Effect of swelling clays in the instability of clayey soils Case study: Quicksand and Quickclay

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Abstract: The aim of this work is to study the effect of swelling clays on the instability of two soils, quicksand and quickclay, famous for their high damaging effect. The complex flow behavior of these materials is based on the X-Rays diffraction characterization results and the preparation of laboratory quicksand and laboratory quickclay, which mimic exactly the flow behavior of these two natural soils. We show that a spectacular liquefaction of the Quicksand and Quickclay occurs when a stress is applied to the material. By constructing both 'laboratory quicksand' and 'laboratory Quickclay', we demonstrate that the liquefaction is due to the structure of these two soils. The presence of both swelling clays and salt play a key effect on the instability of the two soils.

Keywords: Quicksand, Quickclay, Clay, Rheology, landslides.

I- Introduction

Although the name of the two well known unstable soils quicksand and quickclay are quite similar there effects are completely different. Quicksand is the generic name for unstable soils reputed to trap anyone who treads on it. Hollywood produced dozens of movies in which people drown in quicksand; the most classic one is probably "The Hound of the Baskervilles". In the movie a young lady (and later on almost Sherlock Holmes himself, also) disappears into 'wet' quicksand.

On the other hand Quickclay is an unstable soil responsible for a completely different phenomenon; landslides. Many deadly landslides in Norway, Sweden, Canada and Russia happened because of the presence of the quickclay.

II- X-Ray diffration charaterisation of the quicksand and quickclay

II-1- X-Ray diffration charaterisation of the quicksand

The quicksand samples are collected in the region of Qom, in Iran, having one of the largest and most notorious quicksand-areas in the world. The X-Ray results show that the mineralogical composition of the quicksand from Iran consist principally of around 50% Gypsum and Calcite, 35% Quartz and Albite and other primary minerals, the rest is represented by the clays. We therefore, focus on the clay fraction (size of the particles < 2µm). This fraction is separated from the rest by sedimentation and a mineralogical characterization by mean of X-ray analysis is conducted (See Figure 1.). We observe small reflections at 7Å which represent Chlorite and Kaolinite, the reflection at 10Å represents the illite. At 14Å we observe the most intense peak and this represents smectite.

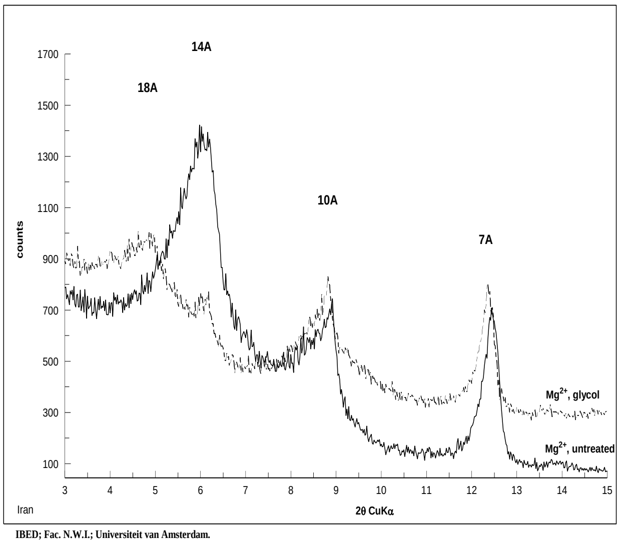

Figure 1: X-ray analysis of the clay fraction (size of the particles < 2µm). We represent the X-Ray pattern of the quicksand sample untreated and the one treated by the ethylene glycol in the same graph.

II- 2- X-Ray diffration charaterisation of the quickclay

The natural sample used in this study is a natural product collected from 10m depth at Tiller, Trondheim (Norway). The results of the X-Ray pattern show that the

bulk sample consists of 60-80 weight % of clays muscovite/illite (10Å peak), chlorite (14Å and 7Å peak), and some kaolinite (7Å peak) and ≈ for 20-40 weight % primary minerals like quartz, amphibole, feldspar and pyrite. See Figure 2.

