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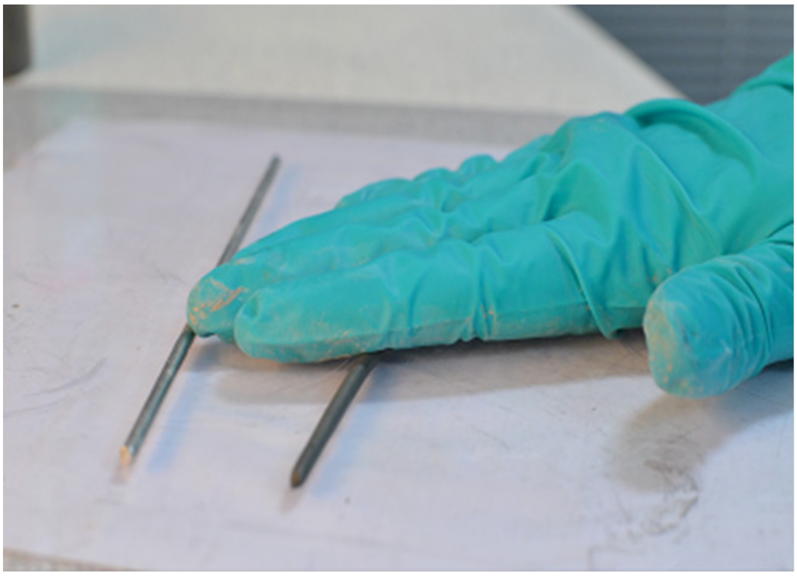
Statens vegvesen

Measurement of plastic limit of cohesive soils

R&D Project Status Report

STATENS VEGVESENS RAPPORTER Nr. 208



Tine Sæther og Marco Wendt

Statens vegvesens rapporter

NPRA reports
Norwegian Public Roads Administration

Tittel
Measurement of plastic limit of cohesive soils

Undertittel
R&D Project Status Report

Forfatter
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Avdeling
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Tewodros Haile Tefera/ Marco Wendt

Godkjent av
Frode Oset

Emneord
consistency limits, liquid limit , plastic limit, plasticity index , clay, silt

Sammendrag
Statens vegvesen har initiert i 2011/12 et FoU-prosjekt som handler om måling av plastisitetsgrense wP for finkornet jord. Denne rapporten oppsummerer arbeidet som er utført hittil, og rapporterer resultater av arbeidet som er utført. FoU-prosjektet baserer seg på artikkelen «A new method of measuring plastic limit of fine materials» Publisert i det internasjonale tidsskrift «The International Journal of Geotechnique» ved Sivakumar et al. (Sivakomar 2009). FoU prosjekt er initiert av Marco Wendt ved Geoteknisk seksjon i Trafikksikring, Miljø og Teknologiavdelingen, Vegdirektoratet.

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Summary
The Norwegian Public Roads Administration (NPRA) currently has an on-going R&D project regarding the measurement of plastic limit of cohesive soils. This report summarises the work that has been done so far and results of this R&D project. This project is based on the article 'A new method of measuring plastic limit of fine materials' published on the international journal of Géotechnique by V. Sivakumar and his co-authors (Sivakumar 2009). The project is initiated by Marco Wendt at the Geotechnical Section in the Traffic safety, Environment and technology Department, Vegdirektoratet.

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Forord

Statens vegvesen har initiert i 2011 et FoU-prosjekt som handler om måling av plastisitetsgrense w_P for finkornet jord. Denne rapporten oppsummerer arbeidet som er utført hittil, og rapporterer resultater av arbeidet som er utført. FoU-prosjektet baserer seg på artikkelen «*A new method of measuring plastic limit of fine materials*» Publisert i det internasjonale tidsskrift «*The International Journal of Geotechnique*» ved Sivakumar et al. (Sivakomar 2009). FoU prosjekt nr. 603152 er initiert av Marco Wendt ved Geoteknisk seksjon i Trafikksikring, Miljø og Teknologiavdelingen, Vegdirektoratet.

Den fysikalske tilstanden til kohesjonsjord er definert av dens konsistensgrenser. Flytegrense w_L og plastisitetsgrense w_P er vanligvis brukt for å evaluere visse geotekniske parametere av finkornet jord. Måling av w_L er en mekanisk prosess, ref. NS 8002-1982, og mulighet for at feil oppstår under måling er ikke signifikant. Men dette er ikke tilfelle for w_P bestemmelse, til tross for at dagens metode er omfavnet av mange standarder over hele verden. Inkludert Norsk Standard NS 8003-1982. Aktuell metode er basert på en ganske «rå» prosedyre mest kjent som «utrulingsgrense» test, selv om den har vært gjenstand for mye kritikk de siste årene. Forskere har identifisert de vesentlige/primære problemer knyttet til standard evaluering av w_P og, i et forsøk på å forbedre nøyaktigheten, har de utviklet flere reviderte metoder. Mange av dem er basert på "fallende kon metoden" samme som konusforsøk for bestemmelse av w_L, for å komme med et system som er brukervennlig, rimelig og som kan betjenes med et minimum av ferdigheter

Formålet med dette FoU-prosjektet er å undersøke nærmere metoden for å måle plastisitetsgrensen av finkornet jord fra Queen's University Belfast ved Dr V Sivakumar et al., samt studere anvendelsen av den nye teknikken for norske finkornet jord.

Den foreslåtte metoden er også basert på fallende kon, den samme som metoden brukt for w_L analyse, som er basert på energien som forsvinner samtidig som konen trenger inn i jordprøve. Energien som kreves for en kon for å trenge inn i jordmaterialet, fremstilt nær plastisitetsgrensen, vil være 100 ganger høyere enn den for flytegrensen, basert på antagelsen om at udrenert skjærstyrke av jordmaterialet i plastisitetsgrense tilstand er 100 ganger høyre enn den i flytegrense tilstand. Den krevde energien er bestemt ved la en kon med 0,727kg i vekt og en fallhøyde på 200mm før den trenger inn i jordprøven. Metoden ble undersøkt ved hjelp av 11 forskjellige jordprøver og w_P fastsettelse ved bruk av denne metode stemmer bra med de uavhengige målinger utført av 5 forskjellige operatører på samme materialet (Sivakumar 2009). I en tidlig fase av dette prosjektet ble det arrangert en studiereise til Queens University i Belfast inkludert et møte med Dr. Sivakumar, med sikte på å utføre demonstrasjonstest av foreslått instrument på norske leire.

Som en del av vurderingen av standard prosedyre (NS 8003-1980), ble 8 forskjellige jordprøver preparert og oversendt til 6 forskjellige geotekniske laboratorier for bestemmelse av w_P. Videre parallelle tester på standard materiale, Speswhite kaolin, ble utført ved begge metoder, standard prosedyre (NS 8003-1982) og den foreslåtte metoden på disse 6 geotekniske laboratorier inngår i denne studien. Resultatene levert av disse 6 laboratorier er undersøkt og blir presentert i denne rapporten.

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B. Grainsized distribution curves of samples used in the study.
C. Grainsized distribution and reported cone penetration values of Speswhite kaolin.
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0 Symbols and acronyms

LL, w_L	Liquid Limit
PL, w_P	Plastic Limit
I_P	plasticity index ($I_P = w_L - w_P$)
NPRA	Norwegian Public Roads Administration
QUB	Queen's University Belfast

1 Purpose and background of the project

The Norwegian Public Roads Administration (NPRA) currently has an on-going R&D project regarding the measurement of plastic limit of cohesive soils. This report summarises the work that has been done so far and results of this R&D project. This project is based on the article '*A new method of measuring plastic limit of fine materials*' published on the international journal of Géotechnique by V. Sivakumar and his co-authors (Sivakumar 2009). The project is initiated by Marco Wendt at the Geotechnical Section in the Traffic safety, Environment and technology Department, Vegdirektoratet.

The physical properties of fine grained soils can be defined by its consistency limits. Index properties such as the liquid limit (LL, w_L) and plastic limit (PL, w_P) are widely used to evaluate certain geotechnical parameters of fine-grained soils. The method for determining the w_L is a mechanical process, Norsk Standard NS 8002-1982, and the possibility of errors occurring during measurement is not significant. However, this is not the case for the method to determine the w_P of fine grained soils, despite the fact that the current method of measurement is embraced by many standards around the world including Norsk Standard NS 8003-1982. The method in question relies on a fairly crude procedure known widely as the 'thread rolling' test, though it has been the subject of much criticism in recent years. Researchers have identified the main issues or primary problems relating to the standard evaluation of w_P and, in an attempt to improve accuracy, have developed several revised methods. Many of them are based on the falling cone approach used for w_L tests to come up with a device that is more accurate and generally repeatable when performed under similar conditions. The value of the plasticity index I_P can be computed from liquid and plastic limits ($I_P = w_L - w_P$). I_P can be used in soil classification and in correlations with some geotechnical soil properties, for example with soil strength, Figure 1-1.

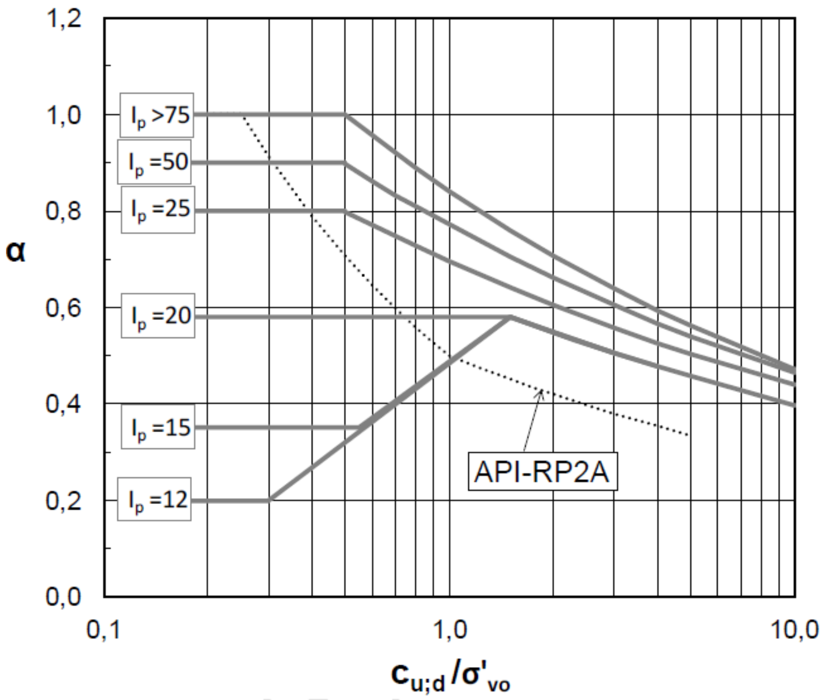


Figure 1-1 Recommended procedure for determining the normalized side friction in clay (Peleveiledning 2012)

The purpose of this R&D project is to investigate more about the proposed new method of measuring plastic limit of fine materials from Queen's University Belfast by Dr V Sivakumar and his co-authors and to study the applicability of the new technique for Norwegian fine soils.

The proposed approach is also based on the falling cone approach used for w_L test and based on the energy that is dissipated as the cone penetrates into the soil. The energy required for penetrating a cone with 30^0 angle into soil, prepared close to the w_P will be 100 times higher than that of the w_L, based on the assumption that the undrained shear strength of soil at w_P = 250 kPa is 100 times higher than that of w_L =2,5 kPa. This required energy was determined by allowing a cone weighing 0.727kg to drop through 200 mm before penetrating the soil. This approach was examined using 11 different soils and the w_P determined using this method corroborate favourably with the independent measurements obtained through 5 different operators on the same soils (Sivakumar 2009). During the earlier phase of this project an educational visit to Queen's University Belfast and meeting with Dr Sivakumar was arranged with the aim of conducting a demonstrational test with the proposed instrument on the Norwegian clay.

As part of the assessment for the standard procedure (Norsk Standard NS 8003-1982) eight different soil samples were prepared and sent to six geotechnical laboratories to determine the w_P. Furthermore test on standard material, Speswhite kaolin, were carried out using both the standard procedure (Norsk Standard NS 8003-1982) and the proposed method at these six geotechnical laboratories included during the study. Results collected from these six laboratories were examined and presented in this report.

2 Determination of consistency limits

Consistency is a term which is used to describe the degree of firmness of a soil in a qualitative manner by using descriptions such as soft, medium, stiff or hard. The physical properties of fine grained soils are considerably influenced by the amount of water present in them. Depending on the water content in the soil the following four stages of states of consistency are used to describe the consistency of the fine-grained soil: (i) the liquid stat; (ii) the plastic state; (iii) the semi-solid state; and (iv) the solid state (Figure 2-1). The boundary water content at which the fine-grained soil undergoes a change from one state to another are called 'consisytency limits'. In 1911 the Swedish soil scientist Albert Atterberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. The w_P is the moisture content that defines where the soil changes from a semi-solid to a plastic state. The w_L is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. Procedures for measuring w_L and w_P are incorporated in various standards. Norsk Standard NS 8000-1982 defines the consistency limits, terms and symbols. Norsk Standard NS 8002-1982 defines apparatus procedure and determination of w_L using fall cone. And Norsk Standard NS 8003-1982 defines laboratory method to determine w_P.

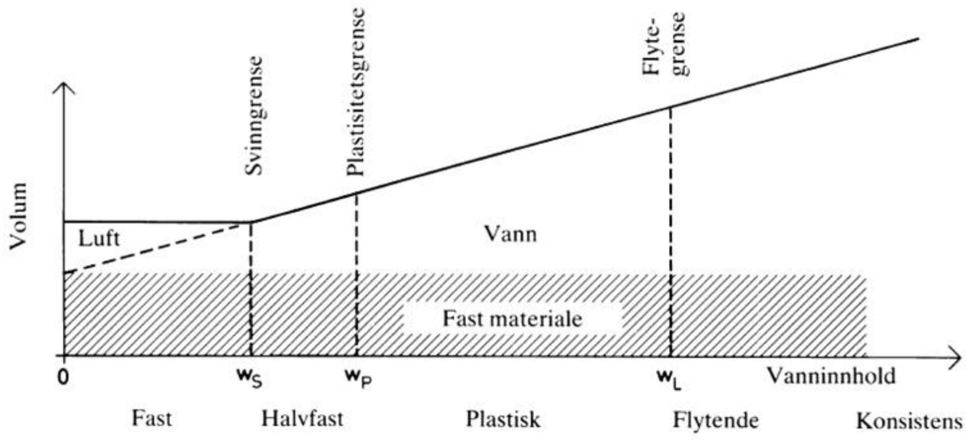


Figure 2-1 Consistency limits (NS 8000-1982)

2.1 Liquid limit, w_L

The test currently used to determine w_L is a mechanical process that is widely known as Casagrande cup and the cone penetrometer or fall-cone test.

According to NS 8002-1982, *Geotechnical testing Laboratory methods Fall cone liquid limi*t, the liquid limit is evaluated by determining the water content of the soil at the point that allows a cone, weighing 60 g and with a tip angle of 60^0, to penetrate the specimen by 10 mm. Usually the test is repeated for various water contents, and the relationship between penetration and water content is established. It is common for this relationship to be linear on semi log scale (Figure 2-2) with w_L being recorded as the water content at 10 mm penetration.

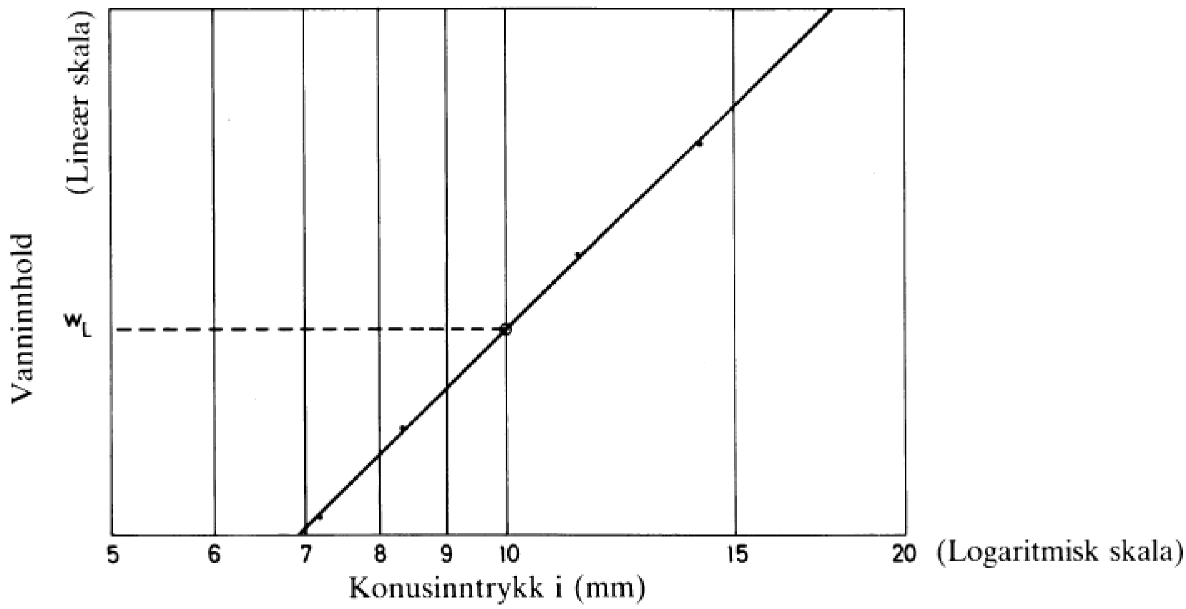


Figure 2-2 Water content vs cone penetration at different water contents (NS 8002-1982)

2.2 Plastic limit, w_P

The laboratory standard used to measure the w_P throughout the world including Norsk Standard NS 8003-1982, *Geotechnical testing Laboratory methods Plastic limit*, still adopts the method suggested by Casagrande (1958). This procedure is not a mechanical process, and w_P is evaluated by determining the water content of the soil when a thread, made by hand-rolling the soil specimen on a glass plate, breaks up at a nominal diameter of approximately 3 mm.

The reliability of the w_P result relies heavily upon the expertise of the operator performing the test. The drawbacks of the test are well documented, and include its highly subjective nature, its over-reliance on operator judgement, and variations in the amount of pressure applied during rolling, the speed of the rolling technique used, and the geometry of the thread. The vagueness of the guidelines on the test procedure, friction between hand, soil and glass, and the risk of contaminating the soil sample all contribute to devaluing the standard thread-rolling method. This method has been described by (Belviso et al. 1985) as ‘a rather crude procedure’, and has long been criticised by others, such as (Houlsby 1982), (Whyte 1982) and (Brown & Downing 2001).

3 Proposed methods for measuring w_P

Various methods of measuring the Plastic Limits have been developed over the past three decades (Sivakumar 2009). This proposed method is based on the principles and procedures of fall cone method to measure the w_L of fine grained soils. The test is repeated for various water contents, at least three times around the w_P of the sample, and the relationship between penetration and water content is established.

The new proposed methods for measuring w_P main considerations were to design a device that is more accurate and generally repeatable when performed under similar conditions. The proposed approach is based on the energy that is dissipated as the cone penetrates into the soil. The w_L of the soil is taken as the water content at which an 80 g cone with a 30^0 cone angle penetrates the soil by 20mm (BS 1377: Part 2: 1990). When this cone penetrates into the soil, the energy released by the falling cone will be dissipated within the soil. Figure 3-1 shows the position of the cone before and after penetration into the soil prepared at the w_L. The energy released by the cone is, the potential energy difference of the cone before and after penetration. The undrained shear strength of the clay at the w_P is approximately 100 times higher than that of the strength at the w_L. If a similar cone (with the same cone angle of 30 degrees) is allowed to penetrate the soil prepared at the w_P to a depth of 20 mm and it is assumed that the soil strains in a similar manner to that of a soil prepared at the w_L (i.e for a similar deformation pattern), the work done in the soil will be 100 times more than that of the work done when the soil is prepared at the w_L. Therefore the required energy to penetrate into the clay prepared at the w_P by a distance h (= 20 mm) is 100 x mgh on the existing cone used in the w_L test. This elevated energy can be achieved in the following ways:

(a) By increasing the cone mass to 8kg with a 30^0 cone angle and allowing the cone to be just in contact with the soil before allowing it to fall, or
(b) By increasing the falling distance of the cone while maintaining the cone mass of 80g, or
(c) By increasing both the cone mass and incorporating falling distance.

Increasing the cone mass to 8kg is not practical as it may bring about health and safety issues during the testing. If cone mass of 80g is to be maintained, then the falling distance of the cone has to be 2m. This is again not a practical option. Therefore option (c) is considered to be more appropriate in order to develop the required energy.

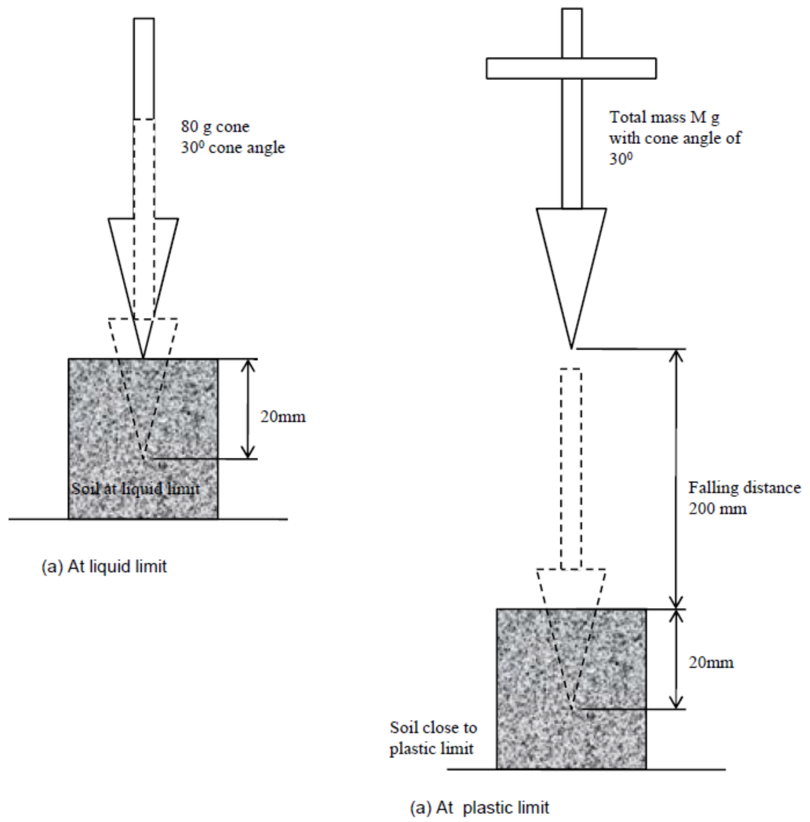


Figure 3-1 Cone penetration at liquid limit and plastic limit (Sivakumar 2011)

The configuration to achieve option (c) is shown in Figure 3-2 where the cone of mass M is allowed to fall from a distance of 200mm, in this present study. Therefore a simple calculation will show that the mass required to obtain the energy which will make the cone penetrate the soil prepared at the w_P by 20mm is about 0.727kg.

