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Plate load testing

Effects of in situ conditions, test procedure and calculation method

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Abstract

The plate load test is a widely used and important test method to determine the bearing capacity of unbound granular materials in the superstructure of a road. The test is based in Boussinesq's formula, which makes general assumptions that are not reasonable when considering the materials used for road construction. The test is thus very dependent on the test procedures, as well as the conditions in the field. The Norwegian Public Roads Administration has defined the plate load test as the only method for final documentation of the quality of compaction of unbound materials, and has defined a set of requirements that every measured point must fulfil. However, a number of contractors have experienced unexplained difficulties with fulfilling the requirements, even after repeated compaction efforts. This thesis aims to assess to what extent the in-situ condition of the road, the superstructure materials and their in-situ state, as well as the test procedure and calculation method affect the results of the plate load tests.

In order to answer the research questions, a document analysis, a case study and a field test were conducted. In the document analysis, national standards and regulations regarding requirements and test procedures for plate load tests from Norway, Sweden, Iceland and Germany were analysed and compared. The case study compared four different road construction sites; (1) a tunnel based project, (2) an urban road project, (3) a new motorway project and (4) a motorway upgrading project, by conducting semi-structured interviews on representatives from the constructor and/or owner builder, collecting measured results from plate load tests conducted on the site, and conducting observations in the field. Additional interviews with individuals with experience from multiple different construction sites, as well as results from plate load test measurements from additional sites were also considered, although not used for direct comparison in the case study. Finally, a field test was conducted using two different test procedures (from R211 and DIN 18134), two different plate sizes (diameter 300 mm and 600 mm), tested on three different levels in the superstructure (frost protection layer, subbase layer and interlocking layer). The measurements from all plate load tests were processed using three different calculation methods; one based on DIN 18134, another according to R211, and a modified version based on R211.

Most of the interviewees agreed that the in-situ factors that seem to have the most influence on the plate load test results are the moistures content of the superstructure materials, the time between compaction and testing, as well as the use of crushed asphalt and/or insulation materials in the superstructure. These claims need to be verified by further testing, but they provide a good reference point as to which factors to focus on. The results of the field test measurements suggest that the use of an interlocking material on top of the subbase material significantly increases the calculated E-values from the plate load tests. Other comparisons were inconclusive, likely due to the limited number of comparable measurements. Measurements conducted on site 2 were significantly lower than those conducted at site 4, potentially due to the large grain size of the subbase material at site 2, although this has to be investigated further. Measurements conducted on superstructures containing insulation materials on site 4 were also significantly lower than measurements without insulation materials, although the effect of using different test procedures in this case must be assessed. The comparison between the results of different test procedures and calculation methods showed significant differences for some but not all cases, and the factors influencing these test results must therefore be investigated further.

Sammendrag

Platebelastningsforsøk er en viktig og mye brukt forsøksmetode for å vurdere bæreevnen til ubundne granulære materialer i vegkonstruksjoners overbygninger. Forsøksmetoden er basert på Boussinesq sin formel, som er basert på en rekke antakelser som ikke stemmer for materialer som brukes i vegkonstruksjoner. Forsøksmetoden er derfor veldig avhengig av test metoden som brukes, i tillegg til forholdene i feltet. Statens vegvesen har definert platebelastningsforsøk som den eneste testmetoden for sluttdokumentasjon av komprimeringskvaliteten til ubundne granulære materialer, og har også definert krav som skal være oppfylt av alle målte punkter. En rekke entreprenører har imidlertid opplevd uforklarte utfordringer ved å oppfylle kravene, selv etter gjentatte forsøk til tilleggskomprimering. Målet med denne oppgaven er å vurdere i hvilken grad forholdene i feltet, overbygningsmaterialene og deres tilstand i feltet, samt forsøks- og beregningsmetode påvirker resultatene av platebelastningsforsøk.

For å forsøke å svare på forskningsspørsmålene ble det gjennomført en dokumentanalyse, en case studie og et felttest. I dokumentanalysen ble nasjonale standarder og regelverk angående krav og forsøksmetoder for platebelastningsforsøk fra Norge, Sverige, Island og Tyskland analysert og sammenlignet. Case studien sammenligner fire forskjellige veganlegg; (1) et tunnel prosjekt, (2) et bynært vegprosjekt, (3) en ny motorveg og (4) et oppgraderingsprosjekt for en eksisterende motorveg, ved å gjennomføre semistrukturerte intervjuer med representanter fra entreprenør og/eller byggherre, samle inn måledata fra platebelastningsforsøk utført på anlegget, samt gjennomføring av observasjoner i feltet. Ytterligere intervjuer med individer med erfaring fra flere forskjellige anlegg, samt måledata fra flere forskjellige anlegg ble også vurdert, men ikke for sammenligning i case studien. Et felttest ble også gjennomført med to forskjellige forsøksmetoder (fra R211 og DIN 18134), to forskjellige platestørrelser (300 mm og 600 mm diameter), utført på tre forskjellige nivå i overbygningen (frostsikringslag, forsterkningslag og forkilingslag). Måledata'ene fra alle platebelastningsforsøkene ble behandlet med tre forskjellige beregningsmetoder; en basert på DIN 18134, en annen i henhold til R211, og tredje en modifisert versjon basert på R211.

De fleste av intervjuobjektene var enige om at de feltforholdene som påvirker resultatene av platebelastningsforsøk i størst grad er vanninnholdet i overbygnings-materialene, tiden mellom komprimering og forsøksutførelse, samt bruk av knust asfalt og/eller isolasjonsmaterialer i overbygningen. Disse påstandene må bekreftes ved hjelp av videre testing, men de gir en god utgangspunkt for hvilke faktorer bør fokuseres på. Resultatene fra felttestet tyder på at bruk av forkilingsmateriale oppå forsterkningslag øker de beregnede E-verdiene betydelig. Andre sammenligninger gir ikke entydige svar, sannsynligvis grunnet begrenset antall av sammenlignbare målinger. Forsøk utført på anlegg 2 var betydelig lavere enn forsøk utført på anlegg 4, muligens på grunn av grovt material brukt som forsterkningslag på anlegg 2, men det må undersøkes videre. Forsøk utført på overbygninger med isolasjonsmaterialer på anlegg 4 var også betydelig lavere enn forsøk utført uten isolasjonsmaterialer, men for dette tilfellet må effekten av å bruke forskjellige forsøksmetoder også vurderes. Sammenligning av resultater fra forskjellige forsøksmetoder og beregningsmetoder viser en signifikant forskjell for noen og ikke alle tilfeller, så de faktorene som påvirkere disse forsøksresultatene må undersøkes nærmere.

Preface

This document contains the conclusive work of my Master's thesis as a finalizing part of a 2 year Master's programme at the Department of Civil and Environmental Engineering at NTNU, worth 30 credits.

Firstly, I would like to thank my supervisors, Associate Professor at NTNU Helge Mork and Jostein Aksnes at Vegdirektoratet, for their helpful guidance, feedback and discussions about the thesis.

I would also like to thank all of the participants in the interviews for their insightful answers and great hospitality.

Last but not least, I would like to thank my soon-to-be husband, Friðrik Hilmar Zimsen Friðriksson, for the immeasurable support and motivation during my work on the thesis.

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List of Abbreviations

AADT	Annual Average Daily Traffic
ESAL	Equivalent Single Axle Load
FGSV	German Road and Transportation Research Association (Forschungsgesellschaft für Straßen- und Verkehrswesen)
GDPR	General Data Protection Regulation
LWD	Light Weight Deflectometer
NPRA	Norwegian Public Roads Administration
NSD	Norwegian Centre for Research Data (Norsk senter for forskningsdata)
NTNU	The Norwegian University of Science and Technology
PLT	Plate Load Test
SoTA	State of The Art
STA	Swedish Transport Administration

List of Symbols

D	Diameter
E	Modulus of elasticity
ε_z	Vertical strain
f	Stress distribution factor
p	Average loading pressure
Δp	Change in applied load
q	Uniformly applied load
R	Radius
S	Standard deviation
s	Settlement
Δs	Change in settlements
σ_0	Average normal load below the plate at each load step during a plate load test
$\sigma_{1\max}$	Maximum normal load of the *first load cycle* of a plate load test
$\Delta\sigma_z$	Change in vertical stress
ν	Poisson’s ratio
$\bar{x}$	Arithmetic mean
z	Depth

1 Introduction

Society's use of resources and the government's use of funds are two important topics that are regularly discussed, both in media and day-to-day life. The discussion often includes the use of resources and funds for road construction, where the main criticism is the large investments and the limited service lifetime. While the service lifetime of a road is influenced by many different factors, one of the more important ones that is common for all road structures is the compaction of granular materials. The quality of the compaction of the superstructure materials effects the road's bearing capacity, which in turn effects the service lifetime of the road. In order to obtain the highest bearing capacity possible, and thus the longest available service lifetime, one has to compact the granular materials in the road construction as tightly as possible (Mork, 2018). Achieving good quality compaction of granular materials during road construction should therefore be a priority to ensure the best use of society's resources.

To ensure that newly constructed roads reach an adequate service lifetime, the national roads administration in each country usually defines minimum requirements for the level of compaction of granular materials in road structures. The level of compaction can be measured using a number of methods, but one of the oldest and more frequently used is the static plate load test[1] (Briaud, 2013). Although each country defines its own test procedures and result requirements, the plate load tests are generally based on the same theoretical assumptions, and the basic calculation method should therefore in theory be the same for all countries. This is however not the case, as can be seen by comparing the Norwegian calculation method to the German calculation method (Statens vegvesen and Vegdirektoratet, 2018b, Deutsches Institut für Normung, 2012). The effect the different calculation methods have on the plate load test results is unclear, and has not been studied to any significant extent, as far as is known.

The Norwegian Public Roads Administration (NPRA)[2], as many other national roads administrations, has defined both a procedure and requirement values for plate load tests used to determine the quality of compaction (Statens vegvesen and Vegdirektoratet, 2018a, Statens vegvesen and Vegdirektoratet, 2018b). These requirements have been included to some degree in the NPRA's handbooks and guidelines for road construction since the 1980s (Statens vegvesen and Vegdirektoratet, 1980, Statens vegvesen and Vegdirektoratet, 1984), and the test has recently been designated as the sole form of final documentation of the compaction quality of the unbound materials in a road structure (Statens vegvesen and Vegdirektoratet, 2018a). The contractors are therefore obliged to perform plate load tests on the unbound materials of the superstructure and make sure that they meet the requirements defined by the NPRA.

Although the plate load test and the corresponding requirements have been a part of the NPRA's handbooks for decades, fulfilling these requirements seems to be challenging at times. Since the NPRA recently required more use of the plate load test , some contractors have experienced unexplained difficulties when trying to fulfil the

[1] Hereafter only referred to as the plate load test. Other types of plate load tests will be distinguished by an additional, descriptive name, e.g. dynamic plate load test.
[2] In Norwegian: Statens vegvesen, abbreviated SVV

requirements, even with repeated compaction efforts (Brcic, 2018, Folkedal and Bryn, 2018). The reason for the difficulties with fulfilling the NPRA's plate load test requirements in some cases is unknown, and has not been studied to any significant extent, as far as is known.

Based on the aforementioned challenges regarding the fulfilment of the NPRA's requirements for plate load tests, as well as the variety of existing calculation methods, the following research questions have been posed:

- Which in-situ factors affect the results of plate load tests?
- In what way does the material in the superstructure and its in-situ state affect the results of plate load tests?
- In what way do the test procedure and the calculation method for the E-modulus affect the results of plate load tests?

This thesis seeks to answer the research questions posed above, in part or fully, by studying in-situ plate load tests.

The thesis is divided into 7 chapters, where this introduction chapter is the designated first chapter. The second chapter presents theoretical literature related to the research questions and is divided into 3 sub-sections. The first sub-section presents general theory of compaction of granular materials in the field. The second sub-section presents the theory behind the plate load tests, as well as theory about how the test affects the material being tested. The third and final sub-section of chapter 2 presents the results of a State of The Art literature review (SoTA) on the topic of plate load tests. Chapter 3 is a document review, presenting the contents of different national documents that define test procedures and requirements for plate load tests. First, national documents throughout the years from Norway are presented, followed by national requirement documents from Sweden, Iceland and Germany. Chapter 4 describes the test methods used in order to answer the research questions. The chapter starts with describing a document analysis and literature review, followed by a description of a case study of road construction sites, interviews and data files collected, and lastly a field test where multiple plate load tests were conducted. Chapter 5 presents the results of the test methods described in chapter 4, organized into similar sub-sections as chapter 4, followed by a discussion of the results in chapter 6. Finally, chapter 7 presents the conclusion of the thesis, including recommendation for future research.

2 Theory

2.1 Compaction of granular materials

In general, the main aim of compacting granular materials is to increase the density of the material by removing the air between the aggregate particles, using mechanical energy. The degree of compaction of granular materials can thus be measured in terms of the dry unit weight or the dry density of the material (Das, 2010, p. 114). The degree of compaction, i.e. the dry density, of granular materials in road structures has a high impact on the road's lifetime and performance. Without adequate compaction, the overall strength of the road structure's subbase and base course can be significantly compromised, especially during heavy loading. Inadequate compaction of the unbound granular layers of a road structure can also cause rutting in the bound layers above. The rutting can be caused by either gradual densification of the unbound layers in the wheel tracks and thus uneven settlements of the road structure, or premature fatigue cracking induced by the relatively low resilient modulus of the unbound materials. To ensure the optimal performance, security and lifetime of the road, proper compaction of the unbound granular layers is essential (Roston et al., 1976, p. 29).

Aggregate materials generally obtain a higher dry density if they are compacted in a wet or moist state, compared to a totally dry material. This is caused by the lubrication effect of the water between the aggregates, which minimizes friction and abrasion of the material (Roston et al., 1976, p. 30). Not all water contents give the same dry density results after compaction, and too much water can obstruct the compaction of the aggregates and result in a lower dry density. Due to this phenomenon, there exists an optimum water content specific to each material and the compaction effort used, that gives the highest dry density for the material. This is an essential element of the much used Proctor compaction test developed in the 1930s (Das, 2010, p. 115 and 118).

Compaction of granular materials in the field is more complex and is influenced by more factors than compaction in a laboratory setting. The degree of compaction that is obtainable in each case mainly depends on the material being compacted, the amount (thickness) of the layer, as well as the compaction equipment and how often they are used (number of passes). The most common form of field compaction equipment are rollers, of which the three most common types are: smooth wheel rollers, pneumatic tired rollers and sheepsfoot rollers. All of the roller types are available as both static and vibratory rollers, and all variations serve different purposes and have different applications in field compactions. Smaller, handheld vibratory compaction devices are also commonly used for more restricted, hard-to-reach areas (Das, 2010, p. 132-134).

While the type of compaction equipment used determines the load size and type (static or vibratory), the number of roller passes also plays a key part in determining the applied compaction effort. In general, a higher number of roller passes results in a higher maximum dry density achieved, as well as a more uniform distribution in the dry density vertically in the material layer. In other words, more roller passes provide a more even compaction throughout the material. This depth effect is limited by the compaction depth range of the compaction equipment in question (Das, 2010, p. 134-136).

2.2 Boussinesq's formula and plate load tests

Rocks, soil and other granular materials used for construction purposes have very varying properties which can vary significantly over short distances. In order to identify and map out these variations in properties, a series of site investigation activities are a necessity on every construction site. This includes both a series of tests conducted in the controlled environment of a lab, as well as a range of in situ tests, conducted directly on the undisturbed material. In situ testing has the advantage of not disturbing the material, and can therefore be a useful way of determining the actual characteristics and behaviour of granular material in the field, especially when the material is sensitive to disturbance (Shukla and Sivakugan, 2011, p. 2).

The plate load test (hereafter referred to as PLT) is an in situ test used to determine the bearing capacity of soil or the layers of a road structure. It can also be used to predict settlements, or to determine the modulus of subgrade reaction[3] (Shukla and Sivakugan, 2011, p. 38-40). The test is one of the oldest in situ tests available (Briaud, 2013, p. 119) and is generally conducted by applying a load in cumulative increments to a rectangular or a circular plate placed on top of the material being tested, and documenting the corresponding settlements. For road construction purposes, the plate is generally circular (Shukla and Sivakugan, 2011, p. 40-42).

The test makes use of Boussinesq's formula to determine the soil's elasticity modulus. The formula, given in Equation (1), estimates the settlement of an elastic half-space loaded over a circular area (Monnet, 2015, Timoshenko and Goodier, 1970, p. 403-405). The formula is based on the assumptions that the material being tested can be represented by a homogeneous and isotropic, linearly elastic half space (Verruijt, 2018, p. 219). For granular materials used in the layers of road structures, these assumptions do not hold true, showcasing one of the weaknesses of the PLT method.

$$s = f \cdot \frac{1 - \nu^2}{E} \cdot p \cdot R \quad (1)$$

Where,
s is the settlement in the centre of the plate [m]
f is the stress distribution factor []
ν is the Poisson's ratio of the soil material []
E is the soil material's modulus of elasticity [Pa]
p is the average loading pressure on the plate [N/m^2]
R is the radius of the plate [m]
(Ullidtz, 1998, Ullidtz, 1987)

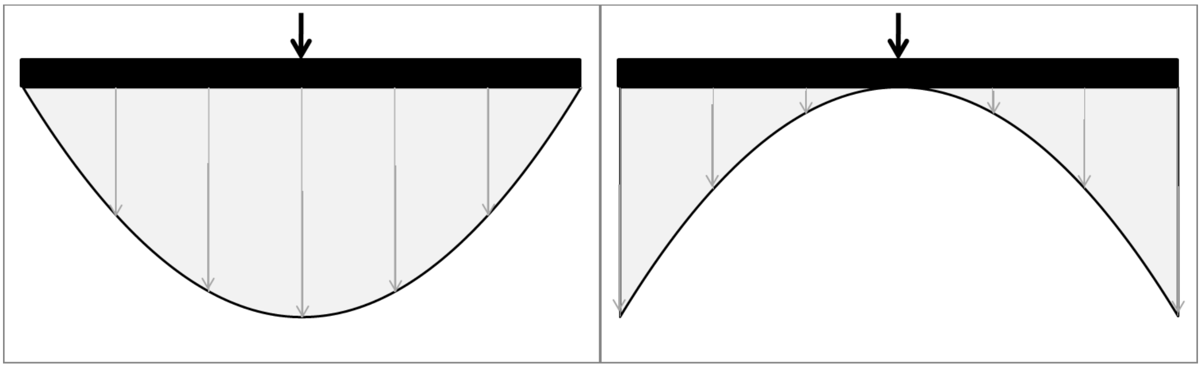
The stress distribution factor, f, in Equation (1) varies based on the assumed distribution of the load to the soil, as given in For the use of PLT in road construction, it is generally assumed that the load is evenly distributed over the circular area (Monnet, 2015, Timoshenko and Goodier, 1970, p. 403-405), making $f = 2$. This is a theoretical interpretation of the stress distribution in the soil, and is unlikely to resemble the actual load distribution in soils used for road construction purposes. The actual load distribution is likely to be parabolic, with a shape dependant on the properties of the material being tested, as illustrated in Figure 2.1 (Ullidtz, 1987). The aforementioned assumption about

[3] The modulus of subgrade reaction is defined as the ratio between the pressure applied to the material to the corresponding settlement in the material (Shukla and Sivakugan, 2011, p. 73)

the load distribution is therefore yet another example of the weaknesses of the PLT used for road construction purposes.

Table 2.1: Values of the stress distribution factor, f, for estimation of a soil's modulus og elasticity using a PLT.

Assumed stress distribution	**Stress distribution factor, f**
Uniform distribution	2
Load distributed through a rigid plate	$\frac{\pi}{2}$
Parabolic distribution in granular soil	$\frac{8}{3}$
Parabolic distribution in cohesive soil	$\frac{4}{3}$



(a) *(b)*

Figure 2.1: Parabolic load distribution in soil during a PLT. (a) Load distribution in granular soil, (b) Load distribution in cohesive soil.

If we assume that Equation (1) holds true for a granular material in a road structure and that $f = 2$ as previously mentioned, we can re-write the equation and solve for the elasticity modulus, since that is the element of the equation we want to measure. If the test is performed relatively fast and it can be assumed that water is not drained from the material, we can assume that the Poisson's ratio of the soil is $\nu = 0{,}5$ (Briaud, 2013, p. 121-122), and we get Equation (2). For tests where the material is drained, the Poisson's ratio is generally assumed to be $\nu = 0{,}35$ (Briaud, 2013, p. 121-122).

$$E = \frac{3}{2} \cdot \frac{p}{s} \cdot R \tag{2}$$

Where all variables are defined as for Equation (1).

Equation (2) is generally used as a basis for the interpretation of the results of a PLT. The detailed procedure and interpretation of the results of the PLTs differs depending on the purpose of the test and the country in question. This will be discussed further in chapter 3, where different national requirements and test procedures are described.

One can also use Boussinesq's formula to determine the change in stress at any point directly beneath the centre of a circular, uniformly loaded area, as is the case for a static PLT. The resulting formula for the change in stress is shown in Equation (3) (Das, 2010, p. 273-274)

$$\Delta\sigma_z = q\left(1 - \frac{1}{\left(\left(\frac{R}{z}\right)^2 + 1\right)^{\frac{3}{2}}}\right) \tag{3}$$

Where,

$\Delta\sigma_z$ is the change in vertical stress [kPa]
q is the uniform load applied on a circular area [kPa]
R is the radius of the circular loaded area [m]
z is the depth under the centre of the circular loaded area [m]

The change in stress directly under the centre of the plate in a PLT is therefore dependant on the size of the plate, as well as the size of the applied load. When the change in stress is given as a fraction of the applied load, $\frac{\Delta\sigma_z}{q}$, and the depth under the plate is given as a fraction of the plate radius, $\frac{z}{R}$, the relationship between stress and depth can be illustrated independent of the size of the applied load and the plate radius. This relationship is illustrated in Figure 2.2.

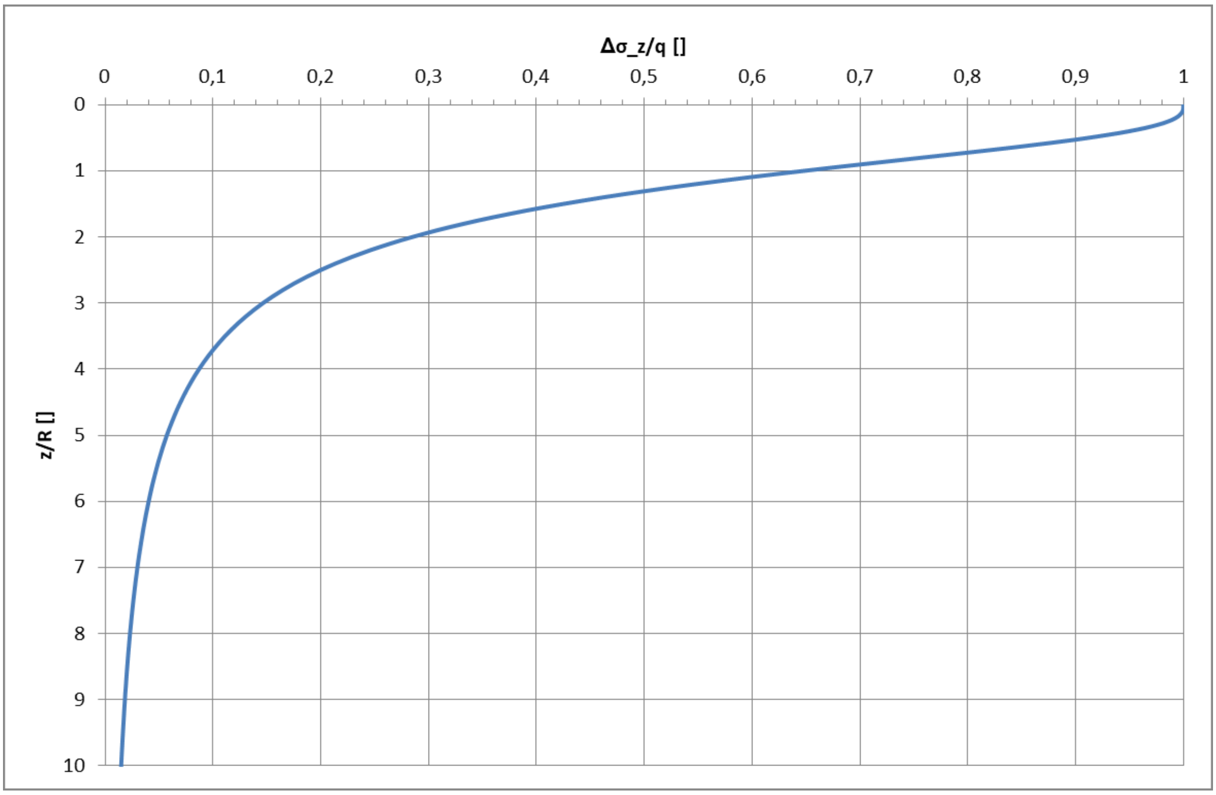


Figure 2.2: Relative change in stress under the centre of a plate during a PLT as a function of depth relative to the plate radius.

As can be seen from both Equation (3) and Figure 2.2, the change in vertical stress never reaches absolute 0, since $\frac{R}{z}$ is never equal to 0. In theory, this means that the effects of a PLT are experienced infinitely far down into the soil. For practical applications in the field, infinity has no meaning, and one has to set limits to determine when the effects of the test on the soil below can be viewed as negligible. Which limit is the most appropriate for this purpose and how it should be defined is debatable and will not be directly addressed here.

The corresponding strain in the soil directly beneath the centre of uniformly loaded, circular area can also be determined using Boussinesq's formula, as shown in Equation (4) (Ullidtz, 1998, p. 25-26).

$$\varepsilon_z = \frac{(1+\nu)q}{E}\left(\frac{\frac{z}{R}}{\left(1+\left(\frac{z}{R}\right)^2\right)^{\frac{3}{2}}} - (1-2\nu)\left(\frac{\frac{z}{R}}{\left(1+\left(\frac{z}{R}\right)^2\right)^{\frac{1}{2}}} - 1\right)\right) \tag{4}$$

Where,

ε_z is the vertical strain at depth z directly beneath the centre of the loaded area []
ν is the Poisson's ratio of the soil material []
q is the uniform load applied on a circular area [kPa]
E is the soil material's modulus of elasticity [kPa]
R is the radius of the circular loaded area [m]
z is the depth under the centre of the circular loaded area [m]

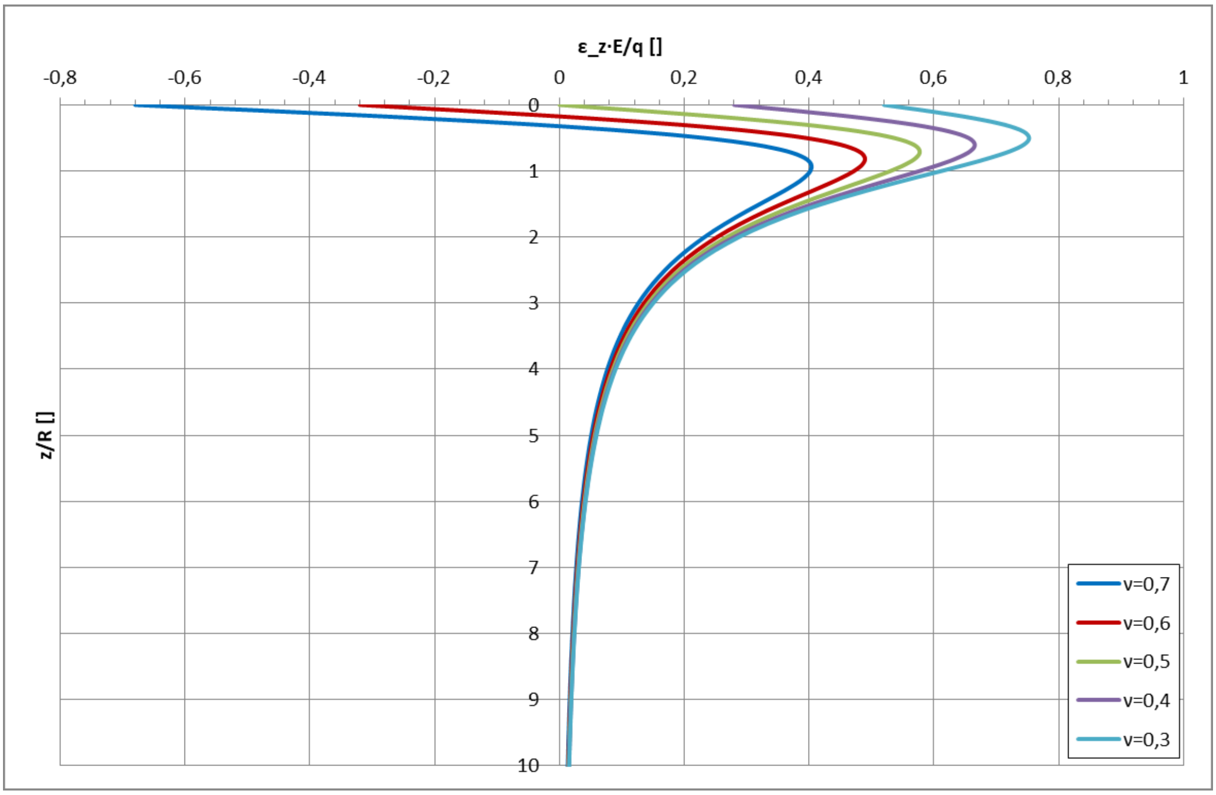


Figure 2.3: Vertical strain multiplied by the factor $\frac{E}{q}$ under the centre of a plate during a PLT, as a function of depth relative to the plate radius.

Contrary to the change in vertical stress in Equation (3), the strain given by Equation (4) (as well as the deflection), is dependent on the properties of the material being tested, namely the Poisson's ration and the modulus of elasticity. As can be seen from Equation (4), the vertical strain decreases with an increasing modulus of elasticity. The change in strain due to changes in the Poisson's ration can be seen in Figure 2.3, which shows the values of strain multiplied by the factor $\frac{E}{q}$, as a function of the relative depth, $\frac{z}{R}$, under the centre of a uniformly loaded circular area, for 5 different values of Poisson's ratio.

As discussed above, the effect of the applied load directly under the centre of the plate decreases rapidly with depth. The change in vertical stress also changes with the vertical distance from the centre of the test plate. The changes in stress at any location in the soil beneath the plate during a PLT can be determined by Equation (5), as described by Ahlvin and Ulery (1962).

$$\Delta\sigma_z = q(A' + B') \tag{5}$$

Where,

$\Delta\sigma_z$ is the change in vertical stress [kPa]

q is the uniform load applied on a circular area [kPa]

A' and B' are functions of the depth and distance of the point of interest relative to the radius of the loaded circular area, $\frac{z}{R}$ and $\frac{r}{R}$. See Appendix 1.

(Ahlvin and Ulery, 1962, p. 10, Das, 2010, p. 275).

The values for A' and B' for a variation of values for z and R, as calculated by Ahlvin and Ulery (1962), can be found in Appendix 1.

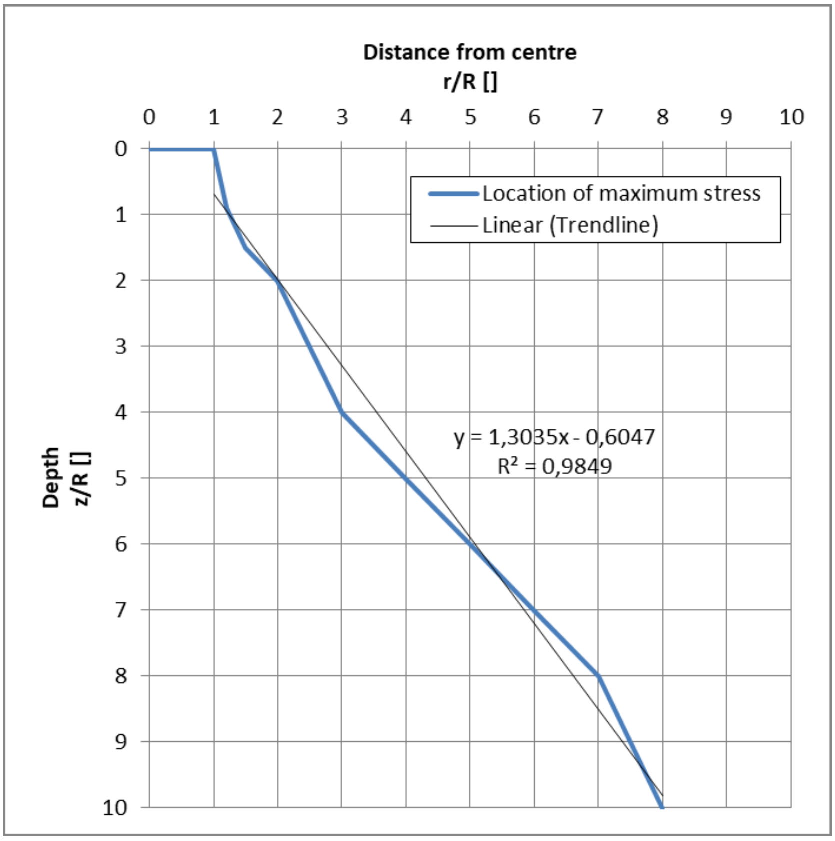


Figure 2.4: The location of the maximum vertical stress experienced by the soil beneath a uniformly loaded circular area, based on values calculated by Ahlvin and Ulery (1962). The blue line represents the location of the maximum stress in the soil, while the black line represents the estimated trendline of the maximum load distribution over distance and depth.

The change in vertical stress as determined by Equation (5) and the values calculated by Ahlvin and Ulery (1962) is quite difficult to present graphically in an easy-to-understand manner. One way of presenting this is to plot the location of the maximum stress in the soil beneath the circularly loaded area, to understand the estimated load distribution over depth and horizontal distance from the plate centre. This is done in Figure 2.4. The actual distribution of the relative change in stress over depth and distance from centre of a plate during a PLT, as calculated by Ahlvin and Ulery (1962), is provided in Figure 2.5.

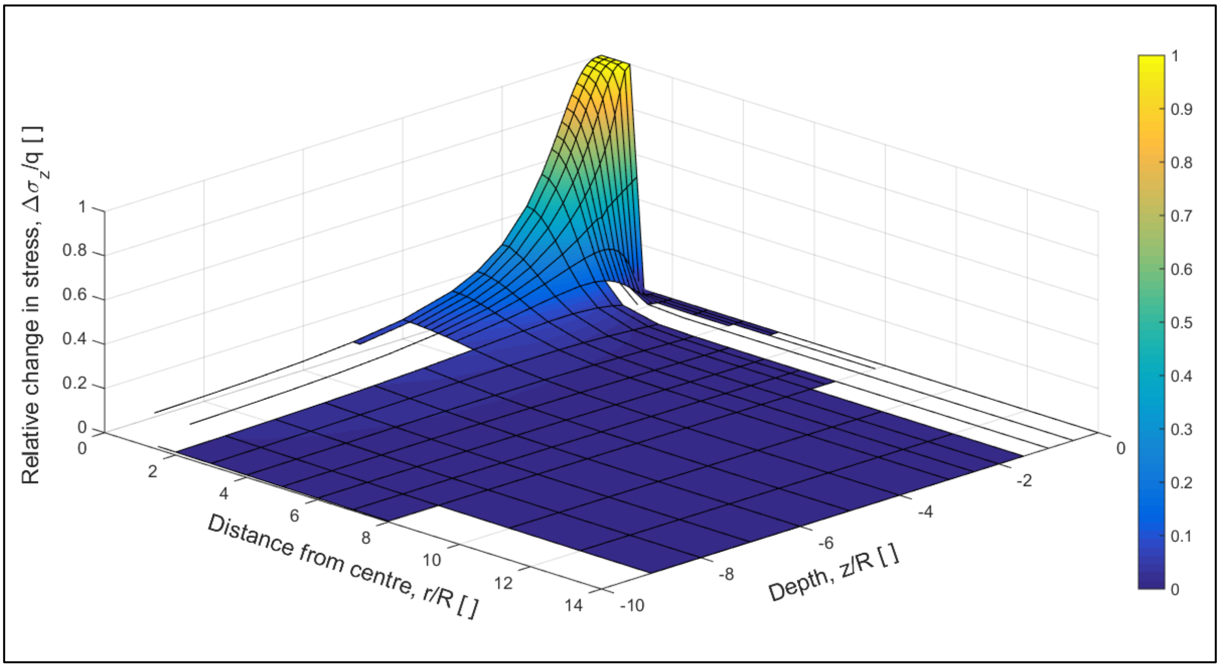


Figure 2.5: Relative change in vertical stress over depth and distance from centre of a plate during a PLT, as calculated by Ahlvin and Ulery (1962).

Ahlvin and Ulery (1962) also determined the formula for the vertical strain at any location in the soil beneath the plate during a PLT, as shown in Equation (6):

$$\varepsilon_z = q \cdot \frac{1+\nu}{E} \cdot \big((1-2\nu) \cdot A' + B'\big) \tag{6}$$

Where,

ε_z is the vertical strain []
q is the uniform load applied on a circular area [kPa]
ν is the Poisson's ration of the soil material []
E is the soil material's modulus of elasticity [kPa]
A' and B' are functions of the depth and distance of the point of interest relative to the radius of the loaded circular area, $\frac{z}{R}$ and $\frac{r}{R}$. See Appendix 1.

