SUBAQUEOUS DISPOSAL AND CAPPING OF DREDGED MATERIAL: SEDIMENTATION AND BEARING CAPACITY

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ABSTRACT
A sedimentation test was designed to investigate the degree of mixing between clayey sediment slurries of dredged materials and settling sandy capping material of limestone origin. The added capping material settled through the tested sediment slurry at water contents higher than 350 % of dry matter, but was retained at the sediment surface at lower water contents. The consolidation rate of the sediment slurry increased when the capping material is mixed with the contaminated sediment, indicating that the limestone is interacting with the clay to increase the compaction of the slurry. These results indicate that the stability of the dredged material can be improved by adding a thin layer of capping material immediately after disposal.

RÉSUMÉ
Un test de sédimentation a été désigné afin d'investiguer le degré de mélange entre des boues de sédiments argileux de matériaux de dragague, et des matériaux sabloneux d'une couche de recouvrement sédimentant d'origine calcaire. Les matériaux de recouvrement ajoutés sédimentent à travers les boues de sédiments testées à des teneurs en eau supérieures à 350% de matière sèche, mais sont piégés à la surface du sédiment pour des teneurs en eau plus faibles. Le degrée de consolidation de la boue de sédiment augmente quand le matériau de recouvrement est mélangé à des sédiments contaminés, ce qui indique que le calcaire intéragit avec l'argile pour augmenter la compaction de la boue. Ces résultats indiquent que la stabilité des matériaux de dragage peut être améliorée en ajoutant une fine couche de matériau de recouvrement immédiatement après le dépôt.

1. INTRODUCTION

Subaqueous disposal was the dominating disposal of dredged material before concern arose regarding the environmental consequences related to this practise during the 80’s and 90’s. Subaqueous disposal is still an important alternative for uncontaminated material or even for contaminated dredged material as long as proper precautions are taken. Precautions for subaqueous disposal usually include precise control during the placement of the dredged material and construction of a protective cap on top of the disposed material.

Contaminated sediments usually have a high content of organic matter and therefore also a high water content and low shear strength. During dredging water is mixed with the sediment causing an additional increase in the water content of the dredged material. The resulting dredged material can have water content 10 – 20 % higher than *in situ* water content if dredged mechanically (Bray et al. 1997) or the water content can increase to 500 % (of dry matter) or more if discharged from a hydraulic dredge (Logigian et al 1994). The resulting disposed dredged material will be very soft and will have a low bearing capacity. This places strong restrictions on the placement technique of the protective cap and on the final thickness of this cap.

A sedimentation test was designed to investigate the degree of mixing between capping material and clayey sediment slurries of dredged materials. The aim was to investigate the bearing capacities of the sediment slurry when capping material with sand sized grains were allowed to settle freely trough the water column.

2. MATERIALS AND METHODS

A large batch (about 250 kg) of silty and clayey contaminated sediment from Bjørvika in Oslo harbour, Norway was collected by grab-sampler as a reference sample for ongoing sediment research at NGI. The content of organic and inorganic contaminants of this sediment is well documented elsewhere (Eek and Hauge 1999, Oen et al. 2003). The sediment was homogenized and sub-samples were prepared for analysis of grain size distribution and water content and for the sedimentation tests.

A well defined crushed material of limestone sieved at 2 mm with a high content of silt and sand sized particles were used as capping material.

The water content of the sediment and the capping material were determined by weighing and drying at 105°C. The grain size distributions were determined by wet sieving and falling drop method (Moum 1965). Table 1 shows water content and grain-size distribution of the sediment and the capping material used in the sedimentation tests.

Table 1. Sediment water content and grain-size distribution

	Water content (as % of dry matter)	*% dry matter < 2um*	*% dry matter 2 – 75 um*	*% dry matter > 75 um*
Sediment from Oslo Harbour	127	28.4	71.0	4,6
Capping material	0.9	0	30,4	69,6

The sedimentation test was done in 2 m high transparent plexi-glass cylinders with 100 mm internal diameter and a total volume of 15.7 l. The cylinders were equipped with a sediment trap fitted in the bottom of the cylinder to collect the settling material. A bolt and nut was attached to the sediment trap to enable undisturbed recovery of the settled material after each test. The cylinder was also equipped with three valves for recovering water samples during the tests. Figure 1 shows the design of the test cylinder used in this experiment.

