Land reclamations of dredged mud

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1. Introduction

Generally, mud dredged from harbour docks and navigation channels in estuaries is dumped at nearby dumping grounds within the system, from where it may be eroded again and partly returned to the original dredging locations. Dredged mud can also be dumped far away (at sea) from the dredging locations. However, this may be expensive if the sailing distance is relatively large.
Another option may be the construction of land reclamations (new nature areas, **Figure 1**) in the form of coastal extensions and/or small islands consisting of compartments (50 to 100 ha) surrounded by low sandy dikes and filled with dredged mud. The water depth of the compartments should be smaller than about 4 to 5 m. An additional advantage of this latter option of a land reclamation of mud is the removal of mud from the system resulting in less turbid water and less dredging activities.
This document presents information on:

- filling of compartments,
- crust formation,
- consolidation of soft fluid mud to firm soil,
- mud pollution.

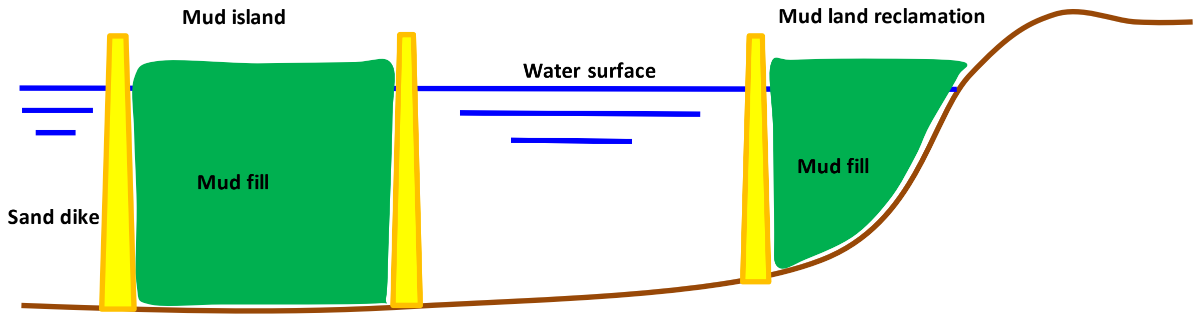

Figure 1 *Mud land reclamation and mud island*

2. Dredging of mud from docks and channels

The mud trapped in docks and channels generally consists of fine sediments (clay/lutum) and a limited amount of organic matter with a dry density of 200 to 300 kg/m^3 (wet density of 1100 to 1200 kg/m^3). The mud properties can be determined using field and laboratory work. The trapping of mud in docks and channels and the subsequent consolidation process leads to thicker layers of mud with higher densities. The lower layers of the mud deposits with densities of 1200 to 1300 kg/m^3 can be dredged away regularly using an Auger-type dredger connected to a pipeline running to the land reclamation site.
If a hopper dredger is used, it can sail to the land reclamation site where it can connect to a pipeline to fill the compartments.

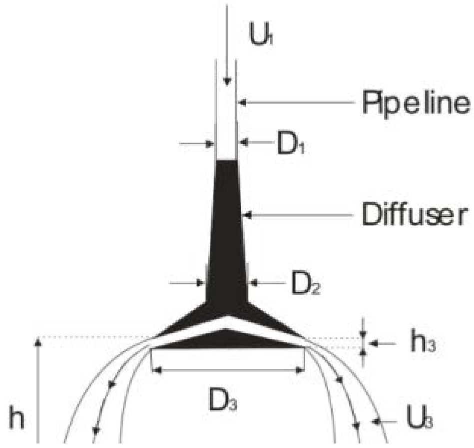

Figure 2 *Diffuser*

3. Filling of compartments

The filling of the compartments at the land reclamation site can be executed mechanically (excavator) or hydraulically (pumping). Hydraulic filling through a pipeline is most likely the most efficient method. The mud slurry can be pumped into the compartments as close as possible to the bottom using a vertically adjustable diffuser (**Figure 2**) so that a thin density flow with low speed and turbulence is generated to avoid segragation. The mud flow will spread out horizontally in the form of a slurry tongue. There should be enough space (minimum 100 m) to allow this process to proceed in a slow and gradual way. The sediments that are carried in the sludge tongue, will mixe with the lower part of the water column and then settle. The sludge should not be pumped at a high level in the water column because this will lead to strong segragation, dispersion and the settling of individual particles. The filling process is schematically shown in **Figure 3**.

