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# Influence of compaction condition on the microstructure of a non-plastic glacial till

## L'influence de condition de compaction sur la microstructure d'un matériau non-plastique

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ABSTRACT
The influence of compaction water content on the structure has been well known for clayey soils, but has never been studied for granular materials. In this paper the effect of compaction moisture on the structure of a non-plastic till is investigated by means of scanning electron microscopy, water retention curve, permeability and mercury intrusion porosimetry tests. The results show that the structure of pulverulized materials, in some degrees similarly to cohesive materials, is affected by the compaction condition. When compacted on the dry side of the optimum water content, the porous system is characterized by a relatively uniform medium pores, while in case of compaction on the wet side, due to formation of coarse aggregates, pores size is very diversified. The few large pores are surrounded by numerous small pores, and the hydraulic behavior of the porous system of the soil is dominated by the small pores.

RÉSUMÉ
L'influence de la teneur en eau de compactage sur la microstructure des sols cohérents a était connue depuis long temps, mais jamais était étudies pour les sols pulvérulents. Dans cet article, ce phénomène est examiné par la courbe de retentions d'eau, les images microscope électronique et les essais de porosimetrie par mercure. Les résultats montrent que les échantillons compactés en coté sec de la teneure en eau optimum possèdent un système poreux uniforme par apport aux échantillons compactés du coté humide, dans lesquelles les diamètres des pores sont diversifiés et les nombreux micropores entourent des macro pores. Ce phénomène est bien confirmé par les résultats des essais de perméabilité et de consolidation.

## 1 INTRODUCTION

Compaction water content has been known for many years to influence the microstructure and behavior of compacted clayey materials (Cabot and Le Bihan, 1993; Prapaharan et al., 1991; Daniel and Benson, 1990 and Mitchell et al., 1965). With increasing water content, the soil fabric of clays becomes increasingly oriented, while dry of optimum compacted clayey soils are rather flocculated. At the optimum water content, an intermediate fabric exists (Lamb, 1958-a). Garcia-Bengochea et al. (1979) reported pore size distribution of a silt-kaolin mixture containing 90% silt and 10% kaolin was also influenced by compaction condition. Lamb (1958-b) reported that, due to a difference in the arrangement of clay particles, the coefficient of permeability of clayey materials compacted dry of optimum is generally much higher than those compacted wet of optimum.

For granular materials, most of researches have been performed to study the influence of compaction methods on the microstructure (Chapuis et al., 1989), and less attention has been paid to the influence of compaction water content.

In this research, the question is whether the microstructure of glacial tills (a granular material composed of gravel and sand with a relatively low percentage of cobble and silt) is influenced by compaction water content.

## 2 MATERIAL AND METHOD

A glacial till designated as LG-4 Till was obtained from James Bay in northwestern Quebec, Canada. Series of tests were carried out on the passing portion of a 5 mm opening sieve which is a well-graded silty sand, containing 57% sand, 41% silt and 2% colloidal particles, with a maximum dry density of 2050 kg/m³ and an optimum water content of 7% (Davoudi, 1999).

As the microstructure, the pore size distribution, the coefficient of permeability and the solid-water characteristic of a soil are obviously related together (Vanapalli et al., 1999; Mitchell et al., 1965 and Fredlund et al., 1997), the investigation was done using the results of three series of tests: Mercury Intrusion Porosimetry, Scanning Electron Microscopy, and water retention curves. All tests were carried out on two groups of specimens, dry and wet, and their results were compared. Dry group are specimens being compacted on the dry side of the optimum water content, and the wet group on the maximum workable moisture, 9%. All specimens were compacted to 96-100% of maximum dry density.

## 3 MERCURY INTRUSION POROSIMETRY (MIP) TESTS

According to Lawrence (1978), Kenny (1980) and Reed et al. (1980) the mercury intrusion can be used as a reliable technique for the study of soil structure. Three specimens compacted at different water contents, Table 1, were prepared and tested based on standard ASTM D4404-84. A complete cycle of ascending and descending pressure was applied to the mercury and at each pressure step the volume of the intruded and extruded mercury was measured. The results showed that the percentage of micropores (<6.3 μm) decreases from 61.9% to 49.8% and 47.7% as the compaction water content decreases from 8.5% to 6.9% and 6%, respectively.

Table 1- Characteristics of mercury intrusion porosimetry test specimens

| Specimen | Compaction Water Content (%) | Void Ratio | Dry Mass (gr.) |
|---|---|---|---|
| PR4-8 | 8.5 | 0.314 | 4.6208 |
| PR7-7 | 6.87 | 0.344 | 4.3371 |
| PR6-6 | 5.97 | 0.336 | 6.0392 |

Open macropores volume (OM) in terms of percentage of total porous volume is illustrated versus compaction moisture in Figure 1 showing an increase of 15.6% with a decrease of 2.5% in compaction water content. It rises from 18% to 29.7% and 33.6% in samples PR4-8, PR7-7 and PR6-6, respectively. Contrarily, the percentage of trapped porous volume (TP) is directly related to the compaction water content, particularly for water contents less than the optimum. It increases as much as 20% with an increase of 2.5% in compaction moisture.

