 2.5. and step 3.3)

4. Estimate coarse aggregate: (First estimate of aggregate weight)

The total amount of dry aggregates will be calculated as follows:

Knowing that

$$V = m/x \rho$$

$$V_{ag} = V_{total} - V_{water} = V_{cement} - V_{air}$$

$$A_g = \rho_{ag} \times (1000 - C/\rho_c - A'/\rho_a - p) \quad [\text{kg/m}^3]$$

Where:

ρ_{ag} = relative density of aggregates (2,7 kg/dm³);

ρ_c = relative density of cement (3,0 kg/dm³);

p = void parameter (table 11), when not using additives, (when using additives the parameter will be computed according to laboratory tests).

5. Gradation of aggregate

Table 7 ⇒ percentage limits of aggregate passing.

The amount of aggregate for each grade is found as follows:

$$A_{gi} = A_g \times \frac{p_i - p_{i-1}}{100} \quad (\text{kg/m}^3)$$

Where:

A_g = amount of aggregates (kg);

p_i = percent passing by mass through sieve "i";

p_{i-1} = percent passing by mass through sieve "i-1";

6. Adjustment for moisture in the aggregate:

The following moisture adjustment should be made to the aggregate so that the water content of the concrete will not be affected by the natural moisture content of the aggregate.

$$\Delta A = \sum A_{gi} \times \frac{u_i}{100} \quad (\text{l/m}^3)$$

Where:

A_{gi} = amount of aggregate from sieve "i" (kg);

u_i = free moisture of sieve "i" (%);

n = total numbers of sieves.

$$A^* = A' - \Delta A \quad (\text{l/m}^3)$$

The free amount of moisture from fine aggregates ($U_{FA}\%$), is calculated as follows:

$$\Delta A_{FA} = \sum A_{gi} \times \frac{u_i}{100} \quad \text{kg/m}^3$$

The free amount of moisture from coarse aggregates ($U_{CA}\%$), is calculated as follows:

$$\Delta A_{CA} = \sum A_{gi} \times \frac{u_i}{100} \quad \text{kg/m}^3$$

The total amount of free moisture is calculated as follows:

$$\Delta A = \Delta A_{FA} + \Delta A_{CA} \quad \text{kg/m}^3$$

Adjusted amount of water: $A^* = A' - \Delta A$ (kg/m³)

7. Adjustment of total amount of the aggregates by sieve sizes:

The total amount of aggregates by sieve sizes, is found as follows:

$$A_{gi}^* = A_{gi} \times \left(1 + \frac{u_i}{100} \right) \quad (\text{kg/m}^3)$$

Where:

A_{gi} - amount of aggregate from sieve "i" (kg);
 u_i = free moisture of sieve "i" (%).

8. Final adjustment of aggregate weight:

The total amount of aggregates, is found as follows:

$$A_g^* = \Delta A_{gi}^* \quad (\text{kg/m}^3)$$

Where:

A_g^* = adjusted amount of aggregate from sieve "i" (kg);

n = number of sieves sizes.

$$A_g^* = \sum A_{gi}^* \quad \text{kg/m}^3$$

9. Total mass of concrete produced:

The total mass of concrete produced will be calculated as follows:

$$G_c = A^* + C^* + A_g^*$$

G_c will be compared with the value of normal weight concrete that ranges between 2160 to 2560 kg/m³

10. Trial batch: Using the proportions developed in the above steps, a 30-liter concrete trial batch is made using only as much water as needed to reach the desired slump.

Three separate concrete batches should be prepared, as:

- a primary batch with ingredients as calculated;
- a second batch with a cement content increased with 7% but minimum 20 kg/m³ in comparison with the primary batch, maintaining constant the water and aggregate quantities (according to the primary batch calculations);
- a third batch with a cement content reduced with 7% but minimum 20 kg/m³ in comparison with the primary batch, maintaining constant the water and aggregate quantities (according to the primary batch calculations);

From all three batches minimum 12 concrete samples should be tested for compressive strength (according to STAS 1275-88);

Six samples should from every batch should be tested after 7 days (according to STAS 1275-88), the adopted preliminary concrete mix design will be the one for which the determined strength are equal to the ones indicated by the Concrete Practice Code NE 012-1999;