(Ahlvin and Ulery, 1962, p. 10).

The values for A' and B' for a variation of values for z and R, as calculated by Ahlvin and Ulery (1962), can be found in Appendix 1.

As for the maximum stress, the maximum strain distribution is also difficult to illustrate. Figure 2.6 shows the location of the maximum strain in the soil beneath the circularly loaded area. Figure 2.7 illustrates the actual distribution of the strain over depth and distance from centre of a plate during a PLT, as calculated by Ahlvin and Ulery (1962).

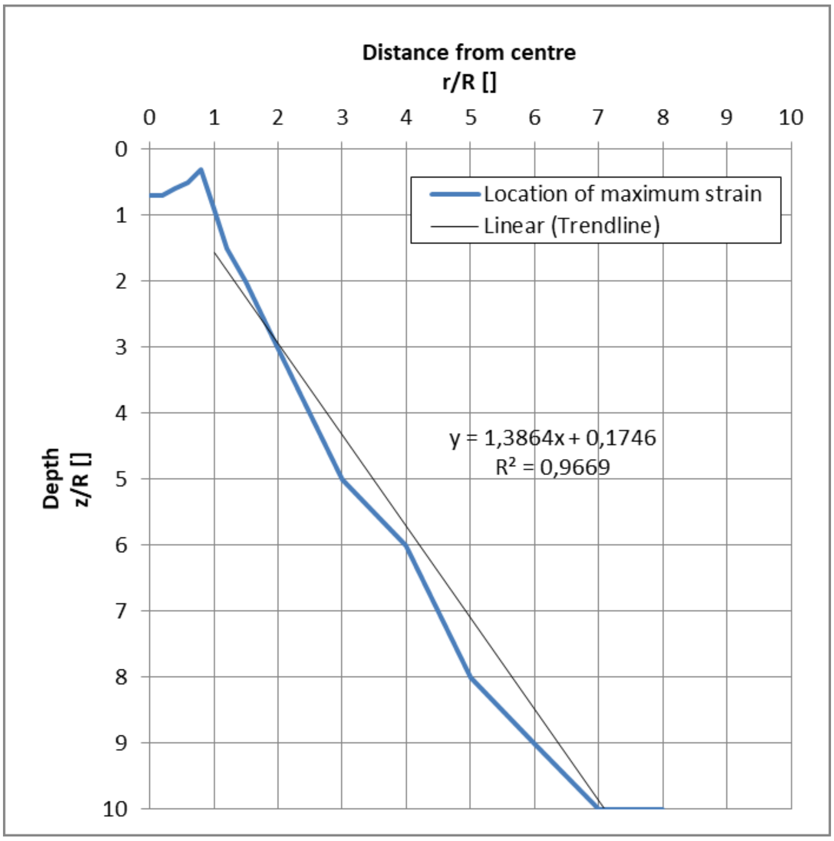


Figure 2.6: The location of the maximum vertical strain experienced by the soil beneath a uniformly loaded circular area, based on values calculated by Ahlvin and Ulery (1962). The blue line represents the location of the maximum strain in the soil, while the black line represents the estimated trendline of the maximum strain distribution over distance and depth.

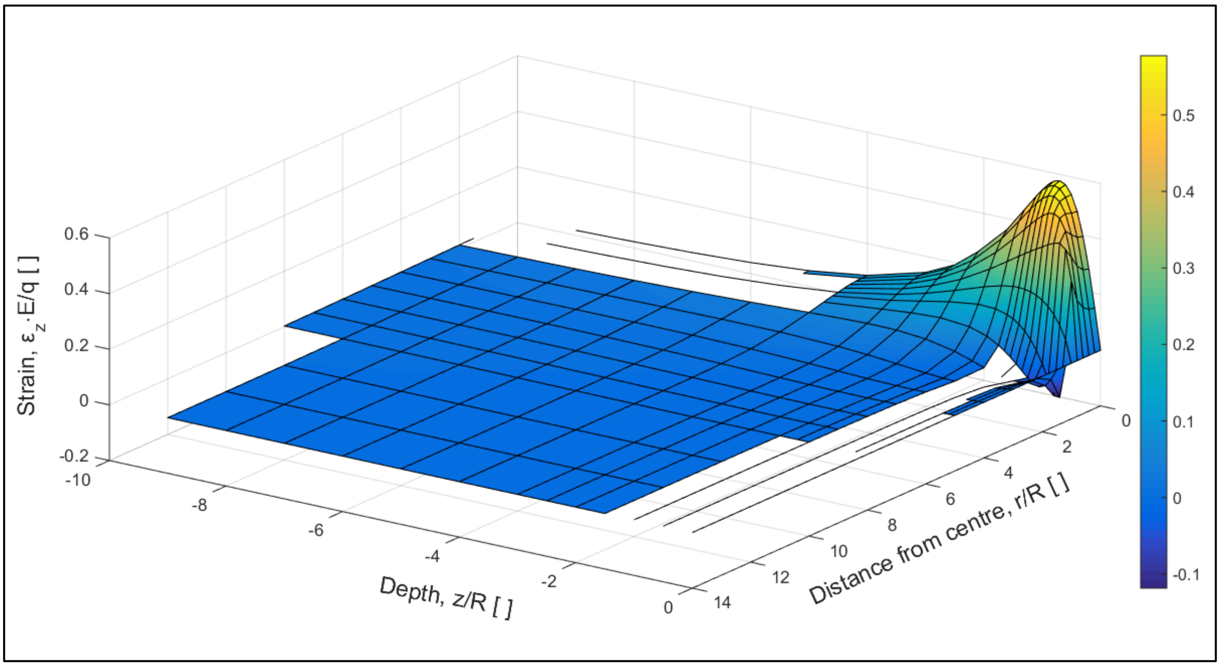


Figure 2.7: Change in vertical strain over depth and distance from centre of a plate during a PLT, as calculated by Ahlvin and Ulery (1962)

The relationships between the depth, horizontal distance from plate centre and the change in stress and strain presented in the equations and figures above are only true for materials that can be represented by a homogeneous and isotropic half space. For road structures, where the materials are divided into layers with different material properties, one has to take into consideration the difference in each layer's stiffness.

Burmister (1965) and Fox (1948) considered a pavement system consisting of two layers, a base course layer of thickness h_A with material properties E_A and v_A on top of a subgrade layer of infinite thickness with material properties E_B and v_B. Assuming there is no slip along the contact area of the two layers, Burmister (1965) and Fox (1948) derived equations for the stresses experienced in the two material layers. The factors that influence the relative stress distribution in the material layers were found to be the ratio between the modulus of elasticity of the two materials, E_A/E_B, the ratio between the radius of the plate and the layer thickness of the top layer, R/h_A, and the Poisson's ratios of the two materials, v_A and v_B. The equations themselves are quite complicated and the calculations are too extensive for the scope of this thesis, and will therefore not be discussed further. Figure 2.8 illustrates the relative change in stress as a function of depth under the centre of a plate during a PLT for a case where $R/h_A = 1$ and $v_A = v_B = 0{,}5$, based on the findings of Burmister (1965) and Fox (1948).

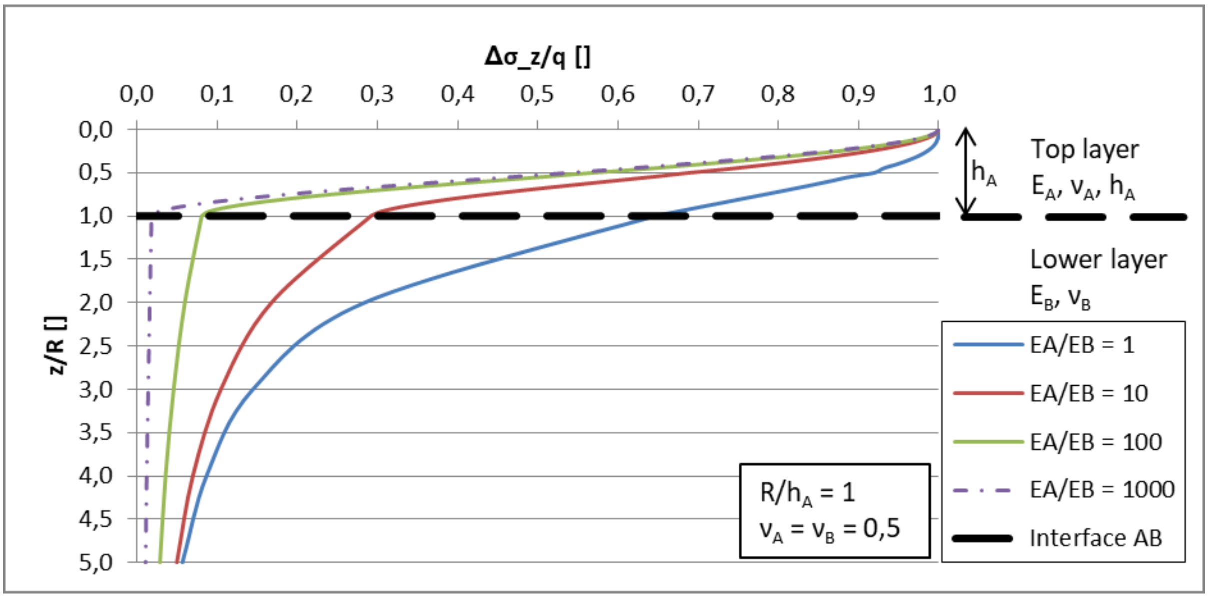


Figure 2.8: Relative change in stress over depth under the centre of a plate during a PLT for a two-layer system, where $\nu_A = \nu_B = 0{,}5$ and $R/h_A = 1$, displayed for four different ratios of E_A/E_B. Based on calculations by Burmister (1965) and Fox (1948).

Burmister (1966) and Acum and Fox (1951) also considered a three layered pavement system; a base course layer of thickness h_A with material properties E_A and v_A, a subbase layer of thickness h_B with material properties E_B and v_B, which both rest upon a compacted subgrade layer of infinite thickness with material properties E_C and v_C. The assumption of no slip between the contact areas of the layers is also used here to derive the equations for the stresses and strains experienced in the material layers. The factors that influence the relative stress distribution in the material layers of a three-layer system were found to be the ratio between the modulus of elasticity of the materials, E_A/E_B and E_B/E_C, the ratio between the radius of the plate and the layer thickness of the middle layer, R/h_B, the ratio between the thickness of the top and middle layer, h_A/h_B, and the Poisson's ratios of the materials, ν_A, ν_B and ν_C. As for the two layer system, the equations and calculations for the three layer system are too extensive for the scope of this thesis, and will therefore not be discussed further. Figure 2.9 illustrates the relative change in stress at the interfaces between the layers of a three-layered structure, under the centre of a plate during a PLT for a case where $\nu_A = \nu_B = \nu_C = 0{,}5$; $h_A/h_B = 1$ and $R/h_B = 1$, based on the findings of Burmister (1966) and Acum and Fox (1951)[4].

It is worth mentioning that in his calculations, Burmister (1965, p. 26), (1966, p. 37-38) uses a Poisson's ratio of $\nu = 0{,}2$ for granular materials (e.g. base course, subbase, sand subgrade) and $\nu = 0{,}4$ for asphalt layers and clay soil subgrades, without expanding on where these numbers originate from. This contradicts the usual assumption for PLTs, where the Poisson's ratio is assumed to be $\nu = 0{,}5$ for materials used for road construction purposes. Fox (1948) and Acum and Fox (1951) use the more widely used assumption of $\nu = 0{,}5$, and their calculations have therefore been used as a basis for Figure 2.8 and Figure 2.9.

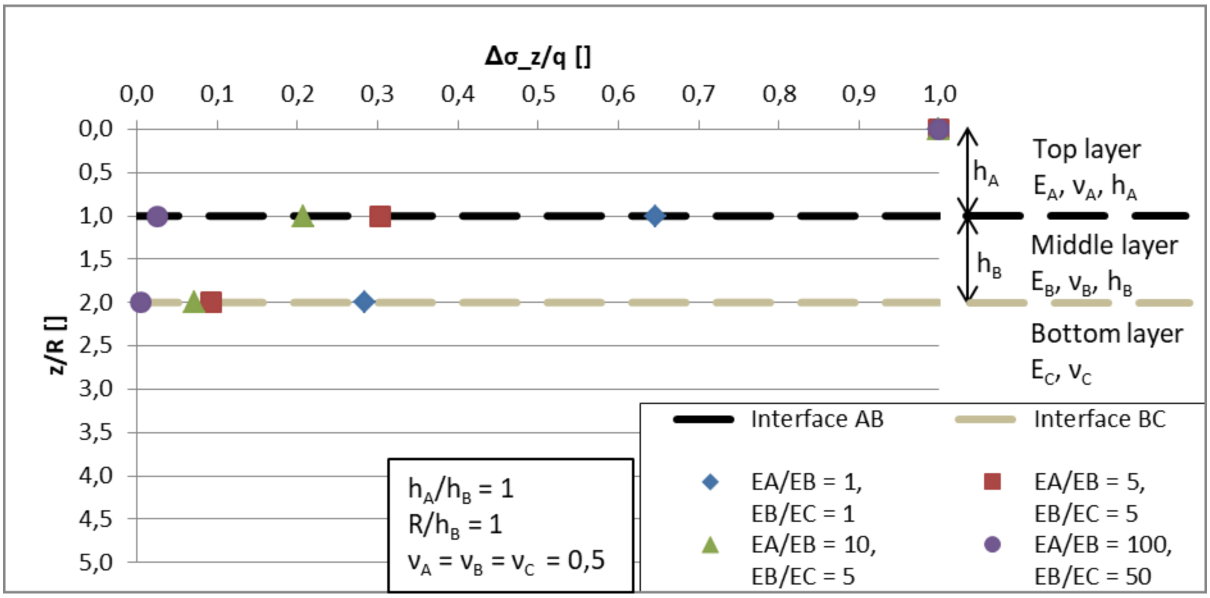


Figure 2.9: Relative change in stress at the interfaces under the centre of a plate during a PLT for a three-layer system, where $\nu_A = \nu_B = \nu_C = 0{,}5$; $h_A/h_B = 1$ and $R/h_B = 1$, displayed for four different ratios of E_A/E_B and E_B/E_C. Based on calculations by Burmister (1966) and Acum and Fox (1951).

As for Boussinesq's formula, all of the aforementioned theories and equations assume that the material being tested is perfectly elastic. It is, however, important to note that the materials in a layered pavement system are not perfectly elastic, and the theory does therefore not fully represent the behaviour of such materials. The behaviour of the materials in a layered pavement system is complicated, and there is currently no existing fully representable theory to describe it. The aforementioned theory can therefore serve as an adequate base theory to predict the behaviour of such materials, but one should avoid accepting the theory as the unquestionable truth (Burmister, 1965, p. 3).

[4] The figure only shows the calculated values for the relative stress at the interfaces between the three layers, since Acum and Fox (1951) have only provided these values in their article. The equations for the relative stress outside of the interfaces are quite extensive and complicated and out of the scope of this thesis, and the values outside of the interfaces have therefore not been calculated.

2.3 Plate load tests in the field

As mentioned in the previous section, the theoretical assumptions that the PLT is based on are quite far from the actual circumstances when the test is used on granular materials in the field, especially when considering materials used in road construction. This does not necessarily mean that it is unreasonable to use the theory and the PLT on materials in the field, but rather that there are more factors that can influence the end results than those presented in the equations above. What those factors are and how they influence the test results are two questions that are not easily answered. However, several researchers have attempted to answer both of these questions to some extent. This section provides an overview of the findings of a number of studies focusing on the different factors that can influence the results of a PLT conducted on granular materials in the field.

Araújo et al. (2017) investigated the effect of the size of the plate on the results of a PLT conducted on a layer of sand. The same series of loads were applied to three circular plates with three different diameters, 0,3 m; 0,5 m and 0,8 m. The test results show a non-linear relationship between plate settlements and plate sizes, where the larger plate sizes lead to larger settlements. However, Araújo et al. (2017) also discussed other studies that had found contradictory results, some which back up the findings of Araújo et al. (2017), and other which disagree with those findings. This, in addition to the fact that Araújo et al. (2017) base their findings on only three PLTs, suggest that more research is needed on this topic and on a larger scale in order to draw a robust conclusion. The test procedure used in the study conducted by Araújo et al. (2017) is somewhat different to the usual test procedures used for determining the bearing capacity of layers in a road structure. The PLTs were carried out using a so-called quick maintained load, where the load is kept constant for a short amount of time and the settlement is measured at several different times during each load step. The effect the test procedure may have on the transferability of the results of the study is uncertain.

Fu et al. (2016) used a two dimensional discrete element procedure to simulate shallow PLTs, and then used the model to study the effects of the plate size and the plate roughness on the results of the PLT. Similarly to the in-situ study conducted by Araújo et al. (2017), Fu et al. (2016) also found a non-linear relationship between settlements and plate size. Additionally, Fu et al. (2016), found a non-linear relationship between the size of the testing plate and the ultimate bearing capacity of the soil. Furthermore, they found that the plate roughness has a significant effect on the measured bearing capacity, as well as the failure mode of the tested soil. The quality and applicability of these results are of course dependent on the quality and reliance of the model and boundary conditions applied in the study. Whether or not the results of this study can be transferred to real-life in-situ tests is therefore uncertain.

A study conducted by Barnard and Heymann (2015) investigated the effect of levelling the unevenness of the testing surface using different types of levelling materials. They hypothesized that the roughness of the test surface could cause plastic deformations at the interface between the plate and the soil during a PLT, which might affect the results of the PLT. Barnard and Heymann (2015) compared the results of six different PLTs conducted with three different surface preparation methods; no levelling material at all, levelling using fine sand, and levelling using gypsum plaster. The tests were conducted on a firm clayey silt material in South Africa using a modified PLT, to try to minimize the effects of the surface unevenness on the results of the test. The modification of the PLT consisted of inserting telescopic probes into the soil beneath the centre of the test plate in order to measure the relative displacement in the soil at two different points. Thus the internal soil stiffness can be determined based on the displacement of the soil below the surface. The stiffness values obtained by the PLTs were then compared to the stiffness values obtained through the telescopic probes. The results show that surface levelling with gypsum plaster resulted in the most consistent stiffness values, and that levelling without the use of a levelling material could result in stiffness values up to 50% lower than the values obtained from the telescopic probes. Barnard and Heymann (2015) proceed to recommend surface levelling with gypsum plaster when conducting PLTs on soil. However, they do mention that due to the relatively low strength of the gypsum plaster, it might not be well suited as a surface levelling material when conducting a PLT on rock or rock masses, since the gypsum can break before deformation is experienced in the material being tested. The limited number of tests conducted in this study creates a need for further testing before a decisive conclusion on the matter can be drawn. The modification of the PLT also makes the transferability of the results uncertain, although Barnard and Heymann (2015) argue that the diameter of the central hole for the telescopic probe should be small enough relative to the plate size to have insignificant effect on the results of the PLT.

In her master's thesis on Continuous Compaction Control, Fladvad (2012) assessed the effect of using gypsum plaster as a levelling layer between the plate and a base course material. She compared the results of a PLT conducted with a levelling layer of gypsum plaster to the results of a test without any levelling. The results of the test show that in general, the tests conducted without a levelling layer result in a lower bearing capacity than the tests conducted with gypsum plaster. This is especially apparent for the first loading cycle, where E_1 is significantly lower for tests without levelling compared to the tests with gypsum plaster. The results of the two methods become more similar the more the granular layer is compacted. Fladvad (2012) suggests that the gypsum plaster provides an extra stability during the PLT, making the bearing capacity of the granular material seem higher than it actually is. She also suggests that if PLTs without a levelling layer are to be permitted in the national standards[5], the requirements for the E_2/E_1 ratio should be reconsidered, since the significantly lower E_1 value of the tests without a levelling layer will mainly effect that requirement.

Krawczyk et al. (2015) studied the effect of different types of counterweights used during a PLT. They conducted PLTs on three different layers of materials; only the subgrade (a mixture of sand, gravel and clay), a layer of crushed stone on top of the subgrade, and a layer of crushed stone above a layer of cement stabilized aggregate material on top of the subgrade. Two different counterweights were used during the tests on each of the material layers; a heavy vehicle (truck) with the PLT equipment mounted to the back of the vehicle, and an excavator with the PLT equipment mounted to the bucket. The results of the study show that the weight and the type of counterweight used during the test have a significant effect on the results of the test, especially the measured values of elasticity after the second loading cycle (E_2). The measured values for E_2 were consistently lower for the test using the excavator as counterweight, compared to using

[5] At the time of the publication of the thesis, the use of gypsum plaster as a levelling layer for a PLT was required according to the Norwegian handbook describing the test procedure (Statens vegvesen and Vegdirektoratet, 1997). In the most recent version of the handbook, this requirement has been removed, and no levelling material is mentioned in the description of the test procedure (Statens vegvesen and Vegdirektoratet, 2018b). The requirements in the Norwegian handbooks regarding PLTs are summed up in section 3.

the heavy vehicle (truck). However, due to the limited number of tests conducted in this study, further testing is needed before a final conclusion can be made.

Adam et al. (2009) conducted a numerical analysis of a static PLT and dynamic PLT using a Light Falling Weight Device (LFWD) to estimate the effect of layered structures on the results of the tests. They also assessed the reliability of the methods separately by objectively evaluating the assumptions and simplifications made for each method. For the static PLT, Adam et al. (2009) identify the following weaknesses with the method:

- The subsoil and rock materials used in road structures are not linearly elastic, thus contradicting one of Boussinesq's assumptions.
- The layers of a road structure are generally not identical, and the test material is therefore not homogeneous, as Boussinesq assumed.
- The material is plastically deformed during the test in the area under and closest to the plate.
- The subgrade is also compacted during the test, and the results of the tests are therefore dependent on the loading history of the material and subgrade.
- The load is applied using a counterweight, leading to the material being loaded at one point (under the test plate), while simultaneously being unloaded at another (the counterweight). The load is therefore only re-distributed between the two points.
- The settlement measurements are effected by the movement of the reference point of the measuring device. The load from the test induces settlements in the reference point, and thus decreases the measured settlements, compared to the actual settlements.

Adam et al. (2009) thus conclude that the deformation modulus determined by a static PLT is not a pure material parameter, since it also depends on various other factors regarding the test procedure. Different national requirements are therefore not comparable if they are also based on different test procedures, e.g. differences in the magnitude of the applied load.

A study conducted by Dasaka et al. (2014) identified uncertainties related to the conduction of PLTs, which can lead to unreliable and incomparable results. The study is based on Indian regulations and test procedures, but can be useful to identify similar uncertainties in other procedures and regulations. Dasaka et al. (2014) identified the following main uncertainties related to the PLT procedure:

- The magnitude of each loading increment. Different load increments give different settlement measurements, regardless of if the maximum load applied is the same or not.
- The maximum duration of each loading step. The maximum waiting time required before changing the load effects the settlement measurements, especially if the load is not maintained until the settlements are stable.
- Whether the load is maintained constant during each load increment, or is only applied momentarily and then released. Non-maintained loads giver lower settlements than maintained loads, and can therefore overestimate the bearing capacity of the soil.

According to the results of Dasaka et al. (2014), it is therefore very important that the PLTs are conducted following the same test procedures, if they are to be compared to requirements or other test results.

Cho and Mun (2014) developed a model to determine the quality of a repetitive static PLT, based on a set of previously conducted tests considered to be of high quality. The model detects outliers compared to the quality measurements, and can thus predict if the input measurements are likely to be faulty or not. The model is not capable of determining what is the cause of the faulty measurements, but can serve as a basis to assess when tests should be repeated due to a possible error in the test procedure.

Costa et al. (2003) studied the effect of negative pore water pressure (matric suction) in soil on the results of PLTs. Ten tests were performed on unsaturated Laterite soil with different suction conditions. The results of the tests show that the matric suction greatly affects the results of a PLT, and that an increase in matric suction leads to less settlements, i.e. a stiffer soil. The limited number of tests in the study makes the conclusion indecisive, and further testing is needed to obtain decisive results.

Choi et al. (2018) compared the results of PLTs for different permeable base course materials. These materials are open-graded, to allow precipitation to infiltrate through the pavement and the underlying road structure. In addition to that, they compared the results of the tests after a different number of passes of a 10-ton vibratory roller. According to their findings, the E_2 value of the open-graded material is highly dependent on the type of material used in the permeable base course, where materials with larger particles have a higher E_2 value than materials with smaller particles. Selecting the right material for the road structure is therefore very important. The test results were compared to German and Korean requirements for PLTs, and all of the tested materials met the requirements for E_2, but not for the ratio requirement E_2/E_1. Choi et al. (2018) argue that this is because the requirements are defined for dense-graded materials, and other requirements should be defined for open-graded material because they behave differently. However, due to the limited number of tests conducted in this study, more testing is needed before decisive conclusions can be drawn.

Hidalgo-Signes et al. (2016) studied the effect on the bearing capacity of adding recycled rubber tires to the sub-ballast of a railway, using a PLT. Three different mixtures with three different rubber contents were tested and compared with a control sample with no rubber added. A static PLT was conducted both before and after a dynamic loading test, showing the effect of the loading history, as well as the effect of the type of compaction methods used (static or dynamic). The results of the study show that the higher the rubber content in the test material, the lower the E_2 value, and the lower the bearing capacity of the structure. Larger settlements were experienced for the static PLT conducted before the dynamic load test, compared to the static PLT performed after the dynamic load test. However, more research is needed to conclude decisively on that matter.

Based on the literature discussed in this section, not much has been done to study the effect of the calculation method for the E-modulus or the effect of Norwegian superstructure materials on the results of a PLT conducted on the base course of a road structure.

3 Document review - National standards and guidelines

The following section provides a short summary of different national standards regarding plate load testing.

3.1 Norwegian national standards and guidelines

The PLT has been included in the NPRA's handbooks since at least the 1980s. During that period the defined test result requirements have not changed much, although the way the requirements are defined has changed slightly.

3.1.1 Handbook 018 from 1980

Handbook 018 Road construction from 1980 permits the usage of a PLT to determine the degree of compaction of a base course layer, but only if the nominal maximum size of the aggregates is ≤ 150 mm. The defined requirements for the results of the PLT are only specified for the E_2/E_1-ratio, and the values are said to be "desired results", although the exact meaning of that term is not specified further (Statens vegvesen and Vegdirektoratet, 1980, p. 129). The criteria for the results of the PLT as defined in the NPRA handbook from 1980 are shown in Table 3.1. Note that the criteria are defined based on which road class the road in question belongs to. The term road class has later been abandoned by the NPRA and is not used in later versions of the handbooks, and will therefore not be discussed further in this report.

Table 3.1: The defined Norwegian criteria for the results of the PLT as defined by the NPRA handbooks in 1980 (Statens vegvesen and Vegdirektoratet, 1980)

	Road class[6]	
	III-IId	IIc-Ia
E_2/E_1	≤3,5	≤2,5

3.1.2 Handbook 015 from 1984

Handbook 015 Field test from 1984 describes how the PLT should be conducted. It specifies that the test is used to estimate the stability and bearing capacity of the different layers in the pavement, as well as for the soil beneath. Additionally, the method can be used as a control method to determine the quality of the compaction of a pavement layer. Regardless of the reason for testing, the elasticity of the granular material is calculated using Equation (7) (Statens vegvesen and Vegdirektoratet, 1984, p. 136-140):

$$E = \frac{3}{4} \cdot \frac{\Delta p}{\Delta s} \cdot D \tag{7}$$

[6] The criteria for the results of the plate load test in the NPRA handbooks from 1980 were dependant on which road class the road in question belonged to. The term road class was later abandoned and is not used in the more recent versions of the handbooks. This term and what each road class implies will therefore not be discussed further.

Where,

E is the elasticity of the soil for the load cycle in question [MPa]

Δp is the change in load on the plate [kN/m^2]

Δs is the change in settlements in the soil [mm]

D is the diameter of the plate [m]

The test procedure is described in detail in *Handbook 015*. The most important details of the procedure are summed up below:

The testing plate shall be round and made of steel, with a diameter of 0,3 m and a thickness of 12 mm. For measurements conducted on the subbase or base course, the contact point of the counterweight to the ground must not be closer to the plate than 1,5 m. A thin layer of gypsum plaster shall be placed between the top of the layer being tested and the testing plate. The plaster layer must not be thicker than 2-3 mm. The testing plate shall be in a horizontal position at the beginning of the PLT. Before the start of the test, the plate shall be loaded with 20 kN/m^2 for a few seconds. After that, the gauge of the Benkelman beam is reset to zero (Statens vegvesen and Vegdirektoratet, 1984, p. 139). Figure 3.1 shows the necessary test equipment used to perform a PLT, excluding the counterweight. Figure 3.2 shows the setup of the test equipment during a PLT, including the counterweight (a roller in this instance, but other types of counterweights may also be used). In the field, PLTs are usually performed with the addition of some sort of computer device which shows the instantaneously logged measurements from the data logger. This gives the tester real-time information about the applied load and measured settlement, as well as information about the required loads of each load step in the load cycles. Additionally, the computer device is generally programmed to calculate the E-values of the test and display the results and whether or not the requirements are met instantaneously.

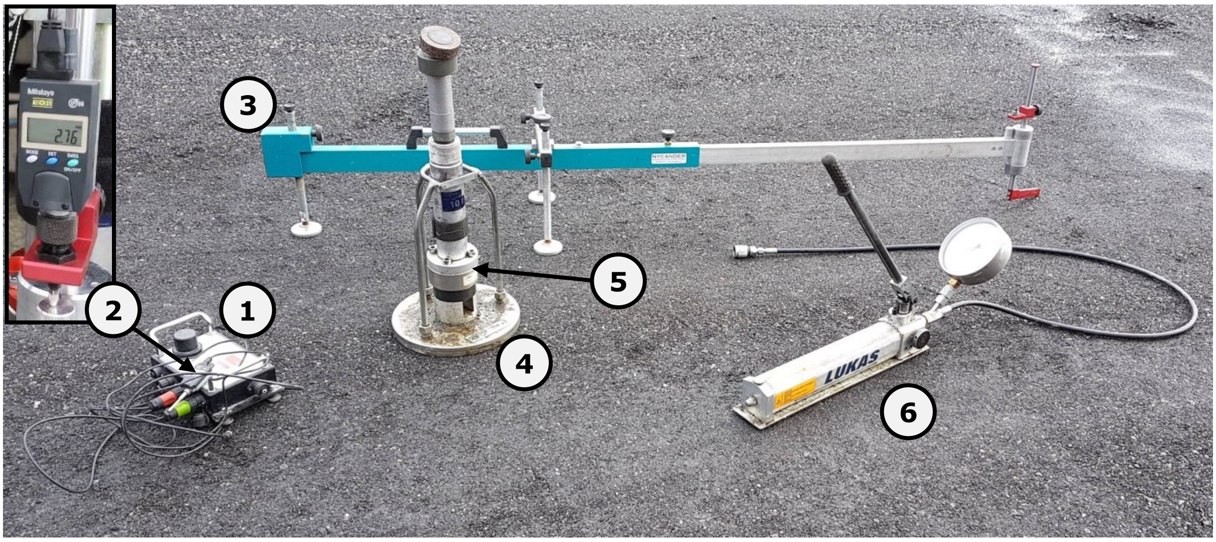


Figure 3.1: The necessary test equipment used for a PLT. The counterweight used to apply load on the plate is not shown. (1) Data logger to record the measurements from the two measuring devices (2) settlement measuring dial gauge, (3) Benkelman beam, (4) 300 mm diameter plate with compartments for mounting on counterweight, (5) load cell to measures the load exerted on the plate, (6) hydraulic jack.

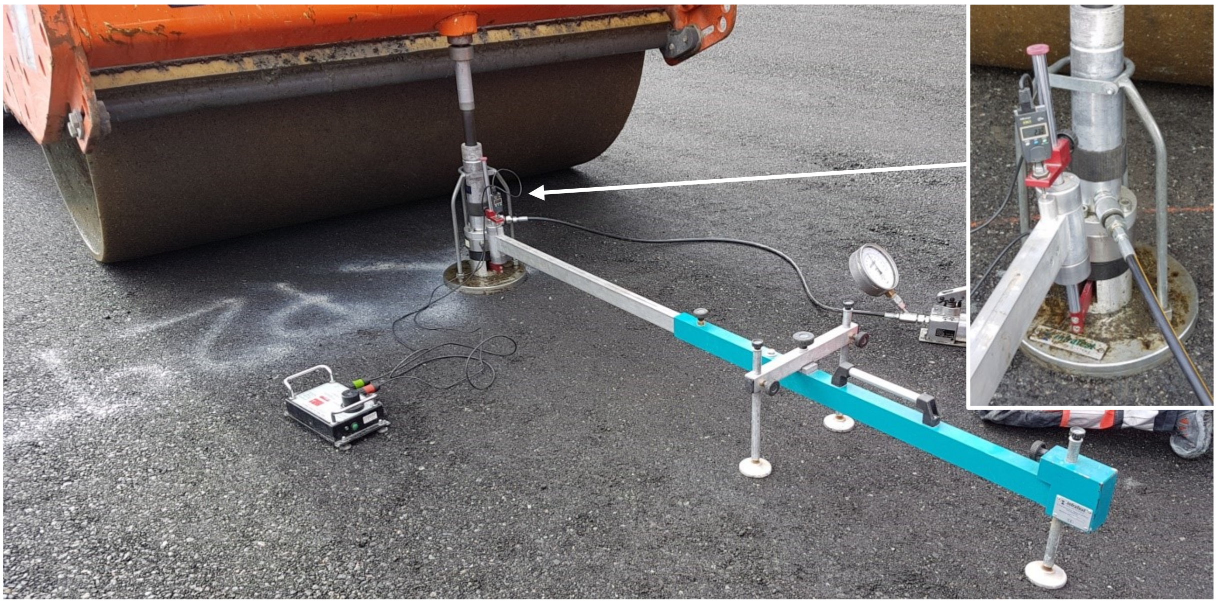


Figure 3.2: Instrument setup of a PLT.

The load during the test is applied in five different steps; 50, 180, 300, 420 and 600 kN/m^2. The load in each step is kept constant until the settlements in the material have ceased, alternatively when the gauge shows a movement of 0,02 mm/min or less. The total settlement for each load step is registered before moving on to the next one. After one load cycle has been applied, the load is decreased slowly down to zero. A second load cycle is then applied in the same place, following the same procedure as before. The registrations from the two loading cycles are plotted on a load-settlement diagram, as well as the unloading cycles (Statens vegvesen and Vegdirektoratet, 1984, p. 139). An example of such a diagram is shown in Figure 3.3.

The registrations from the PLT described above are then used to calculate the corresponding E_1 (first loading cycle) and E_2 (second loading cycle) values for the test, using Equation (7), using the definitions for Δp and Δs given in Equations (8) and (9):

$$\Delta p = p_2 - p_1 \quad (8)$$

$$\Delta s = s_2 - s_1 \quad (9)$$

Where,

Δp is the change in load on the plate [kN/m^2]

p_2 <u>for the first load cycle</u>: the load corresponding to 70% of the maximum applied load [kN/m^2]
<u>for the second load cycle</u>: the highest load step to which the load-settlement relationship can be approximately represented by a straight line from p_1 [kN/m^2]

p_1 is the load corresponding to 30% of the maximum applied load [kN/m^2]

Δs is the change in settlements in the soil [mm]

s_2 is the settlement corresponding to load p_2 [mm]

s_1 is the settlement corresponding to load p_1 [mm]

(Statens vegvesen and Vegdirektoratet, 1984, p. 139)

The ratio between the calculated E_1 and E_2 values is then determined and compared to the requirements described in *Handbook 018*.

