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قسم التعليم الأساسي للعلوم و التكنولوجيا
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Practical Work Manual

Construction Materials Module

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CHAPTER 02:

LIST OF SYMBOLS AND ABBREVIATIONS

ρ : Density (kg/m^3)

γ : Unit weight (kN/m^3)

E : Elastic modulus or Young's modulus (Pa or MPa)

ν : Poisson’s ratio (dimensionless)

σ : Stress (Pa, MPa)

ε : Strain (dimensionless)

τ : Shear stress (Pa, MPa)

G : Shear modulus (Pa)

K : Bulk modulus or compressibility modulus (Pa)

μ : Friction coefficient (dimensionless)

η : Viscosity (Pa·s)

φ : Angle of internal friction (degrees)

C : Cohesion (Pa, kPa)

f'c : Compressive strength of concrete (MPa)

Ec : Elastic modulus of concrete (Pa or MPa)

ft : Tensile strength of concrete (MPa)

εc : Unit strain of concrete in compression

C25/30 : Concrete strength class (25 MPa for cylindrical compressive strength and 30 MPa for cubic compressive strength)

w/c : Water/cement ratio (dimensionless)

Fc : Applied force during compression test

dmax : Maximum aggregate size (mm)

CEM I : Cement type (pure Portland cement)

W : Mass of water (kg)

A : Mass of aggregates (kg)

fy : Yield strength of steel (MPa)

fu : Ultimate tensile strength of steel (MPa)

Es : Elastic modulus of steel (Pa or MPa)

εy : Unit strain at yield strength

A% : Elongation at fracture (%)

Re : Conventional yield strength (MPa)

Rm : Maximum tensile strength (MPa)

ρs : Density of steel (kg/m^3)

γd : Dry unit weight (kN/m^3)

γsat : Saturated unit weight (kN/m^3)

γw : Unit weight of water (kN/m^3)

Gs : Specific gravity of solid particles (dimensionless)

e : Void ratio (dimensionless)

Sr : Degree of saturation (%)

Dr : Relative density or degree of compaction (%)

k : Permeability coefficient (m/s)

c : Soil cohesion (Pa, kPa)

φ : Angle of internal friction (°)

Cu : Undrained cohesion (Pa or kPa)

Cc : Compression index

Cr : Recompression index

Dmax : Maximum aggregate size (mm)

Dmin : Minimum aggregate size (mm)

D10 : Effective size, particle diameter where 10% of the sample is finer (mm)

D30 : Particle diameter where 30% of the sample is finer (mm)

D60 : Particle diameter where 60% of the sample is finer (mm)

Cu : Coefficient of uniformity (D60/D10)

Cc : Coefficient of curvature or concavity (D302)/(D60×D10)(D30^2)/(D60 \times D10)(D302)/(D60×D10)

Gs : Specific gravity of aggregates (dimensionless)

n : Porosity (%)

ρs : Density of aggregates (kg/m^3)

C3S : Tricalcium silicate (main component of cement)

C2S : Dicalcium silicate

C3A : Tricalcium aluminate

C4AF : Tetracalcium aluminoferrite

Blaine fineness : Measurement of cement fineness (m^2/kg)

T : Initial and final setting time (minutes or hours)

Ca(OH)2 : Calcium hydroxide or lime

M : Bending moment (N·m or kN·m)

Q : Shear force (N or kN)

N : Axial force (N or kN)

V : Shear force (N or kN)

I : Moment of inertia (m^4)

S : Elastic section modulus (m^3)

fmax : Maximum stress in a section (Pa or MPa)

T : Torsional moment (N·m)

LE : Elastic limit (MPa)

LU : Ultimate limit (MPa)

Φb : Diameter of rebar (mm)

A_b : Cross-sectional area of a steel bar (mm^2)

εpl : Plastic strain

εel : Elastic strain

ψ : Creep coefficient (dimensionless)

FOREWORD

This practical workbook on "Construction Materials" has been designed for the training of second-year LMD students in the Engineering and Public Works stream. It has been written in a simplified manner to make it easier to understand, master and deepen knowledge of the physical and mechanical properties of construction materials, which is essential for the construction of buildings and structures in general, and for the application of building stability calculations. It covers the main tests that determine the essential physical and mechanical characteristics of materials. By carrying out all these tests, students will be able to characterize the physical and mechanical parameters of construction materials.

This handout is divided into three chapters according to the LMD second-year syllabus. The first chapter provides a general introduction to building materials, their classification and properties. The following chapter illustrates in detail the operating procedures for each manipulation, and their relevance to the construction industry in general. Finally, the 3rd chapter is devoted to a glossary highlighting all the definitions useful for carrying out and understanding these tests.

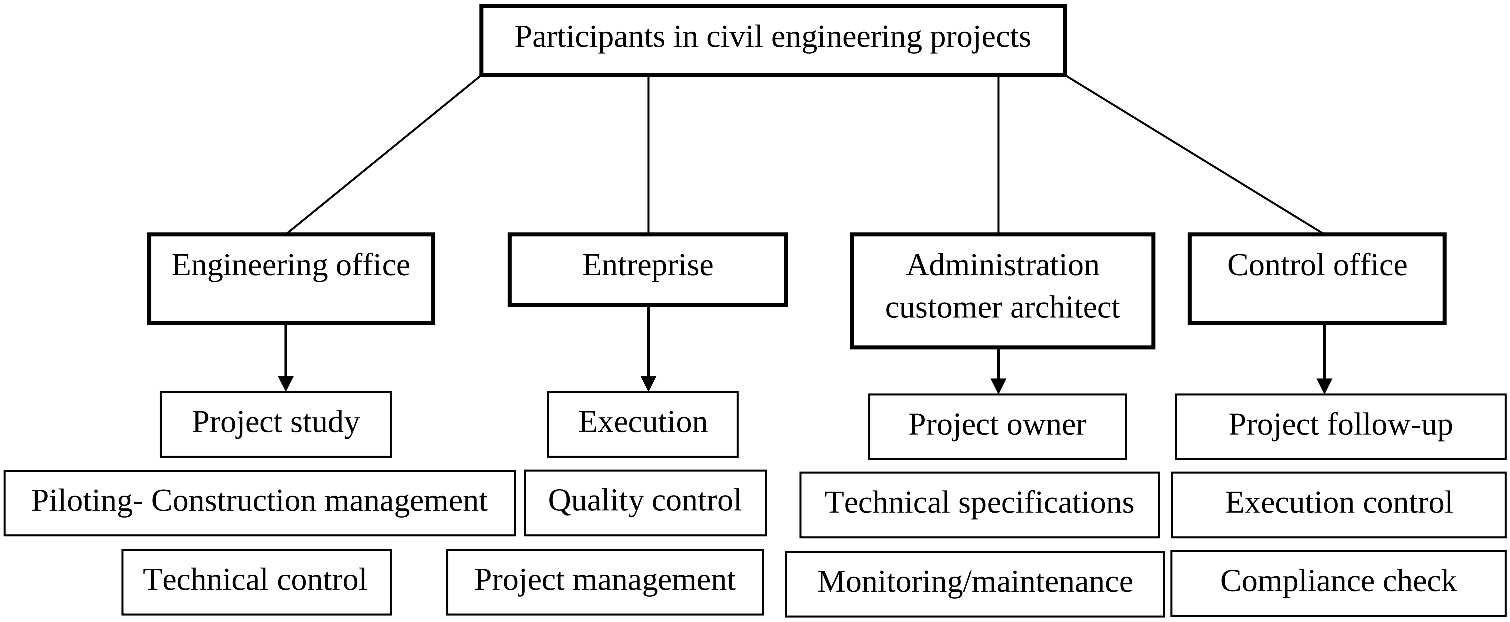
However, throughout this book, I've tried to give all due attention and care, from a pedagogical and technical point of view, in order to expose you, in a useful way, to the importance of Construction Materials.

Dr KHALFI Yassine

INTRODUCTION

The designer, builder and maintainer of a structure need to be fully aware of the physical, mechanical and hydric properties of the materials at their disposal. This will enable them to make the right choices to achieve rigid, efficient, economical and durable constructions.

As the diagram below illustrates, civil engineering professionals need to know about materials, whatever their field of activity.



Contractors and construction materials

Engineers must be able to

- Know the different materials available
- Determine material properties
- Select materials
- Check the quality of materials
- Interpret test or expert reports
- Know the application techniques
- Prescribe material specifications
- Check the durability of materials
- Diagnose sources of pathology in materials
- Develop new materials
- Improve certain material properties
- Supervise and train control personnel

Chapter 1. General Information on Construction Materials

1.1 Definitions

Construction materials include all materials used to build reinforced concrete or steel structures [1], as well as those widely used in public works (roads, bridges, airfields......etc.).

1.2 Classification of construction materials

There are three main types of classification [2]:

a) Scientific classification: In materials science, according to composition and structure, materials are classified as follows:

- Metals and alloys
- Polymers
- Ceramics

b) Basic materials and products :

- Base materials or raw materials (clays, stones, wood, limestone, metals).
- Materials produced and composites (cement (limestone+clay), alloys, concrete, ...)

c) Practical classification: In construction, materials are classified according to their field of use and their main properties (strength, compactness, etc.):

- Strength materials: These are materials that have the property of resisting stresses (own weight, overload, earthquake......): among the most frequently used materials are : Stone, terracotta, wood, concrete, metal, etc.

