A study on the influence of water and fines on the deformation properties of unbound aggregates

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ABSTRACT: To achieve proper stability in base coarse materials, there is a variety of parameters to optimize. The response of the material is a combination of several factors, such as grading, water content, material strength, stress level etc. It is well known that the grading of a material is important for the stability and that a well graded material normally gives better stability than a single sized or a less graded material.

In the Norwegian guidelines for pavement design there are restrictions to ensure that the fines content is under a certain level to ensure a none-water susceptible material and hence avoid loss of bearing capacity during spring thaw.

In this study the main focus is to study how the deformation properties, elastic as well as permanent deformation behavior, are affected by different combinations of water content, grading and material strength. The grading of the material is based on the gradation curves for base course material in the Norwegian guidelines for pavement design, which is based on the fuller curve.

Cyclic triaxial tests have been used to study the material behaviour in the laboratory.

KEY WORDS: Granular materials, fines, water susceptibility, triaxial testing

1. INTRODUCTION

The scope of this laboratory study is to verify the current knowledge on the influence of water and fines on granular base behaviour under traffic loading. The basis is the fuller curve, where two different grading coefficients are used to investigate the influence of grading – in particular the finer part of the curve.

Different rock types in combination with different crushing methods results in differences in the grain shape. This will be the case for all particles throughout the particle size distribution, not only for the coarse part of the material. Each material type may thus have different specific surface area even when having the same particle size distribution, which in turn gives differences in the material properties, among these the suction. The suction of a material is mainly linked to the finest particles, and is a material property characteristic for the fines and its ability to keep the water inside the pore system (Noss 1978). Clay is for instance an example of a material in which the fines have a large specific surface area, thus having a high suction.

It is well known that pavement performance is strongly affected by the presence of water in the pore system of the unbound material Design and construction of granular layers should be done with the intention of keeping the construction unsaturated at all times (Ekblad, 2004).

2. MATERIALS AND METHODS

2.1 Mineralogy

In this study two materials were tested, one hard gneiss (Gneiss 1) from a quarry in Askøy outside Bergen in Norway (LA = 17.1) and one weaker gneiss (Gneiss 2) with about 30 % mica taken from a quarry near Göteborg in Sweden (LA = 24).

Gneiss 1:
By microscope studies of the material, two variants of this type of gneiss were identified; one with foliation and one homogeneous type more like granite. The main minerals are quartz and feldspar, which both are hard minerals. The texture of the rock is very fine-.grained, the mineral grains ranging from 0.2 to 1.5 mm.

Gneiss 2:
This is a fine to medium grained gneiss with megacrysts of plagioclase. The bondage between the individual mineral grains in this rock type is quite good, and there are only small amounts of fissures in the structure. The main minerals are plagioclase, mica and quartz. Remark that this rock type contains approximately 33 % mica. As mica is a soft mineral which is easily worn, it is likely to suggest that the fines will be dominated by this mineral.

Mica is a soft and elastic mineral which occurs in a variety of rock types. Mica is often reported to be a problematic mineral in unbound aggregate as well as in asphaltic mixtures. Aggregate containing mica has low resistance to abrasion. Unbound layers of crushed rock with considerable amounts of mica are known to be difficult to compact. The reason is probably partly due to the elasticity of the mineral particles, and partly due to the shiest particle form. The E-modulus in unbound aggregate is shown to decreases with increasing mica content. It is also well known that mica-rich aggregate frequently cause serious problems in frost affected areas during thaw weakening if water is available for the pavement or near under the pavement.

The behavior is, of course, connected to the quantity of the mineral. Orientation and distribution of the mineral in the material is also of importance. Rock types with high mica content are often inhomogeneous. Failure in a rock material often follows the layers of mica (Höbeda 1987). Aggregate with high mica contents are mechanically weak, and the fines content may increase significantly over time due to crushing under by traffic loading and climate weathering.