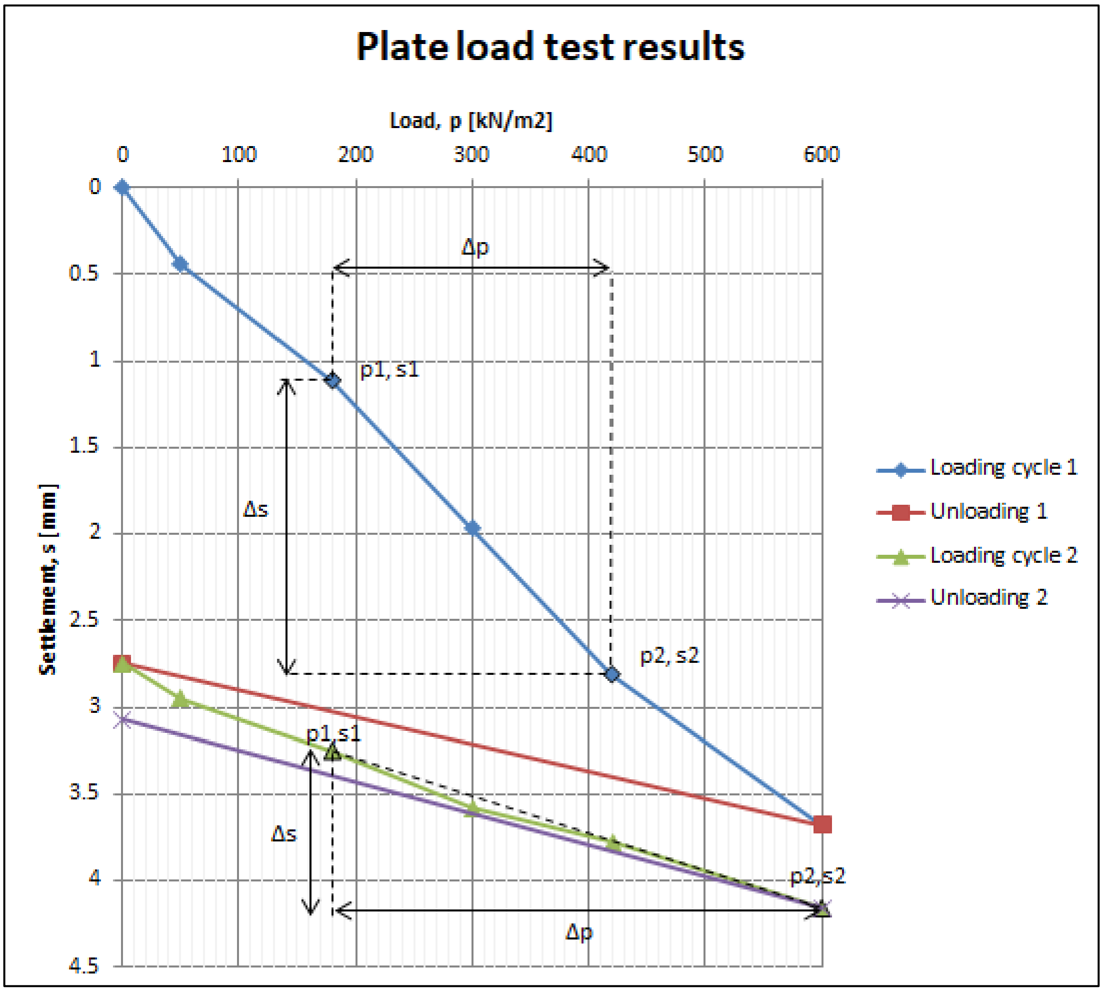


Figure 3.3: An example of the graphical presentation of the results of a PLT, as described in the Norwegian Handbook 015 from 1984 (Statens vegvesen and Vegdirektoratet, 1984)

3.1.3 Handbook 018 from 1992

In NPRA's *Handbook 018* from 1992, the PLT is only mentioned in a comment as a possibly relevant control method to evaluate the quality of the compaction of a subbase layer. No requirements are mentioned for the results of the PLT in this version of the handbook (Statens vegvesen and Vegdirektoratet, 1992, p. 189).

3.1.4 Handbook 015 from 1997

Handbook 015 from 1997 describes the PLT in process description number 15.328. Here, it is described as a method to test the quality of the compaction of a granular material, or as a way of estimating the bearing capacity and stability. The method described in this version of the handbook is similar to the method described in the version from 1984 (Statens vegvesen and Vegdirektoratet, 1997).

3.1.5 Handbook 018 from 1999 and 2005

In *Handbook 018 Road construction* from 1999, guideline values for the results of a PLT are introduced again, this time including values for E_2 and sorted by layer in the road structure (Statens vegvesen and Vegdirektoratet, 1999, p. 166). These values are presented in Table 3.2. Note that these values are not presented as absolute requirements in this version of the handbook. Furthermore, the PLT is not mentioned in the discussion of quality control of the compaction of the base course in this version of the handbook (Statens vegvesen and Vegdirektoratet, 1999).The same guideline values are also presented in the 2005 version of the handbook (Statens vegvesen and Vegdirektoratet, 2005, p. 203)

Table 3.2: The defined Norwegian guideline values for the results of the PLT as defined by the NPRA handbooks in 1999 and 2005 (Statens vegvesen and Vegdirektoratet, 1999, Statens vegvesen and Vegdirektoratet, 2005)

Layer	**E_2/E_1**	**E_2 [MPa]**
Subbase	≤2,5	150
Embankment, top 3 m	≤3,5	120
Embankment, below top 3 m	≤3,5	90

3.1.6 Handbook 018 from 2011

In the 2011 version of *Handbook 018*, the PLT is mentioned as one of the possible methods to calibrate roller programs[7] for construction sites with at least 5000 m^2 of road (Statens vegvesen and Vegdirektoratet, 2011, p. 249). The result values for the PLT are now presented as requirements and not guidelines, and they also apply for quality control of the compaction of the base course (Statens vegvesen and Vegdirektoratet, 2011, p. 250). Table 3.3 shows the defined requirements.

Table 3.3: The defined Norwegian requirements for the results of the PLT as defined by the NPRA handbooks in 2011 (Statens vegvesen and Vegdirektoratet, 2011)

Layer	**E_2/E_1**	**E_2 [MPa]**
Subbase and base course	≤2,5	>150
Embankment, top 3 m	≤3,5	>120
Embankment, below top 3 m	≤3,5	>90

The 2011 version of *Handbook 018* also introduces a requirement for documentation of the compaction of the unbound pavement layers, where the PLT is described as one of the possible methods (Statens vegvesen and Vegdirektoratet, 2011, p. 254).

3.1.7 Handbook N200 from 2014 and 2018

In 2014 the NPRA's handbook system was reorganized, resulting in new identification numbers for the handbooks. Former *Handbook 018* is therefore now called *Handbook N200* (Statens vegvesen and Vegdirektoratet, 2014a). In this version, the requirements for the results of the PLT were also reorganized, and now only apply for the base course, subbase and frost protection layers. Additionally, the new version of the handbook now defines requirements for where and when the PLTs should be conducted. It is now required to conduct the test at least 3 times for 3 different levels of compaction[8], where the tests are spread over a distance of at least 50 m (Statens vegvesen and Vegdirektoratet, 2014a, p. 255). The requirements for the results of the PLT in the 2014 version of *Handbook N200* are presented in Table 3.4. The updated version of the handbook from 2018 also defines the same values (Statens vegvesen and Vegdirektoratet, 2018a).

[7] Norwegian: Valseprogram.
[8] In this handbook, the term "different level of compaction" refers to different number of passages of compaction equipment, such as rollers. Measurements done after 3 different levels of compaction might therefore refer to measurements done after e.g. 4, 8, and 10 passings of a roller over the layer in question.

Table 3.4: The defined Norwegian requirements for the results of the PLT as defined by the NPRA handbooks in 2014 and 2018 (Statens vegvesen and Vegdirektoratet, 2014a, Statens vegvesen and Vegdirektoratet, 2018a)

Layer	**E_2/E_1**	**E_2 [MPa]**
Subbase and base course	≤2,5	>150
Frost protection layers of sand, gravel and rock	≤3,5	>120

The requirement for documentation of compaction has also been changed in the 2014 version, and the PLT is now the only mentioned method used for final documentation. The number of PLTs required to document the quality of compaction varies depending on the use of continuous response measurement during compaction. For projects where continuous response measurements are used, one PLT should be taken every 250 m in each lane, specifically in weak points according to the response measurements. Where continuous response measurements are not used, one PLT should be performed every 100 m in each lane (Statens vegvesen and Vegdirektoratet, 2014a, p. 256). This is also the case for the 2018 version of the handbook (Statens vegvesen and Vegdirektoratet, 2018a).

3.1.8 Handbook R211 from 2014

As for the other NPRA handbooks, former *Handbook 015* also got a new number in 2014 and is now called *Handbook R211*. As for the previous version, the handbook describes the test procedure in process description number 15.328. The method description in this version of the handbook is similar to the method descriptions in the previous versions (Statens vegvesen and Vegdirektoratet, 2014b).

3.1.9 Handbook R211 from 2018

In the 2018 version of *Handbook R211*, the method description has been reformulated and updated. The layer of plaster underneath the testing plate is not used anymore, and the testing plate is now placed directly upon the material being tested. Furthermore, an additional loading step has been added to each loading cycle, and the 6 steps are now 50, 180, 300, 420, 500 and 600 kN/m^2. Other parts of the method description are similar to previous versions. It is worth mentioning that in this version of the method description, a precautionary note is included, stating that the national standard *NS 3458* is always valid over *Handbook R211* at any given time (Statens vegvesen and Vegdirektoratet, 2018b, p. 202-204).

3.1.10 National standards NS 3458:2004 and NS 3420-J:2008

The national standard *NS 3458:2004 Compaction – requirements and execution* discusses the PLT as a possible control method for quality of compaction of unbound granular materials. The standard does not describe the test method in detail, nor define criteria for the results of a PLT. It specifies that the test result criteria must be determined before the test is conducted, and refers to NPRA *Handbook 018* for possible guideline values (Standard Norge, 2004).

The standard *NS 3420-J:2008 Description guide for buildings, construction sites and installations: Part J: road and rail work* notes that the compaction of granular materials can be quality controlled using the PLT. This is however limited to granular materials with aggregate size ≤ 150 mm. The test method itself and test result requirements are not discussed in the standard (Standard Norge, 2008).

3.2 Standards and guidelines from other countries

3.2.1 Sweden

In Sweden, the Swedish Transport Administration (STA)[9] defines the requirements for the bearing capacity of a road structure in the requirements document *TDOK 2013:0530 Unbound layers in road structures*. According to the document, the bearing capacity shall be tested for all road construction projects with AADT ≥ 1000 and a construction size of at least 5000 m^2. The bearing capacity can be measured using two methods (Trafikverket, 2017a, p. 37-38); a set of PLTs analysed using a specific statistical analysis defined by the STA (Vägverket, 1994a), or a type of continuous compaction control[10], using special measuring equipment on the rollers performing the compaction (Vägverket, 1994b). For the purposes of this thesis, only the requirements defined for the PLTs will be discussed further.

The requirements for the PLTs are defined for both the values of single measurements, as well as for the statistical distribution of the set of measurements. The set of measurements should either include n = 8 or n = 5 measurements, and at least n-1 measurements should fulfil the requirement values for single measurements (Trafikverket, 2017a, p. 37-38). The requirements for the bearing capacity of a base course in a flexible road structure, measured using a set of PLTs, as defined by the STA, are shown in Table 3.5. The corresponding requirements for the bearing capacity of the layer beneath the subbase are shown in Table 3.6. The same requirements for the bearing capacity for a stiff road structure are shown in Table 3.7 and Table 3.8. In all four tables, $\bar{x}_{E_2}$ represents the average of the calculated E_2 values, and S represents the standard deviation of the set of measurements (Vägverket, 1994a).

TDOK 2013:0530 also describes some preconditions for measuring the bearing capacity of unbound granular materials in a road structure. According to the document, the bearing capacity of the base course shall be measured using a PLT performed as described in document *TDOK 2014:0141 Determination of bearing capacity characteristics using static plate loading*. The PLT must only be performed if both the base course material and the sub-soil are unfrozen (Trafikverket, 2017a, p. 72-73).

Table 3.5: The defined Swedish requirements for the results of a PLT on a base course or the topmost unbound granular layer in a flexible road structure, as defined by the STA in TDOK 2013:0530 (Trafikverket, 2017a).

Requirements for the base course (or the topmost unbound layer) in a flexible road structure	
Requirements for the set of measurements	$\bar{x}_{E_2}$
If number of measurements, n = 8	≥ 140 + 0,96·S
If number of measurements, n = 5	≥ 140 + 0,83·S
Requirements for every measured point*	E_2/E_1
If E_2 ≤ 140 MPa	≤ 2,8
If E_2 > 140 MPa	≤ 1+0,013·E_2

*At least n-1 of the tested points must fulfil these requirements. A single measurement is considered unacceptable if E_2 < 125 MPa

[9] The requirements for road construction in Sweden were previously determined by the state agency Vägverket. In 2010, Vägverket was liquidated and replaced by the STA (Trafikverket, 2017b).
[10] In Norwegian: Kontinuerlig komprimeringskontroll

Table 3.6: The defined Swedish requirements for the results of a PLT on the layer beneath a subbase in a flexible road structure, as defined by the STA in TDOK 2013:0530 (Trafikverket, 2017a).

Requirements for the layer beneath the subbase in a flexible road structure	
Requirements for the set of measurements	$\bar{x}_{E_2}$
If number of measurements, n = 8	$\geq 40 + 0{,}96 \cdot S$
If number of measurements, n = 5	$\geq 40 + 0{,}83 \cdot S$
Requirements for every measured point*	E_2/E_1
If $E_2 \leq 40$ MPa	$\leq 3{,}5$
If $E_2 > 40$ MPa	$\leq 1+0{,}063 \cdot E_2$

*At least n-1 of the tested points must fulfil these requirements. A single measurement is considered unacceptable if $E_2 < 32$ MPa

Table 3.7: The defined Swedish requirements for the results of a PLT on a base course or the topmost unbound granular layer in a stiff road structure, as defined by the STA in TDOK 2013:0530 (Trafikverket, 2017a).

Requirements for the base course (or the topmost unbound layer) in a stiff road structure	
Requirements for the set of measurements	$\bar{x}_{E_2}$
If number of measurements, n = 8	$\geq 120 + 0{,}96 \cdot S$
If number of measurements, n = 5	$\geq 120 + 0{,}83 \cdot S$
Requirements for every measured point*	E_2/E_1
If $E_2 \leq 120$ MPa	$\leq 2{,}8$
If $E_2 > 120$ MPa	$\leq 1+0{,}015 \cdot E_2$

*At least n-1 of the tested points must fulfil these requirements. A single measurement is considered unacceptable if $E_2 < 105$ MPa

Table 3.8: The defined Swedish requirements for the results of a PLT on the layer beneath a subbase in a stiff road structure, as defined by the STA in TDOK 2013:0530 (Trafikverket, 2017a).

Requirements for the layer beneath the subbase in a stiff road structure	
Requirements for the set of measurements	$\bar{x}_{E_2}$
If number of measurements, n = 8	$\geq 55 + 0{,}96 \cdot S$
If number of measurements, n = 5	$\geq 55 + 0{,}83 \cdot S$
Requirements for every measured point*	E_2/E_1
If $E_2 \leq 55$ MPa	$\leq 3{,}5$
If $E_2 > 55$ MPa	$\leq 1+0{,}046 \cdot E_2$

*At least n-1 of the tested points must fulfil these requirements. A single measurement is considered unacceptable if $E_2 < 45$ MPa

The procedure for performing the PLT for Swedish roads is described in the requirements document *TDOK 2014:0141.* The method described here is based on the German standard *DIN 18134* (Trafikverket, 2014, p. 4). The most important details of the procedure are summed up below:

The PLT can be conducted using 3 different sizes of circular plates; 300 mm, 600 mm or 762 mm. However, to determine the bearing capacity of layers in a road structure, a plate with a diameter of 300 mm should be used (Trafikverket, 2014). Some of the values discussed later in this section have different requirements based on the diameter of the plate that is used to conduct the test. For the purposes of this report, only the requirements that apply for a diameter of 300 mm and 600 mm will be discussed. Where the requirements differ between the plate sizes, values for 300 mm plates will be given as usual in the text, while values for 600 mm plates will follow in parentheses.

As for the Norwegian test method, the PLT is performed using the test equipment shown in Figure 3.1 and the test setup shown in Figure 3.2. The plate must be placed horizontally, with an allowable error margin of 7°. A 1 mm thick layer of fine levelling sand can be used to level out any unevenness on the test surface. The majority of the material being tested should have a grain size smaller than or equal to 1/4 of the diameter of the test plate, but the exceptional occurrence of individual stones larger than that in the material is accepted. The counterweight for the loading equipment (normally a truck or an excavator) should be placed so that the contact point of the counterweight to the ground is situated at least 0,75 m (1,10 m) away from the testing plate. Before the test is conducted, a pre-loading step is performed for 30 seconds, using a load of 0,01 MN/m^2. Thereafter, the settlement measuring equipment is reset to zero. The first loading cycle is conducted in 7 loading steps until either of the two following criteria are met; the total settlement has reached 5 mm (7 mm), or the maximum load has reached 0,5 MN/m^2 (0,25 MN/m^2). If the former criterion is met first, the material is considered too weak for the test, and the test must be altered to fit the material's reduced bearing capacity. If the latter criterion is met first, the second loading cycle can be performed. The 7 load steps are; 0,08; 0,16; 0,24; 0,32; 0,40; 0,45 and 0,50 MPa (the individual load steps corresponding to the 600 mm plate size is not provided in this document). The load of the first load step should be kept constant for 2 min, while the loads of the following steps should be kept constant for at least 1 min, or until the settlements stop changing. Changes to the loads shall be made 2 minutes after the previous load step has been finalized, however, this time can be shortened to 1 minute when the test is conducted on materials in the superstructure of a road. Following the first loading cycle is an unloading cycle, which should be conducted in 3 steps; 50%, 25% and 0% of the final maximum load of the first load cycle. After full unloading, a second loading cycle is conducted. This loading cycle is conducted similarly to the first loading cycle, except this time the last load step is excluded. For a 300 mm plate, the second load cycle thus has a maximum load of 0,45 MPa, and a total of 6 loading steps (Trafikverket, 2014).

After the test has been conducted, the measured loads and settlements are used to calculate the values of E_1 and E_2. This is done by plotting the measured values of each of the loading cycle into a load-settlement graph, and approximating a second degree polynomial function to each set of measurements. This can be done using a pre-programmed computer[11], while still making sure that the approximation is done objectively. To exclude the effect of the pre-loading, the pre-loading step (i.e. the point where $s \approx 0$ mm) is not used when adjusting the polynomial function to the points in the first loading cycle. An example of the graphical presentation of the results of a PLT, as well as an approximation of the corresponding polynomial, is presented in Figure 3.4. The approximation will result in an equation similar to Equation (10) (Trafikverket, 2014).

[11] As mentioned in the description of the Norwegian test procedure, these calculations are usually performed instantaneously in the field using a pre-programmed computer device that is linked directly to the data logger. The E-values are thus an instantaneous output of the computer device.

$$s = a_0 + a_1\sigma_0 + a_2\sigma_0^2 \quad (10)$$

Where,

s	is the deformation under the centre of the plate [mm]
σ_0	is the average normal load[12] below the plate at each load step [MN/m^2]
a_0, a_1, a_2	are constants determined by the method of least squares

The values for E are then calculated for each load cycle using Equation (11) (Trafikverket, 2014).

$$E = 1{,}5 \cdot R \cdot \frac{1}{a_1 + a_2\sigma_{1max}} \quad (11)$$

Where,

E	is the modulus of elasticity of the soil for the load cycle in question [MPa]
R	is the plate radius [mm] (150 mm in this case)
a_1, a_2	are constants from the approximated polynomial function of the load cycle
$\sigma_{1\max}$	is the maximum normal load of the *first load cycle* [MN/m^2] (0,5 MN/m^2 in this case)

Note that the load value used to calculate the modulus of elasticity in Equation (11) is the maximum normal load of the first load cycle, $\sigma_{1\max}$, regardless of which load cycle the modulus of elasticity is being calculated for. In other words, the maximum normal load of the *first* load cycle should be used when calculating both E_1 and E_2.

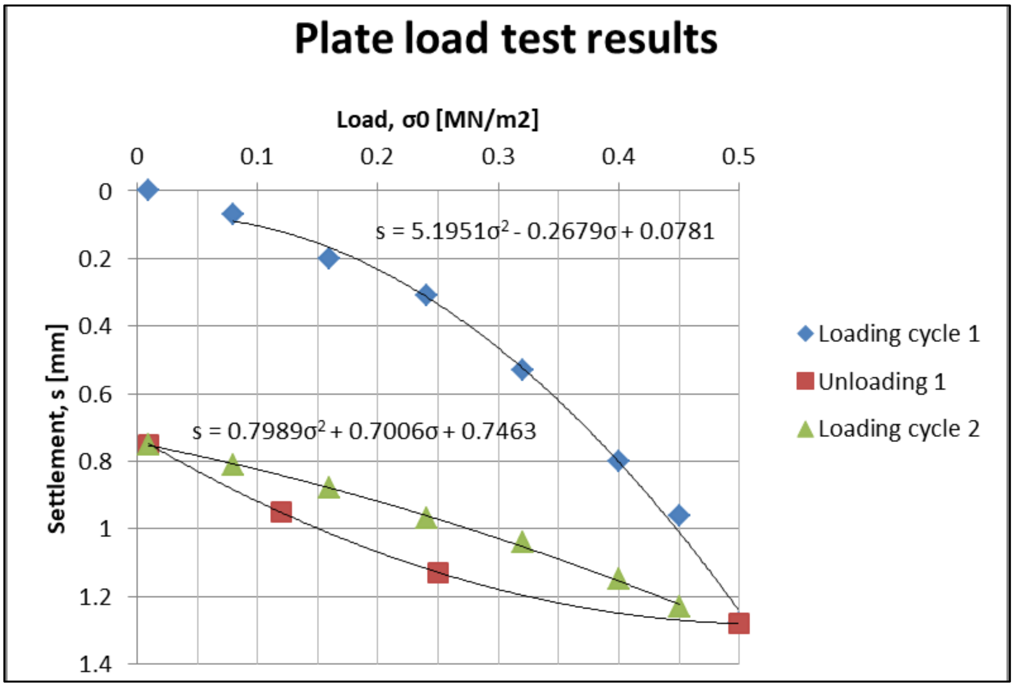


Figure 3.4: An example of the graphical presentation of the results of a PLT based on the Swedish calculation method, as described in TDOK 2014:0141 (Trafikverket, 2014).

[12] The exact meaning of the term "average normal load" is not specified in this document. The term likely refers to the average load in the material beneath the plate during each load step, since the load can vary over the loaded area as discussed in section 2.2 (see Figure 2.1). It may also refer to the average load applied to the area during each load step, since the load tends to change over the time of the load step. Since this document is based on the German standard *DIN 18134*, the former definition is considered to be more likely, see description of the German standard below.

3.2.2 Iceland

The Icelandic road administration, Vegagerðin, defines the requirements for bearing capacity in the document *Directions for bearing capacity of roads*, from 2013, which is based on the requirements in the Norwegian handbook *018*[13] (Sigursteinsson et al., 2013, p. 1). The document specifies that the bearing capacity of base courses of crushed rock shall be tested using a PLT, using a plate with a diameter of 300 mm and a maximum load of 0,5 MPa. The results of the test must fulfil the following requirements: E_2 > 160 MPa and E_2/E_1 < 2,2 (Sigursteinsson et al., 2013, p. 22). Further specifications about how the PLT should be conducted are not discussed in this document, but the authors refer to the document *Material tests and requirements – directions for design, production and construction* for further details regarding materials used in road design (Sigursteinsson et al., 2013, p. 1).

The document *Material tests and requirements – directions for design, production and construction* was last updated in 2018, and specifies somewhat different requirements for the results of the PLT than the document discussed above. The requirements in this document are said to be based on requirements in the Norwegian handbook *N200* from 2014 and the Swedish handbook *ATB Väg* from 2005. Here, the PLT is only mentioned as one of the possible methods of ensuring sufficient compaction of the base course in a road structure, although some limitations have been set to the use of the other methods. The available methods for estimating the compaction of the base course in a road structure, as well as their limitations and/or requirements, are listed in Table 3.9 (Vegagerðin, 2018a, p. 20-21).

Table 3.9: The available methods in Iceland for estimating the compaction of the base course in a road structure, as defined by Vegagerðin in Material tests and requirements – directions for design, production and construction (Vegagerðin, 2018a).

Method	**Limitations and requirements**
Number of passes by compaction equipment counted (manually)	Shall always be done
Response measurements using automated measuring equipment on roller	Must be calibrated using other methods, preferably PLT
Density measurements, either by a) Nuclear equipment b) Sand volumeter	a) Limited to a maximum aggregate size of the base course material of 25 - 30 mm b) Same as a). Also very time consuming
Plate load test	Used where $AADT_{\text{heavy vehicles}}$ > 400, or for calibration of response measurements
Height measurements	Applicable for all cases, but only used as a primary control method in exceptional circumstances

The requirements for the results of the PLT, as defined in *Material tests and requirements – directions for design, production and construction*, are presented in Table 3.10 (Vegagerðin, 2018a, p. 45).

[13] Which version of handbook *018* is used as a reference is not specified in the document.

Table 3.10: The defined Icelandic requirements for the results of a PLT on a base course, as defined by Vegagerðin in Material tests and requirements – directions for design, production and construction (Vegagerðin, 2018a).

$AADT_{heavy\ vehicles}$	**E_2 [MPa]***	**E_2/E_1**
≥ 400	≥ 120	≤ 2,5
≥ 100	≥ 120	≤ 3,0
< 100	≥ 120	≤ 3,5

*Single measurements are allowed to fall up to 10 MPa short of the requirements listed for E_2 in the table. The average of all of the conducted measurements shall fulfil the requirements in the table (Vegagerðin, 2018a, p. 45).

The procedure for the PLT is described in an appendix to the document *Material tests and requirements – directions for design, production and construction*. The most important details of the procedure are summed up below:

The PLT is performed using the test equipment shown in Figure 3.1 and the test setup shown in Figure 3.2. A plate with a diameter of 300 mm is most often used. A pre-load of 0,08 MPa is applied to the material, followed by a 5 step load cycle up to a maximum load of ca. 0,5 MPa. The first load cycle is followed by an unloading, which then is followed by a second load cycle similar to the first one. The measured loads and settlements are plotted in a load-settlement graph, and the slope of the lines of each of the load cycle is determined. The values for E_1 and E_2 are calculated using the same equation as in the Norwegian procedure description (Equation (7)) (Vegagerðin, 2018b, p. 64-66). No further description of the procedure is provided in this document.

3.2.3 Germany

As mentioned previously, the Swedish procedure for plate load testing is based on the German standard *DIN 18134 Soil - Testing procedures and testing equipment - Plate load test* (Trafikverket, 2014, p. 4). It is therefore appropriate to take a closer look at that standard. The standard does not define any requirements for the values of conducting the PLT, but defines the procedure for conducting the test. The most important details of the procedure are summed up below:

The PLT should be conducted using a round test plate. 3 different sizes are available according to the standard; 300 mm, 600 mm and 762 mm. However, a plate diameter of 300 mm shall be used to determine the bearing capacity of materials used for road construction (Deutsches Institut für Normung, 2012). Some of the values discussed later in this section have different requirements based on the diameter of the plate that is used to conduct the test. For the purposes of this report, only the requirements that apply for a diameter of 300 mm and 600 mm will be discussed. Where the requirements differ between the plate sizes, values for 300 mm plates will be given as usual in the text, while values for 600 mm plates will follow in parentheses.

Similarly to the test procedures from the other countries, the PLT is performed using the test equipment shown in Figure 3.1 and the test setup shown in Figure 3.2. The plate should be placed horizontally on top of the material being tested. To level out any unevenness of the testing surface, a few millimetre thick layer of either levelling sand or gypsum plaster can be placed underneath the plate prior to the test. The test plate should not be placed directly on top of particles that are larger than 1/4 of the test plate diameter. The counterweight for the loading equipment (normally a truck or an excavator) should be placed so that the contact point of the counterweight to the ground is situated at least 0,75 m (1,10 m) away from the testing plate. Before the test is conducted, a pre-load of 0,01 MN/m^2 is applied to the material being tested. The measuring equipment is then reset to zero 30 seconds (or more) after the pre-load has been applied. Each load cycle should consist of at least 6 equally incremented load steps up until the maximum load of 0,5 MN/m^2 (0,25 MN/m^2) (Deutsches Institut für Normung, 2012). The standard does not specify exactly which load steps should be performed for each of the load cycles, but the following suggestion is made in an appendix to the standard: 0,010 (the pre-load); 0,080; 0,160; 0,240; 0,320; 0,400; 0,450 and 0,500 MN/m^2 (0,010 (the pre-load); 0,020; 0,040; 0,080; 0,120; 0,160; 0,200 and 0,250 MN/m^2). If the settlements reach 5 mm (8 mm) before a load of 0,5 MN/m^2 (0,25 MN/m^2) is reached, the load corresponding to the 5 mm (8 mm) settlements is considered the maximum load. The test is then continued with the new maximum load. Load transitions between stages should be completed within 1 minute. Each load step must be held constant for at least 2 minutes before any changes are made to the load, however, this time can be shortened to 1 minute for tests performed on materials in a road's superstructure. The load and the corresponding settlement are recorded at the end of each load step. After the first loading cycle, an unloading cycle is performed. The load should be released in 3 stages; 50%, 25% and ca. 2% of the maximum load. Finally, a second load cycle is applied similarly to the first load cycle, except only up to the second to last load step. Neither the measuring equipment nor the counterweight used should be subjected to vibration or other disturbances during the test (Deutsches Institut für Normung, 2012).

After the test has been conducted, the measured loads and settlements are plotted into a load-settlement graph. The data from each loading cycle is approximated using a second degree polynomial curve with the help of computer software[14], resulting in an equation similar to Equation (10)[15]. The pre-loading step is excluded from this approximation. Finally, the values for E_1 and E_2 are calculated using Equation (11)[16] (Deutsches Institut für Normung, 2012).

The standard (including appendices) also includes requirements and instructions for the calibration of the measuring equipment. The equipment should be calibrated at least once a year, and always before the first delivery or after the equipment has been repaired to any extent. The maximum allowable error during calibration for the force[17] measurements (i.e. the error limit that if exceeded requires a reset of the measurement device) is 1% of the maximum applied force for loading cycles, and 2% of the maximum applied force for unloading cycles. The maximum allowable error of the zero value, 1 minute after the load is removed, is 0,2% of the maximum applied force. For the settlement measurements, the measuring equipment must be reset if one of the settlement measurements during the calibration differs from the actual measurement by more than 0,04 mm (Deutsches Institut für Normung, 2012).

The link between Boussinesq's formula and Equation (11) is explained in detail in appendix B of the standard *DIN 18134*. Here, Equation (11) is derived from Equation (7)

[14] As mentioned in the description of the Norwegian test procedure, these calculations are usually performed instantaneously in the field using a pre-programmed computer device that is linked directly to the data logger. The E-values are thus an instantaneous output of the computer device.
[15] See description of the Swedish plate load test procedure.
[16] See description of the Swedish plate load test procedure.
[17] The corresponding load is calculated based on the force measurements

by approximating the second degree polynomial with the secant through the reference points ($\sigma = 0{,}3 \cdot \sigma_{1max}$; $s = s(0{,}3 \cdot \sigma_{1max})$) and ($\sigma = 0{,}7 \cdot \sigma_{1max}$; $s = s(0{,}7 \cdot \sigma_{1max})$). The derivation is as follows (Deutsches Institut für Normung, 2012):

$$
\begin{aligned}
E &= \frac{3}{2} \cdot R \cdot \frac{\Delta\sigma}{\Delta s} \\
&= \frac{3}{2} \cdot R \cdot \frac{0{,}7 \cdot \sigma_{1max} - 0{,}3 \cdot \sigma_{1max}}{(a_0 + a_1 \cdot 0{,}7 \cdot \sigma_{1max} + a_2 \cdot (0{,}7 \cdot \sigma_{1max})^2) - (a_0 + a_1 \cdot 0{,}3 \cdot \sigma_{1max} + a_2 \cdot (0{,}3 \cdot \sigma_{1max})^2)} \\
&= \frac{3}{2} \cdot R \cdot \frac{0{,}4 \cdot \sigma_{1max}}{a_1 \cdot 0{,}4 \cdot \sigma_{1max} + a_2 \cdot (0{,}7^2 - 0{,}3^2) \cdot \sigma_{1max}^2} \\
&= \frac{3}{2} \cdot R \cdot \frac{1}{a_1 + a_2 \cdot \sigma_{1max}}
\end{aligned}
$$

(Deutsches Institut für Normung, 2012)

The German requirements for the results of the PLT on the subsoil or substructure are defined in the document *Additional technical conditions of contract and directives for earthworks in road construction : ZTV E-StB 09*, by the German Road and Transportation Research Association (FGSV). The document differentiates between the requirements regarding modulus of deformation, and the methods used to test if the obtained results are adequate (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012).

For the subsoil and/or the substructure beneath the superstructure, the requirements for the modulus of deformation vary based on the defined construction class[18] of the road structure, as well as the frost susceptibility of the subsoil and/or substructure, as shown in Table 3.11. The modulus of deformation is generally determined by conducting a static PLT according to *DIN 18134*, but for subsoils and/or substructures of non-frost-susceptible soils, the standard also allows the modulus of deformation to be determined by a dynamic PLT, with a different set of requirements. The standard permits up to 10% of the total set of measurements to fall short of the requirements defined in Table 3.11, and also allows for a somewhat decreased E_2 values on non-frost-susceptible soils if measures are taken to increase the superstructures stability in the subbase and/or base course. If the requirements in Table 3.11 cannot be met by compaction of the subsoil or substructure, the subsoil or substructure must be stabilized by other means to obtain a high enough E_2 value, or the thickness of the unbound layers in the superstructure must be increased to increase the overall stability of the road structure (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 44-45).

The attained quality of compaction of the superstructure layers is determined using three different methods, for three different circumstances; (1) tests conducted in accordance to a test plan, (2) dynamic tests covering the full area of the material layer, and (3) tests conducted in order to monitor working procedures. Each of the methods evaluates the quality of compaction of a specific material layer which has been compacted and processed under uniform conditions, using a set of measurements conducted on the material layer. Varying materials and/or conditions call for multiple sets of measurements in order to evaluate the quality of compaction. Each set of measurements is treated as one sample, and is approved or rejected as a whole set rather than individual

[18] The term "construction class" is not defined in the document ZTV E-StB 09, but it refers to another document by the FGSV for the definition. Unfortunately, the document that contains the definition of "construction class" has not been translated to English and is therefore only available in German. Due to the author's limited knowledge of the German language, this term will not be discussed further in the thesis.

measurements (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 79-80). When determining the bearing capacity and the deformation behaviour of the subsoil/substructure using the static or the dynamic PLT, either method 1 or 3 may be used as a basis for accepting or rejecting the set of measurements. Method 2 may be used for this purpose in exceptional cases (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 89).

Table 3.11: The defined German requirements for the results of static PLTs on the subsoil or substructure, as defined by FGSV in ZTV E-StB 09 (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)

Type of subsoil	**Requirement for E_2 on the road bed [MN/m^2]***
Non-frost-susceptible soil or substructure, construction classes SV and I to IV**	≥ 120***
Non-frost-susceptible soil or substructure, construction classes V and VI**	≥ 100***
Frost susceptible soil or substructure	≥ 45
Frost susceptible soil or substructure after qualified soil improvement	≥ 70

*A maximum of 10% of the total performed number of measurements are permitted to have results that are lower than the specified values.
**The modulus of deformation can alternatively be determined by a dynamic plate load test, with another set of requirements.
***In cases where these requirements cannot be met on the subsoil directly, measures can be taken to increase the stability of the subbase and/or base course instead. In these cases, the obtained E_2 values on the subsoil must be at least 100 MN/m^2 for construction classes SV and I to IV, and at least 80 MN/m^2 for construction classes V and VI.

For the first method, tests conducted in accordance to a test plan, the set of measurements consists of a random sample of measurements where the location of each test point within the test area is determined at random. The sample size, n, is determined based on the size of the test area and specifications of the test plan. An example of the sample sizes for a simple test plan, based on the size of the test area is provided in Table 3.12. The arithmetic mean, $\bar{x}$, and the standard deviation, s, are calculated for the set of measurements and used to define the statistical test quantity z, as follows (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 80-82):

$$z = \bar{x} - k \cdot S \tag{12}$$

Where,
z is the statistical test quantity used to evaluate if the test set if approved or rejected []
$\bar{x}$ is the arithmetic mean of the set of measurements [MN/m^2]
k is the acceptance factor, set to 0,88 in this case
S is the standard deviation of the set of measurements [MN/m^2]

The set of measurements are accepted if the statistical test quantity, z, is greater or equal to the specified requirements, and rejected if not (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 80-82).

Table 3.12: An example of the German requirements for sample size for a simple test plan, based on the size of the test area, as defined by FGSV in ZTV E-StB 09 (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)

Size of test area, A [m²]	**Sample size, n []**
A ≤ 1000	4
1000 < A ≤ 2000	5
2000 < A ≤ 3000	6
3000 < A ≤ 4000	7
4000 < A ≤ 5000	8
5000 < A ≤ 6000	9

The second test method, dynamic tests covering the full area of the material layer, consists of using response measurements, calibrated to the values from either a static or dynamic PLT, to estimate the quality of compaction of a material layer. This method is recommended where the daily construction output is high and the soil is mostly uniform, where the subject of the assessment is the uniformity of the compaction, or where the quality of compaction is to be evaluated continuously during construction. Tests using response measurements are highly recommended for the contractors' self-monitoring of the quality of compaction. This method also relies on a statistical test quantity based on the arithmetic mean and the standard deviation of a set of measurements to determine if the set of measurements are accepted or rejected (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 82-84).

Method 3, tests conducted in order to monitor working procedures, is generally used to determine a compaction plan. The test results are accepted or rejected based on a statistical test quantity calculated from the arithmetic mean and the standard deviation of a set of measurements. The sample size varies based on the type and size of the test section and the acceptance criteria varies accordingly. Table 3.13 shows the acceptance criteria based on the sample size (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 84-85).

Table 3.13: German acceptance criteria for PLTs conducted to monitor working procedures, as defined by FGSV in ZTV E-StB 09 (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)

Sample size, n []	**Acceptance criteria***
2	Accept if $\bar{x} - 1{,}28 \cdot S \geq T_M$
3	Accept if $\bar{x} - 1{,}15 \cdot S \geq T_M$
≥ 4	Accept if $\bar{x} - 0{,}88 \cdot S \geq T_M$

* $\bar{x}$ represents the arithmetic mean of the set of measurements, s represents the standard deviation of the set of measurements, and T_M represents the defined requirements for the test results

The degree of compaction of the subsoil should generally be determined from the dry density of a sample and given as a percentage of the maximum dry density determined by the Proctor compaction test. When the subsoil consists of either coarsely grained or mixed grained soils with fines content less than 15%, the degree of compaction can also be determined by either a static or a dynamic PLT (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012, p. 87-89). Table 3.14 contains the German guide values for the estimated requirement for E_2 and E_2/E_1 measured by the indirect PLT, corresponding to the different requirements for the degree of compaction determined by a direct measuring method.