- Protective materials: These are materials with the property of coating and protecting the main construction materials against external actions, such as: Coatings, Paints, Bitumens, etc.

1.3. Materials properties

The main properties of materials [3] can be divided into several groups:

- Physical properties: which measure the behavior of materials to the action of temperature, humidity (density; density, porosity, absorption, permeability, shrinkage (swelling) etc.);
- Chemical properties: characterize the behavior of materials in a reactive environment. (chemical corrosion, acid attack, etc.).
- Mechanical properties: reflect the behavior of materials when deformed by forces. (compressive strength, tensile strength, flexural strength, torsional strength, etc.)

- Thermal properties: (expansion, fire resistance and behavior, etc.)

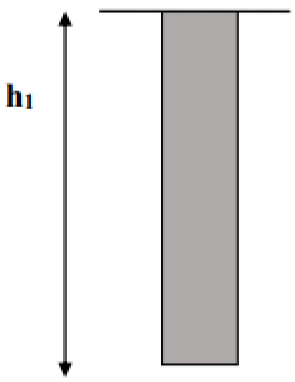
1.3.1. Physical properties

- Density

Density is the degree to which the mass of a body is filled by solid matter. It is calculated as the ratio of the density of the material to that of water at a temperature of 20°C. It is expressed without unit.

- Apparent density

This is the mass of a body per unit of apparent volume in its natural state (including voids and capillaries). It is expressed in (gr/cm^3; kg/m^3; T/m^3). The density of a material can be determined using the following formula:



$$\gamma_{ap} = \frac{M_s}{V_{ap}}$$

Figure 1.1. Measurement of apparent density

where :

M_s: mass of a dry body.

V_{ap}: apparent volume.

- Absolute density

This is the mass of a body per unit absolute volume of solid matter (volume of matter alone, not including voids and pores). It is expressed in (g/cm^3, kg/m^3 or T/m^3). Figure 1.1 explains the method for determining the absolute density of a material.

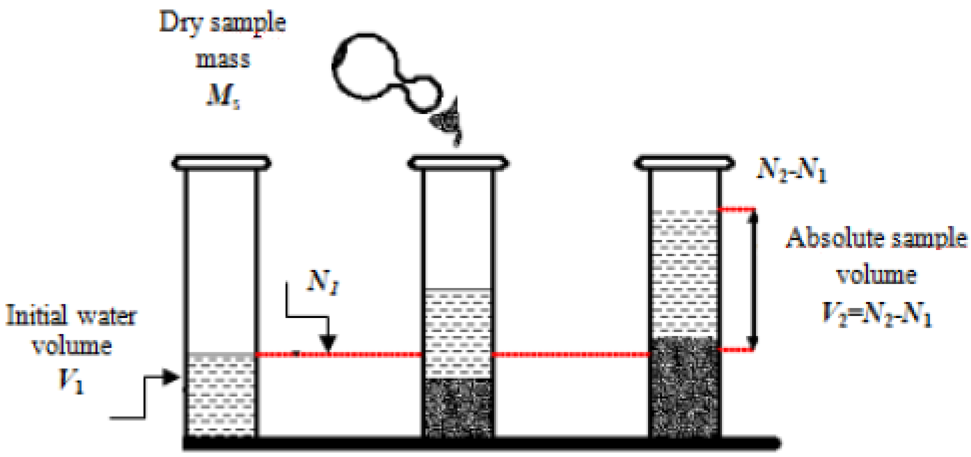


Figure 1.2. Measurement of absolute density [3].

$$\gamma_{ab} = \frac{M_s}{N_2 - N_1}$$

Example: Determine the bulk and absolute densities of 15/25 sand and gravel.

Sand

$$\gamma_{ap} = \frac{M_s}{V_{ap}} = \frac{1.54}{1} = 1.54 \text{ kg/l}$$

$$\gamma_{ab} = \frac{M_s}{N_2 - N_1} = \frac{2.55}{2-1} = 2.55 \text{ kg/l}$$

Gravel

$$\gamma_{ap} = \frac{M_s}{V_{ap}} = \frac{1.41}{1} = 1.41 \text{ kg/l}$$

$$\gamma_{ab} = \frac{M_s}{N_2 - N_1} = \frac{2.58}{2-1} = 2.58 \text{ kg/l}$$

- Porosity and compactness

Porosity is the ratio of the void volume to the total volume of the material.

$$P = (V_{\text{voids}}/V_{\text{solid}}) \times 100(\%)$$

Compactness is the ratio of solid volume to total material volume.

$$c = (V_{solid}/V_{total})100(\%)$$

Porosity and compactness are linked by the following relationship: $p + c = 1$

Porosity and compactness are often expressed as percentages (%). The sum of the two is then equal to 100%.

- Moisture

Moisture is an important property of building materials. It is the actual water content of a material contained in its pores. Moisture is generally denoted by W and expressed as a percentage (%). The moisture content of any material can be determined using the following formula:

$$W = (G_h - G_s / G_s) \times 100\%$$

where

G_s: dry mass of sample (after oven drying)

G_h: wet mass of sample.

The moisture content of materials depends on many factors, especially the atmosphere in which they are stored, wind, temperature and material porosity.

- Mass water absorption capacity "Ab"

Water absorption by immersion is the difference between the mass of a sample saturated in water and its dry mass. Water absorption is calculated as follows:

$$Ab = (M_{sat} - M_{sec} / M_{sec}) \times 100$$

With :

M_{sec}: dry mass of the sample after oven drying at 105°C.

M_{sat}: mass of sample saturated in water (after 24 hours).

The degree of absorption can be determined by the following formula:

$$H_p = (G_{ab} - G_s / G_s) \times 100\ \%$$

With :

G_{ab}: absorbent mass.

G_s: dry mass of sample.

V_0: apparent volume of material

1.3.2. Chemical properties

Chemical properties determine the chemical stability of a material, which is the ability of this material in service to resist the chemical action of acids or the action of atmospheric factors such as humidity, temperature, etc.

1.3.3. Mechanical properties

The mechanical properties of materials are characterized by their ability to withstand any external stress (compression, traction, bending, creep.........etc.). It is defined by the maximum breaking stress of a material under external loading (force, weight......). A distinction is made between :

- Compressive strength,
- Tensile strength (direct or bending).

Chapter 2. Operating Mode of Practical Work

2.1. Volumetric mass of cement, sand and gravel

The volumic mass is an essential parameter when designing a concrete mix, for example. In particular, this parameter makes it possible to determine the mass or volume of the different granular classes mixed together to obtain a concrete with specified characteristics. Density is one of the main properties of building materials. In this tutorial, we'll be learning about and calculating the density of materials using several methods.

A- Apparent volumic mass [4]

2.1.1. Definition of apparent volumetric mass

The Apparent volumic mass of a material is the volumic mass of a cubic meter of the material in a heap, including both permeable and impermeable voids in the particle as well as voids between particles.

The Apparent volumic mass of a material may have a different value depending on whether it is determined from compacted or non-compacted material.

The Apparent volumic mass of an aggregate depends on its shape and grain size, as well as the degree of compaction and moisture content. The apparent value is used to determine the volume proportions of the various concrete components. This method, however, is fraught with risks due to overrun. It is the mass of a body per unit of apparent volume, after oven drying at 105±5C°, noted γ_{ap} and expressed in (g/cm^3, kg/dm^3, t/m^3). $\gamma_T = M_T/V_T$ …..[kg/m^3]

2.1.1.1. Purpose of the test

Determine the apparent density of the material, i.e. its density in its natural state (in the presence of pores).

2.1.1.2. Materials used

- Technical balance accurate to 1 g.
- 1L container.
- Funnel.
- Small flat metal ruler.
- 0.08 mm sieve for cement.
- 3.5 mm sieve for sand.

Analysis materials: sand, gravel and cement.

2.1.1.3. Operating mode

For aggregates (gravel and sand) :

- Sieve the sand through the 3.5mm sieve.
- Weigh the 1L empty volume container (m_1).

- Fill the container through the funnel with a drop distance of 15cm.
- Flatten the top layer of the container using a ruler which is moved back and forth, and weigh the full container: i.e. m_2 (g) its mass.

For cement :

- Sieve the cement through the 0.08mm sieve.
- Fill the container through the funnel with a drop distance equal to or less than 5cm.
- Level off the material in the top layer of the container.
- The filled container is weighed, i.e. its mass is m_2 (g).

Note :

The operation is performed three times for the three materials.

Results obtained :

The density is given by : $\rho = (m_2-m_1)/V_0$

Table 2.1. Summary table of bulk density test results

Materials / Characteristics	Gravel			Sand			Cement		
m_1 (kg)									
m_2 (kg)									
m_2-m_1 (kg)									
V (m^3)									
ρ (kg/m^3)									

B- Absolute volumic mass [4]

2.1.2. Definition of absolute volumetric mass

The absolute density ρ_s is the mass per unit volume of the material making up the aggregate, without taking into account any voids that may exist within or between grains. ρs should not be confused with density ρ, which is the mass of material per unit volume, including both grains and voids. Densities are expressed in t/m^3, kg/dm^3 or g/cm^3.