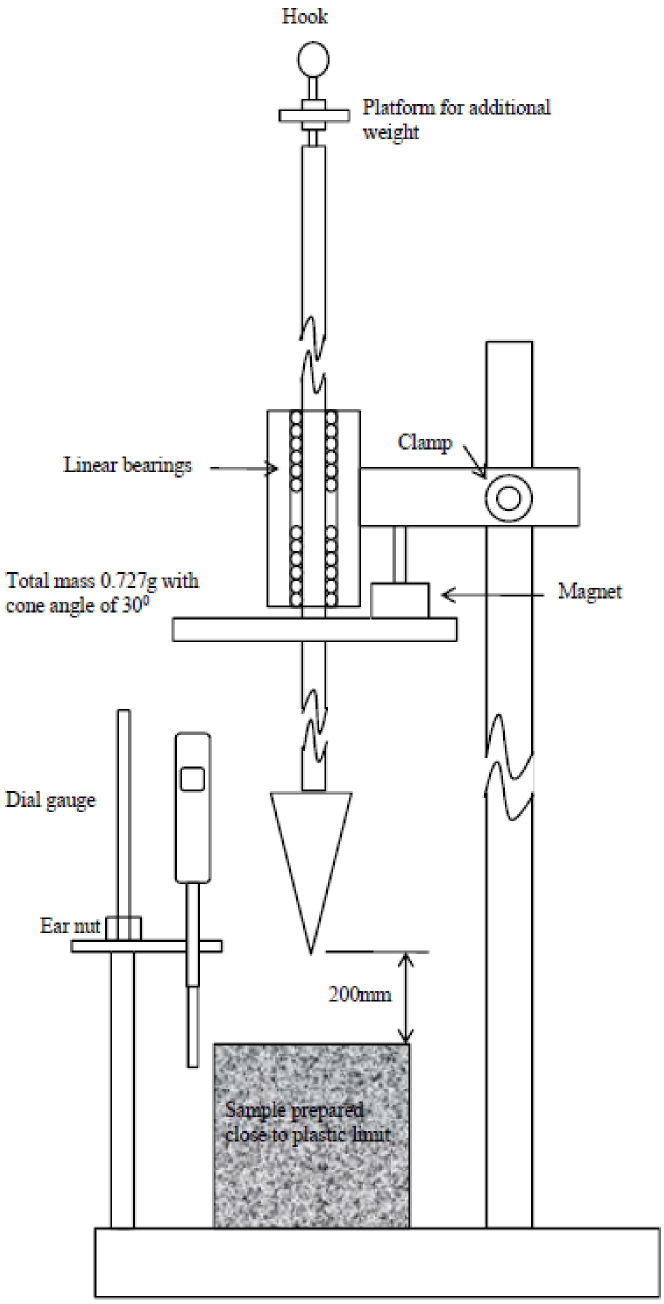


Figure 3-2 Proposed plastic limit measuring device (Sivakumar 2011)

The above is the premise on which the new equipment was developed. Figure 3- 2 shows a schematic diagram of the device (not drawn to scale). A standard cone is attached to a slender rod, having a total mass of 0.727kg and this is fed through linear bearings. A thin metal disk is located just above the cone and it is held in position by a magnet attached to the frame. A digital dial gauge is attached to a tie rod which is held in position by a wing-nut so that it can be moved away during cone penetration and bought back into position when taking penetration readings. The magnet is operated using a two-way switch such that when the polarity is changed the magnetic field changes from North to South or South to North. The option of turning off the power to release the magnet was not selected since it may leave the 0.727kg mass with some residual magnetic flux and the cone may not depart from the magnet immediately when the power is turned off. A photograph of the device is shown in Figure 3-3.

Figure 3-3 Proposed plastic limit measuring device

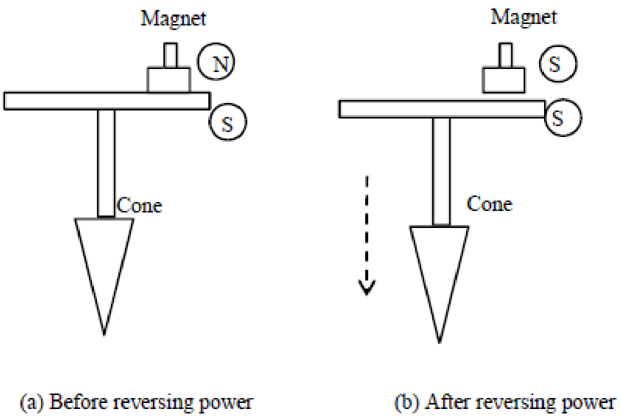


Figure 3-4 Change of polarization (Sivakumar 2011)

4 Educational visit to Queen's University Belfast

During the earlier phase of this project an educational visit to Queen's University Belfast was arranged. Marco Wendt and Tewodros Tefera both from the Geotechnical Section in the Traffic safety, Environment and Technology Department, Vegdirektoratet took part in this educational visit from the 31st May to 2nd June 2011. The focus of the visit was to meet Dr Sivakumar at Queen's University Belfast, the main author of the article '*A new method of measuring plastic limit of fine materials*' published on the international journal of Géotechnique (Sivakumar 2009) . During the visit a demonstrational test to measure the w_P on the Norwegian clay with the modified falling cone apparatus were conducted.

4.1 Sample preparation

The samples for testing were prepared according to BS 1377: Part 2: 1990, dry preparation method, by sieving dry material through 425 µm. About 200 g of dry material was mixed with de-aired water in order to achieve a water content somewhere around the w_P and this was achieved by mixing the soil in a mini food mixer (Figure 4-1 and Figure 4-2) and storing the wet soil for 24 hrs.

The soil sample was carefully placed in layers and compacted into the standard cup of diameter 55 mm and 40 mm deep used for measuring w_L (BS 1377: Part 2: 1990). A collar was attached to the standard cup, Figure 4-3, to allow the production of a sample higher than the cup height, and the extra height was carefully trimmed off at the end of the sampling process.

Figure 4-1 Mini food mixer used to mix the dry sample with distilled water

Figure 4-2 Sample preparation demonstration at Queen's University Belfast.

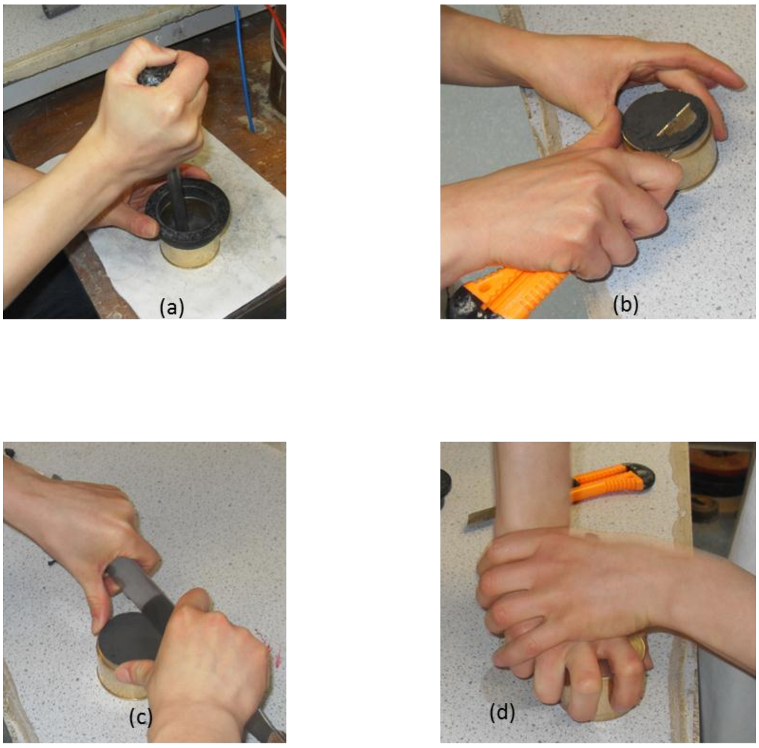


Figure 4-3 (a) Sample compaction with a collar attached to the standard cup, (b) and (c) Carefully trimming off the extra height at the end of sample preparation process and (d) levelling the surface of the sample.

The sample was prepared by compacting layer by layer to get a uniform bulk density. Each layer, 0,5 – 1,0 cm, was tamped using a 0.25 kg brass rod with a diameter of 25 mm. When kneading was complete, the collar was removed and the soil in the cup was levelled off using a wire saw or a cutting tool. There were some concerns about the repeatability of this procedure (Sivakumar 2009)., particularly with regard to generating samples with similar bulk densities at a given water content. Accordingly, many trials were conducted to assess the repeatability and to perfect the reproduction of similar samples. One important aim here was to rule out the influence of any additional energy being exerted by the tamping rod. If the soil is saturated, then additional energy delivered by the tamping process will not influence the bulk density of the soil in the cup. This was independently verified by statically compacting the soil in the cup using various predetermined vertical pressures (500, 1000 and 1500 kPa). It transpired that the variation in the initial bulk density at given water contents was only about ±0.5%. Note that this observation is valid only if the material is prepared at water contents close to or above w_P.

4.2 Testing

The sample was ready for testing after it was carefully prepared and the extra height was carefully trimmed off and levelled. The cup was then placed on the cone penetrometer base plate and, making sure that the cone tip was resting on the rim of the cup, the digital gauge was set to zero, Figure 4-4(a). The cone was then retrieved back to its position 200 mm from the sample, Figure 4-4(b). The cone was allowed to fall and the final reading was taken, Figure 4-4 (c).

(a) (b) (c)

Figure 4-4 Testing: (a) setting zero reading, (b) retrieving the cone back to its position, and (c) final reading.

4.3 Tests on Norwegian clay

Five soil samples were sent to Queen’s University Belfast just before the educational visit to determine the w_P using the modified falling cone method. Three clay samples from E18 Østfold-Vinterbro, and two clay samples from Fv 455 Buskogen-Alshus were tested, detail description of the samples are included in appendix A. Four of the samples tested were carried out by drying the sample and crushing, whereas the last test was carried out without drying and crushing the sample.

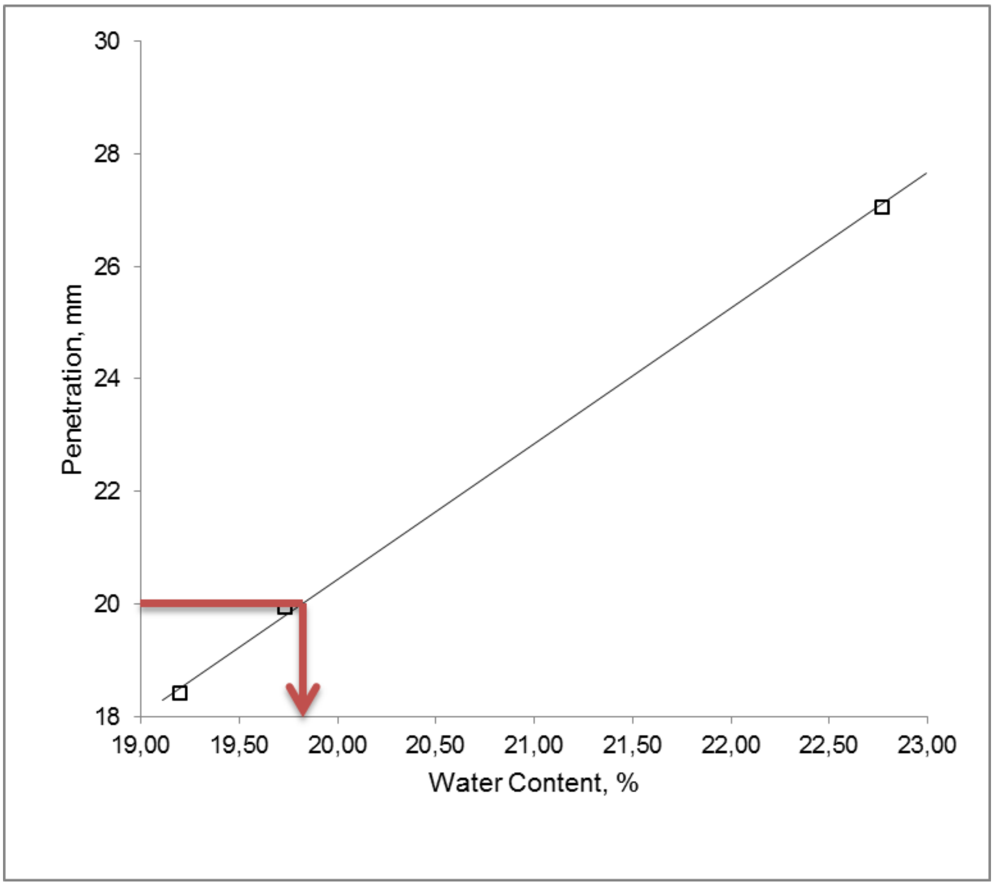
Sample nr.1

Oppdragsnr. 1110030
Location: Fv 455 Buskogen-Alshus
Depth (m): 2,2 – 3,0
Clay content: 20%

Plastic Limit by modified falling Cone Test_0.727kg

TEST NUMBER	1		2		3		4	
WEIGHT OF CUP & WET SOIL (g)	402		404		409		411	
PERCENTAGE OF WATER (%)	21,5		22,5		21		19,5	
CONE PENETRATION (mm)	23,76	23,85	27,09	27,00	19,80	20,06	18,13	18,69
AVERAGE CONE PENET. (mm)	23,8		**27,0**		**19,9**		**18,4**	
CONTAINER NO.	36		31		33		32	
WETSOIL & CONTAINER (g)	34,4488		24,0177		25,709		29,1574	
DRYSOIL & CONTAINER (g)	28,803		20,1881		22,0283		25,0039	
CONTAINER (g)	3,3841		3,3699		3,3789		3,3718	
DRY SOIL (g)	25,4189		16,8182		18,6494		21,6321	
MOISTURE LOSS (g)	5,6458		3,8296		3,6807		4,1535	
MOISTURE CONTENT (%)	22,2		**22,8**		**19,7**		**19,2**	

From the graph below w_P, water content at 20 mm penetration, 19,8 %



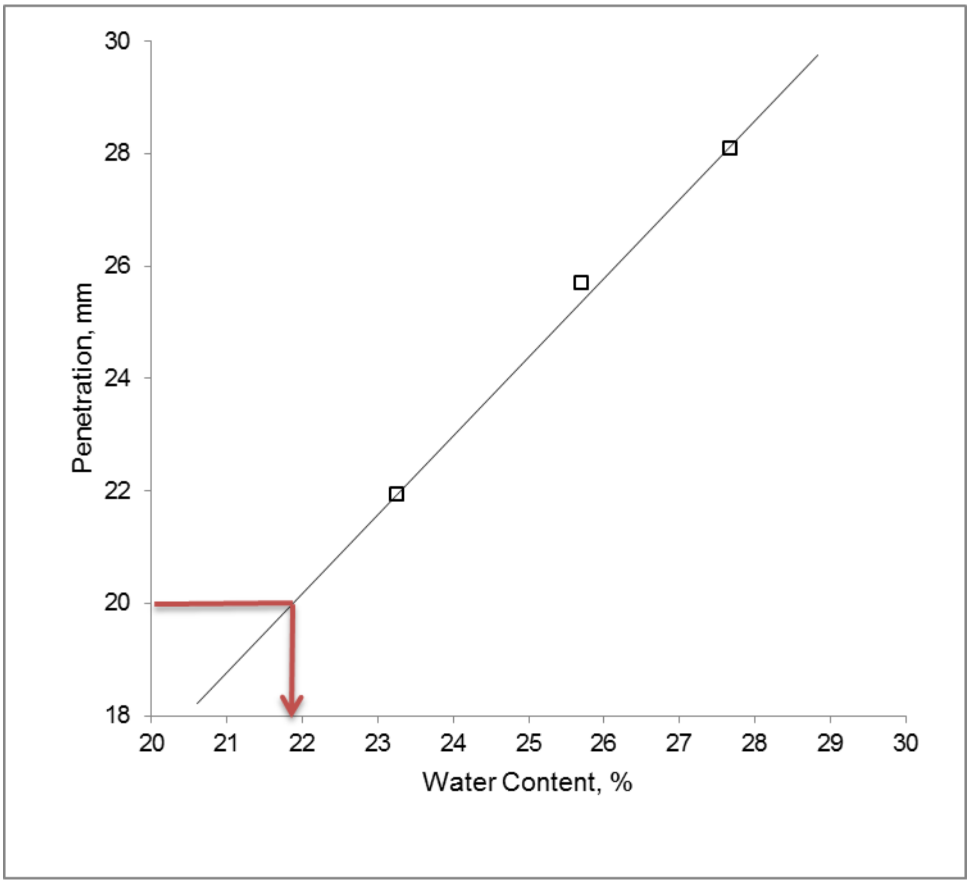
Sample nr.2

Oppdragsnr. 1110223
Location: E18 Østfold-Vinterbro
Depth (m): 3,0 – 4,0
Clay content: 58%

Plastic Limit by modified falling Cone Test_0.727kg

TEST NUMBER	1		2		3		4	
WEIGHT OF CUP & WET SOIL (g)	406		401		398		395	
PERCENTAGE OF WATER (%)	22,5		24		25,5		27	
CONE PENETRATION (mm)	18,67	18,94	22,03	21,83	25,55	25,82	28,00	28,20
AVERAGE CONE PENET. (mm)	18,8		**21,9**		**25,7**		**28,1**	
CONTAINER NO.	38		37		39		40	
WETSOIL & CONTAINER (g)	23,8858		25,4853		25,7527		27,4170	
DRYSOIL & CONTAINER (g)	20,1875		21,3142		21,1741		22,2022	
CONTAINER (g)	3,3838		3,3832		3,3645		3,3580	
DRY SOIL (g)	16,8037		17,931		17,8096		18,8442	
MOISTURE LOSS (g)	3,6983		4,1711		4,5786		5,2148	
MOISTURE CONTENT (%)	22,0		**23,3**		**25,7**		**27,8**	

From the graph below w_P, water content at 20 mm penetration, 21,8 %



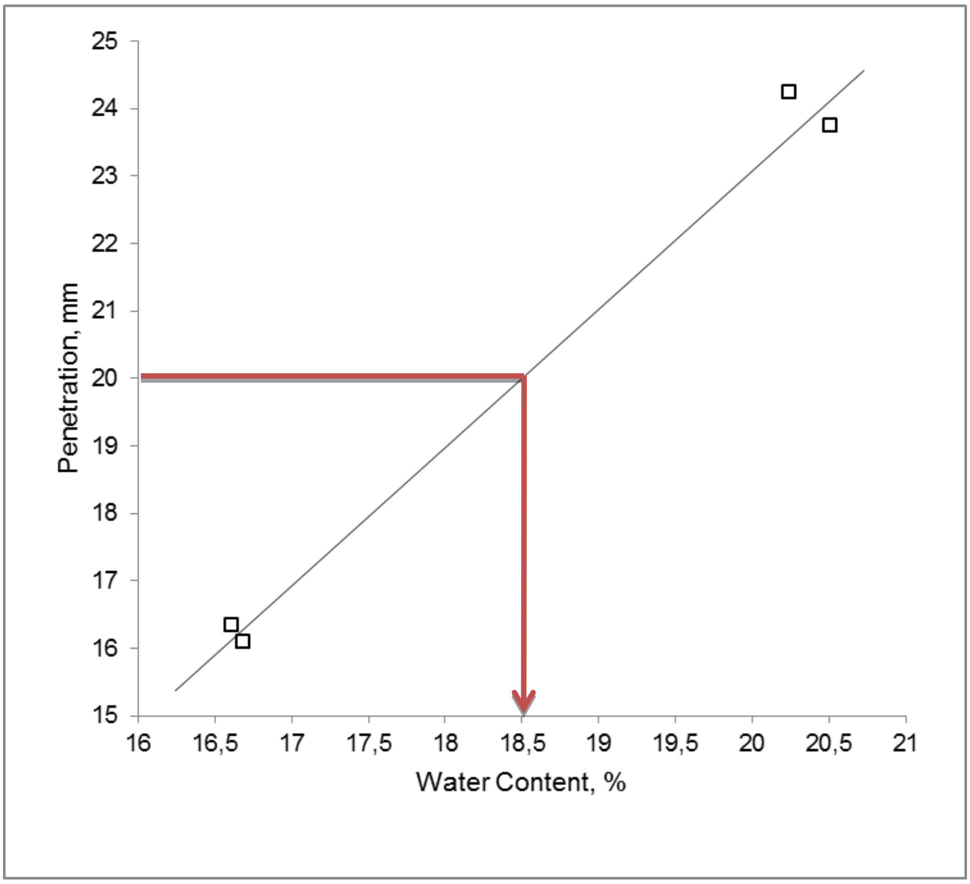
Sample nr.3

Oppdragsnr. 1110223
Location: E18 Østfold-Vinterbro
Depth (m): 4,0 – 5,0
Clay content: 37%