Table 3.14: German guide values for the estimated requirement for E_2 and E_2/E_1 measured by the indirect PLT, corresponding to the different requirements for the degree of compaction determined by a direct measuring method, as defined by FGSV in ZTV E-StB 09 (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)

Soil group[19]	**Degree of compaction [%]**	**Corresponding requirements for results of PLTs**	
		E_2 [MN/m^2]	**E_2/E_1 []***
GW, GI	≥ 100	≥ 100	≤ 2,3
	≥ 98	≥ 80	≤ 2,5
GE, SE, SW, SI	≥ 100	≥ 80	≤ 2,3
	≥ 98	≥ 70	≤ 2,5

*The defined requirement for the ratio E_2/E_1 may be exceeded if the measured value for E_1 is at least 60% of the defined requirement for E_2.

The German requirements for the results of a PLT on the top of unbound granular layers of the superstructure are defined in the document *Guidelines for the standardisation of pavement structures of traffic areas : RStO 12*[20], by FGSV. The requirements for E_2 vary based on the type of pavement structure (asphalt, concrete, block pavement or fully bound pavement), as well as the defined load class. The required values also vary between each layer in the superstructure (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2015, p. 19). Table 3.15 shows the German minimum required values of E_2 for asphalt pavements, based on the layer in the superstructure and the load class. Other values may apply for other types of pavements. No requirements for the ratio E_2/E_1 are defined in this document.

Table 3.15: German minimum required values of E_2 for asphalt pavements, based on the layer in the superstructure and the load class, as defined by FGSV in RStO 12 (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2015)

Minimum required values for E_2 [MPa]							
Layer in superstructure	**Load class**[21]						
	BK100	**BK32**	**BK10**	**BK3,2**	**BK1,8**	**BK1,0**	**BK0,3**
Top of granular base course layer (lower base course)*	150	150	150	150	150	150	120
Top of frost protection layer	120	120	120	120	120	120	100
Top of subsoil	45	45	45	45	45	45	45

*The thickness of the asphalt upper base course layer can in some cases be reduced by 2 cm if the thickness of the granular lower base course layer is increased by 5 cm. In that case, the required minimum value for E_2 is increased to 180 MPa for load classes BK1,8 to BK100, and to 150 MPa for load classes BK1,0 and BK0,3.

[19] The German definition of each soil group will not be discussed further.
[20] Other documents may also define the requirements for the results of the PLT, but their English translation was unfortunately not available. Due to the author's limited knowledge of the German language, these documents were not considered further.
[21] The German load classes correspond to the estimated number of equivalent single axle loads (ESALs) experienced by the road, where BK0,3 corresponds to ESALs ≤ 0,3; BK1,0 corresponds to 0,3 < ESALs ≤ 1,0 etc. The load class BK100 corresponds to ESALs > 32.

4 Methods

This chapter provides an overview of the research methods used in order to attempt to answer the research questions posed above. The research methods used in this study are a document analysis of national standards and regulations in different countries, a case study studying the application and results of PLTs on different construction sites, and a field test using different size plates to conduct a series of PLTs on three different types of material in a superstructure. Each of the research methods are described in the subchapters below.

4.1 Document analysis and literature review

As discussed in previous chapters, the results of PLTs are very dependent on the defined test procedure, i.e. how the test was conducted. In order to compare different test result requirements, it is therefore essential to know the details of the test procedure. Reviewing different national guidelines and procedures and how they have changed throughout the years will provide a greater understanding of how the PLTs are meant to be conducted, as well as what potential weaknesses or problem areas should be focused on. The document analysis focuses on the national standards for PLTs used in Norway and Sweden, as well as touching lightly on the national standards used in Iceland and Germany. Due to the author's limited knowledge of the German language, only documents that have been translated into English were considered when considering the German national standards, rules and regulations.

The current as well as previous national rules and regulations regarding road construction were retrieved from each of the country's national road administration's websites (*Statens vegvesen* in Norway, *Trafikverket* in Sweden, *Vegagerðin* in Iceland and *FGSV* in Germany) in the period from 23. September 2018 to 10. June 2019[22], with the help of the search terms listed in Table 4.1. The Norwegian web-database for national standards, *Standard.no* was also used to retrieve current Norwegian national standards regarding plate load testing. Documents that the already identified documents referenced to were also located and used in the analysis when appropriate.

Table 4.1 An overview of the Norwegian and the corresponding Swedish and Icelandic terms used when finding documents for the document analysis.

Norwegian term	**Swedish term**	**Icelandic term**	**English translation**
Platebelastningsforsøk	Plattbelastningsförsök	Plötupróf	Plate load test
Platebelastning	Plattbelastning	Plötupróf	Plate loading

The national standards, rules and regulations were studied and compared, with special focus put on the test procedures, the calculation methods and the requirements for the results of a PLT. A short summary of the requirements and procedures described in the identified documents can be found in chapter 3.

[22] The retrieval of the relevant documents for the document analysis was partly done in the author's pre-study to the thesis, conducted in the fall of 2018.

In addition to the document analysis described above, a State of The Art literature review (SoTA) was conducted, to document the existing research in the field and to identify the knowledge gap related to the research questions. In order to find literature relevant to the topic of plate load testing, a literature search was conducted in the period from 23. September 2018 to 11. June 2019[23], using the literature search engines/databases Oria, Web of Science, Scopus, Standard.no, Google Scholar and Google. The list of references in the already retrieved literature was also used as a source to locate additional possibly relevant literature. An overview of the Norwegian and the corresponding English search terms used to locate documents for the SoTA literature review are provided in Table 4.2. The search terms used in each of the search engines and databases are summed up in Table 4.3.

Table 4.2: An overview of the Norwegian and the corresponding English search terms used to locate relevant documents in the SoTA literature review

Norwegian term	**Corresponding English term**
Platebelastningsforsøk	Plate load test
	Plate load testing
	Plate-load testing
	Plate-load-testing
	Static plate load test
	Plate-loading test
Platebelastning	Static plate loading
	Plate loading

Table 4.3: An overview of the search terms used in the different searching databases to locate relevant documents in te SoTA literature review

Database	**Searching term**
Oria	Plate load testing
	Static plate load test
	"Plate loading test" (only in title)
	(Title and author of literature from list of references)
Web of Science	"Plate load test"
	"Plate loading test"
	"Plate load testing"
Scopus	"Plate load test" AND "bearing capacity"
	"Plate load test" AND "granular material*"
	"Plate load test" AND pavement
	"Static plate loading test"
	"Static plate load test"
Standard.no	Platebelastning
Google Scholar	(Title and author of literature from list of references)
Google	(Title and author of literature from list of references)

To differentiate between which literature is relevant to the topic of the research questions and which are not, a few relevance criteria were defined. Only those documents that met

[23] The retrieval of the relevant documents for the SoTA literature review was partly done in the author's pre-study to the thesis, conducted in the fall of 2018.

the following criteria considered *relevant* to the SoTA literature review and thus analysed further:

- Plate load testing or plate load test is mentioned in the title, abstract and/or in the introduction. The method should also be mentioned in the keywords, if they are available.
- The test is conducted on unbound granular materials, or other materials commonly used in road structures. Literature that discusses the test being applied to other materials, e.g. solid rock, is not of interest.
- The test used in the literature is a static plate load test. Literature discussing dynamic or cyclic plate load tests is not of interest unless supplied with some kind of comparison to a static plate load test.
- The plate load test itself or its results are assessed or compared in any way, e.g. based on different measuring equipment, ground conditions or compaction of the soil.

In addition to the relevance criteria defined above, some additional criteria were defined in order to identify literature that was not relevant. Documents that met the following criteria were considered *irrelevant* or *not useful* to the SoTA literature review and were thus not analysed further:

- The plate load test is only used as a method to determine the stiffness of compaction of a soil without comparison to other methods or conditions, and the test method is not assessed further.
- Other types of test or equipment are used to predict the results of a plate load test, eliminating the need for plate load tests all together. This type of literature normally aims to calibrate some alternative measuring method to the results of a plate load test.
- The goal of the literature is to modify the plate load test in some way, and the document does not assess or consider the conventional use of the test.
- Any literature for which the full text document was not available or accessible through NTNU's licenses at the time of the literature search.
- Any literature for which the full text document was not available in English or a Nordic language[24] at the time of the literature search.

A summary of the identified literature in the SoTA literature review is provided in chapter 2.3.

4.2 Case study

A case study comparing the PLT results of 4 different construction sites was conducted in order to attempt to identify some of the factors that influence the results of PLTs conducted in the field. The system at hand is very complex and is easily disturbed, since the PLT was developed based on general assumptions about the material being tested, as discussed in chapter 2. A case study was deemed a more suitable method than using computer models to investigate the factors influencing the results, since the true system and its boundaries are not well known, and the results of a model can only be as accurate as the input values. Additionally, computer models that simulate the behaviour

[24] Here, the term "Nordic languages" includes Norwegian, Swedish, Icelandic and Danish. The term excludes Finnish and Faroese due to the author's limited knowledge of those two Nordic languages.

of granular materials tend to be complicated and time consuming to work with, and a detailed modelling of the situation is therefore out of the scope of this thesis.

Another perk of case studies is that they permit the researcher to choose cases relevant to the research, and one can thus choose to compare cases where inadequate results of a PLT were obtained to cases where the results met the requirements. Case studies focus on the details of each case, the qualitative, which is considered an important part of identifying unknown factors of a phenomena (Flyvbjerg, 2006). Case studies are also practical when the phenomena being studied are broad and complex, and where the context of the phenomena is vital to the understanding of it (Shanks and Bekmamedova, 2018, p. 195). In this research, knowledge of what is causing the problems is limited, so an in depth, qualitative case study of a handful of cases was selected as a research method.

4.2.1 Case study design

The research questions focus on identifying which factors affect the results of PLTs and to what extent. A multiple case, inductive case study, comparing different construction sites with different PLT results was therefore conducted, as this allows for comparison of the phenomena of interest based on different conditions (Shanks and Bekmamedova, 2018, p. 202). Inductive case studies focus on trying to develop a theory based on the data gathered (Shanks and Bekmamedova, 2018, p. 196). Case studies considering multiple cases, as opposed to only one, can be used to showcase contrasting results given different circumstances (Shanks and Bekmamedova, 2018, p. 202). Ideally, the cases chosen for the study should be so-called maximum variation cases. I.e. the cases should vary in one or more identifiable factor that could contribute to altering the outcome. This is a good method to collect information about what factors of a process or a project are related to a specific result or outcome (Flyvbjerg, 2006, p. 230), e.g. which factors of the PLT affect the inadequate results. This was taken into account when the cases for the case study were selected, although the limited number of recruitments was a more demanding factor (see discussion below).

To recruit participants for the study, a recruitment e-mail was sent out to contractors and owner builders[25] of some of the larger ongoing or recently finished road projects in Norway. The NPRA's online database of ongoing road projects was used as a reference to find projects of interest (Statens vegvesen, n.d.-b). The original recruitment e-mail was sent out on February 5th 2019, and subsequent referral e-mails were sent during the rest of February and March. The recruitment e-mail contained a short description of the background and motivation for the thesis, as well as the intentions and plans for execution of the project work. The extent of information needed from the participants, as well as the extent of anonymity was also shortly described in the e-mail. The contents of the recruitment e-mail are provided in Norwegian in Appendix 2.

In an attempt to recruit as many participants as possible, the benefits of participation for the contractors and owner builders were indicated in the recruitment e-mail, as well as in the general correspondence with possible recruitments after the recruitment e-mail. Getting organizations to participate in case studies and provide information can sometimes be challenging. For them to want to participate, the research and the research questions must be interesting and meaningful (Shanks and Bekmamedova, 2018, p. 203-204). For this specific research, the contractors are experiencing problems

[25] In Norwegian: Byggherre

with fulfilling requirements defined by the NPRA. The study aims to shine light on why the inadequate results occur, making that knowledge available to the contractors, which in turn will hopefully make it easier for them to fulfil the requirements in their future projects. Additionally, the thesis studies the Norwegian national requirements and compares them to other national requirement in other countries, which may help to identify if any of the Norwegian requirements or test procedures are unrealistic, unhelpful or unclear. This potential knowledge can serve as a basis to make necessary changes (if any) to the Norwegian rules and regulations regarding PLTs, so that the results of the PLTs are easier to obtain, serving as a benefit for both the contractors and the owner builders.

The confidentiality of the information collected during the study was described in the recruitment e-mail, and was limited to the anonymity of the participants and the projects involved. Limitations regarding the publications of the findings were not mentioned in the e-mail, but the purpose of the data collection was stated to be for use in this thesis. This was done in order to ensure that the researcher and the participants in the study had the same understanding on the degree of confidentiality of the data collected, before the data collection was started, since this is important when collecting data from external firms and organizations (Shanks and Bekmamedova, 2018, p. 203-204). Thus, the participants that answered the recruitment e-mail should be well informed of the intents of using the collected data for the purposes of the thesis. Any limitations or restrictions to the use of any of the collected data were agreed upon with the owner of the information at the time of the delivery of the data.

Collecting the data for the case study was done using three different data collection methods; data file collection, interviews, and observations in the field. Each of the three data collection methods are described in detail in the following sub-sections. These three methods were chosen to ensure that the case study included both qualitative and quantitative data. Additionally, using several different methods and/or sources to collect the same information, i.e. triangulation, strengthens the reliability and the credibility of the results of the study (Shanks and Bekmamedova, 2018, p. 203).

4.2.1.1 Data file collection

This section refers to the collection of logged data and/or information, ranging from digital data files to manual, handwritten documents. The data was collected from the owner of the information, usually the contractor or the owner builder of the project, but also third party companies that performed PLTs on the site. The documentation was generally requested during an in-person meeting, and handed over either in the form of a hard copy handed over in person, or digital files sent to the researcher by e-mail. The types of documents requested include:

- Results of PLTs conducted on the construction site, including the registered load and settlement measurements corresponding to each test.
- Registered information about the conditions of the test site during each of the PLT, e.g. weather and temperature information, the type and state of the subgrade, time of day, etc.
- Information about the compaction of the test site, including compaction equipment used, as well as the compaction plan, estimated water content of the material during compaction, etc.

The main emphasis was put on collecting load and settlement measurements from PLTs conducted on the construction sites (the first of the points listed above), since that information was generally easily obtainable. Results from PLTs conducted while the author was present were preferred[26], but older measurements where the author had not been present were also accepted. Measurements using both 300 mm and 600 mm diameter plates, as well as both Norwegian and Swedish load cycles were accepted. The other requested information was often either not registered by the owner of the data (e.g. the weather and temperature information is often not registered when PLTs are conducted on construction sites), not readily available by the owner to hand over to the author, or the owner did not wish to hand over the data. The information retrieved from the second two points listed above was therefore considered supplementary to the results of the PLTs, and were used to compare the results of different PLT measurements in more detail. The load and settlement measurements of each of the PLTs were used to calculate the E_1 and E_2 values, using three different calculation methods.

The first calculation method, referred to as "Norwegian method 1", is based on the calculation method described in the Norwegian handbook *R211*[27]. The E-values are calculated using Equation (7), using the measurements for the last load step in the second load cycle as a reference point for calculating E_2.

The second calculation method, referred to as "Norwegian method 2", is also based on the calculation method in handbook *R211*, using Equation (7). The only difference is that the measurements for the second to last load step in the second load cycle are used as a reference point for calculating E_2. For cases where the measurements for the second load cycle are practically linear, the first and second calculation methods should produce similar results.

The third calculation method, referred to as "Swedish method", is based on the calculation method described in the Swedish handbook *TDOK 2014:0141*[28], which is based on the method described in the German standard *DIN 18134*[29]. The E-values are calculated using Equation (11), which is based on approximating the measured data with a second degree polynomial similar to Equation (10). The results of the calculations will only be compared to Norwegian and Swedish requirements, and this calculation method is therefore referred to as the "Swedish method" for simplicity, even though the method is originally described in a German standard and can therefore be considered to be originally German.

The calculated results from the three calculation methods were compared to each other, as well as compared to the requirements for E_2 and E_2/E_1 defined in the Norwegian handbook *N200*[30] and the Swedish handbook *TDOK 2013:0530*[31]. The calculated values for E_1 and E_2 were assumed to be approximately normally distributed, and therefore compared using a Student's t-test, to test the statistical significance of the difference between the results. This assumption leads to the consequent assumption that the ratio E_2/E_1 is *not* normally distributed, and the statistical significance of the ratio itself was therefore not tested directly. Instead, the statistical significance of the ratio was tested indirectly by testing the statistical significance of the calculated E-values, using the logic

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[26] See chapter **Error! Reference source not found.** for more details on the author's observations during PLTs
[27] See chapter 3.1 for a summary of the handbook *R211*
[28] See chapter 3.2.1 for a summary of the handbook *TDOK 2014:*0141
[29] See chapter 3.2.3 for a summary of the standard *DIN 18134*
[30] See chapter 3.1 for a summary of the handbook *N200*
[31] See chapter 3.2.1 for a summary of the handbook *TDOK 2013:0530*

that if the difference between one or both of the E-values is statistically significant, then the difference between the ratios might also be statistically significant[32].

In order to account for the incomparability of PLTs performed using different test procedures (Adam et al., 2009), only tests performed using the same test procedures were compared to one another. For PLTs that were conducted using the Norwegian load cycles described in handbook *R211*, the calculated results were compared to the Norwegian requirements defined in handbook *N200*. For PLTs that were conducted using the Swedish load cycles described in handbook *TDOK 2014:0141*, the calculated results were compared to the Swedish requirements defined in handbook *TDOK 2013:0530*. PLTs conducted using a 600 mm plate diameter were conducted using the German test procedure described in *DIN 18134*, since no test procedure is available for this plate size in the Norwegian handbooks. This plate size is not normally used for PLTs conducted for the purposes of road construction (Trafikverket, 2014, Deutsches Institut für Normung, 2012), so the defined requirements for road structures, strictly speaking, only apply for PLTs conducted with a 300 mm plate. For the purposes of this thesis this detail was ignored, and PLTs conducted using a 600 mm plate were compared to the Swedish requirements in handbook *TDOK 2013:0530,* and were only compared to other PLTs using the same plate size. Since there is no existing test procedure for the 600 mm diameter plate size in Norway, these measurements were not compared to Norwegian requirements or measurements performed using Norwegian test procedures.

4.2.1.2 Interviews

To supplement the information collected through data files and other documentation, representatives from the contractor and/or the owner builder of the construction projects were interviewed. Interviews were chosen over questionnaires or surveys, since interviews allow the interviewer[33] to elaborate on the questions if needed, ask follow-up questions and clarify possible misunderstandings, as well as ask more open ended questions than other survey methods (Tanner, 2018, p. 180-181).

The interviews were semi-structured, meaning that the questions asked during the interview were predetermined, while there were no predetermined answer alternatives. This provides the opportunity for the interviewee[34] to answer the questions freely, while the interviewer focuses on asking questions that are important to the study (Williamson, 2018, p. 391-393). This also means that all of the interviewees were asked roughly the same questions, and that the same information can be collected from all of the case specific interviews. Focus group interviews, where a group of people discuss a topic amongst themselves (Williamson, 2018, p. 394), were also considered as a survey alternative. However, due to the potentially sensitive information discussed in the study, this was regarded as an unsuitable data collection method. The interviews were therefore conducted individually, with only one interviewee per interview. Only one interviewer, the author of the thesis, conducted all of the interviews, making sure that the interviews were conducted as similarly as possible.

The interviewees were recruited as part of the recruitment for the case study in general, as described in chapter 4.2.1. The contractors and owner builders that were recruited for

[32] This assumption is not true for all instances where the E-values are significantly different, but it can give a helpful indication of the likelyhood of significant differences.
[33] The term "interviewer" refers to the person conducting the interview, i.e. the author of the thesis.
[34] The term "interviewee" refers to the person being interviewed, i.e. the representative from the contractor or the owner builder.

the case study were asked to recruit interview participants within their line of workers. Only workers with adequate knowledge of the PLTs and the compaction of the materials in the superstructure were recruited for the interviews, to ensure that the interviewees would be able to answer as many of the questions as possible. The interviews were conducted in the period from March 2019 through May 2019. Since the interviewees were able to answer the questions freely, and the fact that none of the case projects are similar, the length of the interviews varied from 30 minutes to 90 minutes. Some of the interviews were conducted with minor interruptions, and were therefore conducted with breaks, making the interview last longer than otherwise necessary.

The interview guide, containing the questions asked during the interviews, is provided in Appendix 3. The questions were chosen based on the previously conducted document review (chapter 3) and the SoTA (chapter 2), as well as the research questions posed above. Care was taken to make sure that every question of the interview served a specific purpose in collecting information, and that no two questions served the exact same purpose. The structure of the interview guide follows the structure recommended by Galletta and Cross (2013). The first part of the interview thus consists of broad and open ended questions to establish trust and context to the rest of the interview, the middle part of the interview is used to collect more detailed information that often requires trust from the interviewee, and the final part of the interview consists of follow-up questions (if any) and the final thoughts of the interviewee. The interview guide was tested on fellow students with no connection to the road construction projects prior to the conduction of the actual interviews. This increases the quality of the interview guide, making sure the questions were understood correctly, that the phrasing of the questions was appropriate, as well as to evaluate the usefulness of the questions (Galletta and Cross, 2013).

The downsides of using interviews as a survey method is that they are resource intensive and time consuming, since they require an interviewer to conduct all of the interviews. This also means that the number of participants is more limited than for other survey methods. The presence of an interviewer can also skew the interviewees' answers, especially regarding subjects that are regarded as socially unacceptable or illegal. Additionally, conducting interviews also raises the problem of the identifiability of the interviewees, which causes some privacy challenges (Tanner, 2018, p. 180-181). Since the case study and the scope of the thesis already limit the number of cases that can be observed, a limited number of participants in the interviews was not considered a flaw to the interview method.

Regarding the issue with the presence of an interviewer skewing the interviewees' answers, care was taken to emphasize to the interviewee that the purpose of the study was not to "catch someone in the act" of doing something wrong, but rather to observe and study. A general information sheet was given to as well as read to the interviewee before the interview was conducted, emphasizing that all information would remain anonymous in the study, both in regards to the individual answering the questions, as well as the company involved and the project in general. The interviewees were also informed of their rights to not answer a question without stating a reason, as well as to end the interview abruptly without stating a reason. The interviews were conducted in private in a place known to the interviewee, e.g. in a meeting room at the office they work at, or in a neutral place, e.g. a hotel conference room, so that the interviewee would not feel intimidated by the setting of the interview. Even though these measures were taken in order to make the interviewee more comfortable during the interviews, the presence of an interviewer may have skewed the answers anyway. This will be discussed further in chapter 6.

The privacy and identifiability issue of the interviews were sought eliminated using guidelines from the Norwegian Centre for Research Data (NSD)[35]. The NSD is to make sure that the research design follows rules and regulations regarding personal privacy (more specifically, the newly implemented GDPR), and all projects that process identifiable personal information must be registered with the NSD (Norsk senter for forskningsdata, 2018). To eliminate the need to register the project, NDS's guidelines on how to design anonymous projects that don't require registration were followed. Recordings cannot be used in anonymous research (Norsk senter for forskningsdata, 2019), and the interviews were therefore not recorded in any way. Instead, the interviewees' answers were noted down on the interviewer's laptop during the interview. The questions in the interview guide were kept general, and special care was taken to not include any questions that would require answers containing identifiable personal information. No identifiable personal information was noted down during the interview.

Since the interviews were not recorded, the transcribed interview should be confirmed by the interview subject subsequent to the interview, to limit misunderstandings and misinterpretations. The interviewee should be informed of how this will be executed prior to, during or directly after the interview (Tanner, 2018, p. 180-181). To ensure minimal confusion and misunderstanding about the transcription document, a general information sheet regarding the transcribed interview was given to as well as read to the interviewee after the interview was completed. The interview was transcribed as shortly after the interview was conducted as possible, at most 2 days after the interview. Special care was taken to make sure that the transcription document did not contain any identifiable personal information, to ensure that the research continued to be anonymous. The transcription document was then sent in the mail to the interviewee's office in the form of a password secured pdf file on a simple USB-drive. The interviewee was given a handwritten note after the interview containing the password to the transcription document. The interviewees were instructed to only contact the interviewer by telephone, and only if they had comments to the transcription document, or if they had not received it after a week had passed from the time of the interview. No contact from the interviewee after the interview had taken place was interpreted as a confirmation that the information in the transcription document was correct.

After the transcribed documents had been approved by the interviewees, the interviews were analysed further, using keywords related to the research questions to locate key elements in the answers. The results of the interviews are described in more detail in chapter 5.1.

4.2.1.3 Field observations

In addition to a data file collection and interviews, observations in the field were conducted where possible and appropriate. On some occasions, the author was invited by the contractor or the owner builder of the project to partake in field measurements or general field observation prior to or after the interviews were conducted. These occasions were used as a supplementary information source to the data file collection and the interviews. The information from field observations were either noted down by the author during the observation, or immediately after the observation had taken place. Since the

[35] In Norwegian: Norsk senter for forskningsdata, abbreviated NSD. The Norwegian abbreviation is used in the text.

field observations are not considered to be a primary data source in the case study, but rather supplementary information provided for some of the cases, the results of the field observation will not be presented directly in the results section (chapter 0) of the thesis, but rather addressed as additional information in either the description of the cases in the study (chapter 4.2.2), or the discussion section (chapter 6).

4.2.2 The cases in the study

This section describes each of the road construction projects considered in the case study part of the thesis. The information provided in this section was largely collected as part of the data file collection and during the interviews for the case study, as described above. None of the information presented in this section is considered to be primary information, but rather supplementary information collected for the purposes of comparing the cases in the study. This information will therefore only be presented in the following subsections. Primary information which has been processed and analysed further will only be presented in the results section of the thesis (chapter 0). In order to respect the anonymity wishes of some of the companies involved, all of the projects considered in the case study, as well as the contractors and owner builders involved in the projects will remain anonymous. Each of the construction sites has therefore been given a site number and a descriptive pseudonym.

Figure 4.1 shows the location of the counties in which the sites are located; site 1 is in Hedmark county, site 2 is in Østfold county, site 3 is in Aust-Agder county and site 4 is in Hedmark county.

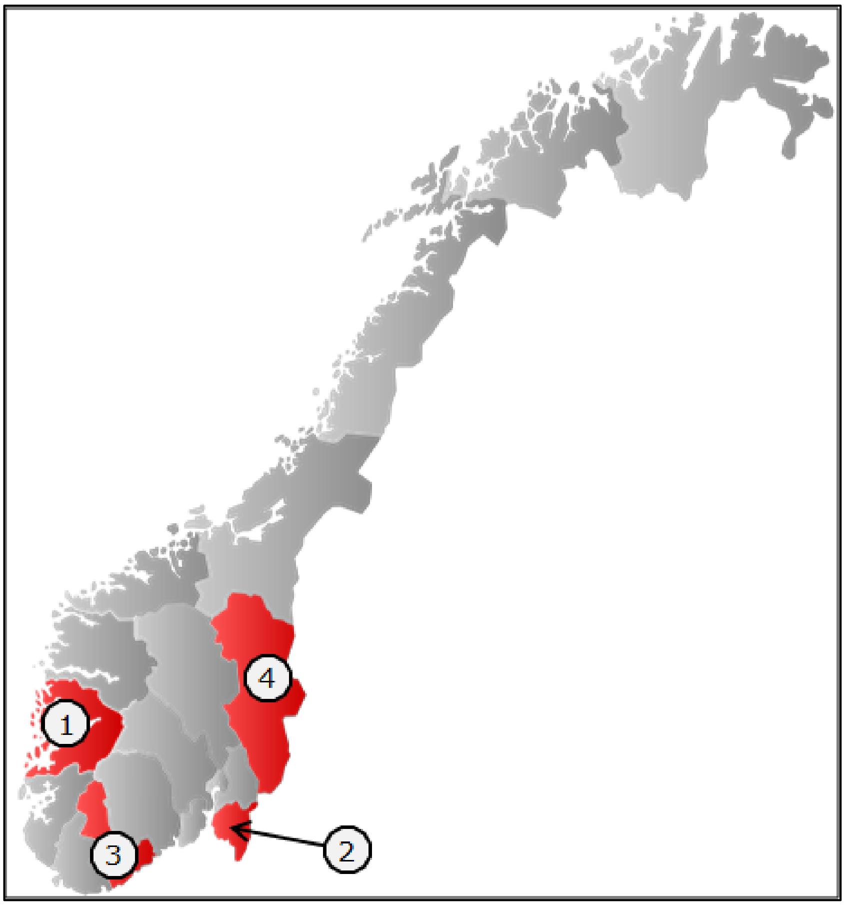
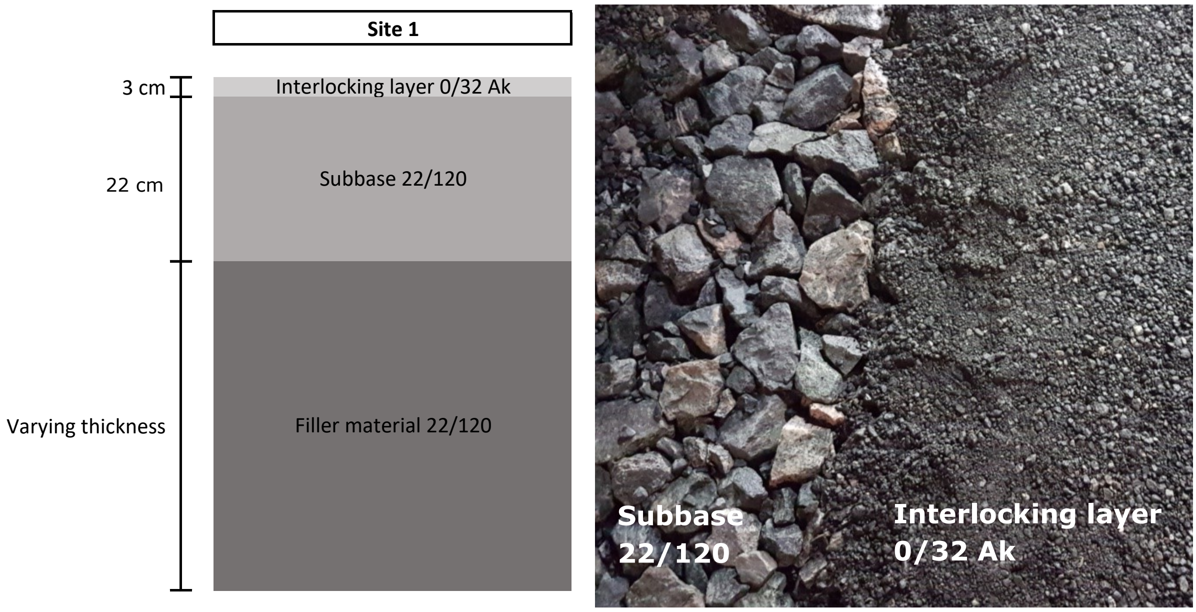


Figure 4.1: The counties in which the sites of the case study are located. (1) Site 1: Hordaland, (2) Site 2: Østfold, (3) Site 3: Aust-Agder, (4) Site 4: Hedmark. Reconstructed with figures by Marmelad (2007c), Marmelad (2007d), Marmelad (2007a), and Marmelad (2007b).

4.2.2.1 Site 1: The tunnel project

The tunnel project is one of many relatively large road construction projects that together are to make up a vast new road system in the county of Hordaland (see Figure 4.1). This particular project mainly consists of new road tunnels, with one tunnel in each driving direction. The data files collected from this construction site are from PLTs conducted the tunnels, two in each direction.

The tunnel profile is blasted from solid bedrock, cleared from debris and then re-filled and compacted up to the road bed level with filler material (22/120[36] crushed rock), before the superstructure is put in place. The superstructure consists of a subbase layer of 22/120 crushed rock, an interlocking layer[37] of 0/32 crushed asphalt (hereafter referred to as Ak), and a bituminous base course, binder course and wear course. Figure 4.2 shows the part of the superstructure on which the PLTs are performed, i.e. the mechanically stabilized materials.



(a) (b)

Figure 4.2: The part of the superstructure at site 1 on which the PLTs are performed. (a) An illustration of the mechanically stabilized part of the superstructure, (b) A photo of the subbase material and the interlocking material.

One of the tunnels (Tunnel 1) contains a deep pipe trench at one side of the tunnel, making the layer of filler material thicker on that side of the road structure than the other. Additionally, this tunnel has a concrete cable trench[38] at each side of the road, limiting the compaction effort allowed at the edges of the road. The climate in the tunnels is consistent with usual tunnel climate, humid with condensation forming on roof and walls, and relatively stable temperature above freezing.

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[36] This expression refers to granular materials whose grading curve fits a specific set of requirements defined by the NPRA in handbook *N200* from 2014 (Statens vegvesen and Vegdirektoratet, 2014a). In the most recent version of handbook *N200*, the expression for this particular material definition has been changed to 22/125 (Statens vegvesen and Vegdirektoratet, 2018a).

[37] In Norwegian: forkilingslag

[38] OPI kanal

The information collected for this site consists of an interview with a representative from the contractor, field inspections where PLTs were conducted and data files from PLTs conducted by the contractor previously during the year. The plans for this site were created before the 2018 version of the Norwegian handbooks were published, and the contract and the requirements in the contract are therefore based on the 2014 versions of the handbooks. This information is relevant for context when referring to requirements and test procedures.

4.2.2.2 Site 2: The urban area project

The urban area project consists of upgrading an existing highly trafficked, two-lane urban road in the county of Østfold, to a four-lane urban road with new public transport and pedestrian infrastructure. The construction site is situated in an urban area, and the upgraded road is therefore largely constructed on previously existing road structures and/or a previously built-up area.

The superstructure consists of a subbase of 22/120 crushed rock, and interlocking material of 0/32 Ak, and a bituminous base course, binder course and wear course. Unfortunately, information about the thicknesses of the mechanically stabilized materials in the superstructure is not available.

The information collected from this site consists of data files from PLTs conducted by the owner builder of the project in 2016, as well as data files from PLTs conducted by an external consultant in 2017. The PLTs performed by the owner builder consist of conventional measurements, measurements conducted after additional compaction (2 passes with vibratory roller with low amplitude, followed by 2 static roller passes), as well as measurements from PLTs conducted on the same point immediately after one PLT test was completed. The plans for this site were created before the 2018 version of the Norwegian handbooks were published, and the contract and the requirements in the contract are therefore based on the 2014 versions of the handbooks. This information is relevant for context when referring to requirements and test procedures.

4.2.2.3 Site 3: The new motorway project

The new motorway project is a large turnkey project[39] involving the construction of a four lane motorway, largely on previously undisturbed terrain in the county of Aust-Agder. The project consists of tunnels, bridges, as well as open stretches of road, however, the data files collected from this site only apply to PLTs conducted on open stretches of road.

The open stretches of the motorway are constructed in highly varying terrain, ranging from deep rock cuts to tall embankments. Parts of the previously existing terrain include bogs[40], requiring the existing soil to be exchanged for new, better suited material for road construction. Most of the motorway is therefore constructed upon a subsoil or substructure considered to fall in the frost susceptibility class T2[41].

The superstructure consists of a subbase of 22/120 material of various thicknesses (depending on the type of subgrade), an interlocking layer of 0/32 crushed rock (hereafter referred to as Fk), and a bituminous base course, binder course and wear

[39] In Norwegian: Totalentreprise
[40] In Norwegian: Myr
[41] The frost susceptibility classes are defined in the Norwegian handbook *N200*. Class T2 is considered "slightly frost susceptible material", which does not require special frost protection in the superstructure (Statens vegvesen and Vegdirektoratet, 2018a)

course. Figure 4.3 shows the part of the superstructure on which the PLTs are performed, i.e. the mechanically stabilized materials.

The information collected from this site consists of an interview with a representative from the owner builder, a general field inspection of the construction site, data files from PLTs conducted by the contractor in 2018, data files from PLTs conducted by an external consultant in 2018, as well as information from the contractor‘s own field experiments on the effects of fines content of the interlocking layer on the results of PLTs.

The plans for this site were created before the 2018 version of the Norwegian handbooks were published, and the contract and the requirements in the contract were therefore originally based on the 2014 versions of the handbooks. However, the contractor and the owner builder mutually agreed some time into the project to update the requirements in the contract to be based on the 2018 versions of the handbooks. This information is relevant for context when referring to requirements and test procedures.