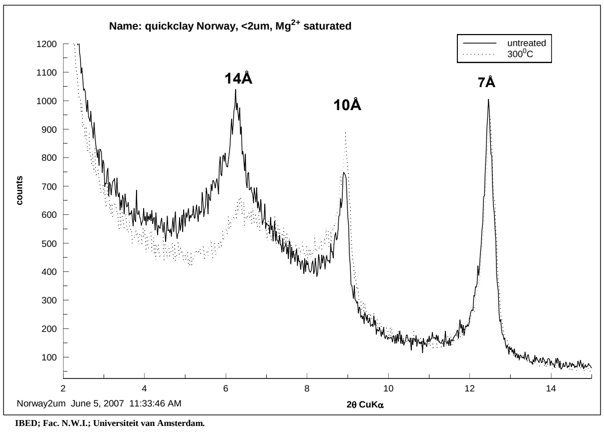

Figure 2. The X-ray diffraction pattern of fine fraction of the sample, size < 2μm. The x-ray analyses were carried out on Mg^{2+} saturated sample at a relative humidity of 55% and on Mg^{2+} saturated and heated sample at 300°C.

As a conclusion, Swelling clay represent an important proportion (≈95%) of the small size fraction of the quicksand sample. the swelling clay represent almost 7% of the bulk sample, the rest being sand, which includes primary minerals and carbonates.
On the other hand quickclay sample is almost 80% clay and the rest are primary minerals. Non swelling clay represents around 97% of the clay size portion and the rest is partially swelling clays.

III- Rheology of the quicksand and quickclay

The composition of the quicksand and quickclay soils consists of sand, clay and water. The question is what is the origin of the quikness of these two soils. When the quicksand or quickclay comes into contact with water, it form a stable gel. The flow behavior of these gel is viscoelastic. This means that it can behave as a solid or a liquid depending on the circumstances. The best experimental technique used to study the flow behavior of such materials and to answer the previous question is rheology.

III-1- Rhology of the quicksand

To investigate the structural cause of the liquefaction and subsequent phase separation, we created "laboratory quicksand" that reproduces almost exactly the rheology of natural quicksand, as shown in figure 3. We prepared the Laboratory quicksand by mixing sand and the swelling clay Bentonite. The sand used is the silica particles with a polydisperse size (50 to 200μm), its density is ≅ 2.9g/l. Different proportions of clay and sand were tried and the different rheological experiments made on the natural quicksand were done on the Laboratory quicksand. The mixture of 90wt% sand and 10wt% Bentonite, to which different amounts of water were added, mimicked of the flow behavior of the natural quicksand best [1].

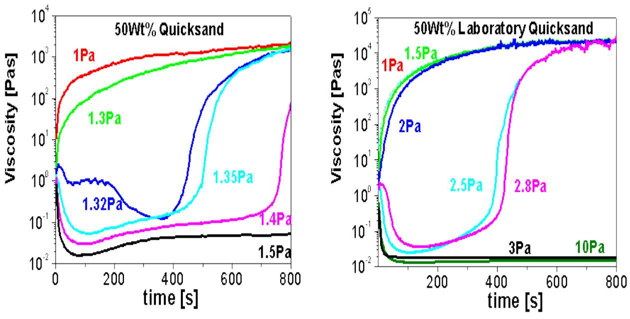

Figure 3. The graph (a) and (b) represent the results of the viscosity bifurcation [2] of the 50 wt % suspensions of quicksand and laboratory quicksand respectively.

III- 2- Rheology of the quickclay

Based on X-Rays diffraction results, we prepared a laboratory quickclay with only illite because it is the most important component. The effect of variation of water content on the flow behavior of the illite suspension is studied by means of the viscosity bifurcation experiment. We followed the same process of preparation for the natural quickclay the preparation as of the illite suspension. We subsequently apply the same constant stress level of 5Pa. The results are shown in the figure 4.