The remaining six specimens shall be testes after 28 days, the results being analyzed for defining the final mix proportioning. The mean strength value for each mix f_{bm} will be adjusted according to the real cement strength value, using the following equation:

$$f_{cori} = \frac{1,15 \text{ class_cement}}{\text{strength_of_cement}} \times f_{bmi}$$

The final mix proportion will be adopted for the batch of which the adjusted recorded strength value (f_{cori}) is equal to the one determined after 28 days indicated by the Concrete Practice Code NE 012-1999 (table 1);

11. Summary of mix design:

Enter batch percentage:%
 Compressive strength at 28 days:MPa
 Slump: Maximummm
 Minimummm
 Nominal maximum size of aggregate:mm
 Water-cement ratio:
 Concrete type
 Air content:%
 Permeability:
 Freeze-thaw:
 Unit weight of aggregates: F.A.kg/m³
 C.A. kg/m³
 Mass of batched concrete: pc =kg/m³

Table 1. Recommended concrete consistencies for different types of construction

Item no.	Type of concrete member	Type of Transport	Consistency	
			Grade	Slump (mm)
1	Plain or reinforced footings, massive elements	Truck, bucket, belt conveyor	T2	30±10
2	Plain or reinforced footings, massive elements, slabs, columns, beams, walls.	Transit mix truck, bucket	T3	70±20
3	Plain or reinforced footings, massive elements, slabs, columns, beams, walls, reservoirs placed by concrete pump	Transit mix truck, pump	T3/ T4	100±20
4	Members and small reinforced monolithic sections with difficulties while compacting	Transit mix truck, bucket	T4	120±20
5	Concrete prepared with plasticizers or superplasticizers additives	Transit mix truck, bucket	T4/ T5	150±30
6	Concrete prepared with superplasticizers additives	Transit mix truck, bucket	T5	180±30

Table 2. Concrete Exposure class in different environmental Conditions

Type of environment	Type or location of structure	
0	1	2
1. Dry environment	a). Moderate	Concrete surfaces protected against weather or aggressive conditions
	b). Severe	Concrete surfaces exposed permanent to temperatures greater than 30 °C
2. Hummed environment	a). Moderate	Concrete surfaces exposed to freezing whilst sheltered from severe rain or freezing whilst continuously submerged under water;
	b). Severe	Concrete surfaces exposed to condensation or alternant wetting and drying; Concrete surfaces exposed to continuous water pressure on one side
3. Hummed environment subjected to freezing and deicing salts	Concrete interior or exterior surfaces exposed to freezing and de-icing salts	
4. Marine environment	a). No freezing	1). Weak aggressive conditions Concrete surfaces exposed permanent to sea water; Concrete surfaces situated over the variation level of the sea
		2). Intensive aggressive conditions Concrete surfaces situated over the variation level of the sea
	b). With freezing	1). Weak aggressive conditions Concrete surfaces exposed indirectly to marine environment Concrete surfaces exposed to freezing sheltered from wetting Concrete surfaces protected against weather without heating
		2). Intensive aggressive conditions Concrete surfaces exposed to marine environment by alternant wetting, drying and salts. Concrete surfaces exposed industrial technological condensation
5. Chemical aggressive environment	a).	Mild chemical aggressive environment
	b).	Moderate chemical aggressive environment
	c).	Severe chemical aggressive environment
	d).	Very severe chemical aggressive environment

Table 3. Requirements for concrete durability assurance according to type of environment conditions

