Warsaw University of Technology

Faculty of Civil Engineering

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BUILDING MATERIALS

LABORATORY

Concrete design: cement paste method

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1. Aim of the task

The aim of the task is to learn the principles of concrete design by the cement paste method and to use this method to design ordinary concrete for the indicated specification.

2. Theorethical bacground

2.1. Definitions according to PN-EN

Concrete – a material resulting from mixing cement, coarse and fine aggregate, water and any possible admixtures and additives, which obtains its properties as a result of cement hydration.

Concrete mix – completely mixed concrete components that are able to be compacted using the chosen method.

Hardened concrete - concrete that is solid and has reached a certain level of strength.

Concrete produced at the construction site – concrete produced at the construction site by the contractor for his own use.

Commodity concrete – concrete delivered as a concrete mix by a person or entity who is not a contractor.

Precast concrete product – a concrete product formed and maturing at a location other than its final location.

Ordinary concrete – concrete with a dry density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3.

Lightweight concrete – concrete with a dry density of not less than 800 kg/m^3 and not more than 2000 kg/m^3. This concrete is produced using only or partly lightweight aggregate.

Heavy concrete – concrete with a dry density greater than 2600 kg/m^3.

High-strength concrete – concrete with a compressive strength class greater than C50/60 for ordinary and heavy concrete and concrete with a higher compressive strength class than LC50 /55 for lightweight concrete.

Designed concrete – concrete whose required properties and additional features are given to the manufacturer, who are responsible for delivering concrete in accordance with the required properties and additional features.

Formula concrete – concrete whose composition and components to be used are given to the manufacturer responsible for supplying concrete with such a specific composition.

Cubic meter of concrete – the amount of concrete mix that, when compacted in accordance with the procedure given in EN 12350-6, occupies a volume of one cubic meter.

Admixture – a component added during the mixing process of a concrete mix in small amounts in relation to the weight of cement to modify the properties of the concrete mix or hardened concrete**.**

Additive – a fine-grained component used for concrete to improve certain properties or obtain special properties; usually added in quantities above 5% of cement; the additive can significantly modify the properties of both concrete mix and hardened concrete.

Aggregate – granular material used in construction; aggregate can be natural, artificial or recycled.

Cement – finely ground inorganic material, which – when mixed with water – gives a cement paste, setting and hardening as a result of hydration reactions and processes, and after hardening remains strong and durable, also under water.

Water/cement ratio – ratio of the effective water content to the mass content of cement in the concrete mix..

Characteristic strength – the value of strength below which may be 5% of the population of all possible strength determinations for a given volume of concrete.

2.2.Introduction do concrete mix design

The concrete design process is aimed at the appropriate selection of qualitative and quantitative components in such a way that both the concrete mix and the hardened concrete have the assumed properties. The basic properties of the concrete mix are consistency and workability, while in the case of hardened concrete the requirements relate in particular to compressive strength, i.e. the appropriate compressive strength class, as well as other features related to its intended use and application (e.g. frost resistance, water resistance).

The main components of the concrete mix are cement, water and fine and coarse aggregate, after mixing it creates a mixture of two phases – (1) cement paste and (2) aggregate grains. Hence, in the paste method, the goal is to determine in a calculation and experimental manner the amount of paste to be added to a given mass of aggregate mix to obtain the assumed consistency of the concrete mix. Then the mass of the individual components in the trial mix and 1 m^3 of concrete mix are calculated.

3. Practical task

3.1. Designing the composition of ordinary concrete mix by three equations method

3.1.1. Materials and equipment

- Cement,
- Tap water,
- Natural aggregate of fractions: 0/2 mm, 2/4 mm, 4/8 mm and 8/16 mm,
- Scale,
- Plastic bowls,
- Metal spoons,
- Proper set for testing the concrete mix consistence (e.g. for Vebe test, slump test),
- Concrete cube molds of dimensions 15 x 15 x15 cm,
- Antiadhesive agent,
- Brush,
- Vibrator.