Plastic Limit by modified falling Cone Test_0.727kg

TEST NUMBER	1		2		3		4	
WEIGHT OF CUP & WET SOIL (g)	417		415		407		407	
PERCENTAGE OF WATER (%)	16,5		18		19,5		21	
CONE PENETRATION (mm)	16,09	16,59	16,01	16,17	24,39	24,08	23,76	23,75
AVERAGE CONE PENET. (mm)	**16,3**		**16,1**		**24,2**		**23,7**	
CONTAINER NO.	48		44		43		49	
WETSOIL & CONTAINER (g)	25,0924		23,8961		22,7880		30,4587	
DRYSOIL & CONTAINER (g)	21,9979		20,952		19,5155		25,8549	
CONTAINER (g)	3,3717		3,3077		3,3517		3,4074	
DRY SOIL (g)	18,6262		17,6443		16,1638		22,4475	
MOISTURE LOSS (g)	3,0945		2,9441		3,2725		4,6038	
MOISTURE CONTENT (%)	**16,6**		**16,7**		**20,2**		**20,5**	

From the graph below w_P, water content at 20 mm penetration, 18,5 %



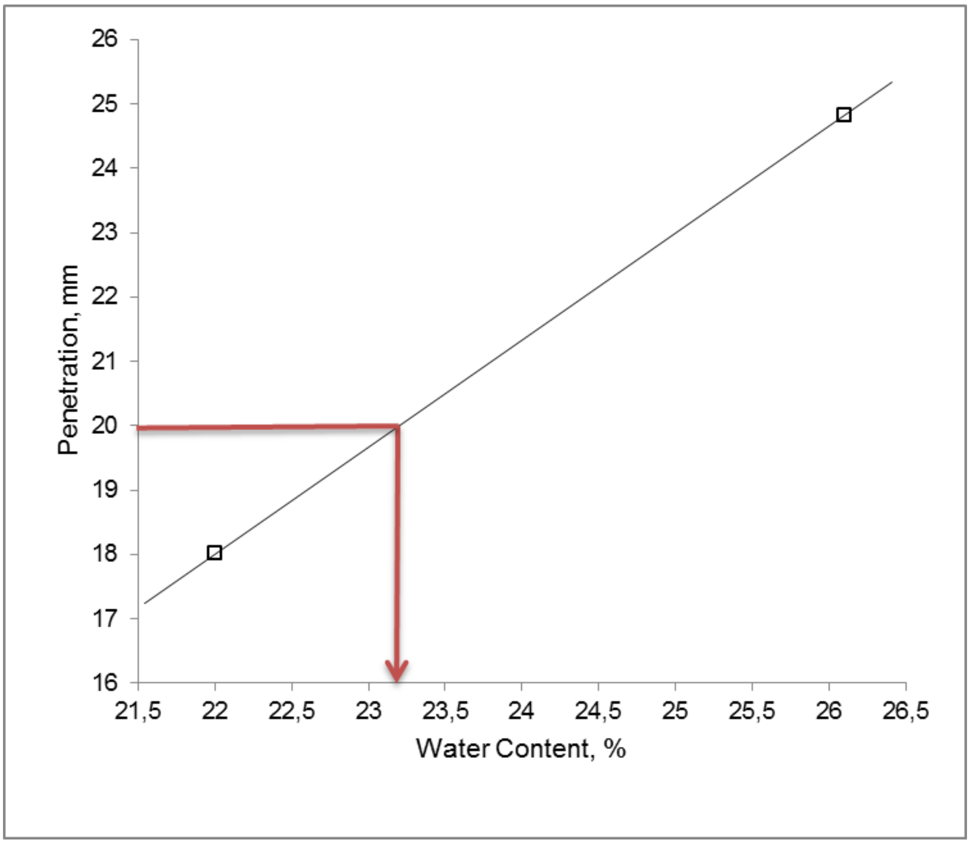
Sample nr.4

Oppdragsnr. 1110030
Location: Fv 455 Buskogen-Alshus
Depth (m): 9,7 – 10,0
Clay content: 35 %

Plastic Limit by modified falling Cone Test_0.727kg

TEST NUMBER	1		2
WEIGHT OF CUP & WET SOIL (g)	396		406
PERCENTAGE OF WATER (%)	30		22
CONE PENETRATION (mm)	24,77	24,86	18,01
AVERAGE CONE PENET. (mm)	**24,8**		**18,0**
CONTAINER NO.	15		2
WETSOIL & CONTAINER (g)	28,6732		30,8262
DRYSOIL & CONTAINER (g)	23,4287		25,8667
CONTAINER (g)	3,339		3,3262
DRY SOIL (g)	20,0897		22,5405
MOISTURE LOSS (g)	5,2445		4,9595
MOISTURE CONTENT (%)	**26,1**		**22,0**

From the graph below w_P, water content at 20 mm penetration, 23,2 %



Sample nr.5

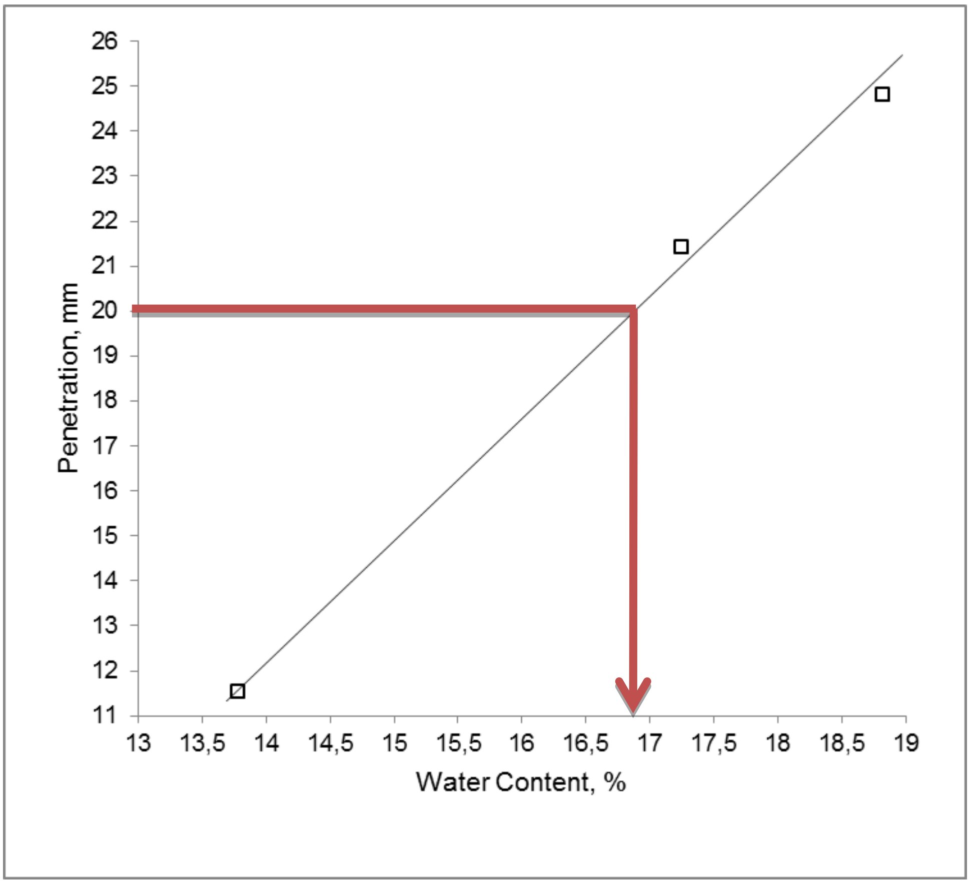
Sample nr. 5 was prepared without drying and crushing.

Oppdragsnr. 1110223
Location: E18 Østfold-Vinterbro
Depth (m): 4,0 – 5,0
Clay content: 37%

Plastic Limit by modified falling Cone Test_0.727kg

TEST NUMBER	1		2		3	
WEIGHT OF CUP & WET SOIL (g)	412		414		422	
PERCENTAGE OF WATER (%)	16,5		21,13		19,5	
CONE PENETRATION (mm)	24,82	24,82	21,13	21,68	11,64	11,42
AVERAGE CONE PENET. (mm)	**24,8**		**21,4**		**11,5**	
CONTAINER NO.	1		3		13	
WETSOIL & CONTAINER (g)	24,3124		22,9479		25,3275	
DRYSOIL & CONTAINER (g)	20,9882		20,0569		22,6639	
CONTAINER (g)	3,3236		3,3003		3,3393	
DRY SOIL (g)	17,6646		16,7566		19,3246	
MOISTURE LOSS (g)	3,3242		2,891		2,6636	
MOISTURE CONTENT (%)	**18,8**		**17,2**		**13,8**	

From the graph below w_P, water content at 20 mm penetration, 16,9 %



4.4 Test results using modified falling cone method

Test results from the five soil samples sent to Queen's University Belfast (QUB) to determine the w_P using the modified falling cone method is summarised below together with results from the SVV sentrallab, Oslo using conventional standard method.

Reported test result from QUB with results from SVV sentrallab, Oslo.

Sample	w_P (%)		Difference
	modified falling cone method	SVV sentarallab. (NS 8003-1982)	
Fv 455 Buskogen-Alshus, Depth (m) 2,2 – 3,0	19,8	24,6	4,8
E18 Østfold-Vinterbro, Depth (m) 3,0 – 4,0	21,8	18,6	-3,2
E18 Østfold-Vinterbro, Depth (m) 4,0 – 5,0	18,5	11,8	-6,7
E18 Østfold-Vinterbro, Depth (m) 9,7 – 10,0	23,2	21,8	-1,4
Fv 455 Buskogen-Alshus, Depth (m) 4,0 – 5,0	16,9	7,0	-9,9

5 Assessments of the standard and proposed falling cone method to measure w_P

As part of the assessment for the standard procedure (Norsk Standard NS 8003-1982) eight different soil samples were prepared and sent to six geotechnical laboratories to determine the w_P. The main focus was to get an over view about the reproducibility of the result by different operators performing the test at different laboratories. For this study four laboratories of the Norwegian public roads administrations from four regions and two private laboratories were included. The following table show laboratories included in the study.

List of geotechnical laboratories included in the study

	laboratory	Address	Contact person
1	SVV, Region midt, Trondheim sentrallab	Vestre Rosten 78 7075 Tiller	Olga Lepkovski 74122394 olga.lepkovski@vegvesen.no
2	SVV, Region nord, Bodø lab	Stormyraveien 61 8008 Bodø	Steinar Heimly 776171810/ 99387340 steinar.heimly@vegvesen.no
3	Løvlien Georåd AS, Hamar	Narmoveien 191, 2318 Hamar	Kristian Storsveen 90043985 Ks@georaad.no
4	SVV, Region øst, Oslo sentrallab	Østensjøveien 34 0667 Oslo	Jan Inge Senneset 2405868/ 99321214 jan.senneset@vegvesen.no
5	Multiconsult, Oslo	Nedre Skøyenvei 2, 0276 Oslo	Ståle Kildahl Staale.kildahl@multiconsult.no
6	SVV, Region sør Skien lab	Bataljonveien 15 3734 Skien	Stig Rønningen 35589655/ 90577778 stig.ronningen@vegvesen.no

5.1 Assessment of the standard procedure

The assessment of the standard procedure to measure w_P using the standard method was carried out on eight soil samples and on standard material (Speswhite kaolin). The following table shows the sample identification number.

List of sample identification number

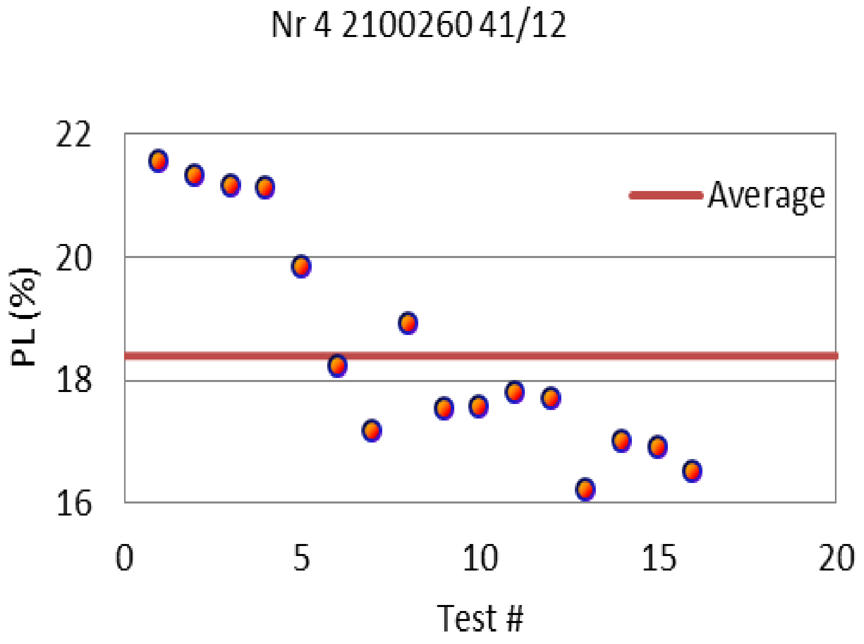
Clay sample nr.	Identification nr.
1	Nr 4 2100260 41/12
2	Nr 4 1120002 3/5
3	Nr 4 1120069 2/4
4	Nr 4 1120252 1/1
5	Nr 450465 H:7003/8
6	Nr 4 50581157/2
7	Nr 4 1120068 1/2
8	Nr 4 1120003 2/2

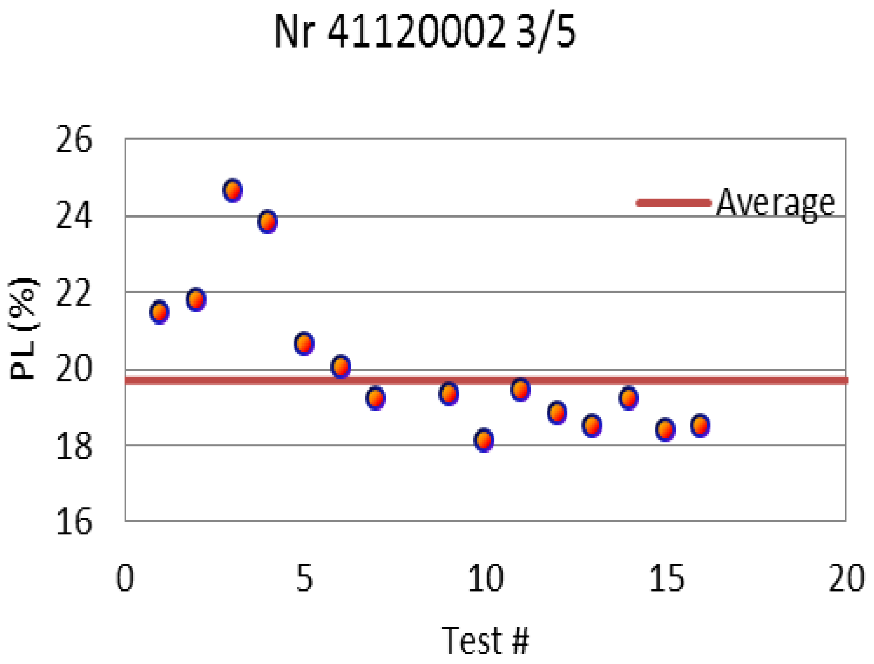
Up to four test results per sample have been reported from the laboratories included in the study. In the table below the average reported w_P values from each of the laboratories using the standard procedure, Norsk Standard NS 8003-1982, are shown.

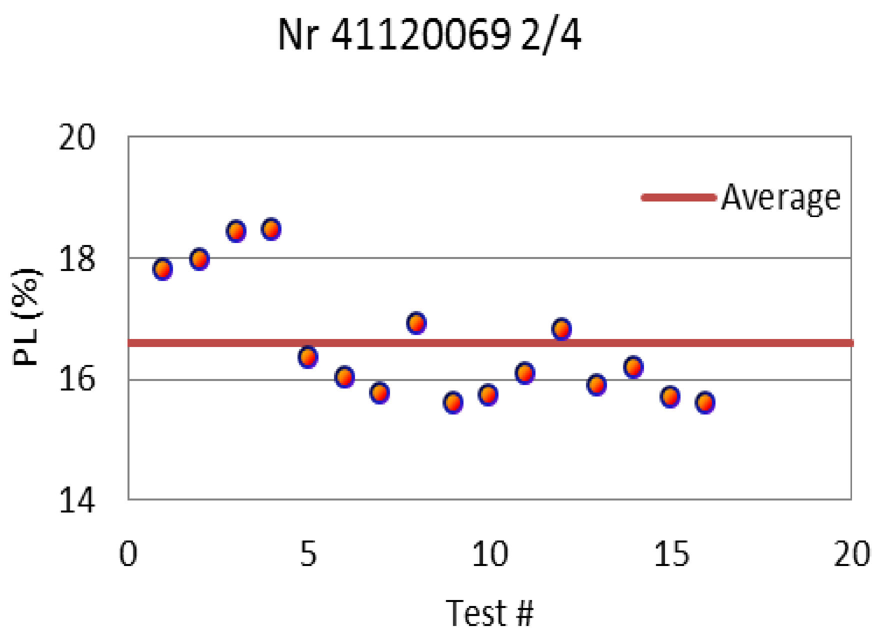
w_P values obtained by six geotechnical laboratories using the standard method

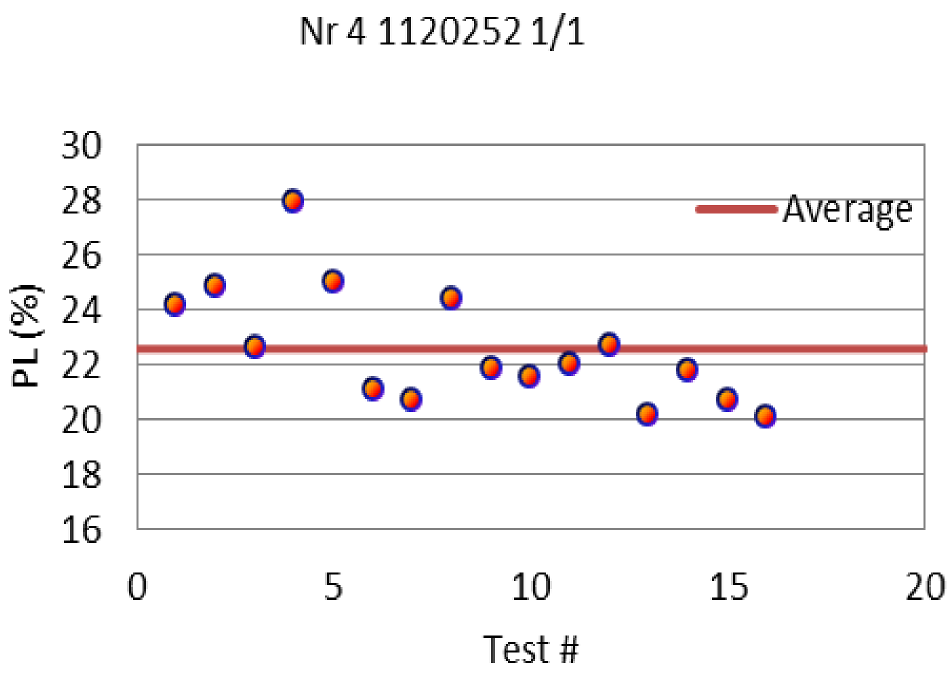
Soil identification nr.	w_P obtained from six laboratories						Average
	1	2	3	4	5	6	
Nr 4 2100260 41/12	21,3	18,4	18,9	17,6	17,8	16,7	18,4
Nr 4 1120002 3/5	22,9	20,0	14,5	18,7	19,1	18,7	19,0
Nr 4 1120069 2/4	18,2	16,0	16,9	15,7	16,5	15,9	16,5
Nr 4 1120252 1/1	24,9	22,3	24,4	21,7	22,4	20,7	22,7
Nr 450465 H:7003/8	24,4	20,2	23,9	21,8	20,5	21,1	22,0
Nr 4 50581157/2	23,9	21,9	23,9	21,0	20,9	19,1	21,8
Nr 4 1120068 1/2	22,0	19,6	21,6	19,3	19,0	18,3	20,0
Nr 4 1120003 2/2	21,4	19,3	20,5	18,2	18,6	20,7	19,8
Speswhite kaolin	36,1	29,7	34,5	31,5	31,8	29,9	32,3

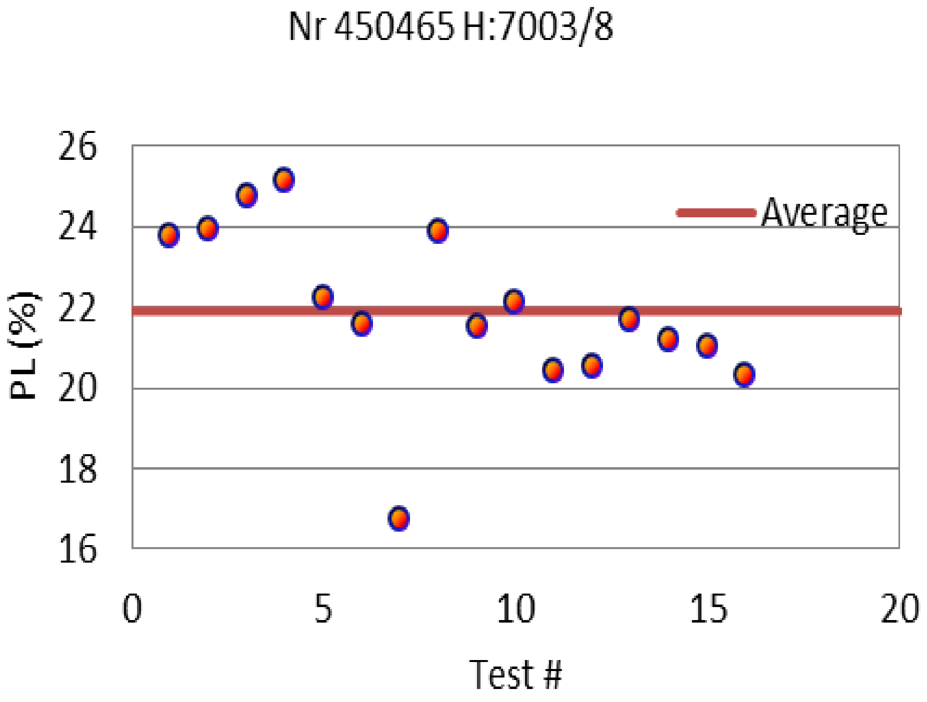
Detailed reported test results for each of the soil sample and Speswhite kaolin are presented in the following figures. The figures also show the variation of all reported w_P values from the average value for each of the soil sample and Speswhite kaolin.