2.1.2.1. Purpose of the test

The purpose of this test is to determine the mass of a granular fraction when, for example, preparing a concrete mix. In particular, this parameter makes it possible to determine the mass or volume of the different granular classes mixed to obtain a concrete with specified characteristics.

2.1.2.2. Materials used

- Technical balance accurate to 1g.
- Graduated test tube.

- Funnel.
- Pycnometer.
- 0.08 mm sieve for cement.
- 3.5 mm sieve for sand.

Analysis materials: sand, gravel and cement.

2.1.2.3. Operating mode (Graduated-tube method)

This method is very simple and fast. It uses standard laboratory equipment. However, its accuracy is poor.

1. Fill a graduated cylinder with a volume V_1 of water.

2. Weigh a dry sample M of aggregate (approx. 300g) and place in the test tube, taking care to eliminate any air bubbles.

3. The liquid rises in the test tube. Read the new volume V_2.

The density is then given by: $\gamma = M/(V_2 - V_1)$

For best results, use a 500 cm3 glass e-tube. V_1 and V_2 levels should be read at the bottom of the meniscus formed by the water. Water has a tendency to rise to a height of 1 to 2 mm at the edges of the test tube, which of course distorts the volume reading if the reading is taken at the top of the meniscus.

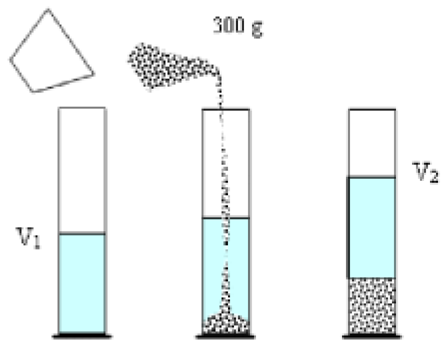


Figure 2.1. Graduated cylinder method [1]

Results obtained :

Table 2.2. Summary table of absolute density test results

Materials / Characteristics	Gravel			Sand		
V_1 (cm^3)						
V_2 (cm^3)						
V_2-V_1 (kg)						
M (kg)						
γ (kg/m^3)						

Cement: The pycnometer method is used:

The principle consists in measuring the displacement of the level of the liquid contained in a narrow-necked container when the powder is introduced, the absolute volume of which is sought. The method requires a precise balance and a liquid which is inert with respect to the powder; for cement, petroleum or benzene is used.

1-Pour the benzene into the pycnometer (densimeter) up to level A (corresponding to volume V_1 (cm^3) of benzene at temperature 20°c ± 2°c ;

2- Weigh 50 g of cement (M_0).

3- Pour the cement into the densimeter little by little until the benzene level reaches any line B.

4- Fill the pycnometer with volume V_2.

The absolute density of cement is given by the following relationship:

$$\gamma = M_0/[V_p-(V_1+V_2)]$$

M_0 : cement mass ;
V_p: Volume of pycnometer;
V_1 : Initial volume of Benzene;
V_2: Volume to complete the filling of the pycnometer;

The results are shown in the table below

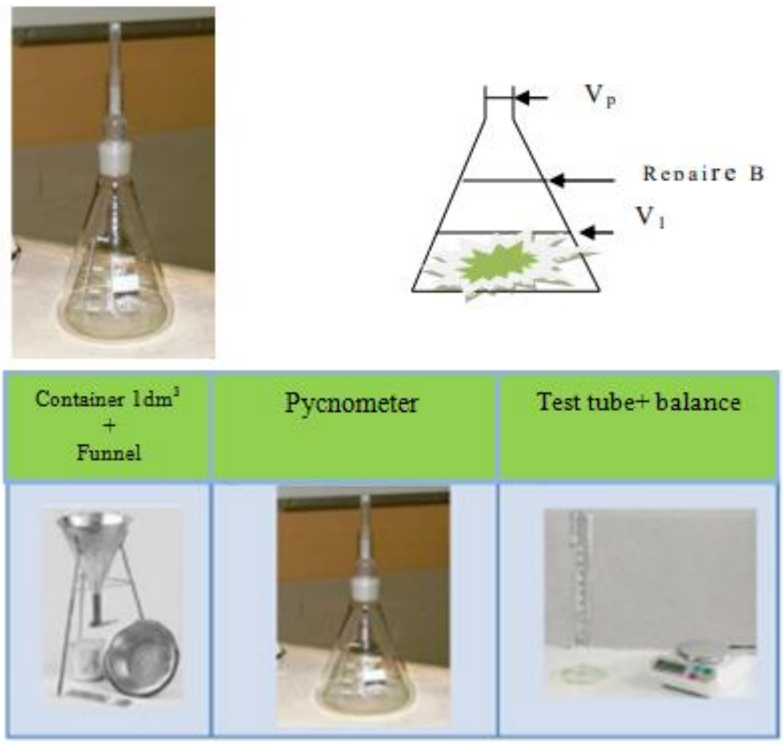


Figure 2.2. Pycnometer method [1]

Table summarizing results for the three trials.

Table 2.3. Summary table of absolute density test results by the pycnometer method

	Trials N°1	**Trials N°2**	**Trials N°3**
M_0 (kg)			
V_p (kg)			
V_1 (cm^3)			
V_2 (cm^3)			
V_1+V_2(cm^3)			
V_p-(V_1+V_2)			
γ (g/cm^3)			

2.2. Grading curves for sand and gravel [5]

Granulometric analysis is the process of studying the distribution of the different grains in a sample, according to their characteristics (weight, size, etc.). Usually, granulometric analysis provides the proportions of grains of different diameters; this analysis can be carried out either by sieving or by sedimentation in water, in application of Stokes' law.

Depending on the size and number of grains making up an aggregate, it is referred to as fines, sand, gravel or pebble. However, for a given aggregate, not all its constituent grains are of the same size. This is why we classify the grains on a series of interlocking sieves. The mesh size of the sieves decreases from top to bottom. The aggregate is placed on the highest sieve and, by vibration, the grains are distributed among the different sieves according to their size.

2.2.1. Definition

***a) Gravel* :** Gravel is produced by the weathering and erosion of rocks. Strongly flowing streams (see Rivers) and glaciers can transport it over long distances before it settles. Fragments transported by water are worn and rounded, while those transported by ice have sharp, angular edges. On the other hand, gravel transported by rivers varies less in size than that transported by glaciers. Gravel is also found on beaches subjected to powerful wave action. Beach gravel is very round and smooth.

***b) Sand* :** Sand results from the erosion and alteration of quartz-rich rock by physical processes (wind, flowing water) or chemical processes (dissolving action of water). The sand grains that form are generally large and angular, difficult to transport by wind and water. The largest grains of sand are found along rivers, seashores and desert regions. In fluvial environments, the grains are little worn and therefore remain large and angular. In continental environments, wind and water wear away sand grains, modifying their shape (or morphoscopy) over geological time: worn sand grains become blunt and shiny (coastal environments), or round and matte (aeolian environments). As they become rounder, the grains become smaller. Sands can also consolidate and cement later on, giving rise to sandstones (quartz sandstones, calcareous sandstones).

***c) Granularity* :** Grain size distribution (state). Granulometry: Study of granularity.

d) Sieve: Part of the sample passed through the mesh of a sieve.

e) Refusal: Part of the sample which has not passed through the sieve.

f) Cumulative refusal: This is the sum of all refusals, that of the sieve itself plus all refusals from larger mesh sieves. It can be expressed in grams or in % of cumulative rejects.

2.2.2. Purpose of the test

- Determine the size and percentage by weight of the different aggregate forms making up the samples.

- Draw grading curve.

- Determine fineness modulus.

2.2.3. Test principle

The test consists in classifying the various grains making up the sample using a series of sieves, nested one on top of the other, with openings decreasing in size from top to bottom. The material under study is placed at the top of the sieves, and the grain classifications are obtained by vibrating the sieve column for five minutes for sand and seven minutes for gravel. The various rejects from each sieve are then taken and weighed.

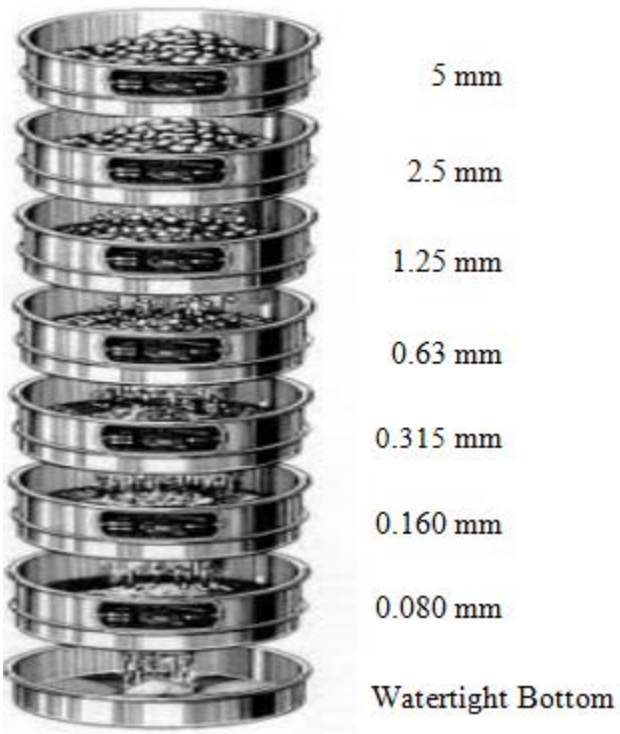
2.2.4. Materials used

- A series of sieves with a square metal mesh between d and D, with a bottom and a cover. Sieve sizes are 0.063 mm; 0.125 mm; 0.250 mm; 0.500 mm; 1 mm; 2 mm; 4 mm; 8 mm; 16 mm; 31.5 mm; 63 mm.

