Influence of Degree of Saturation on Bearing Capacity and Compaction of Glacial Till Embankments

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ABSTRACT: In Sweden the consumption of aggregate each year equates to eight tons per capita and is responsible for half of all goods transportation in Sweden. Approximately 20 million tons of aggregate material is transported to different road construction sites each year. With a more balanced and active design code site-won materials could be utilised as an alternative to imported rock fill. This would not only reduce transportation costs but also minimise impact on the environment. This paper explores the possibility of utilising site-won glacial till in road pavement construction above the current permitted level of capping layer level. The bearing capacity of glacial till at three different sites is investigated with corresponding laboratory tests on compaction properties, since compaction is a crucial factor in the bearing capacity obtained. Results are compared with the criteria specified in the Swedish design code for each structural road layer. It will be shown that a fill with moderate fines content, compacted close to its optimum water content, meets the requirements for a sub-base material on bearing capacity. This is due to the influence of negative pore pressure and its positive impact on shear strength. Certain areas of uncertainty remain such as frost susceptibility and the effects of seasonal variation on degree of saturation beneath a paved construction and should be tackled in the future. To enable future implementation of tills in structural road layers a new approach to managing fills on site is required which covers crucial issues such as weather conditions and timing of the construction works.

KEY WORDS: Static plate load bearing test (SPB), Glacial till, Degree of saturation, Proctor compaction

1 INTRODUCTION

More than 75 percent of the land surface of Sweden is covered by glacial till. Even though till is encountered in almost every road construction site their use as a construction material is very limited, and it is primarily used as an embankment fill material. This is due to the variability in mechanical properties of different glacial tills, and the plentiful supply of naturally occurring gravel and rock fill, which have properties that are usually better and more predictable.

In 1996 the Swedish authority introduced a new law, (SFS, 1995) concerning tax on sand and gravel from natural deposits. Approximately 50 percent of the total aggregate supplied was used for road construction, (SGU, 2004) which makes it the largest individual consumer. The majority of the road network has been constructed with rock fill or natural gravel, which has previously been considered an unlimited resource. The general aim of the law was to promote better sustainability and raise interest in other alternatives.

Greater utilization of site-won material will not only reduce transportation costs of site-imported materials but also reduce disposal costs for glacial till. In 1999 (SFS 1999) a second tax on natural deposits was introduced which may lead to greater focus on site-won materials.

Since the largest consumer of aggregates is road construction it is an interesting field for developing use of till as an alternative construction material. Till materials have large variance in grain size distribution, which has a large influence on the mechanical properties, such as the bearing capacity and frost susceptibility.

The road infrastructure in Sweden is primarily designed according to the Swedish design code for roads, Allmän teknisk beskrivning Väg, (ATB VÄG). Guidelines in the code are crude and a more balanced approach is needed to increase use of till materials.

A number of till materials could be used as lower sub-base material according to the requirements on grain size distribution. Use of till material at higher levels in the road pavement would be economically adventurous. The bearing capacity is a measure of the materials ability to resist permanent deformation and is therefore a decisive parameter in the usage of materials for road construction. The most important factor used for increasing bearing capacity is compaction, since it increases density and induces large horizontal stresses.

Well-graded tills with high fines content are difficult to compact in comparison to more even graded till with lower fines content, because of the influence of water content on compactability. Compaction has to be conducted at optimum water content, and the water content is difficult to change at the site. However, if compaction is successful the till will obtain a high bearing capacity, which may increase due to negative pore pressures, (suction), and consequently increases in effective stresses.

The magnitude of the negative pore pressure depends on the water content or moreover the degree of saturation. This relationship is often illustrated in a water characteristic curve, water retention curve or pF-curve (the p is analogy with logarithmic scale of acidity and F stands for “free energy”), and the shape of this curve is mainly influenced by the grain size distribution and relative density of the material. The curve is usually presented in logarithmic scale, due to the high negative pressure at low degrees of saturation.

Frost susceptibility is of major concern in road construction because of its effect on the long-term performance of roads. Today’s classification systems of frost susceptibility are crude estimations based on experience from different constructions in field, a more balanced approach is needed.

The scope of this work has been to study embankments constructed with till and investigate under what conditions the bearing capacity will be sufficiently high so it can be used as a conventional sub-base material.