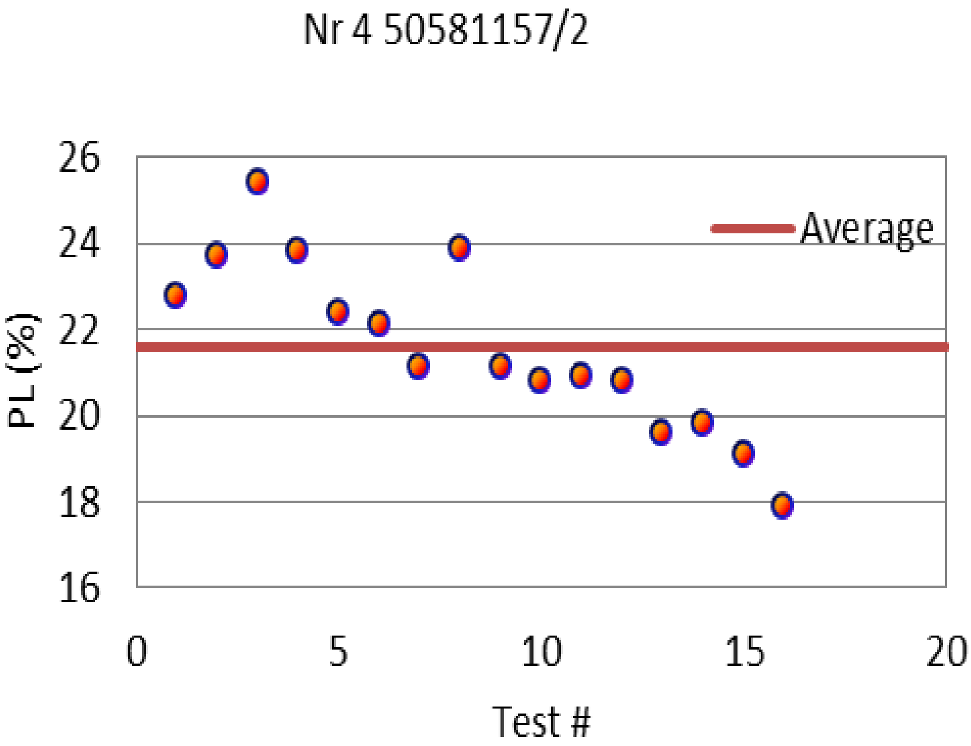


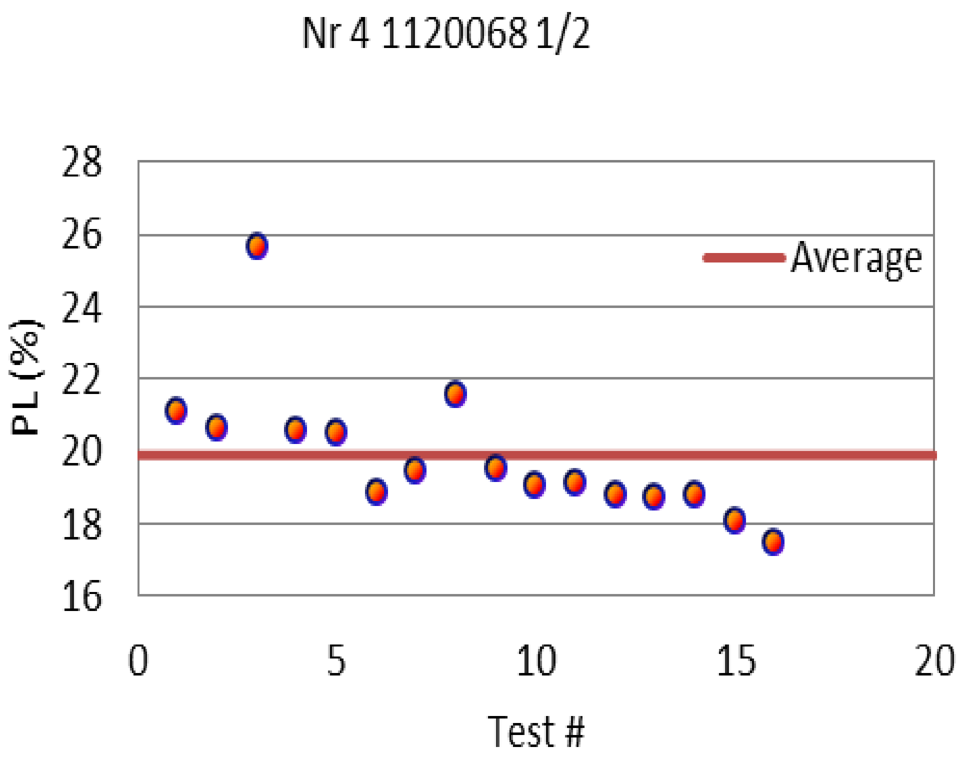


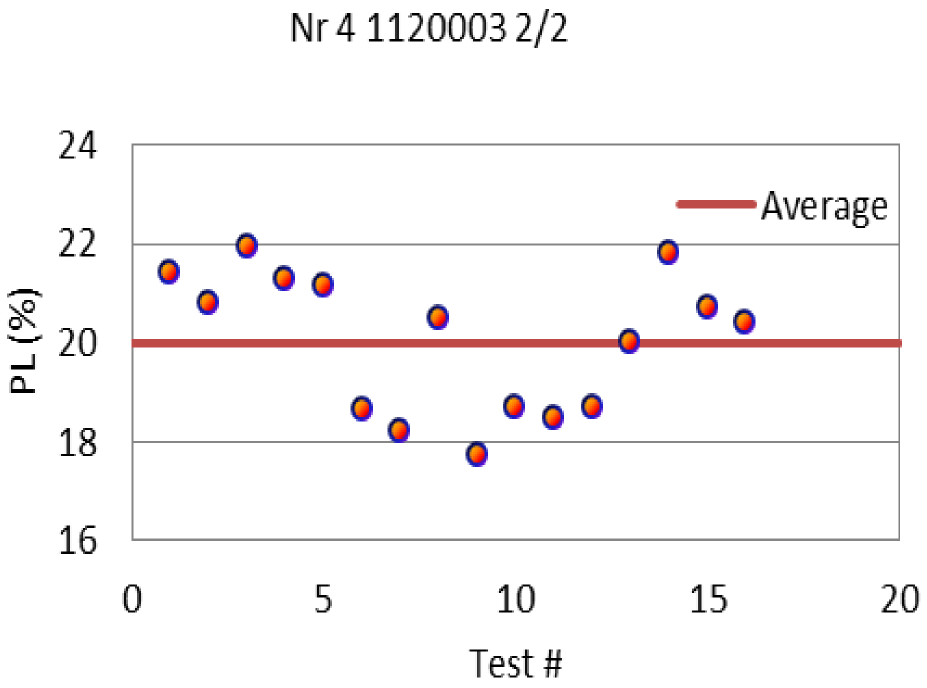

Nr 41120069 2/4
20
18
16
14
PL (%)
Average
0
5
10
15
20
Test #

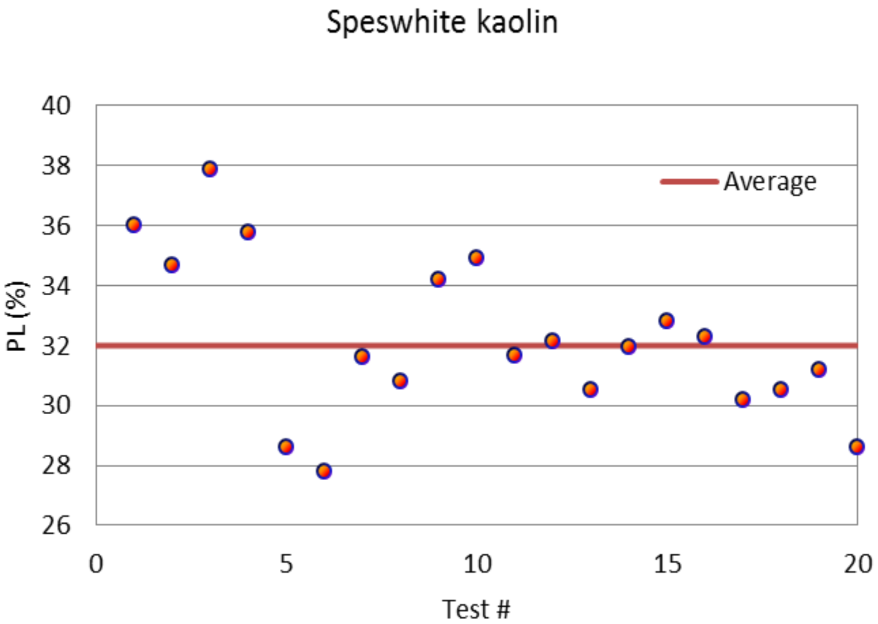

Nr 4 1120252 1/1
30
28
26
24
22
20
18
16
PL (%)
Average
0
5
10
15
20
Test #


Nr 450465 H:7003/8
PL (%)
Test #
Average
26
24
22
20
18
16
0
5
10
15
20


Nr 4 50581157/2
PL (%)
Test #
Average
26
24
22
20
18
16
0
5
10
15
20


Nr 4 1120068 1/2
28
26
24
22
20
18
16
PL (%)
Average
0
5
10
15
20
Test #


Nr 4 1120003 2/2
24
22
20
18
16
PL (%)
Average
0
5
10
15
20
Test #



5.2 Assessment of the proposed modified falling cone method

The proposed modified falling cone method was evaluated by conducting tests on Speswhite kaolin at those six geotechnical laboratories included in this test program. The procedure was first demonstrated to the operators performing the test. And later the operators prepared themselves two samples with slightly different water content and determined the penetration. The demonstration includes preparation of samples close to the expected w_P of the material and steps to determine penetration of the falling cone in the sample with the corresponding water content of the sample. Parallel tests were also carried out using the standard method, Norsk Standard NS 8003-1982, to determine the w_P of the same material.

Figure 5-1 Sample preparation for the modified falling cone test method

Figure 5-2 Parallel tests to determine the w_P of Speswhite kaolin using the proposed falling cone and standard method

In the Figure 5-3 below the reported cone penetration values at the corresponding water contents are summarised, detailed reported results are shown in Appendix C. From the curve the w_P value of the Speswhite kaolin can be then determined at the corresponding water content to 20 mm penetration.

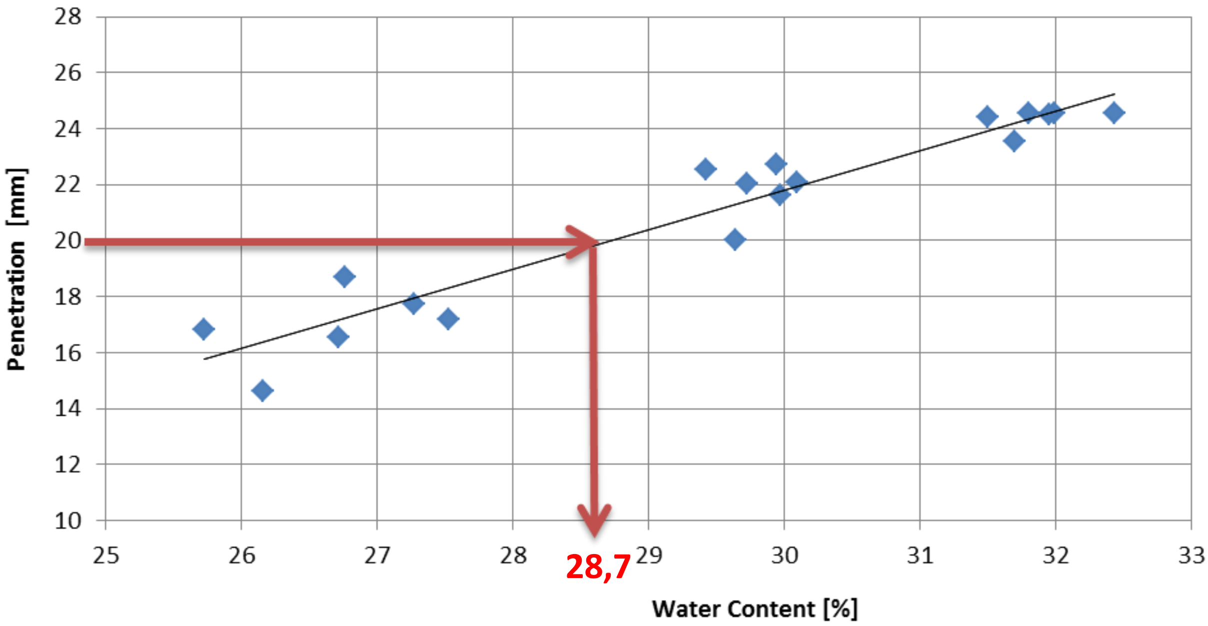


Figure 5-3 Reported cone penetration with the corresponding water content of Speswhite kaolin.

In the table below the reported w_P values from each of the laboratories using the modified falling cone method and the standard method are summarised.

w_P values obtained by six geotechnical laboratories

Sample	Method	w_P obtained from six laboratories (%)						Average	Difference
		1	2	3	4	5	6		
Speswhite kaolin	Falling cone	27,9	29,3	27,9	29,0	28,8	29,2	28,7	3.6
	Standard	36,1	29,7	34,5	31,5	31,8	29,9	32,3	

6 Conclusions and recommendations

Various methods of measuring the Plastic Limits have been proposed over the past three decades. The modified falling cone method studied in this project is based on the principles and procedures of fall cone method to measure the w_L of fine grained soils. The proposed approach is based on the energy that is dissipated as the cone penetrates into the soil. The reported test results on Speswhite kaolin using the standard procedure and the proposed modified falling cone method shows some promising results. All reported results using the standard method, shown in the table below, are more than the values obtained using the proposed modified falling cone method.

Reported w_P values of Speswhite kaolin

Sample	Method	w_P obtained from six laboratories (%)						Average
		1	2	3	4	5	6	
Speswhite kaolin	Falling cone	27,9	29,3	27,9	29,0	28,8	29,2	28,7
	Standard	36,1	29,7	34,5	31,5	31,8	29,9	32,3
	Difference	8,2	0,4	6,6	2,5	3,0	0,7	3.6

The study shows a possibility to make the procedure a mechanical process to measure the w_P of fine grained soils. Based on this study the following recommendations are made regarding to sample preparation and the proposed modified falling cone apparatus.

6.1 Sample preparation

There are some concerns about sample preparation procedure. Using the modified falling cone method to determine w_P, the test is repeated for various water contents, at least three times around the w_P of the sample. Comparing to the standard procedure it takes more time to prepare samples for testing. During this study it was observed that it takes 20 to 30 minutes per sample. Accordingly it was observed that it takes 60 – 90 minutes to complete one test. Whereas the time required using the standard procedure is 10 – 20 minutes.

This need to be further studied to come up with a mechanical procedure to prepare samples with similar bulk densities at a given water content.

6.2 Proposed modified falling cone apparatus

The proposed modified falling cone apparatus concept is based on the falling cone approach used for w_L test and based on the energy that is dissipated as the cone penetrates into the soil There is a clear difference between the BS and NS regarding to the apparatus used to determine w_L. These differences are as shown in the table below: the weight of the cone (80 g vs 60 g), cone angle (30^0 vs 60^0) and penetration of the specimen (20 mm vs. 10 mm). Therefore it is recommended to study the apparatus based on the NS cone angle and penetration depth by keeping the same cone weight 0,727 kg and 200 mm falling distance.

Table showing cone penetration requirements (CEN ISO/TS 17892-12:2004)

Cone penetration requirements	80 g/30^0	60 g/60^0
Initial penetration	about 15 mm	about 7 mm
Penetration range	15 to 25 mm	7 to 15 mm
Maximum difference between two successive tests	0,5 mm	0,4 mm
w_L determined from penetration of:	20 mm	10 mm

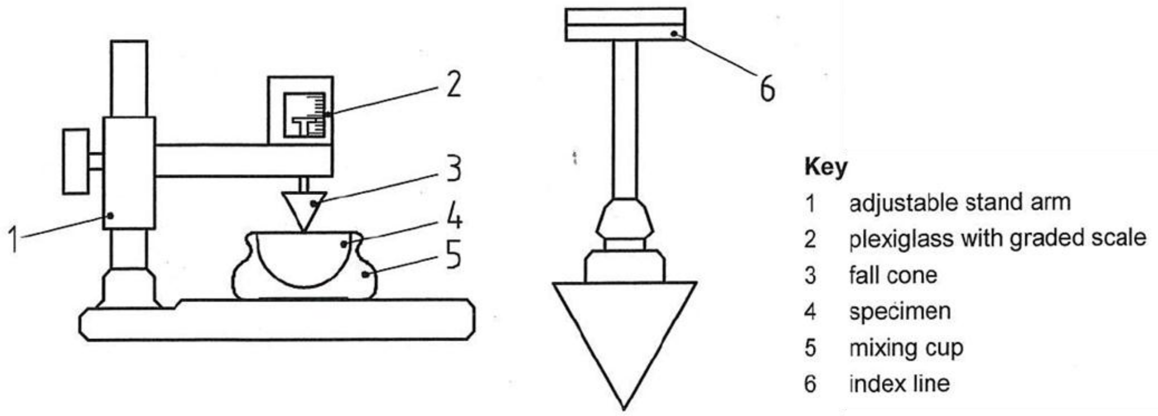


Figure 6-1 Example of fall cone equipment (CEN ISO/TS 17892-12:2004)

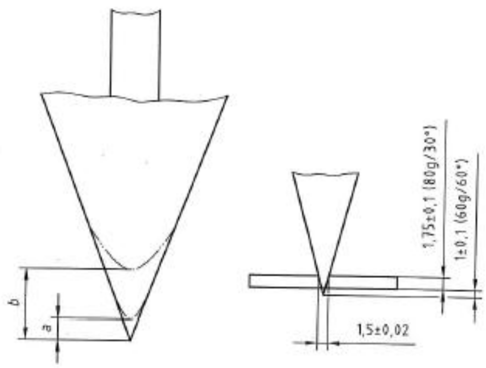


Figure 6-2 Fall cone (CEN ISO/TS 17892-12:2004)

7 References

/1/ Sivakumar, V., Glynn, D., Cairns, P. & Black, J. A.(2009), *A new method of measuring plastic limit of fine materials*. Géotechnique 59, No. 10,. 813-823

/2/ Sivakumar, V., Henderson, L., Moorhead, C.M., Hughes , D. & Sivakumar , S.(2011), *Measurements of the Plastic Limit of Fine Soils: Further Development*. Submitted for publication to Géotechnique

/3/ Belviso, R., Ciampoli, S., Cotecchisa, V. & Federico, A. (1985) *Use of the cone penetrometer to determine consistency limits*. Ground Engng 18, No. 5, 21–22.

/4/ Houlsby, G. T. (1982). *Theoretical analysis of the fall cone test*. Géotechnique 32, No. 2, 111–118.

/5/ Brown, P. J. & Downing, M. C. (2001). *Discussion of fall-cone penetration and water content relationship of clays*. Géotechnique 51, No. 2, 181–187.

/6/ NS 8002-1982, *Geotechnical testing Laboratory methods Fall cone liquid limi*t.

/7/ NS 8003-1982, *Geotechnical testing Laboratory methods Plastic limit.*

/8/ Statens vegvesen (2010), *Håndbok 016 Geoteknikk i vegbygging.*

/9/ Statens vegvesen (2005), *Håndbok 014 Laboratorieundersøkelser.*

/10/ Norsk Geoteknisk Forening (2005), *Peleveiledningen.*

Appendix A

Soil samples sent to QUB.