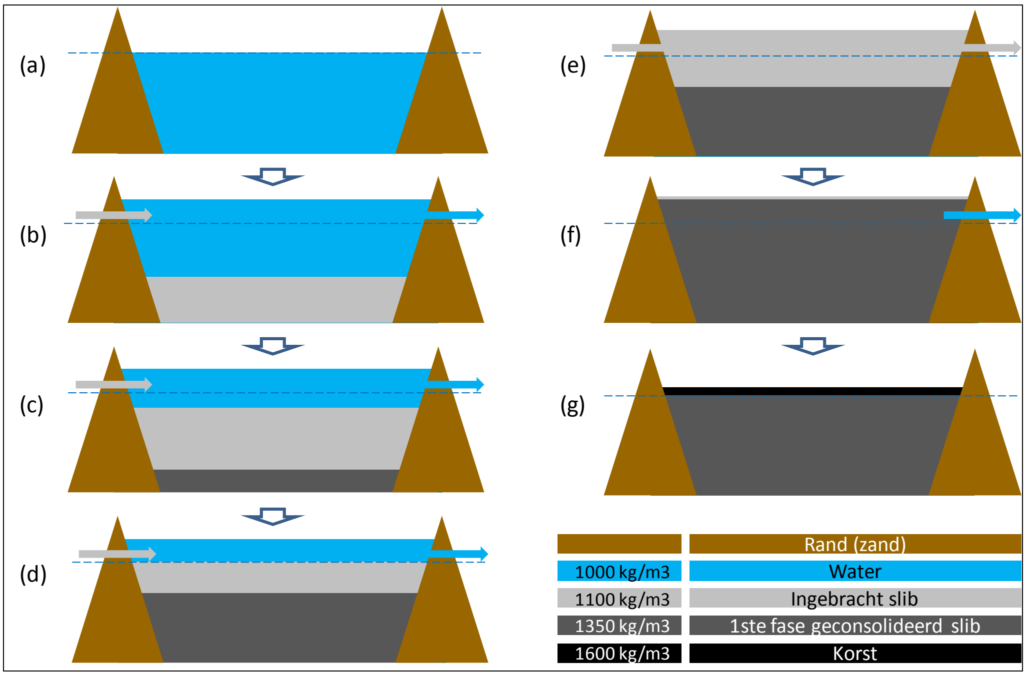

Figure 3 *Schematic filling of compartment*

Type	Weight (kg)	Leg/Foot surface (cm^2)	Load (kg/cm^2)	Bearing capacity (kg/cm^2)
Small animals	5	10 to 20	0.25 to 0.5	
Male person	80	50 to 100	0.8 to 1.6	
Weak muddy soil; wet density = 1300-1400 kg/m^3				0.1-0.3
Moderately weak soil; wet density = 1400-1500 kg/m^3				0.3-0.5
Firm clay/soil; wet density = 1500-1700 kg/m^3				0.5-1
Very firm clay/soil; wet density = 1700-1900 kg/m^3				3-5
Sand; wet density = 1900-2000 kg/m^3				> 10

Table 1 *Load and bearing capacity of soil (Van der Veen, 1962)*

4. Crust formation

4.1 General

The required bearing capacity of the soil surface is approximately 0.5 to 1 kg/cm^2 to allow small animals and people to walk over the soil surface. **Table 1** gives an overview of various types of loads and bearing capacities of soils . The crust of the soil (top layer of 0.5 m) must have a wet density of about 1500 to 1700 kg/m^3 in order to have a bearing capacity of 0.5 to 1 kg/cm^2. The crust formation process is highly dependent on the density of the top soil layer. Two situations are possible:

1. soft mud soil with initial density of 1300 to 1400 kg/m^3 (mechanically placed using an excavator);
2. soft mud sludge with initial density of 1100 to 1200 kg/m^3 (hydraulically pumped using a pipeline).

4.2 Top layer consisting of soft soil (1200 to 1400 kg/m^3)

A top soil layer with a relatively high initial wet density of 1200 to 1400 kg/m^3 can only be obtained by mechanical placement using a crane or an excavator (Haasnoot and De Vos 2010; Roukema et al. 1998). The soil with a maximum layer thickness of about 2 m should be placed mechanically with a surface level of about 1 m above the surrounding water surface or ground water table. The soil surface will dry out by evaporation and by plants/vegetation extracting moisture from the soil. This reduces the water content and the mineral and organic particles are attracted to each other by capillary forces resulting in a more firm soil. The drying process will result in (visual) cracking if the percentages of clay and organic materials are sufficiently high. Cracking stimulates the penetration of air, which enhances chemical and biological aging (riping) processes depending on the soil composition and environmental conditions.
Aging (riping) is a natural and irreversible process of drying and oxidation, through which the largely anaerobic mud sludge turns into a more compact and permeable soil material. Thus, the soil material changes gradually from a thin, wet slurry into a more solid and firm soil. Depending on the initial dry mass and the physical composition, the soil volume may reduce with 30% to 70%.
The ripening process can broadly be divided into three sub-processes:

- physical aging (decrease of water content with cracking and subsidence of the soil);
- bio/chemical aging with oxidative conversions (oxidation of organic matter) and
- (micro) biological aging with microbial degradation.

Aging can be significantly promoted by rapid drainage of surface water (due to precipitation), so that it cannot penetrate into the soil. This requires effcient drainage of surface water by a system of gullies and ditches or through drainage pipes in the bottom.

The most important processes in the physical riping processes are: evaporation, precipitation and seepage/drainage. Generally, the drainage of water through seepage will be very low (less than 0.1 mm/day), because the water level in the compartments will be equal or only slightly higher than that of the surrounding water.

The evaporation of surface water in sunny summer periods with temperatures between 20° and 25° is of the order of 5 mm/day. If the annual rainfall is of the order of 1000 mm or 3 mm/day, the dominant evaporation in the summer can lead to a relatively dry top soil layer. The evaporation is determined by two factors:

- open-ground evaporation (evaporation) and
- crop/plant evaporation (transpiration).

Evaporation is limited to the top layer of the soil and will significantly decrease in time due to crust formation. The drying of the deeper layers strongly depends on the drainage system.
In a dry summer period of about 4 weeks, a layer of water of about 100 to 150 mm can be removed through evaporation, resulting in a solid crust of about 1500 kg/m^3. One relatively long dry period is extremely important. The soil is then sufficiently firm for the planting of vegetation. Aging can be accelerated by sowing and growing of reed. Reed can grow in soft soil and stimulate the aging process by transpiration processes.
The stages of soil improvement by reed growth are (see **Figure 4**):

- reed is sowed/planted on the thin crust after an initial dry period;
- reed accelerates dewatering under the dry crust resulting in quicker consolidation; crust becomes thicker and sinks;
- new mud sludge can be pumped on the sinking crust.

In this way the soft holocene surface layer can consolidate in about 2 to 3 years to more firm soil with a wet density of about 1500 kg/m^3. The total layer thickness will decrease by 40% to50%.