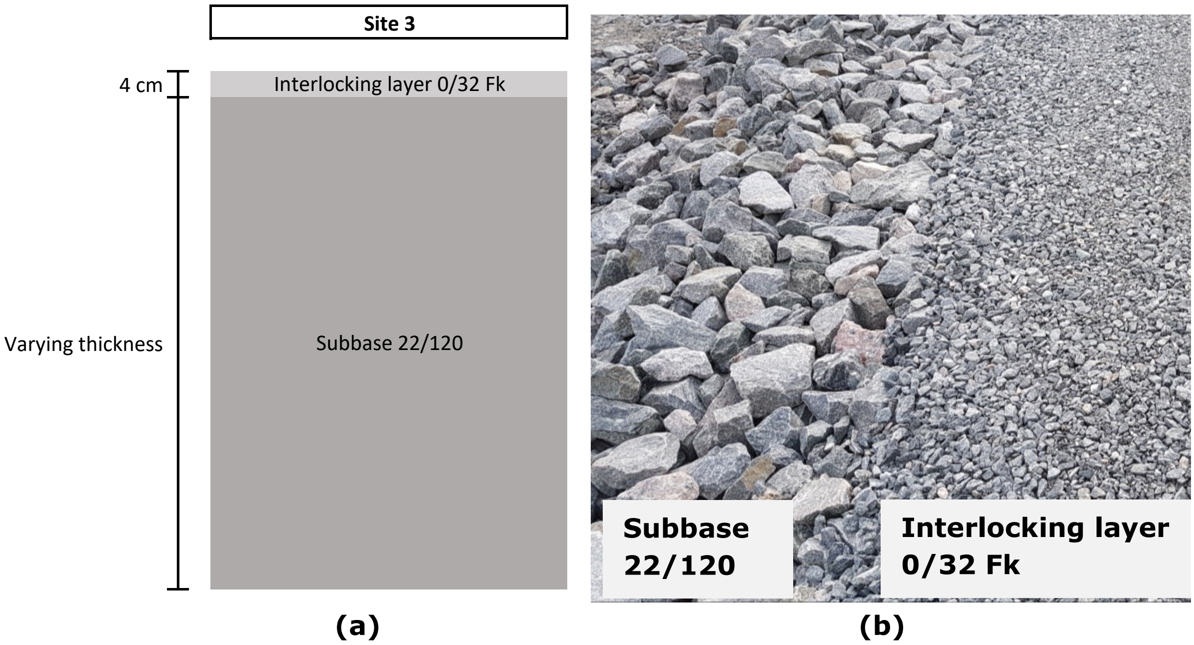


Figure 4.3: The part of the superstructure at site 3 on which the PLTs are performed. (a) An illustration of the mechanically stabilized part of the superstructure, (b) A photo of the subbase material and the interlocking material.

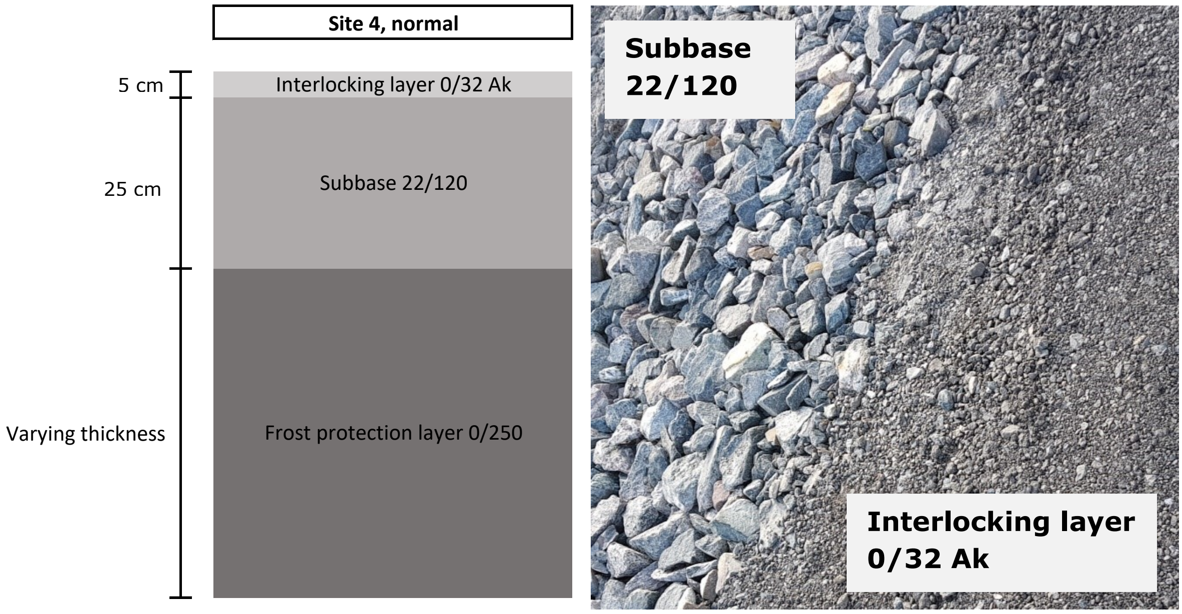
4.2.2.4 Site 4: The motorway upgrading project

The motorway upgrading project is one part of a larger motorway construction project in the county of Hedmark. This particular subproject is a turnkey project that involves upgrading an existing motorway by adding lanes and separating the driving directions. Some parts of the new motorway is thus constructed on the existing motorway, while other parts are constructed in the side terrain of the existing motorway.

Where the motorway is constructed in the side terrain (i.e. not on top of the pre-existing motorway), the superstructure consists of a frost protection layer of 0/250 crushed rock (various thickness), a subbase of 22/120 crushed rock, an interlocking layer of 0/32 Ak, and a bituminous base course, binder course and wear course. Figure 4.4 shows the part of the general superstructure on which the PLTs are performed, i.e. the mechanically stabilized materials.

A part of the motorway is constructed on problematic subsoil that has to be removed if disturbed. To avoid having to excavate and change out the subsoil, an alternative superstructure, with a thinner frost protection layer, was chosen for the Alum Shale area. This superstructure consists of a frost protection layer of 0/250 crushed rock, a 10 cm thick XPS insulation boards enclosed in a protection layer of 0/20 sand, a subbase of 22/120 crushed rock, an interlocking layer of 0/32 Ak, and a bituminous base course, binder course and wear course. Figure 4.5 shows the part of the XPS containing superstructure on which the PLTs are performed, i.e. the mechanically stabilized materials.

The information collected from this site consists of an interview with representatives from the contractor, a field inspection during which PLTs were performed, data files from PLTs conducted with the contractor, as well as data files from previously conducted PLTs on road sections containing XPS boards. The plans for this site were created before the 2018 version of the Norwegian handbooks were published, and the contract and the requirements in the contract are therefore based on the 2014 versions of the handbooks. This is relevant for context when referring to requirements and test procedures.



(a) **(b)**

Figure 4.4: The part of the superstructure at site 4 on which the PLTs are performed. (a) An illustration of the mechanically stabilized part of the superstructure, (b) A photo of the subbase material and the interlocking material.

The PLTs performed with the contractor on the construction site were performed on the 13th of May between 18 and 21 in the evening, and the 14th of May between 8 and 10 in the morning. The weather was sunny with no precipitation and calm to no wind on both days, with temperatures ranging from 12°C to 9°C during the tests on the 13th, and 5°C to 8°C during the tests on the 14th. The temperature on the day before the PLTs were conducted (12th of May) ranged from 4°C to 9°C during the day, with temperatures dropping to around 0°C the night before the tests. The weather on the 12th of May was sunny with no precipitation.

A total of 6 PLTs were conducted with the contractor, 3 on the 13th and 3 on the 14th. The tests were performed on top of the interlocking layer, as part of the routine PLT documentation of compaction on the construction site. The placement of each test was decided by the contractor, following the general 1 per 250 m[42] and one per lane rule defined in handbook *N200* (Statens vegvesen and Vegdirektoratet, 2014a). Additionally, 17 measurements with a light weight deflectometer (hereafter referred to as LWD) were performed by a master student from NTNU, 10 of which corresponded with 5 of the PLTs. Thus, LWD measurements were performed once directly before and once directly after 5 of the PLTs conducted, and 7 individual LWD measurements were conducted on the interlocking layer without any link to PLTs. The LWD measurements should not have any significant effect on the results of the PLTs, due to the limited weight and impact force of the measurement device (10 kg dropped from a relatively short height). The results of the LWD measurements will not be used in this thesis, and will therefore not be discussed further.

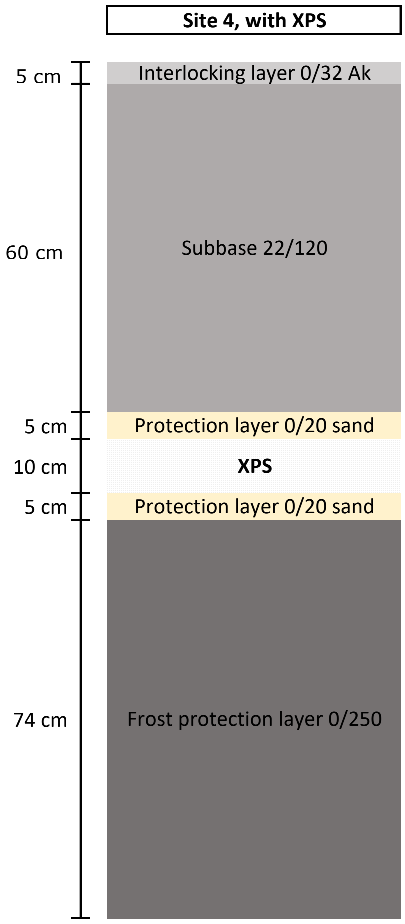


Figure 4.5: An illustration of the mechanically stabilized part of the superstructure of site 4 where XPS is used

4.3 Other interviews and data files

In addition to the interviews conducted for the case study, interviews with people with experiences from PLT measurements on a number of different road construction projects were conducted. These interviews were conducted in a similar manner as the case study interviews (see chapter 4.2.1.2), with the exception that case specific questions were altered during the interviews to be broader and less case specific. The interviewees were also allowed to talk more freely than in the case study interviews, and these interviews

[42] 1 per 250 m is used because of the use of response measurements

therefore lean more towards being unstructured interviews, although still falling in the category of being semi-structured (Williamson, 2018, p. 391-393). One interview was conducted in a non-neutral place unknown to the interviewees due to logistical challenges. In order to minimize the interviewer's presence affecting the answers, this interview was conducted with two interviewees, in an attempt to make the interviewees more comfortable in the non-neutral space.

The interviewees were recruited in a similar manner as was done for the case study interviews, although the interviewees in these interviews were not employed to work on one construction site at a time. The interviewees in this category range from suppliers of construction materials to the construction sites, to specialists in conducting field tests on construction sites, such as PLTs.

Furthermore, some additional data files with results of PLTs conducted on projects not considered in the case study were also collected. These were treated in the same way as data files collected for the case study, and the E_1 and E_2 values were calculated using the same three calculation methods (see chapter 4.2.1.1). These data files were used as additional data material to compare the results of the three different calculation methods, but will not be included in the case study part of the thesis, due to either the limited amount of information provided about the construction sites, or the dissimilarities of the construction sites to those of the case study. A short description of each of the non-case study construction sites is provided below.

Site 5: New motorway in the county of Buskerud. Limited information about the project is provided.

Site 6: A parking lot and internal road system on a privately owned property. Other rules and regulations apply for this project.

Site 7: A motorway upgrading project in the county of Telemark. Limited information about the project is provided.

Site 8: A municipal road, water and wastewater project in the county of Vestfold. Other rules and regulations apply for this project.

Site 9: An urban road upgrading project in the county of Buskerud. Limited information about the project is provided.

Site 10: A motorway upgrading project in the counties of Sogn og Fjordane and Oppland. Limited information about the project is provided.

4.4 Field test

A field test was conducted in collaboration with the NPRA and Skanska AS on the work site of the road construction project Rv. 3/Rv. 25 Løten-Elverum, in Hedmark county, Norway. The test was conducted on March 28th 2019 in a section of the project midway between Løten and Elverum. Figure 4.6 shows the location of the field test.

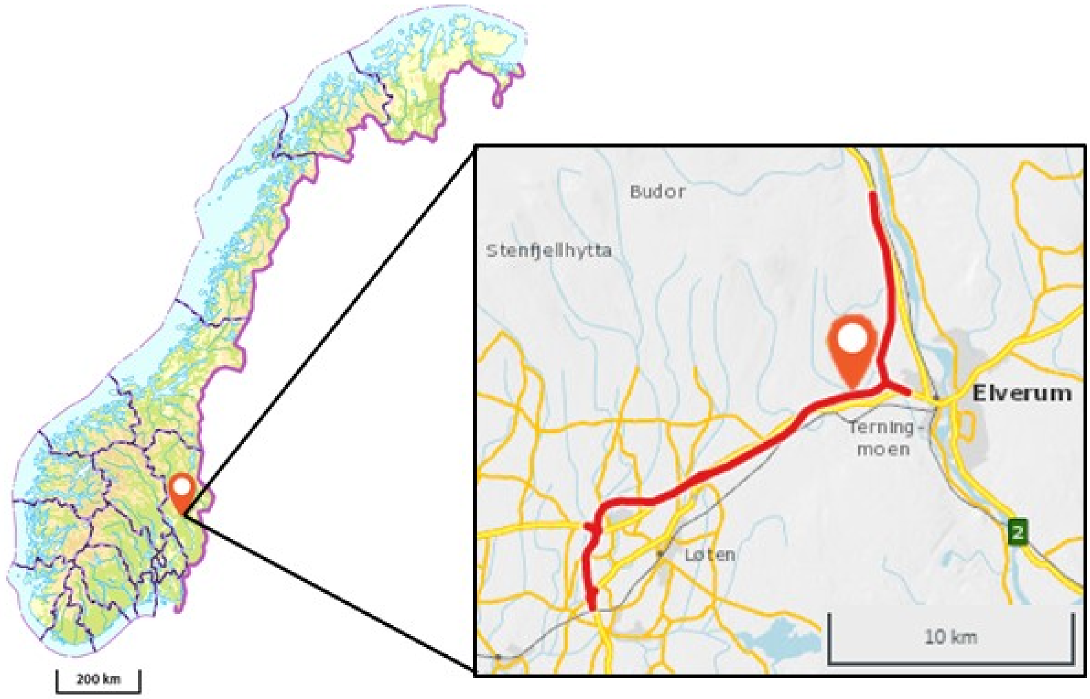


Figure 4.6: The location of the field test at the construction site of Rv. 3/Rv. 25 Løten-Elverum, in the county of Hedmark. The red lines on the map show the location of the new road and the orange marker marks the location of the field test. Reconstructed with maps by Kartverket (n.d.), and Statens vegvesen (n.d.-a).

The test was conducted between 10:00 in the morning and 18:00 in the evening. The temperature ranged from 1°C to 11°C during the test, while the temperature had dropped to -4°C the night before the test. The weather was cloudy to partly cloudy with calm to moderate wind and no precipitation. The weather the day before the test was similar, except with somewhat colder temperatures.

The test consisted of 36 test points distributed over 3 test areas which each had a different superstructure material combination. An overview of the test setup within test area 1 is provided in Figure 4.7. The other test areas had similar test point setups.

The materials of the test section were laid out and compacted by the contractor (Skanska AS) prior to the test date. The frost protection layer was 1,8 m thick and consisted of 0/300 crushed rock material. The frost protection material had been laid out and compacted in layers quite some time before the test was to be conducted and covered the whole width of the future road structure (roughly 16 m). The subbase material and the interlocking material were laid out and compacted in a 5 m wide test section the day prior to the test day. The subbase consisted of a 30 cm thick layer of 22/120 crushed rock material, and the interlocking layer consisted of a 4 cm thick layer of 0/32 crushed rock material. The test section was thus 5 m wide, and was divided into 3 different test areas. Area 1 consisted of a subbase layer and a frost protection layer, area 2 consisted of an interlocking layer, a subbase layer and a frost protection layer, while area 3 only consisted of a frost protection layer. An illustration showing the superstructures used in each test area is provided in Figure 4.8. Figure 4.9 shows the actual materials used in the test areas, with a 1 m measuring stick for reference.

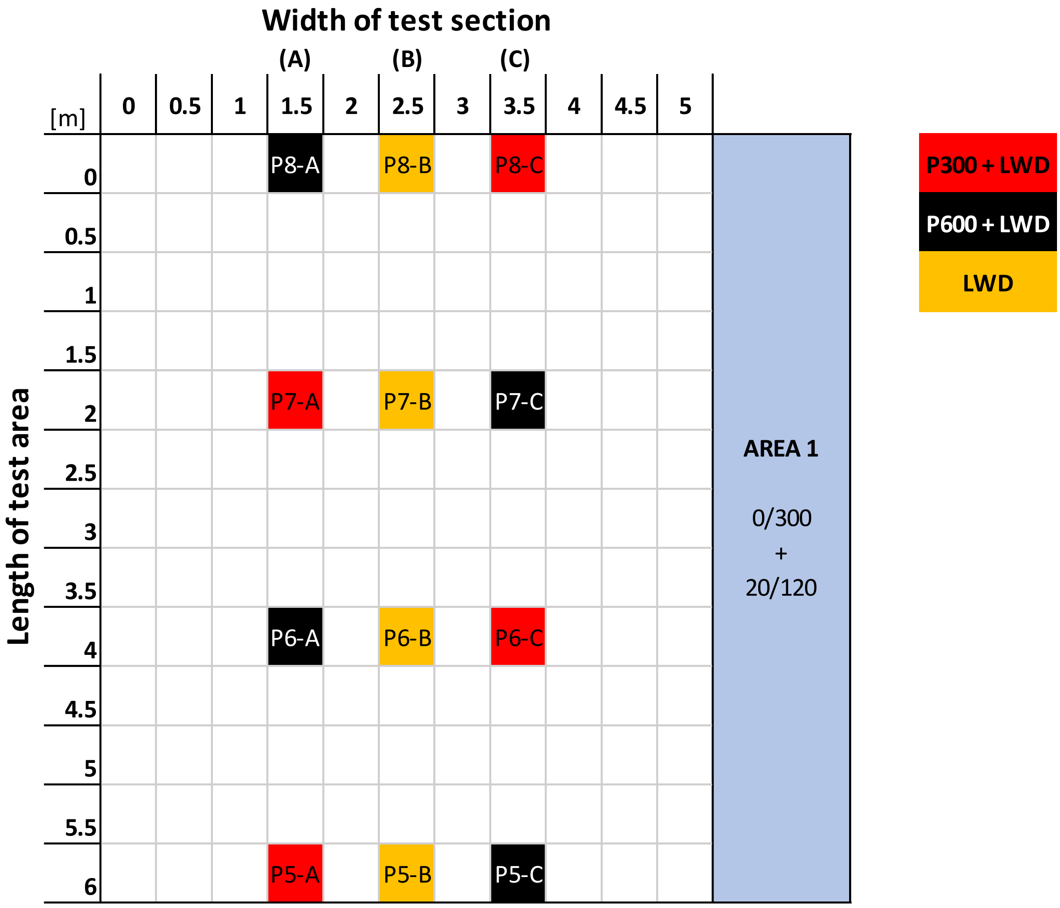


Figure 4.7: An overview of the setup of test points within area 1 of the field test conducted on March 28th. Red test points represent PLTs with a plate diameter of 300 mm, black test points represent PLTs with a plate diameter of 600 mm, and yellow test points represent measurements with a LWD only. All test points were measured with a LWD, including those where PLTs were conducted. A detailed setup of all of the three areas is provided in Appendix 4.

Each of the test areas contained 12 test points which were organized into three lines of four, as shown in Figure 4.7. For simplicity, each line was assigned a reference letter, A, B and C, and each row of test points was assigned a number, P1, P2, P3 and so forth. The test areas were thus organized into a grid of test points, where each test point was assigned a unique reference name based on its corresponding line and row, e.g. P6B for the test point in row 6 and line B. Due to restrictions with the placement of the PLT counterweight, lines A and C were placed 1,5 m from the edge of the test section, while line B was placed in the centre between lines A and C. The rows of test points were placed at a 2 m interval within each test section. Test rows 1-4 were designated to test area 3, rows 5-8 were designated to test area 1, and rows 9-12 were designated to test area 2. An illustrative, detailed overview of each of the test areas and the test points is provided in Appendix 4.

All of the test points were measured with a LWD, both prior to and after the PLTs were conducted. PLTs were only conducted on test points in lines A and C, with plate diameters altering between 300 mm and 600 mm. Each test area thus contained 4 points measured with a 300 mm diameter plate, and 4 points measured with a 600 mm diameter plate.

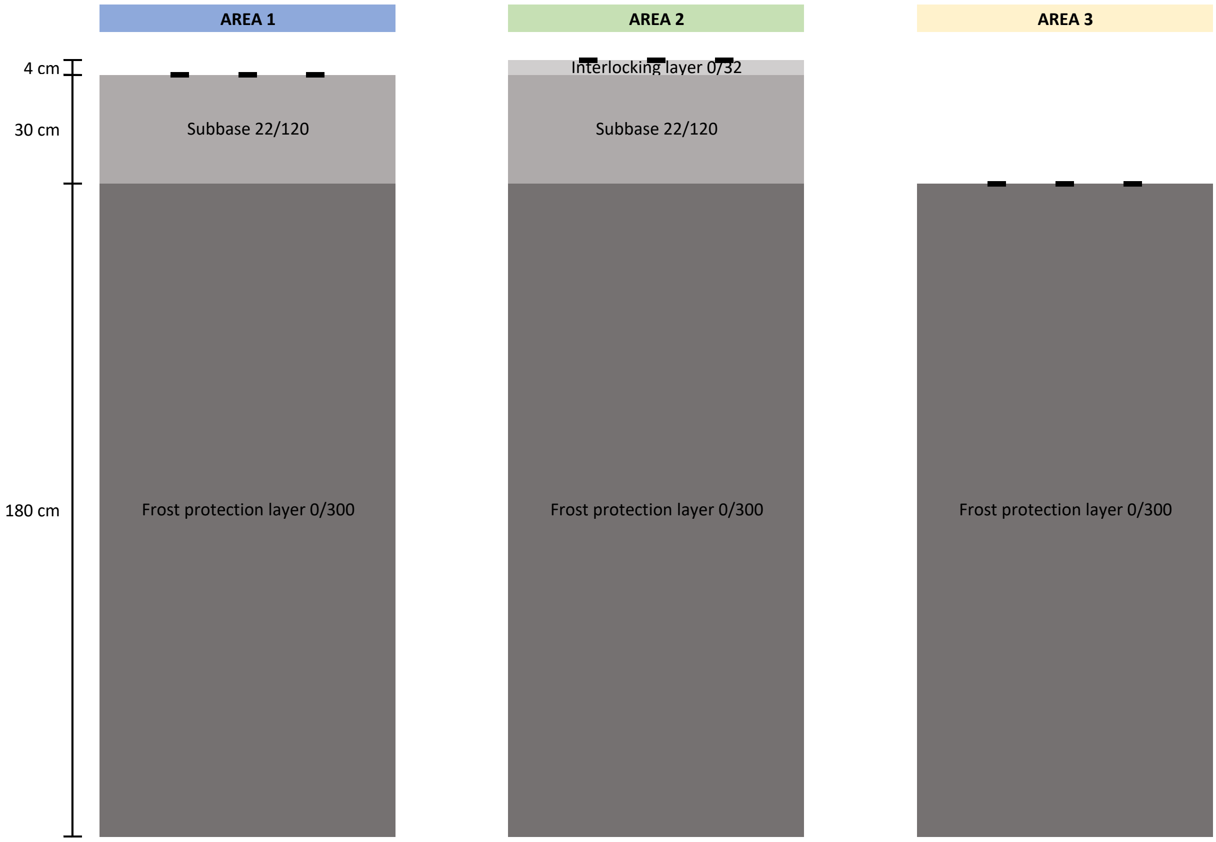


Figure 4.8: The superstructures of each test section. Area 1 consists of a subbase and a frost protection layer, area 2 consists of an interlocking layer, a subbase and a frost protection layer, and area 3 consists only of a frost protection layer.

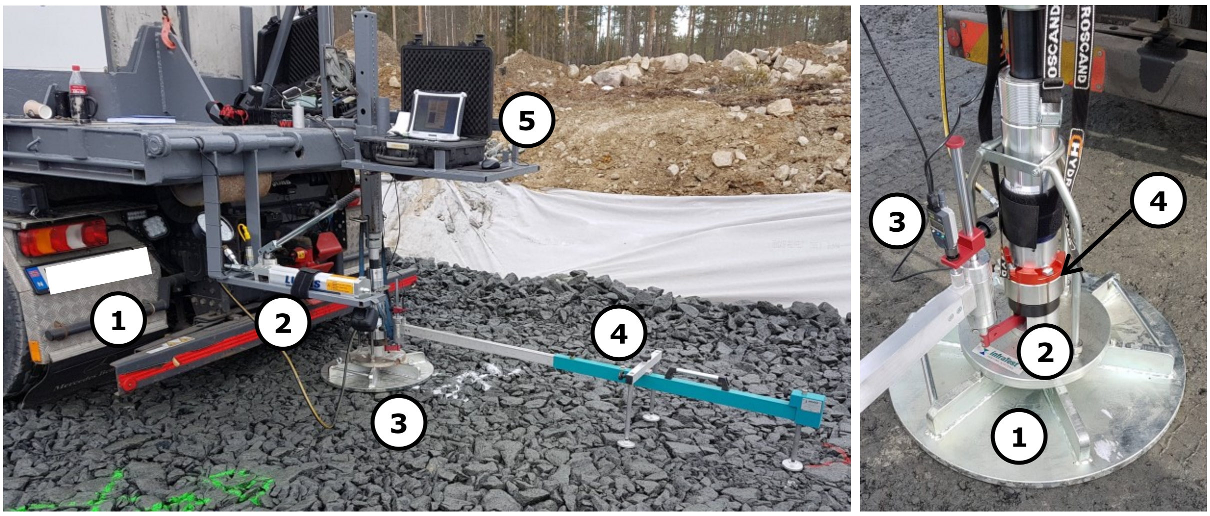
(a) (b) (c)

Figure 4.9: The materials used in the superstructure of the test areas. The measuring stick shown in the figures is 1,0 m long. (a) The frost protection layer, 0/300 crushed rock. (b) The subbase material, 20/120 crushed rock. (c) The interlocking material, 0/32 crushed rock.

Since PLTs can be quite time consuming to perform, these tests were performed by two separate teams using two separate sets of measuring equipment, one team from the NPRA, and another team from an external consultant hired by Skanska AS. The test points were divided between the two teams, so that the NPRA team measured all points in test area 1 and line A only in test area 2, while the external consultant team measured all points in test area 3 and line C only in test area 2. The LWD measurements were performed by a separate team consisting of students and a post-doctoral researcher from NTNU.

The PLTs were performed using standard measuring equipment, as described in chapter 3. The PLTs conducted with a 300 mm plate were conducted in accordance to the specifications of the Norwegian handbook *R211* (see Statens vegvesen and Vegdirektoratet (2018b) or chapter 3.1 above), while the PLTs conducted with a 600 mm plate were conducted in accordance to the German standard *DIN 18134* (see Deutsches Institut für Normung (2012) or chapter 3.2.3 above), since the Norwegian handbooks don't contain any specifications or information about the use of 600 mm plate. The only deviation from the German standard when performing the 600 mm diameter PLTs was that the loads were not kept constant for 1 min for each of the load steps, but rather for a few seconds before the next load step was started. Both of the teams that performed the tests used a truck as a counterweight for the measurements. Figure 4.10 shows the test setup for a PLT conducted with a 600 mm diameter plate. The test setup for a PLT conducted with a 300 mm diameter plate is similar, except the 600 mm diameter plate is omitted.

The LWD measurements will not be used in this thesis and will therefore not be discussed further. Due to the limited weight and impact force used during the LWD tests (10 kg dropped from a relatively short height), the LWD measurements should not have any significant effect on the results of the PLTs.



(a) **(b)**

Figure 4.10: The setup of a PLT using a 600 mm plate (a) Test equipment setup: (1) Truck used as counterweight, (2) a hydraulic jack, (3) test plate, (4) Benkelman beam, (5) a laptop with test software and real-time test results. (b) A close up of the test plate setup, (1) 600 mm diameter plate (For a PLT using a 300 mm diameter plate, this plate is omitted), (2) 300 mm diameter plate, (3) dial gauge measuring the displacement at the centre of the test plate, (4) load cell measuring the load applied to the test plate.

The results of the PLTs were treated in the same way as the data files collected for the case study, as described in chapter 4.2.1.1 above. The load and settlement measurements were used to calculate the E_1 and E_2 values for each test point, using the three calculation methods "Norwegian method 1", "Norwegian method 2" and "Swedish method", as described in chapter 4.2.1.1. The calculated results were then compared to the requirements for E_2 and E_2/E_1 defined in the Norwegian handbook *N200*[43] and the Swedish handbook *TDOK 2013:0530*[44]. In addition to comparing test results from PLTs using the same load cycles (as was done for the data files in the case study), the results of PLTs conducted with a 300 mm diameter plate and 600 mm diameter plate were also compared, since the PLTs in the field test were conducted in the same conditions.

[43] See chapter 3.1 for a summary of the handbook *N200*
[44] See chapter 3.2.1 for a summary of the handbook *TDOK 2013:0530*

5 Results

This chapter presents the results of the case study, other interviews and data files collected, as well as the results of the field test.

5.1 Case study

The results of the case study will be presented in terms of each case, as well as a comparison of the cases of the study. This includes both results from the case study interviews as well as the collected data files. The first four sub-sections present the results of each of the sites in the case study, while the fifth sub-section presents the results of comparing the cases.

5.1.1 Site 1: The tunnel project

5.1.1.1 Interview

In general, the interviewee felt that it can be quite challenging, though not impossible, to fulfil the requirements for PLTs defined in the Norwegian handbooks.

The compaction plan for the site is determined based on measurements conducted using levelling measurements[45] and response measurements. During compaction, the roller driver decides how many roller passes to perform in each situation, based on the compaction plan as well as the response measurements provided by the roller equipment, to ensure adequate compaction and minimal crushing of the granular materials. In the tunnel with the pipe trench (Tunnel 1), there are two separate compaction plans for the road's cross section; one for the trench side and another for the other side. The compaction plans do not vary over the length of the tunnels.

The same type of superstructure material is used for the whole project. The blasted rock from the tunnel is crushed and used for the filler material and the subbase, where the subbase material is generally of higher quality than the filler material. Different places in the tunnel provide different quality rock, so due to logistical benefits, some sections of the tunnels are constructed with filler material with material qualities adequate for use in the subbase layer. Milled asphalt is delivered from an external supplier and stored in piles on site before it is crushed for use in the interlocking layer. Some parts of the project were constructed with an interlocking layer of milled asphalt, where the crushing step was skipped.

Compaction of the superstructure material is done in layers to ensure that all parts of the material are compacted adequately. Vibratory compaction is used for all layers of the filler material and the subbase, while the interlocking layer is compacted using 2 vibratory roller passes, followed by 4-5 static roller passes. The PLTs are generally performed as shortly before asphalting as possible, to ensure that the superstructure materials have rested and hardened as much as possible. It is also essential to have enough time between the PLTs and the asphalting, to ensure adequate time to perform corrective measures if the results of the PLTs are inadequate. The time between

[45] In Norwegian: Nivellement

completion of compaction and plate load testing is generally around 2 weeks for roads inside the tunnels and about 5 days for roads outside of the tunnels.

There are only two people that conduct PLTs on this site, hereafter referred to as the site's test performers. The tests are only conducted for final documentation of compaction and are therefore only performed on top of the interlocking layer. The PLTs are performed once every 250 m in each lane (due to the use of response measurements), in the points where the response measurements are the lowest. Where the response measurements are relatively similar for the whole section, the test is performed in the centre of each lane. No levelling material is used under the plate, but care is taken to brush away any loose material before the test is conducted, since the test performers experience better test results when this is done. A roller is generally used as counterweight for the measurements. The loads are applied according to handbook *R211*, and a handheld computer device calculates the results of the PLT automatically using the Swedish calculation method, giving instantaneous information about whether the test requirements are fulfilled or not.

An especially challenging section with regards to the results of PLTs was in Tunnel 1, with the deep pipe trench and the concrete cable trenches[46]. A part of the pipe trench filled up with water prior to the construction of the superstructure in this section, and the pre-placed filler material was excavated from the trench in order to remove the accumulated water. New filler material and the road's superstructure were then laid out and compacted as normal. This section was constructed with milled asphalt as the interlocking layer, and filler material that is not of subgrade material quality. The response measurements during compaction were consistently lower than the target values, even after the number of roller passes was increased from the defined value in the compaction plan. Special care was taken to ensure minimal crushing of the material during the additional compaction. The PLTs in this section were performed closer together than required by the handbooks, and the results were consistently poor over the whole section.

Tunnel 2 was generally problem-free in regards to the results of PLTs. The tunnels are similar excluding the deep pipe trench and the concrete cable trenches in Tunnel 1. The concrete cable trenches in Tunnel 1 limit the compaction effort used to compact the materials in the tunnel, so the materials in Tunnel 1 are compacted using lighter compaction equipment than in Tunnel 2. A section in Tunnel 2 that was exceptionally problem-free was compacted during a period when there was minimal construction traffic through the tunnel, leading to minimal interruption in the signal between the total station and the roller. There was therefore minimal gap in the registered compaction data for this particular section in Tunnel 2.

The interviewee believes that the results of PLTs are not always representative of the quality of the compaction work. The PLTs should be used as a control method to check if everything is going according to the plan, but the totality of the compaction work should be considered more important. Deviations will always occur during construction, especially on larger construction sites, and the margins that determine if a PLT fulfils requirements are often very small. So one inadequate PLT is not necessarily representative of the quality of work done.

[46] OPI kanal

5.1.1.2 Data files

The calculated values for measurements conducted on site 1 are presented in Figure 5.1, Figure 5.2 and Figure 5.3. A more detailed overview of the measurements and the calculations corresponding to each PLT is provided in Appendix 6.

Figure 5.1 shows the calculated values for E_1 for the four measurements provided by the contractor. As can be seen from the figure, there is generally little difference between the E_1 values calculated using the Norwegian method and the Swedish method, except for measurement S1-M1. The difference between the Norwegian and the Swedish calculation method for this set of measurements is not statistically significant at the 95% confidence level, based on a two-sided, paired t-test, as presented in Table 5.1.

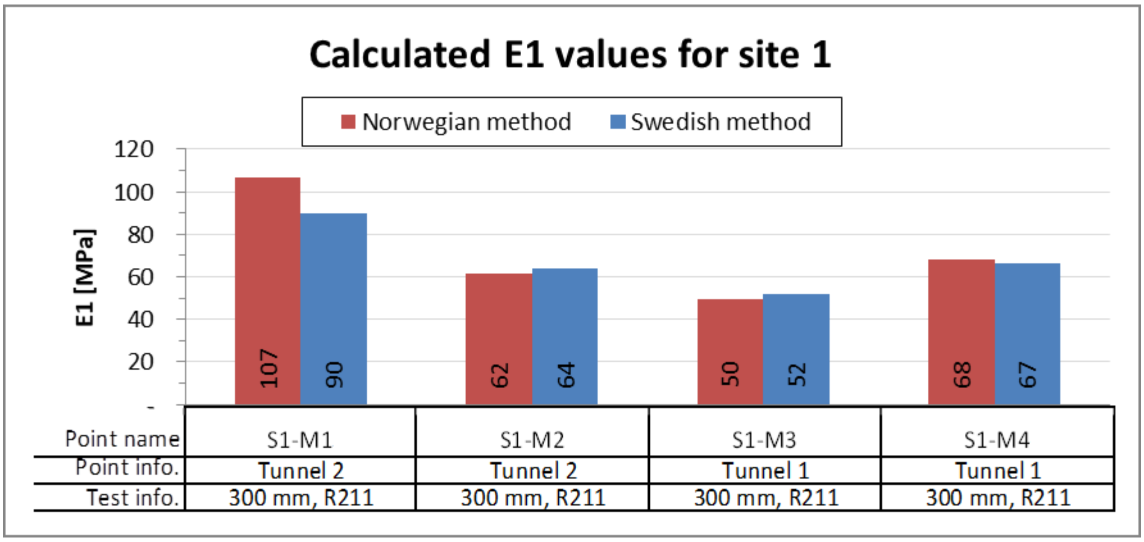


Figure 5.1: Calculated E_1 values for measurements conducted on site 1.

