Wydział
Inżynierii Lądowej

Didactic materials for Undergraduate (BSc) studies

conducted in English for the course

Building Materials 2 – laboratory

Lightweight concrete design:

ITB method

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1. Aim of the task

The aim of the task is to learn the principles of lightweight concrete design by the ITB method and to use this method to design lightweight concrete with lightweight aggregate for the indicated specification.

2. Theoretical background

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 to lightweight 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 present 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 (LC X/Y), as well as other properties related to its intended use and application (e.g. frost resistance).

Lightweight concretes due to their structure are divided into compact concretes, semi-compact concretes and hollow concretes. Lightweight concretes due to the terms of application are divided into construction concrete, insulation concretes and construction-insulation concretes. They are manufactured in solely or in partially from lightweight aggregates, which are classified as artificial aggregates produced, among others as a result of heat treatment of the raw materials. The density of lightweight concrete in the dry state varies from 800 kg/m^3 to 2000 kg/m^3. Lightweight aggregates used for lightweight concrete include: lightweight expanded clay aggregate (LECA or exclay), pollytag, fly ash-slag expanded aggregate, slag, etc. Natural and broken aggregates as well as various additives are also used. Admixtures and additives are also applied to lightweight aggregate concrete.

When designing lightweight concrete, the universal methods of the ordinary concrete design are not used, because lightweight concrete is made of lightweight aggregates that are characterized with different properties. In most cases, experimental and computational methods adapted to the type of granular filler are used to design the composition of lightweight aggregate concrete.

The lightweight aggregate concrete design method was developed at the Building Research Institute (ITB) in Warsaw. This is one of several methods for determining the composition of concretes with expanded clay aggregates. The method is aimed at the appropriate qualitative and quantitative selection of components in such a way that the concrete mix and hardened concrete obtain the assumed level of properties. The method includes three stages: (I) establishing initial assumptions, (II) qualitative selection, control and evaluation of components and (III) quantitative selection of components of the concrete mix. The selection of the mass contents of components is made using graphs presenting the relation between the content of particular component (cement or water or aggregate of 0/4 mm, 4/8 mm and 8/16 mm fraction) and the mean compressive strength (f_{cm}) of concrete. The separate graphs are elaborated for various types (marks) of expanded clay aggregate.

3. Practical task

3.1. Designing the composition of lightweight concrete mix by ITB method

3.1.1. Materials and equipment

- Cement,
- Tap water,
- Natural sand, fraction: 0/2 mm
- Artificial lightweight clay aggregate of fractions: 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 lightweight concrete mix by ITB 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 type and fractions of the used lightweight aggregate determine the type of lightweight concrete structure and its application, i.e. in the case of lightweight compact concrete (for construction, higher strength) all aggregate fractions (fine and coarse aggregate) are used, while designing hollow concrete (insulating, lower strength) only coarse aggregate is used, while higher strength concrete uses natural sand instead of lightweight sand is used. In the case of ITB method, the mass of individual aggregate fractions is taken from the charts (Fig. 1), while in other methods the contents of individual aggregate fractions should be chosen according to Table 1 and simultaneously follow the principle according to which the approximate amount of aggregate (A) in 1 m^3 of concrete mix should be:

$$A = 1{,}0 \div 1{,}1\rho_{nz}$$

where: ρ_{nz} – bulk density of aggregate in compacted state [kg/m^3]

Table 1. Approximate contents of expanded clay aggregate in lightweight concrete

Fraction	**Content [%]**	
	Compact concrete	**Semi-compact concrete**
0/4 mm	50 – 60	20 – 30
4/8 mm	25 – 20	40 – 35
8/16 mm	25 – 20	40 – 35

At this stage, it is also necessary to determine the loose density of individual fractions of expanded clay aggregate and on this basis determine the brands:

LECA fraction 4/8 mm $\rho_{nl}^{4/8}$ [kg/m^3]

LECA fraction 8/16 mm $\rho_{nl}^{8/16}$ [kg/m^3]

The components used to make the concrete mix should be thoroughly tested and meet the requirements of the relevant subject standards.