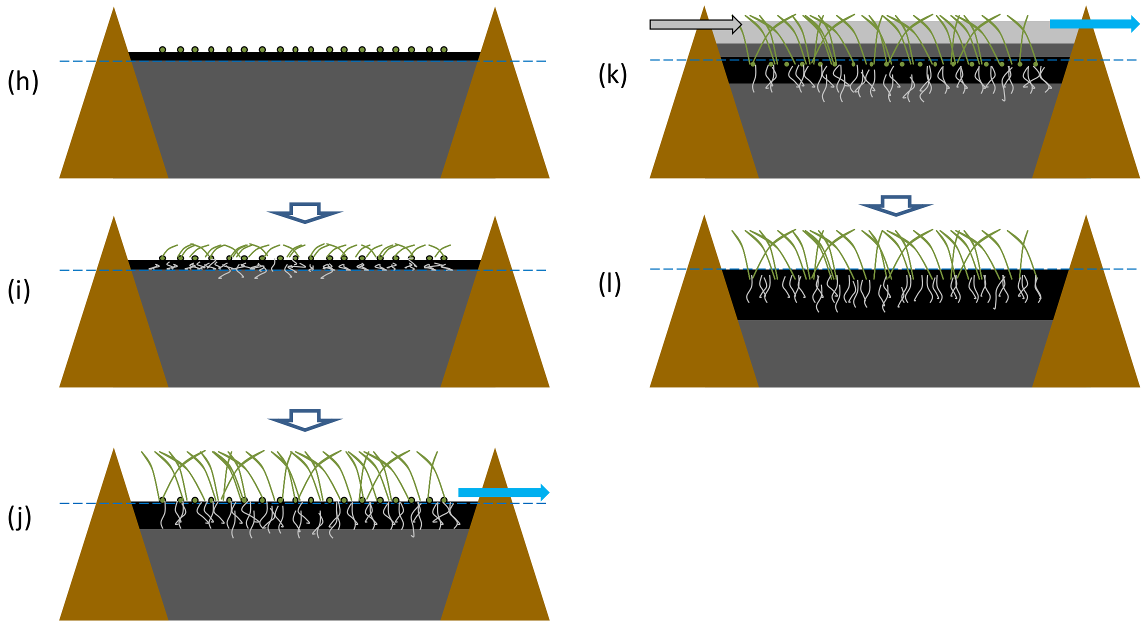

Figure 4 *Crust formation through vegetation*

4.3 Top soil layer consisting of soft mud sludge (1100 to 1200 kg/m^3)

If the mechanical placement of the top soil layer is not feasible, the only other option is the hydraulic placement of mud through a pipeline. The hydraulic pumping of a mud slurry will result in a relatively low density of the soil in the range of 1100 to 1200 kg/m^3. The water/mud level in the compartments (closed ring dike) should be at least 1 m above that of the surrounding waters. The drying process depends on the relative magnitudes of the rainfall, evaporation and drainage of water through seepage flow.
The amount of seepage water depends on the water level difference between the inside and the outside of the compartments and the permeability of the soil plus (sandy) ring dikes. The seepage flow out of a compartment of 50 ha can be calculated with: Q = k h (H/B) L where k = permeability coefficient < 10^{-6} m/s for muddy soils, h = layer thickness of soil = 5 m, H = water level difference = 1 m, B = dike width = 10 m, L = dike length = 5000 m.
This gives a seepage flow: Q = 0.0025 m^3/s = 200 m^3/day or a water level reduction within the compartment of about 0.4 mm/day for a surface of 50 ha. As the rainfall and evaporation are of the order of 2 to 5 mm/day, the contribution of seepage flow is negligibly small.
Only in a very dry summer period of approximately 4 weeks, there will be adequate evaporation to remove a layer of water of 100 to 150 mm through evaporation. When the soil becomes dry after a sunny summer period, the top layer consists of loose mineral and organic particles surrounded by bound water films. The top layer has a soft consistency with a density of 1400 to 1500 kg/m^3. Possibly there will be a thin and moderately firm crust. The soil will have insufficient capacity for the planting of vegetation.
If the amount of water extracted from the top layer by evaporation is compensated by rainfall, the moisture content of the top layer will not go down and hence aging can not occur. In this situation, the soil surface will sink by internal consolidation with an in thickness growing water layer on top of it. The surface water layer will continuously have to be removed through drainage (pumping), so that the crust formation can proceed in the next dry period. In a summer with intensive rainfall, there will be a continuous thin layer of water on the soil surface. Regular refilling with mud sludge will be necessary.
The crust formation cycle in this rainy regime will be about 5 to 10 years:

- 5 years from soft fluid mud under water (wet density 1200 kg/m^3) to soft soil under water (1400 kg/m^3);
- 3 to 5 years from soft soil under water to moderately firm soil above water (1500 kg/m^3).

Eventually, there will be a crust of moderately firm soil (1500 kg/m^3) with a thickness of approximately 0.5 to 1 m resting on package of soft subsoils (clay/peat/sand) with a wet density of 1400 kg/m^3. The crust will not consolidate further due to regular addition of rainwater. Only in long dry summer periods the density of the top soil layer can increase further. The soft subsoil will consolidate in about 100 years to firm soil with a density of 1700 kg/m^3.

