2. MIX DESIGN

2.1 General

Concrete is the material formed by mixing cement, aggregates and water, with or without the incorporation of admixtures and additions, which develops its properties by hydration of the cement. The general concept for concrete mix design as presented herein is in full compliance with the most spread existing standards for concrete production, such as the *European Standard for concrete: EN 206* [3]. For the present application, a concrete volume is assumed that contains certain amounts of ***cement, additions (optional), aggregates, water, and admixtures (optional)*** *only*, see Fig. 2.1.1. To the above materials ***entrained or entrapped air*** should be added.

CONCRETE :

Cement:	main constituents: portland clinker, blast furnace slag, silica fume, pozzolanic materials (natural or natural calcined pozzolanas), fly ash (siliceous or calcareous), burnt shale, and limestone minor additional constituents: all main constituents except clinker calcium sulphate, additives
+	
Additions:	type I (filler aggregate, pigments), type II (fly ash, silica fume)
+	
Aggregates:	fine, coarse
+	
Water:	mixing water
+	
Admixtures:	retarder, accelerator, air-entraining, plasticizer, superplasticizer, etc.
+	
Air:	entrained, entrapped

Figure 2.1.1 Constituent materials for concrete composition.

All these materials have to comply with the corresponding standards for the constituent materials, for instance in the case of European Standards: EN 197 (Cement), EN 450 (Fly ash for concrete), EN 13263 (Silica fume for concrete), EN 12620 (Aggregates for concrete), EN 1008 (Mixing water for concrete), EN 934-2 (Admixtures for concrete), etc.

In Fig. 2.1.2, the part (tab) of the logical flowchart of EUCON® for the desing of the concrete mix is presented. The tab contains:

- a field that the user introduces the **input data** for cement, additions, admixtures, water, aggregates, and air.
- a **calculation button**, and
- a field of the **output results** including the *aggregate content* in order to achieve the mass balance requirements.

CONCRETE MIX DESIGN

INPUT

Cement (Cement type according to EN 197, standard strength class, early strength class. Composition of cement in clinker, other main constituents, minor additional constituents, and calcium sulphate. Cement density and cement content)

Additions (Additions type I: filler aggregate and/or pigments, density and content. Additions type II: siliceous or calcareous fly ash and/or silica fume, fly ash density and content, silica fume density and content)

Admixtures (Admixture type: retarder, accelerator, air-entraining, plasticizer, superplasticizer, other. Density, solid content, dosage. Total admixture content)

Water (Water/cement ratio, effective water content, water from admixtures, water added, water density)

Aggregates (Aggregate type, maximum nominal upper aggregate size, aggregate density)

Air (Entrapped-air content, entrained-air content, total air content)

▼

CALCULATION

(Aggregate content, aggregate/cement ratio, fresh concrete density)

Figure 2.1.2 Logical diagram for computer design of concrete mix.

A general view of this tab is given as Fig. 2.1.3. The user has to fill in the "white boxes" (where applicable) and then to press the calculation button in order to complete the mix proportioning for the concrete. For the algebraic formulae used for these calculations and further questions, **please always advise the *Theoretical Background* [1], chapter 2**. In the sequence, each part of this tab is discussed in detail.