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).

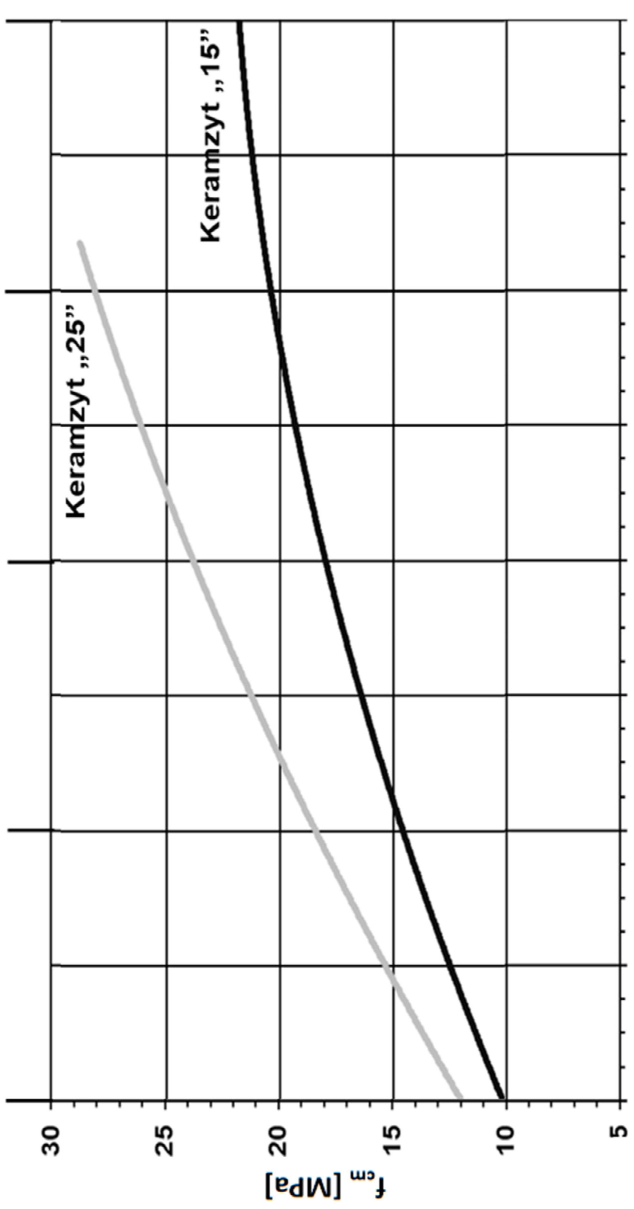
To determine the composition of the lightweight concrete mix, follow these steps:

- Calculation of the average (mean) f_{cm} based on characteristic strength f_{ck}:

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

where: f_{cm} – average compressive strength [MPa], 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);