2 FIELD MEASUREMENTS

The field tests were conducted during the construction of a new section of a road, E4 between Markaryd and Strömsnäsbruk, in the southern part of Sweden. Three sites were chosen in areas where the new road is constructed on an embankment of sufficient to ensure that the obtained bearing capacity originate from the embankment material only.

All measurements were made on the sub-grade, which consisted of compacted glacial till. The test sites where selected to provide a wide range of fines contents and degree of saturation.

2.1 The sub-grade of glacial till

In the area of stuffy, the thickness of glacial till varies from 7-10 meters with dominating fractions of sand and silt. The granulometric composition of till is strongly dependent on the lithology together with distance of transportation and topographic composition, (Lundquist, 1983). Research has shown that usually around 80 percent of the bulk material is of local origin and has only been transported short distances. The bedrock in the area is a part of the Baltic Shield, which consists of several different rock types. The most common rock in this area is red gneiss with a granite composition. This hard bedrock often produces sandy to a fine sandy till with large boulders in comparison with sedimentary bedrock that often forms clay till.

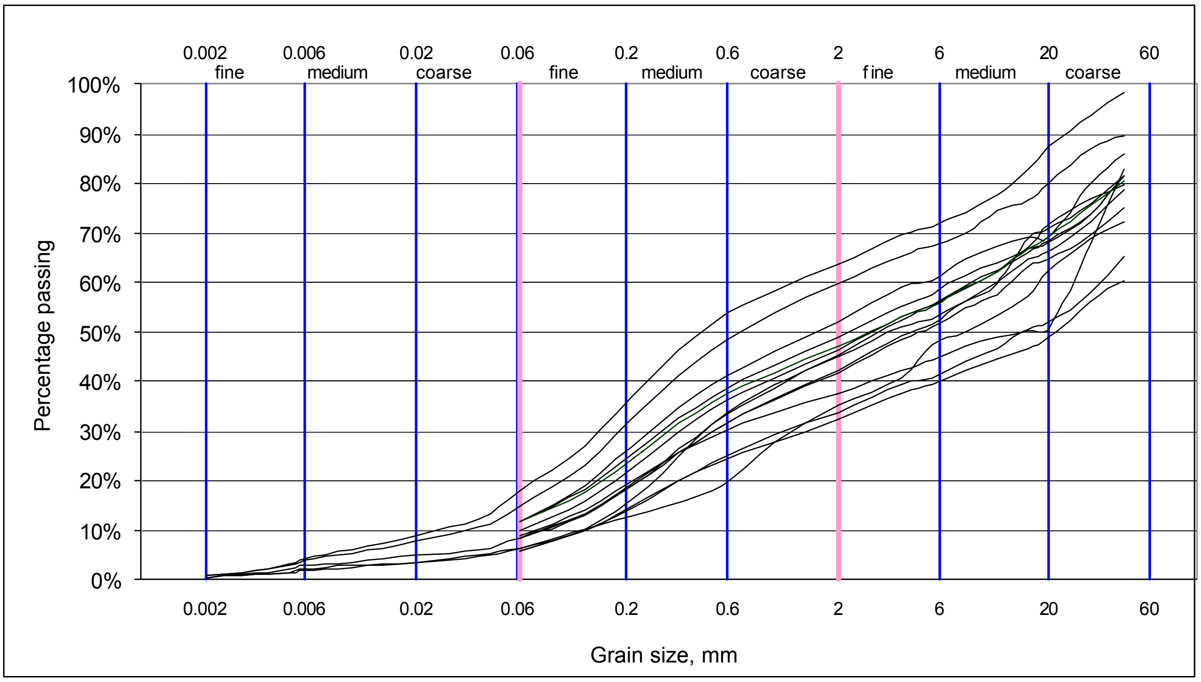

Figure 1: Grain size distribution for the different till materials

The grain size distribution for the different till materials at the site are presented in Figure 1, the fines content varies from 6 to 18 percent, which has great influence on compaction properties and thus the bearing capacity.

2.2 Test procedure

At each trial site five to six measuring points where chosen randomly and the following properties were determined;

- density and water content with nuclear device.
- bearing capacity by static plate load bearing test (SPB).

These measurements on the sub-grade were conducted four to five times with compaction in between, 4 roller passes at low amplitude and two static passes each time. The compaction was performed by a vibratory roller, Dynapac CA 302 D, with a static line load of 38 kN/m. The roller has three standard operating conditions; high amplitude with a frequency of 30 Hz, low amplitude with a frequency of 33 Hz and static compaction without vibration.