3.1.2. Task completion

Designing the composition of ordinary concrete mix by three equations method consists of the following stages:

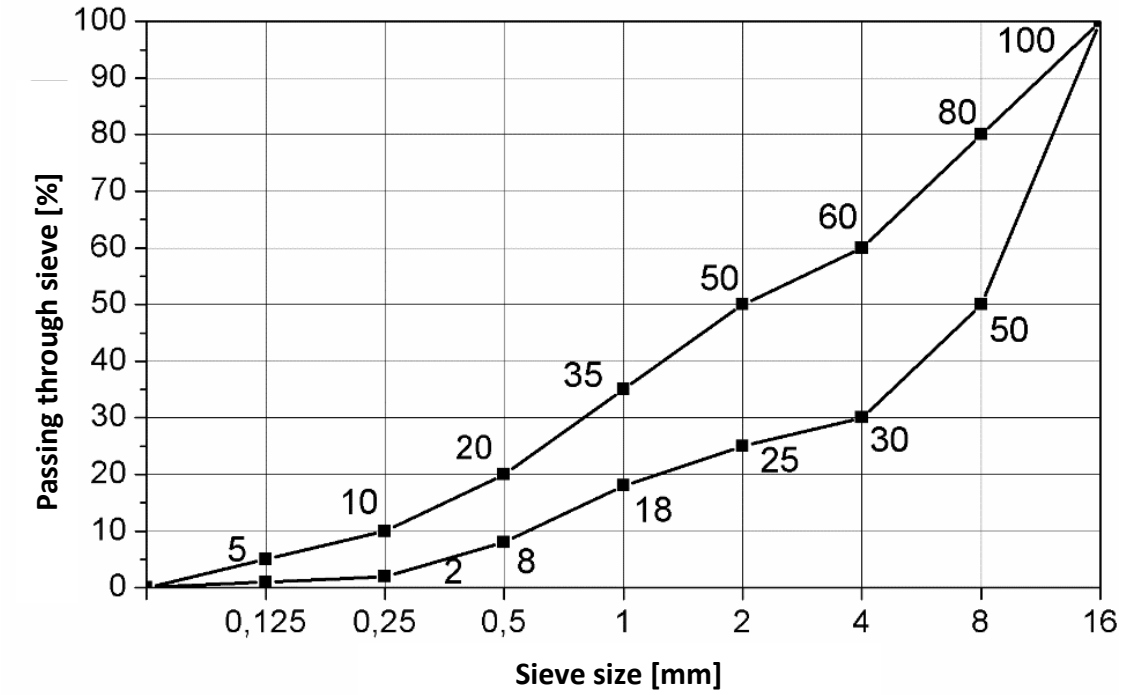
I. Preliminary assumptions for the concrete mix and concrete

Considering the purpose of the concrete and conditions indicated by the teacher – the type of structure (monolithic reinforced concrete structure, monolithic concrete structure, precast structure, massive structure, other types of structure), minimum structure size, reinforcement spacing, reinforcement cover thickness, etc., assumptions should be made regarding the designed concrete mix/concrete – purpose, exposure class, consistence class, strength class, maximum grain size class, type of specimens for testing the compressive strength, method of concrete mix compaction, concrete maturing conditions and others.

II. Qualitative selection, control and testing of concrete mix components

Selection of the type of materials (components) used to design the concrete mix - selection of the type of water, type and class of cement, aggregate type, aggregate

fractions (taking into account the determined class of the maximum aggregate grain size - Fig. 1, Table 1). The components used to make the concrete mix should be thoroughly tested and meet the requirements of the relevant subject standards.



Fig, 1. Limiting curves of aggregate for concrete with an upper grain size of 16 mm recommended in the standard PN-B 06250

Table 1. The selected aggregate mix for ordinary concrete

Fraction [mm]	Content [%]
0/0,125	
0,125/0,0,25	
0,25/0,5	
0,5/1	
1/2	
2/4	
4/8	
8/16	
	Σ = 100%

III. Quantitative selection of concrete mix components

(preliminary determination of the amount of components in the concrete mix and checking in a calculation and experimental way the correctness of the designed composition, making possible corrections to the composition and developing a working recipe).