5. Consolidation of fluid mud to firm soil

5.1 Consolidation process

The sedimentation and consolidation process of suspended mud at the bottom of the water column can be divided into four phases (see also **Figure 5**):

- hindered settling in which the particles and flocs move slowly downward hindered by the return flow of water displaced by the moving sediments; the sediment concentrations are approximately 10 to 50 kg/m^3 (wet density of 1010 to 1050 kg/m^3);
- transitional phase (fluid mud) in which the particles and flocs make contact with each other resulting in a significant decrease of the effective sedimentation velocity (wet density of 1050 to 1100 kg/m^3);
- primary consolidation phase in which there is a slow building up of contact forces (grain stresses) and pore water is driven out; an initial soil structure (matrix) is formed with small dewatering channels (cracks) through which water can escape; the concentration at which there is a matrix-structure is the gel-concentration with values of 100 kg/m^3 for pure clay such as kaolinite and 100 to 300 kg/m^3 for mud with organic material (wet density of 1100 to 1200 kg/m^3);
- secondary consolidation stage in which the floc network strength begins to develop at a wet density of 1200 to 1400 kg/m^3; the time scale depends on the upper load and drainage rate. If no drainage is present, the typical time scale is of the order of tens to hundreds of years.

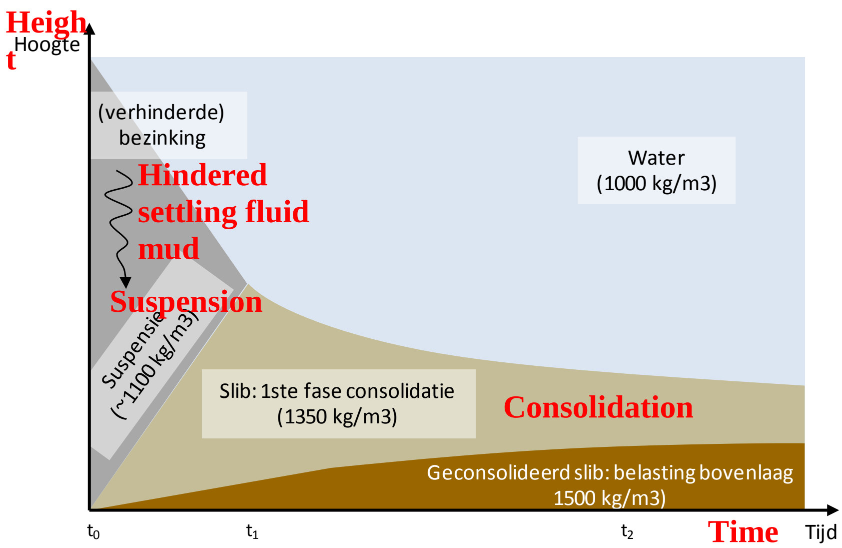

Figure 4 *Schematic development of mud suspension to firm soil*

Consolidation is a process that requires space, time and drainage. Space because the fluid mud has to be pumped into the compartments as gradual as possible with low velocities to suppress turbulence. Time because the extrusion of pore water goes slow. Experimental results show that the consolidation (soil surface sinking) of hydraulically filled compartments is of the order of 0.01-0.03 m/month (0.3 m/year) without drainage.

Table 2 provides an overview of the volume densities and consolidation times of different types of soil.

Soil type	Dry volume weight c_{dry} (kg/m^3)	Wet volume weight ρ_{wet} (kg/m^3)	Specific volume weight ρ_s (kg/m^3)	Porosity p (-)	Consolidation time up to 95% of the final value T_{end} (years)
Soft to firm soil (under water)					
Sand (0.062 to 2 mm) Silt (0.032 to 0.062 mm)	1550± 50	1950± 50	2650	42%	<< 1 year (very solid soil)
Moderate firm holocene clay in soil under (fresh) water; mechanically placed	1350 ± 50	1850± 50	2650	50%	> 100 years to ρ_{wet} = 1900 (firm soil)
Soft holocene clay in soil under (fresh) water; mechanically placed	800± 100	1500± 50	2650	70%	> 100 years to ρ_{wet} = 1700 kg/m^3 (moderately firm soil)
Soft Holocene clay/20% peat mixture in soil under water; mechanically placed	600±100	1350±50	2300	75%	> 100 years to ρ_{wet} = 1500 (very moderately firm soil)
Fluid mud mixtures (under water)					
Pure clay (kaolinite) in salt water, layer = 0.3 m	100	1100	2650	95%	1 week to ρ_{wet} = 1400 (soft soil)
Bangkok mud in salt water, layer= 1 m	200	1150	2500	92%	0.75 years to ρ_{wet} = 1300 (soft soil)
Bangkok mud in salt water, layer= 2 m	200	1150	2500	92%	3 years to ρ_{wet} = 1300 (soft soil)
Slufter mud in salt water, bottom layer of 1 m with upper layers of 15 to 20 m	375	1250	2500	85%	10 years to ρ_{wet} = 1400 (soft soil)
Sandy mud mixture (fine sand/clay/20% peat) after hydraulic dredging	500 ± 100	1300± 50	2300	80%	1 year to ρ_{wet} = 1800 (moderately firm soil)
Mud (clay/20% peat) mixture after hydraulic dredging	300± 100	1200±50	2300	85%	5 years to ρ_{wet} = 1400 (soft soil)
Mud (clay/50% peat) mixture after hydraulic dredging	200±100	110±50	1800	90%	> 10 years to ρ_{wet} = 1200 (soft soil)
Soft soil (above water)					
Soft holocene clay/20% peat above ground water; mechanically placed	600±100	1350± 50	2300	75%	3 years to ρ_{wet} = 1700 (moderately firm soil above water)
Soft Holocene peat/20% clay above ground water; mechanically placed	300±100	1050±50	1300	75%	3 years to ρ_{wet} = 1200 (moderately firm soil above water; peat like)

Peat = mixture of organic/planttype materials with specific mass of 1000 ±100 kg/m^3;
Peat/peat= dry on land after 0.5 to 1 year; Formulas: $\rho_{wet} = \rho_{water} + [(\rho_s - \rho_{water})/\rho_s]\ c_{dry} = 1000 + 0.62\ c_{dry}$; $p = 1 - c_{dry}/\rho_s$