- ± 0.1% precision balance

- Ventilated oven

- Sieves with square openings of standardized dimensions are made either from wire mesh or by drilling holes in sheet metal. Sieves, with round holes drilled in sheet metal, are no longer used. For test work with reproducible results, we recommend the use of an electric sieving machine that imparts a horizontal vibratory motion, as well as vertical shaking, to the sieve column.



Sieve Column

Vibratory Sieve Shaker

Sieves

Figure 2.3. Series of wire mesh sieves [6]

Materials used :

1- Sand : 0/5 mm.
2- Gravel : fractions 3/8 and 8/16.

Sample preparation

The quantity to be used must meet a number of requirements:

- The quantity must be large enough for the sample to be representative.

- It must be small enough to ensure that the test duration is acceptable and that the sieves are not saturated and therefore inoperative.

In practice, the mass to be used is as follows: M = 0.2 D where M is the sample mass in Kg and D is the diameter of the largest granule in mm.

2.2.5. Description of the test

- The material is oven-dried at a maximum temperature of 105°C.

- Place the sieves one on top of the other, in an order such that the openings progress from the bottom of the column to the top.

- The bottom of the column is fitted with a watertight bottom to collect the fillers.

- At the top, a cover prevents any loss of material.

The material is poured into the top of the sieve column, which is vibrated by the electric sifter. The sieving time varies according to the type of machine used, but also depends on the material load present on the sieve and its opening.

Sieving is considered complete when the rejects do not vary by more than 1% between two sequences of sieve shaker vibrations.

The reject from the sieve with the largest mesh size is weighed. Let R1 be the mass of this reject. The reject from the next-lowest sieve is weighed with the previous reject. R2 is the mass of the second reject.

This operation is continued for all the sieves in descending order of opening. This gives the mass of cumulative rejects Rn at the different levels of the sieve column. The sieves on the bottom of the column are also weighed.

The sum of the cumulative rejects measured on the various sieves and the sieves on the bottom (fillers) must coincide with the weight of the sample introduced at the top of the column.

Results:

The results will be presented in tabular form and translated into a grading curve.

A – Sand :

Table 2.4. Summary table of sand sieve analysis results

Sieve opening in mm	Refusal in grams	Sieve size in gram	Cumulative sieves (%)
5			
2.5			
1.250			
0.630			
0.315			
0.160			
Bottom			
Total			

B – Gravel :

Table 2.5. Summary table of gravel sieve analysis results

Sieve opening in mm	Refusal in grams	Sieve size in gram	Cumulative sieves (%)
16			
10			
8			
5			
3			
Bottom			
Total			

- Determine the fineness modulus of the sand;

- Draw the grading curve for the sand studied;

- Plot the grading curve for the gravel fractions studied.

$$M_f = \sum \frac{\text{of cumulative refusals (\%)}\left(0.16; 0.315; 0.63; 1.25; 2.5; 5mm\right)}{100}$$

Plotting the grading curve:

Simply plot the various cumulative sieve percentages on a semi-logarithmic sheet:

- Abscissa: mesh dimensions, logarithmic scale
- ordinate: percentages on an arithmetic scale.
- The curve must be drawn continuously.

Example:

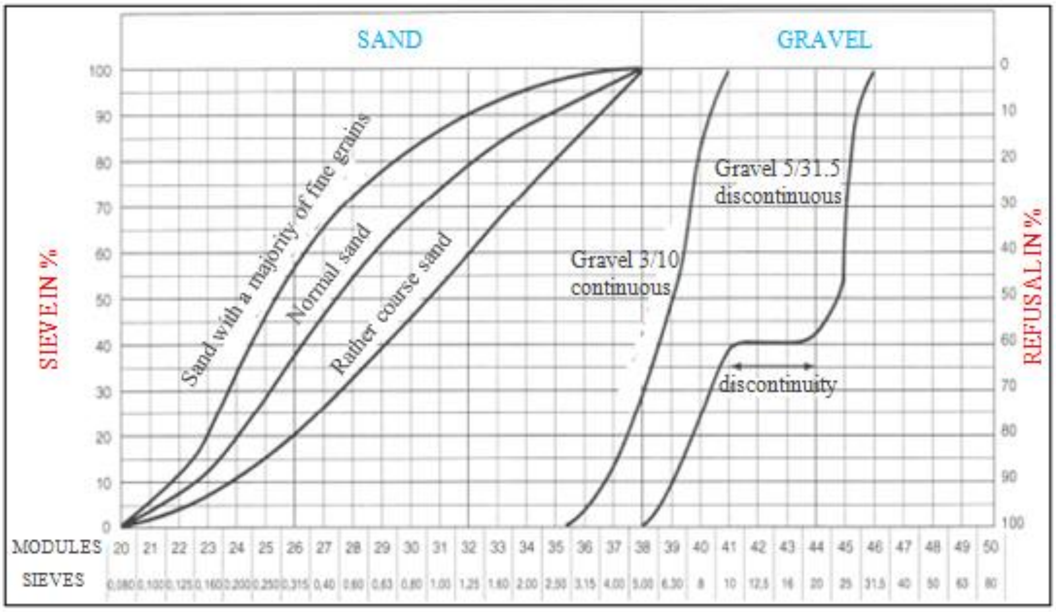


Figure 2.4. French specification range for sand and gravel for hydraulic concrete

Comments and conclusions:

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2.3. Water content and sand expansion [7]

A- Sand expansion

2.3.1. Definition

The overrun coefficient is the ratio between the wet sand height (H H) and its dry height (H S). This coefficient varies as a function of moisture %, and the apparent volume of a sand depends on its compactness, porosity and water content.

NB: the overrun coefficient reaches its maximum between 3% and 7% moisture content.

2.3.1.1. Purpose of the test

Aggregates delivered to the job site are rarely dry, but often contain a percentage of moisture (moisture content), which needs to be known to determine the quantity of mixing water. In addition, the volume of sand varies according to its moisture content, so it's essential to know this variation when dosing by volume.

2.3.1.2. Equipment used

* Technical balance at 0.01g

* Oven at 1 -105°c - 110°c

* Graduated glass test tube.

* Containers

* Mason's trowel

* Sieve N° 5mm

Analysis material :

"Wadi sand, quarry crushed sand

2.3.1.3. Operating mode

- Sieve the dry sand through the N° 5 mm sieve.

- Weigh a quantity of perfectly dry sand corresponding to 500g(Ms).

- Pour the sand into a 1000 cm3 graduated cylinder and measure its height (Hs).

- Pour the sand into a container and add the mass of water corresponding to 1% of the mass of dry sand. Once the mixture has homogenized, pour it into the glass measuring cylinder and measure the height (H1) of the wet material.

- Carry out the same procedure for a sand moisture content of 1%, 2%, 3%, 4%, 7%, 9%, 11%, 13% and 15%, noting the results obtained for the different dosages.

- Draw the curve showing the variation of the overrun coefficient as a function of the % moisture content of the sand.

Figure 2.5. Sand bulking test [2]

Results:

The results obtained are shown in the following table:

H_s= 330 ml, Dry sand mass = 500g

H_s: height of sand in dry state.