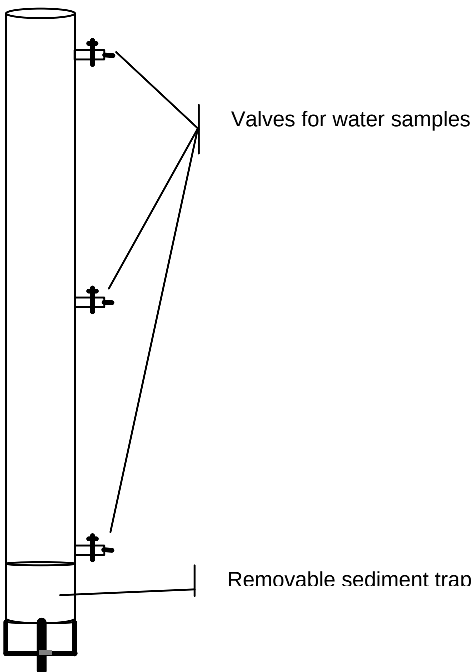

Figure 1. Test cylinder

For each sedimentation test a fresh sub-sample of 200 g of wet sediment, equivalent to 88 g dry matter (dm), were suspended in 15.7 l of seawater in the cylinders. After thorough homogenization in the water column, the stirring was stopped to allow the sediment to settle. The height of the sediment building up at the bottom of the cylinder was recorded as soon as a visible sediment layer appeared at the bottom and until the added materials had settled and consolidated to give a stable height. Water samples were collected during the course of the tests to determine dry matter content of the water phase above the settled sediment.

Three parallel tests were made with only contaminated sediment. From these tests the development of height of settled sediment and water content in the sediment was interpreted. Based on this information capping material was added to the cylinder from the top at six different times during the self-consolidation of the sediment.

The water content of the sediment in the sediment trap were calculated from the height of the settled sediment and the amount of dry matter in the settled sediment corrected for measured dry matter content in the water phase. The calculated water content of the settled sediment at the time of added capping material is given in table 2.

Table 2. Sediment conditions when adding capping material

Settling time (min.)	*26*	*61*	*150*	*232*	*340*	*4352*
Sediment height (cm)	10.3	6 85	5.26	4.65	4.33	3.50
Water content (% of dm.)	1350	631	440	372	351	245

After 2 days the sediment had consolidated to a sediment height of 3.4 cm (±0.2 cm) in the sediment trap at the bottom of the cylinder. The water was drained from the lower valve above the settled sediment and the trap was removed from the cylinder. The settled sediment was divided into 1 cm layer. Each layer was analysed for grain size distribution.

3. RESULTS AND DISCUSSION

Figure 2 illustrate the development of the height of the settled sediment in the three parallel sedimentation tests with only contaminated sediment. The results show that the settled sediment rapidly builds up to a height of 9.6 cm (±1.2 cm) corresponding to an average water content of 1350 % of dm. From the maximum height, the sediment consolidates with an asymptotic decrease in sediment height stabilizing at 3.4 cm (±0.2 cm) corresponding to an average water content of 245 % of dm.

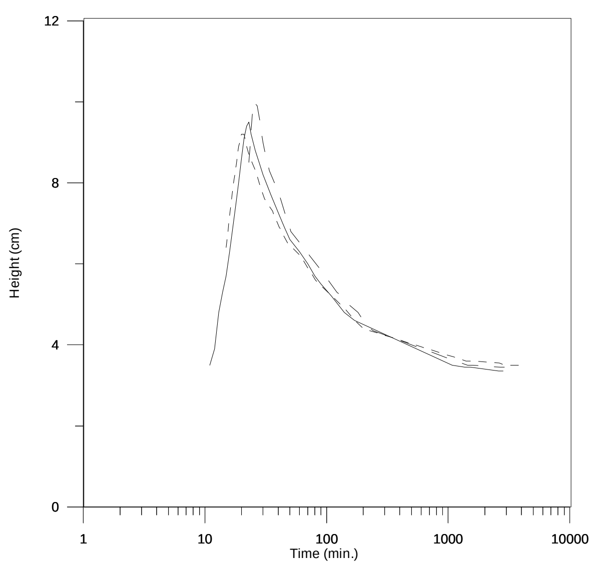

Figure 2. Height of settled sediment in three parallel sedimentation tests (no capping material).

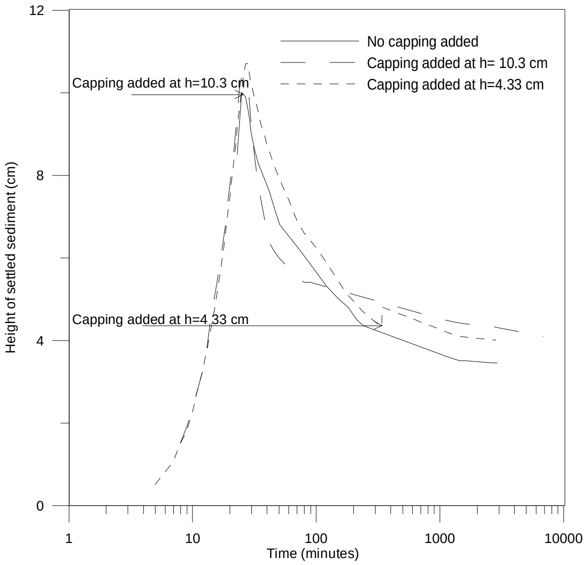

Figure 3. Height of settled sediment with capping added at different times.

Figure 3 shows the sediment height during sedimentation, consolidation and placement of the capping material in one sedimentation test without capping material and two selected tests with contaminated sediment and capping material.