Table 2 *Overview of soil types, volume densities and consolidation times*

Figure 6 shows the consolidation of the wet and dry density of mud in salt water for various types of mud (Van Rijn 1993, 2006). To obtain a wet density above 1300 kg/m^3, a consolidation time of at least 100 days (3 months) is required. The results of Bangkok-mud show that a layer of 1 m consolidates significantly faster than a layer of 2 m. The lower layers of Slufter-mud situated under a total soil package of 15 to 20 m (depot Rotterdam 1987-1994; Wichman 1995) have consolidated in about 7 years to a wet density of 1400 kg/m^3. The density of the top layer does not increase much in time (1250 kg/m^3) due to regular filling with new mud sludge. Laboratory test results show that the thickness of the mud layers should be limited (up to 1 to 2 m thick) as the dewatering process proceeds slow for increasing thickness (without additional drainage).

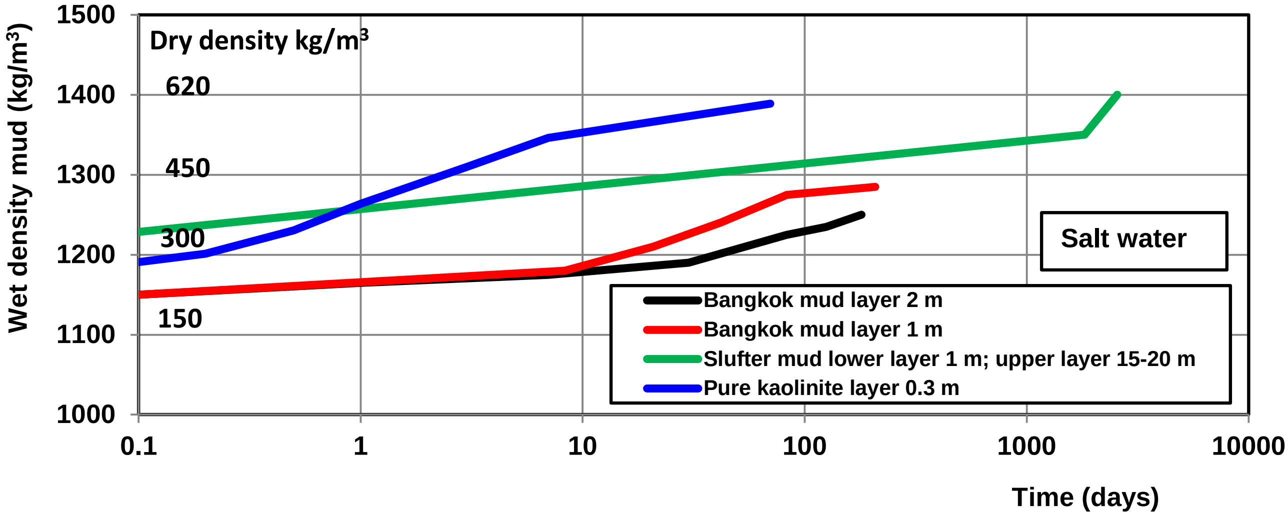

Figure 6 *Wet mud density as a function of time*

5.2 Effect of upper load (thin sand layer) on consolidation of mud

Dankers (2006) has carried out tests in a sedimentation column with small amounts of fine and coarse sand (approximately 10 grams; 0.11 mm; 0.36 mm) which are settling on a liquid mud layer (in salt water).

The dry density of the top mud layer was 50 to 100 kg/m^3. The sand concentration was < 10 kg/m^3.
The test results show:

- falling sand grains disturb the mud surface; the sand grains penetrate through the mud surface and slowly move down through small dewatering channels (cracks);
- small accumulations (pockets) of sand in the mud layer; smaller sand particles are partly stopped by the mud structure; larger sand grains reach the bottom of the column;
- the effective settling velocity of the sand particles decreases by a factor of 3 to 10 depending on the mud concentration; the consolidation of the mud (sink velocity of mud surface) increases by 10%.

Based on these results, the presence of a thin sand layer (0.5 m) on top of a soft mud layer may accelerate the consolidation of the mud layer by improving the permeability so that the pore water can be driven out more quickly. Torfs et al. (1996) have also shown that sand layers can speed up the consolidation process.

5.3 Simple consolidation model

The dry volume density (c) of soil under water consisting of organic matter, clay/lutum, silt and sand with a layer thickness of 1 to 5 m can be described by (Van Rijn, 1993, 2006):

$$c_{end} = 500\,(1 + \alpha_b)\,(1 - f_{org})\,f_{clay} + 1200\,f_{silt} + 1550\,f_{sand} \qquad (1)$$

in which: c = dry end density (kg/m^3), f = fraction size ($\sum f = 1$), f_{org}= fraction of organic material (0 to 0.5), f_{clay} = fraction of clay (0 to 0.5), f_{silt}= fraction of silt, f_{sand}= fraction of sand, α_b = coefficient upper load (0.1 to 0.3 depending on the layer thickness of sand or silt).
For example: $\alpha_b = 0$, f_{org}= 0.2, f_{clay}= 0.4, f_{silt}= 0.3, f_{sand}= 0.1 gives: c_{end}= 160 + 360 + 155 = 675 kg/m^3.

The wet density this:

$$\rho_{wet} = \rho_{water} + [(\rho_s - \rho_{water})/\rho_s]\,c_{dry} = 1000 + 0.62 \times 675 = 1420 \text{ kg/m}^3 \qquad (2)$$

Figure 7 shows Equation (2) for ρ_{water} = 1000 kg/m^3 and ρ_s= 2650 kg/m^3.

