Round robin investigation on the cyclic triaxial test for unbound granular materials

I. Hoff
SINTEF, Technology and Society, Road and Railway Engineering, Trondheim, Norway

H. Arvidsson
Swedish National Road and Transport Research Institute, Highway Engineering, Linköping, Sweden

S. Erlingson
University of Iceland, Engineering Research Institute, Reykjavik, Iceland

L. J. M. Houben
Delft University of Technology, Road and Railway Engineering, Delft, The Netherlands

P. Kolisoja
Tampere University of Technology, Institute of Structural Engineering, Tampere, Finland

C. W. Schwartz
University of Maryland, Civil Engineering, College Park, Maryland, USA

ABSTRACT: A new European standard for cyclic triaxial testing of unbound granular materials was approved by CEN in 2004. In the final stages of preparation of the standard it was decided to organize a round robin analysis with invitation to laboratories in Europe that have been doing research using this type of tests. Nine different laboratories received the material and six laboratories performed the tests. Only one material at one target dry density and water content was investigated. Most of the laboratories performed three parallel tests. This is obviously too few tests for a statistically sound validation of the tests. However, some indication about the accuracy of the test was found.

KEY WORDS: Triaxial testing, unbound granular materials, round robin test, resilient modulus.

1 BACKGROUND

Cyclic triaxial testing of unbound granular materials has been developed in several laboratories over the last decades. A lot of different testing procedures have been used, and a lot of variation in sample preparation techniques and testing equipment exist.

A new European standard (CEN 2004) on triaxial testing was approved in 2004. One of the main purposes of making this standard has been to promote the test and make it easier for new laboratories to start using it.

However, to increase the reliability of the test it is necessary to compare results performed at different laboratories. This will also help in understanding how different ways of performing the test will influence the results.

Preferably many different materials should be tested at different compaction levels and moisture contents. However, due to limited resources, only one material was tested at one level of dry density and moisture content. The test focused on resilient testing. But some laboratories also performed the Multistage test that also gives information about the resistance against permanent deformations.

2 PARTICIPATING LABORATORIES

A total of six laboratories performed the tests according to Table 1. Three additional laboratories received the materials but could not for different reasons perform the tests. The tests were performed from the summer of 2003 until February 2005.

Table 1: Participating laboratories

Laboratory	**Contact person**	**Resilient testing**	**Multistage testing (MS)**
SINTEF/NTNU, Norway	Inge Hoff	X	X
Swedish National Road and Transport Research Institute (VTI), Sweden	Håkan Arvidsson	X	
Tampere University of Technology, Finland	Pauli Kolisoja	X	
Univ. of Maryland, USA	Charles W. Schwartz	X	X
University of Iceland,	Sigurdur Erlingsson	X	
Delft University of Technology, The Netherlands	Lambert Houben	X	X

3 MATERIAL

In this investigation only one type of material has been used. The selected material is a gneiss from Askøy, outside of Bergen. It is of good quality and typical for materials used in road construction in Norway. The material is metamorphic, granitic gneiss that consists of quarts and feldspar with smaller amounts of amphibole, titanite and mica. Some of the properties are listed in Table 2.

Table 2: Characteristics of the Askøy material

Specific density	2690 kg/m^3
Los Angeles value	14.5
Modified Proctor density	2186 kg/m^3
Modified Proctor optimal moisture content	5 %

The material was sieved and combined to a well graded Fuller curve (Figure 1):

$$p = \left(\frac{d}{D} \right)^n$$

Where:
p = percentage passing sieve
d = sieve size
D = maximal grain size, 22 mm
n = 0.5

