oe4625 Dredge Pumps and Slurry Transport

Vaclav Matousek

October 13, 2004

Delft University of Technology

2. SOIL-WATER MIXTURE AND ITS PHASES

SOIL PROPERTIES

LIQUID PROPERTIES

MIXTURE PROPERTIES

SOIL PROPERTIES

SIZE OF PARTICLE & SOIL

DENSITY OF PARTICLE & SOIL

PARTICLE SIZE

Classification and identification of soil

Particle size distribution (PSD)

Characteristic sizes

Classification & Identification

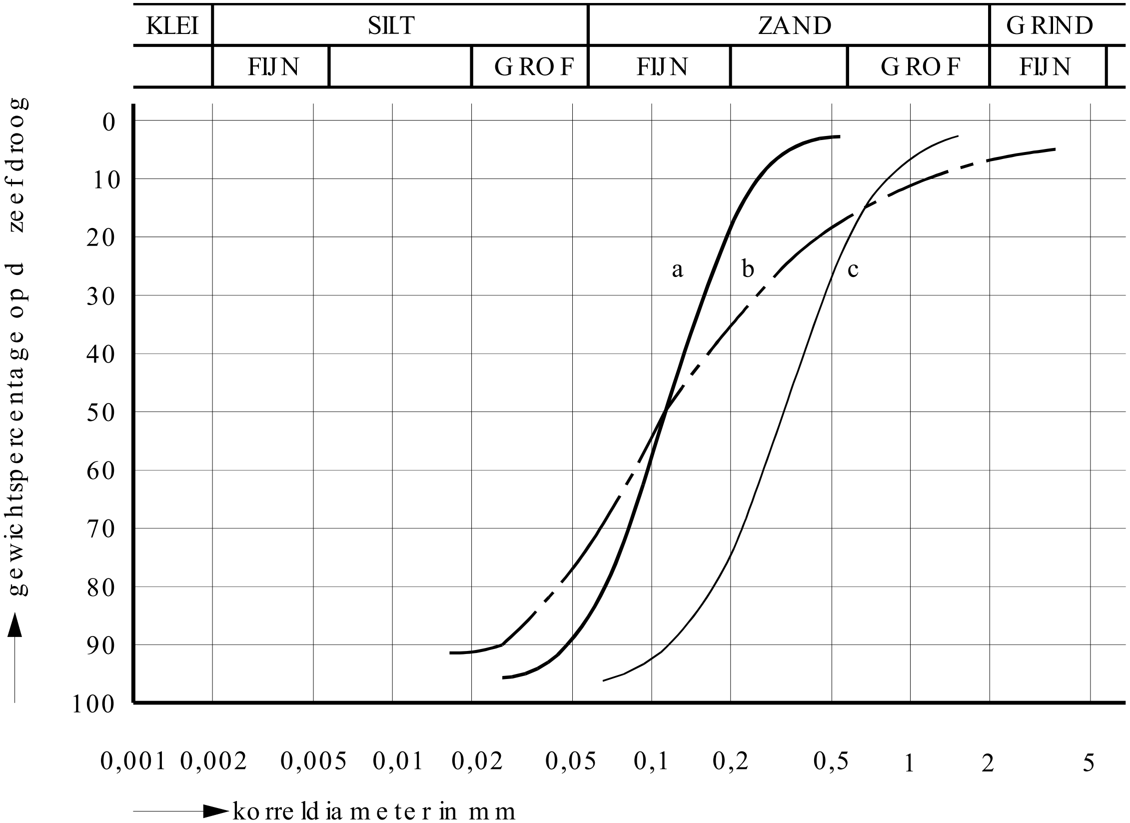
Main type of soil		Particle size	
		Identification	size in [mm]
Boulders	Granular Non-cohesive	-	> 200
Cobbles		-	200 – 60
		Coarse	60 – 20
Gravel		Medium	20 – 6
		Fine	6 – 2
		Coarse	2 – 0.6
Sand		Medium	0.6 – 0.2
		Fine	0.2 – 0.06
		Coarse	0.06 – 0.02
Silt	Cohesive	Medium	0.02 – 0.006
		Fine	0.006 – 0.002
Clay		-	< 0.002

Particle Size Distribution (PSD)