2.2 Grain size distribution

The fuller curve was first described by Fuller and Thompson (1907) on concrete design. They concluded that a curve made by the formula (Eq 1) with a grading coefficient of 0.5 would give a well-graded curve with maximum density for spherical particles. Crushed rock will deviate from the spheres when it comes to maximum density. Experience shows that maximum density for crushed rock is achieved at lower grading coefficients than 0.5, more close to 0.4. (Ekblad 2004)

$$P = \left(\frac{d}{D_{Max}}\right)^n \qquad \text{(Eq. 1)}$$

where;
P = percent smaller than d
D_{Max} = the maximum particle size
n = the grading coefficient

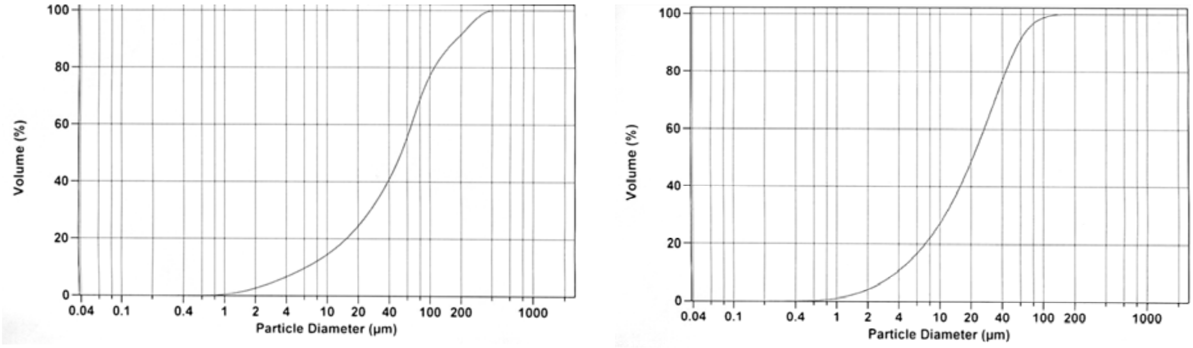
Figure 1: Material grading

In this study n = 0.5 and 0.35 was chosen. The grading was 0-22 mm, so the maximum grain size was 22.4 mm. Using Equation 1 the curves were calculated and used in the study as shown in Figure 1.

2.3 Characterization of fines

The properties of the fines were investigated to see if there were any differences in the two material types and if the results from the triaxial testing were linked to the material properties of the fines. The grading of material <0.063 mm was determined by Coulter analysis (COULTER LS 230). Results are shown in Figure 2.

The specific surface area of the fines was also determined for the two materials by BET analysis (DIN 66131). The results are presented in Table 1. If we look at both Figure 2 and Table 1 we can see that the curve for Gneiss 1 is less fine than the one for Gneiss 2. Table 1 show that the specific surface for the fines from Gneiss 2 is about three times as large as for Gneiss 1.



Grading of fines Gneiss 1

Grading of fines Gneiss 2

Figure 2: Characterization of material < 0.063 mm by Coulter Analysis

Table 1: Specific surface area of material < 0.063 mm (BET-method)

Material type	Specific area [m^2/g]
Gneiss 1	1.58
Gneiss 2	4.73

2.4 Moisture content

Maximum dry density and optimum water content was found for each material type according to Modified Proctor. Specimens with different water contents were tested with the repeated load procedure in the triaxial chamber. Table 2 show the water contents and corresponding degree of saturation used in these tests.

Table 2: Actual water content and degree of saturation in samples tested

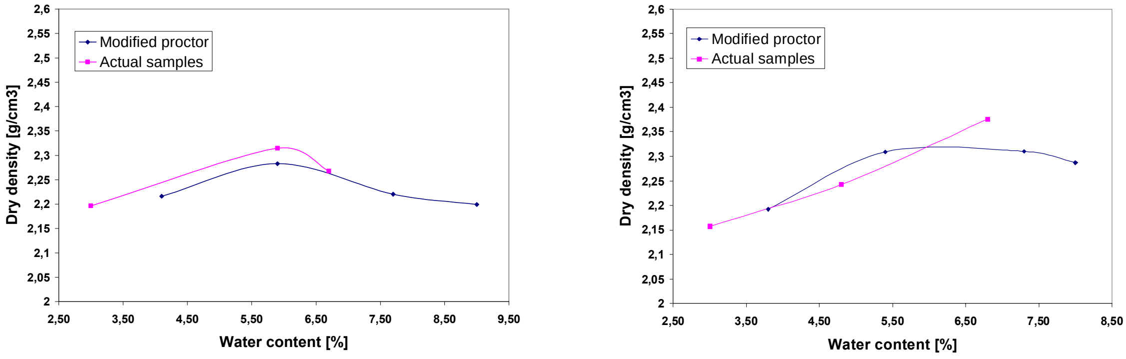
Material	Grading coefficient	Water content [%]	Degree of saturation
Gneiss 1	n = 0,35	3.0	0.15
Gneiss 1	n = 0,35	5.9	0.38
Gneiss 1	n = 0,35	6.7	0.39
Gneiss 1	n = 0,5	3.0	0.14
Gneiss 1	n = 0,5	4.8	0.27
Gneiss 1	n = 0,5	6.8	0.52
Gneiss 2	n = 0,35	4.0	0.18
Gneiss 2	n = 0,35	5.2	0.23
Gneiss 2	n = 0,35	6.0	0.26
Gneiss 2	n = 0,5	3.7	0.17
Gneiss 2	n = 0,5	4.9	0.22
Gneiss 2	n = 0,5	6.1	0.33

