2. Particle size distribution of soils

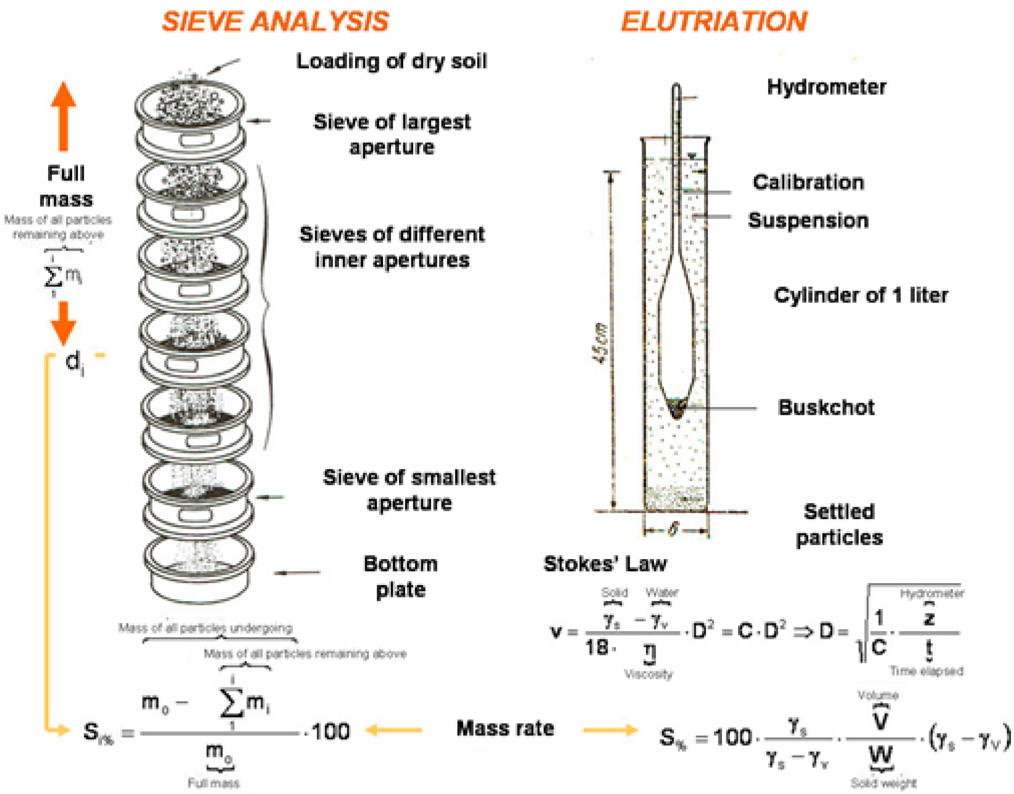
Characterization of particles is based on their size. Grain size can be typified by nominal diameter. The aperture of screens (rounded) or sieves (square) that lets a particle through identifies the nominal diameter. The nominal diameter of smaller particles is defined as the diameter of a ball of the same material as the particle with the same sedimentation speed in a liquid. The widely varying range of nominal diameter is divided into fractions.

The particle fraction names of Figure 1.8 can be used based on the new European Standard of soil classification. (The former Hungarian Standard named the particle fraction between 0.1 and 0.02 mm-s sandflour.) The abbreviations of fraction names originate from the first letters of English fraction names.

Soils of natural origin consist of a variety of particle sizes, or even several fractions. Thus, the size of particles can be characterized by **grain size distribution** showing the probability of occurrence of particle sizes. The grain size distribution is determined by **sieve analysis** and/or **elutriation (sedimentation technique)** (Figure 1.7-1.8). In the course of sieve analysis – according to the definition of nominal diameter – the mass rate of particles falling through sieves of different apertures is determined.

In geotechnical practice particle size analysis of fine particles is determined by elutriation, where density of the aqueous suspension of the soil sample is measured, and shows the settling velocity of particles. **Stokes' Law** says that settling velocity is proportional to the square of the spherical particle diameter.

The density of the soil-liquid suspension is proportional to the proportion of the particles not settled. By measuring density during sedimentation, related nominal diameters and mass rates can be determined. Stokes' Law is applicable only for spherical particles; real grain size distribution can be derived by correction.



$$v = \frac{\gamma_s - \gamma_v}{18 \cdot \eta} \cdot D^2 = C \cdot D^2 \Rightarrow D = \sqrt{\frac{1}{C} \cdot \frac{z}{t}}$$

$$S_{i\%} = \frac{m_0 - \sum_1^i m_i}{m_0} \cdot 100$$

$$S_{\%} = 100 \cdot \frac{\gamma_s}{\gamma_s - \gamma_v} \cdot \frac{V}{W} \cdot (\gamma_s - \gamma_v)$$

Figure 1.7: Sieve analysis and elutriation (Mecsi, 2009)