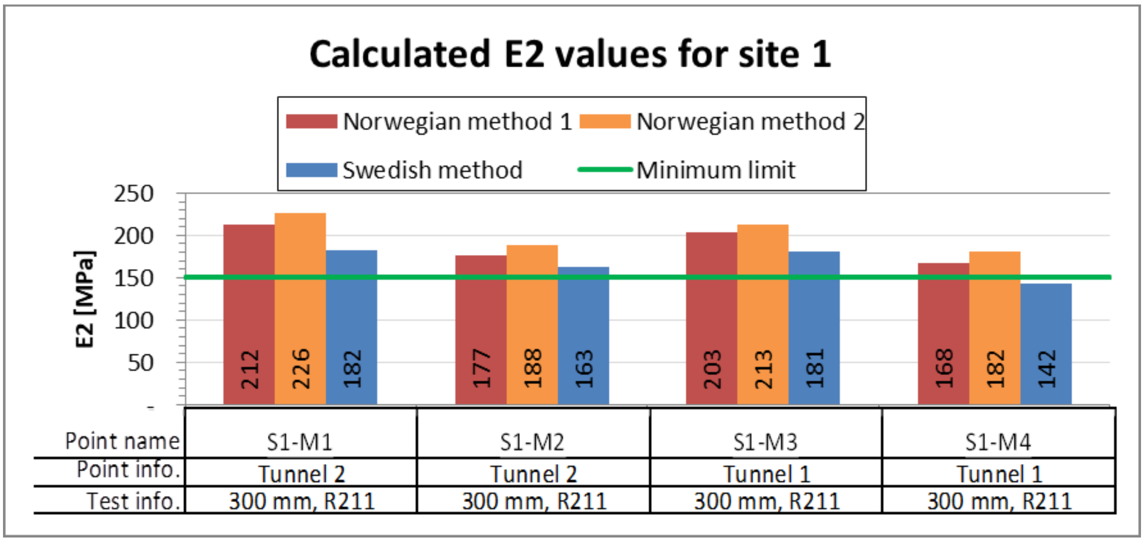


Figure 5.2: Calculated E_2 values for measurements conducted on site 1. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200, *150 MPa.*

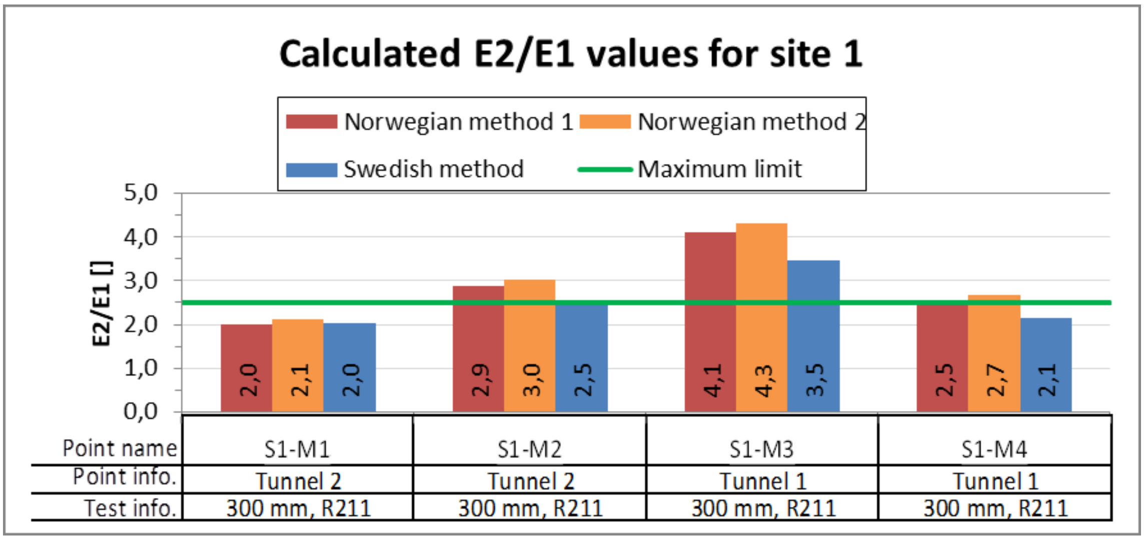


Figure 5.3: Calculated E_2/E_1 values for measurements conducted on site 1. The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook N200*; 2,5.*

Table 5.1: The results of a two-sided, paired t-test comparing the calculation methods used for the measurements at site 1, presented in Figure 5.1 and Figure 5.2. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

P-values from t-tests for site 1, comparison of calculation method			
E1	**E2**		
NOR vs SWE	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
0,51	**0,01**	**0,00**	**0,00**

The calculated values of E_2 for site 1 are presented in Figure 5.2. As can be seen from the figure, all of the calculated values meet the minimum requirement for E_2, except the result for measurement S1-M4 using the Swedish calculation method. The difference between the calculation methods is more apparent for the E_2 value than for the E_1 value, and the difference is also statistically significant at a 95% confidence level, as can be seen in Table 5.1.

Figure 5.3 shows the calculated values for the ratio E_2/E_1 for site 1. Only one of the measurements, S1-M1, meets the minimum requirements for the ratio for all calculation methods. Similarly, only one of the measurements, S1-M3, exceeds the minimum limit for all calculation methods. The remaining two measurements fall either above or below the minimum limit for some of the calculation methods.

As described in the interview section for this site, the two tunnels have different cross sections, leading to a different thickness of the filler material layer. Additionally, the interviewee described Tunnel 1 as being more problematic than Tunnel 2. However, as can be seen from Table 5.2, a comparison of the measurements in Tunnel 1 and Tunnel 2 shows that the measured differences are not statistically significant at a 95% confidence level, given the set of measurements provided. The statistical insignificance of this test can stem from the small sample size provided, since the test only assesses two sets of two measurements. To see if that is likely to be the case, two additional fictive measurements were created for each tunnel, with values equally distanced in the range between the actual measurements. Table 5.2 shows that the comparison with the fictive values leads to the difference between the E_1 values calculated with the Swedish method becoming statistically significant at a 95% confidence level. This does not guarantee that the difference between the measurements in the two tunnels is statistically significant, but it indicates that if the number of measurements provided were greater, that it is likely that the difference would be statistically significant, given that the actual measurements already provided are representative of the total population.

Table 5.2: The results of a two-sided t-test assuming different variances, comparing the measurements in Tunnel 1 and Tunnel 2 at site 1, presented in Figure 5.1 and Figure 5.2. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for site 1, comparison of Tunnel 1 and 2				
	E1		E2		
	NOR	SWE	NOR 1	NOR 2	SWE
Only true measurements	0,45	0,38	0,75	0,74	0,68
With fictive measurements	0,07	**0,04**	0,43	0,41	0,31

5.1.2 Site 2: The urban area project

No interviews were conducted for this site, and all information collected in addition to the PLT measurements discussed below were collected through documentation provided by the owner builder of the project. The documentation suggests that the subbase material used could be coarser than the conventional 22/120 material.

5.1.2.1 Data files

The calculated values for conventional PLT measurements conducted on site 2 are presented in Figure 5.4, Figure 5.5 and Figure 5.6. A more detailed overview of the measurements and the calculations corresponding to each PLT is provided in Appendix 6.

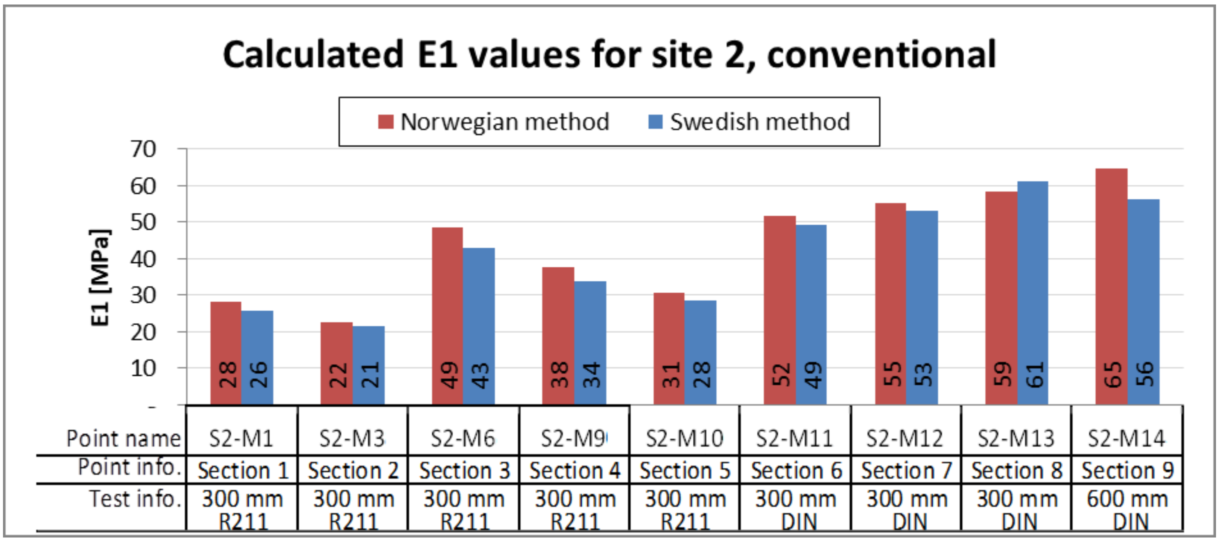


Figure 5.4: Calculated E_1 values for the conventional PLT measurements conducted on site 2. Each of the conventional measurement was conducted in a separate cross section, referred to as "section" in the figure.

Figure 5.4 shows the calculated values for E_1 for the 9 conventional measurements conducted at 9 different cross sections of the road in site 2. The first 5 of the conventional PLTs (cross section 1 to 5) were conducted according to the Norwegian handbook *R211*, while the last 4 conventional PLTs (cross section 6 to 9) were conducted according to the German standard *DIN 18134*. The tests at cross section 6 to 8 were conducted with a 300 mm plate, while the test at cross section 9 was conducted with a 600 mm plate. The results for E_1 based on the Swedish calculation method are consistently lower than the Norwegian method for all of the measurements, except for measurement S2-M13. This difference is, however, only statistically significant at the 95% confidence level for the tests performed according to *R211*, and not for the tests conducted according to *DIN 18134*, as shown in Table 5.3. The E_1 values of the PLTs conducted according to *R211* are also consistently lower than for those conducted according to *DIN 18134*. This difference is also statistically significant at the 95% confidence level, for both the Norwegian and the Swedish calculation method, as shown in Table 5.4.

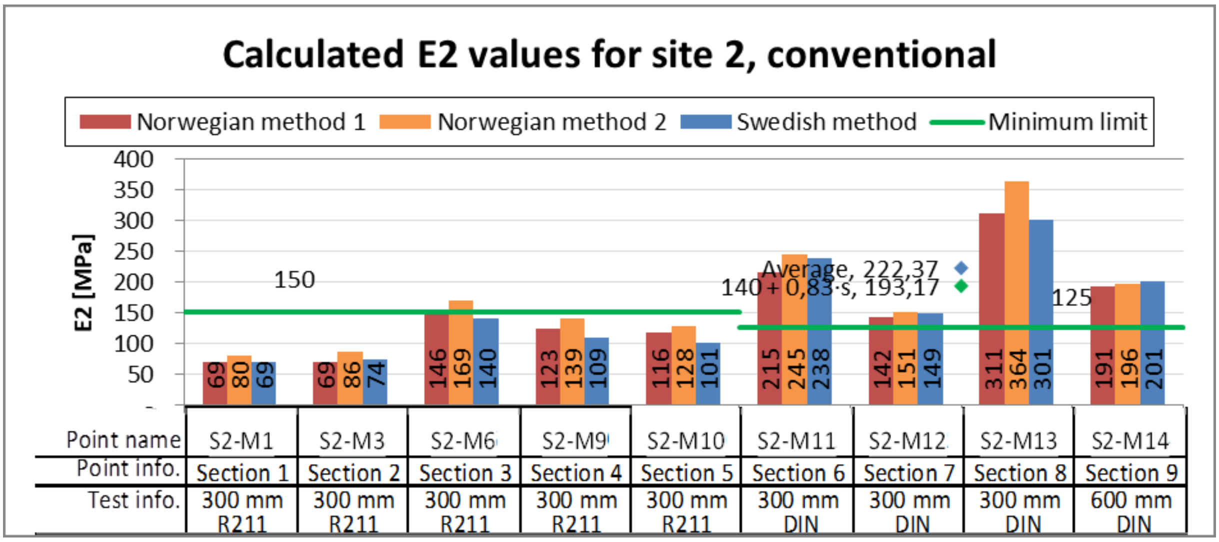


Figure 5.5: Calculated E_2 values for conventional measurements conducted on site 2. The minimum limit shown on the figure correspond to the minimum limit for each E_2 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All four measurements conducted according to* DIN 18134 *are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are only 4 measurements.*

Figure 5.5 shows the calculated E_2 values for the conventional PLTs performed on site 2. Since the tests were performed using different test procedures, the results of PLTs conducted according to *R211* are compared to the minimum limit for E_2 values as defined in the Norwegian handbook *N200*, while the PLTs conducted according to *DIN 18134* are compared to the minimum limit for the average of the E_2-values as defined in the Swedish handbook *TDOK 2013:0530*. To be able to compare the results to the Swedish requirements, all of the measurements conducted according to the German test procedure are considered to belong to the same set of requirements, even though one of the test is conducted using a different plate size than the others. The requirements defined for a sample of n = 5 tests are also used, even though there are only 4 measurements conducted according to the German test procedure. Only one of the PLTs conducted according to *R211* reaches the minimum limit, and only for one of the calculation methods. For the test conducted according to *DIN 18134*, all of the tests reach the minimum limit for all of the calculation methods, and the average of the measurements also fulfils the defined minimum limit for the average.

The difference between the calculated E_2 values using the different calculation method is statistically significant at the 95% confidence level for Norwegian method 2 and the Swedish method, for both test procedures. The difference is also statistically significant for the Norwegian method 1 and 2 for the Norwegian test procedures, while other differences are not statistically significant at this confidence level, as shown in Table 5.3. The difference between the results from the two test procedures is not statistically significant at the 95% confidence level, as evident by the p-values shown in Table 5.4.

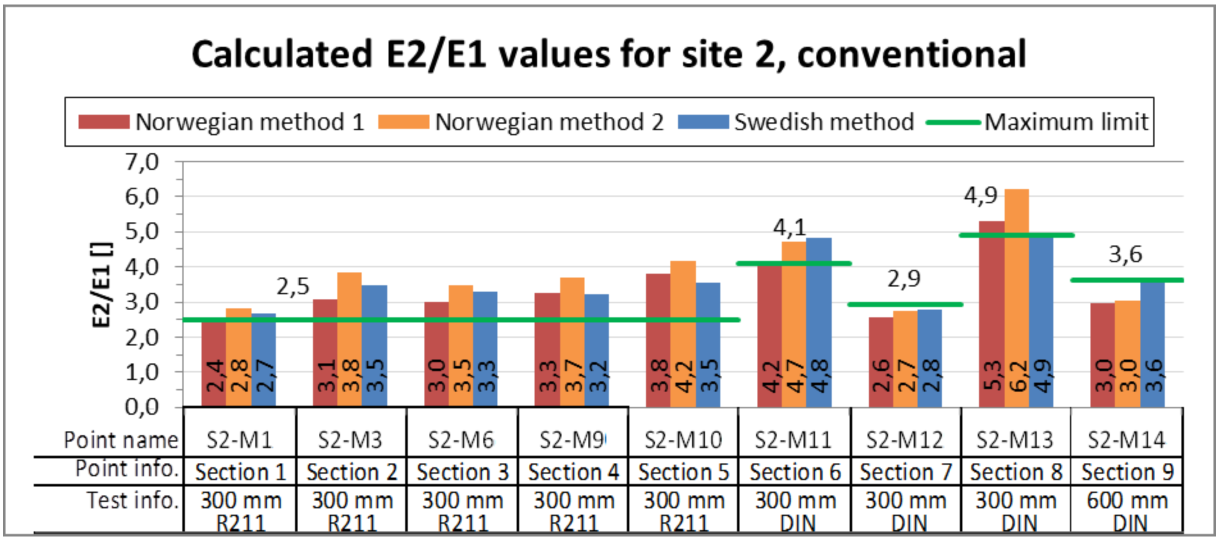


Figure 5.6: Calculated E_2/E_1 values for conventional measurements conducted on site 2. The maximum limit shown on the figure correspond to the maximum limit for E_2/E_1 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The limits for the measurements conducted according to* DIN 18134 *are based on the E_2 values calculated using the Swedish calculation method.*

Figure 5.6 shows the calculated E_2/E_1 ratios for the conventional PLTs performed on site 2. Similarly to the requirements for the E_2 value, the values of the PLTs performed according to *R211* are compared to the maximum value for E_2/E_1 as defined in the Norwegian handbook *N200*, while those performed according to *DIN 18134* are compared to the maximum value as defined in the Swedish handbook *TDOK 2013:0530*. As can be seen from the figure, only one measurement conducted according to *R211*, S2-M1, fulfils the requirement for the ratio, and only for one of the calculation methods, while failing the requirement for the other two. Two of the measurements conducted according to *DIN 18134* fulfil the requirement values.

Table 5.3: The results of a two-sided, paired t-test comparing the calculation methods used for the conventional measurements at site 2, presented in Figure 5.4 and Figure 5.5. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for conventional PLTs at site 2, comparison of calculation method			
	E1	**E2**		
	NOR vs SWE	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
300 mm, R211	**0,02**	0,21	**0,01**	**0,00**
300 mm, DIN	0,73	0,56	**0,01**	0,55

Table 5.4: The results of a two-sided t-test assuming different variances, comparing the results of PLTs conducted on site 2 according to R211 *and* DIN 18134*, presented in Figure 5.4 and Figure 5.5.*

P-values from t-tests for site 2, comparison of 300 mm tests				
E1		**E2**		
NOR	**SWE**	**NOR 1**	**NOR 2**	**SWE**
0,01	**0,00**	0,13	0,16	0,09

In addition to conventional PLTs, supplementary PLTs with two types of added compaction efforts were performed for 3 of the defined cross sections. All of the additional PLTs, as well as the conventional PLTs they are compared to, were conducted according to *R211*. The results of these tests are provided in Figure 5.7, Figure 5.8 and Figure 5.9. The first type of PLTs conducted in the three cross sections, referred to as "Normal" in the figures, are conventional measurements. The results of these conventional PLTs are also presented in Figure 5.4, Figure 5.5 and Figure 5.6. The second type of PLTs conducted in the cross sections, referred to as "PLT2" in the figures, are PLTs that are performed directly after and in the same spot as the first, conventional PLTs. This type of PLT was not performed in cross section 1. The third type of PLTs, referred to as "add. Comp." in the figures, are PLTs performed in the same cross section (but not exact same point) as the conventional PLTs, after an additional compaction with a roller has been performed. The additional compaction efforts consist of 4 vibratory roller passes with low amplitude, followed by 2 static roller passes.

Figure 5.7 shows the calculated E_1 values for the supplementary measurements with additional compaction effort. As can be seen from the figure, the values calculated using the Norwegian and Swedish calculation methods are relatively similar for all of the PLTs, except for measurement S2-M7. The difference between the two calculation methods is not statistically significant at the 95% confidence level for this set of measurements, as evident by the p-values presented in Table 5.5. The difference between the E_1 values for the conventional PLTs compared to the other types of PLTs is not statistically significant at the 95% confidence level either, given the measurements provided, as evident by the p-values presented in Table 5.6. By looking at the values displayed in Figure 5.7, one can reasonably deduct that the reason for the statistical insignificance of the difference between the PLT types is due to the limited sample size, at least for the comparison of the conventional PLTs to the second PLT measurements. This suspicion is backed up by the inclusion of fictions values in the comparison of the PLT measurements. For the

“Normal vs. add. Comp.” comparison, the mean of the calculated values was added as a fictive measurement. For the “Normal vs. PLT 2” comparison, two sets of fictive measurements were created, with values equally distanced in the range between the actual measurements. As can be seen in Table 5.6, the inclusion of the fictive measurements in the comparison resulted in statistical significance at a 95% confidence level for the difference between the E_1 value of the conventional PLT and the PLT after additional roller compaction, using the Swedish calculation method, as well as for both calculation methods for the comparison of the conventional PLT and PLT 2.

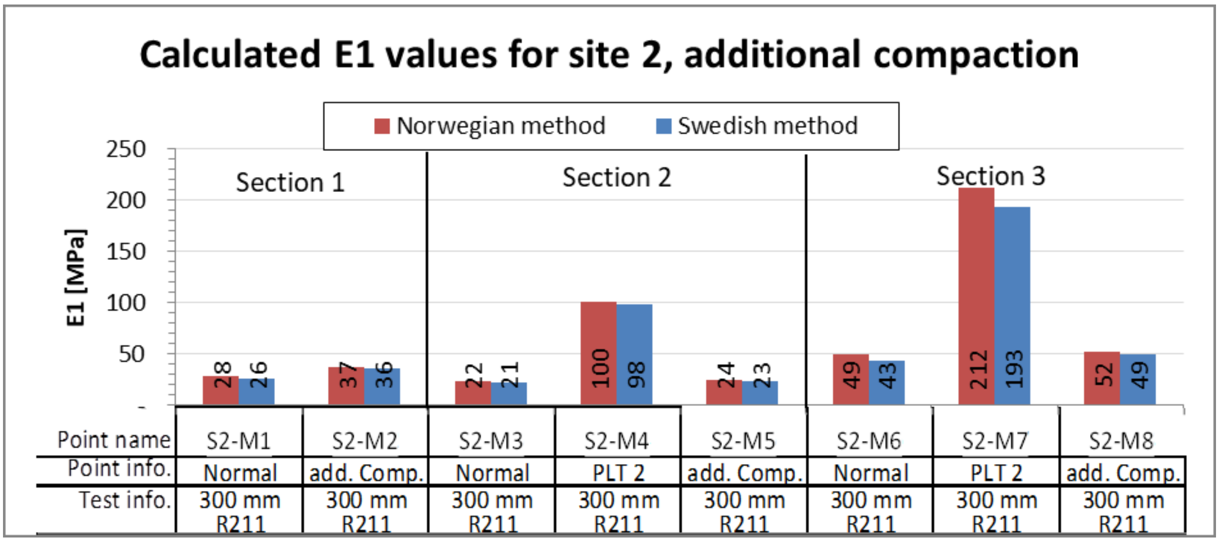


Figure 5.7: Calculated E_1 values for measurements conducted after additional compaction efforts on site 2. The additional PLTs were performed on 3 of the cross sections, referred to as “sections” in the figure.

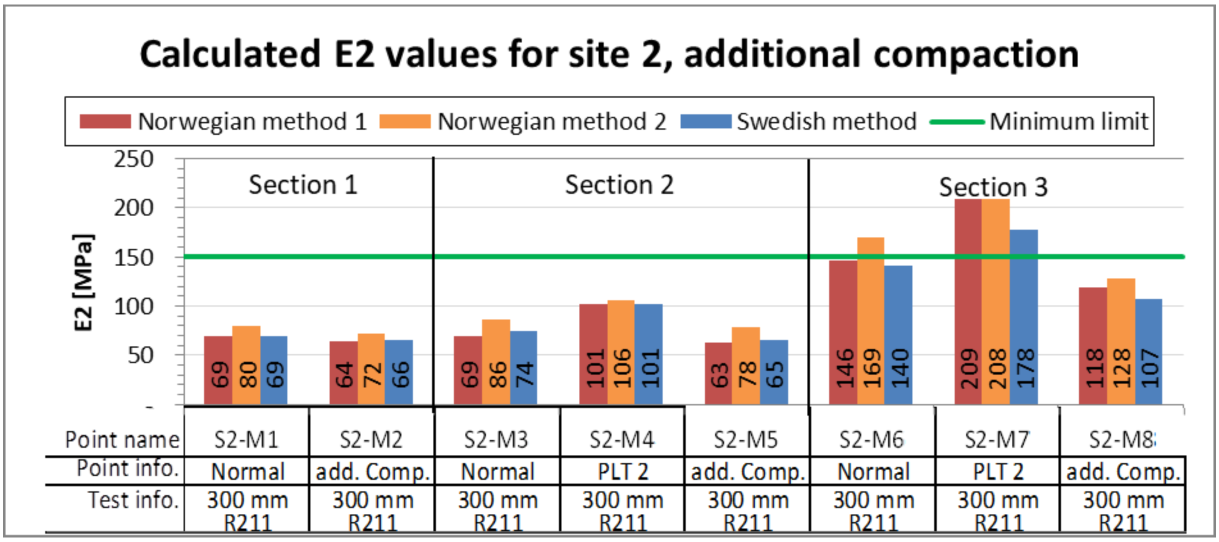


Figure 5.8: Calculated E_2 values for measurements conducted after additional compaction efforts on site 2. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200*, 150 MPa.*

Figure 5.8 shows the calculated E_2 values for the supplementary measurements with additional compaction effort. As can be seen from the figure, none of the calculated E_2 values for cross section 1 and 2 fulfil the minimum requirement defined in the Norwegian handbook *N200*, not even the second PLT in cross section 2. Only the value for the second PLT in cross section 3 fulfils the minimum requirement for all calculation methods, and only the Norwegian method 2 value for the conventional PLT of the cross section. The difference between the calculation methods is not statistically significant at a 95% confidence level, except for the difference between Norwegian method 1 and 2, as can be seen from the values in Table 5.5. The difference between the values before and after the additional compaction efforts is not statistically significant at a 95% confidence level, given the data provided, as can be seen from Table 5.6. However, as with the values for E_1, it is reasonable to suspect that the statistical insignificancy stems from the limited sample size. The difference between the conventional PLTs and the second PLTs is statistically significant at a 95% confidence level when the fictive measurements described above are included, while the difference between the conventional PLTs and the PLTs after additional roller compaction remains statistically insignificant.

It is also interesting to compare the E_2 values of the conventional PLTs to the E_1 values of the second PLTs. For both cross section 2 and 3, the E-values increase stepwise between the consecutive load cycles, from E_1 of PLT 1, to E_2 of PLT 1, up to E_1 of PLT 2. However, the increase between the load steps of the second PLT, from E_1 of PLT 2 to E_2 of PLT 2, is minimal. This suggests that applying additional load cycles after the second PLT is unlikely to result in changes in the calculated E-values.

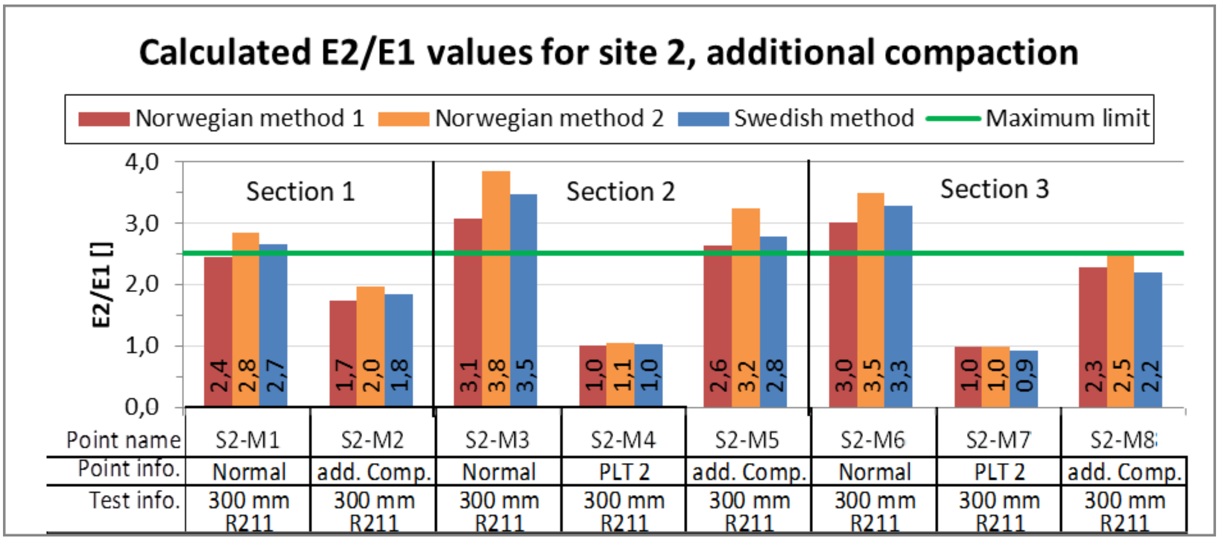


Figure 5.9: Calculated E_2/E_1 values for measurements conducted after additional compaction efforts on site 2. The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook N200*; 2,5.*

The calculated E_2/E_1 ratios for each of the supplementary tests are shown in Figure 5.9. The figure shows that none of the conventional PLTs fulfil the maximum requirement for the ratio defined in the Norwegian handbook *N200*, except for the conventional value for cross section 1 calculated using Norwegian method 1. All except one of the PLTs with additional compaction efforts (S2-M5) fulfil the maximum requirement for the ratio. Interestingly, the ratio for both of the second PLT measurements is approximately 1 for all of the calculation methods. In other words, for both of the second PLT measurements, $E_2 = E_1$. This suggests that the E-values in the points measured have become relatively stable, and that minimal changes in the load-settlement curves should be expected, even with further compaction (given that no crushing of the material occurs). This is even more interesting given that the E_2 value of the second PLT measurement in cross section 2 did not fulfil the defined requirements.

Table 5.5: The results of a two-sided, paired t-test comparing the calculation methods used for the measurements with added compaction effort at site 2, presented in Figure 5.7, Figure 5.8 and Figure 5.9. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for PLTs with added compaction at site 2, comparison of calculation method			
	E1	E2		
Comparison	**NOR vs SWE**	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
PLT 2	0,43	0,50	0,41	0,60
Add. Comp.	0,17	0,59	0,08	**0,03**

Table 5.6: The results of a two-sided, paired t-test comparing the results of PLTs with added compaction efforts conducted on site 2, presented in Figure 5.7 and Figure 5.8. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for PLTs with added compaction at site 2, comparison of additional compaction efforts				
	E1		E2		
Comparison	**NOR**	**SWE**	**NOR 1**	**NOR 2**	**SWE**
Normal vs add. Comp.	0,16	0,12	0,23	0,23	0,24
Normal vs add. Comp. with fictive measurements	0,05	**0,04**	0,09	0,09	0,10
Normal vs. PLT 2	0,22	0,20	0,20	0,20	0,10
Normal vs. PLT 2 with fictive measurements	**0,01**	**0,01**	**0,01**	**0,01**	**0,00**

5.1.3 Site 3: The new motorway project

5.1.3.1 Interview

The interviewee felt that the compaction work on the site in general had gone pretty well and without major issues. The contractor experienced some challenges with PLTs early on in the project, but after the requirements of the 2018 version of handbook *N200* were implemented in the projects, those challenges seem to have been solved.

The project consists of one main road (the motorway) with high traffic volumes and a few smaller side roads with lower traffic volumes. The main road is constructed with a subbase of 22/120 crushed rock and an interlocking layer of 0/32 Fk, while the lower volume roads are constructed with a subbase of 22/90 crushed rock and a lower base course of 0/32 Ak. The roads are mainly constructed on top of subsoil in the frost susceptibility class T2. The embankments in the project approach 20 m in height in some places, and are constructed of local crushed rock in class T2. The material for base courses and interlocking layers are provided by an external supplier, while the subbase material and the filler material in the embankments is local material from the site and is crushed and stored on site by the contractor. Not all of the local, crushed rock has adequate material properties to be used in the subbase, and is therefore used as filler material in embankments instead. The filler material is therefore generally of lower quality than the material in the subbase.

The contractor organizes and conducts all of the required PLTs themselves. Since this is a turnkey project, the owner builder is not obliged to perform any follow-up tests to monitor the work of the contractor, but is in turn responsible for approving the PLT results and any deviations from the requirements. In the early stages of the projects, when the contractor was experiencing difficulties with the results of PLTs, both the contractor and the owner builder hired an external consultant to perform PLTs, as well as to give advice on the tests.

The requirements in the 2018 version of handbook *N200* were incorporated into the project's contract soon after the version was published. This was done for two major reasons; to be able to use local, crushed rock in the subbase, and to attempt to get better results from PLTs. The local crushed rock used in the superstructure meets the material requirements in terms of the LA-value, but not in terms of the Micro-Deval value based on the requirements in the 2014 version of *N200*. In the 2018 version, the requirements for the Micro-Deval value have been changed, and the local crushed rock fulfils those new requirements. Thus, by incorporating the requirements in the 2018 version of the handbook into the contract, the subbase material could be produced on site, and didn't need to be purchased from an external supplier. Additionally, the requirements for the interlocking layer were changed in the 2018 version of the handbook. The 2018 version permits a greater fines content in the interlocking material than the 2014 version, yet simultaneously sets stricter requirements for the allowable thickness of the interlocking layer than the earlier version of the handbook. The estimated fines content of the interlocking material after the implementation of the 2018 version of the requirements is between 5% and 6%, when the material has been compacted (measurements at the crushing plant show a fines content of ca. 4%), while the 2014 version of *N200* required the fines content to be no higher than 3%. The interviewee believes that the increased fines content in the interlocking layer is the reason for the positive change in the PLT results. This has been tested by the contractor on a test section on site, but without conclusive results.

Another change that was implemented at the same time as the requirements from the 2018 version of the handbooks were incorporated into the contract, is the time between the compaction of the interlocking layer to the performance of the PLTs. Before the change, the PLTs were performed almost immediately after compaction, while after the change, the PLTs are performed at least 1 day (preferably 2 days) after the compaction is completed.

In addition to the aforementioned changes, the contractor and the owner builder of the project have agreed upon a common, less strict interpretation of the number of measurements that must be approved for a test section. Contrary to the requirements in *N200*, a test section is approved without any further consideration if 9 out of 10 tests fulfil the requirements. If less than 9 out of 10 tests fulfil the requirements, the test section is not approved, and a deviation report must be filled out.

The compaction of the superstructure materials has generally been unproblematic in regards to plate load testing, with the exception of the materials in the main road structure prior to the implementation of the requirements in the 2018 version of *N200*. The materials where the challenges were experienced were compacted in the spring and summer of 2018 in generally dry weather without significant precipitation. The challenges were not experienced after the new requirements were implemented. Fulfilling the requirements for the PLTs has not been challenging for the materials in the lower volume roads. The interviewee believes this is due to the difference in the grading curve of the superstructure materials of the low volume roads compared to the main road, and suspects that the finer grade material gives better results from the PLTs.

5.1.3.2 Data files

The calculated values for measurements conducted on site 3 are presented in Figure 5.10 to Figure 5.15. A more detailed overview of the measurements and the calculations corresponding to each PLT is provided in Appendix 6.

Figure 5.10 and Figure 5.11 show the calculated E_1 values for the PLTs provided for site 3, conducted with a 300 mm and 600 mm diameter plates, respectively. Four of the tests performed with a 300 mm diameter plate were conducted according to the procedure described in the Norwegian handbook *R211*, while five of them were conducted according to the German standard *DIN 18134*. All five of the tests performed with a 600 mm plate diameter were conducted according to *DIN 18134*. Only two of the PLT measurements (S3-M3 and S3-M4) were conducted after the requirements from the 2018 version of handbook *N200* were incorporated into the contract, so all of the other measurements were constructed with in accordance to the requirements of the 2014 version. As can be seen from the two figures, three of the tests (S3-M4, S3-M6 and S3-M8) have noticeably higher values than the others, reaching values of over 120 MPa for both calculation methods. The difference between the calculation methods is not statistically significant at a 95% confidence level, except for the tests conducted with a 600 mm diameter plate, as can be seen from the p-values provided in Table 5.7. The difference between the measurements conducted with the 2018 version requirements from *N200* (measurement S3-M3 and S3-M4) and the corresponding measurements conducted according to *R211* with the 2014 version requirements is not statistically significant at a 95% confidence level, as evident by the p-values in Table 5.8. As for previous comparisons of small sample sizes, the statistical insignificance can stem from the limited amount of data provided. Two additional fictive measurements were created for each set of measurements, with values equally distanced in the range between the actual measurements. A comparison of the actual and the fictive measurements shows that the difference between the values is statistically significant at a 95% confidence level. This indicates that if the provided actual measurements are representative of the population, an analysis of a greater number of measurements would possibly conclude that the difference is statistically significant at a 95% confidence level. The results of a comparison of the test procedures and plate sizes used, excluding the two measurements performed after the incorporation of the 2018 version requirements (tests S3-M3 and S3-M4), are presented in Table 5.9. The differences between the measurements conducted according to R211 and the measurements conducted according to *DIN 18134* are statistically significant at a 95% confidence level for both plate sizes used, while the difference between the plate sizes of measurements conducted according to *DIN 18134* are not.