H_i: height of wet sand

Table 2.6. Summary table of sand bulking test results

I (%)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
H_i										
C_f										
V (%)										

$C_f = H_i / H_s$ $V (\%) = [(H_i - H_s)/H_s] \times 100\%$

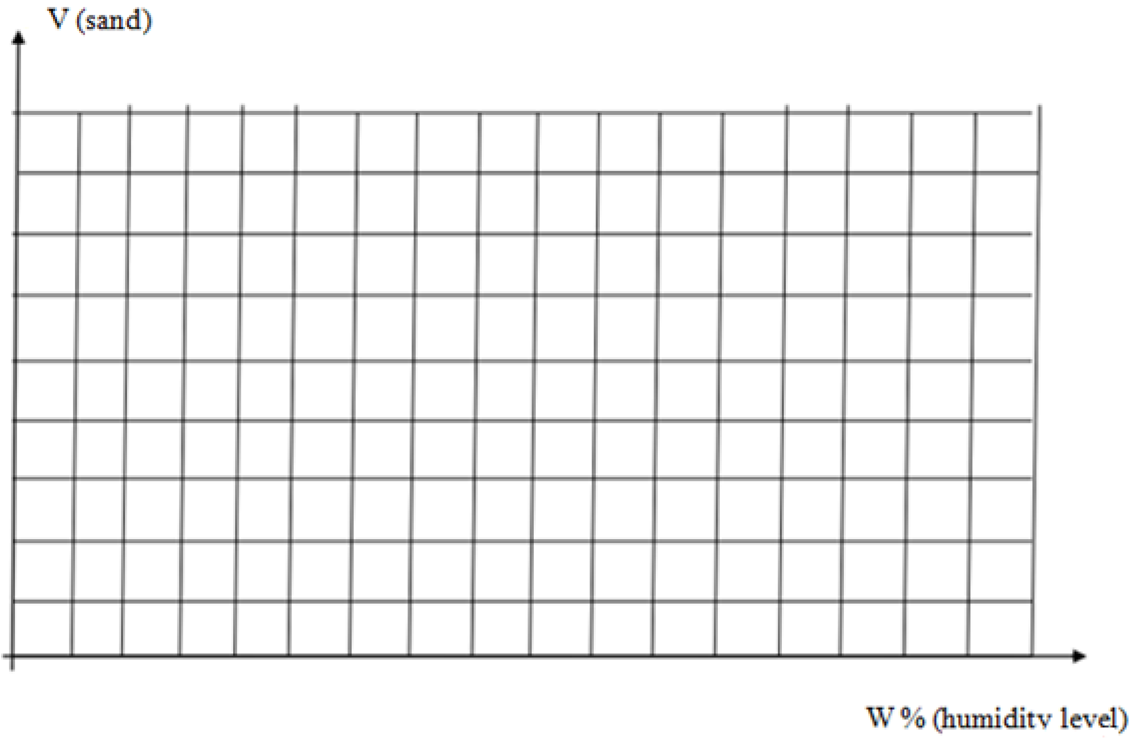

Figure 2.6. Variation curve of the bulking factor depending on sand moisture content (%)

Comments and conclusions:

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B- Water content [7]

2.3.2. Definition

The water content of a material is the ratio of the weight of water contained in that material to the weight of the same dry material. Water content can also be defined as the weight of water *w* contained per unit weight of dry material.

$$w = E/P_s = [(P_h - P_s)/P_s]\text{x}100\%$$

E: weight of water in the material;
P_h : weight of wet material;
P_s: weight of dry material.

2.3.2.1. Purpose of the test

The aggregates used to make concrete generally contain a certain amount of water, which varies according to weather conditions. The mixing water actually used is therefore equal to the theoretical amount of water minus the water contained in the aggregates. It is therefore necessary to have the means to measure the amount of water in the aggregates.

Figure 2.7. Water content test

2.3.2.2. Test principle

Oven drying.

- - Place a specified quantity of moist test material in a pre-numbered and tared petri dish,
- - Weigh the batch and place it in an oven for 24 hours at a temperature of 105°Celsius,
- - After drying, weigh the sample a second time,
- Deduct the wet and dry masses of the sample and calculate its water content (w).

2.4. Porosity of sand and gravel [8]

2.4.1. Definition

Porosity is the set of voids (pores) in a solid material, filled by fluids (liquid or gas). It is a physical quantity that conditions the flow and retention capacities of a substrate. Porosity is generally calculated as the ratio of void volume to material volume

P= Void volume / Total volume

2.4.2. Test principle

The test consists in saturating the open porosity of the grains making up the granular material with water. The material is immersed in an aqueous solution to saturate it. When cold, the test takes time.

To accelerate the process, the temperature of the water is gradually increased. The thermal gradient causes the air in the pores to expand over time. This gas leaves the pores more easily, to be replaced by liquid water. Water thus saturates all the voids more quickly.

2.4.3. Operating mode

- Prepare a 1kg dry sample, i.e. M_0,

- Place the sample in cold water and boil for 2 hours, to expel air from the pores and saturate them with water,

- Remove the sample from the water and wipe each grain with a cloth, weigh the new mass, i.e. M_1,

Analysis materials :

Dune sand, quarry sand and gravel.

Calculate porosity :

$$P(\%) = \frac{M_1 - M_0}{V} \quad \text{With} \quad V = \frac{M_0}{\rho_{ab}} \rightarrow P(\%) = \frac{M_1 - M_0}{M_0} x \rho_{ab} X100$$

Porosity is also calculated from test measurements of apparent and absolute density.

$$P(\%) = \frac{\text{Void volume}}{\text{Total volume}} \rightarrow P(\%) = \frac{V_t - V_{S.V}}{V_t} = \frac{\frac{V_t}{M} - \frac{V_{S.V}}{M}}{\frac{V_t}{M}} \times 100 = \frac{\frac{1}{\rho_{ap}} - \frac{1}{\rho_{ab}}}{\frac{1}{\rho_{ap}}} \times 100$$

$$\rightarrow P(\%) = (\frac{1}{\rho_{ap}} - \frac{1}{\rho_{ab}})\rho_{ap} x100 = (1 - \frac{\rho_{ap}}{\rho_{ab}})x100 ,$$

$$\text{So} \quad P(\%) = \frac{\rho_{ab} - \rho_{ap}}{\rho_{ab}} x100$$

Results :

Table 2.7. Summary table of porosity test results for gravel and sand

	Trials N°1		**Trials N°2**		**Trials N°3**	
	ρ_{app}	ρ_{ab}	ρ_{app}	ρ_{ab}	ρ_{app}	ρ_{ab}
Gravel						
Dune sand						
Quarry sand						
Porosity gravel						
Porosity quarry sand						
Porosity dune sand						

Average porosity (%) gravel: P_G (%)=........

Average porosity (%) quarry sand: P_{QS} (%)=........

Average porosity (%) dune sand: P_{DS} (%)=........

2.5. Gravel volumetric coefficient [8]

A- Aggregate volumetric coefficient

2.5.1. Definition

The volumetric coefficient is a numerical quantity used to characterize an aggregate. The CV of a grain is the ratio of the volume V of the grain to the smallest volume of the sphere circumscribing the grain with diameter d.

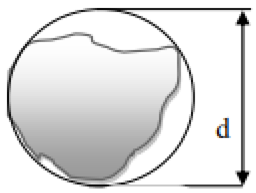
Aggregate shape :

The shape of an aggregate is defined by three geometric quantities:

- length L, the maximum distance between two parallel planes tangent to the ends of the aggregate.

- Thickness E, minimum distance between two parallel planes tangent to the aggregate.

- Size G, dimension of the square mail of the sieve through which the aggregate passes.



$$C_{Vi} = \frac{V_i}{\frac{\pi.d_i^3}{6}} , \quad C_V = \frac{\sum V_i}{\sum \frac{\pi.d_i}{6}}$$

$$V_i = \frac{\pi.d_i^3}{6}$$

Figure 2.8. Shape of an aggregate

Analysis materials:

Crushed limestone gravel, rolled gravel with diameters greater than 5mm.

2.5.1.1. Operating mode

- Take 250g of a sample with diameters greater than 5mm.
- Present each grain in the notches of the gauge and note the volumes of the circumscribed spheres found, i.e. V_1, the smallest volume of the circumscribed spheres.
- Place the grains in the test tube containing water and note the volume V_2 at the end.
- Calculate the volumetric coefficient of each grain C_{vi}, then the volumetric coefficient of all grains C_v.

B- Aggregate flattening coefficient

2.5.2. Definition

The production of cement concrete, as well as the manufacture of pavement bodies and wearing courses, requires the use of only aggregates with a fairly compact shape, to the exclusion of flat aggregates. This is because flat aggregates do not produce very compact concrete, and cannot be used in road construction because they lead to slippery wearing courses.

Determining the flattening coefficient is one of the tests used to characterize the more or less massive shape of aggregates.

2.5.2.1. Purpose of the test

Measuring the flattening coefficient (FC) characterizes the shape of aggregates.

The CA is obtained by performing a double dry particle size analysis, using successively, and for the same aggregate sample :

- A series of standardized square-mesh sieves,

- A series of parallel-slotted sieves of standardized widths.

The flatter the gravel, the less easily it can be placed in roads or concrete, and the more brittle it is. It is therefore important to control the flattening coefficient of each grading.

Under the same conditions $L \leq G \leq E$, we can also determine :

- The Elongation Index $\beta \leq G/L \leq 1$

- The Flattening Index $\alpha \leq E/L \leq 1$

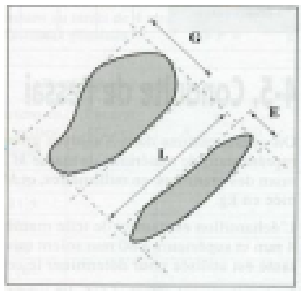


Figure 2.9. Dimensions of an aggregate.

Aggregate shape influences :

- Ease of placing and concrete compaction.

- The compactness of the mix, i.e. the volume of voids to be filled by the cement paste.

Grain surface finish influences :

- Mix compactness.

- Aggregate adhesion to cement paste.