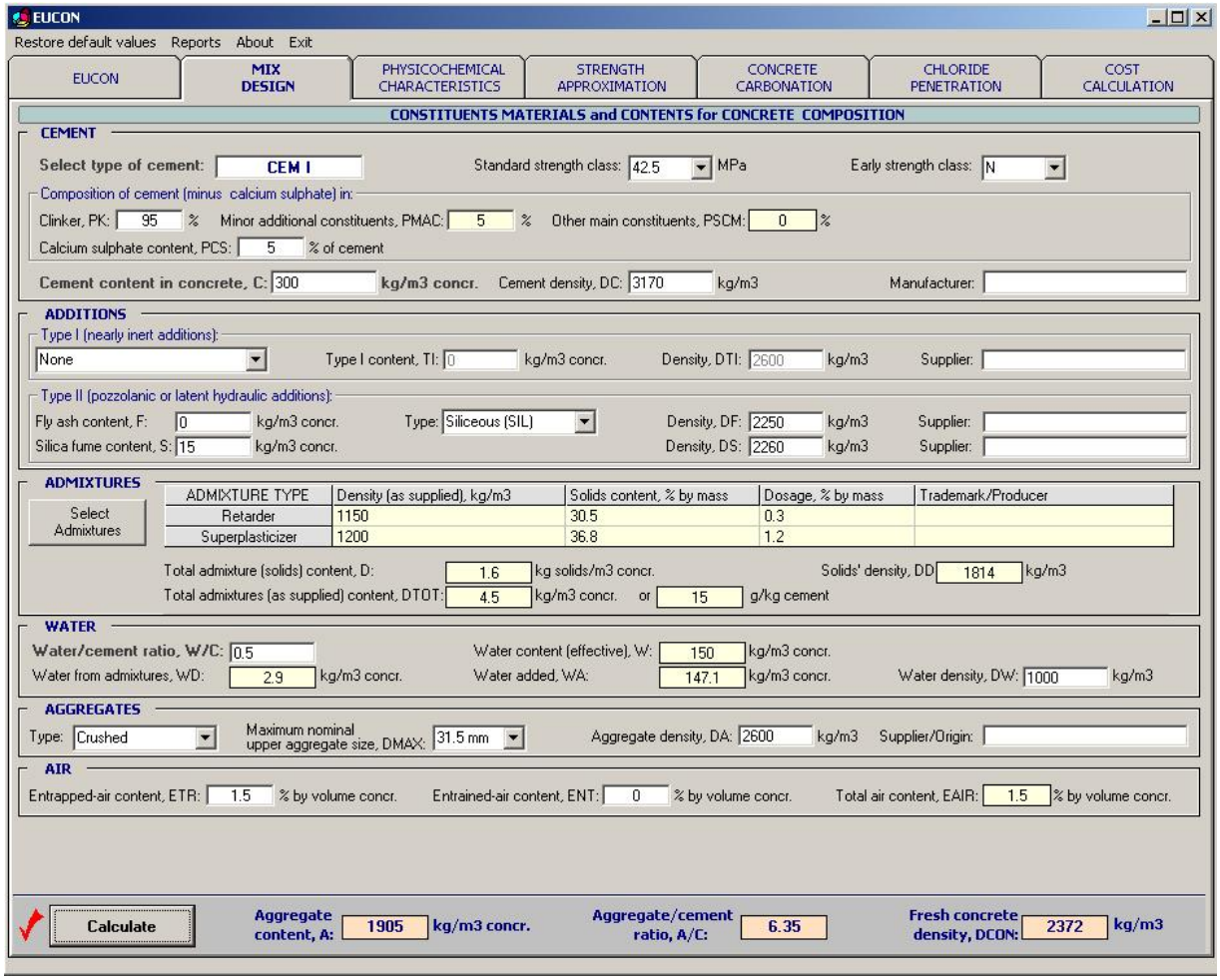

Figure 2.1.3 General view of the tab "MIX DESIGN" of the EUCON® program.

