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*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, 1 st 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 $m^3$ 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 $m^3$ 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, G150[2].

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.

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:

    $\phi_{max}$ ≤1/4 of narrowest dimension of structural member;
    ≤1/3 thickness of slab
    ≤1/6 reservoir wall thickness
    ≤spacing between re-bars – 5 mm
    ≤1,3 x concrete cover of re-bars
    ≤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 / 3,5 | C 4 / 5 | C 6 / 7,5 | C 8 / 10 | C 12 / 15 | C 16 / 20 | C 18 / 22,5 | C 20 / 25 | C 25 / 30 | C 28 / 35 | C 30 / 37 | C 32 / 40 | C 35 / 45 | C 40 / 50 | C 45 / 55 | C 50 / 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 ⇒ class of exposure
Requirements of grade and durability, obtained form table 3 and 4.

[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: $P^{10}4$ , $P^{10}8$ , $P^{10}12$ , $P4^{20}$ , $P8^{20}$ , $P12^{20}$).

[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).

1. **W/C ratio:**
   Table 3 ⇒ suggested w/c ratio.
2. **Cement content:**
   Table 4 ⇒ suggested minimum cement content *C* (kg/m$^3$).

**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/m$^3$).
3. **Aggregates**:
   a) **Selection of aggregates by type** (table 14).
   b) **Nominal maximum size of aggregates**: Computed according to the following restrictions:
   $\phi$max ≤ minimum dimension of bearing member/4;
   $\phi$max ≤ thickness of slab/3;
   $\phi$max ≤ thickness of reservoir wall/6;
   $\phi$max ≤ minimum distance between rebars – 5 mm;
   $\phi$max ≤ 1,3 x reinforcement concrete cover;
   $\phi$max ≤ 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/m$^3$)
   Correction of water quantity according to maximum nominal size aggregate ⇒ W' = W x c (kg/m$^3$).
   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* ρ:
   V ag = V total – V water = V cement – V air
   Ag = ρag x (1000 – C/ρc - A'/ρa - p) [kg/m$^3$]
   Where:
   ρag = relative density of aggregates (2,7 kg/dm$^3$);
   ρc = relative density of cement (3,0 kg/dm$^3$);
   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:

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

   Where:
   Ag = amount of aggregates (kg);
   pi = percent passing by mass through sieve "i";
   pi-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.

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

   Where:
   Agi = amount of aggregate form sieve "i' (kg);
   ui = free moisture of sieve "i" (%);
   n = total numbers of sieves.
   A* = A' - ΔA (l/m$^3$)
   The free amount of moisture form fine aggregates ($U_{FA}$%), is calculated as follows:

$$\Delta A_{FA} = \Sigma A_{gi} x \frac{u_i}{100} \text{ kg/m}^3$$

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

$$\Delta A_{CA} = \Sigma A_{gi} x \frac{u_i}{100} \text{ kg/m}^3$$

   The total amount of free moisture is calculated as follows:

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

   Adjusted amount of water: A* = A' - ΔA (kg/m$^3$)

7. **Adjustment of total amount of the aggregates by sieve sizes**:
   The total amount of aggregates by sieve sizes, is found as follows:
   $$A^*_{gi} = A_{gi} x\left(1 + \frac{u_i}{100}\right) \quad (kg/m^3)$$
   Where:
   Agi - amount of aggregate form sieve "i' (kg);
   ui = free moisture of sieve "i" (%).
8. **Final adjustment of aggregate weight**:
   The total amount of aggregates, is found as follows:
   $Ag^* = \Delta$ Agi * (kg/m$^3$)
   Where:
   $Ag^*$ = adjusted amount of aggregate form sieve "i' (kg);
   n = number of sieves sizes.
   $Ag^* = \Sigma A^*gi$ kg/m$^3$
9. **Total mass of concrete produced**:
   The total mass of concrete produced will be calculated as follows:
   $G_c = A^* + C' + Ag^*$
   $G_c$ will be compared with the value of normal weight concrete that ranges between 2160 to 2560 kg/m$^3$
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/m$^3$ 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/m$^3$ in comparison with the primary batch, maintaining constant the water and aggregate quantities (according to the primary batch calculations);

From all three batches din 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:

$$f_{cori} = \frac{1{,}15 class\_ciment}{strength\_of\_cement} x f_{bmi}$$

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: Maximum .......mm
    Minimum .......mm
    Nominal maximum size of aggregate:......mm
    Water-cement ratio: .......
    Concrete type .......
    Air content: .......%
    Permeability: .......
    Freeze-thaw: .......
    Unit weight of aggregates: F.A. .......kg/m$^3$
    C.A. ...... kg/m$^3$
    Mass of batched concrete: ρc = .......kg/m$^3$