The better the shape, the closer it is to a sphere or cube:

Table 2.8. Table of aggregate shapes

Cubes, spheres	Three roughly equal dimensions (good compactness)
Platelets	One dimension much smaller than the other two (poor compactness)
Needles	One dimension much larger than the others (very poor compactness)

Figure 2.10. Slotted sieves for various classes [9]

Table 2.9. Slotted sieves for various granular classes

Granular class d_i / D_i (mm)	63/80	50/63	40/50	31,5/40	25/31,5
Slot width	40	31,5	25	20	16
Granular class d_i / D_i (mm)	20/25	16/20	12,5/16	10/12,5	8/10
Slot width	12,5	10	8	6,3	5
Granular class d_i / D_i (mm)	6,3/8	5/6,3	4/5	—	—
Slot width	4	3,15	2,5	—	—

2.5.2.2. Conducting the trial

1- Sieve the test sample of dry mass m0 on the sieves specified according to granular class.

2- Weigh separately all the grains of each elementary aggregate di/Di, ranging from 4 mm to 80 mm, i.e. $m_1=\Sigma Ri$

3- Pass all the grains of each elementary aggregate di/Di, between 4 mm and 80 mm, separately over the corresponding slotted grid and weigh the passing separately from each slotted grid i.e. $m_2 = \Sigma\, m_i$

4- Eliminate all grains passing through the 4 mm sieve and retained on the 80 mm sieve and weigh.

The flattening coefficient of the sample is :

$$A = \frac{m_2}{m_1} x100$$

$$\frac{m_0 - (\sum R_i + \sum (masse.\acute{e}\lim in\acute{e}es))}{m_0} x100 = ... \leq 1\%$$

2.6. Sand equivalent [11]

The sand grains, of the same origin as the aggregates, have a diameter of less than 3 mm. This sedimentary rock must be clean and free of clay dust.

There are cement concretes or mortars, containing only sand, cement and water.

It is mainly used in masonry to bind bricks or breeze-blocks, and to render walls.

Sand is an important constituent of most soils, and is abundant as a surface deposit along rivers, lake and sea shores, and in arid regions.

Different types of sand are used in glassmaking, in foundries to make molds, and in the manufacture of ceramics, plasters and cements.

2.6.1. Sand equivalent

Aggregate cleanliness can be assessed in a number of different ways, such as the methylene blue test, the 10% fines sand equivalent test, etc., but in this practical work, we're only going to talk about the sand equivalent test. Again, this is a standardized experiment, the results of which each quarry must be able to supply for its own sands. It is used to determine the percentage of fines in sand.

A washing solution (sold ready-to-use) is placed in a specially designed test tube with two marks, up to the first mark. Add a quantity of dry sand and wait 10 minutes. The test tube is then shaken (at a rate of 90 strokes in 1 minute, with 30 cm beats) and filled with washing solution up to the second mark. After 20 minutes, the sand has settled to the bottom and the fines form a layer of "mud" on top. We then measure the total height (sand + fines) and the height of the clean sand, and calculate the percentage of the latter.

This percentage is called the sand equivalent (S.E.). If the height of the clean sand is measured with a ruler, this is called E.S.V. (E.S. at sight). If you use a piston (more precise), you call it E.S.P. (E.S. at the Piston).

2.6.2. Purpose of the test

The purpose of this test is to measure the cleanliness of sand used in concrete composition. The test consists in separating the fine particles contained in the soil from the coarser sandy elements. A standardized procedure is used to define a sand equivalent coefficient that quantifies the cleanliness of the sand.

2.6.3. Test principle

The test is carried out on the 0/3 mm fraction of the sand to be studied. The sample is washed according to a standardized process and left to stand. After 20 minutes, the following is measured:

- height h_1: clean sand + fine elements,

- height h_2: clean sand only.

The sand equivalent is deduced from the relationship below. The sand equivalent test - is used to determine the degree of cleanliness of the sand:

$$ES = (h_1/h_2)x100$$

Depending on whether the height h_2 is measured visually or using a piston, the ESV (visual sand equivalent) or ESP is determined.

Figure 2.11. Sand equivalent test [3]

2.6.4. Materials used

- 3.16 mm mesh sieve with bottom
- Spatula
- Precision balance
- Stopwatch
- 500mm ruler
- Test tubes
- Tared piston
- Wide-mouth funnel
- Stirring machine
- Washing solution

Analytical materials:

Dune sand, quarry crushed sand.

a- Preparation of sand samples :

- Pass the sample through a 3.16 mm sieve.

- Allow to dry to 1% moisture content.

b- Washing solution preparation :

-111g calcium chloride.

480g pharmaceutical-grade glycerine.

-120.13g of 4 % by volume aqueous solution of pharmaceutical-grade formaldehyde.

-Distilled water is added.

2.6.5. Operating mode

- Pour the solution into the tube (Plexiglas test tube) up to the bottom line.
- Pour a quantity of sand (120g) into the tube for 10 minutes to absorb the water.
- Close the test tube and stir for 30 seconds.
- Leave for 20 minutes without vibration.
- Read H_1 and H_2 heights from the ruler H'_2 from the piston.
- Repeat the same experiment another time.

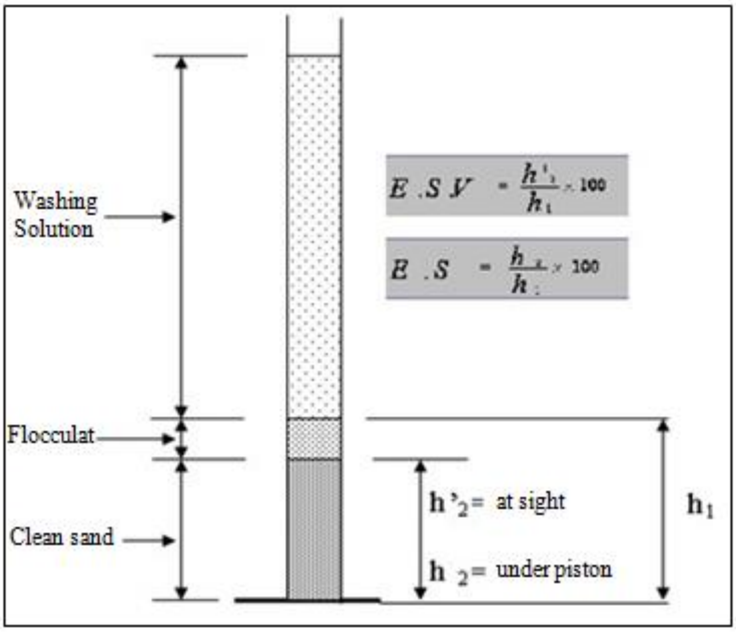


Figure 2.12. Sand equivalent test at sight and under piston.

Results :

Test results are reported in the table below.

Visual sand equivalent E.S.V: E.S.V = (H_2/H_1) x100%.

H2: height of clean sand determined visually.

Piston sand equivalent E.S.P: E.S.P = (H'_2 /H_1) x100%.

H'_2: height of clean sand determined by piston.

H_1: height of clean sand + imputed height.

Table 2.10. Summary table of sand equivalent test results

Measures	**H_1(cm)**	**H_2(cm)**	**H'_2(cm)**	**E_{sv}(%)**	**E_{sp}(%)**
Trials N°1					
Trials N°2					
Trials N°3					

Sand classification:

Based on the results obtained, we classify sand as follows:

Table 2.11. Sand classification and quality

E_{sv}visual (%)	**E_s piston (%)**	**Sand quality**
$E_{sv} < 65$	$E_s < 60$	Sable argileux : à ne pas utiliser
$65 \leq E_{sv} < 75$	$60 \leq E_s < 70$	Slightly clayey sand: suitable for common concrete with a high risk of shrinkage
$75 \leq E_{sv} < 85$	$70 \leq E_s < 80$	Clean sand: suitable for high-quality concrete.
$E_{sv} \geq 85$	$E_s \geq 80$	Very clean sand: almost total absence of clay fines

Comments and conclusions:

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2.7. Cement consistency and setting test [12]

A- Cement paste setting test

Once the anhydrous cement has been mixed with water, hydration begins, and the properties of the resulting paste change over time. As long as hydration is not too advanced, the paste remains more or less malleable or even plastic, but after a certain time, the material becomes increasingly difficult to work and its temperature rises: it sets and resembles a solid.

2.7.1. Aim of the trial

It is essential to know when cement pastes (hydraulic binders) start to set and when they finish setting, so as to be able to assess the time available for the correct placement of the mortars and concretes that will subsequently be made. Tests are carried out using the Vicat needle, which gives two practical reference points: the start of setting and the end of setting.

2.7.1.1. Test principle

The test consists of monitoring the consistency of a paste of standardized consistency; the apparatus used is a Vicat device fitted with a 1.13 mm diameter needle. When, under the effect of a 300 g load, the needle stops at a distance d from the bottom of the mold such that d= 4mm ± 1 mm, we say that the start of setting has been reached. This moment, measured from the start of mixing, is known as the "setting start time", while the "setting end time" is the time at which the needle is no more than 0.5 mm from the bottom of the mold.

2.7.1.2. Materials required

- Air-conditioned room: The test must be carried out in a room with a temperature of 20° C± 1° C and a relative humidity of over 90%. In the absence of such relative humidity, the test sample may be stored in water maintained at 20° C± 1° C between two measurements.