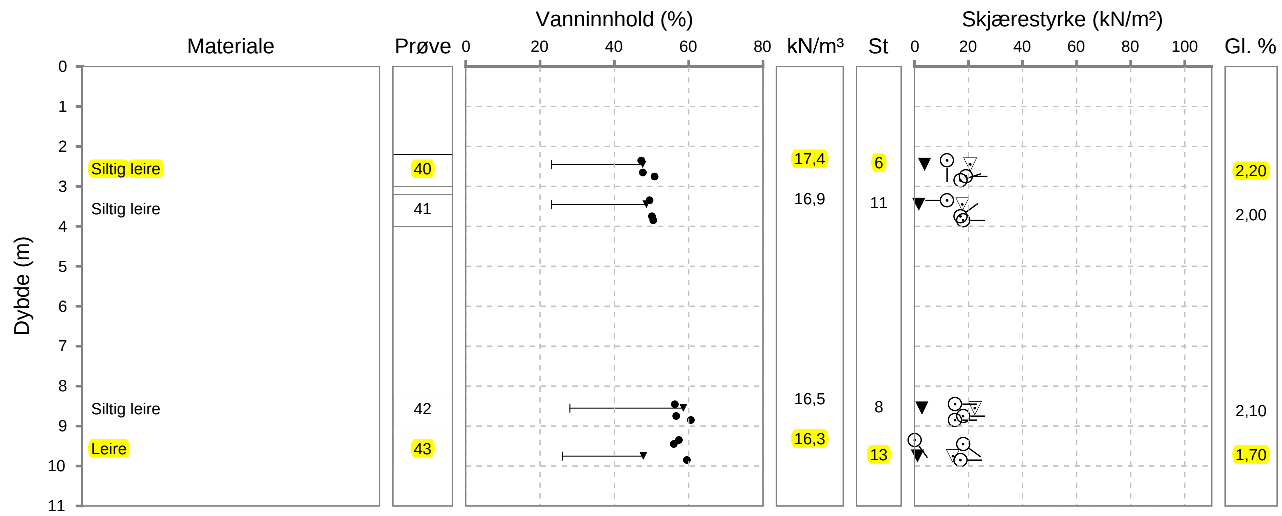
Prøvingslaboratorium: Sentrallaboratorium OSLO - I henhold til H014 labprosess: 14425, 14426, 14433, 14441, 14442, 14445, 14471, 14472

Region Øst

Geoteknisk undersøkelse - Borprofil

Oppdragsnr.1110030 Navn Fv. 455 Buskogen - Alshus

Prøveserie 3 Km/*profil *3 Asvstand høyre kant Analyseår 2011 Prøvetype 54 mm



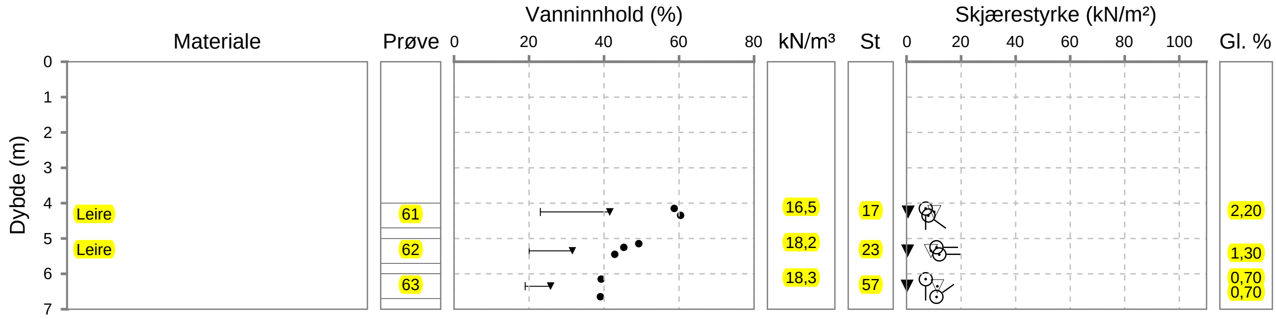
Prøver sendt til Belfast er 40 og 43.

Prøvingslaboratorium: Sentrallaboratorium OSLO - I henhold til H014 labprosess: 14425, 14426, 14433, 14434, 14441, 14442, 14445, 14471, 14472

Geoteknisk undersøkelse - Borprofil

Region Øst

Oppdragsnr.1110223	Navn	E18 Østfold gr.-Vinterbro					
Prøveserie 59	Km/*profil	*S5-9	Asvstand høyre kant	Analyseår	2011	Prøvetype	54 mm



Prøver sendt til Belfast er 61, 62 og 63.

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

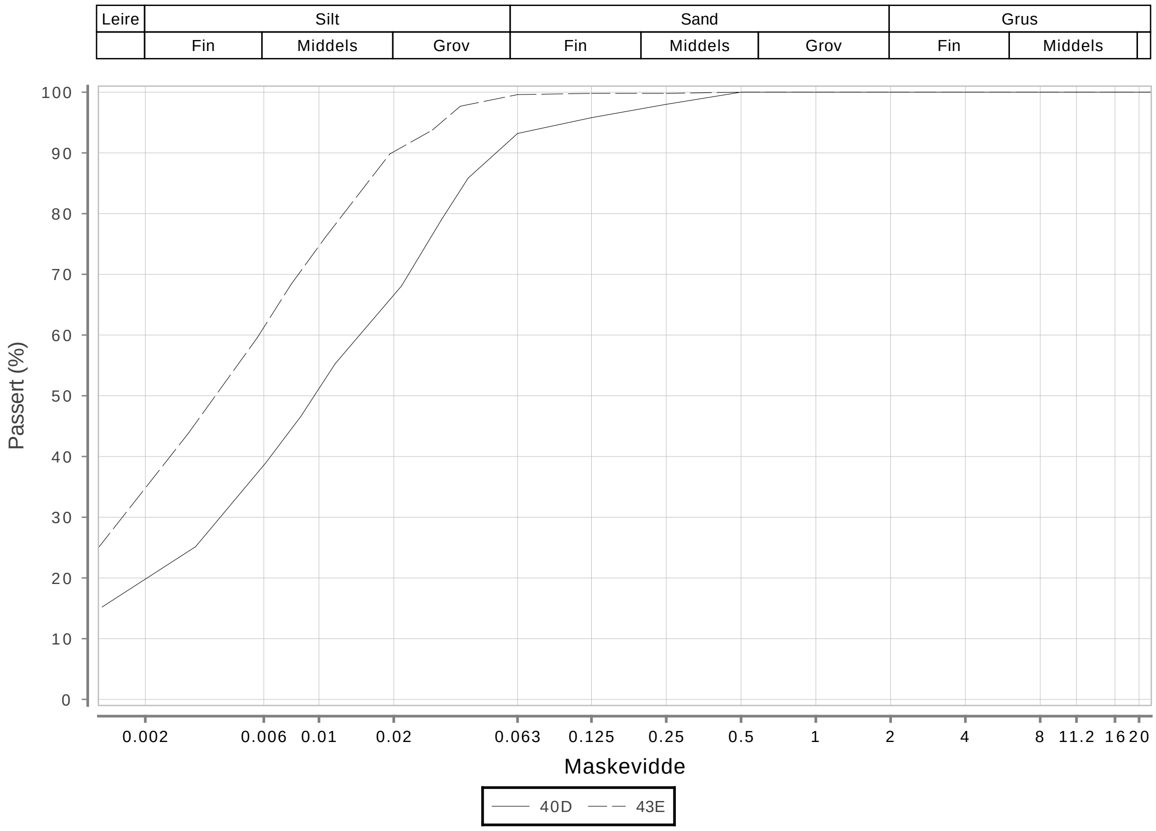
Oppdragsnr.	**1110030**	Oppdragsnavn	**Fv. 455 Buskogen - Alshus**
Prosjektnr.	**104541**	Prosjektnavn	**fv 455 g/s-veg fra Buskogen ti**
Ansvarsområdenr.	**15110**	Ansvarsområdenavn	**Plan og trafikk Østfold**

Serienr. 3, Hullnr. 3

Sylinder / Pose nr.	40D	43E			
Uttaksdato	16.03.2011	16.03.2011			
Uttatt kl.					
Analysetype	Våtsikt	Våtsikt			
Humus (Glødetap)	2.2	1.7			
Vanninnhold (%)	47.6				
% <63µm av <delsikt	93.2 (20 mm)	99.6 (20 mm)			
% <20µm av <delsikt	66.6 (20 mm)	90.2 (20 mm)			

Siktedata - Passert (%)

	µm				mm							
Pr.nr.	63	125	250	500	1	2	4	8	11.2	16	20	22.4
40D	93.2	95.8	98.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
43E	99.6	99.8	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
40D	FV455		*3	0.0	2.2 - 3.0	Siltig leire, humusholdig	*8.6	T4
43E	FV455		*3	0.0	9.2 - 10.0	Leire, humusholdig	*7.8	T4

Sted:__________________ Dato:________ Signatur:__________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen Region Øst

Kornkurve

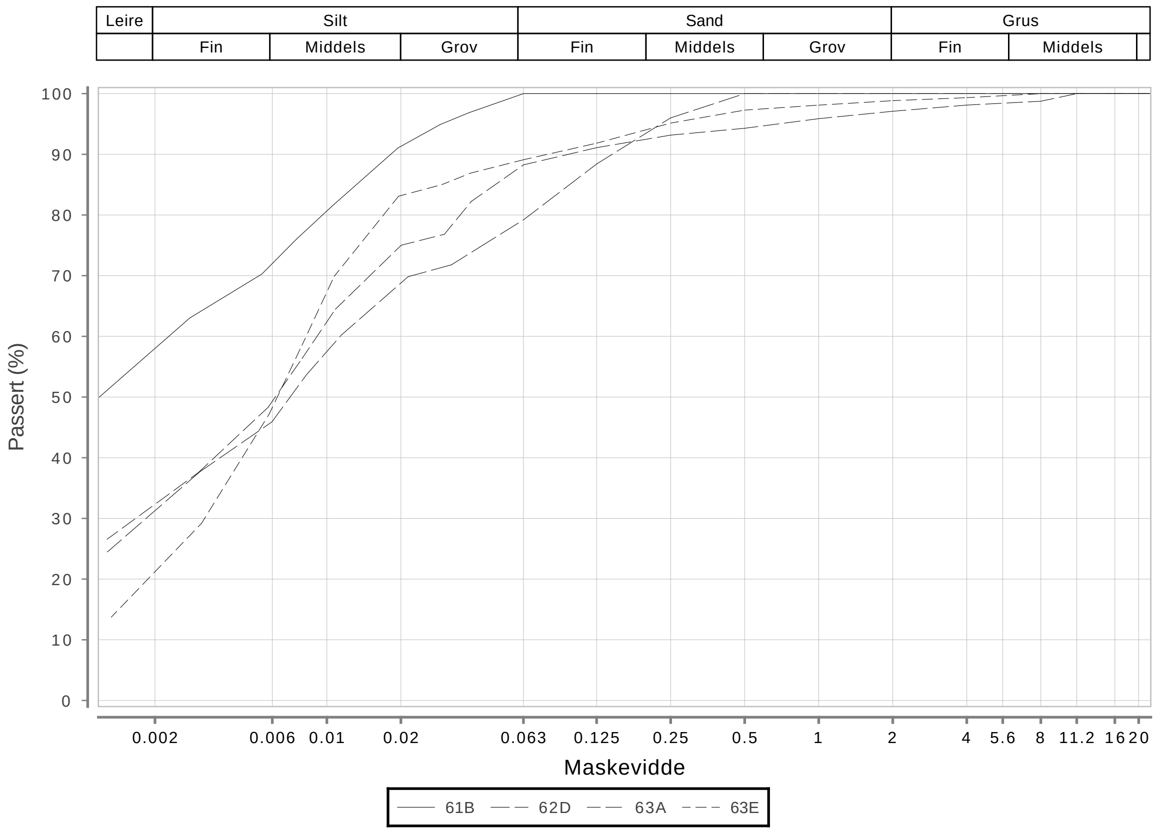
Oppdragsnr.	**1110223**	Oppdragsnavn	**E18 Østfold gr.-Vinterbro**
Prosjektnr.	**101751**	Prosjektnavn	**E 18 ØSTFOLD GR. - VINTERBRO**
Ansvarsområdenr.	**13020**	Ansvarsområdenavn	**E18 Ørje-Vinterbro**

Serienr. 59, Hullnr. 59

Sylinder / Pose nr.	61B	62D	63A	63E	
Uttaksdato	19.04.2011	19.04.2011	19.04.2011	19.04.2011	
Uttatt kl.					
Analysetype	Våtsikt	Våtsikt	Våtsikt	Våtsikt	
Humus (Glødetap)	2.2	1.3		0.7	
Vanninnhold (%)		42.8	39.3		
% <63µm av <delsikt	0.0 (20 mm)	79.2 (20 mm)	88.3 (20 mm)	89.1 (20 mm)	
% <20µm av <delsikt	91.3 (20 mm)	68.8 (20 mm)	75.0 (20 mm)	83.2 (20 mm)	

Siktedata - Passert (%)

	µm				mm								
Pr.nr.	63	125	250	500	1	2	4	5.6	8	11.2	16	20	22.4
61B	100.0	100.0	100.0	100.0	100.0	100.0	100.0		100.0	100.0	100.0	100.0	100.0
62D	79.2	88.4	96.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
63A	88.3	91.1	93.2	94.3	95.9	97.1	98.1		98.7	100.0	100.0	100.0	100.0
63E	89.1	91.8	95.1	97.3	98.1	98.8	99.3		100.0	100.0	100.0	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
61B	EV18		*S5-9	0.0	3.0 - 3.7	Leire, humusholdig	0.0	T3
62D	EV18		*S5-9	0.0	4.0 - 4.7	Leire, humusholdig	*32.4	T4
63A	EV18		*S5-9	0.0	5.0 - 5.7	Leire	0.0	T4
63E	EV18		*S5-9	0.0	5.0 - 5.7	Siltig leire	*5.5	T4

Sted:__________________ Dato:_________ Signatur:__________________

Appendix B

Grainsized distribution curves of samples used in the study.

Clay samples tested		Labsys: Oppdragsnr. 1120434 Projektnr. 104078 Region Øst	
Sample nr.	Identification nr.	Serienr.	Hullnr.
1	Nr 4 2100260 41/12	2	2100260
2	Nr 4 1120002 3/5	4	1120002
3	Nr 4 1120069 2/4	5	1120069
4	Nr 4 1120252 1/1	6	1120252
5	Nr 450465 H:7003/8	7	50465
6	Nr 4 50581157/2	8	1120003
7	Nr 4 1120068 1/2	9	1120068
8	Nr 4 1120003 2/2	Borprofil	50581

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen Region Øst

Kornkurve

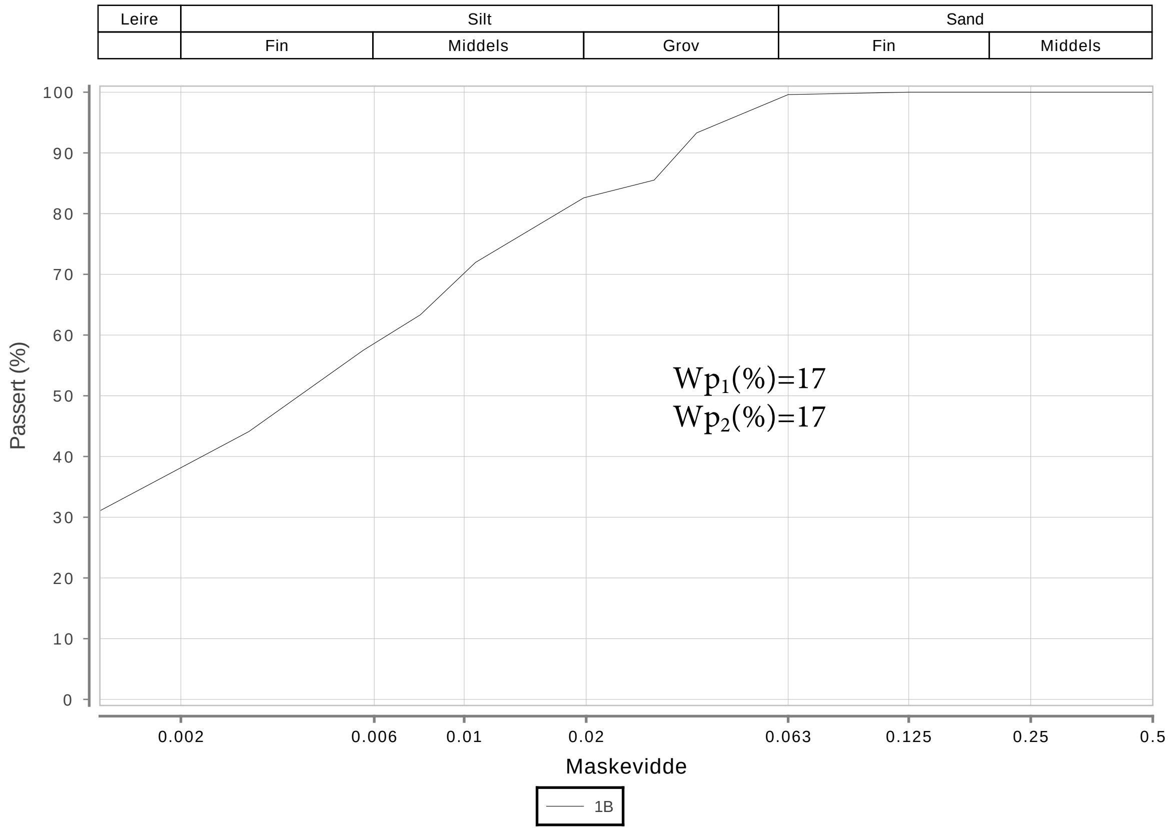
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 2, Hullnr. 2100260

Sylinder / Pose nr.	1B				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	99.6 (20 mm)				
% <20µm av <delsikt	82.7 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1B	99.6	100.0	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1B					1.0 - 2.0	Leire	0.0	T4

Sted:__________________ Dato:________ Signatur:__________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen Region Øst

Kornkurve

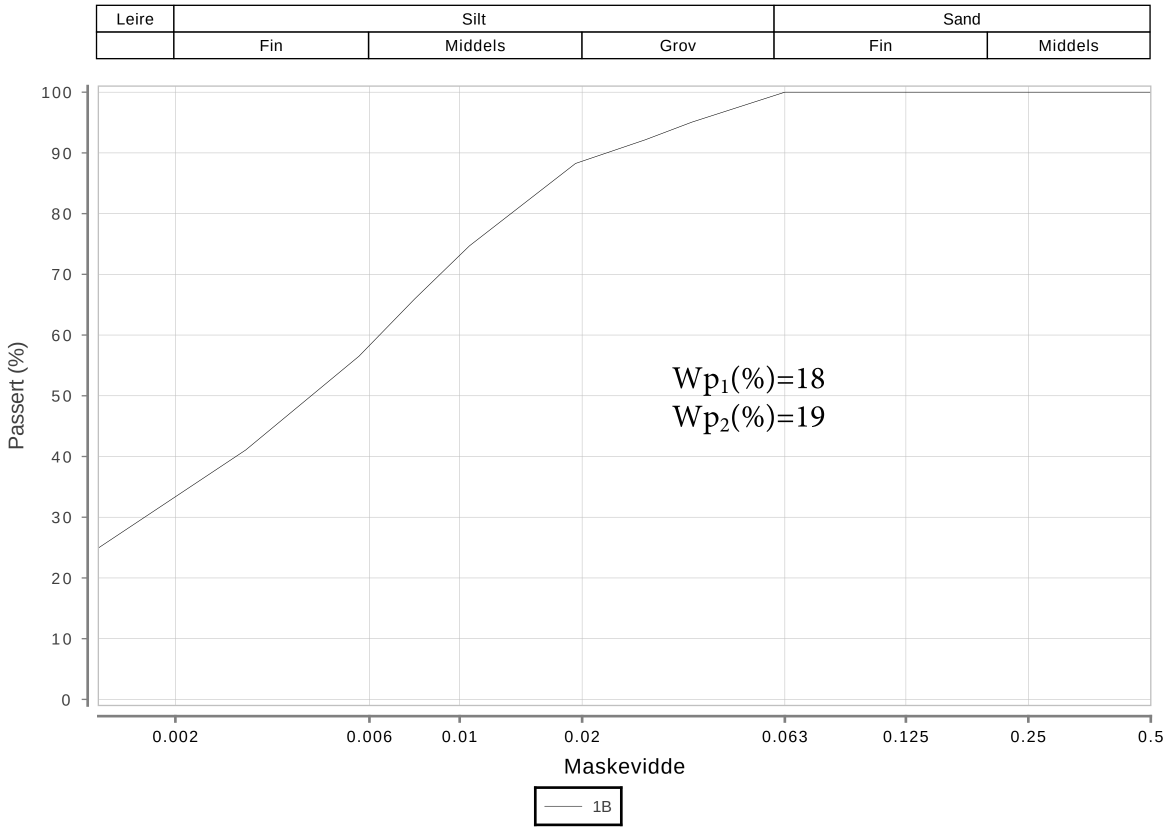
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 4, Hullnr. 1120002

Sylinder / Pose nr.	1B				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	0.0 (20 mm)				
% <20µm av <delsikt	88.6 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1B	100.0	100.0	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1B					1.0 - 2.0	Leire	*8.3	T4

Sted:___________________ Dato:_________ Signatur:___________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

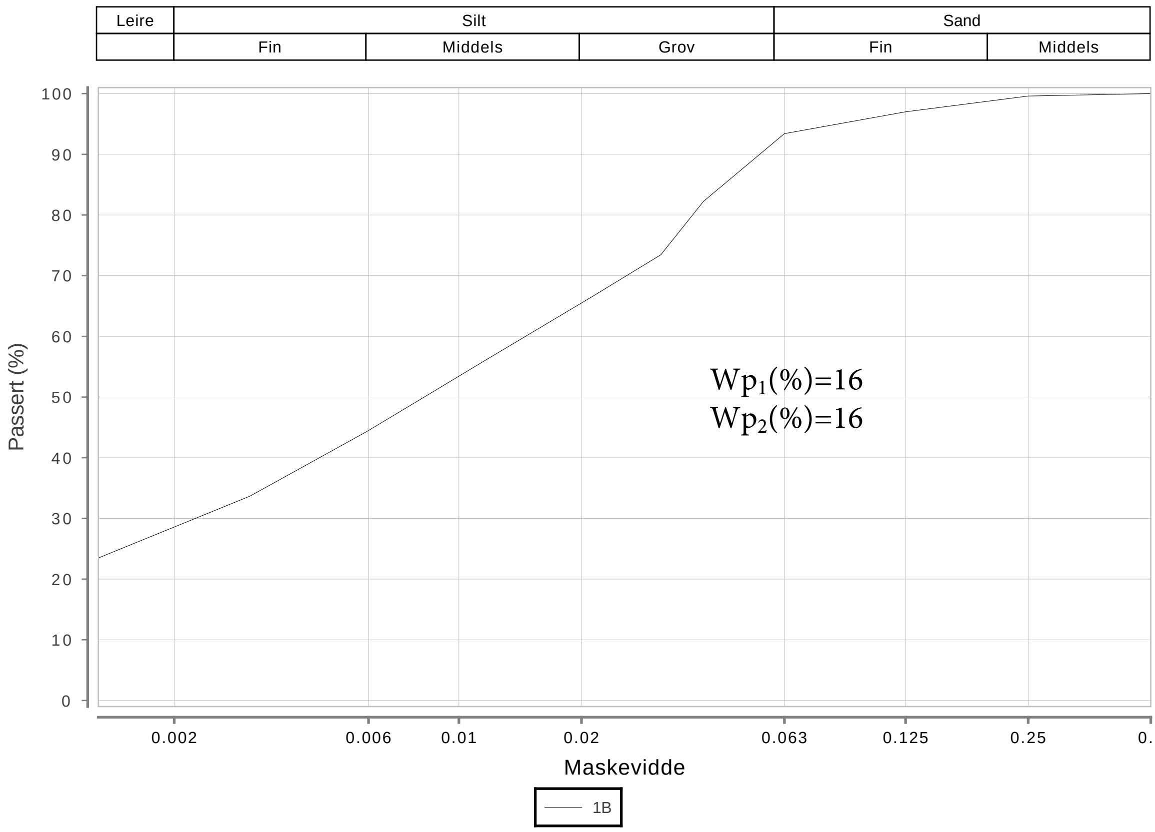
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 5, Hullnr. 1120069