Soil sample was taken and analysed in the laboratory for determination of the grain size distribution, water content and compaction properties.

2.3 Test equipment

The density was measured with a nuclear device, C-200, which measures on the surface without any probe. The material is exposed to a known amount of gamma radiation from a radioactive source and the Geiger-Mueller detector tube measures the amount of reflected radiation from the material to the gauge indicator. There is a correlation between reflected radiation and water content and density, which is used for transformation of the received radiation. This is only approximate since the relationship is different for all materials. Therefore this method only gives a good indication of relative changes in water content and thus should not be used for measurement of absolute values.

The SPB tests is a standard test for quality control of pavements and is utilised in several national codes for road construction since the bearing capacity is a good indicator of future risk of pavement rutting, (Andersson et al. 1998). The tests were performed according to the Swedish Road Administration publication, (VVMB606, 1993), standard equipment was used. In the test, a predetermined load-sequence consisting of two stepwise loading sequences with an intermediate unloading sequence in between was used to determine a relation between load and deformation. The deformation modulus, Ev, for the underlying soil can then be calculated using the theory of elasticity. The deformation modulus is determined as the secant modulus after a regression analysis of the load displacement curve.

2.4 Results

The measured bearing capacity and dry density at different water contents are presented in Figure 2 and Figure 3. The till material is completely saturated in Figure 2 and the results indicate that there is no obvious decrease or increase in bearing capacity despite the large increase in dry density with decreasing water content. The measured bearing capacity is still quite high, about 125 MPa, which according to ATB-väg is acceptable for a sub-base layer.

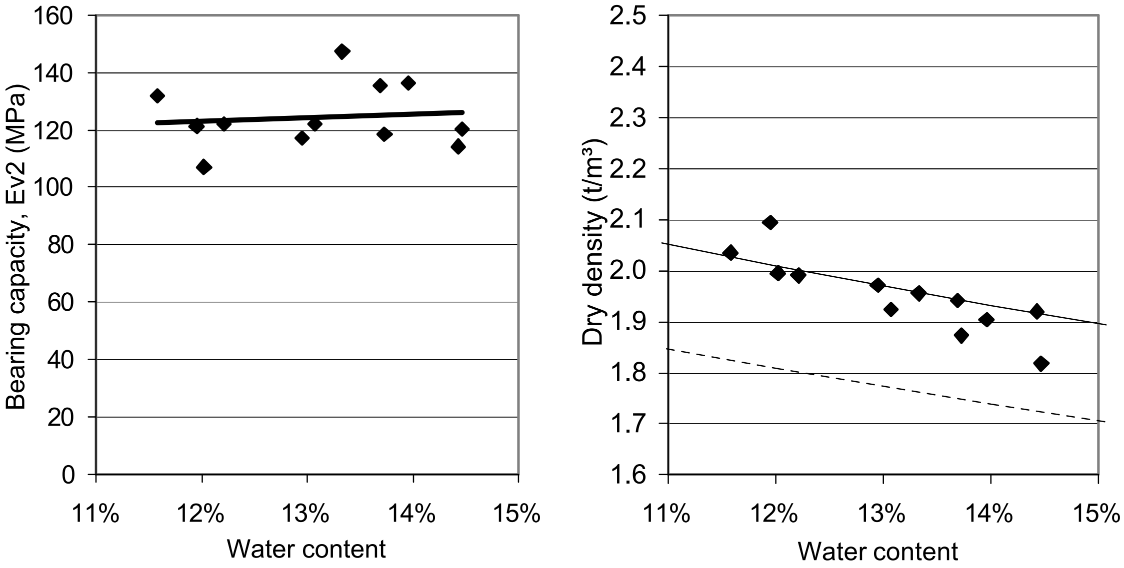

Figure 2: Bearing capacity and dry density at different water content, (saturated soil) presented with a line for saturation (-) and air content of 10 % (- -).