1	2	3	4	5
sieve opening [mm]	**weight fraction [g]**	**percentage of total weight, pi [%]**	**cumulative % mass**	**characteristic particle size, di [mm]**
0.85	0	0	100	0.85
0.6	6.7	0.67	99.33	0.6
0.5	37.7	3.77	95.56	0.5
0.42	447.8	44.78	50.78	0.42
0.355	366.4	36.64	14.14	0.355
0.3	74.2	7.42	6.72	0.3
0.21	55.1	5.51	1.21	0.21
0.15	10.6	1.06	0.15	0.15
0.00	1.5	0.15	0	0.00
	1000	100		

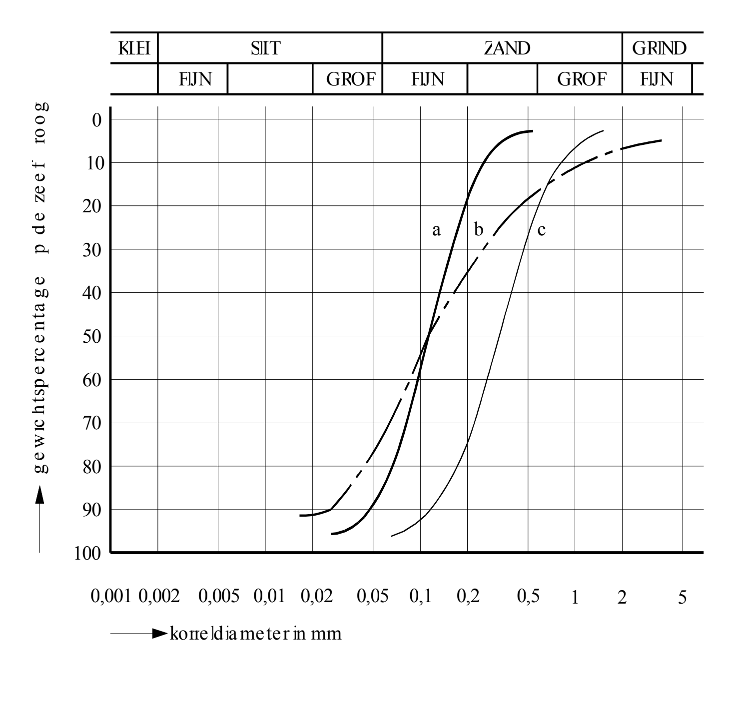
Particle Size Distribution (PSD)

(%)	zand a (μm)	zand b (μm)	zand c (μm)
10	250	1300	850
20	180	500	620
30	150	270	500
40	140	170	400
50	120	120	350
60	90	75	290
70	75	55	240
80	60	40	180
90	40	25	130
Totaal	1105	2555	3560
dmf	123	284	396



Characteristic Sizes

If a sample of soil is composed of particles of different sizes, the soil particles are represented by a characteristic size (diameter):



Mass-median diameter : d_{50} [mm]

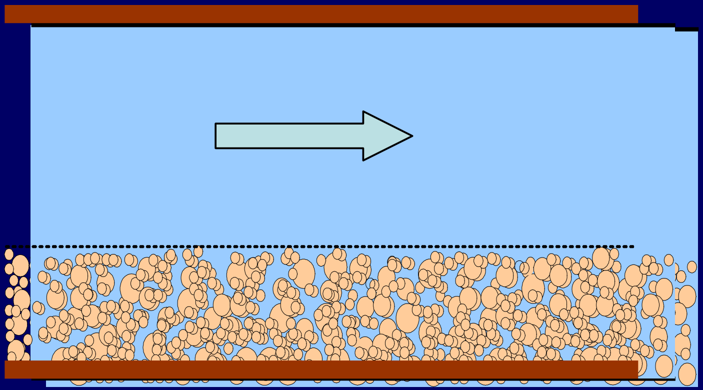
The 85%-diameter : d_{85} [mm]

Mean diameter : $$d_s = \frac{\sum_i d_i p_i}{\sum_i p_i} = \frac{\sum_i d_i p_i}{1.00} \quad \text{[mm]}$$

Decisive particle diameter: $$d_{mf} = \frac{d_{10} + d_{20} + \ldots\ldots\ldots\ldots + d_{80} + d_{90}}{9}$$

Density of Submerged Soil (granular body)

The density of a granular body is given by the density of solid particles and the density of liquid in the pores.



The porosity of granular body $$n = \frac{\text{Volume pores in gran. body}}{\text{Total volume granular body}} \quad [-]$$

The typical value of the sand-bed porosity is 0.4, 40 per cent of the total volume.