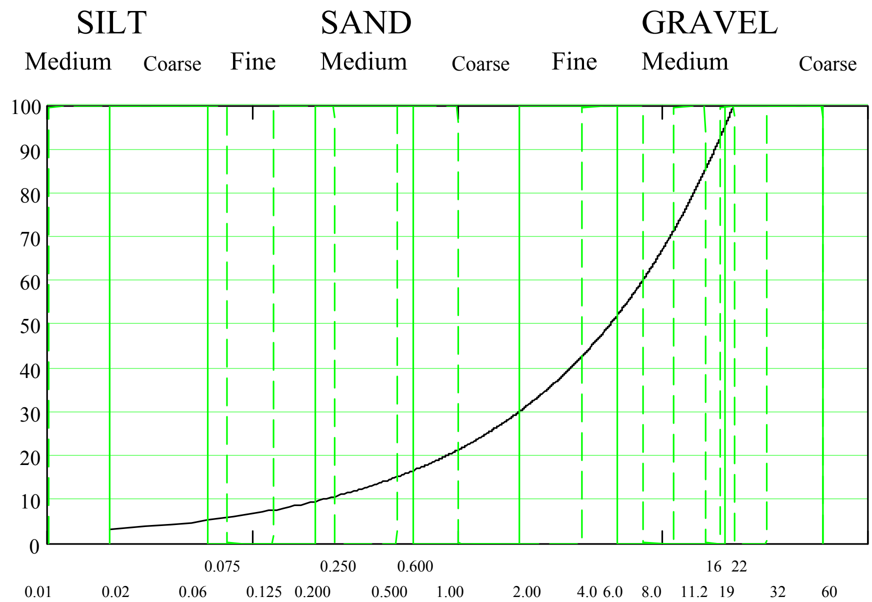

Figure 1: Grain size distribution of tested material

The material was delivered in five fractions taken from normal production in the quarry. The quarry at Askøy produces materials in relative large quantities and the quality is quite constant. The material was taken from production at the same time and shipped to the different laboratories,

4 SAMPLE PREPARATION

The material was tested by the Modified Proctor test to determine the maximal proctor density. For the round robin test the target density was selected to be 97 % of modified proctor giving a target density of 2120 kg/m^3. The method of compaction was open to the different laboratories, but all laboratories were encouraged to try to compact the samples as close as possible to the target density.

The material was compacted and tested at moisture content of 3 %. Table 3 shows the achieved densities for all the laboratories.

Table 3: Sample preparation at different laboratories

Laboratory	**Sample diameter (mm)**	**Compaction method**	**Moisture content (%)**	**Dry density (kg/m^3)**
SINTEF/NTNU	150	Vibratory hammer	3	2.101
Maryland	150	Impact hammer (Modified Proctor)	3.7	2.108
VTI	150	Vibrocompresseur	2.9	2.114
Tampere	300	Vibratory hammer	2.9	2.119
Iceland	150	Impact hammer (Modified Proctor)	2.7	2.209
Delft	300	Vibratory plate	2.2	2.126
SINTEF/NTNU Multistage	150	Several methods	3	2.124
Delft Multistage	300	Vibratory hammer	2.3	2.114
Maryland Multistage	150	Impact hammer (Modified Proctor)	3.3	2.089

Earlier investigations have shown that the compaction method influences the result from cyclic triaxial testing (Hoff, 2004). This is especially important for testing of resistance against permanent deformations, but also to some extent important for resilient modulus testing.

The dry densities achieved are relatively close to the target density with a maximal deviation of 4.2 %. No systematic relation between the achieved density and the resilient modulus could be found for these samples.

5 PROCEDURE FOR RESILIENT TESTING

5.1 Resilient modulus testing

The resilient behaviour of the material represents the behaviour during one load application. The results of the test can be used to determine values of the elastic modulus of the material for different stress levels, or parameters of non-linear elastic models that can be used in analytical pavement design procedures.

In this test, a cyclic conditioning is first applied to stabilise the permanent strains of the material and attain a resilient behaviour. This conditioning is performed by applying a large number of cycles of a stress path that corresponds to the maximum stress level applied during the test. The resilient behaviour is then observed for several stress paths applied each one with a small number of cycles on the same specimen (Table 4).

Table 4: Stress levels for the resilient behaviour test

High stress level			Low stress level		
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
20	0	30	20	0	20
20	0	50	20	0	35
20	0	80	20	0	50
20	0	115	20	0	70
35	0	50	35	0	35
35	0	80	35	0	50
35	0	115	35	0	70
35	0	150	35	0	90
35	0	200	35	0	120
50	0	80	50	0	50
50	0	115	50	0	70
50	0	150	50	0	90
50	0	200	50	0	120
50	0	280	50	0	160
70	0	115	70	0	70
70	0	150	70	0	90
70	0	200	70	0	120
70	0	280	70	0	160
70	0	340	70	0	200
100	0	150	100	0	90
100	0	200	100	0	120
100	0	280	100	0	160
100	0	340	100	0	200
100	0	400	100	0	240
150	0	200	150	0	120
150	0	280	150	0	160
150	0	340	150	0	200
150	0	400	150	0	240
150	0	475	150	0	300

5.2 Multistage testing

The multi-stage procedure described in the new EN-standard (CEN 2004) is well suited for relative comparison of resistance against permanent deformation between different materials. The procedure also gives information about the resilient modulus.