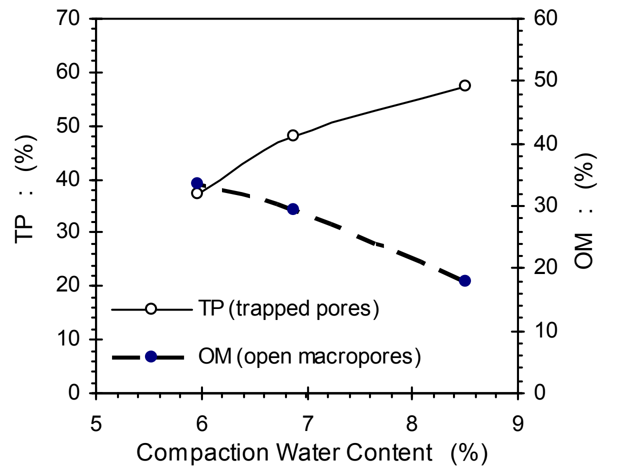



Fig 1- Volumetric percentage of open micropores and all trapped pores as a function of compaction water content

4 WATER RETENTION CURVE (WRC) TESTS

Vanapalli et al. (1999) reported that the solid-water-air interaction of a soil is influenced by its structure. Miller et al (2002) used the WRC for studing the effect of compaction moisture on the characteristics of compacted soils. It is known that at a given moisture content, the magnitude of soil matric suction (*u*) is inversely related to the largest radii of meniscus which in turn, is a function of the microstructure. The WRC was investigated for three specimens compacted at three different moistures and the results are presented in Table 2 and Fig. 2. All the tests were run in drainage process based on ASTM D2325-68.

The WRC of specimen t-w1-6 compacted near the optimum water content is considered as the reference. Its degree of saturation at the end of submergence was 85.6%. The curve shown has two breaking points. The first one corresponds to a 69 cm water suction, at which degree of saturation is 81%, and is considered as the *air entry value* of the specimen (AEV). At this pressure, air starts to enter the largest pores (macropores) and pushes out a portion of pore water (Fredlund & Rahardjo, 1993). As the air pressure is increased, smaller pores start losing water, on one hand, and simultaneously more water is removed from the macropores. At the second breaking point, at a suction of 129 cm of water, degree of saturation has decreased to 55% and the rate of water removal drops sharply. This point is referred to as the *micropore suction point* (MSP). The number and the diameter of undrained micropores decrease as suction increases, and the remaining water approaches the *residual water content*. The segment between the two breaking points reflects mainly the desaturation of macropores, while segment beyond the second breaking point reflects the desaturation of micropores.

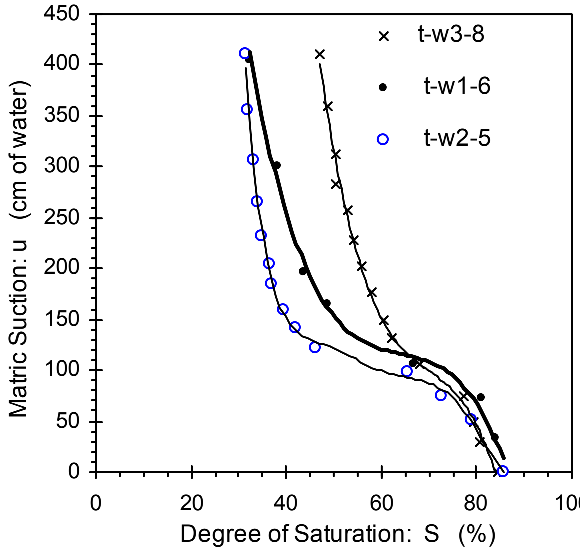



Fig 2- Water retention curve (WRC) for specimens compacted at different water contents

The results of t-w2-5 compacted dry of optimum moisture and t-w3-8 compacted wet of the optimum show quite different behaviors. The main difference is related to their macropore segment. The position of this segment of the three curves with respect to each other indicates that the radius of interconnected macropores is inversely proportional to the compaction water content. The slope of this segment reflects the diversity of interconnected macropores radius. The increasing slope from specimen t-w2-5 to t-w3-8 indicates that the macropores are more uniform in specimen compacted dry of optimum, and more diversified when compacted on the wet side. The horizontal projection of the segment reflects the interconnected macropores volume and, as shown by the figure, is inversely proportional to the compaction moisture content.

Table 2 shows AEV is proportional to the compaction water content and increases from 50 to 74 cm. Comparison of the saturation degree of specimens at MSP, also reveals the volume occupied by micropores is directly proportional to the compaction moisture.

5 SCANNING ELECTRON MICROSCOPY (SEM) TESTS

Two samples were compacted at 4.76% and 8.71% moistures to almost identical porosity of 26.7% and 26.2%, respectively. Once dried, were intruded by proxy resin, and after being hardened were cut, finished and prepared for scanning.