Table 2 shows the actual water content and the degree of saturation for all samples tested. For Gneiss 1 a higher degree of saturation is achieved than for the Gneiss 2. The highest degree of saturation is 52 %.

3. TRIAXIAL TESTING

3.1 Compaction

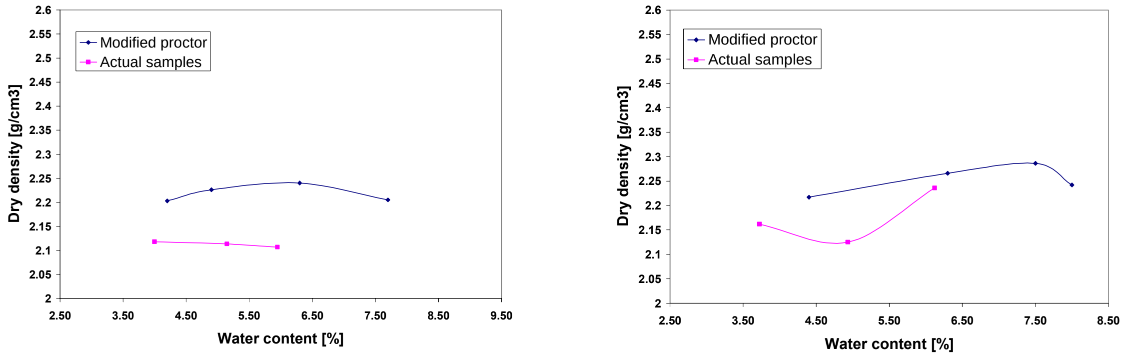
The Kango vibrating hammer was used for compaction of the samples for triaxial testing. Five equal layers were compacted to the optimum dry density found by the Modified Proctor procedure. In the figures below the dry density found by Modified Proctor and the actual dry densities of the samples tested are shown.



Grading n = 0.35

Grading n = 0.5

Figure 3: Dry densities and actual densities for samples of Gneiss 1



Grading n = 0.35

Grading n = 0.5

Figure 4: Dry densities and actual densities for samples of Gneiss 2

For Gneiss 1 grading n=0.35 we seem to have fitted our samples quite well with moisture content and dry density near the optimum found by Modified Proctor. For the samples with n=0.5 a higher level of compaction is achieved than the one found by Modified Proctor. Here the Modified Proctor show marked optimum water content on the curve.

For Gneiss 2 the dry density is less than found by Modified Proctor for both gradings. We can alsosee that the moisture content as well as dry densities are somewhat different from the Modified Proctor graphs. The Modified Proctor does not give marked optimum water content for the material. This may affect the results from the triaxial testing.

3.2. Testing procedure

The CEN-specifications (CEN, 2000) for repeated load triaxial testing was used as testing procedure. To get as much information as possible from each sample, the multistage loading procedure for high stress level was used. This gives a possibility to obtained information on both the elastic response and the permanent deformation behaviour as the loading is interrupted when the axial permanent deformation reaches 0.5 % for each sequence.

It was necessary to extend the three last sequences to obtain as high stresses as needed for some of the samples. A slightly modified testing procedure was used compared to the CEN standard. The loading sequences are shown in the table below.