To determine the composition of the concrete mix, follow these steps:

- Calculation of the cement-water ratio c / w using the Bolomey strength condition and the equation combining the designed average f_{cm} strength and characteristic strength f_{ck}:

$$f_{cm} = A_{1,2} * \left(\frac{c}{w} \mp 0.5\right)$$

$$f_{cm} = f_{ck} + 2\sigma$$

where: f_{cm} – average compressive strength [MPa], A_1 and A_2 - coefficients depending on the cement class and type of aggregate, C - mass of cement, W - water mass, f_{ck} - characteristic compressive strength [MPa], 2σ - compressive strength reserve (adopts equal to standard deviation if known, and if it is not known according to the standard, the value of 2σ = 3 ÷ 6 MPa is assumed);

- Determination of the needed amount of the cement paste and particular components

First, the mass of aggregate mix (indicated by the teacher) should be assumed, which will allow the preparation of a concrete mix with a volume sufficient to carry out the consistence test and the actual volume of the concrete mix, and prepare a specimen for testing the concrete strength. Then, using the calculated w/c ratio value, calculate the mass of paste and the mass of water and cement that are necessary for its preparation:

$$P = \frac{A}{3} \text{ [kg]}$$

$$W = \frac{P}{\frac{c}{w} + 1} \text{ [kg]}$$

$$C = W * \frac{c}{w} \text{ [kg]}$$

where: P – paste mass, A – aggregate mass, W – water mass, c/w – water/cement ratio, C –cement mass;

- Determining the amount of individual aggregate fractions and making an aggregate mix from them into a trial concrete mix.

Calculate the mass of individual fractions included in the aggregate mix with a mass equal to A, according to the aggregate grain size determined in stage II (Table 2).

Table 2. The selected aggregate mix for ordinary concrete

Fraction [mm]	Content [%]
0/0,125	
0,125/0,0,25	
0,25/0,5	
0,5/1	
1/2	
2/4	
4/8	
8/16	
	Σ = 100%

- Experimental and computational verification of the correctness of the designed composition, which requires preparation of a test income with a volume sufficient to carry out the necessary tests of the concrete mix and concrete. For this purpose, cement and water as well as aggregate fractions should be weighed from the thickest to the smallest. Next, weigh the bowl moistened with water (together with the spoon) and prepare the leaven in it;
- Addition of cement paste to the prepared aggregate in the amount necessary to achieve the consistency of the concrete mix assumed in the first stage;
- Testing the consistency of the concrete mix by the slump test or Vebe test and determining the required class according to Table 3 or Table 4, if the consistence is as per the assumed for the next steps;

Table 3. Consistence class according to Vebe test

Class	Vebe time [s]
V1	30 ÷ 21
V2	20 ÷ 11
V3	10 ÷ 6
V4	5 ÷ 3

Table 4. Consistence class according to slump test

Class	Slump [mm]
S1	od 10 do 40
S2	od 50 do 90
S3	od 100 do 150
S4	od 160 do 210
S5	> 220

- Testing the real volume of the mix V_r.
- Preparation of a 15 x 15 x 15 cm cubic specimen for testing the compressive strength after 28 days of curing;
- Determine the mass of paste used for the concrete mix preparation:

$$P_U = P - P_M$$

where: P_U – mass of paste used to prepare the concrete mix with assumed consistence, P - paste mass calculated on the basis of the aggregate mass adopted A, P_M – paste mass remaining in the bowl;

- Calculation of the masses of components (water and cement) of the used paste P_U:

$$W_2 = \frac{P_1}{\frac{c}{w} + 1} \text{ [kg]}$$

$$C_2 = W_1 * \frac{c}{w} \text{ [kg]}$$

- Calculation preliminary composition of concrete mix per 1 m^3:

$$C_2 = \frac{C}{V_r} * 1000 \text{ [kg]}$$

$$W_2 = \frac{W}{V_r} * 1000 \text{ [kg]}$$

$$A_2 = \frac{A}{V_r} * 1000 \text{ [kg]}$$

where: C_2 – cement mass per 1 m^3 of concrete mix [kg], C – cement mass per preliminary concrete specimen [kg], W_2 – water mass per 1 m^3 of concrete mix [kg], W – water mass per preliminary concrete specimen [kg], A_2 – aggregate mass per 1 m^3 of concrete mix [kg], A – aggregate mass per preliminary concrete specimen.