2.2 Cement

Cement identification

Cement type:	By clicking on the near "white box", a "select cement type" window opens. Click on the cement main type (CEM I, CEM II, CEM III, CEM IV or CEM V) that you want to use in the mix, select the exact cement type, and click on the button "**v**" to introduce it into the mix (always advise Table 2.2.1 for cement notation according to EN 197-1 [2]). LIMITS: You have to select a cement type from the open window exclusively. If the construction is an old one and a past cement type might be used, or another cement standard is applied, or more than one cement used, then you have to select the closest cement type from the 27 types existing on EN 197, and to adjust the composition. DEFAULT VALUE: CEM I
Standard strength class:	Use the button "▼" and select the standard strength class of cement according to EN 197-1 and EN 196-1. UNITS: MPa LIMITS: You have to select among the values 32.5, 42.5, and 52.5 MPa, only. It has a significant effect on 28-days strength. If another cement standard is applied, then you have to select the closest cement's standard strength class from the above. DEFAULT VALUE: 42.5 MPa
Early strength class:	Use the button "▼" and select the early strength class of cement according to EN 197-1 and EN 196-1. LIMITS: You have to select among the values N (ordinary early strength) and R (high early strength), only. It has a significant effect on 2- and 7-days strength. If another cement standard is applied, then you have to select the closest cement's early strength class from the above. DEFAULT VALUE: N
Manufacturer (optional)	The name of the cement manufacturer.

Table 2.2.1 Types of common cements according to European Standard EN 197-1*.

Main types	Nota-tion	Main constituents**									Minor addit. const.
		K	S	D	P	Q	V	W	T	L/LL	
PORTLAND CEMENTS											
CEM I	I	95-100	-	-	-	-	-	-	-	-	0-5
PORTLAND-COMPOSITE CEMENTS											
CEM II	II/A-S	80-94	6-20	-	-	-	-	-	-	-	0-5
	II/B-S	65-79	21-35	-	-	-	-	-	-	-	0-5
	II/A-D	90-94	-	6-10	-	-	-	-	-	-	0-5
	II/A-P	80-94	-	-	6-20	-	-	-	-	-	0-5
	II/B-P	65-79	-	-	21-35	-	-	-	-	-	0-5
	II/A-Q	80-94	-	-	-	6-20	-	-	-	-	0-5
	II/B-Q	65-79	-	-	-	21-35	-	-	-	-	0-5
	II/A-V	80-94	-	-	-	-	6-20	-	-	-	0-5
	II/B-V	65-79	-	-	-	-	21-35	-	-	-	0-5
	II/A-W	80-94	-	-	-	-	-	6-20	-	-	0-5
	II/B-W	65-79	-	-	-	-	-	21-35	-	-	0-5
	II/A-T	80-94	-	-	-	-	-	-	6-20	-	0-5
	II/B-T	65-79	-	-	-	-	-	-	21-35	-	0-5
	II/A-L	80-94	-	-	-	-	-	-	-	6-20	0-5
	II/B-L	65-79	-	-	-	-	-	-	-	21-35	0-5
	II/A-M	80-94	6-20								0-5
	II/B-M	65-79	21-35								0-5
BLASTFURNACE CEMENTS											
CEM III	III/A	35-64	36-65	-	-	-	-	-	-	-	0-5
	III/B	20-34	66-80	-	-	-	-	-	-	-	0-5
	III/C	5-19	81-95	-	-	-	-	-	-	-	0-5
POZZOLANIC CEMENTS											
CEM IV	IV/A	65-89	-	11-35					-	-	0-5
	IV/B	45-64	-	36-55					-	-	0-5
COMPOSITE CEMENTS											
CEM V	V/A	40-64	18-30	-	18-30			-	-	-	0-5
	V/B	20-38	31-50	-	31-50			-	-	-	0-5

* The composition is expressed as % by mass of the main and minor additional constituents.

** Notation **exclusively** for the present table: portland clinker (K), blast furnace slag (S), silica fume (D), pozzolana (natural, P or natural calcined, Q), various fly ashes (siliceous, V or calcareous, W), burnt shale (T), and limestone (L or LL).