The density of granular body $$\rho_{si} = \rho_s (1\text{-n}) + \rho_f \text{n} \quad [\text{kg/m}^3]$$

The typical value of the soil density is 2000 kg/m^3 for a submerged sand bed.

Density and Porosity of Soil

	Density of solids [kg/m3]	Density of soil in situ (wet) [kg/m3]	Porosity n [%]
silt	2650	1100 - 1400	80 - 90
loose clay	2650	1400 - 1600	60 - 80
packed clay	2650	1800 - 2000	35 - 50
sand with clay	2650	1800 - 2000	40 - 50
sand	2650	1900 - 2000	35 - 45
coarse sand with gravel	2650	2050 - 2200	28-36
clay boulders	2650	2320	20

LIQUID PROPERTIES

DENSITY OF LIQUID

VISCOSITY OF LIQUID

Density and Viscosity of Liquid

The density and viscosty of liquid vary with temperature. Sensitivity to pressure can be neglected, the liquids are considered incompressible.

The density of liquid $$\rho_\mathrm{f} = \frac{\text{Mass liquid}}{\text{Volume liquid}}$$ [kg/m^3]

The typical value of the liquid density is 1000 kg/m^3 for tap water.
The sea water is heavier, round 1025 kg/m^3.

The dynamic viscosity of liquid (Newton's law of viscosity) $$\mu_\mathrm{f} = \frac{\text{Shear stress}}{\text{Velocity gradient}} = \frac{\tau}{\frac{du_x}{dy}}$$ [Pa.s].

The kinematic viscosity of liquid $$\nu_\mathrm{f} = \frac{\text{Dynamic viscosity}}{\text{Density of liquid}} = \frac{\mu_f}{\rho_f}$$ [m^2/s].

Density and Viscosity of Liquid

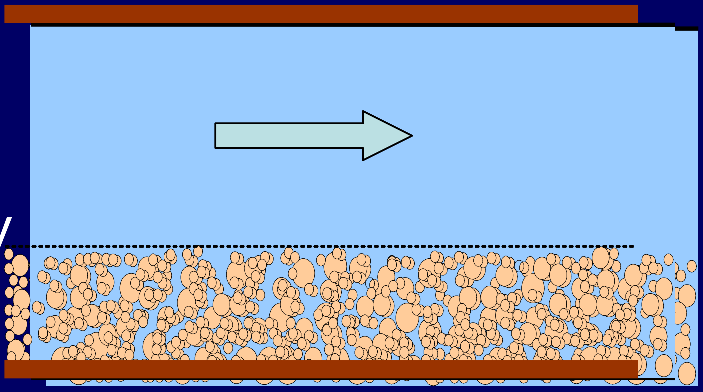
Temperature T [°C]	Density, [kg/m^3]	Dynamic viscosity, [Pa.s]	Kinematic viscosity, [m^2/s]	Vapour pressure, [Pa]
0	999.8	1.781×10^{-3}	1.785×10^{-6}	0.61×10^{3}
5	1000.0	1.518×10^{-3}	1.519×10^{-6}	0.87×10^{3}
10	999.7	1.307×10^{-3}	1.306×10^{-6}	1.23×10^{3}
15	999.1	1.139×10^{-3}	1.139×10^{-6}	1.70×10^{3}
20	998.2	1.002×10^{-3}	1.003×10^{-6}	2.34×10^{3}
25	997.0	0.890×10^{-3}	0.893×10^{-6}	3.17×10^{3}
30	995.7	0.798×10^{-3}	0.800×10^{-6}	4.24×10^{3}

MIXTURE PROPERTIES

DENSITY OF MIXTURE

SOLIDS CONCENTRATION IN MIXTURE

Solids Concentration in Mixture



Mixture is composed of two phases: solids and liquid.

The density of mixture is determined from the density of solid particles and the density of liquid. The proportion of the phases is given by the parameter called CONCENTRATION OF SOLIDS.

The concentration of solids in mixture $C_v = \frac{\text{Volume solids in mixture}}{\text{Total volume of mixture}}$ [-].