Item no.	Concrete mix components	Environment conditions for concrete table 2													
		1a	1b	2a	2b	3	4a1	4a2	4b1	4b2	5a	5b	5c	5d	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	Water: Cement Ratio														
	Plain concrete	-	0,65	0,55	0,55	0,50	0,55	0,55	0,50	0,50	0,55	0,50	0,45	0,40	
	Reinforced concrete	0,85	0,80	0,55	0,50	0,50	0,50	0,50	0,45	0,45	0,55	0,50	0,45	0,40	
	Prestressed concrete	0,80	0,55	0,55	0,50	0,50	0,50	0,50	0,45	0,40	0,55	0,50	0,45	0,40	
2	Minimum cement content (kg/m³)														
	Plain concrete	150	300	250	300	350	350	350	350	350	350	350	400	450	
	Reinforced concrete	300	300	350	350	350	350	400	400	400	350	350	400	450	
	Prestressed concrete	350	350	350	350	350	400	400	450	350	350	400	450	450	
3	Percent of air entrained (%), min.														
	Max. size aggregate 31mm	-	-	4	4	4	-	-	4	4	-	-	-	-	
	Size aggregate 16 mm	-	-	5	5	5	-	-	5	5	-	-	-	-	
	Max. size aggregate 7 mm	-	-	6	6	6	-	-	6	6	-	-	-	-	
4	Frost resisting aggregates	-	-	Yes	Yes	Yes	-	-	Yes	Yes	-	-	-	-	
5	Watertightness grade, min.														
	Plain concrete	-	-	P4 ¹⁰	P4 ¹⁰	P8 ¹⁰	P4 ¹⁰	P4 ¹⁰	P8 ¹⁰	P8 ¹⁰	P4 ¹⁰	P8 ¹⁰	P12 ¹⁰	P12 ¹⁰	
	Reinforced concrete	-	-	P4 ¹⁰	P8 ¹⁰	P8 ¹⁰	P8 ¹⁰	P8 ¹⁰	P12 ¹⁰	P12 ¹⁰	P4 ¹⁰	P8 ¹⁰	P12 ¹⁰	P12 ¹⁰	
	Prestressed concrete	-	-	P4 ¹⁰	P8 ¹⁰	P8 ¹⁰	P8 ¹⁰	P12 ¹⁰	P12 ¹⁰	P4 ¹⁰	P8 ¹⁰	P12 ¹⁰	P12 ¹⁰	P12 ¹⁰	
6	Frost resistance														
	Plain concrete	-	-	G50	G100	G150	-	-	G150	G150	-	-	-	-	
	Reinforced concrete	-	-	G100	G150	G150	-	-	G150	G150	-	-	-	-	
	Prestressed concrete	-	-	G100	G150	G150	-	-	G150	G150	-	-	-	-	

Table 4. Grading classes

Consistency	Grading class in accordance to the cement content (Kg/m³)		
	£ 300	300-450	> 450
T2	I	II	III
T3 and T3/T4	I	I (II)*	II (III)*
T4, T4/T5, T5	-	I	II

* Recommended when the concrete does not have tendency of honeycombing

** Upper and lower limit of gradation are as follows (annex 5): Table 5.1. to 5.6 for aggregate size 0...7 mm; 0...16 mm; 0...20 mm; 0...31 mm; 0...40 mm; 0...71 mm.

Table 5. Upper and lower Limits of gradation

Table 5.1 Aggregates between 0...7 mm

Limits	Cumulative percent passing by mass (%)			
	0,2	1	3	7
Max.	12	40	70	100
Min.	3	25	54	95

Table 5.2 Aggregates between 0...16 mm

Grading class	Limits	Cumulative percent passing by mass (%)				
		0,2	1	3	7	16
I	Max.	15	45	65	85	100
	Min.	10	35	55	75	95
II	Max.	10	35	55	75	100
	Min.	5	25	45	65	95
III	Max.	5	25	45	65	100
	Min.	1	15	35	55	95

Table 5.3. Aggregates between 0...20 mm

Grading Class	Limits	Cumulative percent passing by mass (%)				
		0,2	1	3 (9)	7 (10)	20
I	Max.	15	40	60	80	100
	Min.	10	30	50	70	95
II	Max.	10	30	50	70	100
	Min.	5	20	40	60	95
III	Max.	5	20	40	60	100
	Min.	1	10	30	50	95

Table 5.4. Aggregates between 0...31 mm

Grading Class	Limits	Cumulative percent passing by mass (%)					
		0,2	1	3	7	16	31
I	Max.	15	40	50	70	90	100
	Min.	10	30	40	60	80	95
II	Max.	10	30	40	60	80	100
	Min.	5	20	30	50	70	95
III	Max.	5	20	30	50	70	100
	Min.	1	10	20	40	60	95