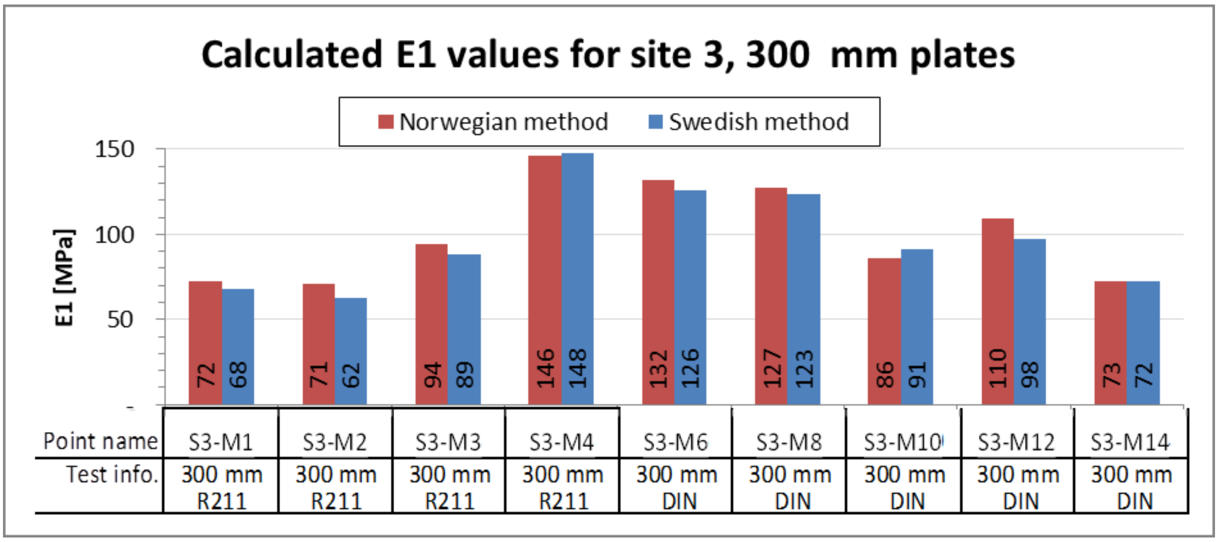


Figure 5.10: Calculated E_1 values for measurements conducted with 300 mm diameter plates on site 3

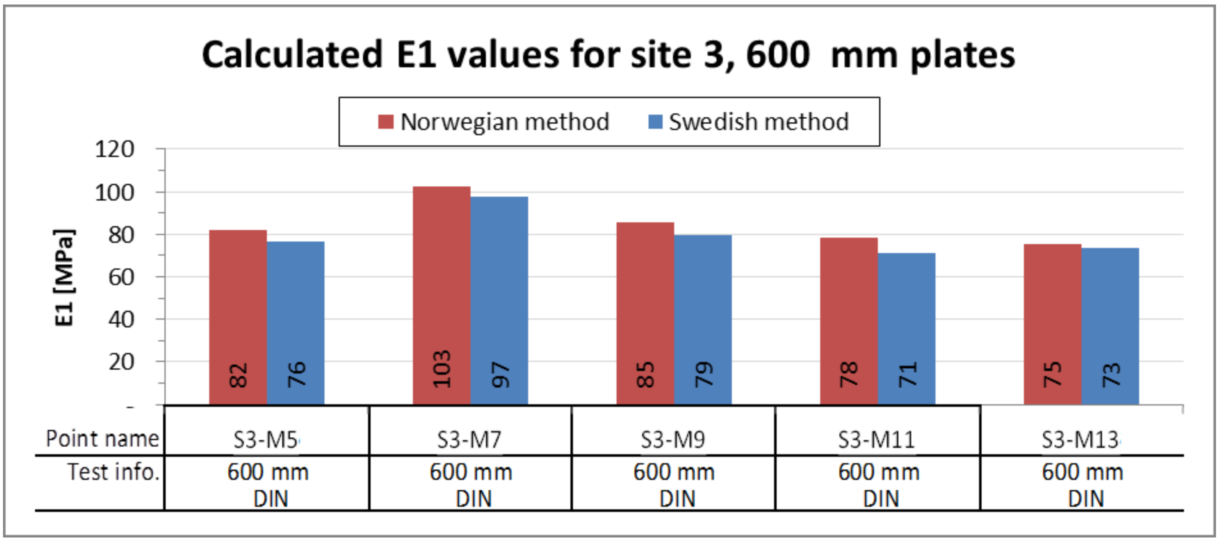


Figure 5.11: Calculated E_1 values for measurements conducted with 600 mm diameter plates on site 3

Figure 5.12 and Figure 5.13 show the calculated E_2 values for the PLTs provided for site 3, conducted with a 300 mm and 600 mm diameter plates, respectively. As can be seen from the figures, all of the calculated E_2 values fulfil the defined minimum requirements, except for the value for S3-M2 calculated using the Swedish calculation method. The averages of the test performed according to *DIN 18134* also fulfil the defined minimum requirements for the average of measurements. All calculations to determine the requirements for measurements conducted according to *DIN 18134* are based on the results of the Swedish calculation method. The differences between the calculation methods are not statistically significant, except for the difference between Norwegian method 2 and the Swedish method for PLTs conducted with 600 mm diameter plates, as can be seen from Table 5.7. The difference between the measurements performed pre and post incorporation of the 2018 version requirements, for PLTs conducted according to *R211* is not statistically significant at a 95% confidence level, regardless of whether fictive measurements are included or not. The p-values for this comparison can be found in Table 5.8. There is a statistically significant difference at a 95% confidence level between the measurements conducted with 300 mm diameter plates according to *R211* and *DIN 18134*, for all calculation methods. The difference between the tests conducted according to *DIN 18134* with 300 mm and 600 mm plate diameters is not statistically significant at a 95% confidence level, except for the Swedish calculation method. The difference between tests conducted with 300 mm plates according to *R211* and 600 mm plates conducted according to *DIN 18134* is not statistically significant for any of the calculation methods. The p-values for the comparisons of different plate sizes and test procedures are provided in Table 5.9.

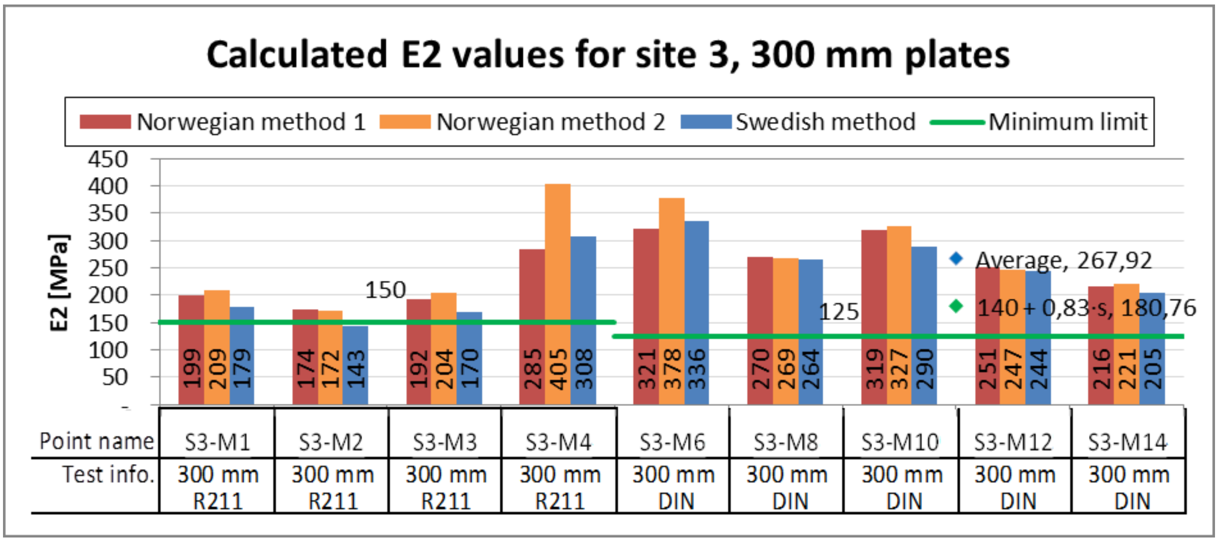


Figure 5.12: Calculated E_2 values for measurements conducted with 300 mm diameter plates on site 3. The minimum limit correspond to the minimum limit for E_2 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All five measurements conducted according to* DIN 18134 *are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5.*

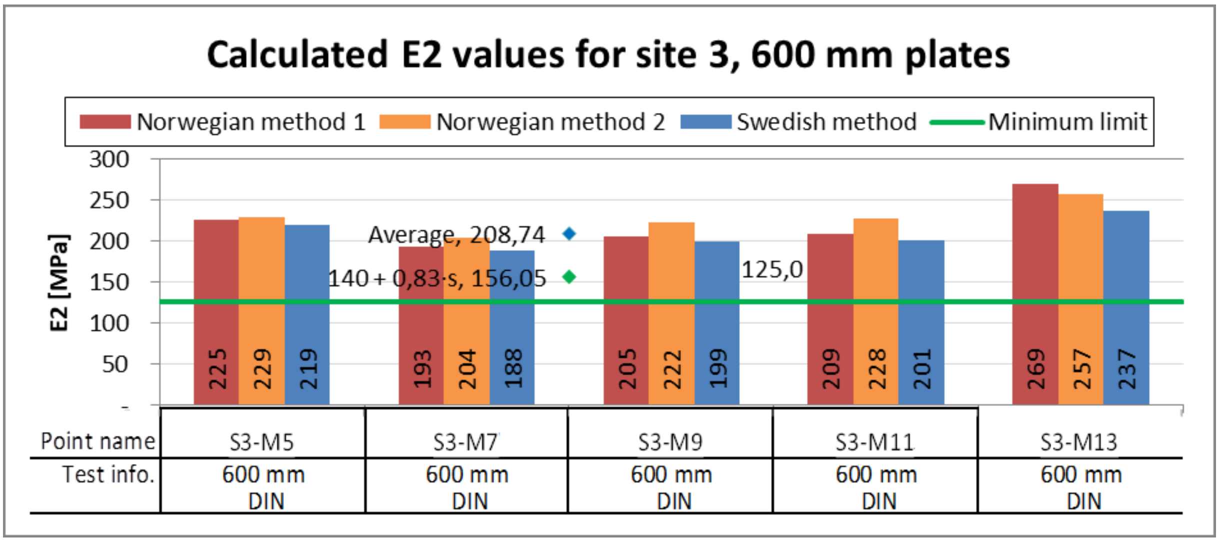


Figure 5.13: Calculated E_2 values for measurements conducted with 600 mm diameter plates on site 3. The minimum limit corresponds to the minimum limit for E_2 on top of a base course as defined in the Swedish handbook TDOK 2013:0530*. The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All five measurements are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5*

The calculated E_2/E_1 ratios for the PLTs provided for site 3, conducted with a 300 mm and 600 mm diameter plates, are presented in Figure 5.14 and Figure 5.15, respectively. As can be seen from the two figures, all of the points fulfil the defined minimum requirement for the ratio, except measurement S3-M1 and the value from Norwegian method 2 for measurement S3-M4. The maximum limits defined by the Swedish handbook *TDOK 2013:0530* are noticeably higher than the requirement defined in the Norwegian handbook *R211*, which effects the number of accepted PLTs greatly in this case.

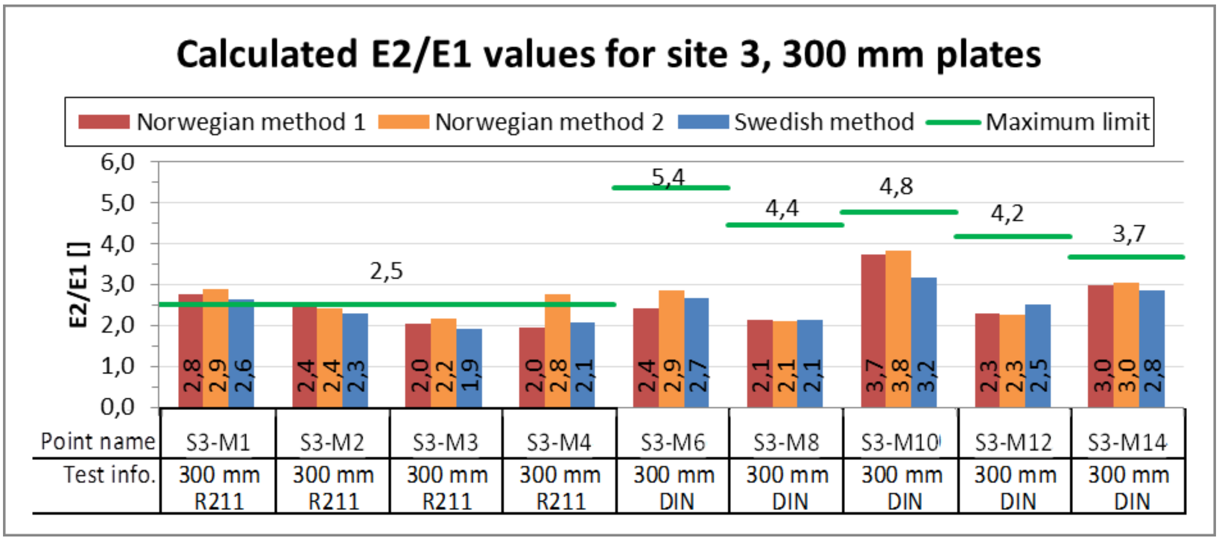


Figure 5.14: Calculated E_2/E_1 values for measurements conducted with 300 mm diameter plates on site 3. The maximum limit shown on the figure correspond to the maximum limit for E_2/E_1 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The limits for the measurements conducted according to* DIN 18134 *are based on the E_2 values calculated using the Swedish calculation method.*

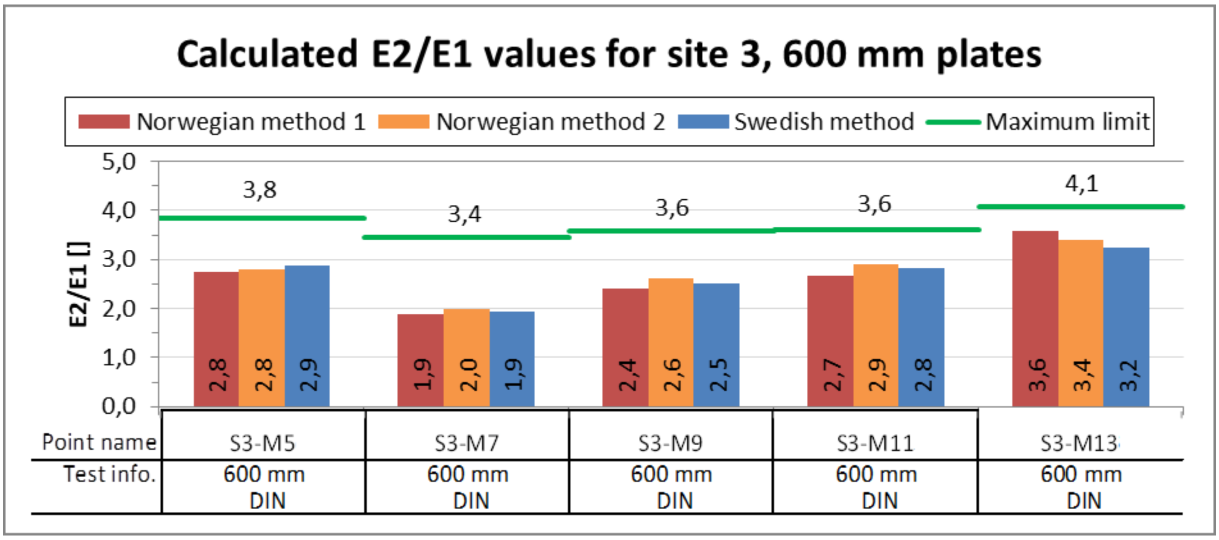


Figure 5.15: Calculated E_2/E_1 values for measurements conducted with 600 mm diameter plates on site 3. The maximum limit shown on the figure corresponds to the maximum limit for E_2/E_1 on top of a base course as defined in the Swedish handbook TDOK 2013:0530*. The limits are based on the E_2 values calculated using the Swedish calculation method.*

Table 5.7: The results of a two-sided, paired t-test comparing the calculation methods used for the measurements at site 3, presented in Figure 5.10 to Figure 5.13. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for site 3, comparison of calculation method			
	E1	**E2**		
Comparison	**NOR vs SWE**	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
300 mm, R211	0,16	0,37	0,06	0,31
300 mm, DIN 18134	0,32	0,35	0,07	0,32
600 mm, DIN 18134	**0,00**	0,09	**0,00**	0,24

Table 5.8: The results of a two-sided t-test assuming different variances, comparing the measurements at site 3 with 2014 version requirements and 2018 version requirements of handbook N200, presented in Figure 5.10 and Figure 5.12. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for site 3, comparison of results with 2014 version vs 2018 version of N200				
	E1		**E2**		
	NOR	**SWE**	**NOR 1**	**NOR 2**	**SWE**
Only true measurements	0,31	0,32	0,46	0,45	0,46
With fictive measurements	**0,02**	**0,02**	0,08	0,07	0,08

Table 5.9: The results of a two-sided t-test assuming different variances, comparing the different test procedures and plate sizes at site 3, presented in Figure 5.10 to Figure 5.13. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for site 3, comparison of plate sizes and test procedures				
	E1		**E2**		
	NOR	**SWE**	**NOR 1**	**NOR 2**	**SWE**
300 mm R211 vs 300 mm DIN 18134	**0,04**	**0,02**	**0,01**	**0,04**	**0,02**
300 mm DIN 18134 vs 600 mm DIN 18134	0,15	0,09	0,06	0,10	**0,05**
300 mm R211 vs 600 mm DIN 18134	**0,05**	**0,04**	0,15	0,25	0,18

5.1.4 Site 4: The motorway upgrading project

5.1.4.1 Interview

The interviewees think that the compaction of superstructure materials has gone well in general, but that it can be challenging to fulfil the requirements for PLTs. They have noticed a negative difference in the PLT results if there is less than optimal time available, and if the weather has been rainy or humid. Digital equipment and measurements have also caused some challenges due to poor connection between the devices, since many of the processes using the devices are performed simultaneously.

There are 2 workers on the site that are responsible for performing the PLTs and oversee the compaction process in general (hereafter referred to as the site's test performers). The test performers are trained in how to perform the test before they are made responsible for them, to try to ensure that the tests are performed as similarly as possible. The contractor uses both 600 mm and 300 mm plates for testing, although the 600 mm plates are only used as an internal control method for compaction of coarse material, and can not be used as formal documentation of compaction. The tests using the 300 mm diameter plate are performed according to *R211*, while the tests using the 600 mm diameter plate are performed according to the German standard *DIN 18134*. The tests using a 300 mm plate diameter are performed on top of the interlocking layer, every 250 m in each lane (due to the use of response measurements in the rollers), in convenient place within the cross section, often the centre of the lane. The tests are usually performed at least 3 days after the compaction has been completed, but this varies based on the progress and time constraints of the overall project. The use of levelling material under the test plate is generally omitted, since the test performers feel that the pre-loading step of the test procedures evens out any unevenness on the surface. A thin layer of fine sand is occasionally used where it is deemed necessary. The E-values are calculated automatically by the PLT measuring equipment, and the results of the tests are available instantaneously after the test is finished. The E-values were previously calculated according to the method described in the German standard *DIN 18134* (referred to as the Swedish calculation method in the thesis) for both plate sizes, but are now calculated according to *R211* for the 300 mm diameter plate.

The superstructure used in the project includes a frost protection layer of 0/250 crushed rock, a subbase of 22/120 crushed rock, and an interlocking layer of Ak. Some areas are also constructed with XPS insulation boards beneath the frost protection layer, due to problematic subsoil conditions. The crushed rock material is delivered to the site from an external supplier that crushes local rock from the area. The supplier stores most of the material before it is used, but it was previously stored by the contractor in heaps on site.

It was especially challenging to fulfil the PLT requirements on the section where the XPS insulation was used in the superstructure. The section was compacted in the fall of 2018, continuously over a relatively long period with varied weather conditions. The response measurements were consistently lower over the areas with the XPS boards, as well as being very homogeneous with a noticeable divide where the superstructure changed to not include the XPS. The PLTs were also performed continuously during period following the compaction period, at least 3 days after the compaction was completed. The weather was cloudy and humid over the whole test period, with frost in the early morning. The tests were taken when the frozen water in the superstructure had melted, and the moisture content in the interlocking layer was noticeably high during the whole period. The first set of tests did not fulfil the requirements and the contractor decided to redo the measurements after a few days had passed to see if the waiting time alone would improve the results. The measurements were redone twice with improved results each time. However, none of the final tests in this section of the road reached the required limits, and the owner builder of the project accepted the poor values in that area after a deviation report had been filed. The test performer believe that the poor results stem from the use of both Ak and the XPS, and that the first set of results were poor due to the amount of water in the Ak, while the last set of results were poor due to the use of the XPS boards.

There are generally no consequences for the contractor when the PLTs don't fulfil the requirements, and the tests are therefore usually not redone. The asphalt is usually laid out on top of the interlocking layer regardless of the results of the PLTs due to time constraints. The contractor made an exception for the XPS section because there was time available to redo the tests, and they wanted to test if the time aspect alone made a difference, without any additional compaction effort.

There are no sections in particular that have been especially problem-free in regards to the PLT requirements. It has generally been rather unpredictable whether the PLTs fulfil the requirements or not, and the requirement for the ratio between the E-values is generally more challenging to fulfil. The test performers believe that the results of the PLTs are very dependent on the time that passes between the compaction has been completed up until the PLT is conducted, as well as the moisture content in the superstructure materials, where a short amount of time and a high moisture content influence the results negatively. The test results are therefore influenced greatly by the weather the days prior to the tests as well as during the test, and the superelevation and overall geometry of the road, although there seems to be little difference between tests performed in soil cuts compared to tests performed on embankments. Tests performed during a rainy period in a low point in the road geometry will thus likely lead to relatively poor test results. Ak seems to be especially sensitive to the moisture content. The contractor has plans to test if the moisture content in the superstructure can be controlled by using side-less tents to cover the road prior to testing.

The interviewees think that the Norwegian requirements for PLTs are unreasonable, since they don't differentiate between which materials are used in the superstructure, and no deviations are allowed. They think that the German and Swedish requirements are more reasonable, since they allow for some deviation.

5.1.4.2 Data files

The calculated values for measurements conducted on site 4 are presented in Figure 5.16, Figure 5.17 and Figure 5.18. A more detailed overview of the measurements and the calculations corresponding to each PLT is provided in Appendix 6.

Figure 5.16 presents the calculated E_1 values for the eleven PLTs provided for site 4. Five of the measurements (S4-M1 to S4-M5) were conducted in 2018 on sections of the road where the superstructure contains XPS insulation boards, using the test procedure described in the German standard *DIN 18134*. The six remaining measurements (S4-M6 to S4-M11) were conducted in 2019 while the author was present, on sections of the road without any use of XPS boards, using the test procedure described in the Norwegian handbook *R211*. As can be seen from the figure, there is little to none difference between the values calculated according to the two calculation methods, especially for the measurements conducted on the superstructure with XPS boards. The p-values shown in Table 5.10 also confirm that the difference between the calculation methods is not statistically significant at a 95% confidence level. There is, however, a noticeable difference in the values measured on the superstructure with XPS boards compared to those measured with no XPS boards. The values in Table 5.11 also show that this difference is statistically significant at a 95% confidence level. Since the tests with and without XPS boards are also conducted using two different test procedures, it cannot be reasonably assumed that the difference in the measurements stems solely from the XPS boards. The difference related to the difference in test procedures is also present in the measurements, and it is impossible to determine how much of the difference stems from the different test procedures and how much of it stems from the difference in superstructure.

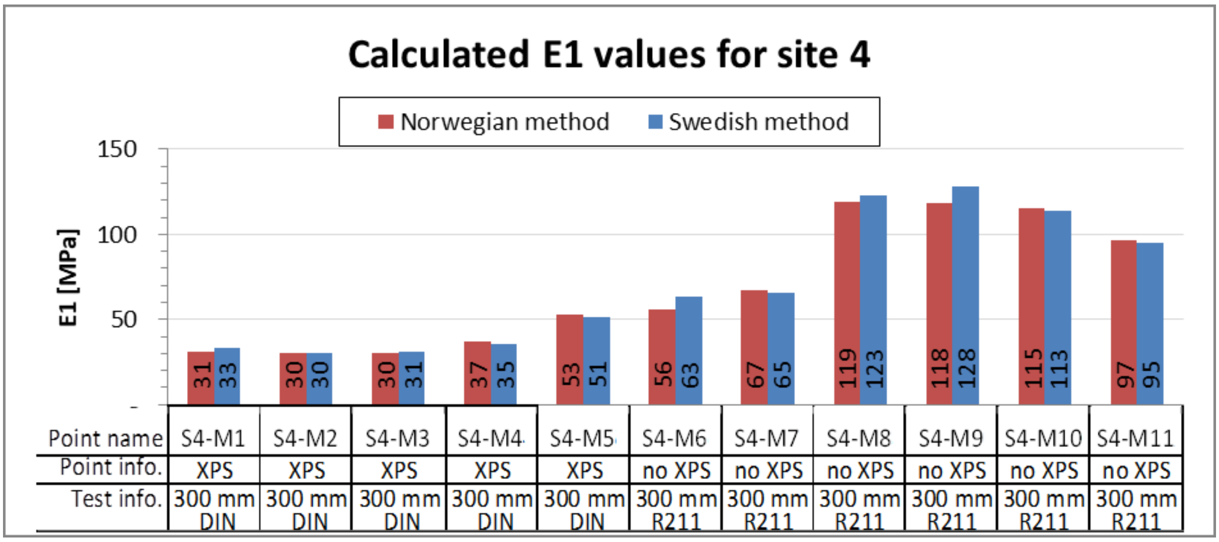


Figure 5.16: Calculated E_1 values for measurements conducted on site 4.

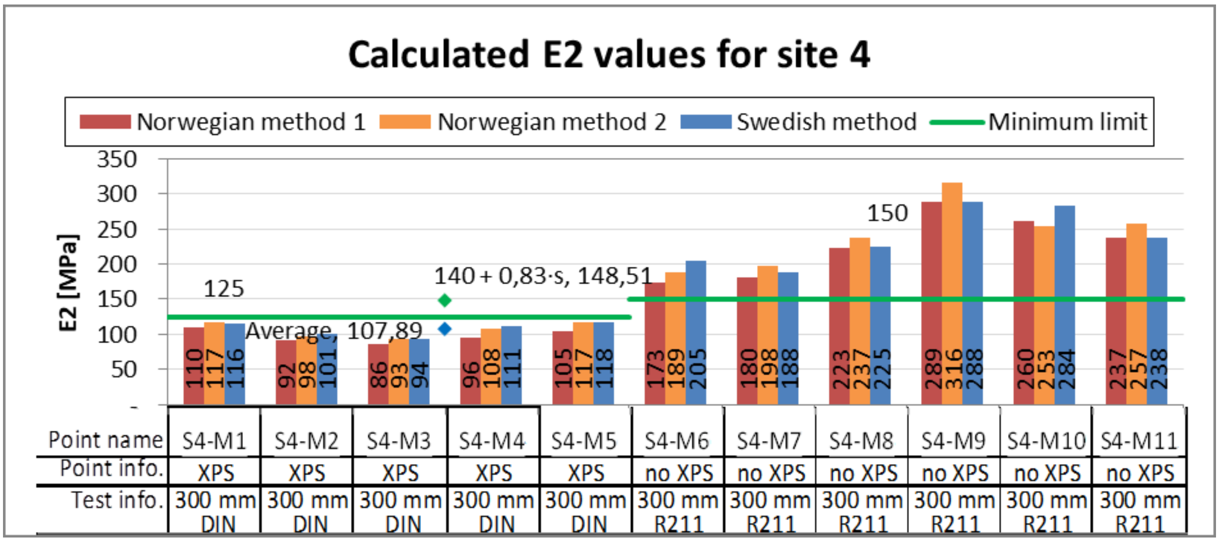


Figure 5.17: Calculated E_2 values for measurements conducted on site 4. The minimum limit shown on the figure correspond to the minimum limit for E_2 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All five measurements conducted according to* DIN 18134 *are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5.*

The calculated E_2 values for the PLTs provided for site 4 are presented in Figure 5.17. As can be seen from the figure, none of the measurements conducted on the section of the road containing XPS boards fulfil the minimum requirement, while all of the measurements conducted on the section without XPS do. Additionally, the average of the measurements conducted on the road section with XPS does not meet the defined minimum requirement for the average. All calculations in order to determine the requirements for measurements conducted according to *DIN 18134* are based on the results of the Swedish calculation method. The difference between the calculation methods Norwegian method 1 and Norwegian method 2 is statistically significant at a 95% confidence level for both sets of measurements, and the difference between the Norwegian method 1 and the Swedish method for the XPS measurements is also statistically significant at a 95% confidence level. The differences between other calculation methods are not statistically significant at this confidence level, as can be seen from the p-values presented in Table 5.10. As for the E_1 values, the difference between the measurements conducted on the road section with XPS compared to the road section without XPS is statistically significant at a 95% confidence level. This is presented in Table 5.11.

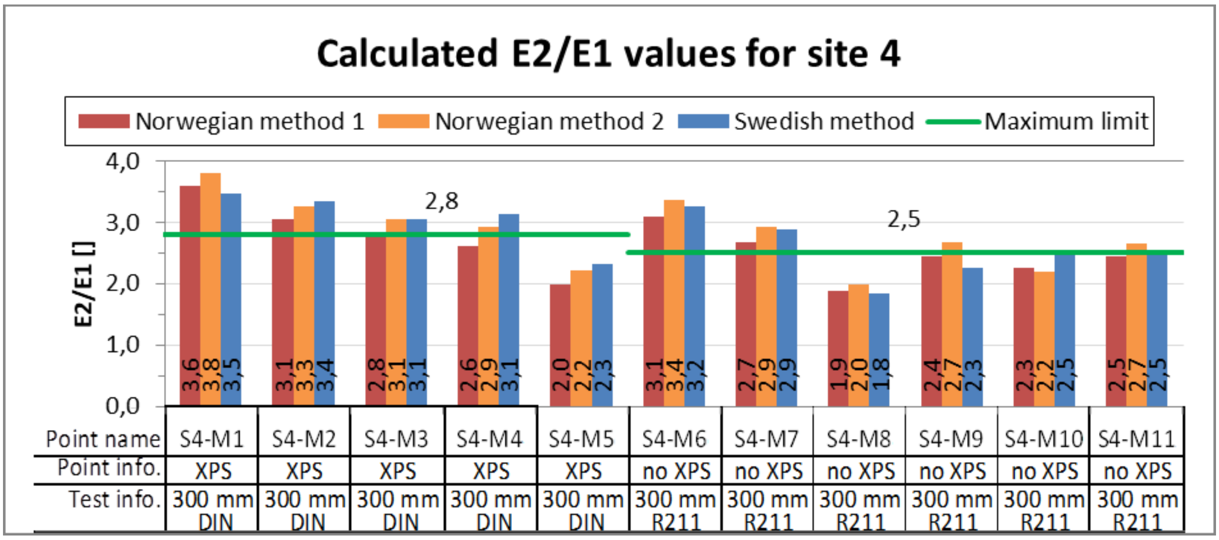


Figure 5.18: Calculated E_2/E_1 values for measurements conducted on site 4. The maximum limit shown on the figure correspond to the maximum limit for E_2/E_1 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and as defined in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The limits for the measurements conducted according to* DIN 18134 *are based on the E_2 values calculated using the Swedish calculation method.*

Figure 5.18 shows the calculated E_2/E_1 ratios for the measurements provided for site 4. As can be seen from the figure, only one measurement of the PLTs conducted on the road section with XPS (S4-M5) meets the maximum requirement value for all calculation methods, and two measurements (S4-M4 and S4-M3) meet the requirement for Norwegian method 1 only. Two of the measurements conducted on the road section without XPS (S4-M8 and S4-M10) fulfil the maximum requirement for all of the calculation methods, while two additional measurements (S4-M9 and S4-M11) fulfil the requirement for Norwegian method 1 and the Swedish method, but not for Norwegian method 2. All of the other measurements exceed the defined maximum requirements.

Table 5.10: The results of a two-sided, paired t-test comparing the calculation methods used for the measurements at site 4, presented in Figure 5.16 and Figure 5.17. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for site 4, comparison of calculation method			
	E1	E2		
Comparison	**NOR vs SWE**	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
300 mm, R211 (no XPS)	0,29	0,11	0,71	**0,03**
300 mm, DIN 18134 (XPS)	0,96	**0,00**	0,10	**0,00**

Table 5.11: The results of a two-sided t-test assuming different variances, comparing the measurements at site 4 on superstructures with XPS to those without XPS, presented in Figure 5.16 and Figure 5.17. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

P-values from t-tests for site 4, comparison of results with XPS vs no XPS				
E1		E2		
NOR	**SWE**	**NOR 1**	**NOR 2**	**SWE**
0,00	**0,00**	**0,00**	**0,00**	**0,00**

5.1.5 Comparison of the cases

In addition to comparing PLT measurements within each case, the cases were also compared to each other. The p-values of a two sided t-test assuming different variances for each of the site comparisons are presented in Table 5.12.

Four different comparisons were made between the sites of the case study. Site 3 and 4 were compared in order to compare the use of Ak and Fk in the interlocking layer of a superstructure. Site 3 and 4 are the most similar when it comes to superstructure, moisture content, type of road and traffic volume, and were therefore chosen for this comparison. Only the measurements of the superstructure without XPS were included from site 4, and only the measurements conducted according to R211 were included from site 3. The comparison was divided into two, separating the measurements from site 3 based on whether the superstructure materials comply with the 2014 or 2018 version of handbook *N200*. As can be seen from Table 5.12, there is statistically significant difference at a 95% confidence level between the E_1 values of site 4 and the measurements from site 3 that are compliant with the 2014 version of *N200*, when using the Swedish calculation method, but not the Norwegian calculation method. The same can be said about the difference between the E_2 values of the two sites. Site 4 thus has significantly higher E-values than the measurements from site 3 compliant with the 2014 version of *N200*, but only when using the Swedish calculation method. There is no statistically significant difference between the E-values of site 4 and the measurements from site 3 that are compliant with the 2018 version of *N200*. Since the number of measurements conducted according to R211 on site 3 is quite limited, two additional fictive measurements were created for each set of measurements from site 3, with values equally distanced in the range between the actual measurements. As Table 5.12 shows, the addition of the fictive measurements did not result in drastic changes in the statistical significance of the differences between the measurements. Given that the actual measurements provided are representative of the total population, it is therefore reasonable to assume that analysing a greater number of measurements from site 3 is not likely to result in a statistically significant difference at a 95% confidence level.

Site 1 and 4 were compared in order to compare the effect of the moisture content in the Ak of the interlocking layer on the results of PLTs. These two sites were chosen since the relative moisture content in the superstructure materials can be predicted quite accurately, since the moisture content in the tunnels in site 1 is relatively high with little variation throughout the year, and the author was present during the measurements at site 4 and can verify that the moisture content during the measurements was relatively low. The comparison was divided into two, separating the measurements from site 1 based on whether they were taken in tunnel 1 or 2. As can be seen from Table 5.12, there is statistically significant difference at a 95% confidence level between the E_2 values of site 4 and the measurements from site 1 conducted in Tunnel 2, when using the Swedish calculation method. The same can be said for the E_1 values of site 4 and the measurements from site 1 conducted in Tunnel 1, when using the Swedish calculation method. Since the number of measurements conducted in each tunnel on site 1 is quite limited, two additional fictive measurements were created for each set of measurements from site 1, with values equally distanced in the range between the actual measurements. As Table 5.12 shows, the addition of the fictive measurements did not result in drastic changes in the statistical significance of the differences between the measurements in Tunnel 2. Given that the actual measurements provided are representative of the total population, it is therefore reasonable to assume that analysing a greater number of measurements from Tunnel 2 at site 1 is not likely to result in a statistically significant difference at a 95% confidence level. The same thing can not be said about Tunnel 1, and a further analysis with a greater number of measurements from Tunnel 1 at site 2 is necessary to draw definitive conclusions.

Site 1 and 3 were also compared in order to assess the difference between the use of Ak and Fk in the interlocking layer if the moisture content is high. This comparison is considered reasonable despite the fact that the moisture content is most likely only high in the interlocking layer at site 1, due to the fact that compaction of Ak generally requires higher moisture content than for compaction of other materials (Statens vegvesen and Vegdirektoratet, 2014a, p. 268). The comparison was divided into four, separating the measurements from site 1 based on whether they were taken in tunnel 1 or 2, and separating the measurements from site 3 based on whether the superstructure materials comply with the 2014 or 2018 version of handbook *N200*. As can be seen from Table 5.12, there is no statistically significant difference at a 95% confidence level between any of the calculated E-values at site 1 and 3. The calculated E-values for the two sites can therefore not be regarded as significantly different. As mentioned before, the number of measurements used for comparison for both of these sites is quite limited, and two additional fictive measurements were therefore created for each set of measurements from both sites. As Table 5.12 shows, some of the calculated E_1 values became statistically significantly different at a 95% confidence level when including the fictive measurements. Given that the actual measurements provided are representative of the total population, it is therefore reasonable to assume that analysing a greater number of measurements from site 1 and 4 could result in a statistically significant difference between the E-values of the two sites.

Finally, site 2 and 4 were compared in order to compare the difference the coarseness of the subbase material makes on the results of PLTs. Both of the sites construct roads upon previously compacted areas, i.e. on top of or in the vicinity of already existing infrastructure, making the comparison of these two sites the most appropriate. Only the measurements of the superstructure without XPS were included from site 4, and only conventional measurements conducted according to *R211* were included in the comparison from site 2. As can be seen from Table 5.12, there is a statistically significant difference between all of the calculated E-values of site 2 and 4, and site 4 can be said to have significantly higher E-values than site 2, for all calculation methods.

Table 5.12: The results of a two-sided t-test assuming different variances, comparing the cases in the case study. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for case study				
	E1		**E2**		
Comparison	**NOR**	**SWE**	**NOR 1**	**NOR 2**	**SWE**
Site 3 (2014 req.) vs Site 4	0,09	**0,04**	0,13	0,14	**0,05**
Site 3 (2014 req.) vs Site 4 With fictive measurements	0,09	**0,04**	0,08	**0,04**	**0,00**
Site 3 (2018 req.) vs Site 4	0,51	0,62	0,85	0,64	0,99
Site 3 (2018 req.) vs Site 4 With fictive measurements	0,16	0,28	0,69	0,25	0,98
Site 1 Tunnel 2 vs Site 4	0,71	0,32	0,28	0,28	**0,02**
Site 1 Tunnel 2 vs Site 4 With fictive measurements	0,47	0,15	0,15	0,14	**0,01**
Site 1 Tunnel 1 vs Site 4	0,06	**0,03**	0,19	0,14	0,06
Site 1 Tunnel 1 vs Site 4 With fictive measurements	**0,02**	**0,02**	0,08	0,07	**0,00**
Site 1 Tunnel 2 vs Site 3 (2014 req.)	0,68	0,53	0,75	0,60	0,65
Site 1 Tunnel 2 vs Site 3 (2014 req.) With fictive measurements	0,29	0,12	0,42	0,20	0,26
Site 1 Tunnel 1 vs Site 3 (2014 req.)	0,40	0,56	0,97	0,80	0,99
Site 1 Tunnel 1 vs Site 3 (2014 req.) With fictive measurements	**0,05**	0,16	0,91	0,52	0,97
Site 1 Tunnel 2 vs Site 3 (2018 req.)	0,41	0,38	0,51	0,51	0,51
Site 1 Tunnel 2 vs Site 3 (2018 req.) With fictive measurements	**0,05**	**0,04**	0,11	0,11	0,11
Site 1 Tunnel 1 vs Site 3 (2018 req.)	0,23	0,28	0,45	0,48	0,46
Site 1 Tunnel 1 vs Site 3 (2018 req.) With fictive measurements	**0,01**	**0,02**	0,07	0,09	0,08
Site 2 vs Site 4	**0,00**	**0,00**	**0,01**	**0,01**	**0,00**

5.2 Other interviews and data files

This section presents the results of the interviews conducted and data files collected that don't refer to the cases of the case study. The interviews provide insight into the experience of people that have been involved in PLTs for multiple different road construction projects, and the data files show measurements collected from a wider range of projects than the case study, although the information gathered about the projects may be limited.