Sylinder / Pose nr.	1B				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	93.4 (20 mm)				
% <20µm av <delsikt	65.5 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1B	93.4	97.0	99.6	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1B					1.0 - 2.0	Siltig leire	*22.1	T4

Sted:________________ Dato:________ Signatur:________________

Kornkurve

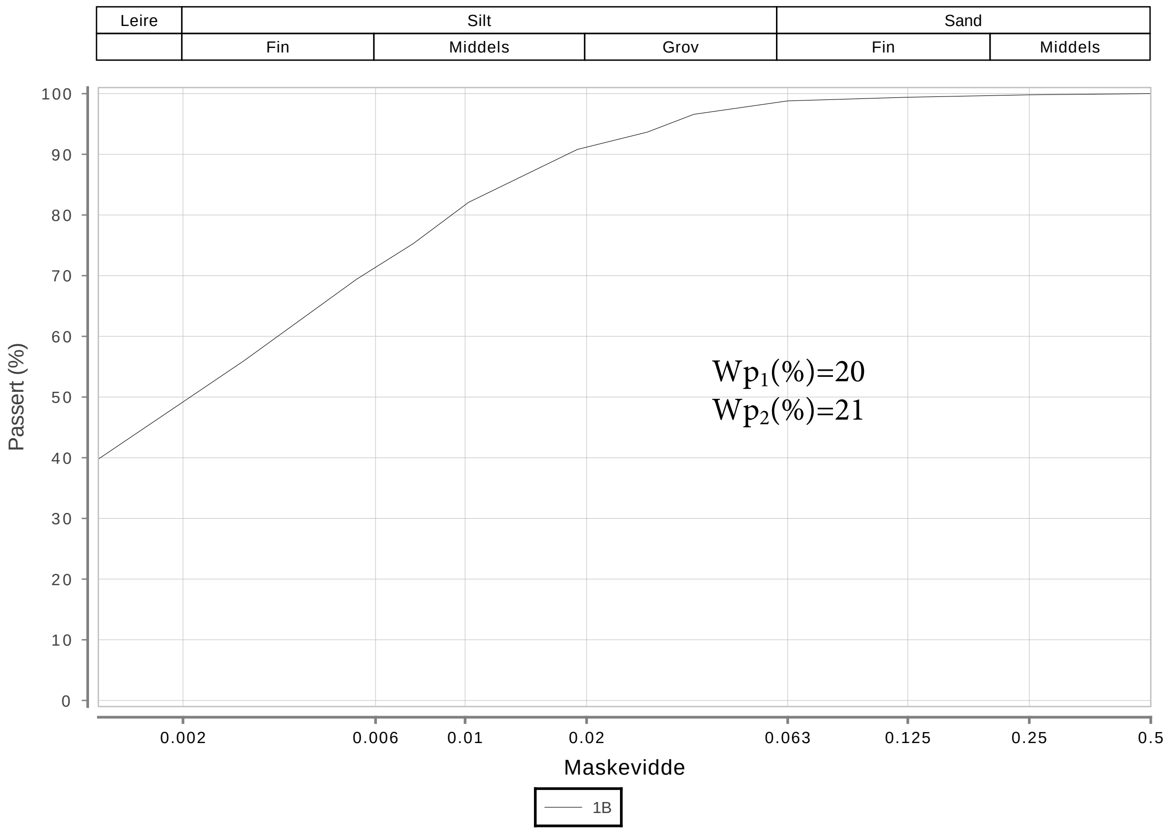
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 6, Hullnr. 1120252

Sylinder / Pose nr.	1B				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	98.8 (20 mm)				
% <20µm av <delsikt	91.2 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1B	98.8	99.4	99.8	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1B					1.0 - 2.0	Leire	0.0	T3

Sted:____________________ Dato:_________ Signatur:____________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

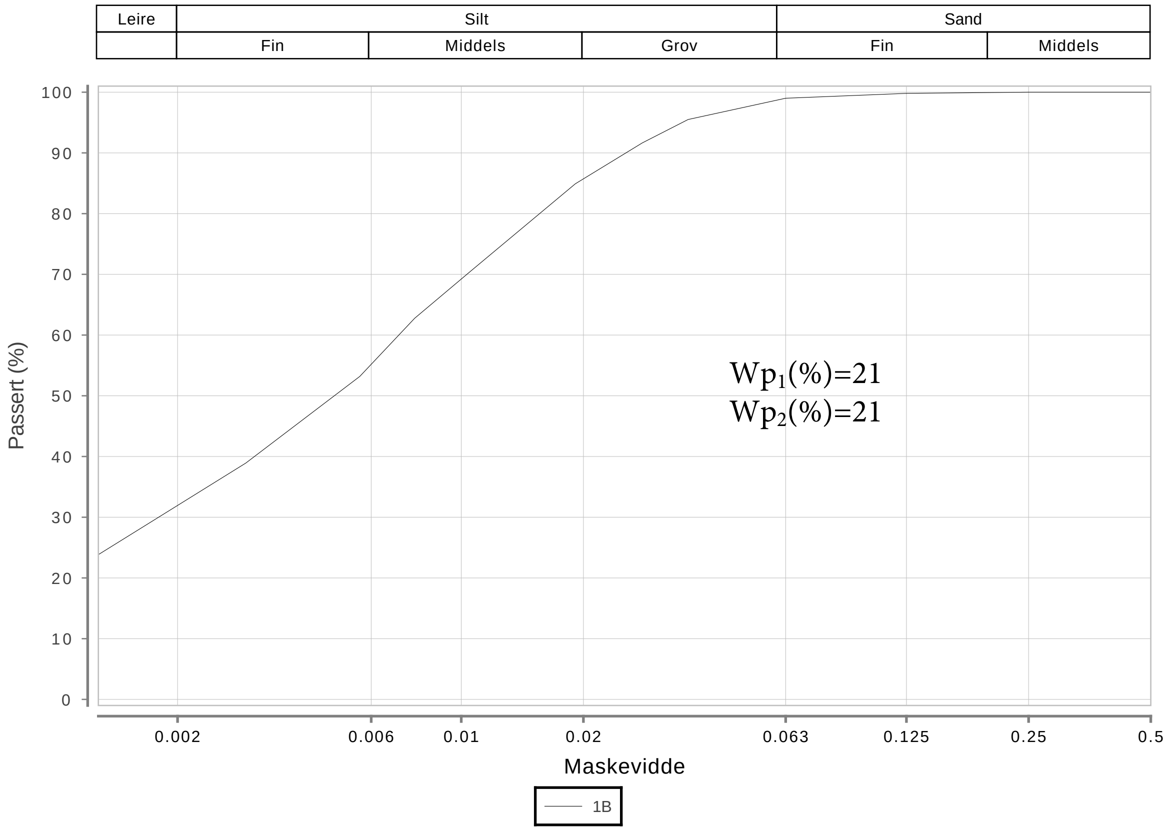
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 7, Hullnr. 50465

Sylinder / Pose nr.	1B				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	99.0 (20 mm)				
% <20µm av <delsikt	85.7 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1B	99.0	99.8	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1B					1.0 - 2.0	Leire	*9.3	T4

Sted:____________________ Dato:_________ Signatur:____________________

Statens vegvesen

Region Nord

Kornkurve

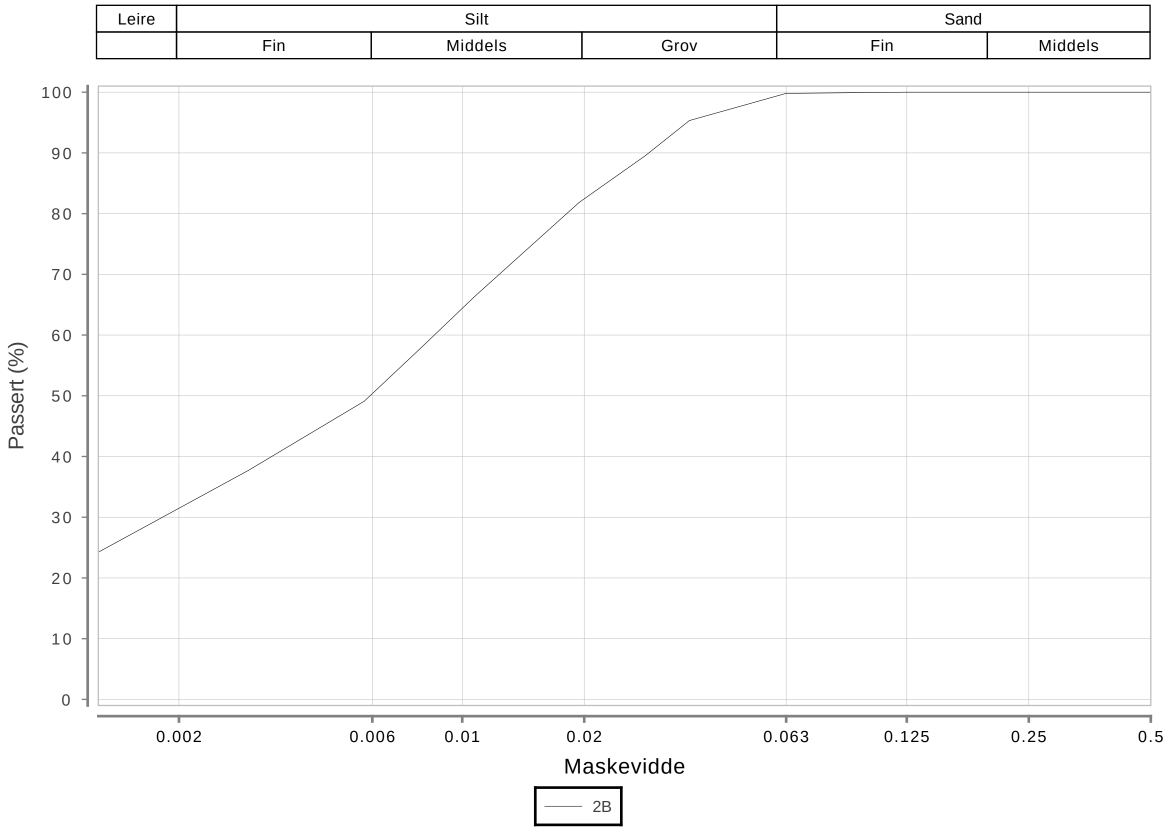
Oppdragsnr.	**N50581**	Oppdragsnavn	**Brattåsen-Lien**
Prosjektnr.	**502269**	Prosjektnavn	**E6 Brattås-Lien (reg.plan)**
Ansvarsområdenr.	**53060**	Ansvarsområdenavn	**E6 Helgeland**

Serienr. 157, Hullnr. 141

Sylinder / Pose nr.	2B				
Uttaksdato	04.05.2012				
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)	0.0				
Vanninnhold (%)					
% <63µm av <delsikt	99.8 (20 mm)				
% <20µm av <delsikt	82.4 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
2B	99.8	100.0	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
2B					4.0 - 4.8	Leire	*11.3	T4

Sted:__________________ Dato:________ Signatur:__________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

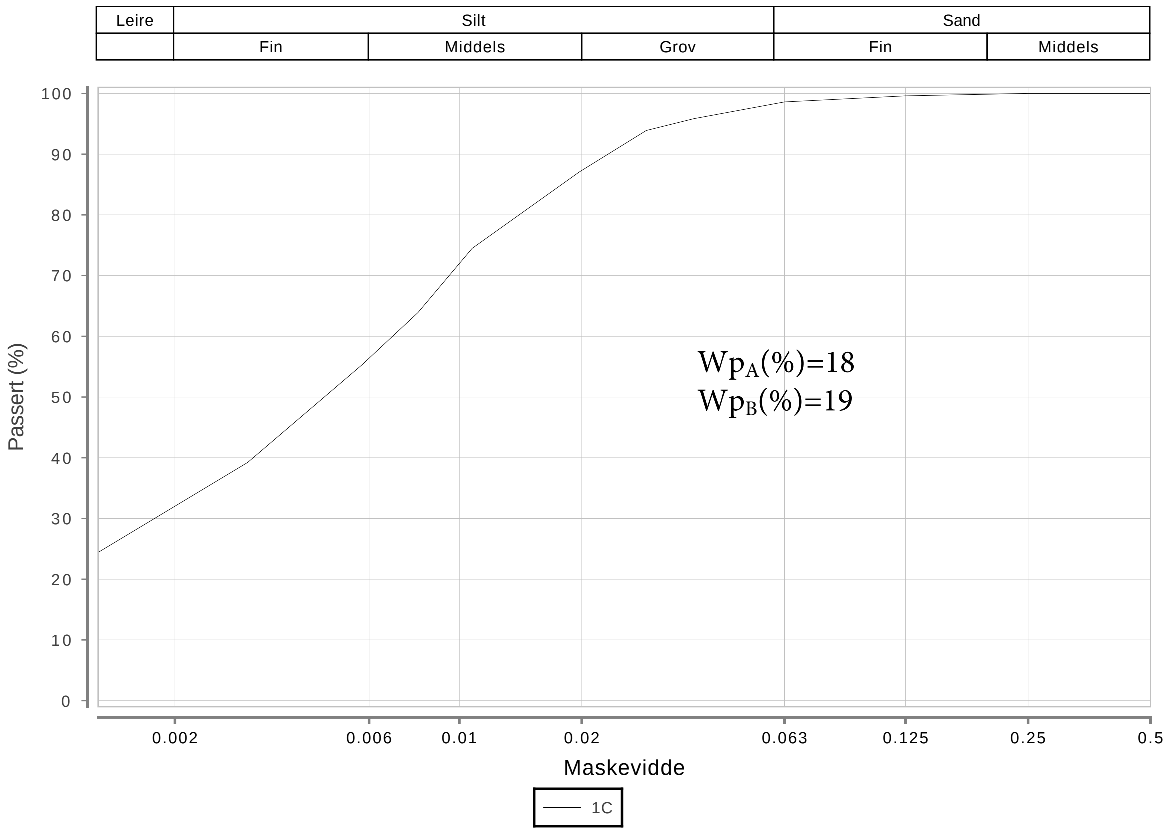
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 9, Hullnr. 1120068

Sylinder / Pose nr.	1C				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	98.6 (20 mm)				
% <20µm av <delsikt	87.3 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1C	98.6	99.6	100.0	100.0



Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1C					1.0 - 2.0	Leire	*8.2	T4

Sted:__________________ Dato:________ Signatur:__________________

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

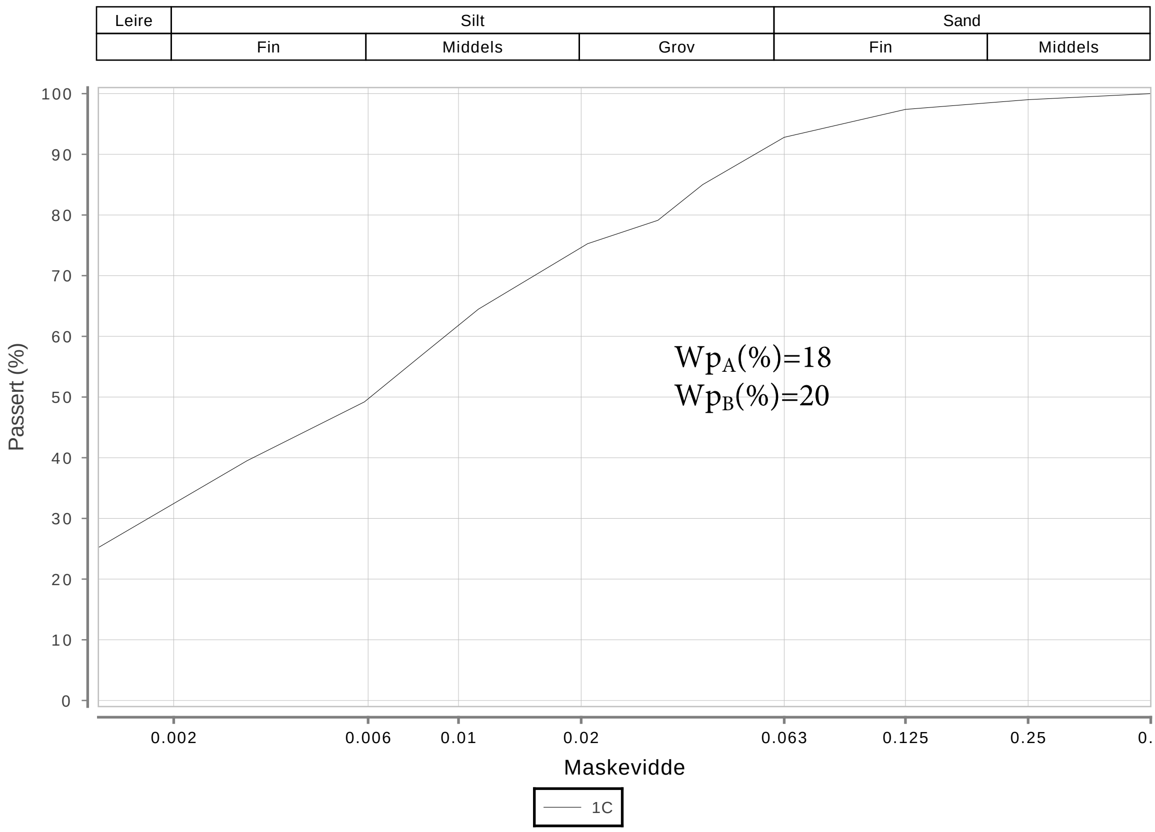
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 8, Hullnr. 1120003

Sylinder / Pose nr.	1C				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	92.8 (20 mm)				
% <20µm av <delsikt	74.6 (20 mm)				

Siktedata - Passert (%)

	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1C	92.8	97.4	99.0	100.0



$Wp_A(\%)=18$

$Wp_B(\%)=20$

Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1C					1.0 - 2.0	Leire	0.0	T4

Sted:__________________ Dato:________ Signatur:__________________

Appendix C

Grainsized distribution and reported cone penetration values of Speswhite kaolin.