- Standardized mixer: with a 5-liter tank capacity and a mixing paddle capable of rotating at 2 speeds (slow 140 rpm and fast 285 rpm).

- Vicat device (named after the French engineer). The device consists of a 40 mm-high truncated-cone mold and a sliding rod fitted with a 1.13 mm-diameter needle at the end.

- Balance accurate to 0.1 g.

- Stopwatch accurate to 0.1 s.

2.7.1.3. Conducting the trial

The test procedure is set out in standard EN 196 -3, and involves making a paste of standardized consistency:

2 kg of cement, a pure paste with a W/C ratio of 0.26. This will enable 5 molds to be prepared. To speed up the process, calcium chloride ($CaCl2$) is dissolved in the batch water,

taking 2% of the water weight calculated for the batch as the CaCl2 weight. Pour the water with the dissolved setting gas pedal into the mixer tank containing the cement, and start the two stopwatches (one for the batch, the other for the time base for handling).

Operation	Introducing cement	Introducing water	Get started	Scraping the bowl	Get started
Operation time		5 to 10 seconds	90 seconds	15 seconds	90 seconds
Mixer condition	Stopped		Slow speed	Stopped	Slow speed

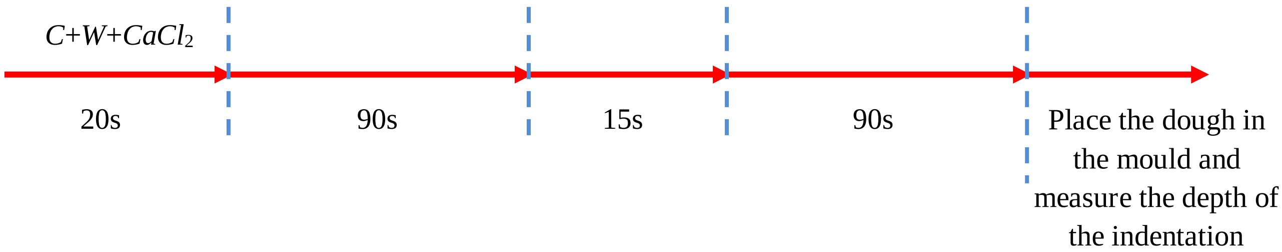


Figure 2.13. Setting evolution of a cement paste over time.

The dough is then quickly poured into the truncated cone-shaped mold placed on a glass plate, without excessive settling or vibration. Excess paste is removed by a back-and-forth movement with a trowel held perpendicular to the upper surface of the mold. The whole assembly is then placed on the Vicat machine platen.

Four minutes after the start of mixing, the needle is brought to the surface of the sample and released without momentum (no speed). The needle then sinks into the paste. When it has stopped (or after waiting 30 sec.), measure the distance d between the tip of the needle and the base plate. Repeat the operation at suitably spaced intervals (~10 -15mn) until d=4mm ± 1mm. This time, measured to the nearest 5 min, is the setting time for the cement under study.

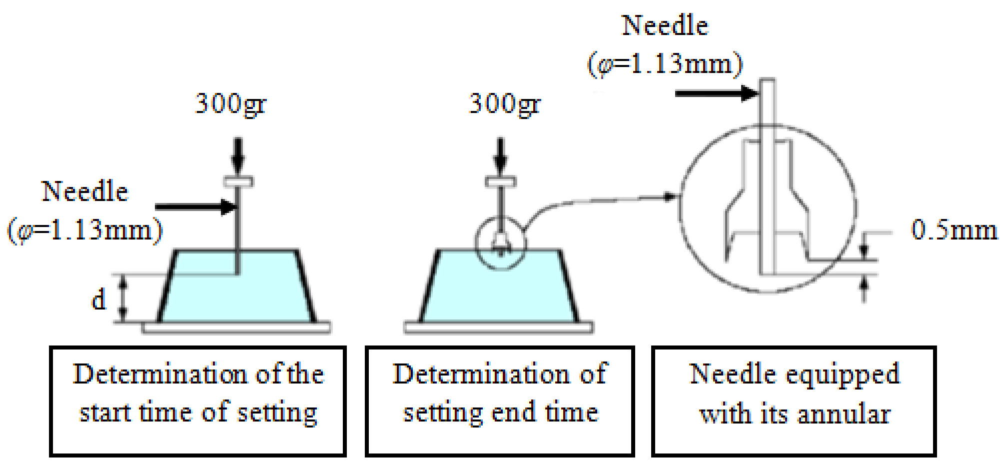


Figure 2.14. Vicat apparatus with removable needle [13].

B- Cement consistency test

2.7.2. Aim of the trial

The consistency of the dough characterizes its fluidity. There are two types of test to assess this consistency.

1. The consistency test carried out with the Vicat apparatus in accordance with standard 196 -3.

2. The cone flow test, in accordance with standard NF P-18-358. The consistency of cement paste is a characteristic that evolves over time. To be able to study the evolution of consistency as a function of different parameters, it is necessary to be able to start from a consistency that is the same for all the pastes studied.

The aim of this test is to define such a consistency, known as "standardized consistency".

2.7.2.1. Test principle

Consistency is assessed here by measuring the penetration of a cylindrical rod into the dough under constant load. The greater the penetration, the more fluid the consistency. Consistency assessed in this way is referred to as "Vicat consistency".

2.7.2.2. Materials required

- a mixer with a 5-liter capacity tank and a mixing paddle capable of rotating at 2 speeds (slow 140 rpm and fast 285 rpm).

- a Vicat device consisting of a 40 mm-high truncated-cone mold and a sliding rod fitted at the end with a 10 mm-diameter probe. The sliding part has a total mass of 700 g (including the removable probe).

- a balance capable of weighing to within 1 g.

- a stopwatch accurate to 1s.

2.7.2.3. Conducting the trial

500 g of cement are weighed and introduced into the mixer tank. The chosen quantity of water is added to the cement in 5 to 10 seconds.

Immediately start the mixer at low speed for 90 sec. Stop the machine for 15 sec. and use a small trowel to scrape back into the batch any paste adhering to the bowl beyond the mixing zone. Restart the machine for 90s at low speed.

Operation	Introducing cement	Introducing water	Get started	Scraping the bowl	Get started
Operation time		5 to 10 seconds	90 seconds	15 seconds	90 seconds
Mixer condition	Stopped		Slow speed	Stopped	Slow speed

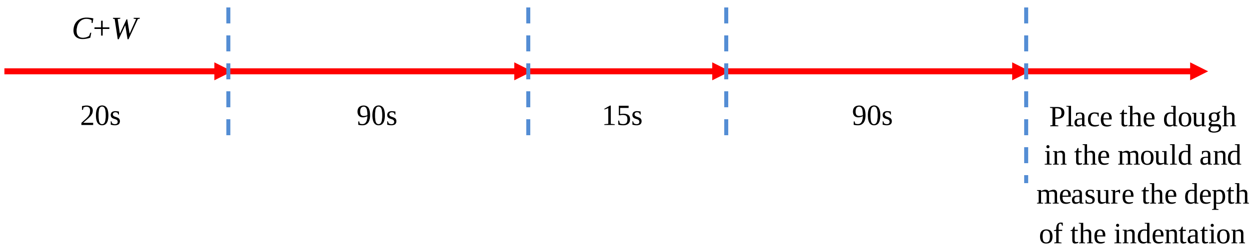


Figure 2.15. Consistency evolution of a cement paste over time

The paste is then rapidly introduced into the truncated cone-shaped mold placed on a glass plate, without excessive settling or vibration; excess paste is removed by a back-and-forth movement with a trowel held perpendicular to the upper surface of the mold. The whole assembly is then placed on the Vicat machine platen.

Four minutes after mixing begins, the probe is brought to the top surface of the sample (truncated-cone mold) and released without momentum. The probe then sinks into the paste.

When the probe is immobilized (or after 30 s of waiting), the distance "d" separating the end of the probe from the base plate is measured.

This distance (d) characterizes the consistency of the dough under study.

- If (d) = 6mm ± 1mm, the consistency of the dough studied is said to be normalized. (Normalized consistency).

- If (d) does not reach this value (i.e. d >7 mm or d < 5mm), the test should be repeated with a different W/C ratio until the desired consistency value is reached.