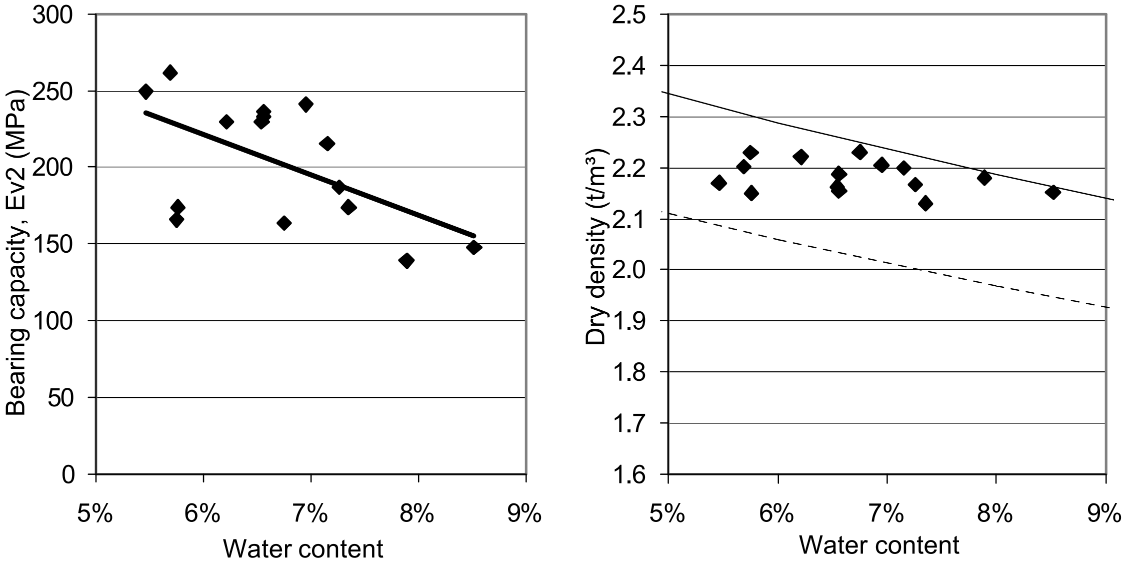

Figure 3: Bearing capacity and dry density at different water contents, (unsaturated) presented with a line for saturation (-) and air content of 10 % (- -).

The result during unsaturated conditions is shown in Figure 3 and at lower water contents, the obtained results vary greatly from the previous figure. There is a distinct increase in bearing capacity with decreasing water content, while there is only is a small increase in dry density. The obtained bearing capacity is, in comparison to results on conventional pavement materials, surprisingly high and much higher then normally achieved with rock fill. At eight to nine percent water content, the material probably is completely saturated, which is reflected by the low bearing capacity.

The presented results emphasize the importance of water content, since it is decisive in the achieved bearing capacity as well as for the dry density. An increase in dry density is obtained as long as the material is not completely saturated. This increase in density is followed by a distinct increase in bearing capacity. The results also show that even a small increase in dry density result in a much larger increase in bearing capacity at low water contents.

This explains the results shown in Figure 4 where the obtained dry density is plotted against the number of performed roller passes. The average dry density after each compaction sequence only shows a small increase. It was found that, despite rather good weather conditions (summer), the till material in the embankment rapidly became saturated after a few over passes. However, the performed compaction is not futile since the material become more homogeneous, which is indicated by decreased scattering with number of over passes.