Laboratorium: Sentrallaboratoriet Oslo - I henhold til H014 labprosess: 14.432, 14.433, 14.434

Statens vegvesen

Region Øst

Kornkurve

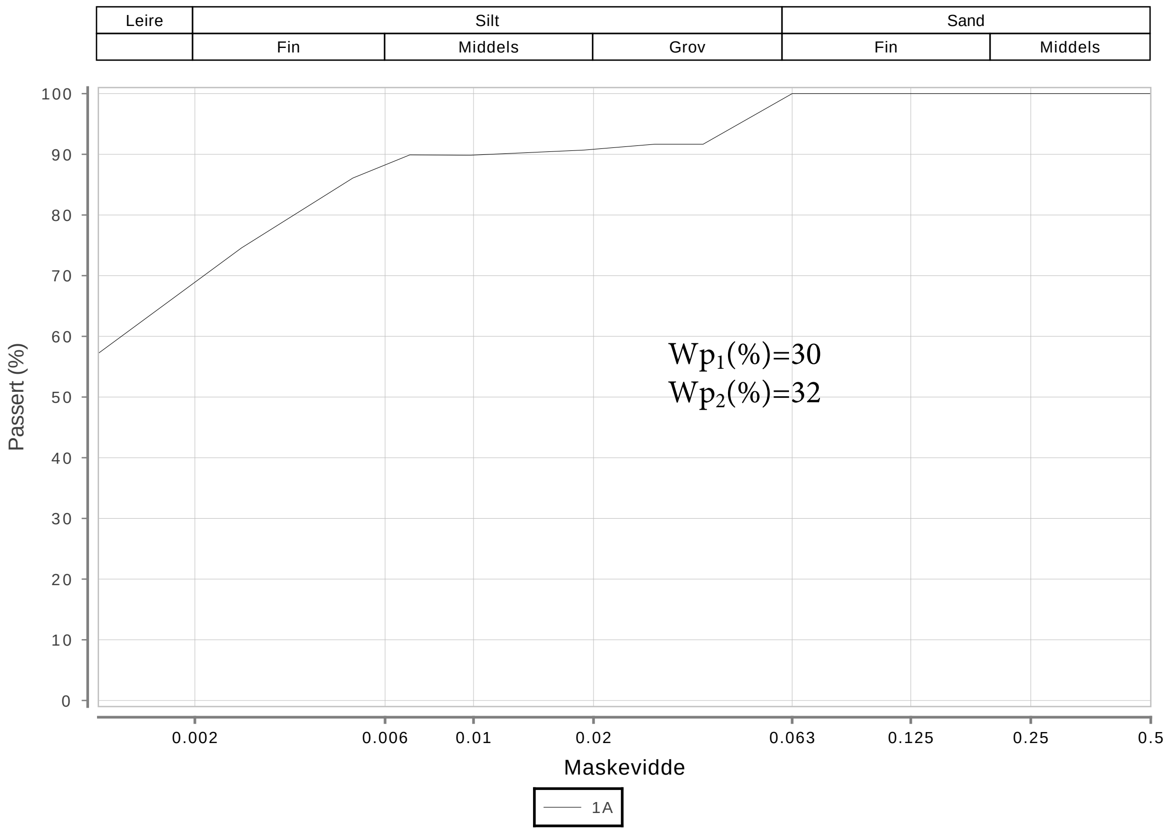
Oppdragsnr.	**1120434**	Oppdragsnavn	**FoU, bestemmelse av Ip**
Prosjektnr.	**104078**	Prosjektnavn	**Bestemmelse av plastisitetsindeks, Ip (16050 Ressu**
Ansvarsområdenr.		Ansvarsområdenavn	

Serienr. 1, Hullnr. 1

Sylinder / Pose nr.	1A				
Uttaksdato					
Uttatt kl.					
Analysetype	Våtsikt				
Humus (Glødetap)					
Vanninnhold (%)					
% <63µm av <delsikt	0.0 (20 mm)				
% <20µm av <delsikt	90.8 (20 mm)				

Siktedata - Passert (%)

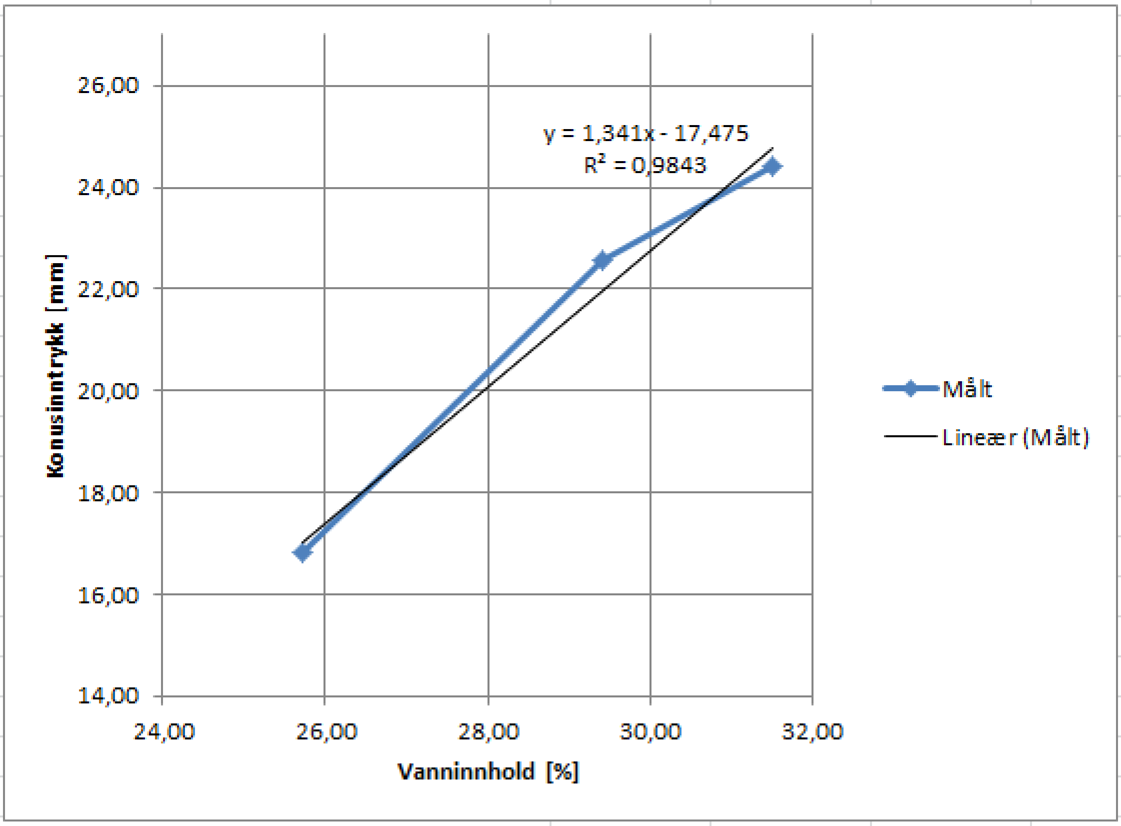
	µm			
Pr.nr.	**63**	**125**	**250**	**500**
1A	100.0	100.0	100.0	100.0



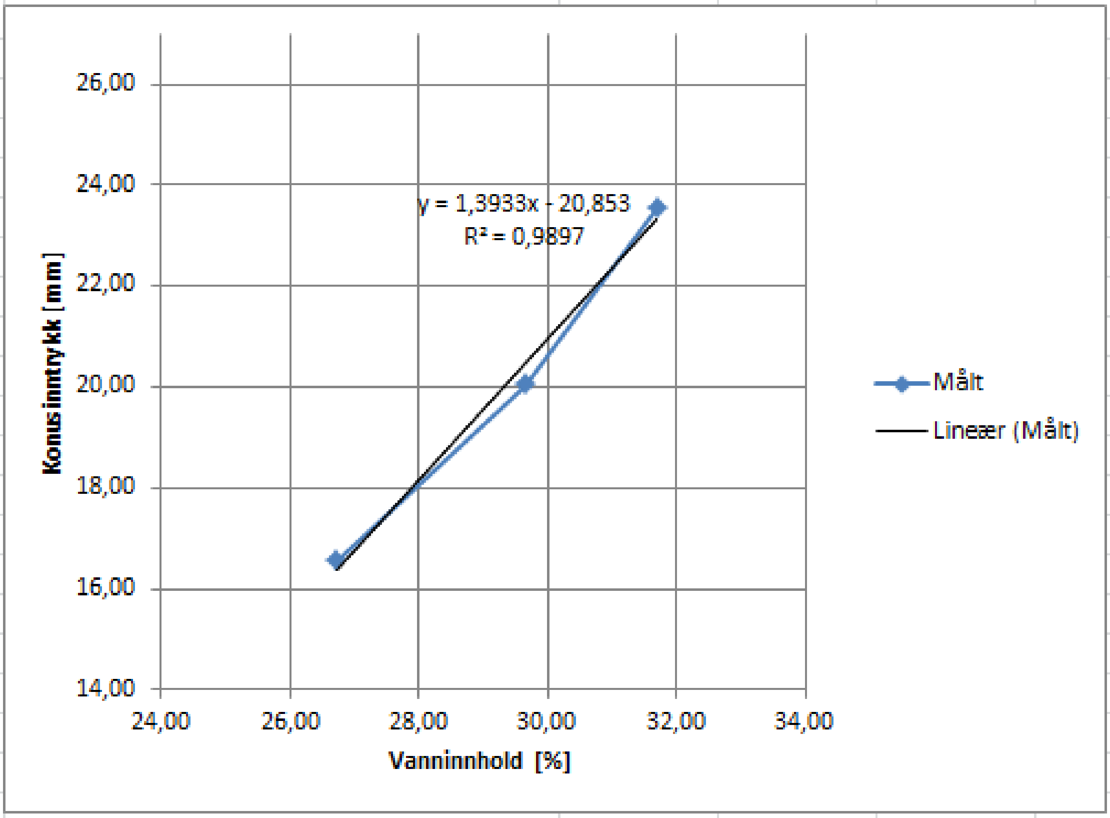
Syl/pose	Vegnr	HP	Km/*profil	Avst.cl	Dybde	Jordart	Cu	TG
1A	EV6		*1		8.0 - 8.8	Leire	0.0	T3

Sted:__________________ Dato:________ Signatur:__________________

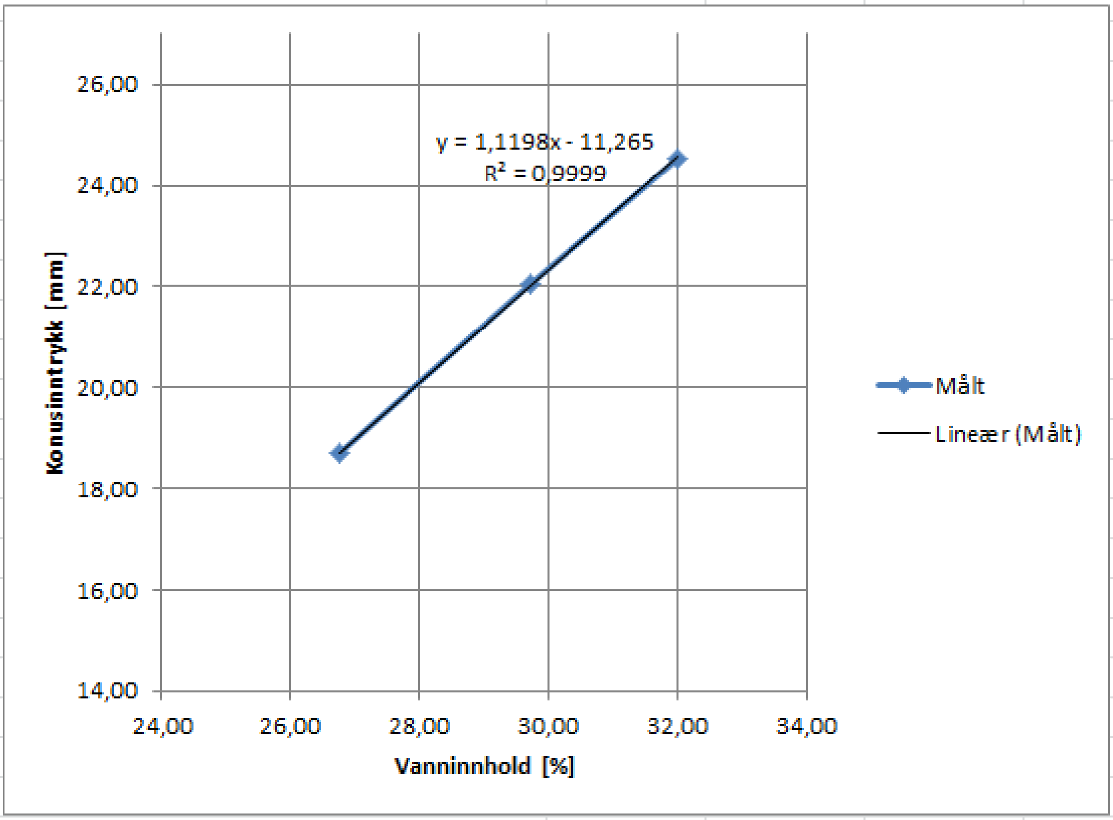
Plastisitetsgrensemåling med 727g-konus	Region midt, Trondheim		04.sep.12
	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	378,59	374,04	372,36
Idealvekt full kopp (g)	403,28	397,93	394,93
Komprimeringsgrad (%)	93,88	94,00	94,29
inntrykk konus (mm)	16,82	22,55	24,41
Våtvekt, Kaolin (g)	41,98	45,65	73,57
Tørrvekt, kaolin (g)	33,83	35,76	56,46
tara (g)	2,15	2,15	2,15
kopp nr	-	-	9,00
gram vann (g)	8,15	9,89	17,11
tørrmasse(g)	31,68	33,61	54,31
Vanninnhold, Kaolin (%)	25,73	29,43	31,50
Vanninnhold ved 20mm-konusinntrykk [%]:	**27,9**		



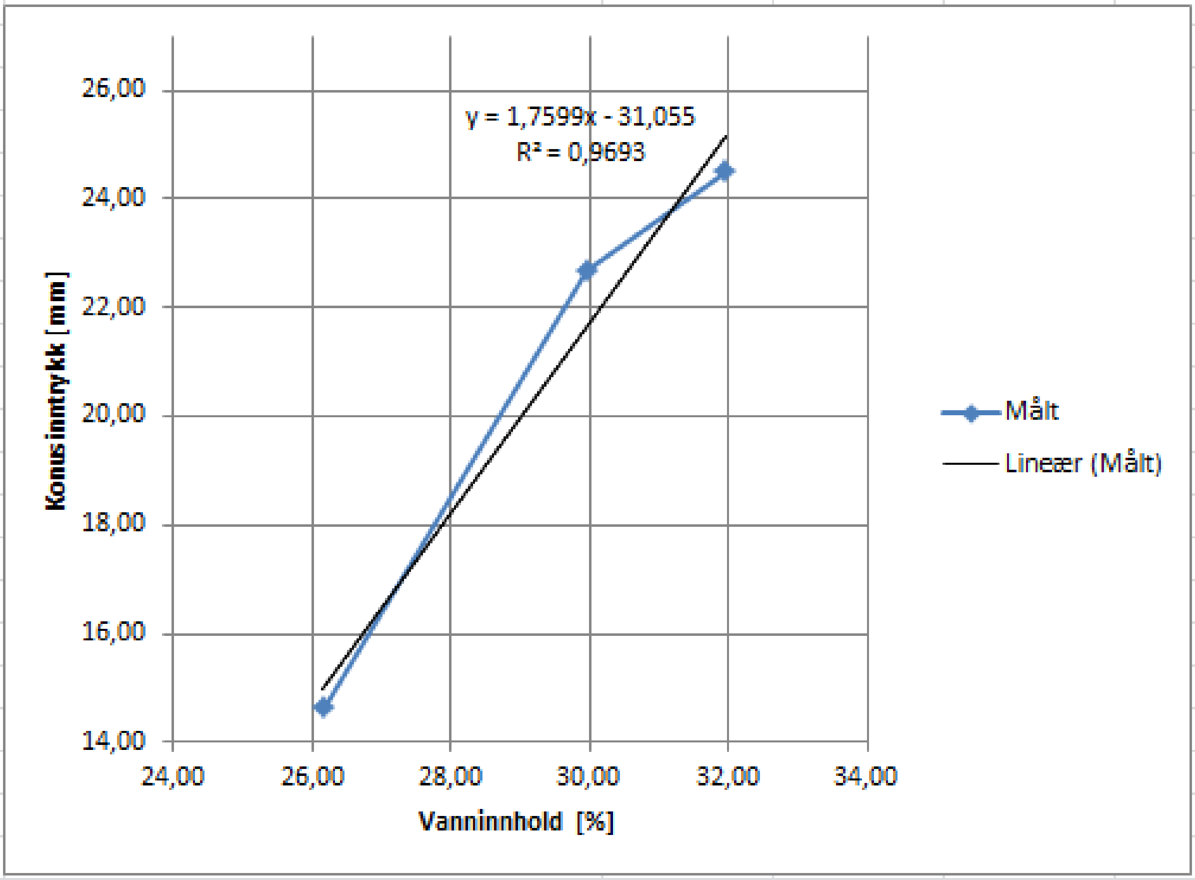
Plastisitetsgrensemåling med 727g-konus	Region nord		18.sep.12
	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	377,40	375,10	372,90
Idealvekt full kopp (g)	402,42	398,18	395,19
Komprimeringsgrad (%)	93,78	94,20	94,36
inntrykk konus (mm)	16,54	20,04	23,56
Våtvekt, Kaolin (g)	28,03	36,24	39,60
Tørrvekt, kaolin (g)	22,58	28,45	30,59
tara (g)	2,18	2,17	2,17
kopp nr	15	A	1015
gram vann (g)	5,45	7,79	9,01
tørrmasse(g)	20,40	26,28	28,42
Vanninnhold, Kaolin (%)	26,72	29,64	31,70
Vanninnhold ved 20mm-konusinntrykk [%]:	**29,32**		



Plastisitetsgrensemåling med 727g-konus	Løvlien, Hamar		20.aug.12
	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	0,00	0,00	0,00
Idealvekt full kopp (g)	0,00	0,00	0,00
Komprimeringsgrad (%)	0,00	0,00	0,00
inntrykk konus (mm)	18,70	22,05	24,55
Våtvekt, Kaolin (g)	98,14	71,55	77,43
Tørrvekt, kaolin (g)	84,48	63,00	66,03
tara (g)	33,45	34,24	30,40
kopp nr	-	-	9
gram vann (g)	13,66	8,55	11,40
tørrmasse(g)	51,03	28,76	35,63
Vanninnhold, Kaolin (%)	26,77	29,73	32,00
Vanninnhold ved 20mm-konusinntrykk [%]:	**27,9**		

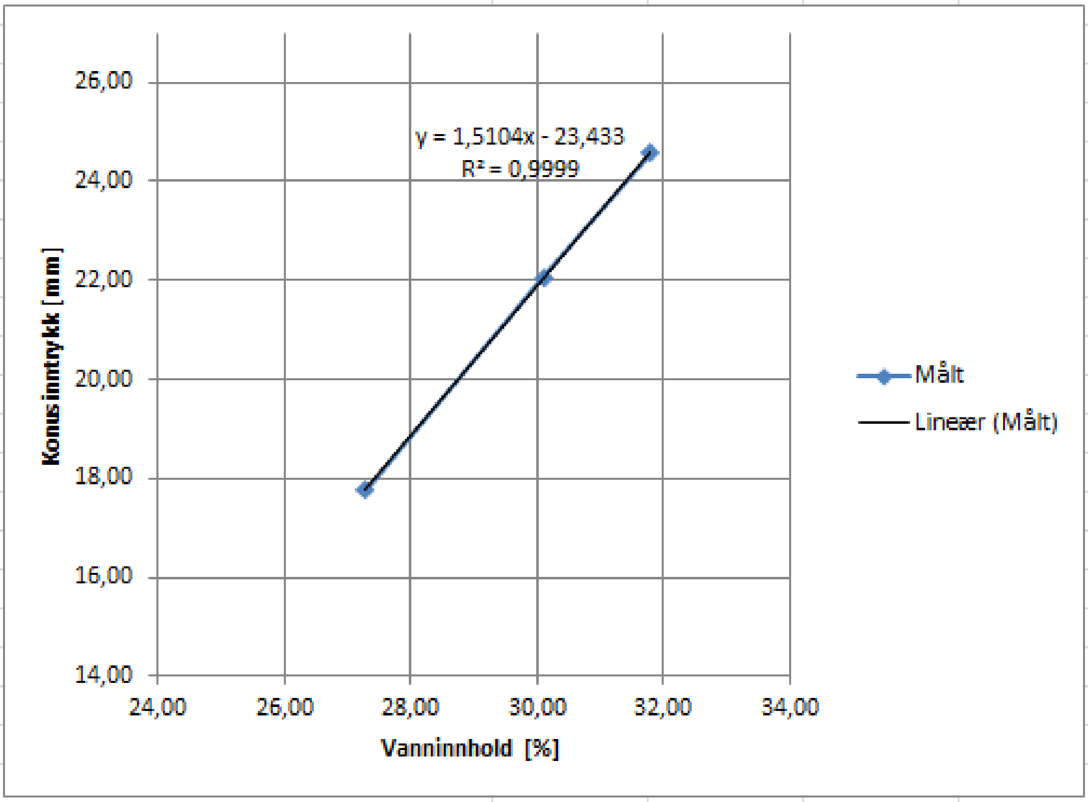


Plastisitetsgrensemåling med 727g-konus	Region øst		30.aug.12
	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	378,93	373,80	372,64
Idealvekt full kopp (g)	403,23	397,74	394,83
Komprimeringsgrad (%)	93,97	93,98	94,38
inntrykk konus (mm)	14,62	22,70	24,49
Våtvekt, Kaolin (g)	37,28	30,46	38,82
Tørrvekt, kaolin (g)	29,55	23,44	29,42
tara (g)	0,00	0,00	0,00
kopp nr	14	15	16
gram vann (g)	7,73	7,02	9,40
tørrmasse(g)	29,55	23,44	29,42
Vanninnhold, Kaolin (%)	26,16	29,95	31,95
Vanninnhold ved 20mm-konusinntrykk [%]:	**29,0**		



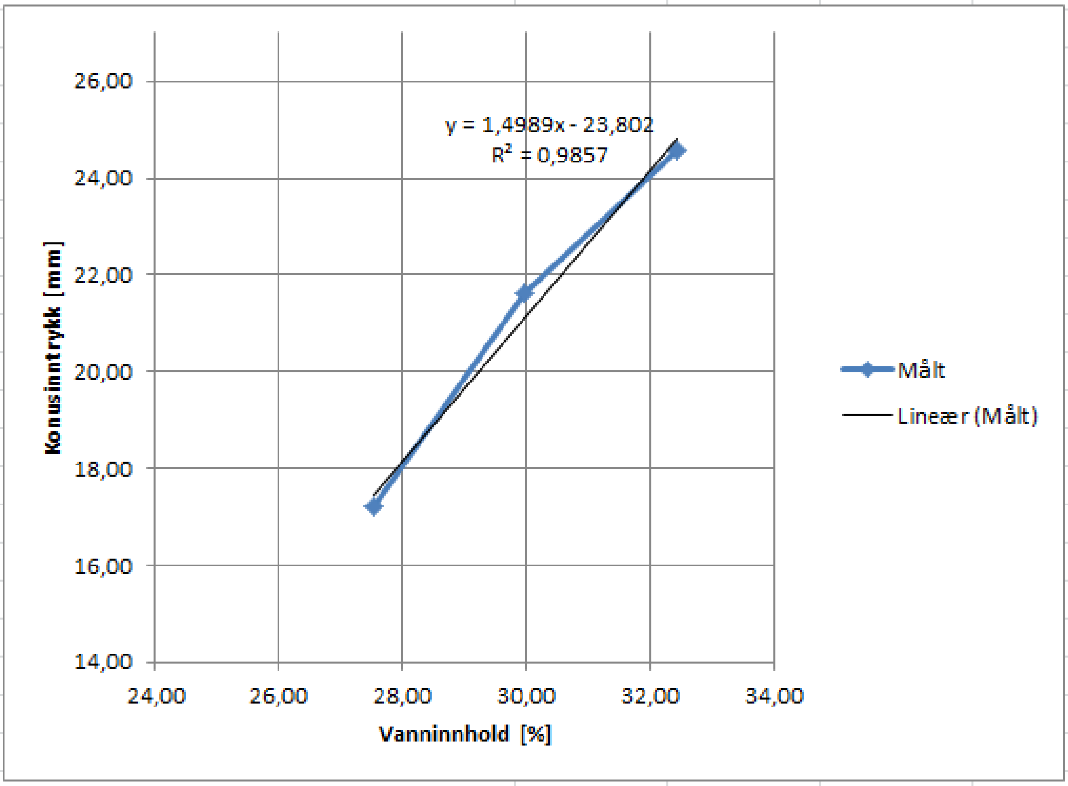
Plastisitetsgrensemåling med 727g-konus	Multiconsult, Oslo		23.aug.12