Figure 4 presents sand content of the different layers in the settled sediment from six sedimentation tests with capping added at different times and one test with only contaminated sediment. These results show that in the settled sediment in the test conducted only with contaminated sediment the greatest sand content is found at the bottom of the sediment and the sand content is decreasing towards the sediment surface.

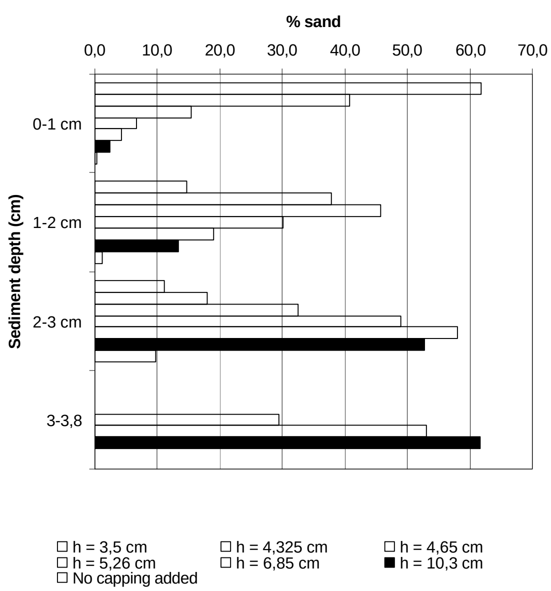

Figure 4 Percent sand in the sediment in layers in settled sediment.

When the capping material is added the total sand content in the settled sediment increases. This is because the sand content in the capping material is higher than in the sediment.

When the settled sediment reaches its highest volume and highest water content at h = 10.3 cm after about 25 minutes of sedimentation, most of the sand in the capping material added at this time is settling through the sediment at the bottom of the test cylinder. The addition of capping material at this stage results in only a small increase in sand content at the sediment surface. Results from the other tests shows that the retention of capping material on the sediment surface increases as the consolidation is allowed to progress before adding the capping material.

Comparing the two tests where capping material were added at sediment height of 4.65 cm (water content of 372 %) with adding the capping material at sediment height of 4.33 cm (water content of 351 %) shows that the amount of sand in the sediment surface increases from 15 % to more than 40 %. This means that the tested sediment reaches a bearing capacity that can bear most of the sand in the capping material when the sediment has a water content between 351% and 372%. The plot of sediment height (figure 3) from the test where capping is added at h = 4.33 shows an increase in height immediately after the capping material is added meaning that most of the capping material is resting on top of the settled sediment at this stage. This was also clearly visible during the test (Figure 5).

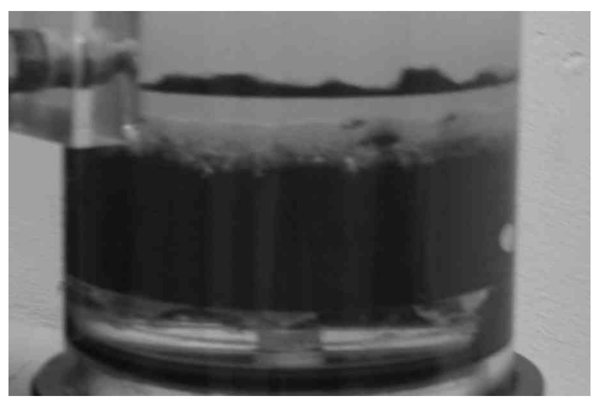

Figure 5 Capping material on top of settled sediment

Figure 3 shows that, the height of the settled sediment after 2 days of consolidation is higher in the tests where capping material were added than without capping material. This is because the settled sediment consists of more material in these cases (contaminated sediment + capping material). However the plot of sediment height after adding capping material at h=10.3 cm shows that the decrease in sediment height was faster immediately after the addition of capping material. This means that the consolidation of the mixture of the settled sediment and the capping material is faster than consolidation of contaminated sediment alone. This observation can be explained by increased attractive forces between clay particles and between clay particles and fine grained particles of the calcareous capping material. Since the water content of the settled sediment is very high when this observation is made the increased attractions between particles can cause flocculation and a denser packing in the slurry resulting in the observed increase in consolidation. These mechanisms are most likely similar to the interaction occurring when soft clays are stabilized with lime (Rogers et al 1996).

4. CONCLUSIONS

The fact that sand sized capping material can be placed on top of sediment with a water content of 350 % shows that it is possible to place a thin capping layer on top of dredged material soon after sub-aqueous disposal. The increased consolidation rate caused by the capping material indicate that the bearing capacity of the sediment can be improved by adding a small lime bearing capping layer immediately after disposal, and that a larger cap could thereafter be placed on top of the first cap.

However, there are still great uncertainties on how placement techniques and density flow during placement of capping materials will affect the stability and bearing capacity of dredged materials.

Further investigations are presently conducted at NGI to learn more about the mechanisms that determines the consolidation rate and the stability of dredged material under influence of different capping materials.

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