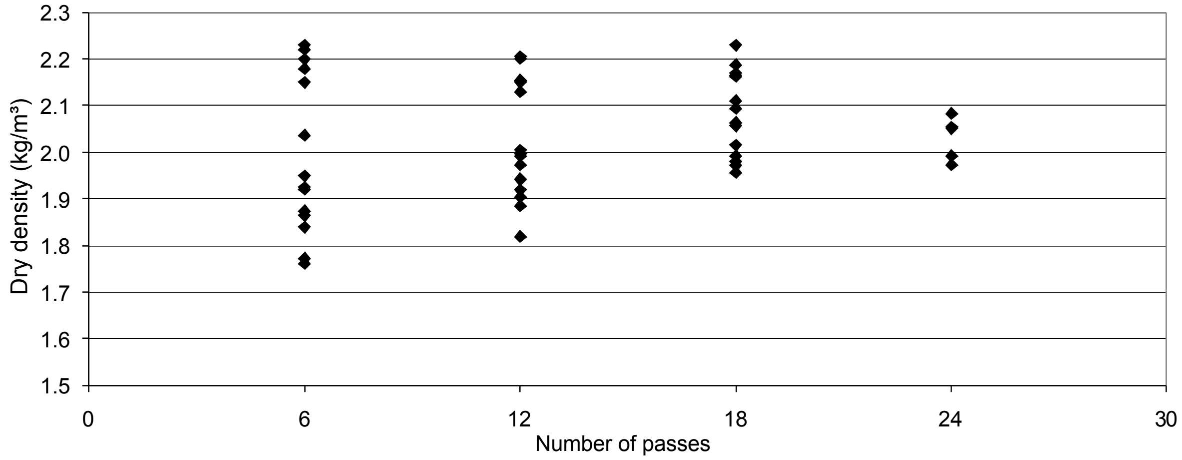

Figure 4: Dry density at different amount of compaction

It is well known that there is a correlation between the shear strength and deformation properties of an unbound granular material, (Boyce, 1976) and (Pappin, 1979). This explains the high bearing capacity of unsaturated soil, since negative pore pressures will occur when the soil is loaded. The negative pore water pressure will increase the effective stresses and thereby the shear strength of the material, which in turn improves the materials ability to resist elastic and plastic deformations.

High excess pore water pressure will on the other hand be generated when a saturated soil is loaded. This explains the lack of correlation between bearing capacity and water content, as well as dry density.

The relation between the degree of saturation and matrix suction of a soil can be illustrated in a soil water characteristic curve. Such curves were evaluated for natural till slopes in Lund, outside of Stockholm, (Esbeby, 1989). Some of the materials studied by Espeby are comparable to the materials in Markaryd and can be used for rough estimations of negative pressure at different degrees of saturation. In Figure 5 a water characteristic curve for a gravely sand with fines content of 10 % and a silty sand with a fine content of 20 % are presented and it is evident that even small changes in degree of saturation results in rapid increase in matrix suction, (negative pore pressure). It can also bee seen that there are differences in the development of negative pore water pressure between the two materials, which can partly explain the scatter in the results of bearing capacity tests from the site.

Only limited research of water content profiles beneath pavements has been conducted thus it is hard to find relevant data within the subject. A reasonable assumption of a seasonal variation in degree of saturation could be 80 % to 95 %, which results in a negative pore pressure varying from 25 to 100 kPa. This is never taken into account in road design, since the soil is assumed to be fully saturated. It has been shown by, (Ekdahl et al 2004) that even a base-layer material will develop a negative pressure varying between 25 to 40 kPa under a paved surface.

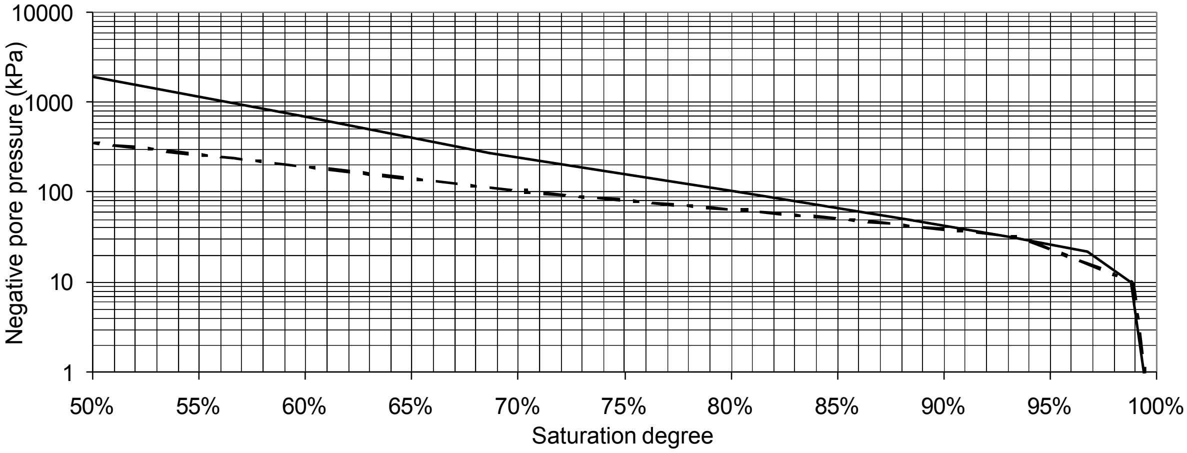

Figure 5: Water retention curve for gravel (after Espeby, 1989).

The requirement according to ATB Väg (2003) is a bearing capacity of 140+0.83s MPa at the base layer, (s = standard deviation). The results presented indicate that as long as the till material is unsaturated it fulfils the requirement set for a base course material.