- Equation of tightness (tightness condition) check:

$$\frac{C}{\rho_C} + \frac{A}{\rho_A} + W = 1000 \pm 2\%$$

where: C – cement mass per 1 m^3 of concrete mix [kg], ρ_C – cement density ($\rho_C = 3{,}1\ \text{kg/dm}^3$), A – aggregate mass per 1 m^3 of concrete mix [kg], ρ_K – gęstość kruszywa ($\rho_k = 2{,}65\ \text{kg/dm}^3$), W – water mass per 1 m^3 of concrete mix [kg].

If the tightness condition is not met, the calculated masses of the concrete mix components are adjusted (with constant value of c/w ratio);

- Checking if the designed composition of the concrete mix meets the requirements specified in the exposure class - requirements for maximum w/c ratio, minimum cement mass content, minimum compressive strength class (after testing the compressive strength);
- Providing a laboratory composition (the final composition per 1 m^3 of the concrete mix meeting the assumptions for aggregate in the air-dry state) – Table 4;

Table 4. Laboratory composition per 1 m^3 of concrete mix

Component		Mass [kg]
Cement		
Water		
Aggregate	0/2 mm	
	2/4 mm	
	4/8 mm	
	8/16 mm	

- Composition for works on the site:

a) Composition per 1 m^3 of concrete taking into account the aggregate humidity (Table 5):

$$P_w = P\left(1 + \frac{w_d}{100}\right) \quad [\text{kg}]$$

$$A_w = A\left(1 + \frac{w_g}{100}\right) \quad [\text{kg}]$$

$$W_w = W - [(P_w - P) + (A_w - A)] \quad [\text{kg}]$$

where: w_d – water content of sand fraction 0/2 mm [%], w_g – water content of aggregate of fraction 2/16 mm [%], P_w – corrected mass of sand [kg], P – mass of sand [kg], A_w – corrected mass of aggregate of fraction 2/16 mm [kg], A – masa of aggregate of fraction 2/16 mm [kg], W_w – corrected water mass [kg], W – water mass [kg].

Table 5. Composition per 1 m^3 of concrete mix taking into account the aggregate humidity

Component		Mass [kg]
Cement		
Water		
Aggregate	0/2 mm	
	2/4 mm	
	4/8 mm	
	8/16 mm	

b) Calculation of the mass of components per one concrete mixer or mixer, taking into account the aggregate moisture (Table 6):

Calculation of the capacity of the mixer:

$$V_r = V_t * \alpha$$

where: V_r – mixer real volumetric capacity, V_t – theoretical mixer volume (data given by teacher), α – expansion coefficient equal 0,85

Calculation of the components masses per one mixer:

$$C_r = C * \frac{V_r}{1000} \text{ [kg]}$$

$$W_r = W * \frac{V_r}{1000} \text{ [kg]}$$

$$P_r = P * \frac{V_r}{1000} \text{ [kg]}$$

$$A_r = A * \frac{V_r}{1000} \text{ [kg]}$$

where: C_r – corrected cement mass [kg], C – cement mass [kg], P_r – corrected mass of aggregate 0/2 mm [kg], P – mass of aggregate 0/2 mm [kg], A_r – corrected mass of aggregate 2/16 mm [kg], A – mass of aggregate 2/16 mm [kg], W_r – corrected water mass [kg], W – water mass [kg].

Table 6. Composition per one concrete mixer volume, taking into account the aggregate humidity

Component		Mass [kg]
Cement		
Water		
Aggregate	0/2 mm	
	2/4 mm	
	4/8 mm	
	8/16 mm	

c) Calculation of the mass of components taking into account dosing of cement with full bags and aggregate humidity:

The composition of the concrete mix should be recalculated by rounding the mass of cement so that it is divisible by the mass of the cement bag (25 kg) and given in Table 7.

Table 7. Composition per one concrete mixer, taking into account the aggregate humidity and cement dosing with full bags

Component		Mass [kg]
Cement		
Water		
Aggregate	0/2 mm	
	2/4 mm	
	4/8 mm	
	8/16 mm	

4. Laboratory report

The laboratory report should include:

I. Subject, aim and scope of research (containing basic information about tested materials/products, test methods, requirements),

II. Tests results with proper units (results obtained in the laboratory prepared in the indicated manner, e.g. put in the proper tables),

III. Conclusions (bulleted statements formulated based on the results obtained),

IV. Bibliography (list of references to the literature or www used to prepare the report)