The load is applied stepwise in five sequences for each level of confining pressure. Table 5 shows the load levels used for strong samples. A similar table exists for use on weaker samples with lower stress levels.

Table 5 Stress levels for multistage loading procedure (high stress)

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						

For each sequence the test is interrupted when all steps are completed or an axial permanent strain of 0.5 % is reached. The test is then continued by applying the next sequence. For each step 10 000 continuous sine shaped load pulses are applied. This procedure reveals the resistance against permanent deformations and the resilient modulus for a range of stress levels. The resilient modulus is interpreted for the last part of a load step if the rate of permanent deformation is not too high.

6 RESULTS OF RESILIENT MODULUS TEST

The resilient modulus (M_r) can be calculated using the following formula for cyclic triaxial tests with constant confining pressure:

$$M_r = \frac{\Delta\sigma_d}{\Delta\varepsilon_a}$$

Where:
M_r = Resilient modulus
$\Delta\sigma_d$ = Applied deviatoric stress
$\Delta\varepsilon_a$ = Measured axial resilient strain

For this type of material the resilient modulus is stress dependent non-linear. This means that the resilient modulus increases for increasing levels of mean stress. This behaviour could be modelled using one of several proposed material models for this type of material. For this purpose this is not necessary. To compare the results the resilient modulus interpolated for three different levels of mean stress has been used. Figure 2 illustrates how the three different values have been found for one of the tests performed.

The measured resilient modulus values for all laboratories are presented in Table 6 and Figure 3.