	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	377,42	373,60	373,02
Idealvekt full kopp (g)	401,04	396,96	394,50
Komprimeringsgrad (%)	94,11	94,12	94,56
inntrykk konus (mm)	17,75	22,07	24,57
Våtvekt, Kaolin (g)	26,13	32,72	44,68
Tørrvekt, kaolin (g)	20,53	25,15	33,90
tara (g)	0,00	0,00	0,00
kopp nr	100	20	9
gram vann (g)	5,60	7,57	10,78
tørrmasse(g)	20,53	25,15	33,90
Vanninnhold, Kaolin (%)	27,28	30,10	31,80
Vanninnhold ved 20mm-konusinntrykk [%]:	**28,8**		



Plastisitetsgrensemåling med 727g-konus	Region sør, Skien		21.aug.12

	Forsøk nr 1	Forsøk nr 2	Forsøk nr 3
Vekt av kopp + kaolin (g)	376,54	374,21	372,16
Idealvekt full kopp (g)	400,68	397,15	393,58
Komprimeringsgrad (%)	93,98	94,22	94,56
inntrykk konus (mm)	17,20	21,63	24,56
Våtvekt, Kaolin (g)	34,08	36,43	34,62
Tørrvekt, kaolin (g)	27,19	28,53	26,67
tara (g)	2,16	2,17	2,16
kopp nr	38	39	41
gram vann (g)	6,89	7,90	7,95
tørrmasse(g)	25,03	26,36	24,51
Vanninnhold, Kaolin (%)	27,53	29,97	32,44
Vanninnhold ved 20mm-konusinntrykk [%]:	**29,2**		

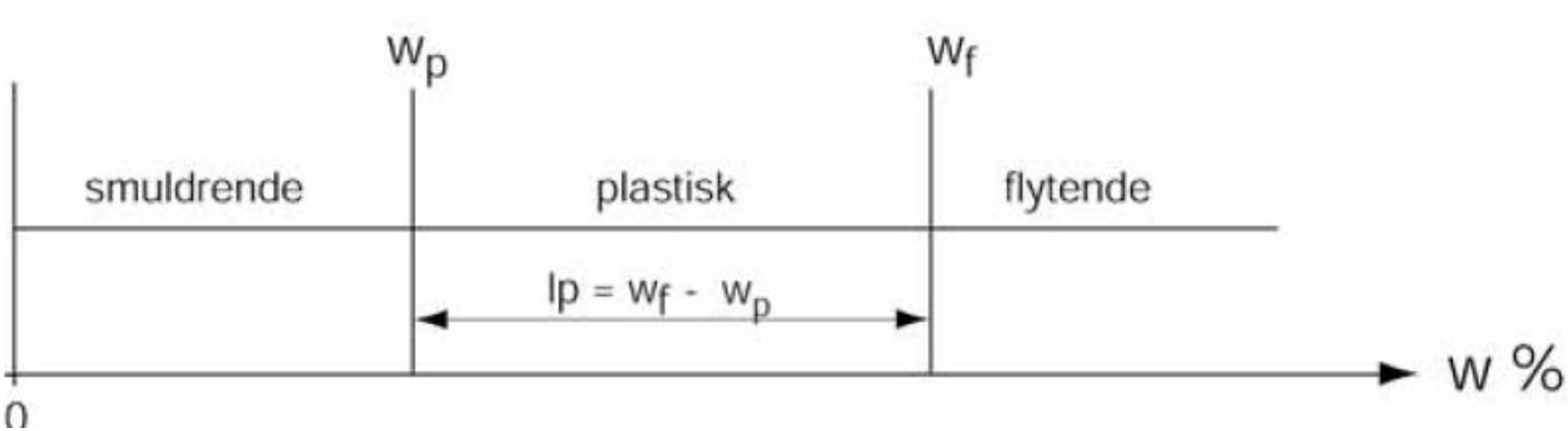


Appendix D

Background to the proposed method, short summary.

Statens vegvesen

Ny metode for måling av plastisitetsgrense



- Måling av flytegrensen blir gjennomført med konus. NS flytegrensen bestemmes ved 10mm inntrykk (60g /60° konus).

- Måling av plastisitesgrense blir gjennomført med rulle-metode, utviklet av Casagrande i 1958. Spredning i wp, avhengig hvem og hvor analysen tas, kan være 8 – 12%.

Bakgrunn for den nye metoden for måling av plastisitetsgrense

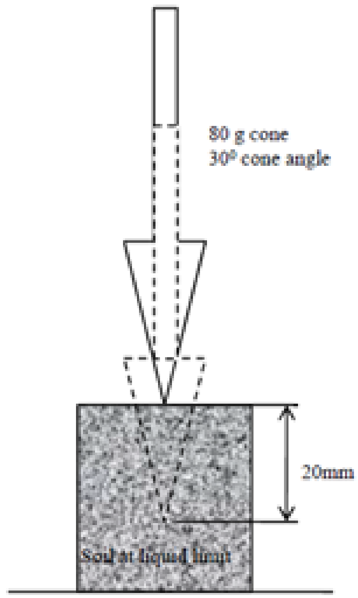
- I 2009 ble det publisert en artikkel i fagbladet 'Geotechnique' hvor det ble presentert en ny metode for måling av plastisitetsgrensen som har vist seg for å være enklere og mer pålitelig. Metoden ble utviklet av Dr. V. Sivakumar fra Queens University i Belfast.

Sivakumar, V. *et al.* (2009). *Géotechnique* **59**, No. 10, 813–823 [**doi:** 10.1680/geot.2009.59.10.813]

A new method of measuring plastic limit of fine materials

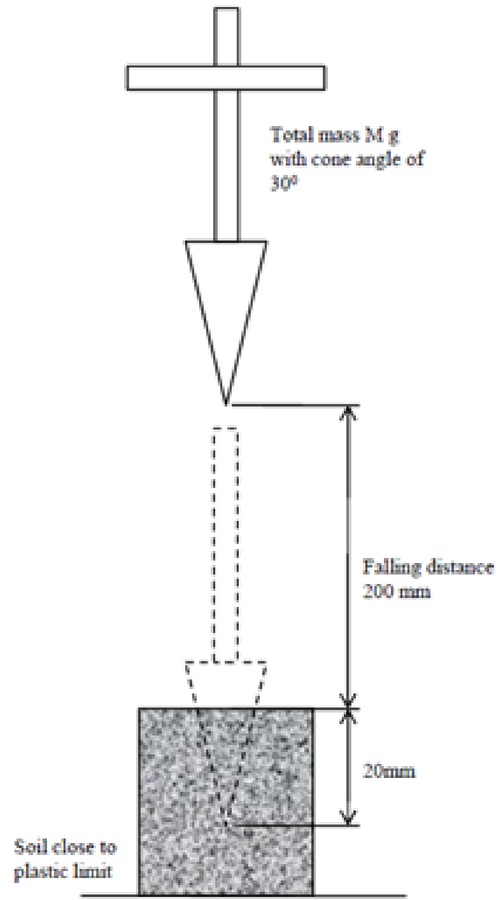
V. SIVAKUMAR*, D. GLYNN†, P. CAIRNS* and J. A. BLACK‡

Bakgrunn for den nye metoden for måling av plastisitetsgrense



(a) At liquid limit

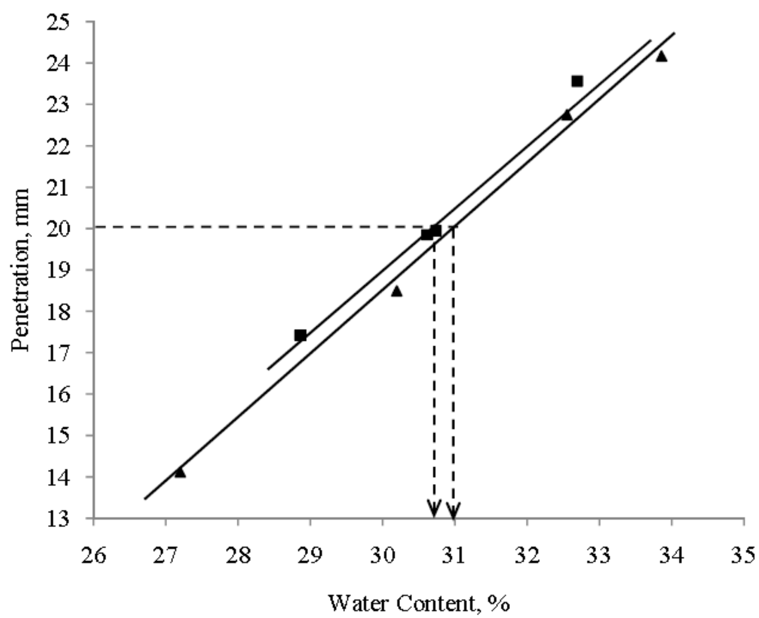
flytegrensen med konus (BS)



(a) At plastic limit

Bakgrunn for den nye metoden for måling av plastisitetsgrense

- Målemetoden for bestemmelsen av plastisitetsgrensen med konusapparatet bygger på linearitet mellom vanninnholdet og konusinntrykket (0,729 kg /30° konus – 20mm).



Sivakumar, V. *et al.* (2009). *Géotechnique* **59**, No. 10, 813–823 **[doi:** 10.1680/geot.2009.59.10.813]

A new method of measuring plastic limit of fine materials

V. SIVAKUMAR*, D. GLYNN†, P. CAIRNS* and J. A. BLACK‡

Table 2. Clay mineralogy and percentage of clay-, silt- and sand-size particles

Soil type	Clay minerals	Clay % (<2 μm)	Silt % (2–63 μm)	Sand %			
				63–250 μm	250–500 μm	500 μm–1 mm	1–2 mm
Kaolin (KC)	Q, CH, K	54	46	0	0	0	0
Belfast clay (BC1)	Q, F, C, D, CH, M, S	46	49	2	1	1	
Belfast clay (BC2)	Q, F, CH, M, S	25	59	8	2	3	1
Mudstone (MU)	Q, F, D, CH, M, V, PA, T	7	62	4	7	13	5
Sleech (SL)	Q, F, P, CH, M,	10	85	4	0	0	0
Glacial till (GT1)	Q, F, CH, M, S	11	38	33	15	2	0
London clay (LC1 F)	Q, F, M, S, K	53	44	0	0	2	0
London clay (LC2 F)	Q, F, M, K, V	47	45	1	2	3	0
London clay (LC1 J)	Q, F, M, S, K	16	60	10	10	4	0
London clay (LC2 J)	Q, F, M, S, K	21	71	4	1	2	0
China red clay (CH)	Q, F, CH, M, S	12	55	5	17	10	0
Winnipeg clay (WP)	Q, F, C, D, M, K, V, T	72	25	2	2	0	0
Saskatchewan clay (SK)	Q, F, D, M, S, K	67	30	1	2	0	0
Vancouver clay (VC)	Q, F, A, CH, M	61	39	0	0	0	0
Norway clay (NR)	Q, F, A, CH, M	19	80	1	0	0	0

F, Fricton-on-Sea, J, Jarwick.
Q, quartz; F, feldspar; C, calcite; D, dolomite; P, pyrite; A, amphibole; Ch, chlorite; M, muscovite/illite; S, smectite; K, kaolinite; V, vermiculite; PA, palygoriskite; T, titanite.

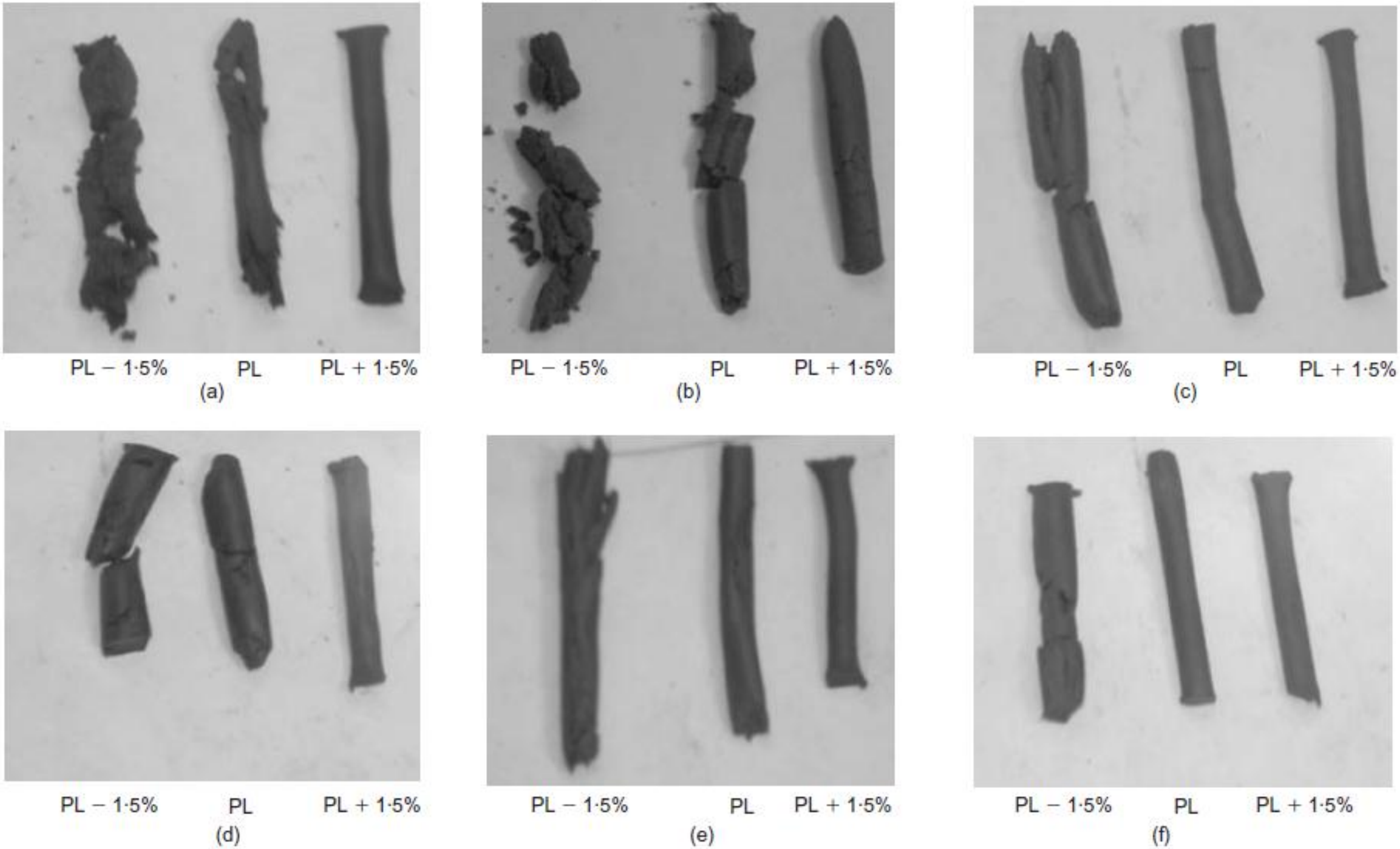


Fig. 8. State of soils prepared at water content close to plastic limit: (a) Norway clay; (b) mudstone; (c) London clay; (d) Belfast clay; (e) China red clay; (f) Winnipeg clay

Table 3. PL values obtained by four different operators using standard and new method

Soil type	PL obtained by four operators (standard method): %					PL by new method: %	LL: %
	1	2	3	4	Average		
Kaolin (KC)	31·0	37·4	29·9	35·4	33·4	34·1	68·0
Belfast clay (BC1)	26·8	25·9	–	–	26·3	27·1	57·0
Belfast clay (BC2)	17·5	22·1	30·8	26·1	24·1	31·9	60·2
Mudstone (MU)	33·1	42·5	29·3	36·7	35·4	35·4	59·0
Sleech (SL)	47·0	53·7	60·1	54·4	53·8	41·6	111·0
Glacial till (GT1)	16·8	15·7	–	–	16·3	19·9	32·0
Glacial till (GT2)	15·2	13·9	19·3	16·2	16·2	18·5	35·5
London clay (LC1 F)	22·2	27·8	47·1	33·4	32·6	39·6	90·8
London clay (LC2 F)	22·5	31·0	41·4	32·8	31·8	41·0	86·2
London clay (LC1 J)	17·5	16·1	21·2	18·9	18·4	22·8	43·4
London clay (LC2 J)	22·0	30·2	35·8	32·7	30·2	39·6	83·3
China red clay (CH)	–	–	–	–	–	22·0	–
Winnipeg clay (WP)	26·5	33·2	29·3	34·4	30·8	37·5	67·4
Saskatchewan clay (SK)	21·1	31·9	42·5	37·6	33·3	42·2	89·9
Vancouver clay (VC)	–	–	–	–	–	34·5	–
Norway clay (NR)	14·4	16·4	18·7	18·9	17·9	18·4	34·5

F, Fricton-on-Sea; J, Jarwick.

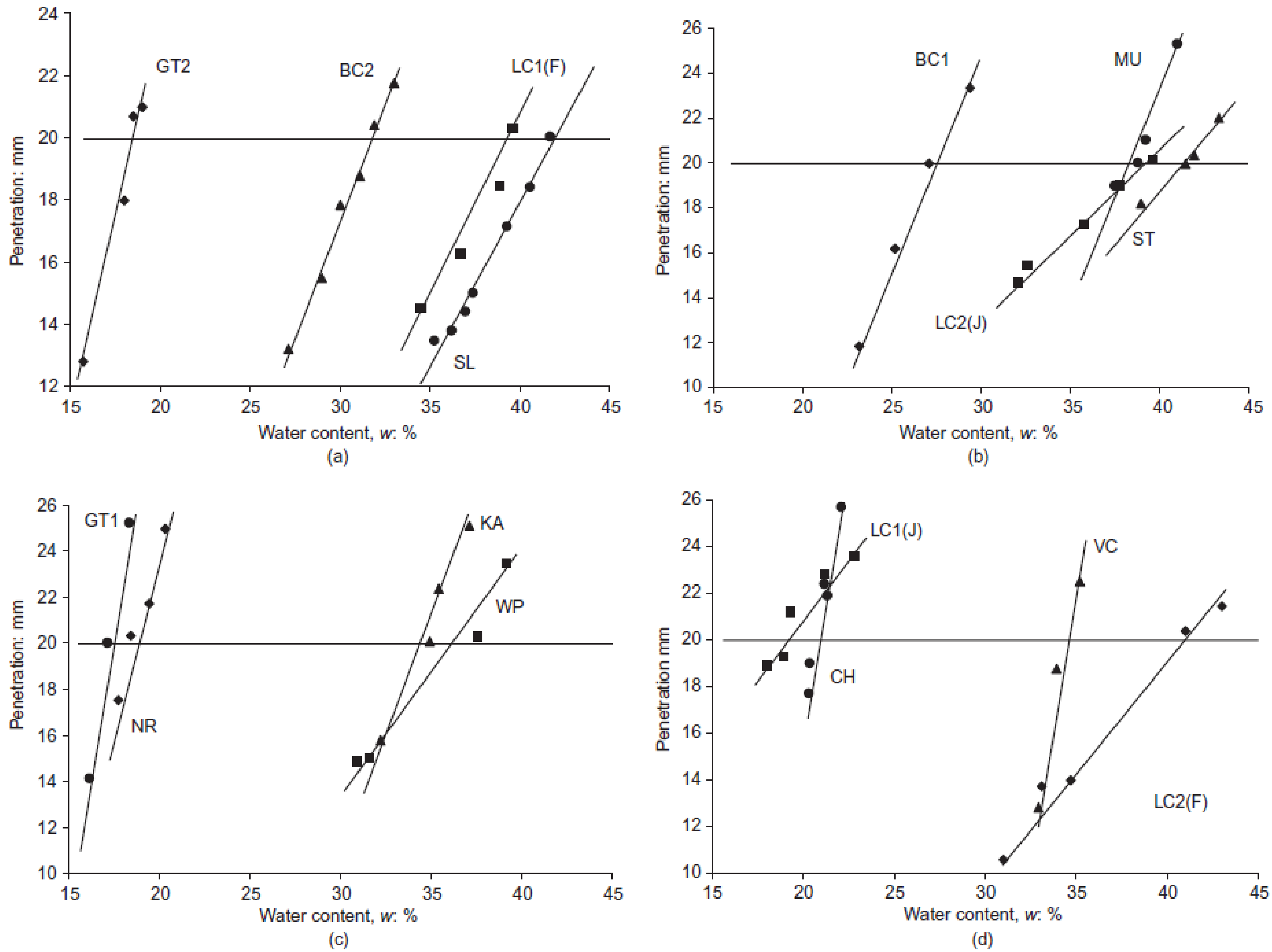


Fig. 6. Cone penetration against water content of soils close to plastic limit

Sammenligning rulling – konus SVV FoU prosjekt

Reported PL values of Speswhite kaolin

Sample	Method	PL obtained from six laboratories (%)						Average
		1	2	3	4	5	6	
Speswhite kaolin	Falling cone	27,9	29,3	27,9	29,0	28,8	29,2	28,7
	Standard	36,1	29,7	34,5	31,5	31,8	29,9	32,3
	Difference	8,2	0,4	6,6	2,5	3,0	0,7	3.6

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