The specimens were scanned by means of backscattered electrons in a 1.5 mm wide strip along their diameter, and a part of recorded images at scale 1:50 are presented in Figure 3. Based on this scale, grains of 0.25 to 3.75 mm diameter, represent silt

Table 2- Characteristics of specimens of water retention tests and the results

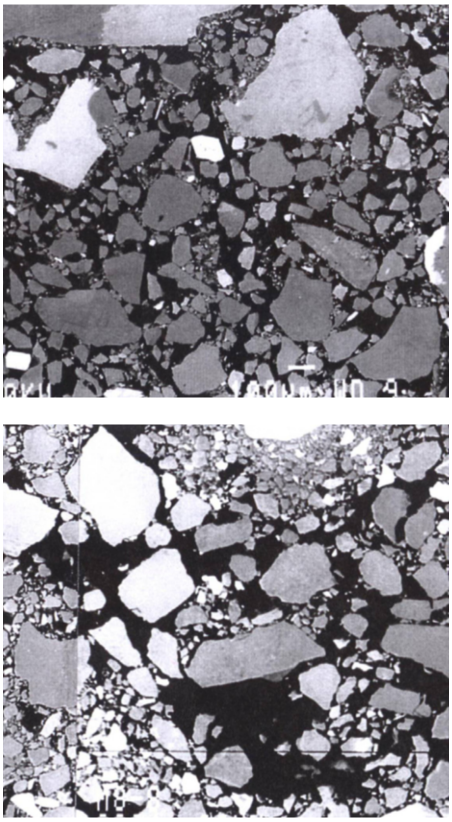
| Test No | End of Compaction | | End of Submergence | | Air Entry Value (AEV) | | Micropore Suction Point (MSP) | |
|---|---|---|---|---|---|---|---|---|
| | Void Ratio | $w$ (%) | $S$ (%) | $u$ (cm) | $S$ (%) | $u$ (cm) | $S$ (%) | $u$ (cm) |
| t-w2-5 | 0.346 | 5.19 | 85.8 | 0.0 | 79 | 50 | 46 | 122 |
| t-w1-6 | 0.357 | 6.3 | 85.6 | 0.0 | 81 | 69 | 55 | 129 |
| t-w3-8 | 0.346 | 8.63 | 84.4 | 0.0 | 77 | 74 | 62 | 134 |

particles and therefore make up a large proportion of the sample, as do sand particles. The micropore family is detected at 0.3 mm and smaller, and cannot be analyzed by these images. The global porous system and the structure of the mass can nevertheless be investigated and evaluated.

In sample M5-5, compacted 2.24% dry of optimum (Figure 3-*a*), silt particles are well distributed between the sand grains such that each of them contributes individually in the skeleton of the mass. The void space thus is well distributed between the grains and eventually between the tiny aggregates formed by the fine silts. This arrangement results in a porous system composed of relatively uniform macropores, as well as of micropores. Most of the macropores have a radius of the order of 25 µm with a maximum measured of the order of 50 µm. Macropores appear to be fairly well interconnected, which results in a high contribution to water flow. As revealed in the figure, most of the porous volume belongs to the macropore family, as was found during the mercury intrusion porosimetry tests. In sample M8-8 compacted wet of optimum, Figure 3-*b*, silt particles gather around the sand grains and form coarse aggregates. This arrangement results in the formation of a few large macropores and several smaller macropores. A wide range of macropore radii is observed, the largest being in the vicinity of 130 µm, while most of them are surrounded by micropores. This arrangement results in either increasing the tortuousity within the macropore system, and/or isolating the macropores and preventing them from contributing substantially to water flow.

## 6 SUMMARY AND CONCLUSION

The scanning electron microscopy and the mercury intrusion porosimetry tests show that the microstructure of LG-4 till is significantly affected by the moisture content at which it is compacted. When compacted on the wet side of the optimum, the silt particles gather around the sand grains and form coarse aggregates, which can be easily deformed and pushed into large interaggregate pores under any applied pressure. A larger proportion of the porous volume is composed of micropores surrounding the fewer large macropores resulting in either a considerable degree of tortuousity within the macropore system, or prevents macropores from fully contributing the water flow. Furthermore, macropores and particularly well-interconnected macropores occupy less volume compared to the samples compacted on the dry side of the optimum. If compacted on the dry side, the particle arrangement is much more uniform with little aggregation of particles. The void space is well distributed between particles, relatively uniform macropores are formed, and most of the porous volume is composed of macropores. These arrangement results either the hydraulic conductivity to be two times higher than wet specimens, and in case of loading the applied force to be distributed between all grains and consequently a lesser deformation is produced. Due to the dominance of micropores in specimens compacted wet of optimum, the matric suction corresponding to a given moisture content is much higher than that for a soil compacted on the dry side of optimum. Similarly, its air entry value and matric suction corresponding to the residual moisture is higher.



*(a)*

*(b)*

Fig 3- Microphotographs of specimens compacted at different water contents (w): *a*)w=%4.76; *b*)w=%8.71. (scale 1:50)

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