Table 5.5. Aggregates between 0...40 mm

Grading Class	Limits	Cumulative percent passing by mass (%)						
		0,2	1	3 (5)	7 (10)	20	40	
I	Max.	15	30	45	60	80	100	
	Min.	10	20	35	50	70	95	
II	Max.	10	25	35	50	70	100	
	Min.	5	15	25	40	60	95	
III	Max.	5	15	25	40	60	100	
	Min.	1	5	15	30	50	95	

Table 5.6. Aggregates between 0...71 mm

Limits	Cumulative percent passing by mass (%)								
	0,2	1	3	7	16	25	31	40	71
Max.	8	18	32	45	61	70	77	84	100
Min.	1	6	13	22	38	50	57	68	95

Table 5.7. Aggregates between 0...71 mm

Limits	Cumulative percent passing by mass (%)								
	0,2	1	3	7	16	25	31	40	71
Max.	8	18	32	45	61	70	77	84	100
Min.	1	6	13	22	38	50	57	68	95

Table 6. Types of cement according to romani-an standards (SR)

Type	Sort	SR	Admixture		Grade
			%	Type	
1	2	3	4	5	6
Portland Cement (without admixtures)					
I	Normal Portland cement (without admixtures)	SR 388	-	-	32,5; 42,5; 52,5 32,5R;42,5R; 52,5R
Composite Cements (with admixtures)					
II A-M	Portland cement composite	SR 1500	6-20	Mixture of slag, ash, lime, pozzolan	32,5; 42,5; 52,5 32,5R;42,5R; 52,5R
II A-S	Portland cement with slag			Granulated blast furnace slag	
II A-V	Portland cement with ash			Pulverized fuel ash	
II A-P	Portland cement with natural pozzolan				
II A-L	Portland cement with lime			Lime	
II B-M	Portland cement composite	SR 1500	21-35	Mixture of slag, ash, lime, pozzolan	32,5; 42,5 32,5R; 42,5R
II B-S	Portland cement with slag			Granulated blast furnace slag	
II B-P	Portland Cement with natural pozzolan				
II B-L	Portland cement with lime			Lime	
III A	Blast furnace cement	SR 1500	36-65	Granulated blast furnace slag	32,5; 32,5R
IV A	Pozzolan cement	SR 1500	11-35	Pozzolan and ash	32,5; 42,5; 32,5R
V A	Composite cement	SR 1500	18-30	Granulated blast furnace slag + ash pozzolans	32,5; 32,5R
Limited hydration Cements					
HI	Cement without mixture				
HI/A-S		SR 3011	6-20	Granulated blast furnace slag	32,5; 42,5; 52,5
HI/B-S	Cement with slag		21-35		
HI/A			36-65		
Sulfate resistant cements					
SRI	Cement without admixture				32,5; 42,5; 52,5
SRI/A-S	Cement with slag	SR 3011	6-20	Granulated blast furnace slag	
SRI/A-P	Pozzolan cement		6-20	Natural pozzolan	
SRI/B-S	Cement with slag		21-35	Granulated blast furnace slag	
SRI/A	Cement with slag		36-65	Pulverized fuel ash	

Table 7. Approximate equivalency between manufactured cement according to SR and STAS

Item no.	Cements according to S.R.		Approximate equivalency with STAS	
	Type	S.R.	Type	STAS
0	1	2	3	4
1	II B- S 32.5	1500	M 30	1500
2	II A-S 32.5		Pa 35	
3	I 32.5	388	P 40	388
4	I 42.5		P 50 (P45)	
5	H I 32.5	3011	H 35	3011
6	H II / A-S 32.5		H 35	
7	SR I 32.5	3011	SR 35	3011
8	SR II / A-S 32.5		SRA 35	

Table 8. Recommended cement types used for concrete work in normal conditions of exposure