Cement composition

Clinker, PK:	The percentage of clinker (including the various additives) in the cement (minus calcium sulphate). You may change the default value, within the permitted range, if you have an accurate composition from the cement manufacturer. UNITS: % by mass LIMITS: given in the column K of Table 2.2.1, according to the cement type used. DEFAULT VALUE: the lower limit in the column K of Table 2.2.1, plus 10 for all CEM III, CEM IV/B, and all CEM V.
Minor additional constituents, PMAC:	The percentage of minor additional constituents in the cement (minus calcium sulphate). You may change the default value, within the permitted range, if you have an accurate composition. For CEM I you may change this value by changing accordingly the PK. UNITS: % by mass LIMITS: 0-5%, except CEM II/A-D, where it is 0-4% DEFAULT VALUE: 5 %, except CEM II/A-D, CEM III, where it is 4%
Other main constituents, PSCM:	The percentage of supplementary cementing materials (SCM) in the cement (minus calcium sulphate). It shall be: (PSCM = 100 – PK – PMAC), and thus is not permitted to write on ("yellow box") in order to ensure mass balance satisfaction. You may change this value, within the permitted range, by changing accordingly the PK and PMAC. In the case of cement type CEM V, these composite cements contain, apart the clinker, certain amounts of both slag and other pozzolanic materials, and then the PSCM is separated in **PSL** (%), referring to slag percentage in cement, and **PPO** = (PSCM – PSL), referring to the other pozzolanic materials. UNITS: % by mass LIMITS: given in the column of main constituents, but K, on the Table 2.2.1, according to the cement type used. DEFAULT VALUE: that calculated from the equation (PSCM = 100 – PK – PMAC), using the default values for PK and PMAC.
Calcium sulphate content,	The percentage of calcium sulphate in the cement. You may change the default value, within the permitted range, if you have an accurate one

PCS:	from the cement manufacturer. UNITS: % by mass LIMITS: 1-10% DEFAULT VALUE: 5 %

Cement content and density

Cement content, C:	Introduce the total cement content in the concrete volume. UNITS: kg cement / m^3 of concrete LIMITS: 0<C<DC DEFAULT VALUE: 300 kg/m^3
Cement density, DC:	Introduce the particle density of cement. UNITS: kg/m^3 LIMITS: 2000 – 4000 kg/m^3 DEFAULT VALUE: DC = 3200 (PK/100) + 2600 (100 – PK)/100

2.3 Additions

Type I (nearly inert additions)

Type I:	Use the button "▼" and select the type I addition (nearly inert). LIMITS: choose between none, filler aggregate conforming to EN 12620, pigments conforming to EN 12878, or both filler aggregate and pigments. DEFAULT VALUE: No
Type I content, TI:	Introduce the Type I additions' content in the concrete volume. UNITS: kg Type I addition / m^3 of concrete LIMITS: 0≤TI<DTI DEFAULT VALUE: 0 kg/m^3
Type I density, DTI:	Introduce the particle density of Type I additions. UNITS: kg/m^3 LIMITS: 1000 - 4000 DEFAULT VALUE: 2600 kg/m^3

Supplier (optional)	The name of the Type I additions' supplier.

Type II (pozzolanic or latent hydraulic additions)

Fly ash content, F:	Introduce the fly ash content in the concrete volume. Fly ash shall conform to EN 450 or a European Technical Approval, or a relevant national standard or provisions. We suppose that *when a type II addition is used directly in concrete, only a cement type CEM I is permitted.* UNITS: kg fly ash / m^3 of concrete LIMITS: 0≤F<DF DEFAULT VALUE: 0 kg/m^3
Fly ash type:	Use the button "▼" and select the fly ash type. LIMITS: choose between siliceous and calcareous fly ash. DEFAULT VALUE: siliceous fly ash
Fly ash density, DF:	Introduce the particle density of fly ash. UNITS: kg/m^3 LIMITS: 1500 - 4000 DEFAULT VALUE: 2250 kg/m^3 for siliceous fly ash and 2660 kg/m^3 for calcareous fly ash
Supplier (optional)	The name of the fly ash supplier.

Silica fume content, S:	Introduce the silica fume content in the concrete volume. Silica fume shall conform to EN 13263 or a European Technical Approval, or a relevant national standard or provisions. We suppose that *when a type II addition is used directly in concrete, only a cement type CEM I is permitted.* UNITS: kg silica fume / m^3 of concrete LIMITS: 0≤S<DS DEFAULT VALUE: 0 kg/m^3
Silica fume density, DS:	Introduce the particle density of silica fume. UNITS: kg/m^3 LIMITS: 1500 - 4000

	DEFAULT VALUE: 2260 kg/m^3
Supplier (optional)	The name of the silica fume supplier.