Table 3: Loading sequences for multistage loading, high stress level

Sequence 1			Sequence 2			Sequence 3			Sequence 4			Sequence 5		
Confining stress, σ_3 (kPa)	Deviator stress, σ_d (kPa)		Confining stress, σ_3 (kPa)	Deviator stress, σ_d (kPa)		Confining stress, σ_3 (kPa)	Deviator stress, σ_d (kPa)		Confining stress, σ_3 (kPa)	Deviator stress, σ_d (kPa)		Confining stress, σ_3 (kPa)	Deviator stress, σ_d (kPa)	
Constant	min	max	Constant	min	max	Constant	min	max	Constant	min	max	Constant	min	max
20	0	50	45	0	100	70	0	120	100	0	200	150	0	200
20	0	80	45	0	180	70	0	240	100	0	300	150	0	300
20	0	110	45	0	240	70	0	320	100	0	400	150	0	400
20	0	140	45	0	300	70	0	400	100	0	500	150	0	500
20	0	170	45	0	360	70	0	480	100	0	600	150	0	600
20	0	200	45	0	420	70	0	560	100	0	700	150	0	700
									100			150	0	800

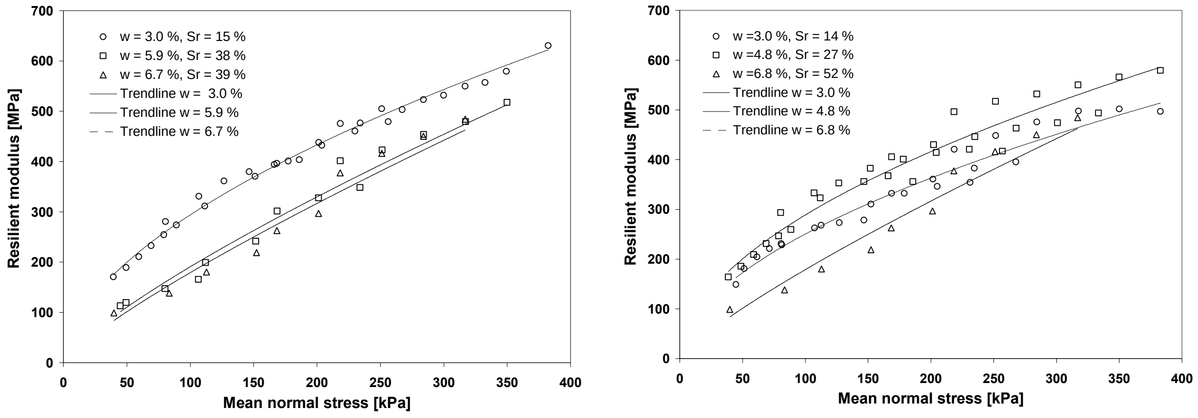
4. RESULTS

4.1 Resilient response

Gneiss 1:

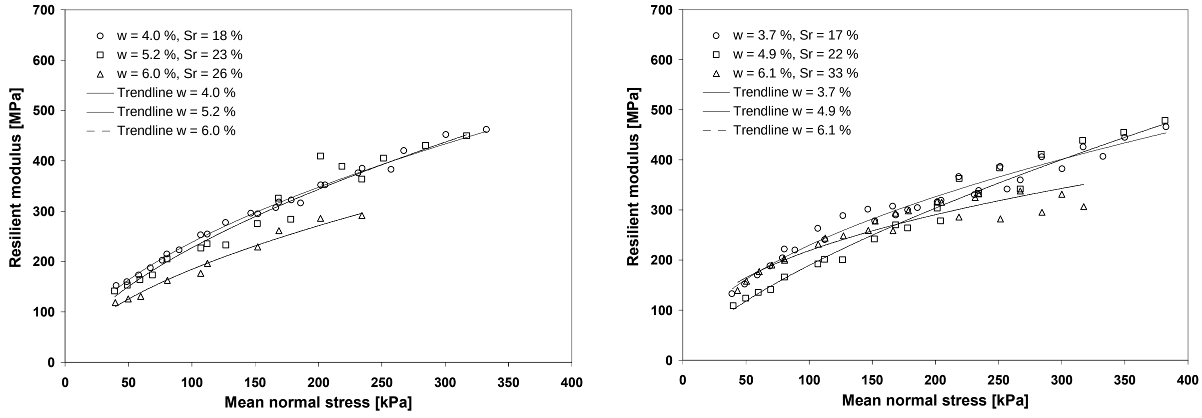
The resilient moduli for the two gradings n=0.35 and n=0.50 shows about the same values for the highest water content of 6.7-6.8 %. The material with highest amount of fines (n= 0.35) show however significantly lower Mr values with increased water contents (w = 3.0-5.9 %). The series with less amount of fines (n=0.50) have about the same module as a function of mean stress for water contents in the range 3.0 to 4.8 %, but lower resilient moduli for w = 6.8.