The requirements as specified in ATB-VÄG with regard mixed grain soils are only viable for use in capping layers. If the soils are to be used in higher layers, the code has to be changed. The requirements today simply stipulate the required number of roller passes at a certain layer thickness and that the air content should be less then 10%. In Figure 2 and Figure 3 the relation between dry density and water content is shown together with an air content of 10 %. It can be seen that the air content cannot solely be used to confirm a desired dry density or bearing capacity.

3 LABORATORY TESTS

3.1 Test procedure

Three different soils were analysed in laboratory. The first two of the materials (M1 and M2) were retrieved from the site and originated from the bedrock in the test site area, while the third material, (N2) originates from another area. The bulk of N2 originates from a harder more fine-grained and dense red porphyry. The till from this area has a low fine content and the grain shape is very angular compared while the two other materials, which have a sub rounded grain shape. The chosen materials made it possible to study the importance of grain shape and varying fine content.

Compaction tests were conducted according to AASHO modified Proctor compaction method C.

3.2 Results

The grain size distribution is presented in Figure 6, and according to the unified soil classification system, (USCS), the materials are classified as silty sand, or sand-silt mixtures, (SM). The fine content varies from 13 to 21 % with one of the materials showing a very high sand content and therefore not only exceeds the code for lower sub-base layer according to fines content but also in gradation.

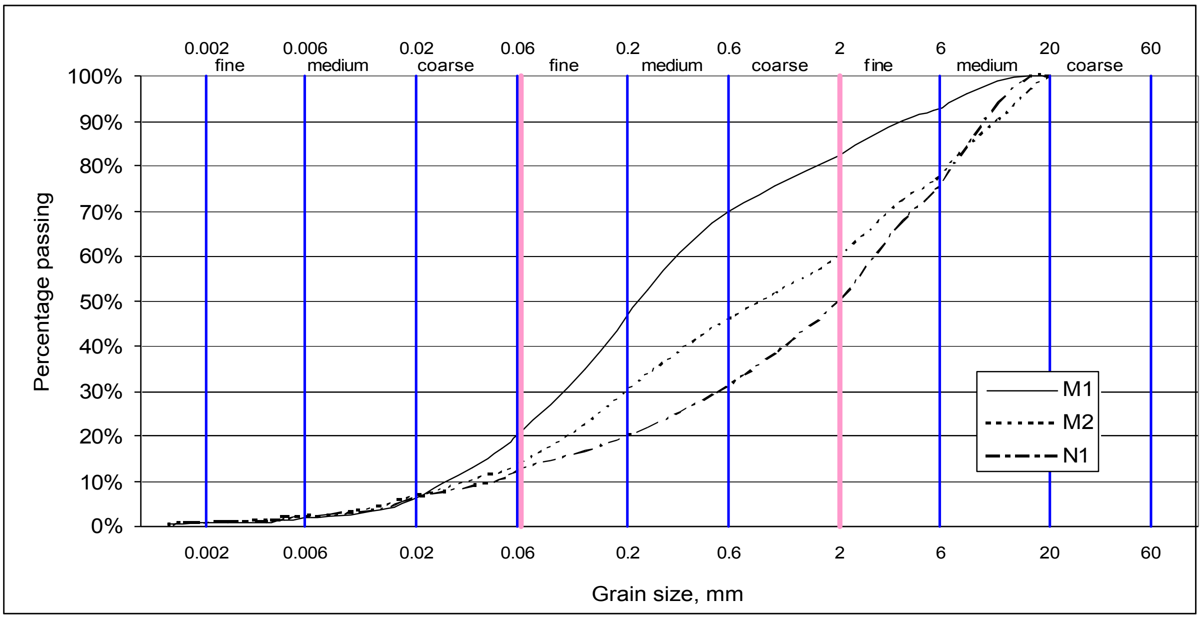

Figure 6: Grain size distribution of the materials.