2.4 Admixtures

Select admixture types:	By clicking on the near box, a "select admixture types" window opens. By using the arrow "→", select between none and available armixture types that you want to use in the mix. By using the arrow "←", remove your selection. In this window you can introduce the admixture density, solids content, dosage and trademark/producer (admixtures shall conform to EN 934-2, default values given below). Click on the button "**v**" to entry your final selection and values. Click on the same box if you want to alter a selection or to correct an admixture characteristic. LIMITS: You have to select none, one or more admixture types from the open window exclusively. You may select an "other type" that you may specify, accordingly. DEFAULT VALUE: None

Admixture type	**Density (as supplied)** kg/m^3	**Solids content,** % by mass	**Dosage,** % by mass cement
None	-	-	0
Retarder	1150	30.5	0.3 (0.2-0.4)
Accelerator	1200	32.0	3.5 (0.5-6)
Air-entraining	1030	12.0	0.10 (0.05-0.2)
Plasticizer	1180	32.0	0.4 (0.3-0.5)
Superplasticizer	1200	36.8	1.2 (0.8-1.5)
Other	1200	32.0	0.5
Total admixture (solids) content, D:	The total admixture (only solids) content in the concrete volume. It is indirectly estimated from the dosages and characteristics of the various admixtures.		

	UNITS: kg admixture solids / m^3 of concrete LIMITS: The total amount of each admixture, if any, shall not exceed the *maximum dosage* recommended by the admixture producer. DEFAULT VALUE: 0 kg/m^3
Total admixtures (as supplied) content, DTOT:	The total admixture (solids and water) content in the concrete volume. It is indirectly estimated from the dosages and characteristics of the various admixtures. UNITS: kg solution / m^3 of concrete or g /kg cement LIMITS: not exceed 50 g of admixture (as supplied) per kg cement unless the influence of the higher dosage on the performance and durability is established. DEFAULT VALUE: 0 kg/m^3
Solids' density, DD:	The solids' density of the admixtures. It is indirectly estimated from the density and solids content of the various admixtures. UNITS: kg/m^3 DEFAULT VALUE: 1800 kg/m^3

2.5 Water

Water/cement ratio, W/C:	Introduce the ratio of the effective water content to cement content by mass in the fresh concrete. UNITS: dimensionless LIMITS: 0.2 – 1.5 DEFAULT VALUE: 0.5
Water content (effective), W:	It is calculated as (W/C)C. If you want to change it, you have to change the water to cement ratio, W/C. UNITS: kg / m^3 of concrete DEFAULT VALUE: 150 kg/m^3
Water from admixtures, WD:	The total water content from admixtures in the concrete volume. It is indirectly estimated from the dosages and characteristics of the various admixtures.

	UNITS: kg / m^3 of concrete DEFAULT VALUE: 0 kg/m^3
Water added, WA:	It is calculated as (W-WD). It is the water that you add to the concrete volume (the mixing water shall conform to EN 1008) including the added water, plus water already contained on the surface of aggregates, plus water in the additions used in the form of a slurry, and water resulting from any added ice or steam heating. The water from admixtures is estimated separately before. UNITS: kg / m^3 of concrete DEFAULT VALUE: 150 kg/m^3
Water density, DW:	Introduce the water density. UNITS: kg/m^3 LIMITS: 900 - 1200 DEFAULT VALUE: 1000 kg/m^3

2.6 Aggregates

Aggregate type:	Use the button "▼" and select the aggregate type. Normal and heavy-weight aggregates are supposed conforming to EN 12620. LIMITS: choose between crushed or rounded. This selection has an effect on concrete strength. DEFAULT VALUE: crushed
Maximum nominal upper aggregate size, DMAX:	Use the button "▼" and select this size, taking into account the concrete cover to reinforcement and the minimum section width. UNITS: mm LIMITS: choose between these values 8, 16, 31.5, 63 mm. This selection has an effect on entrapped-air content and further on strength. DEFAULT VALUE: 31.5 mm
Aggregate density, DA:	Introduce the particle density of aggregates. UNITS: kg/m^3 LIMITS: 1000 - 4000

	DEFAULT VALUE: 2600 kg/m^3
Supplier/ Origin (optional)	The name of the aggregates' supplier or origin.