The series with low amount of fines seems to be less sensitive to small changes in water contents (3.0-4.8 %). Increased water content to w = 6.8 % gave a significantly lower resilient modulus function. However, the modulus for the wet condition are very close for the two series n = 0.35 and n =0.50 under the highest water conditions.



Grading n = 0,35 Grading n = 0,5

Figure 5: Resilient response for Gneiss 1



Grading n = 0,35 Grading n = 0,5

Figure 6: Resilient response for Gneiss 2

Gneiss 2:

This material shows significantly lower resilient moduli than Gneiss 1 under same mean normal stress and corresponding water contents. The material with highest amounts of fines (n = 0.35) have approximately the same modulus function for low and medium water contents (w = 4.0-5.2 %), while increased water content to 6.0 % gives a significantly lower resilient modulus function. The material with low fines contents (n = 0.50) in this case also gives near the same modulus function for the low water contents (w = 3.7–4.9 %), while increased water contents to 6.1 % gives considerable lower resilient modulus under the same mean normal stress for high stress levels only.

The unbound aggregate from Gneiss 2 with considerable amounts of mica gave significantly lower resilient moduli functions than Gneiss 1 from Askøy for high stress levels (≥ 150 kPa).

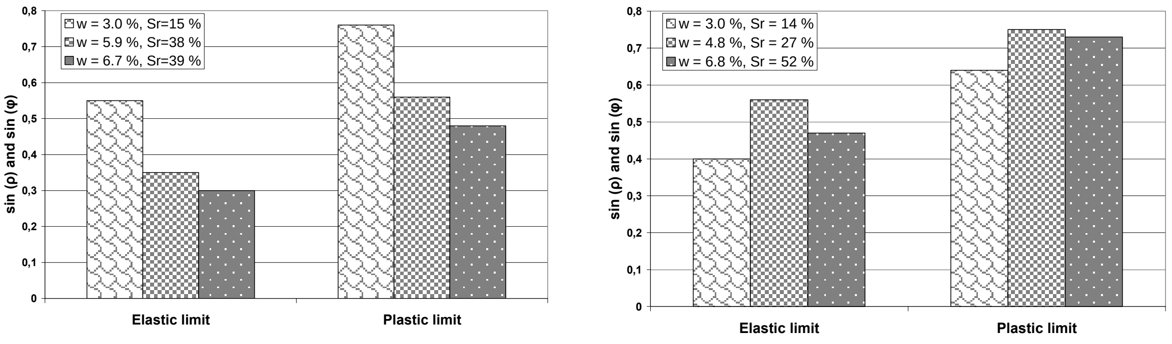
4.2 Plastic response / permanent deformations

The Mohr-Coloumb criterion is used to find the stress envelope for the design stage and the failure stage (plastic area) stress envelope. The equations of these lines are:

Elastic limit: $\sigma_3 = \sin\rho(\sigma_1 - \sigma_3) + a$ (Eq. 2)

Plastic limit: $\sigma_3 = \sin\varphi(\sigma_1 - \sigma_3) + a$ (Eq. 3)

The result of this interpretation for each series is shown by the mean values of sin ρ and sin φ for all series in figure 7 and 8.



n = 0,35

n = 0,5

Figure 7: Elastic and plastic threshold limits on shear stress basis for two different gradings of Gneiss 1

Gneiss 1:

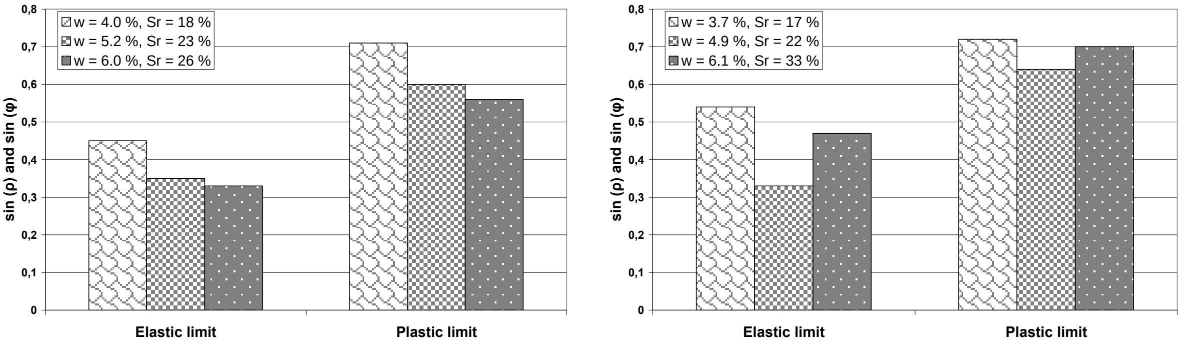
The material with high amount of fines / grading n = 0.35 shows a significant drop in the friction angle on a shear strength basis (ρ and φ) as the water content was increased from 3.0 to 5.9 %. An additional increase in water content did not seem to influence the shear strength so much. This tendency is the same in the elastic as well as in the ultimate stress stage.