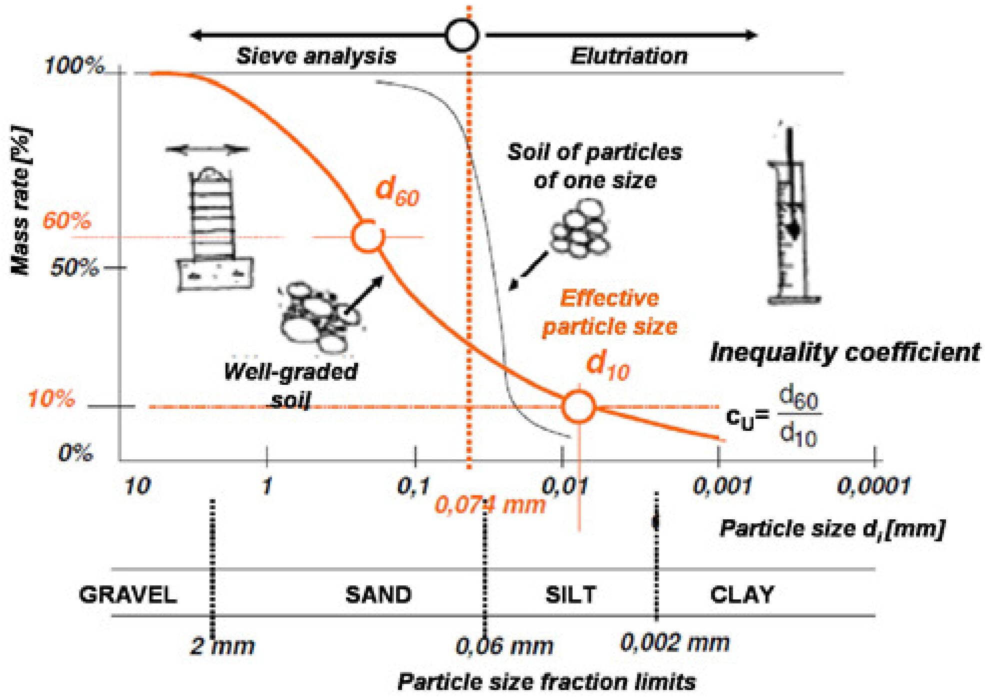


Figure 1.8: Determination of grain size distribution, typical grain sizes, derived parameters (Mecsi, 2009)

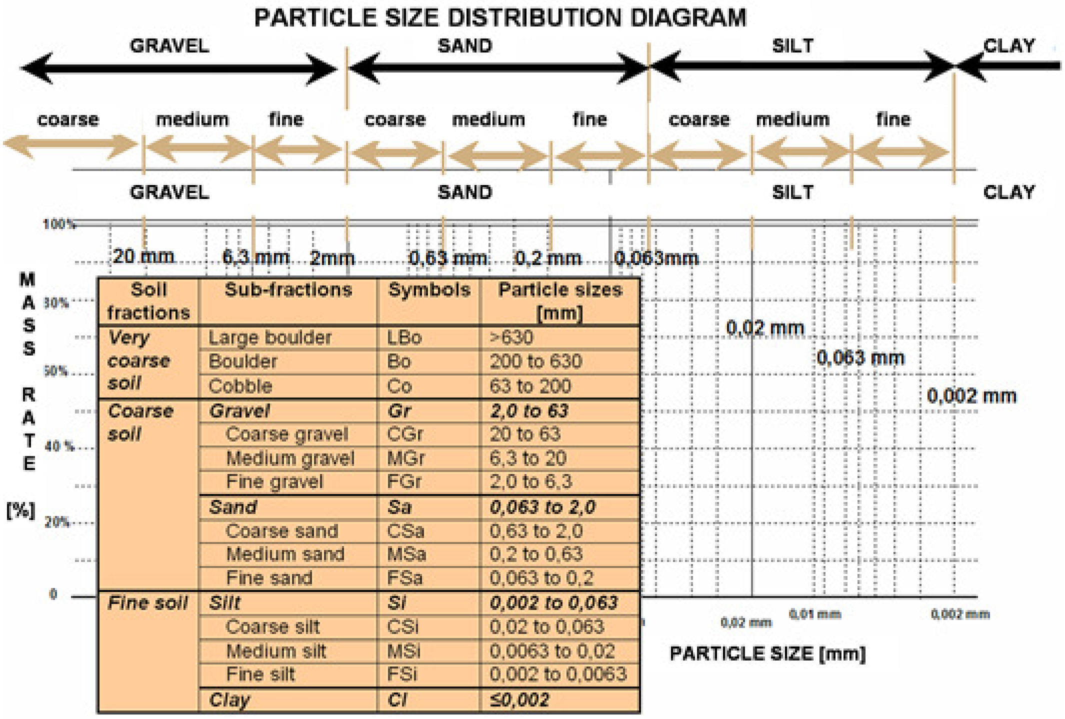
In earth sciences there are other methods for the determination of grain size distribution. Grain size is calculated based on Stokes' Law, but the amount of particles falling out from a certain fraction is measured directly (Köhn pipette method, decantation).