2.7 Air

Entrapped-air content, ETR:	The voids in concrete which are not purposely entrained. It is estimated from the maximum nominal upper aggregate size (data from ACI): *DMAX (mm)* *ETR (%)* 8 3.5 19 2.3 31.5 1.5 63 0.4 The above values assume that the concrete is properly placed and compacted in accordance with ENV 13670 or other relevant standards. However, this value can be change if a poor compaction takes place, and appropriate experimental results can be obtained. UNITS: % volume air /volume concrete LIMITS: 0.1-15%. This selection has an effect on strength and durability. DEFAULT VALUE: 1.2%
Entrained-air content, ENT:	The microscopic air bubbles intentionally incorporated in concrete during mixing, usually by use of a air-emtraining agent. It is estimated from the air-entraining dosage as follows (data from manufacturers): $ENT\ (\%) = 17.8\ (dosage, \%\ by\ mass\ cement)^{0.5}$ However, this value can be change, if you have more accurate results from the admixture provider. UNITS: % volume air /volume concrete LIMITS: 0-15%. This selection has an effect on strength and durability. DEFAULT VALUE: 0%
Air content, EAIR:	The total entrained and entrapped air content of concrete, when compacted in accordance with the procedure given in EN 12350-6. It

	shall be measured in accordance with EN 12350-7. Here is the sum of ETR + ENT. If you want to change it you have to change accordingly the ETR or ENT. UNITS: % volume air /volume concrete LIMITS: 0.1-15%. DEFAULT VALUE: 1.2%

2.8 Calculations

As the **basis** for concrete composition, the volume unit of **1 m^3** of the fresh concrete is selected. By assuming negligible expansion, this volume unit represents also hardened concrete. It must be emphasized that if *a material is added* to this unit, *then an equal volume of another component must be removed* in order to keep the same total volume and a common comparison basis. The following mass balance equation has to be fulfilled:

$$C/DC + TI/DTI + S/DS + F/DF + A/DA + W/DW + D/DD + EAIR/100 = 1 \qquad (2.8.1)$$

This Eq. (2.2.1) may be used to calculate the *aggregate content* if all other composition parameters are known:

$$A = (1 - C/DC - TI/DTI - S/DS - F/DF - W/DW - D/DD - EAIR/100)\, DA \qquad (2.8.2)$$

The *fresh concrete density*, DCON (kg/m^3), is given by:

$$d_{CON} = C + TI + S + F + A + W + D \qquad (2.8.3)$$

click on the "Calculate" button to estimate:

Aggregate content, A:	The total aggregate content in the concrete volume. We suppose that the aggregates are internal saturated by water and their surface is dry. UNITS: kg aggregate / m^3 of concrete

	DEFAULT VALUE: 1933 kg/m^3
Aggregate/cement ratio, A/C:	The ratio of the aggregate content to cement content by mass in the fresh concrete. UNITS: dimensionless DEFAULT VALUE: 6.44
Fresh concrete density, DCON:	The weight of fresh concrete per concrete volume. UNITS: kg/m^3 DEFAULT VALUE: 2383 kg/m^3

By obtaining the above concrete composition (mix design) you may:

- **accept this composition** and continue in the next tab "Physicochemical Characteristics" and further …
- otherwise, **you may change any input data** in order to correct the output results of this tab, **until final acceptance.**
- Always, you may change this composition when you want to improve a concrete property (strength, durability, cost).