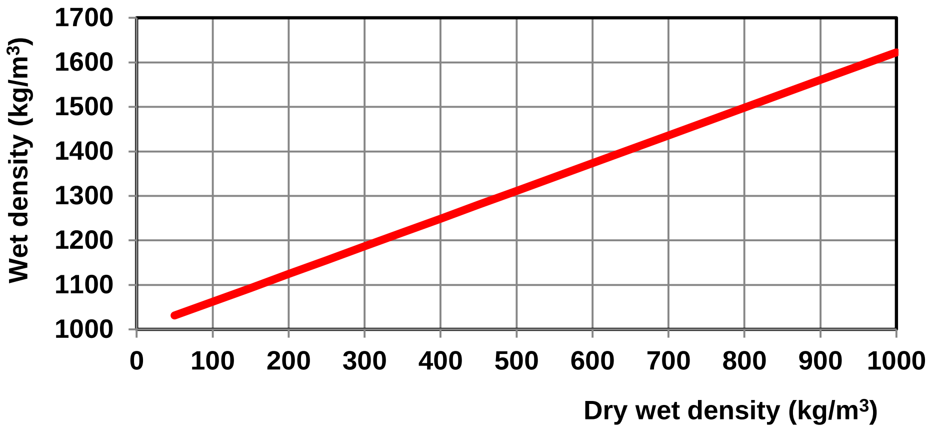

Figure 7 *Dry and wet density*

The consolidation time T_{end} to reach 95% of the final (end) density, can be estimated with:

$$T_{end} = \rho_{water}\, g\, h^2/(4\, \alpha_s\, k) \qquad (3)$$

where: h = layer thickness (m), g = 9.81 m/s^2, k = permeability coefficient < 10^{-6} m/s for muddy soil, α_s = compressibility coefficient of soil (about 10 to 20 N/m^2 for soft soil).
For example: h = 1 m, k = 10^{-6} m/s, α_s = 10 N/m^2, ρ_{water} = 1000 kg/m^3 gives: T_{end} = 0.25 10^9 s $\cong$ 10 years.

The behaviour of the density in time from the initial dry density (c_o) at t = 0 to the final dry density (c_{end}) at t = T_{end} can be described with an exponential (logarithmic) function:

dry density: $c_t = c + (c_{end} - c_t)\,(t/T_{end})^{\gamma}$ (4)

wet density: $\rho_t = \rho_o + (\rho_{end} - \rho_o)(t/T_{end})^{\gamma}$ (5)

Based on the measured behaviour of Bangkok-mud (see **Figure 6**), the exponent is determined on γ= 0.4.

The height h_t at time t of a mud column with an initial height h_o can be described with (continuity):

$$h_t = (c_o/c_t)\, h_o = h_o\, [1 + \{(c_{end} - c_o)/c_o\}\, (t/T_{end})^{0.4}]^{-1} \quad (6)$$

The settlement is: $\Delta h_t = h_o - h_t = h\, (1 - c_o/c_t)$ (7)

Using the above equations, yields:

$$\Delta h_t = h_o\, [1 - \{1 + ((c_{end} - c_o)/c_o)\, (t/T_{end})^{0.4}\}^{-1}] \quad (8)$$

Example 1

c_o= 200 kg/m^3, c_{end}= 500 kg/m^3 and t = 0.25 T_{end}: $\Delta h_{t=0.25Tend}/h_o = 1\text{-}\{1 + (1.5)\,(0.25)^{0.4}\}^{-1} = 1\text{-}(1.86)^{-1} \cong 0.45$
So, at a quarter of the end time the settlement is about 45% of the initial height.
The relative end settlement is: $\Delta h_{t=Tend}/h_o = 1\text{-}\{1 + 1.5\}^{-1} = 1\text{-}(2.5)^{-1} \cong 0.6$ or 60% of the initial height.
So, at a quarter of the end time the settlement already is 0.45/0.6 = 75% of the total settlement.

Example 2

c_o= 250 kg/m^3, c_{end}= 500 kg/m^3 ; h_o= 2.5 m; T_{end} = 10 years.
The consolidation starts after 90 days (construction period).
After 1 year (365 days), a sand layer (upper load) is placed on top of the mud layer to increase the consolidation process. The end density is assumed to increases to: c_{end} = 600 kg/m^3.
The initial density after 1 year is: $c_{o,\,1\,year}$= 340 kg/m^3, see **Figure 8**.

Figure 8 shows the settlement of a mud layer over 10 years without and with upper load. The intial dry density is set to 250 kg/m^3. The total settlement of a mud layer with initial thickness of 2.5 m is approximately 1.3 m after 10 years (without upper load). The end height is 1.2 m. The end dry density is assumed to be 500 kg/m^3 after 10 years. The effect of an upper load (sand layer placed after 1 year) is also shown resulting in an additional settlement of about 0.2 m. The end dry density with upper load is assumed to be 600 kg/m^3.

