CHAPTER 225

CONSOLIDATION AND RHEOLOGICAL PROPERTIES OF MUD DEPOSITS

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Abstract

The temporal evolution of consolidation and associated rheological properties of mud deposits has been studied by means of laboratory experiments for more than 40 sites throughout the world.

Standard procedures have been used for all these experiments.

The present paper describes the experimental procedures and gives a summary of the results obtained.

1. Introduction

Typical engineering studies involving mud carried out for 30 years by SOGREAH(Grenoble) and Laboratoire Central d'Hydraulique de France (Maisons-Alfort) have covered the main fields of port and coastal engineering, namely:

- Maintenance of depths in harbour basins, navigation channels and water intakes,
- Navigation in muddy waters(Brossard et al., 1990),
- Evolution of waste disposal sites.

In order to adequately describe the mechanical properties of mud deposits, standard laboratory experiment procedures have been developed and applied.

Two basic parameters are measured to characterize these properties:

The dry sediment density Ts(z,t) in kg/m3 or g/l
 The yield value ty(Ts) in N/m2

with z : depth in the deposit and t:time
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2. Consolidation experiments

2.1 Description of the procedure

These experiments are carried out in settling tubes 0.10m in diameter. Mud samples are diluted in pure or salt water to obtain an homogeneous fluid mud with an initial dry sediment density (Tsi) varying between 5 and 300 g/l and an initial height (Hi) varying between 0.25 and 3m. The temperature is kept around 20°C. The evolution of the mean dry sediment density is monitored by measuring the position of the water-mud interface.

The density profile over the depth is measured at different time intervals with a gamma-ray source and a detector(non-destructive measurement).The duration of the test is usually 100 days.

2.2 Evolution of the mean dry sediment density

The mean dry sediment density is deduced from the position of the water-mud interface by the relationship:

Tsm(t) = Tsi * [H(t) / Hi](1)

Results are plotted on a semi-log diagram.Typical results are presented hereafter(fig 1).





Figure 1. Consolidation tests - typical results



Figure 2. Consolidation tests:Wouri estuary Influence of the initial dry sediment density



Figure 3. Consolidation tests:Dunkirk harbour Influence of the initial dry sediment density

After 100 days the consolidation process has reached its final state in a few cases.Equatorial muds(Mahury,Douala, Owendo)with high kaolinite contents and a very fine particle size have a very low rate of consolidation and have not reached their final state.European estuarine muds (Loire,Escaut,Gironde,Orne,Dives) are made of a mixture of several clay minerals(illite,smectite, kaolinite,chlorite)and include quartz, feldspar and a variable proportion of silt.In these cases, the consolidation is a function of composition.

The comparison of results with the same initial height but different initial dry sediment densities shows the greater the initial density, the greater the final density. A typical result is shown on fig 2(Wouri estuary,Cameroon).In a few cases,when a small proportion of sand is included in the mud, the opposite trend is observed as shown on fig 3(Dunkirk harbour,France,5% of sand).This is due to the segregation of sand particles, which form thin drained beds increasing the final density.

The comparison of results with the same initial dry density but different initial deposit heights shows that the final density is not too influenced by this parameter when it varies between 0.25 and 3 m.Typical results are shown on fig 4.



Figure 4. Consolidation tests:influence of the initial height of deposit

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2.3 Evolution of the vertical profile

During the consolidation test, a vertical gradient appears and increases with time.Figure 5 shows a typical result in the Gironde estuary.Study of the influence of the initial deposit height shows that the gradient increases when the height decreases(fig 6).These results can be applied to increase the stability of waste disposal sites by depositing thin layess and letting them consolidate a few days in between.



Figure 5. Consolidation tests:Gironde estuary Vertical profiles at differents time intervals (Tsi = 200 g/l ; Hi =0.75 m)



Figure 6. Consolidation tests:Loire estuary Vertical profiles after 6 days(Tsi = 100 g/l) Influence of the initial deposit height

3. Rheological measurements

3.1 Purpose of the measurements

Knowledge of the dry sediment density of a mud deposit is not enough to characterize its mechanical properties in the presence of hydrodynamic forces. Flume tests have given evidence that the erodability of cohesive sediments is primarily a function of their rheological properties, which are not simply related to the dry density.

The complexity of natural sediments precludes a fundamental interpretation of their rheology.That is why a simple and standard procedure has been used in order to obtain good comparative results and be able to develop empirical relationships to be applied in engineering projects.

3.2 Description of the procedure

The measurements are made with a BROOKFIELD LVT viscometer using 4 rotating cylinders with the following dimensions:

| | 1 | 2 | 3 | 4 |
|------------------------|-------|---------|---------|--------|
| diameter(mm) | 18.84 | 10.25 | 5.88 | 3.20 |
| length (mm) | 65.10 | 53.95 | 42.86 | 31.01 |
| range of use (N/m2) | < 1. | 1.to 4. | 4.to 10 | . >10. |

The speed range varies between 0.3 and 60 rpm and the temperature is usually kept at 20°c.

The yield value is determined with the following procedure:

- Strong homogenization of the mud,
- Introduction of the rotating cylinder,
- Keeping at rest during 2 to 5 min in order to avoid thixotropy on one side and consolidation on the other.
- Starting with the lowest speed of 0.3 rpm.

The yield value (τy) is defined as the peak value of the recorded shear stress as illustrated by figure 7. In some cases, rheograms are determined by increasing the speed.

3.3 Typical results

Measurements are carried out with the same mud and different dry sediment densities.Results are plotted on a log-log diagram as illustrated by figure 8. These results show that in many cases,two domains can be observed .At low concentrations the mud sample looks fluid.When the concentration increases,the mud becomes plastic and the yield value increases dramatically. For such a fluid mud,the relationship between the yield value and the dry density is usually of the form:

 $\tau y = C_1 \quad Ts^3 \tag{2}$

For a plastic mud, this relationship becomes:

 $\tau y = C_2 \quad Ts^6 \tag{3}$

 $\rm C_1$ and $\rm C_2$ are parameters depending on the site studied.The limit between the two domains usually lies within 1 to 3 N/m2.

4. Applications

The above measurement data are usually used for particular engineering projects including desk studies, mathematical simulation of mud transport or physical scale models. Two more general applications can be noted: The first deals with navigation in muddy waters where it is necessary to define the nautical depth in the turbidity maximum of many estuaries. Galichon et al(1990) describe in detail the use of the yield value to define the nautical depth in the Gironde estuary.

A second application is the investigation of relationship between the critical shear stress for $erosion(\tau ce)$ under a steady current and the yield value.First results from small-scale flume tests have shown that such a relationship can be written as:

 $\tau ce = 0.17 \sqrt{\tau y}$ for fluid mud

 $\tau ce = 0.10 \tau y$ for plastic mud



Figure 7. Rheological tests:definition of the yield value



Figure 8. Rheological tests:typical results

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