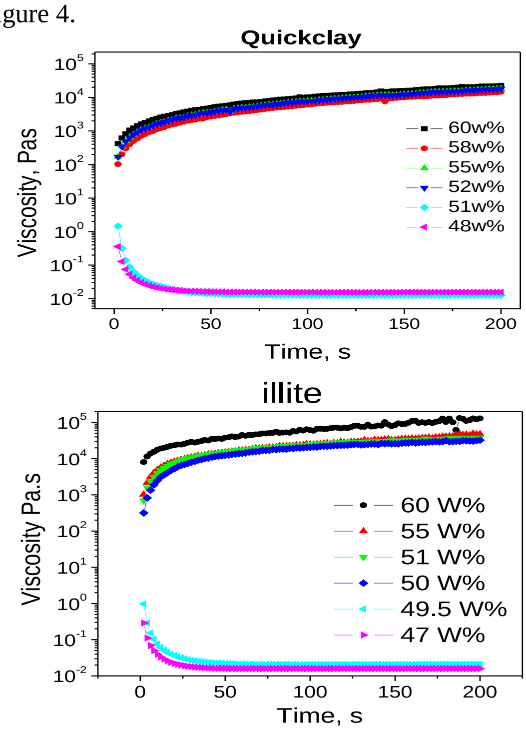

Figure 4. Liquefaction of natural quickclay under an imposed constant stress of 5Pa. Viscosity is plotted against time at constant stress and for the different quickclay suspensions of different water contents indicated in the figure.

The results show that the illite is a good candidate for the laboratory quickclay, but we should also test how sensitive the illite is to the salt content. To study this, we measured the conductivity of the illite and we found a very low value of 63 µS compared to 566µS for the natural quickclay. The effect of salt on the elasticity of the illite suspensions is studied using the dynamic oscillatory measurements. In figure 5 we observe that, even if we do not add any salt, the elasticity of the illite suspensions is subsequently higher than the elasticity of the natural quickclay. The elastic modulus of the illite is very low because the illite suspension is phase separated; The illite particles sediment and form a very rich clay phase in the bottom of the couette cell and very low viscosity water rich phase in the top. The vane geometry with which we study the viscosity is situated in the middle of the couette cell and there is a large space between the lower end of the vane and the bottom of the outer cylinder. When the sample sediments, the apparent value of the G' is very low, because the rheometer mostly measures the elasticity of the supernatant fluid; almost pure water in this case.

When a small amount of salt is added to the suspension, a sharp increase is observed in the suspension with illite particles. We can also see from the Figure 5 that, when we add enough salt we observe a decrease in the G'. All these observations show clearly that the illite alone can not mimic the flow behavior of the natural quickclay.

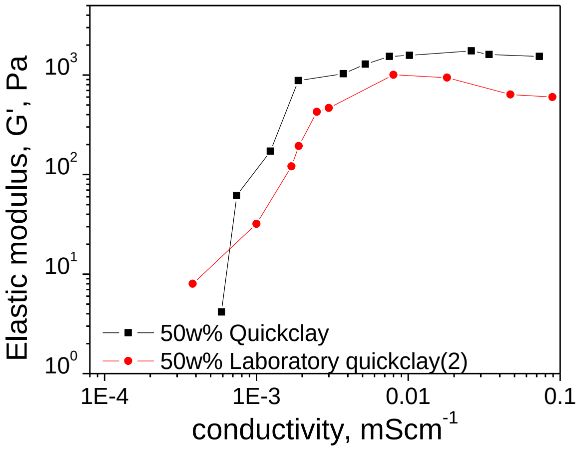

Figure 5. The elastic modulus G´ versus the conductivity of the quickclay suspension and the Laboratory quickclay "3% washed Bentonite + 97% illite".

From the X-ray study we know that the natural quickclay also contains of around 3% of swelling clay. But the problem is that the conductivity of 3wt% swelling clay (bentonite) in water is around 1536 µS, what is much higher than the conductivity of natural quickclay. To solve this problem we prepared a Laboratory quickclay adding 3% of washed bentonite to 97% illite (around 16µm) [2]. We washed the bentonite by suspending it in water then sediment it by the centrifuge, in agreement with the ideas of Rosenqvist that in nature the 'quick' properties appear after the soil has repeatedly been leached by rain [3]. This was also the reason why, in the past, quickclay soils have been successfully stabilized by injection of salt water [4]. The elastic properties of this artificial laboratory quickclay perfectly match that of the natural sample as a function of electrolyte concentration. On the other hand, if no swelling clay is added, the material cannot be stabilized by salt, nor be destabilized by leaching. This shows that the contribution of the few percent of swelling clays is essential for the quickclay behavior.

Conclusion

Quicksand is a loose granular packing of sand particles stabilized by a clay matrix that forms a particulate gel. When we apply a stress higher than the yield stress we liquefy the clay matrix, and the granular assembly collapses, expulsing water.

Quickclay is a very dense suspension of silty sized platelike particles, Under constant gravitaional stress of a sloop of a mountain in nature, this soil can becomes extremely fluid when small variation of the sloop happens (Human's work in the neighborhood), variation in the soil's water content or salt content.

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