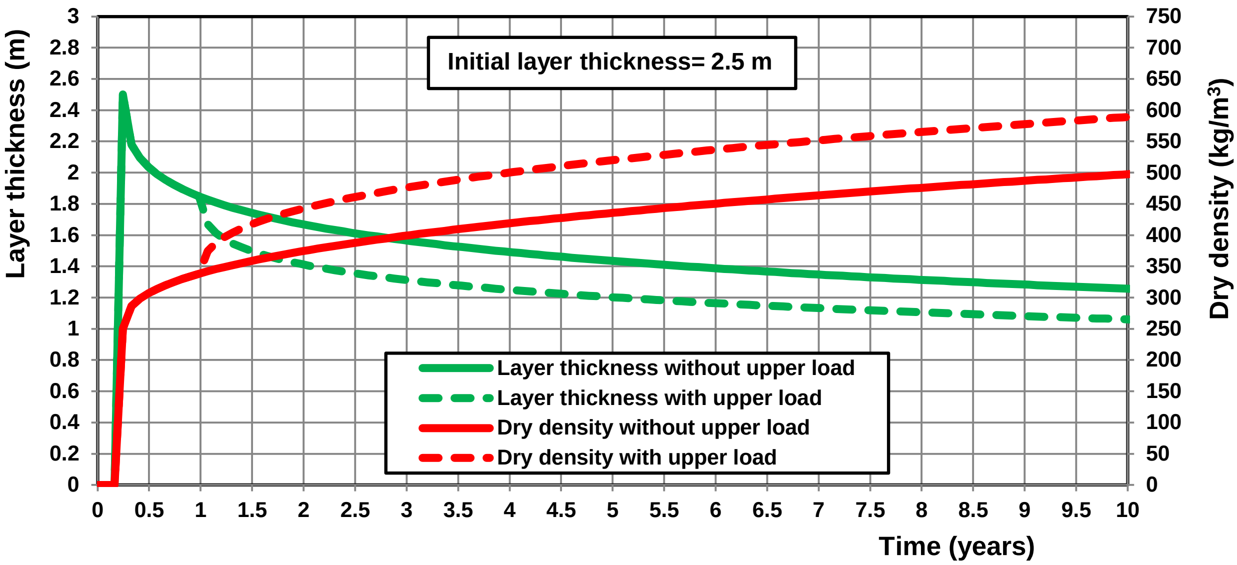

Figure 8 *Settlement and volume density as a function of time; mud layer of 2.5 m*

Example 3

Three mud layers are placed:

Lower mud layer= 2.5 m; initial dry density= 250 kg/m^3; end density= 550 kg/m^3

Sandy drainage layer= 0.5 m;

Middle mud layer= 3 m; initial dry density= 250 kg/m^3; end density= 450/500 kg/m^3

Sandy drainage layer= 0.75 m

Upper mud layer= 2 m; initial dry density= 250 kg/m^3; end density= 500 kg/m^3

Figure 9 shows the consolidation results after 10 years. The total soil package of 8.75 m consolidates to a value of 4.3 m after 10 years (height reduction of about 50%).

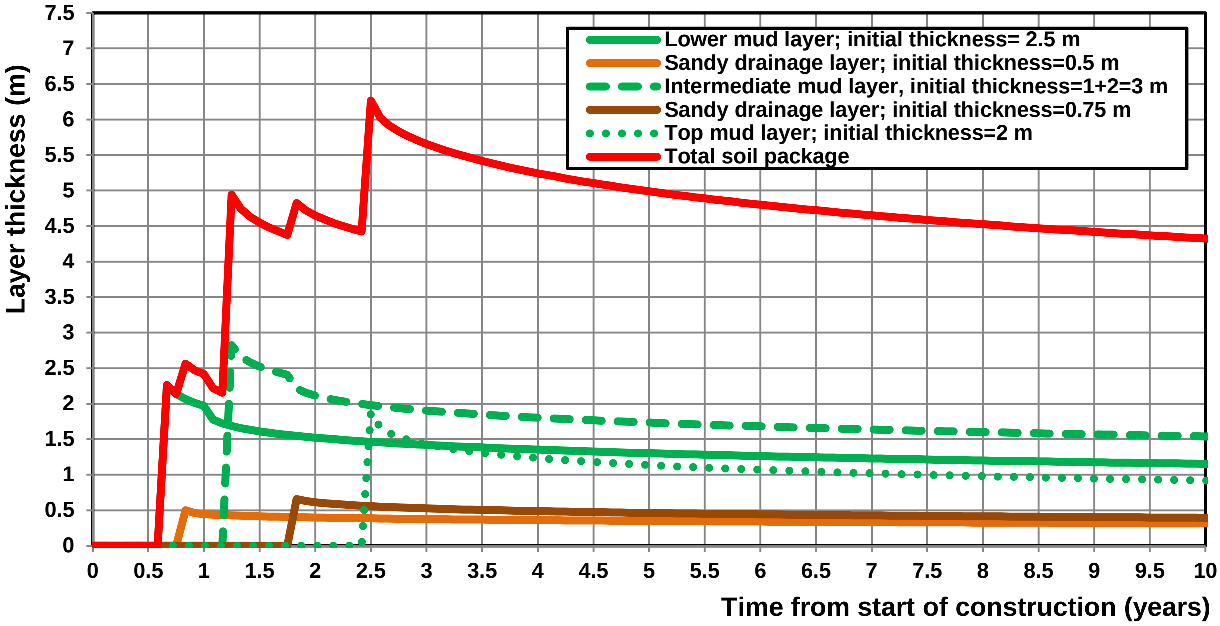

Figure 9 *Settlement as a function of time; package of three mud and two sand layers*

5.4 Consolidation of mud layer package

To obtain a total mud layer package of about 5 m (final stage), the filling and consolidation of the soil layers in the compartments should be carried out in steps, as follows:

- layer of soft fluid mud of about 2.5 m;
- drainage layer of fine sand of 1 m;
- layer of soft fluid mud of 2.5 m;
- drainage layer of sand 1 m, etc.

This package can consolidate in about 3 to 5 years to a package of about 5 m thick due to the presence of horizontal drainage layers of sand (IJburg trial Smits 1998; Dankers 2006 and Torfs et al. 1996). If necessary, drainage columns of sand can be made. Each thin drainage layer of sand should be placed after 3 months on top of the mud layer to be ensured that the mud layer already has a certain structure (matrix).