Item no.	Work conditions and/or member characteristics	Concrete grade	Type of concrete	Recommended types of cement	Usable types of cement
0	1	2	3	4	5
1	Members or constructions with thickness smaller than 1,5m produced in periods other that winter	C 5/4 ...	Plain	(IIIA,IVA,VA) 32,5 IIB - 32,5	(IIIA,IVA,VA)32,5 IIA 32,5
		C 10/8 ...	Reinforced	IIA - 32,5	IIB- 32,5 ⁽¹⁾ ; IIB- 42,5 ⁽¹⁾ ; I 32,5 IIA- 42,5
		C 15/20 ...	Reinforced	I - 32,5	IIA - 32,5R; IIA - 42,5; I - 42,5
		C 20/16	Reinforced (prestressed)	I - 42,5 I - 42,5A	I - 32,5 ⁽²⁾ ; I - 52,5; I 52,5A
		C 25/12 C 30/25 C 35/	High strength reinforcement (prestressed)	I 52,5/ 52,5R; I 52,5A/ 52,5A-R	
		C 37/30 C 40/ C 45/35 C 50/40			
2	Massive members or constructions with thickness equal or larger than 1,5m	< C 15/12 C 15/12	Plain	H IIIA - 32,5	H II/B-S; II B-S 32,5; I A-S 32,5
		C 20/16	Reinforced	H IIA - 32,5	H I-32,5; HII/B-S32,5 ⁽¹⁾ ; II A-S 32,5
		C 25/20 C 30/25 C 35/-	Reinforced	H I - 32,5	II A-S 32,5; H IIA-S32,5; I 32,5
		C 37/30 C 40/ C 45/35 C 50/40	Reinforced (prestressed)	H I - 42,5	H I-32,5 ⁽²⁾ ; I 42,5; HII/A-S 42,5; H42,5/42,5 RA; II A-S 42,5
		C 60/50 C 70/60 C 85/70	Reinforced (prestressed)	H I - 52,5	H IIIA-S 52,5; Hz52,5/52,5-A

Technical notes:

1. During winter conditions it is recommended to use, for members that have thickness over 1,5 m, cements with rapid setting time noted with R.
2. The setting of cement types II B, II H, H II/B-S (that have a maximum amount of mixture of 35%), for reinforced concrete members will be made only with the approval of a specialist institute.

Table 9 Recommended cements types for plain and reinforced concrete works that are exposed to sea water and severe freezing

Item no.	Work conditions and/or Member characteristics	Concrete grade	Type of concrete	Recommend ed types of cement	Usable types of cement
0	1	2	3	4	5
1	Members or constructions with thickness smaller than 1,5m	< C 20/16	Plain	IIA-32,5/32,5R	I-32,5/32,5R
		C20/16-C35/ -	Reinforced	I-32,5/32,5R	IIA-32,5/32,5R I- 42,5A; I - 42,5/42,5R
		C37/30-C50/40	Reinforced	I-42,5 I-42,5/42,5R	I-32,5/32,5R; I-52,5/52,5R
		C 55/45-C85/70	Reinforced	I-52,5A I-52,5/52,5R	
2	Massive members or constructions with thickness equal or larger that 1,5m	< C 20/16	Plain	H IIIA-S32,5	H I-32,5; II A-S32,5
		C 20/16-C 35/	Reinforced	III-32,5	III-42,5
		C 37/30-C50/40	Reinforced	H I-42,5	H I-52,5; I-52,5
		C 55/45-C85/70	Reinforced	H I-52,5	

Table 10. Recommended types of cements for plain and reinforced concrete works that are in contact with aggressive waters

Item no.	Nature of aggressive environment	Grade of aggressive	Recommended types of cement		Usable types of cement	
			Plain concrete	Reinforced concrete	Plain concrete	Reinforced concrete
0	1	2	3	4	5	6
1	Alkalis	Mild	II A	II A-S	I 32,5 H I H III/A-S	I 32,5; H I; H III/A-S
2	Carbon	Mild	II A	II A-S	I 32,5; H I; H III/A-S	I 32,5; H I; H III/A-S
		Severe or very severe	I 32,5;	I 32,5;	H I; SR I	H I; SR I
3	Sulfate	Mild Moderate Moderate	III A; IV A; V A; II B; II A	II A-S	H II A-S	H III/A-S
		Severe or very severe (for all cases)	SR II/B-S SR III/A	SR I SR II/A-S	H II/B-S H III/A	H I; H III/A-S; II A-S
4	Magnesium	Mild	H III/A H II/B-S	H III/A-S	H A-S	H A-S; H I; Sr I; SR III/A-S
		Severe or very severe	SR II/B-S SR III/A	SR II/A-S	H A-S H III/A-S	H A-S; H III/A-S; H I; SR I
5	Nitrogen salts	Mild	H III A H II/B-S	H III/A-S	H A-S	H A-S; H I; SR I; SR III/A-S
		Severe or very severe	SR II/B-S SR III/A	SR II/A-S	H III/A-S	SR I; H I; H III/A-S
6	Base	Mild	H III/A-S	H I	H A-S	H III/A-S; III/A-S; SR I
		Severe	SR III/A-S	SR I	H III/A-S	H I; H III/A-S