**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 grater that 30 $^oC$ | |
| 2. Hummed environment | a). Moderate | Concrete surfaces exposed to freezing whilst sheltered form severe rain or freezing whilst wet | |
| | b). Severe | Concrete surfaces exposed to freezing whilst continuously submerged under water; 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 | 0,65 | 0,60 | 0,55 | 0,50 | 0,50 | 0,50 | 0,50 | 0,45 | 0,45 | 0,55 | 0,50 | 0,45 | 0,40 |
| | Prestressed concrete | 0,60 | 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 | 350 | 400 | 400 | 450 | 350 | 350 | 400 | 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 | - | | $P_4^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_{12}^{10}$ | $P_{12}^{10}$ | $P_4^{10}$ | $P_8^{10}$ | $P_{12}^{10}$ | $P_{12}^{10}$ |
| | Prestressed concrete | - | | $P_4^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_8^{10}$ | $P_{12}^{10}$ | $P_{12}^{10}$ | $P_4^{10}$ | $P_8^{10}$ | $P_{12}^{10}$ | $P_{12}^{10}$ |
| 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 an 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 romanian standards (SR)**

| Type | Sort | SR | Admixture % | Admixture Type | Grade |
|---|---|---|---|---|---|
| 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 | | | | | |
| H I | Cement without mixture | SR 3011 | - | - | 32,5; 42,5; 52,5 |
| HII/A-S | Cement with slag | | 6- 20 | Granulated blast furnace slag | |
| HII/B-S | | | 21-35 | | |
| HIII/A | | | 36-65 | | |
| Sulfate resistant cements | | | | | |
| SRI | Cement without admixture | SR 3011 | - | - | 32,5; 42,5; 52,5 |
| SRII/A-S | Cement with slag | | 6-20 | Granulated blast furnace slag | |
| SRII/A-P | Pozzolan cement | | 6-20 | Natural pozzolan | |
| SRII/B-S | Cement with slag | | 21-35 | Granulated blast furnace slag | |
| SRIII/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 | | Hz 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 … C 10/8 | Plain | (IIIA,IVA,VA) 32,5 IIB - 32,5 | (IIIA,IVA,VA)32,5 IIA 32,5 |
| | | C 15/20 … C 20/16 | Reinforced | IIA - 32,5 | IIB- 32,5[(1)]; IIB- 42,5[(1)]; I 32,5 IIA- 42,5 |
| | | C 25/12 C 30/25 C 35/ | Reinforced | I - 32,5 | IIA - 32,5R; IIA - 42,5; I - 42,5 |
| | | C 37/30 C 40/ C 45/35 C 50/40 | Reinforced (prestressed) | I - 42,5 I -42,5A | I- 32,5[(2)]; I- 52,5; I 52,5A |
| | | C 55/45 C 60/50 C 70/60 C 80/70 | High strength reinforcement (prestressed) | I 52,5/ 52,5R; I 52,5A/ 52,5A-R | |
| 2 | Massive members or constructions with thickness equal or larger than 1,5m | < C 15/12 C 15/12 | Plain | H III/A - 32,5 | H II/B-S; II B-S 32,5; I A-S 32,5 |
| | | C 20/16 | Reinforced | H II/A - 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 II/A-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 II/A-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 | Recommended 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 II/A-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 environ-ment | 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<br>H I<br>H II/A-S | I 32,5;<br>H I;<br>H II/A-S |
| 2 | Carbon | Mild | II A | II A-S | I 32,5;<br>H I;<br>H II/A-S | I 32,5;<br>H I;<br>H II/A-S |
| | | Severe very severe | I 32,5; | I 32,5; | H I;<br>SR I | H I;<br>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 II/A- S |
| | | Severe or very sever (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;<br>H II/A-S;<br>II A-S |
| 4 | Magnesium | Mild | H III/A<br>H II/B-S | H II/A-S | H A-S | H A-S;<br>H I; Sr I;<br>SR II/A-S |
| | | Severe or very sever | SR II/B-S<br>SR III/A | SR II/A-S | H A-S<br>H II/A-S | H A-S;<br>H II/A-S;<br>H I; SR I |
| 5 | Nitrogen salts | Mild | H III A<br>H II/B-S | H II/A-S | H A-S | H A-S;<br>H I; SR I; SR II/A-S |
| | | Severe or very sever | SR II/B-S<br>SR III/A | SR II/A-S | H II/A-S | SR I; H I; H II/A-S |
| 6 | Base | Mild | H II/A-S | H I | H A-S | H II/A-S; II/A-S;<br>SR I |
| | | Severe | SR II/A-S | SR I | H II/A-S | H I;<br>H II/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:

- decrees with 10% when using aggregates size 0...71 mm;
- decrees with 5% when using aggregates size 0...40 mm;
- decrees 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 form the table rise with 10%.
3. According to the environment conditions and exposure the A/C ratio, resulted form 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 fc preliminary ($N/mm^2$) | | Concrete grade | Characteristic strength fc 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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