5.5 Consolidation of top soil layer

The consolidation of the top soil layer depends on the construction method:

- **mechanically placed**: the soft soil will consolidate in about 3 to to 5 years to moderately firm soil with a wet density of 1500 to 1700 kg/m^3;
- **hydraulically pumped**: the top layer will dry out and from cracks, depending on the weather conditions; the crust formation cycle is about 5 to 10 years: from fluid mud suspension under a film of water (wet density of 1200 kg/m^3) to soft soil under water (1400 kg/m^3) in about 5 years and to moderately firm soil above water (1500 to 1700 kg/m^3) in about 3 to 5 years.

Eventually, there will be a crust of moderately firm soil (1700 kg/m^3) with a thickness of 0.5 m on top of a package of muddy soil (clay/peat/sand) with a wet density of 1400 kg/m^3.

6. Water level management

The consolidation of soft soil proceeds most efficient if the soil surface is made as high as possible (order of 1 m) above the surrounding water level to create a water level difference promoting seepage/drainage flows. This requires the presence of permeable (sand) ring dikes, adjustable gates and open connections between the drainage channels, see **Figure 10**. Small-scale wind mills can also be used for the removal of surface water.


Figure 10 *Drainage of water*

A small windmill has a drainage capacity during normal wind conditions (Beaufort scale 3 to 5) of about 10 l/s or 400 m^3/day assuming 10 working hours. This gives a lowering of the water surface level with about 1 mm/day for a compartment area of 50 ha.
An adjustable gate can be used to maintain a certain preset water level in a compartment. A gate having a width of 1 m has a maximum drainage capacity of about 50 l/s or 4000 m^3/day for a water level difference of about 0.5 m, which is a lowering of the water surface of about 5 mm/day for a compartment of 50 ha.

7. Design of outer sand protection dikes

The outer protection (dike/dam) of the land reclamation can be made of:

- steep-sloped sand body protected by stones (0.2 to 0.3 m);
- mild-sloped sand body with a beach (slope of 1 to 25 for 0.2 to 0.3 mm sand).

Figure 11 shows an example of a sand dike with a mild sloping beach.

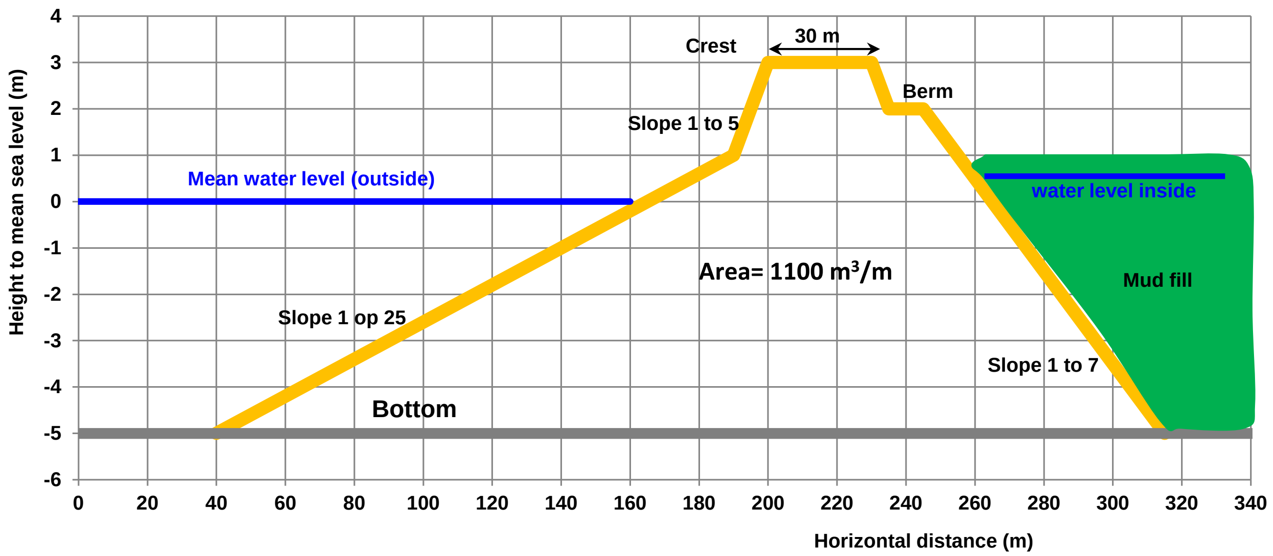

Figure 11 *Sand dike*

9. Mud pollution during construction

Additional turbidity of the water by suspended mud during construction works can occur as a result of:

- dredging of sediment (mud),
- movement of the dredging equipment,
- dumping of sediment (mud) at the reclamation site.

Silt and mud with relatively low settling velocities can easily be transported over long distances. Turbulent processes in the water column will effectively reduce the settling velocities, resulting in additional horizontal spreading of fine sediments. The fine fraction < 5 μm will be remain in suspension over a long period (days/weeks). The fraction from 5 to 20 μm will settle faster (within days) in the direct vicinity of the site.
Dredge plume measurements show that the fine sediment fractions can be spread over a maximum distance of 5 km. In windy conditions (winter) the plume concentrations will be rapidly mixed into the background concentrations of fines stirred up by wave action.
Based on various international studies of mud plumes caused by dredging processes (Van Rijn, 2005), the local increase of the fine sediment concentrations (within 100 m of the dredging site) can be up to 5000 mg/l at the bottom and 200 mg/l near the water surface. Generally, the mud concentrations go back rapidly to the background concentrations (within 1 day).

10. Monitoring Programme

In-situ monitoring is essential and should be focussed on:

- composition, rheology and density of mud to be dredged (in place and time);
- composition, rheology and density of mud dumped in the compartments;
- continuous mud concentration, flow velocity and wave height in various monitoring stations.

11. References

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