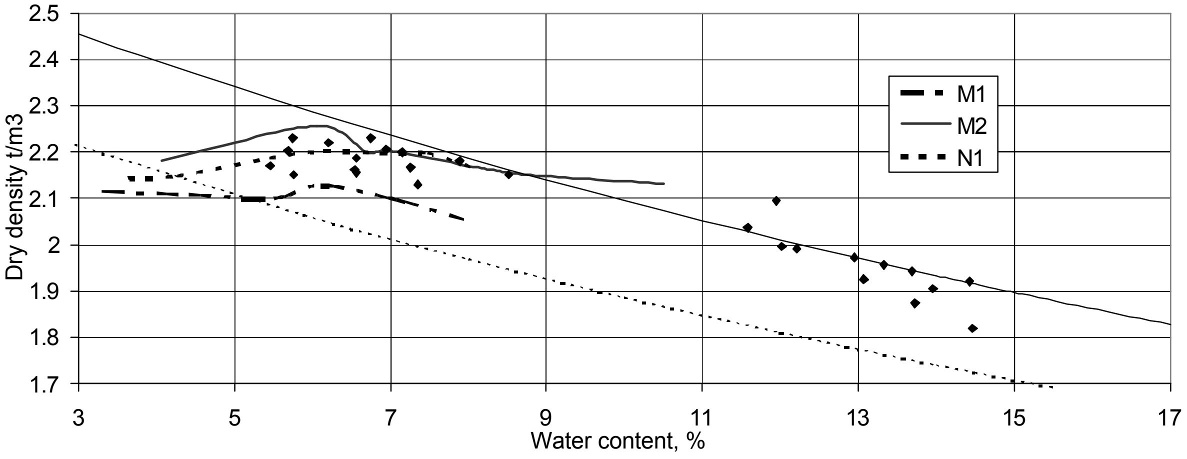

Figure 7: Compaction curves from modified Proctor compaction tests.

The performed modified proctor tests are presented in Figure 7. The maximum dry density varies between 2.13 and 2.26 t/m^3, which is 6 %, at the optimum water content of about 6 %. The M1 material with the highest fine content and more even-graded grain size distribution obtains a lower dry density. It can also be seen that even small changes in grain size distribution influences compaction properties greatly, which may explain the large scatter in results from the field measurements. The very angular N1 material seems to be more difficult to compact than the sub rounded M2 material. The optimum water content determined in the field and the laboratory shows reasonable agreement.

Glacial tills have a large variation in grain size distribution and especially fines content, which makes it hazardous to confirm the desired bearing capacity by just verifying the obtained degree of compaction or for that matter air content.

4 DISCUSSION

The results here presented shows that layers of till material can obtain a very high bearing capacity due to compaction and negative pore pressures and can under such circumstances probably be used for sub-base layers. The grain size distribution is for some till material not that different from the material used in a conventional base layer, which indicates that it could potentially be utilised as a base-layer material.

There is one major difficulty at the construction site, which has to be overcome. The compaction has to be performed at optimum water content, which even in favourable weather conditions is difficult to achieve. The embankment material is, as in these field tests, often compacted to saturation, but at higher water content then desired. It is time consuming to reduce (dry) the water content and the available construction time is often today limited.

Large savings could probably be made if the compaction is performed more thoroughly and at optimum water content, since it will result in a reduction in usage of more expensive rock fill and save natural deposits of gravel. The design criteria in the Swedish code have to be changed and allow till to be used at higher levels in the pavement. The required bearing capacity has to be confirmed with plate bearing tests in combination with determination of dry density and water content, which would indicate the material is unsaturated.

The more qualified use of till material discussed above is based on the assumption that the material always stays unsaturated. Even though the pavement materials are covered with a dense base-layer the water content probably has seasonally variations, which have to be further investigated. The correlation between the obtained bearing capacity and future permanent deformations is often used in design codes. This has been well investigated for conventional pavement materials, but could be questioned for till materials.

The ability of till materials to resist permanent deformations and if it corresponds to the obtained bearing capacity, and to what extent the degree of saturation varies in the pavement has to be further investigated.

5 CONCLUSION

This work shows that the range of applications for till materials quite easily can be broaded, since till under favourable conditions can obtain surprisingly high bearing capacities. The following conclusions can be drawn from the results presented:

- there is a clear relation between dry density and bearing capacity for unsaturated soil.

- matrix suction increases shear strength, which results in a much higher bearing capacity than expected.
- only a small compaction effort is needed in most cases to completely saturate the till material and further compaction becomes futile.
- the obtained bearing capacity on saturated soil is misleading and has to be used together with the degree of compaction and water content

To broaden the usage of mixed grain till material there are certain areas that need to be further investigated:

- correlation between bearing capacity and expected rut depth in a paved construction for these materials.
- seasonal variation in water profile under a paved construction.
- frost susceptibility of different mixed grain tills.
- handling of the material in the field.

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