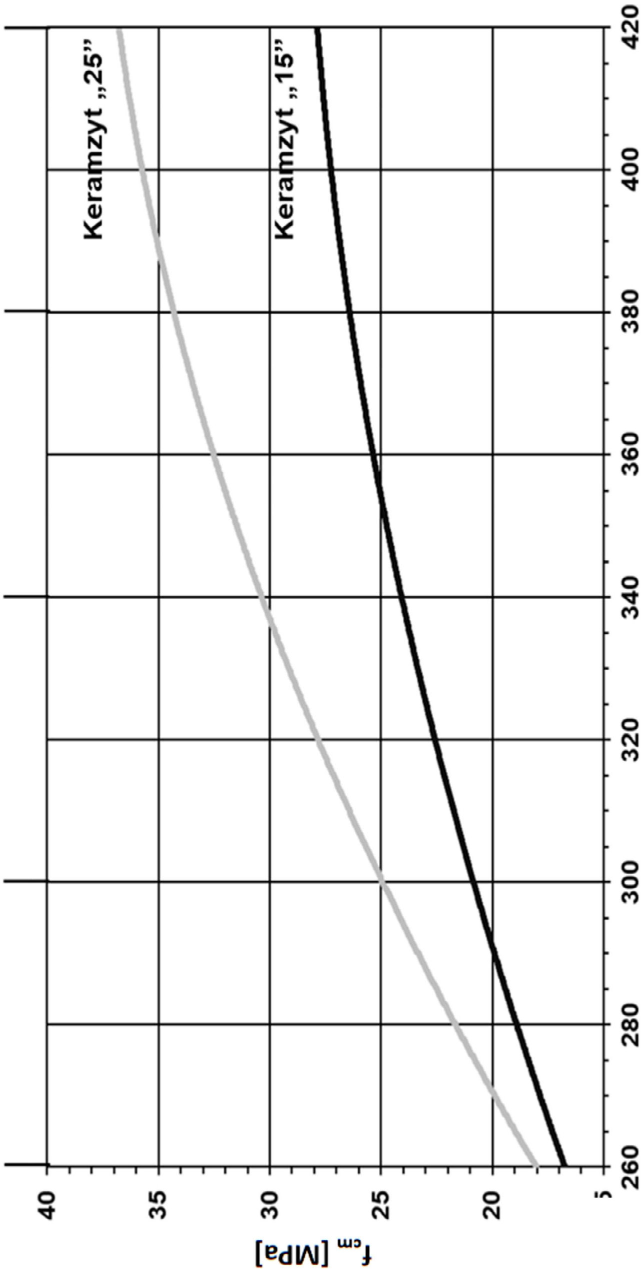
- Taking the mass of cement, water and individual aggregate fractions per 1 m^3 of lightweight concrete mix from the chart containing lightweight sand or natural sand (Fig. 1, Fig. 2, Table 2).



Density of concrete in the air-dry state [kg/m³]	Keramzyt „25"	1400		1440		1470		1500		1530
	Keramzyt „15"	1330		1370		1400		1430		1470
	Cement [kg]	240	260	280	300	320	340	360	380	400
	Water [kg]	215	220	225	230	235	240	245	250	255
	Lightweight sand* [kg]	480	475	470	465	460	455	450	445	440
Keramzyt „25"	4/8 mm [kg] – ρ_{nl} = 800 kg/m³	275		270		265		260		250
	8/16 mm [kg] – ρ_{nl} = 700 kg/m³	275		270		265		260		250
Keramzyt „15"	4/8 mm [kg] – ρ_{nl} = 700 kg/m³	240		235		230		225		220
	8/16 mm [kg] – ρ_{nl} = 600 kg/m³	240		235		230		225		220

*) Sand made of crushed keramzyt or other lightweight sand of type 1 and bulk density in loose state ρ_{nl} = 900 kg/m³

Fig.1. Approximate contents of components in lightweight concrete with lightweight sand (up to class: LC 20/22)



Density of concrete in the air-dry state [kg/m³] – Keramzyt „25"	1660		1680		1710		1740		1760
Density of concrete in the air-dry state [kg/m³] – Keramzyt „15"	1580		1600		1630		1660		1680
Cement [kg]	260	280	300	320	340	360	380	400	420
Water [kg]	180	185	190	195	200	205	210	215	220
Natural sand [kg]	600	595	590	585	580	575	570	565	560
Keramzyt „25" 4/8 mm [kg] – ρ_{nl} = 800 kg/m³	340		335		330		325		320
Keramzyt „25" 8/16 mm [kg] – ρ_{nl} = 700 kg/m³	340		330		320		310		300
Keramzyt „15" 4/8 mm [kg] – ρ_{nl} = 700 kg/m³	300		295		290		285		280
Keramzyt „15" 8/16 mm [kg] – ρ_{nl} = 600 kg/m³	300		290		280		270		260

Fig.2. Approximate contents of components in lightweight concrete with natural sand (up to class: LC 25/28)

Table 2. The composition of the lightweight concrete mix per 1m³ based on the charts (LECA – lightweight expanded clay aggregate)