The material with lower amount of fines / grading n = 0.50 does not show such a tendency, as an increased water content rather seems to increase the mobilized angle of friction (ρ) on a Mohr Coulumb envelope interpretation basis. Additional increased water content from 4.8 % to 6.8 % did not influence the ultimate shear strength for the specimens significantly. However, in the design stress stage / elastic strain range an increase in water content from 4.8 to 6.8 % seems to reduce the friction angle somewhat.

Gneiss 2:

For the unbound material with high fines contents (n = 0.35) and low water content, w= 4.0 % the mobilized friction ρ is somewhat lower than the corresponding value for Gneiss 1, and drops when water content is slightly increased to 5.2 %. The aggregate with smaller amounts of fines shows a reduced angle of friction (ρ and φ) when the water content increases from 3.7 % to 4.9 % and increase again for w = 6.1 %. This might be explained by the change in density that has the same variation, see figure 2. Remark also the flat Modified Proctor curve and the high optimum water content w = 7.6 % in this case.

In the ultimate stress stage (near plasticity stage) the water contents seems to have a significant influence on the friction angle (φ) for the aggregate with high amounts of fines (n = 0.35), but not so pronounced as for Gneiss 1. The material with less amount of fines (n = 0.5) is also in this case less sensitive to variations in water contents, and the variations have the same pattern as in the elastic stress stage.



n = 0,35 n = 0,5

Figure 8: Elastic and plastic threshold limits on shear stress basis for two different gradings of material from test bed in Sweden, Gneiss 2

4.3 Discussion

Ekblad (2004) tested materials with grading coefficients ranging from 0.3 to 0.8. He found that materials with high grading coefficients are less affected by a change in water content. This is mainly connected to the amount of fines in the materials, as the amount of fines in this case also increases with increasing grading coefficient. Ekblad found that an increase in water content causes a reduction in resilient modulus and an increase in Poissons ratio as well. This behavior was more pronounced as the grading parameter is decreased.

Our test series fit well into this picture. We found that the series with low amount of fines and high grading coefficient are less water sensitive than the series with a higher amount of fines and low grading coefficient. We found that the shear strength was higher for the material with high amount of fines under low water content conditions, but this was significantly reduced under a relative small increase of water content. The material with low amount of fines, following the specifications in our guidelines, showed rather an increase in shear strength under wet conditions within the range in these tests.

Both material gradings from Askøy (Gneiss 1) showed near the same resilient modulus function under low water contents. The material with high amount of fines however showed a significant reduction in modulus and resistance to permanent deformations under only slight increased water contents, while the material with low amount of fines had to be influenced by higher water content before a reduction of the resilient modulus and the plastic limit occurred.

The mica-rich gneiss from Gøteborg (Gneiss 2) showed lower resilient moduli under the same mean normal stress compared to gneiss 1 for high stress levels. The materials with high amounts of fines showed lower resilient moduli under the same mean normal stress for high water contents than the materials with low fines contents. These materials were however less influenced by the water content in the ultimate stress stage. The dry density seemed to be more important for the shear strength than the water contents in the ultimate stress stage, while the water content had a significant effect in the elastic stress stage / design stress stage.

5. CONCLUSIONS

In this study the main scope was to investigate the effect of water and fines on the deformation behaviour of granular base materials. These problems are quite complex to investigate because the behaviour is influenced by many variables, as e.g. mineralogy, amount of fines, properties of the fines and compaction level. It must be noted that this is only a limited study with only two materials and two different gradings. However, as can be seen from the discussion, it is possible to see some trends.

Materials with a low grading coefficient are more sensitive to water than the materials with a higher grading coefficient and less fines regarding susceptibility to deformation.

It seems as if the material with a high amount of mica has a lower resilient modulus and is less resistant against permanent deformations than the material with no mica. This may be influenced by the level of compaction achieved for the two materials. As mentioned in chapter 2.1 the mica is not so easy to compact.

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