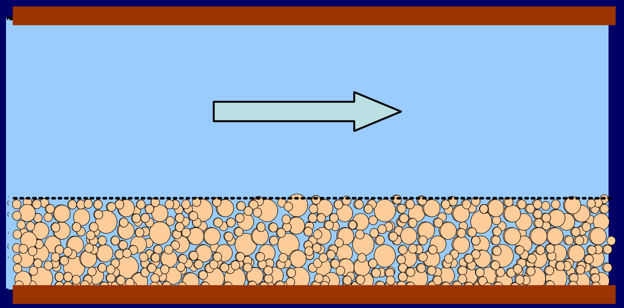
Remark: If the mixture is the granular bed, there is a direct relationship between the solids concentration and porosity in the bed:

$$C_{v,bed} = 1 - n.$$

Thus if the sand-bed porosity is 0.4, then the bed concentration is 0.6, 60 per cent of the bed volume is occupied by solid particles.

TU Delft

Density of Mixture



MASS(mixture) = MASS(liquid) + MASS(solids)

considering MASS = DENSITY (ρ) x VOLUME (U) and $\mathbf{U_m = U_f + U_s}$

$$\boldsymbol{\rho_m U_m = \rho_f U_f + \rho_s U_s = \rho_f (U_m - U_s) + \rho_s U_s}$$

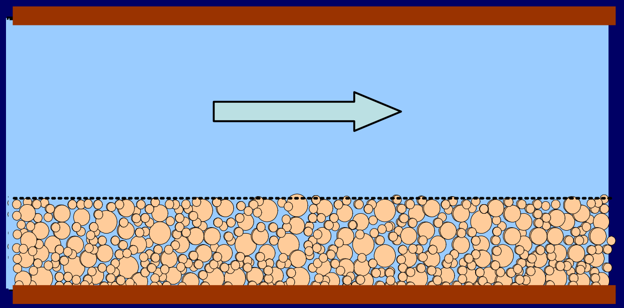
dividing by U_m and considering $\mathbf{C_v = U_s/U_m}$ gives finally

$$\rho_m = \rho_f (1\text{-}C_v) + \rho_s C_v \qquad [kg/m^3].$$

Rearranging gives the relationship between the mixture density and the concentration of solids in mixture

$$C_v = \frac{\rho_m - \rho_f}{\rho_s - \rho_f} \quad [-].$$

Delivered Concentration



Solids concentration in flowing mixture:

There are two possible Control Volumes:

1. CV is the length section of a pipe: $C_{vi} = U_{s,p}/U_{m,p}$ is the *spatial concentration of solids*;
2. CV is the volume moving with the flowing mixture: $C_{vd} = Q_s/Q_m$ is the *delivered concentration of solids*.

TU Delft

Delivered Concentration

In pipe:

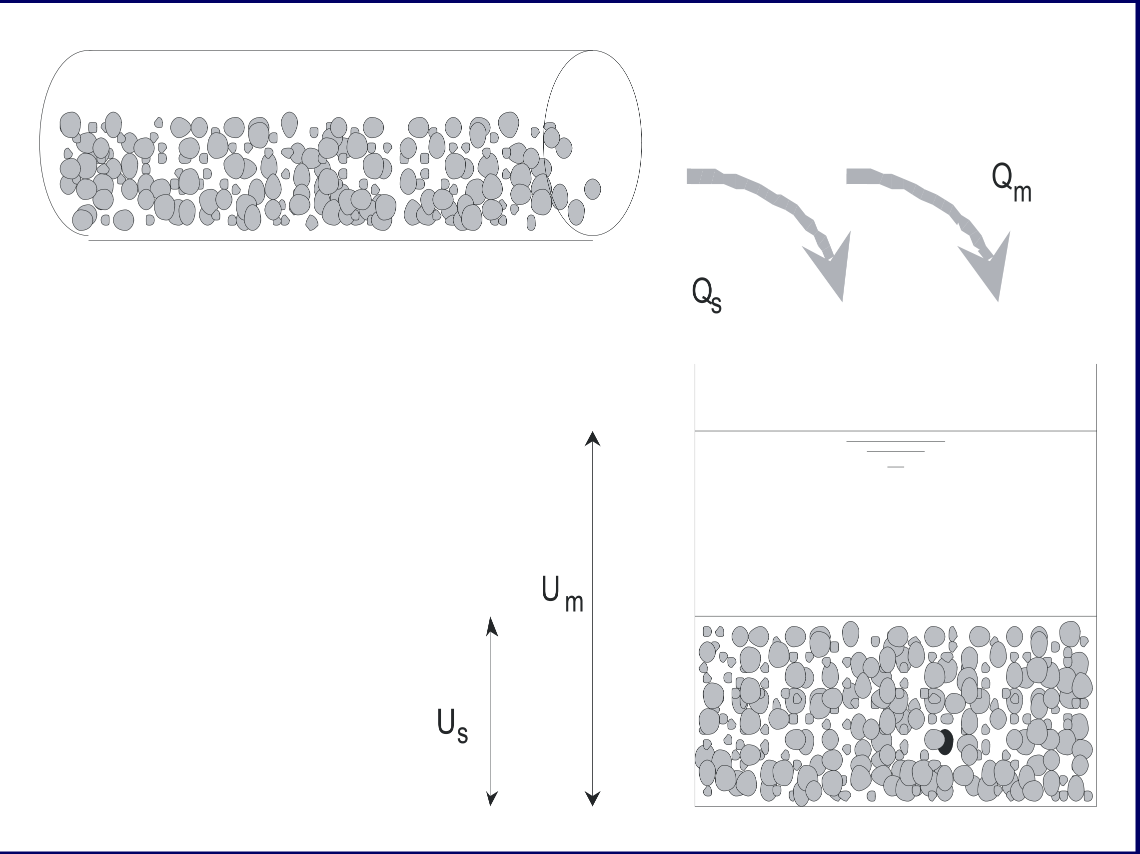
1. $C_{vi} = U_{s,p}/U_{m,p}$

2. $C_{vd} = Q_s/Q_m =$

$= \Delta U_s/\Delta t \,.\, \Delta t/\Delta U_m$

$= U_s/U_m$ in the tank

$C_{vi} >= C_{vd}$



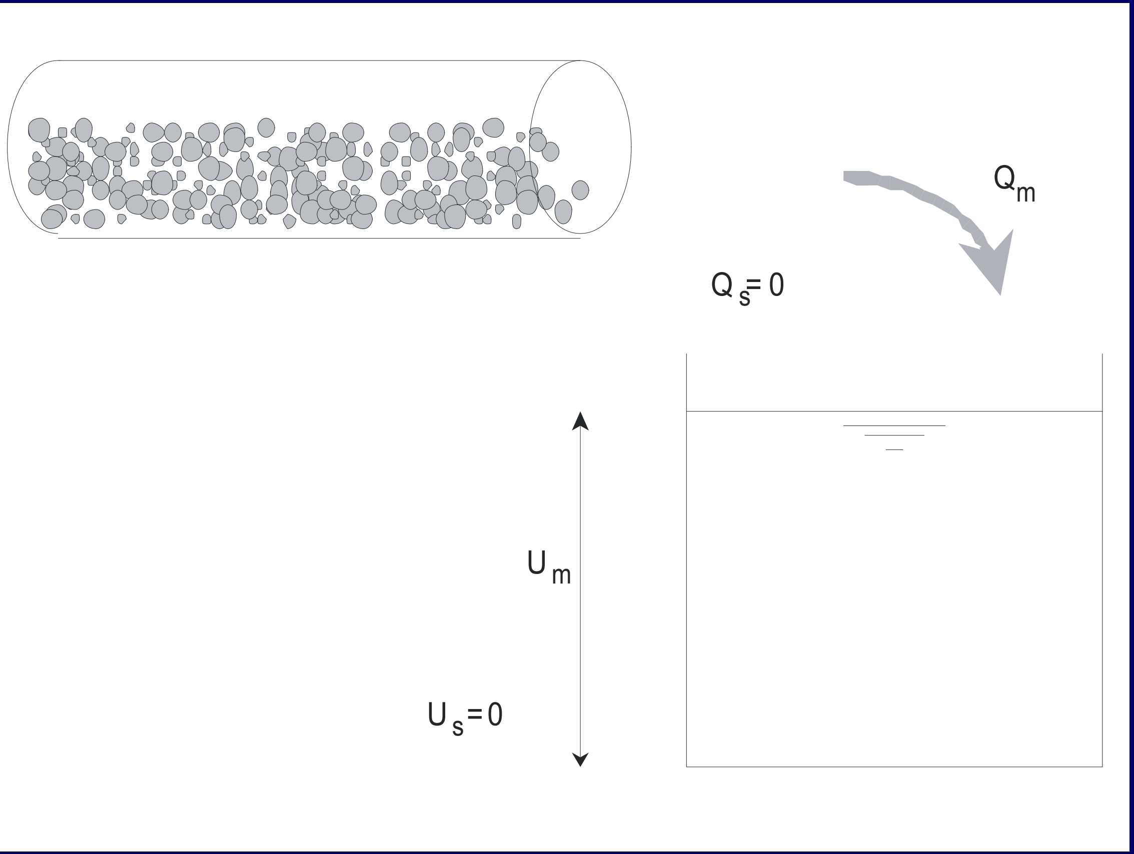
Delivered Concentration

In pipe:

1. $C_{vi} = U_{s,p}/U_{m,p}$

2. $C_{vd} = Q_s/Q_m$

$$C_{vi} > 0$$
$$C_{vd} = 0$$



Delivered Concentration – Practical Values

	Delivered C_{vdsi} in situ [-]	Density of mixture [kg/m3]	Delivered C_{vd} solid grains [-]
CSD without submerged pump	0.25	1250	0.15
CSD with submerged pump	0.30	1300	0.18
Bucket wheel dredge with submerged pump	0.50	1500	0.30
Plain suction dredge	0.40-0.60	1400-1600	0.24 - 0.36
Modern THSD during hopper loading (suction process)	0.30-0.40	1300-1600	0.18 - 0.36
Modern THSD during hopper unloading (pumping to shore)	0.70-0.80	1700-1800	0.42 - 0.48

Slip Between Solids and Liquid

Phases: mixture = liquid + solids

In pipe: $Q_m = Q_f + Q_s$ **i.e.** $V_m.A = V_f.A_f + V_s.A_s$

Spatial concentration: $C_{vi} = U_{s,p}/U_{m,p} = A_s.L/(A.L) = A_s/A$

Delivered concentration: $C_{vd} = Q_s/Q_m = V_s.A_s/(V_m.A) = (V_s/V_m).\ C_{vi}$

The slip ratio (= transport factor): $V_s/V_m = C_{vd}/C_{vi}$

Slip Ratio – Practical Values

	At low C_{vd}	At high C_{vd}
Silt and finer solids	1.00	1.00
Fine to medium sand	0.80-1.00	0.90-1.00
Medium to coarse sand	0.70-0.90	0.85-1.00
Coarse sand	0.65-0.85	0.75-0.95
Fine gravel	0.65-0.85	0.75-0.90
Boulders	0.40-0.65	0.40-0.65

CASE STUDY

Consider that sand particles occupy **27 per cent** of the total volume of a dredging pipeline. The rest is occupied by carrying water. The sand-water mixture is discharged from the dredging pipeline at a deposit site. The porosity of the sand in the deposit site **$n = 0.4$**.

Determine the **density ρ_m** of sand-water mixture in the pipeline and the **weight concentration C_w** of solids in the mixture. Further, determine the **in situ density ρ_{si}** and the **spatial volumetric concentration of in situ sand, C_{vsi}**, in the deposit site and in the pipeline.

CASE STUDY

Inputs:

The spatial volumetric concentration of solids in mixture flow: $C_v = 0.27$

The density of sand particles: $\rho_s = 2650\ kg/m^3$

The density of carrying water: $\rho_f = 1000\ kg/m^3$

Porosity of sand in a granular body: $n = 0.4$.

CASE STUDY

Solution:

a. **Density of mixture (ρ_m) & weight concentration of solids in mixture (C_w)**

Eq. 2.9 determines the density of mixture

$\rho_m = \rho_f(1-C_v) + \rho_s C_v = 1000(1-0.27)+2650x0.27 =$ ***1445.5 kg/m³***.

Eq. 2.10 determines the weight concentration

$$C_w = \frac{\rho_s}{\rho_m} C_v = \frac{2650}{1445.5} 0.27$$ **= 0.495, i.e. *49.5 %*.**

CASE STUDY

Solution:

b. In-situ density (ρ_{si}) & in-situ volumetric concentration of soil (C_{vsi}) in a granular body (sand bed)

According to Eq. 2.3 the porosity $n = \dfrac{\rho_s - \rho_{si}}{\rho_s - \rho_f}$ **and thus**

$$\rho_{si} = \rho_s - (\rho_f - \rho_s).n = 2650 - 1650 \times 0.4 = 1990\ kg/m^3.$$

In the sand bed the density of the sand-water mixture is equal to ρ_{si} and thus $C_{vsi} = 1$ (see Eq. 2.11).

CASE STUDY

Solution:

c. The in-situ volumetric concentration in the pipeline

Eq. 2.12 determines the volumetric concentration of in-situ material in the pipeline as

$$C_{vsi} = \frac{C_v}{1-n} = \frac{0.27}{1-0.4}$$ **= 0.45, i.e. *45 %*.**