Component	**Mass [kg]**
Cement	
Water	
Sand 0/2 mm	
LECA 4/8 mm	
LECA 8/16 mm	

In case of non-compliance of the actual bulk density in a loose state $\rho_{nl}^{4/8}$ i $\rho_{nl}^{8/16}$ with the theoretical bulk density given in the chart (and corresponding to the selected aggregate "mark"), the mass of the aggregate taken from the chart must be corrected (Table 3):

$$A_2^{0/4} = A_1^{0/4}\left[\frac{\rho_{nl\,(rz)}^{0/4}}{\rho_{nl\,(t)}^{0/4}}\right] \text{ [kg]}$$

$$A_2^{4/8} = A_1^{4/8}\left[\frac{\rho_{nl\,(rz)}^{4/8}}{\rho_{nl\,(t)}^{4/8}}\right] \text{ [kg]}$$

$$A_2^{8/16} = A_1^{8/16}\left[\frac{\rho_{nl\,(rz)}^{8/16}}{\rho_{nl\,(t)}^{8/16}}\right] \text{ [kg]}$$

Table 3. The composition of the lightweight concrete mix per 1m³ based on the charts after correction (LECA – lightweight expanded clay aggregate)

Component	**Mass [kg]**
Cement	
Water	
Sand 0/2 mm	
LECA 4/8 mm	
LECA 8/16 mm	

- Preparation of test mix with theoretical volume V_t sufficient to carry out the necessary tests of the concrete mix and the hardened concrete. For this purpose, the aggregate should be weighed starting from the thickest to the finest fraction, then add from 50% to 75% of the mixing water, mix everything and wait 10 - 15 minutes. Next add cement and the remaining amount of water necessary to achieve the assumed consistence;
- Testing the consistence of the concrete mix by the slump test or Vebe test and determining the required class according to Table 4 or Table 5, if the consistence is as per the assumed for the next steps;

Table 4. Consistence class according to Vebe test

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

Table 5. 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. If $V_t = V_r$ no further calculations related to determining the composition are necessary, and when $V_t \neq V_r$, then the mass of the components should be corrected (table 6.):

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

$$P_2 = \frac{P}{V_r} * 1000 \ \ [\text{kg}]$$

$$A_3^{4/8} = \frac{A_2^{4/8}}{V_r} * 1000 \ \ [\text{kg}]$$

$$A_3^{8/16} = \frac{A_2^{8/16}}{V_r} * 1000 \ \ [\text{kg}]$$

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

Tab.6. The composition of the lightweight concrete mix per 1m^3 after correction (LECA – lightweight expanded clay aggregate)

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

- Preparation of a 15 x 15 x 15 cm cube specimen for testing the compressive strength after 28 days of curing;

- Checking if the designed composition of the lightweight 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 7;

Table 7. Laboratory composition per 1 m^3 of concrete mix

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

- Composition for works on the site:
  a) Composition per 1 m^3 of concrete taking into account the aggregate humidity (Table 8):

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

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

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

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].

b) Calculation of the mass of components per one concrete mixer or mixer, taking into account the aggregate moisture (Table 9):

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].

Tab.9. Composition per one concrete mixer volume, taking into account the aggregate humidity

<table>
<tr><th colspan="2">Component</th><th>Mass [kg]</th></tr>
<tr><td colspan="2">Cement</td><td></td></tr>
<tr><td colspan="2">Water</td><td></td></tr>
<tr><td rowspan="4">Aggregate</td><td>0/2 mm</td><td></td></tr>
<tr><td>2/4 mm</td><td></td></tr>
<tr><td>4/8 mm</td><td></td></tr>
<tr><td>8/16 mm</td><td></td></tr>
</table>

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 10.

Tab.10. Composition per one concrete mixer, taking into account the aggregate humidity and cement dosing with full bags

<table>
<tr><th colspan="2">Component</th><th>Mass [kg]</th></tr>
<tr><td colspan="2">Cement</td><td></td></tr>
<tr><td colspan="2">Water</td><td></td></tr>
<tr><td rowspan="4">Aggregate</td><td>0/2 mm</td><td></td></tr>
<tr><td>2/4 mm</td><td></td></tr>
<tr><td>4/8 mm</td><td></td></tr>
<tr><td>8/16 mm</td><td></td></tr>
</table>

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)