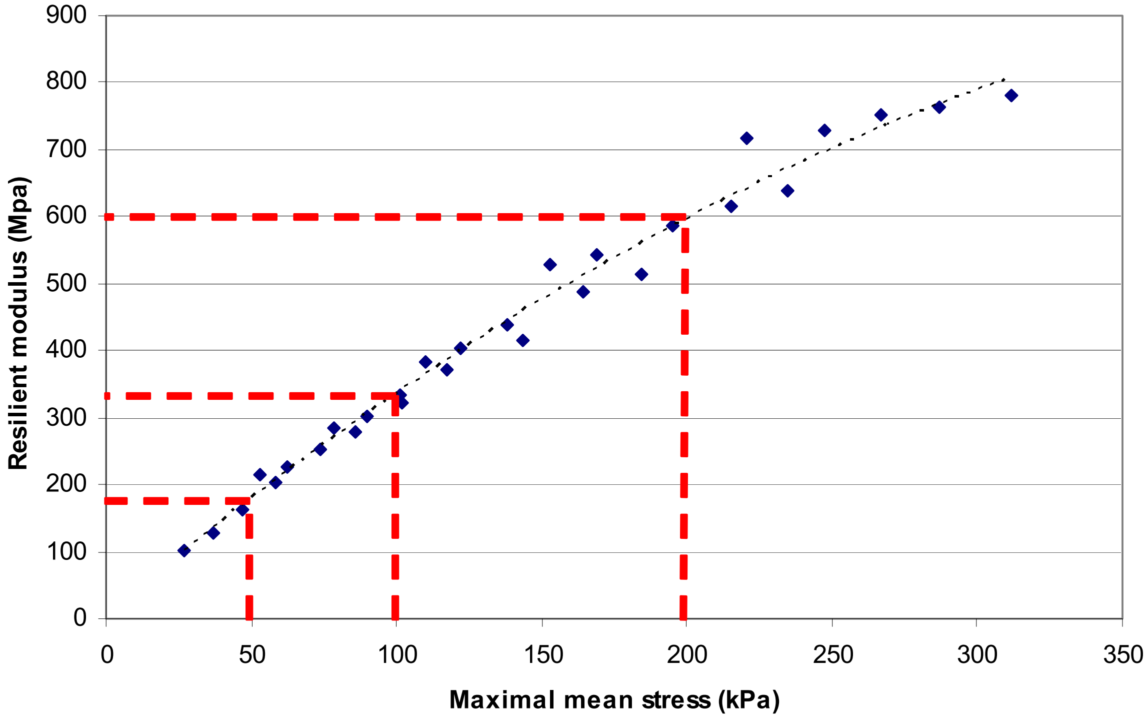

Figure 2: Determination of resilient modulus for three levels of mean stress

Table 6: Resilient modulus measured at different laboratories

Laboratory	**Resilient modulus for different means stress levels (MPa)**			**Deviation from mean value (%)**		
	50 kPa	100 kPa	200 kPa	50 kPa	100 kPa	200 kPa
			Resilient modulus tests			
SINTEF	220	400	700	1.7	16.1	31.0
Maryland	175	330	550	21.8	4.2	2.9
VTI	150	270	450	33.0	21.6	15.8
Tampere	250	330	500	11.7	4.2	6.4
Iceland	180	340	590	19.6	1.3	10.4
Delft	230	350	530	2.7	1.6	0.8
			Multistage loading tests			
SINTEF MS	280	370	510	25.1	7.4	4.6
Delft MS	280	360	460	25.1	4.5	13.9
Maryland MS	250	350	520	11.7	1.6	2.7
Mean	224	344	534			
Max deviation from mean				33.0	21.6	31.0

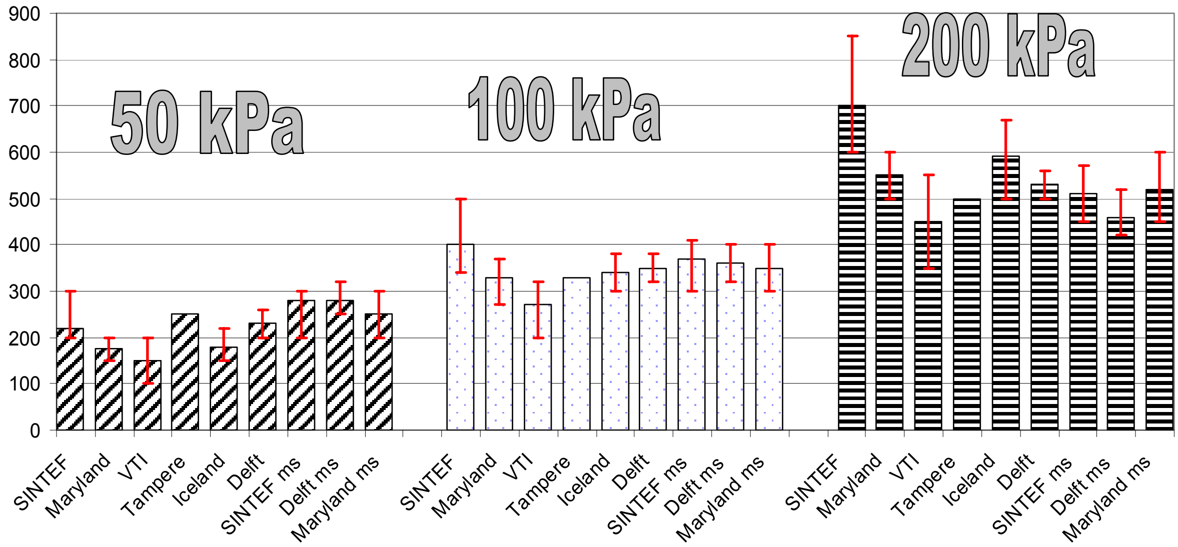

Figure 3: Results from resilient modulus testing at different laboratories for different levels of mean stress.

7 CONCLUSIONS

The results show some variation between laboratories and also some variation for parallel samples tested at the same laboratory. This work shows that it is necessary to run more tests of this type with different materials to get more information about the accuracy of the test and how much variation that could be expected.

This type of testing also increases the focus on accuracy and improvement of equipment.

7.1 Variation between samples at the same laboratory

Most of the laboratories performed three parallel tests on the material. In table 6 and Figure 3 the mean values from these tests are presented. In Figure 3 the differences between high and low values at the same laboratory are indicated. Average deviation from mean value of each laboratory is 23, 17 and 14 % for 50, 100 and 200 kPa mean stress levels.

7.2 Variation between different laboratories

The deviations from overall mean values are shown in Table 6 for each laboratory. The maximal deviation is 32, 22 and 30 % for 50, 100 and 200 kPa mean stress levels.

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