The most expressive way of illustrating grain size distribution is by drawing a graph that which shows the proportion of the mass of particles smaller than a certain diameter compared to the full particle cluster mass. Since particle size varies widely, it is shown in ***logarithmic scale***.

The bounding of soil types and limits of particle fractions are more or less arbitrarily established, but the new European Standard determines the particle fraction limits differently than the former Hungarian Standard does.

The former Hungarian Standard used to name a particle fraction "sandflour", while the European Standard ranks this fraction partly as fine sand, but largely as silt. Hungarian geological practice names the fraction between 0.06-0.002 mm-s "rock flour".

Particle fraction limits according to new European Standards are shown in Figure 1.9.



Soil fractions	Sub-fractions	Symbols	Particle sizes [mm]
Very coarse soil	Large boulder	LBo	>630
	Boulder	Bo	200 to 630
	Cobble	Co	63 to 200
Coarse soil	***Gravel***	***Gr***	***2,0 to 63***
	Coarse gravel	CGr	20 to 63
	Medium gravel	MGr	6,3 to 20
	Fine gravel	FGr	2,0 to 6,3
	Sand	***Sa***	***0,063 to 2,0***
	Coarse sand	CSa	0,63 to 2,0
	Medium sand	MSa	0,2 to 0,63
	Fine sand	FSa	0,063 to 0,2
Fine soil	***Silt***	***Si***	***0,002 to 0,063***
	Coarse silt	CSi	0,02 to 0,063
	Medium silt	MSi	0,0063 to 0,02
	Fine silt	FSi	0,002 to 0,0063
	Clay	***Cl***	***≤0,002***

Figure 1.9: Particle fraction limits and names according to new MSZ EN (Hungarian Standards introducing European Standards) and former MSZ (Hungarian Standard) (Mecsi, 2009)

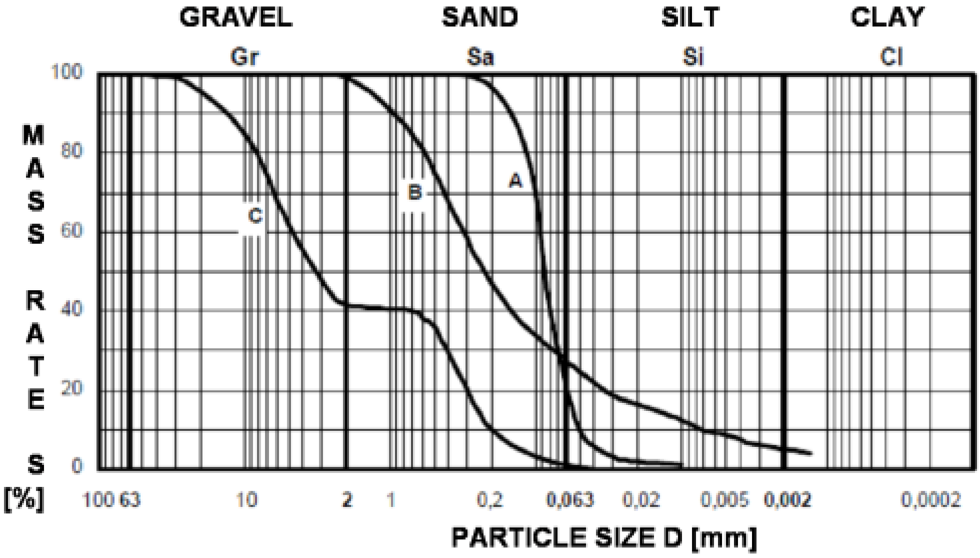
Particle size distribution is often given by only the proportion of each fraction.

There are also several numerical parameters to characterize grain size distribution. The most important parameter is the **inequality coefficient**, calculated by the $c_U = \frac{d_{60}}{d_{10}}$ formula (formerly denoted by *U*). This characterizes the continuity of the grain size distribution and gives information about the compactability of soils. A soil of one particle size with about $c_U = 1.9$ is difficult to compact, in contrast to a mixed soil with higher c_U values.

The parameters of c_U and d_m (the so-called **significant particle size**) play an important role also in the characterization of some kind of sands, which show liquefaction (**quicksand**) under certain adverse circumstances (flow pressure, increasing neutral stress, earthquake, etc.). This is especially characteristic of nearly spherical particles, with $d_m = 0.08 - 0.2\ mm$ and $c_U = 1 - 5$.

The **effective particle size** (d_h) is used for characterizing the water-related behaviour of the particles. It is defined as the diameter of the sphere with equal specific (based on mass unit) surface to the examined soil sample. For approximation $d_h = d_{10}$ can be used.

Some typical particle size distribution (PSD) graphs are shown in Figure 1.10 (from Szepesházi, 2008). The "A" curve belongs to silty sand, consisting of particles of almost the same diameter (so-called quicksand), The "B" curve is a good example of a continous particle size distribution (mixed or well-graded soil), and the "C" curve shows the (stepped) PSD of a fraction-deficient sandy gravel.



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