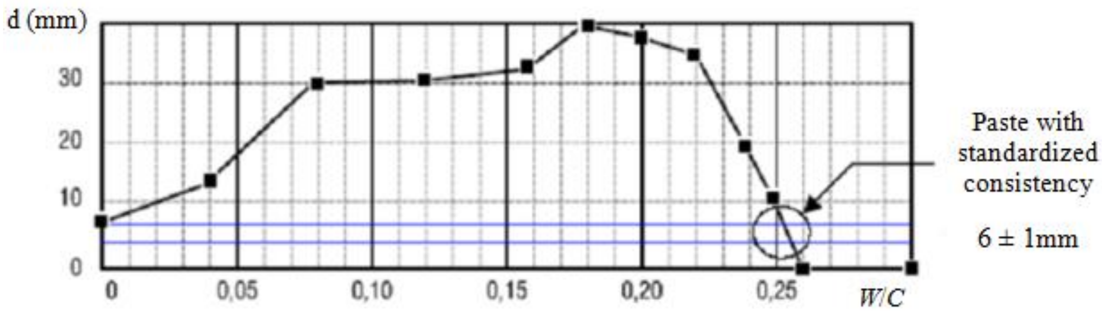


Figure 2.16. Consistency of cement paste as a function of W/C [13]

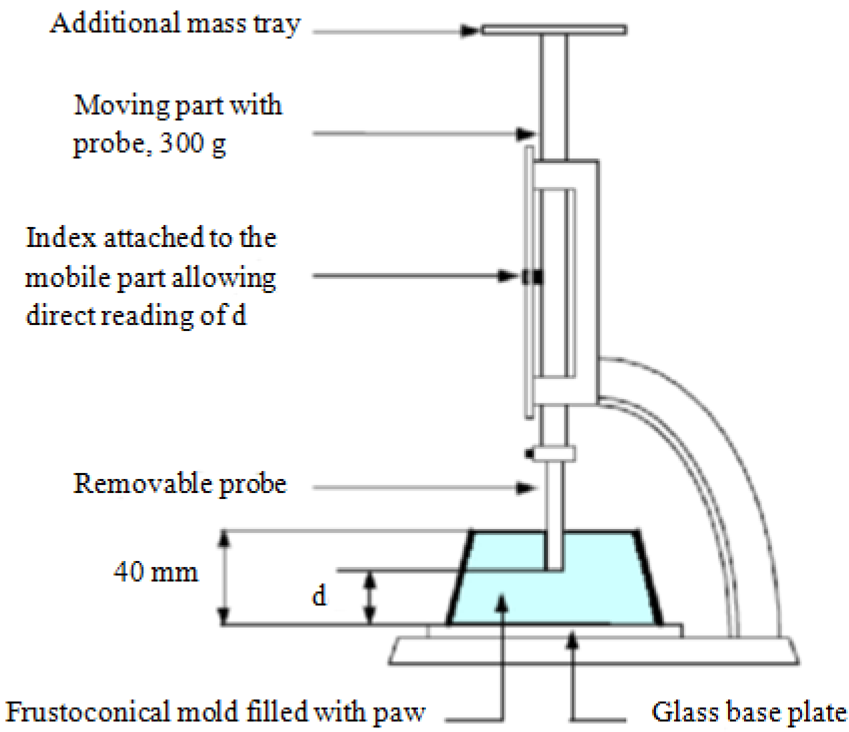
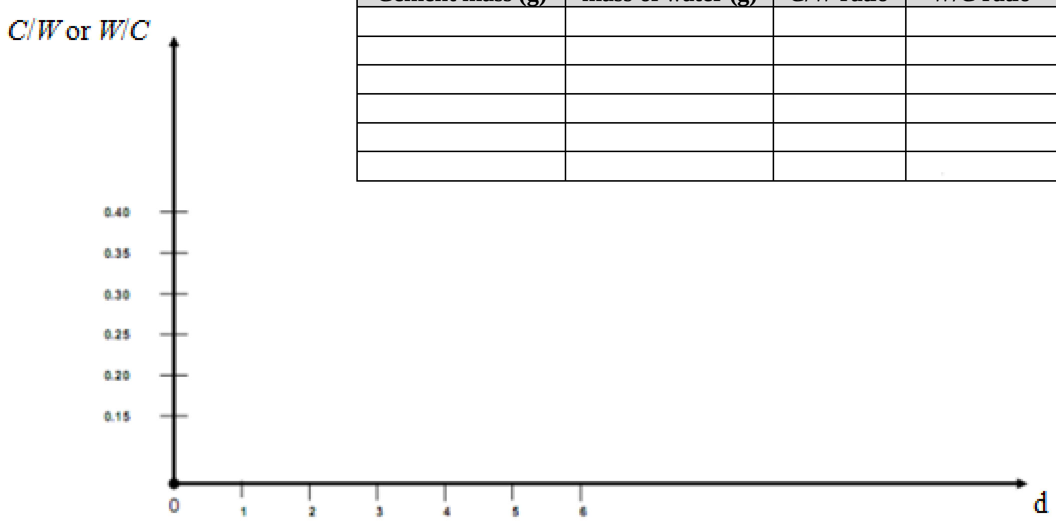


Figure 2.17. Vicat apparatus with consistency probe [13].

Table 2.12. Data collection sheet

Cement mass (g)	mass of water (g)	*C/W* ratio	*W/C* ratio	d



Chapter 3. Glossary

Cement	A powdery material that forms a plastic binding paste with water or a saline solution, capable of agglomerating various substances as it hardens. context "the color vectors are pigments and additives in the form of small, very fine grains, stable in the alkaline medium of cement".
Absorption Coefficient	Ratio of the increase in sample mass after imbibition with water to the dry mass of the sample.
Flattening Coefficient	Index quantifying the shape of an aggregate.
Compactness	For a given material, the ratio of the volume of its solid phase to its total volume.
Concrete components	Concrete components include aggregates, sand, cement and water.
Consistency	Characterizes the greater or lesser fluidity of a cement paste, mortar or concrete. Consistency is assessed by tests that relate it to a numerical value. This value is not independent of the test used, which is why, to be meaningful, the consistency value must be associated with the name of the test used.
Particle size distribution	Graphical representation of particle size analysis results.
d/D	Minimum and maximum dimensions of an aggregate batch, e.g. 0/31.5.
Densimeter	Used to measure the density of a liquid or suspension. Used in granulometric analysis by sedimentometry.
Density	Ratio of the density of a solid to the density of water.
Hardening	A stage in the evolution of mortars and concretes after setting, when the material passes from a plastic state to a solid state and acquires its strength.
Water	A colorless, transparent, odorless, tasteless liquid made of oxygen and hydrogen combined, found almost everywhere in nature.
Sand Equivalent	Index quantifying the cleanliness of sand.
Sand Expansion	Modification of the volume occupied by sand due to its water

	content. Sand does not occupy the same volume when it is dry as when it is damp: the wetter the sand, the more it swells and the more sand needs to be added, for the same volume of binder.
Granularity	Grain size distribution.
Concrete Aggregate	One of the three basic constituents of concrete, along with cement and water, they form the skeleton of concrete.
Granulometry	Grain size determination.
Graves	Granular materials with diameters ranging from 6.3 to 80 mm.
Gravel	Aggregates with a particle size distribution between d greater than or equal to 1 mm and d less than or equal to 125 mm. The designation of the aggregate is qualified by d/D.
Handling	Ability of concrete or mortar to set easily in forms. workability is estimated by consistency tests. also called workability.
Volumic Mass	Mass per unit volume.
Module	Standardized names for different sieves and strainers.
Finesse Module	Parameter quantifying the fineness of a sand.
Workability	A quality that reflects a concrete's suitability for use. for common concretes, it is assessed by a consistency value, determined by the slump of the abrams cone. it allows us to distinguish four standardized classes of concrete: firm (f), corresponding to a slump of less than 4 cm; plastic (p) - slump 5 to 9 cm; very plastic (tp) - slump 10 to 15 cm; and fluid (fl), for a slump greater than 16 cm.
Colander	Round-hole instrument for granulometric analysis (now discontinued).
Cement Paste	This is the binding paste in concrete. The term "fresh cement paste" is used to designate a mixture of water and cement of plastic consistency. Due to hydration, the consistency of this paste evolves over time until it becomes hardened cement paste.
Volumetric Weight G	Wet weight per unit volume.
Volumetric Weight G_d	Dry weight per unit volume.
Volumetric Weight G_s	Weight per unit volume. Average value for aggregates 26.5

	kn/m^3.
Volumetric Weight G_w	Water density = 10 kn/m^3.
Porosity	For a given material, the ratio of the volume of its gaseous and liquid phases to the total volume.
Hardening	This is the property of hydraulic binders to change from a fluid to a solid consistency when they are combined with water: they are said to set. The setting time marks the moment when this change of state accelerates.
Concrete Curing	The physico-chemical reaction of cement in the presence of water produces new combinations called hydrates, enabling inert particles to weld together to form a solid, coherent structure known as concrete.
Sand Cleanliness	See sand equivalent.
Pycnometer	Apparatus for measuring density.
Refusal	Weight of material retained by a sieve.
Sand	Loose sedimentary rock composed of grains, often quartz, ranging in size from 0.02 to 2mm.
Sedimentometry	Fine particle size analysis.
Sieves	Square mesh instrument for particle size analysis.
Sieving	Operation used to perform particle size analysis.
Sieve	Weight of material passing through a sieve.
Water Content W	Quotient of the weight of water in the sample divided by the dry weight.
Vibration	Operation of tightening fresh concrete after it has been placed, in order to improve its compactness. Vibration can be internal or external to the concrete.
Viscosity	Characteristic of a fluid material tending to oppose its flow by gravity. The lower the viscosity of a concrete, the better its workability.
Surface area	For a divided material, the surface area of its constituent grains per unit mass of material.

FS	French standard. Mark indicating compliance with the French standard.
pozzolanic	Refers to the property of certain substances, which are not hydraulic binders, to behave like hydraulic binders when combined with clinker

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