Table 11. Estimated mixing water requirement for various slumps

Concrete grade	Water (l/m ³) of concrete indicated by consistency			
	T2	T3	T3/T4	T4
C 5/4	160	170	-	-
C 10/8...C 25/20	170	185	200	220
> C 30/25	185	200	215	230

Technical notes: The values concerning the quantities of water required for mix specified in annex 13. are valid only if used with natural aggregates size 0...31 mm. They will be increasing or decreasing as follows:

- decreases with 10% when using aggregates size 0...71 mm;
- decreases with 5% when using aggregates size 0...40 mm;
- decreases with 10-20% when using additives;
- increase with 10% when using crushed stone;
- increase with 20% when using aggregates size 0...7 mm;
- increase with 10% when using aggregates size 0...16 mm;
- increase with 5% when using aggregates size 0...20 mm.

Relative Density

Type of material	Density (Kg/dm ³)
Siliceous (stream deposits)	2,7
Calcareous	2,3...2,7
Ceramic	2,7
Basalt	2,9
Cement	3,0

Approximate volume of air-entrainment according to maximum size aggregates

Maximum size of aggregates (mm)	10	16	20	31	40	70
Air-entrainment %	7	6	5	4,5	4	3

Table 12. Maximum values for water: cement ratio after preliminary tests (grade II concrete homogeneity)

Concrete grade	Cement grade		
	32,5	42,5	52,5
C 10/8	0,75		
C 15/12	0,70		
C 20/16	0,60		
C 25/20	0,55		
C 30/25	0,50	0,55	
C 35/	0,45	0,50	
C 37/30	0,40	0,47	
C 40/	0,35	0,45	0,50
C 45/35		0,40	0,45
C 50/40		0,35	0,40
C 55/45		0,33	0,38
C 60/50		0,30	0,35
C 70/			

Technical notes:

1. The values for the table are valid for grade II homogeneity. For grade I, the values rise with 0,05 and for grade III they decrease with 0,05.
2. When using crushed stone the values from the table rise with 10%.
3. According to the environment conditions and exposure the A/C ratio, resulted from annex 2, should not be exceeded.
4. When the concrete is cured in steam rooms, according to the final decrease of strength, the A/C ration values will be adopted as follows:
 - for grade I of homogeneity see table;
 - for grade II of homogeneity, the proposed values for the table decreased by 0,05 (corresponding to grade III).

Table 13. Strength of concrete at 28 days after preliminary tests for grade II homogeneity

Concrete grade	Characteristic strength f _c preliminary (N/mm ²)		Concrete grade	Characteristic strength f _c preliminary (N/mm ²)	
	Cube	Cylinder		Cube	Cylinder
C 10/8	18	14,5	C 40/-	51,5	41
C 15/12	23,5	19	C 45/35	56,5	45
C 20/16	29	23	C 50/40	62,5	50
C 25/20	36	29	C 55/45	68	54,5
C 30/25	42	33,5	C 60/50	73	58,5
C 35/-	47	37,5	C 70/60	84,5	67,5
C 37/30	48	38,5	C 87/70	101	81

Technical notes: For grade I, respectively grade III of homogeneity, of the values required in the table, a certain value will be subtracted or added.

Values that will be subtracted or added to the recommended in the table for grade II, for grade I respectively II of homogeneity

Concrete grade	(N/mm ²) (Cube)	(N/mm ²) (Cylinder)
C 10/8 - C 20/16	3	2,5
C 25/20 - C 37/30	4	3
C 40/- - C 55/45	5	4
C 60/50 - C 85/70	6	5

CONCLUSIONS

The recommendations and proposals for improving the existing concrete mix design are different, according to the factors (human in regard of efficiency of personnel/ labor discipline and technological in regard of production process) that intervene in the achievement of the considered concrete mix at a minimum cost.

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