5.2.1 Interviews

Most of the interviewees mentioned that although the PLT is an important method to evaluate the quality of compaction of superstructure materials, the results of such a test does not tell the whole story. Most of them referenced projects that had been built with PLT results not fulfilling the requirements of handbook *N200*, yet no significant settlement or rutting problems had been observed several years after the roads had been opened to traffic. Many of the interviewees also went on to say that very few road projects actually achieve ideal results from PLTs. The challenges were generally linked to the materials used in the superstructure, the quality of work on the construction site, or the requirements in the Norwegian handbooks *N200* and *R211*. The water content in the superstructure materials, as well as the time between compaction and testing were also identified as very important factors to the results of PLTs.

All of the interviewees had heard of or experienced challenges with fulfilling requirements where insulation or light filler materials were used. The most frequently mentioned challenging materials were foam glass aggregate and XPS boards. Some of the interviewees would like to see different PLT requirements for superstructures containing insulation materials, arguing that the PLT gave the wrong picture of the actual degree of the compaction of the materials. Others wanted a restriction on the use of such insulation materials in the superstructure, arguing that the materials should not be used in the superstructure if they could not fulfil the PLT requirements. One interviewee referenced a road project that had obtained better PLT results on a superstructure including an insulation material, where the subbase material had a smaller grain size than the material that is generally used in subbases in Norway. Other interviewees also pointed out the coarseness of the subbase material as a general culprit for the poor PLT results, since more uniformly graded material generally provide less stability and thus a more flexible road structure than well graded material. As one of the interviewees pointed out, the Norwegian requirements for the subbase material have been changed in recent years, and the amount of fines has been decreased. At the same time, the requirements for the PLTs have been unchanged, even though a less amount of fines in the subbase will inevitably reduce the stiffness of the road structure.

The use of Ak in the interlocking layer was also identified by most of the interviewees as a possible source of challenges. One interviewee claimed that the grading curve of the Ak was often not checked, and that some contractors used milled asphalt instead of Ak even though that is not permitted according to the handbooks. Another interviewee pointed out that even though Ak is treated as a uniform material with predictable material properties in the handbooks, the truth is not so simple. The Ak can be made up of any type of asphalt, but the contractor using the material usually has no knowledge of which type of asphalt was used in each particular case. Different types of asphalt have different material properties, which makes Ak in essence very unpredictable. Additionally, the material properties of asphalt in general are very temperature dependent, so measurements conducted on Ak in cold temperatures could give completely different results than measurements conducted in warmer temperatures. Furthermore, Ak is strictly speaking not an unbound granular material, since it contains a fair amount of bitumen, which could affect the results of PLTs greatly.

The coarseness of the subbase material used in Norway was also a much mentioned topic when discussing the current Norwegian PLT procedure. Most of the interviewees pointed out that the 300 mm diameter plate is too small for testing on top of the subbase material in practise, since the plate should not be used on materials with grain sizes exceeding half the plate diameter, and the Norwegian handbooks allow for some deviation in the grading curve of the superstructure material. It therefore only takes small deviations from the grading curve of the normally used 22/120 material for the grains to have a major effect on the results of the PLTs. Most of the interviewees would therefore like to incorporate the 600 mm diameter plate into the Norwegian procedure description, in order to minimize the effect of the grain sizes in the subbase material.

Many of the interviewees mentioned the homogeneity of the superstructure materials as an important factor for the results of PLTs. The superstructure materials can sometimes be inhomogeneous over the cross section of the road, with finer materials in the centre of the road and coarser material towards the road's shoulders, which can greatly affect the results of PLTs. The thickness and evenness of the layers in the superstructure are also important factors that can influence the results of PLTs. To emphasise the importance of these factors, some of the interviewees referenced a project where the construction had been stopped due to poor PLT results. The superstructure material was inhomogeneous with visual separations, and was excavated and replaced by more homogeneous material. The PLTs conducted on the homogeneous material after the material replacement fulfilled all requirements. One interviewee suggests using response measurements from the rollers more actively to assess the quality of compaction to aid in determining if the superstructure materials are homogeneous enough, since the response measurements provide better information about homogeneity than PLTs.

When it comes to the discussion of the Norwegian PLT requirements in handbook *N200*, the interviewees had differing opinions. Some think that the Norwegian requirements are too strict, and that a certain amount of point should be allowed to deviate from the requirements to a certain degree without the whole test section being rejected, since it is very unrealistic to assume that every point of a large road construction project will have optimal qualities. As one interviewee pointed out, since some deviations in the grading curve of the subbase material is acceptable according to the Norwegian handbooks, it is unreasonable to assume that all PLTs performed on that material will fulfil the requirements. Other interviewees argued that the strict fulfilment requirements could lead to underreporting of PLTs or manipulation of measured data, since it might be easier to change the measured results or not file them at all if no deviation from the requirements is allowed. The small margins for whether measurements are considered acceptable or not also make the manipulation of measurements easier, since it often takes only minimal changes to the measured data to fulfil the requirements. One interviewee even suggests that the contractor should not perform the PLTs themselves, and would rather that responsibility be put on an independent, third party consultant. Another interviewee argued that allowing deviation from the requirements is not necessarily a good solution, since the requirement values must be based on some minimum quality requirements for the road structure and one should therefore aim to meet the defined requirements. It would therefore be more reasonable to keep the strict requirements and rather choose to measure points that are representative of the general compaction quality of each section, rather than measuring the weakest points of the sections. It might be justifiable to accept a handful of measurements that don’t meet the requirements, given that the rest of the measurements are well within the limits.

Most of the interviewees believe that different types of superstructures and different traffic volumes should call for different PLT requirements. As they are defined now, the PLT requirements are the same regardless of the traffic volume and the materials used in the superstructure. One interviewee pointed out that it is highly unlikely that a pedestrian or a bike road will experience the same amount of traffic loads as a high volume motorway, and it is therefore impractical to insist on those two types of roads having the same stiffness and fulfilling the same PLT requirements.

The interviewees expressed different opinions regarding the calculation method used to calculate the E-values. One interviewee claimed that there was no significant difference between results calculated using the two calculation methods. Another interviewee has experienced that the Norwegian calculation method gives more conservative values, especially if the results don’t meet the Norwegian requirements. A third interviewee argues that the Swedish calculation method is a more representative approximation of the measured data, and therefore gives more accurate results, as well as claiming that the Swedish method is more robust against measuring errors and manipulation, since it is based on the complete set of measurements instead of a couple of selected points.

A few of the interviewees had further thoughts on the current Norwegian requirements and working procedures. One interviewee commented on the fact that *N200* does not require the compaction plan to be calibrated to PLTs. The handbook allows for the use of multiple methods to calibrate a compaction plan, one of which is PLTs. It is therefore possible to create a compaction plan based on a reference degree of compaction, without knowing for certain if it fulfils the requirements for the PLT. Without calibrating the compaction plan to PLTs, there is no way of being certain that the reference compaction of the compaction plan actually fulfils the requirements. Another interviewee claims that the requirements defined in the contracts for the construction projects often don’t concur with the requirements in the handbooks. The contract requirements are often not as strict or descriptive as the requirements in the handbooks, so the contractor can be using materials that are perfectly within the contract requirements, but not within the handbook requirements. This can lead to the usage of suboptimal superstructure materials, which is usually not beneficial for the results of PLTs.

Some of the interviewees also discussed the pros and cons of the different types of PLT measuring equipment. There are two types of measuring equipment generally used for PLTs in Norway, one from a Swedish supplier and one from a German supplier. The basic elements of the measuring devices are similar, but the software that guides the test performer during the measurements and calculates the results is different. The Swedish software is fully digital and delivers the results in the form of a pdf. According to one interviewer, the measurements are easily adjustable in the Swedish equipment software, making the manipulation of PLT measurements relatively easy. The German software also provides instantaneous hardcopy printouts of the test results, making the manipulation of the data more difficult. Another interviewer mentioned the difference in the test procedures programmed into the measuring devices. The Swedish software considers a load step to be finished when the change in settlements is within 0,02 mm. This can occur within a few seconds of the load being reached. The German software relies on the user to accept each load step and proceed to the next one, meaning that test performers using German equipment often maintain the load steps for a lot longer time than those that use the Swedish equipment. This can influence the measured settlements, and thus the calculated E-values.

A few of the interviewees suggest introducing sanctions or other similar consequences to contractors for not fulfilling PLT requirements. They believe that the right type of consequences would encourage the contractors to develop routines and working procedures aimed to ensure that the PLT requirements are met. This arrangement would also force the contractors that have shown less interest in the PLT to start to make changes. This would be in contrast to the current emphasis that is put on PLTs, where owner builders often tend to be stricter towards contractors that already have PLT equipment and show interest in improving than towards those that don't.

5.2.2 Data files

The following figures and tables present the results of the calculated E-values for the additional sites 5 to 10. These sites will not be compared directly to the sites of the case study, but will be used to compare the three calculation methods, as well as test procedures, where possible. The statistical significance of the comparison of the results from sites 5 to 10 is assessed using the p-values provided in Table 5.14.

Site 5:

Figure 5.19 and Figure 5.20 present the calculated results of the PLT measurements from site 5. As can be seen from the figures, both of the measurements fulfil the requirements defined in the Norwegian handbook *N200,* for all of the calculation methods. The difference between the values calculated using the three calculation methods is not statistically significant at a 95% confidence level, as the values in Table 5.14 show.

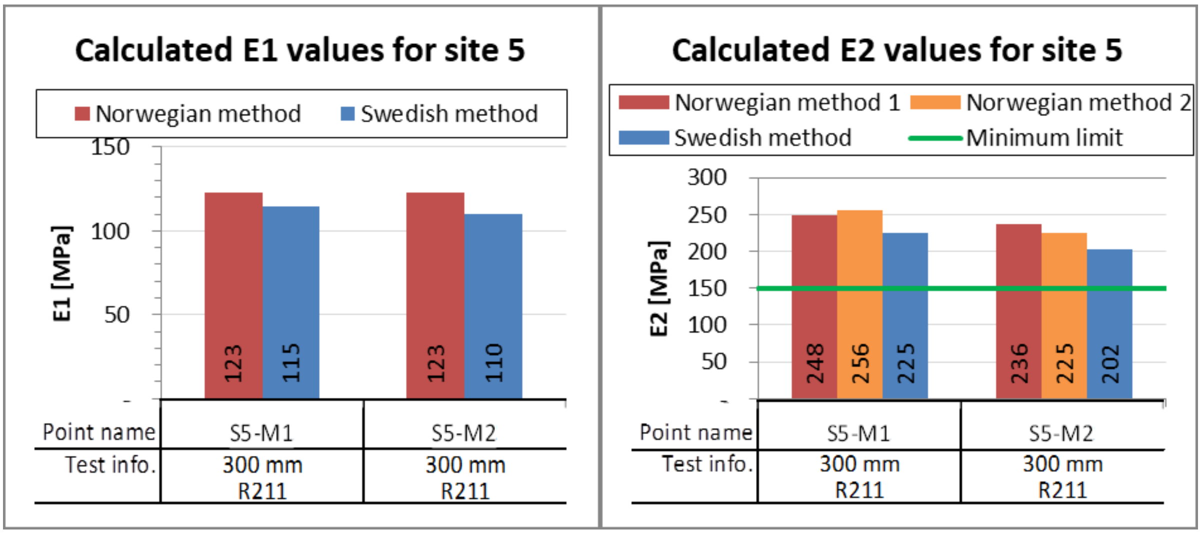


Figure 5.19: Calculated E_1 and E_2 values for measurements conducted on site 5. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200*, 150 MPa.*

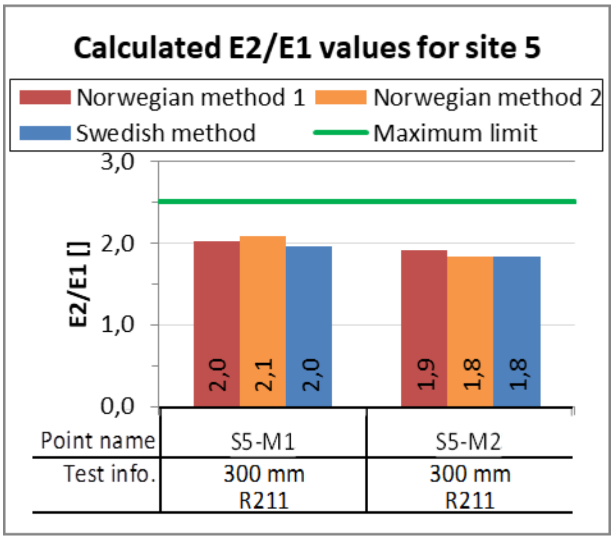


Figure 5.20: Calculated E_2/E_1 values for measurements conducted on site 5. The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook N200*; 2,5.*

Site 6:
Figure 5.21, Figure 5.22 and Figure 5.23 present the calculated results of the PLT measurements from site 6. Three of the measurements (S6-M7, S6-M8 and S6-M9) were conducted with a 600 mm diameter plate according to the German standard *DIN 18134*, while the other measurements were conducted with a 300 mm plate according to *R211*.

As can be seen from Figure 5.21 and Table 5.13, there is a statistically significant difference at a 95% confidence level between the calculated E_1 values for PLTs conducted with a 600 mm plate and a 300 mm plate, regardless of the calculation method. This is also true for the E_2 values, as can be seen from Figure 5.22 and Table 5.13. The values in Table 5.14 suggest that there is no statistically significant difference at a 95% confidence level between the different calculation methods. This applies for E_1 and E_2, as well as PLTs conducted with a 300 mm and a 600 mm plate diameter.

Figure 5.22 shows that only one of the tests conducted with a 300 mm plate diameter does not fulfil the defined requirements for E_2 (S6-M1), and only one of the tests conducted with a 600 mm plate diameter fulfils the defined requirements for all of the calculation methods (S6-M7). One test fails to meet the minimum requirement for all calculation methods (S6-M9). Additionally, the average of the measurements conducted with a 600 mm plate is below the defined requirement for the averages of the measurements. All three measurements conducted according to *DIN 18134* are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are only 3 measurements. All calculations to determine the requirements for measurements conducted according to *DIN 18134* are based on the results of the Swedish calculation method. Figure 5.23 shows that all but one of the measurements (S6-M2) conducted with a 300 mm plate diameter meet the defined requirement for the ratio E_2/E_1 for all calculation methods, while none of the measurements conducted with a 600 mm plate fulfil the requirements.

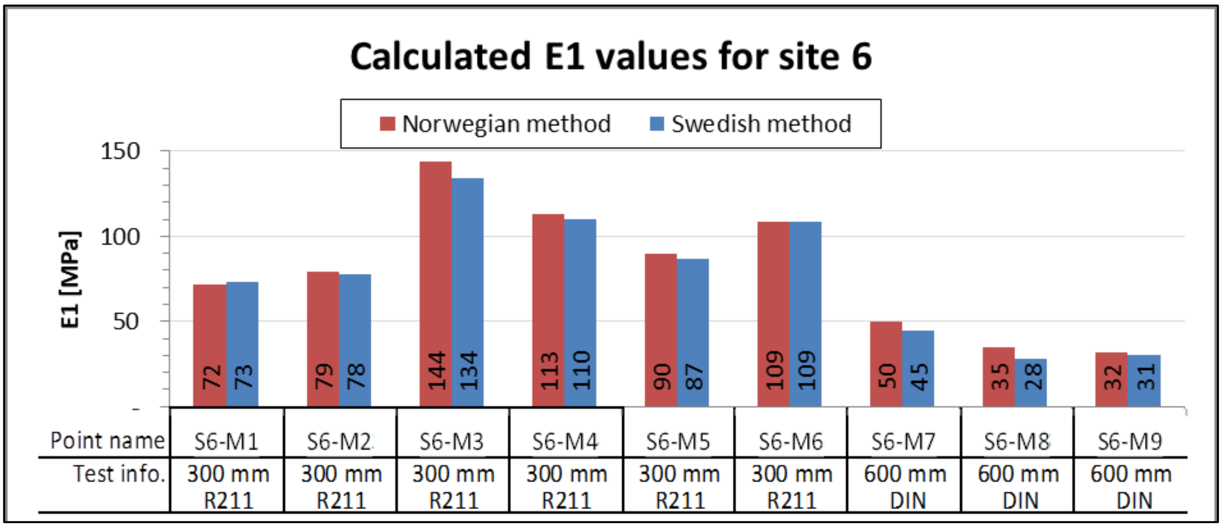


Figure 5.21: Calculated E_1 values for measurements conducted on site 6

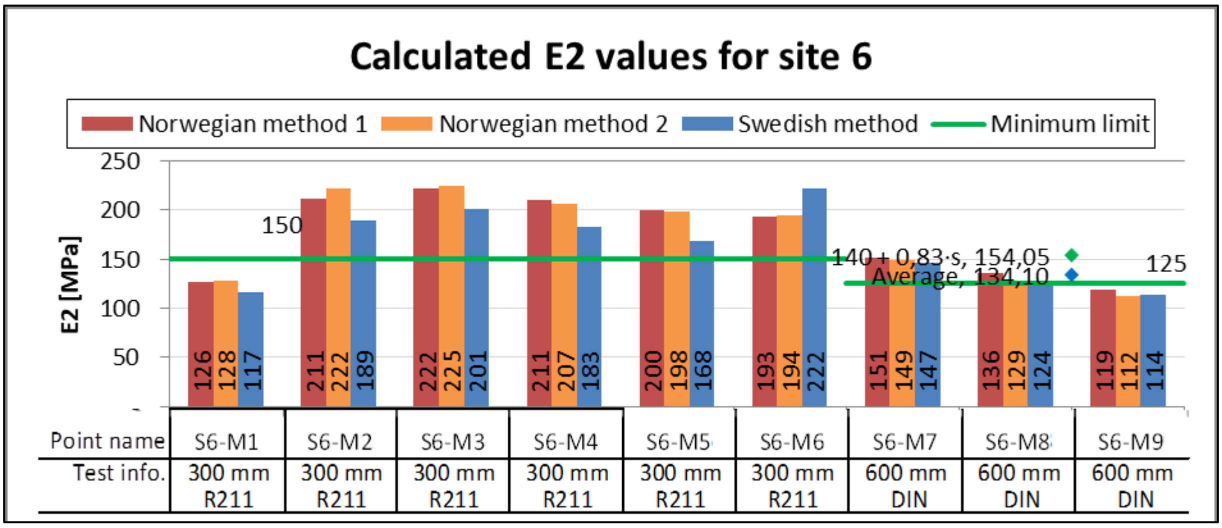


Figure 5.22: Calculated E_2 values for measurements conducted on site 6. The minimum limit correspond to the minimum limit for E_2 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All three measurements conducted according to* DIN 18134 *are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are only 3 measurements.*

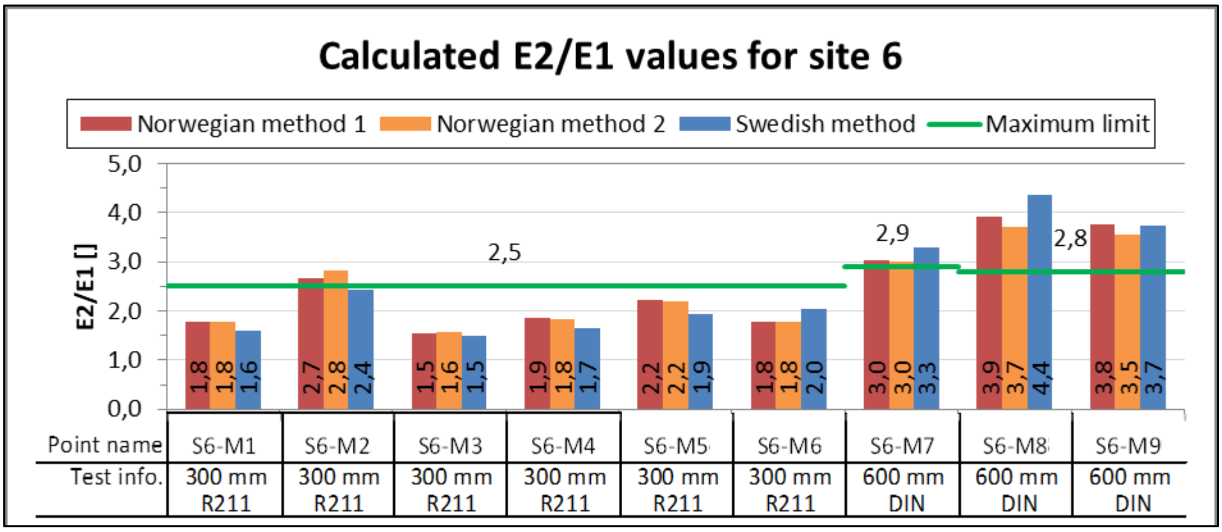


Figure 5.23: Calculated E_2/E_1 values for measurements conducted on site 6. The maximum limit correspond to the maximum limit for E_2/E_1 on top of a base course as defined in the Norwegian handbook N200 *(for PLTs performed according to* R211*), and in the Swedish handbook* TDOK 2013:0530 *(for PLTs performed according to* DIN 18134*). The limits for the measurements conducted according to* DIN 18134 *are based on the E_2 values calculated using the Swedish calculation method.*

Table 5.13: The results of a two-sided t-test assuming different variances, comparing the measurements at site 6 conducted with a 300 mm and 600 mm diameter plate, presented in Figure 5.21 and Figure 5.22. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

P-values from t-tests for site 6, comparison of results conducted with 600 mm plate and 300 mm plate				
E1		**E2**		
NOR	**SWE**	**NOR 1**	**NOR 2**	**SWE**
0,00	**0,00**	**0,01**	**0,01**	**0,02**

Site 7:
Figure 5.24 and Figure 5.25 present the calculated results of the PLT measurements from site 7. As the figures illustrate, there is very little difference between the calculated E_1 value, and only one of the two measurements meets the minimum limit for E_2 for all calculation methods, while the other measurement only meets the limit barely for Norwegian method 2. Both of the measurements exceed the maximum defined limit for the ratio E_2/E_1. The difference between the calculated E-values using the three different calculation methods is very little, except for the E_2 value of measurement S7-M1. This is further confirmed by the values in Table 5.14, which suggest that there is no statistically significant difference between the calculated values at a 95% confidence level.

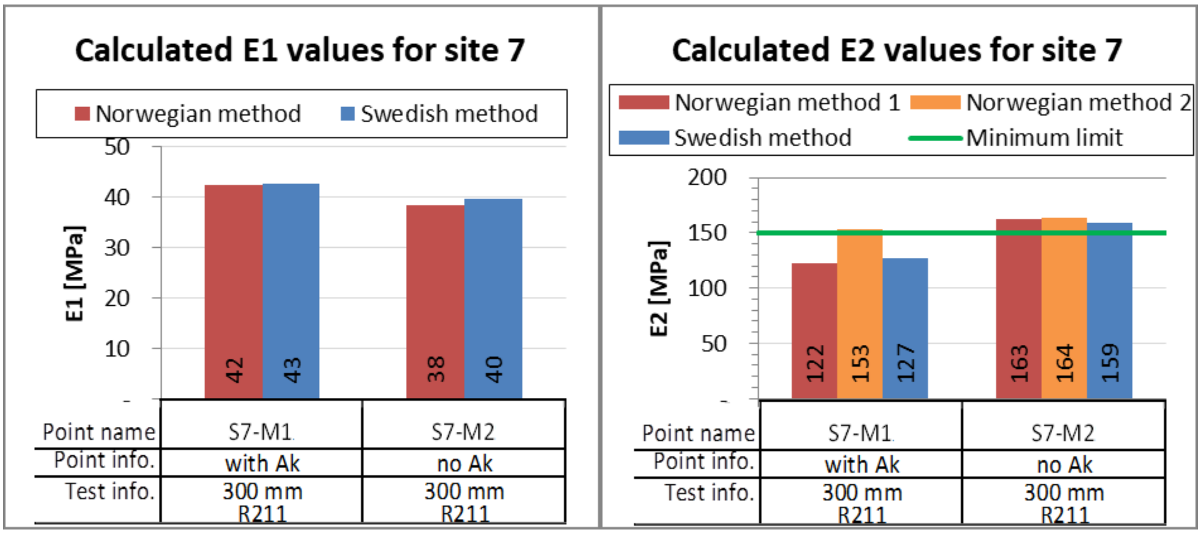


Figure 5.24: Calculated E_1 and E_2 values for measurements conducted on site 7. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200, *150 MPa.*

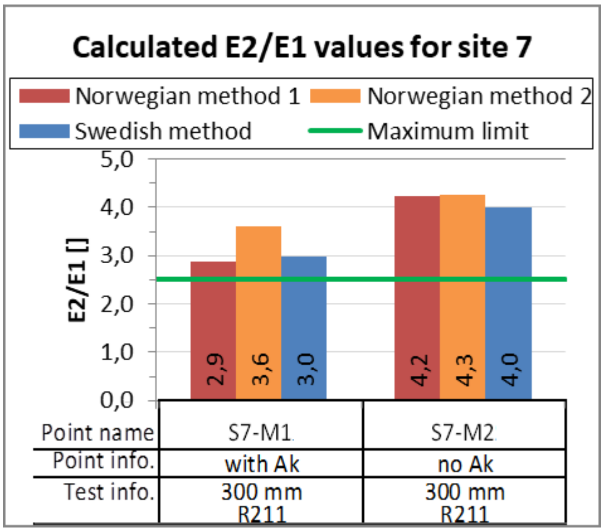


Figure 5.25: Calculated E_2/E_1 values for measurements conducted on site 7. The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook N200; *2,5.*

Site 8:
Figure 5.26, Figure 5.27 and Figure 5.28 present the calculated results of the PLT measurements from site 8. As the figures illustrate, the calculated E_1 values vary quite a lot between the measurements, although both of the calculation methods result in relatively similar values. This is also confirmed by the values in Table 5.14, which suggest that the difference between the values from the two calculation methods is not statistically significant at a 95% confidence level. Only one of the measurements (S8-M4) does not meet the minimum requirement for E_2 for all calculation methods, but is just within the limit for Norwegian method 2. There is a statistically significant difference between the E_2 values of the Swedish calculation method compared to both of the Norwegian methods at a 95% confidence level, as the values in Table 5.14 indicate. There is, however, not a statistically significant difference between the two Norwegian methods at a 95% confidence level. All of the measurements except S8-M3 fulfil the maximum requirement for the ratio E_2/E_1 for all of the calculation methods.

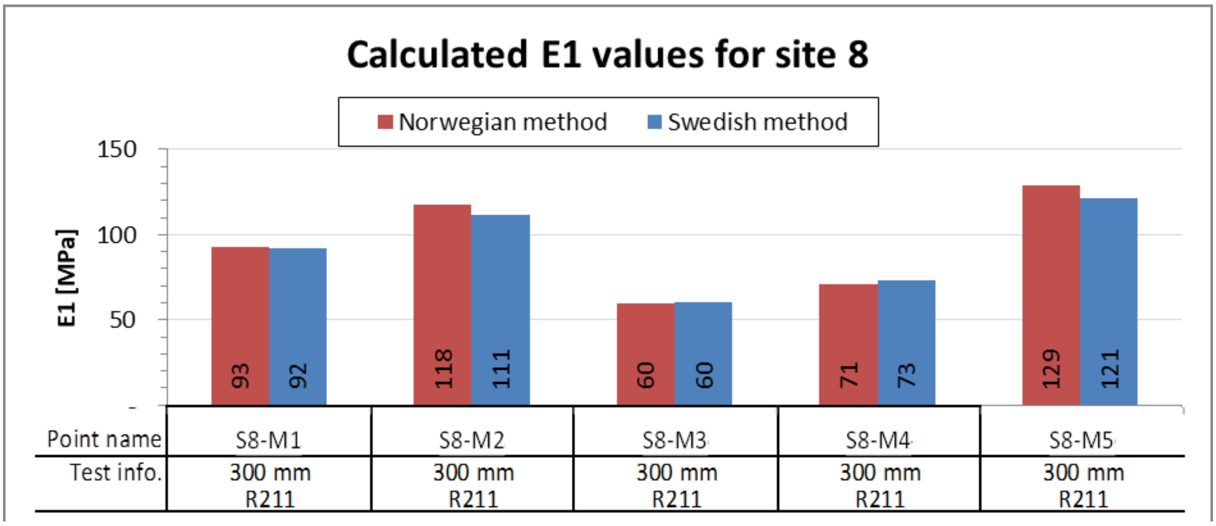


Figure 5.26: Calculated E_1 values for measurements conducted on site 8.

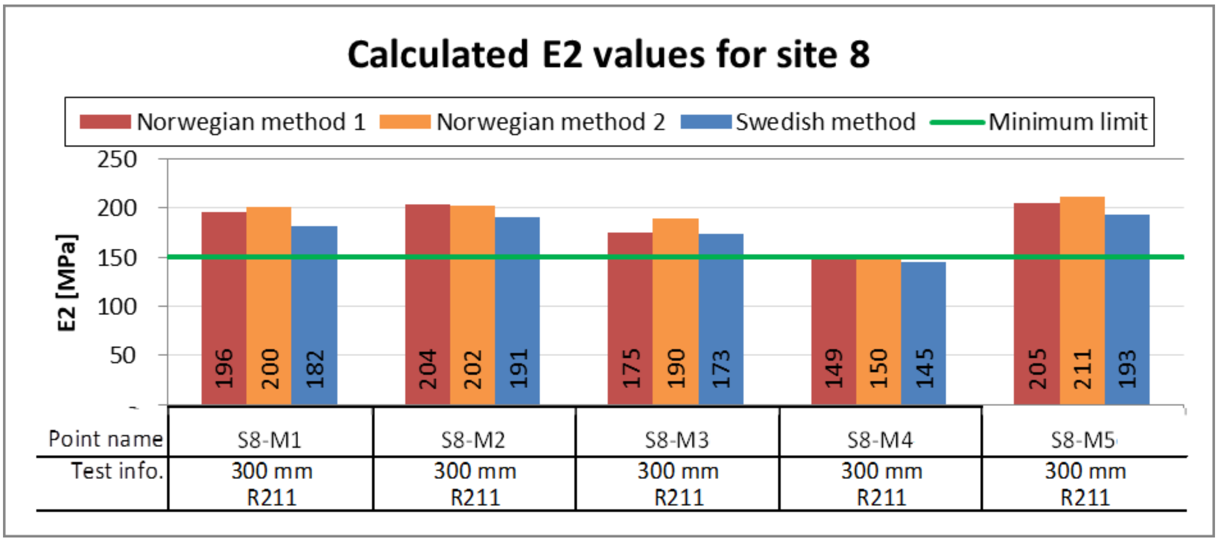


Figure 5.27: Calculated E_2 values for measurements conducted on site 8. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200, *150 MPa.*

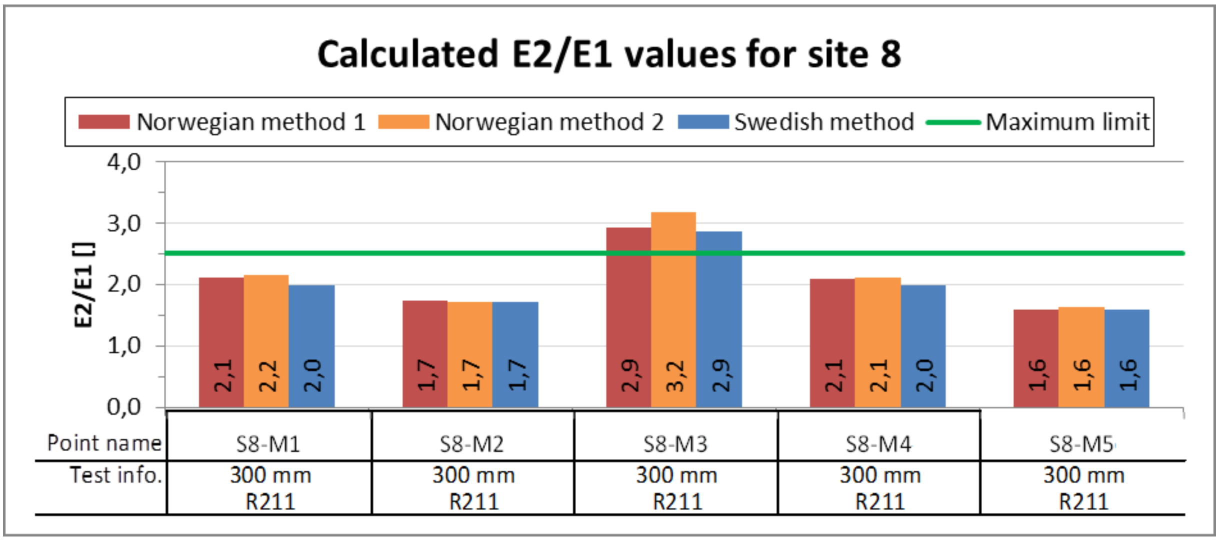


Figure 5.28: Calculated E_2/E_1 values for measurements conducted on site 8 The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook N200*; 2,5.*

Site 9:
Figure 5.29, Figure 5.30 and Figure 5.31 present the calculated results of the PLT measurements from site 9. As can be seen from the figures, the E_1 values resulting from the two calculation methods are relatively similar for all of the measurement. This is further confirmed by the values in Table 5.14, which show that the difference between the E_1 values from the two calculation methods is not statistically significant at a 95% confidence level. There is greater variation between the results of the three calculation methods for the E_2 values, as can be seen in Figure 5.30. The values in Table 5.14 suggest that there is a statistically significant difference at a 95% confidence level between the E_2 values calculated using the Swedish method compared to both of the Norwegian method, but not between the two Norwegian methods. All of the measurements fulfil the defined minimum requirement for E_2 for all of the calculation methods. Additionally, the average of the measurements fulfils the defined requirement for the average of the calculated E_2 value. All six of the measurements are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are six measurements. All calculations done in order to determine the requirements are based on the results of the Swedish calculation method. Half of the measurements exceed the defined maximum limit for the ratio E_2/E_1 for all of the calculation methods, while the other half fulfils the requirement for all calculation methods.

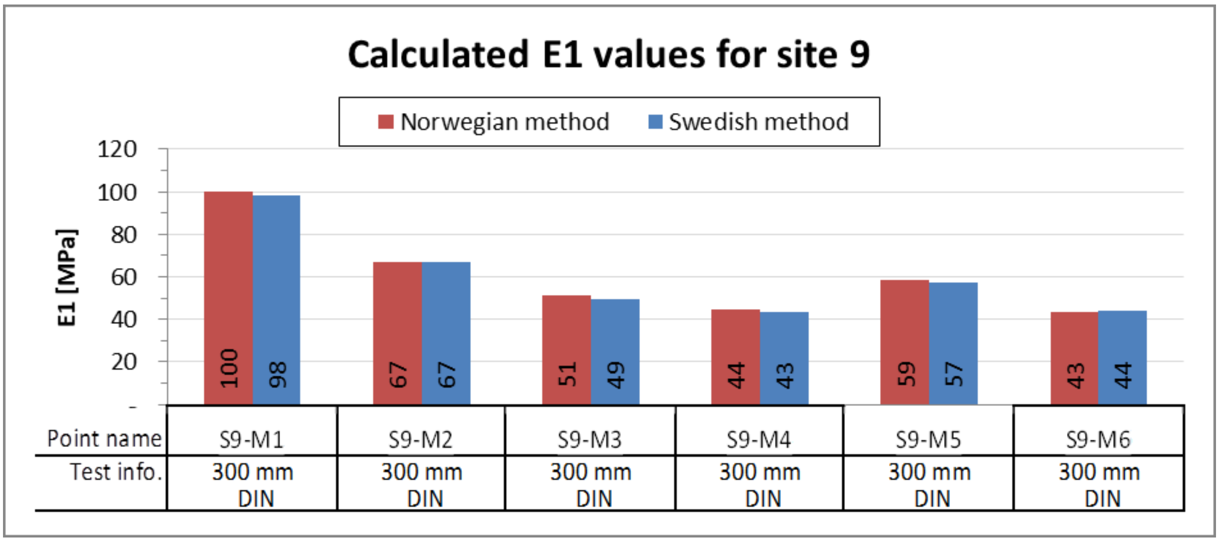


Figure 5.29: Calculated E_1 values for measurements conducted on site 9

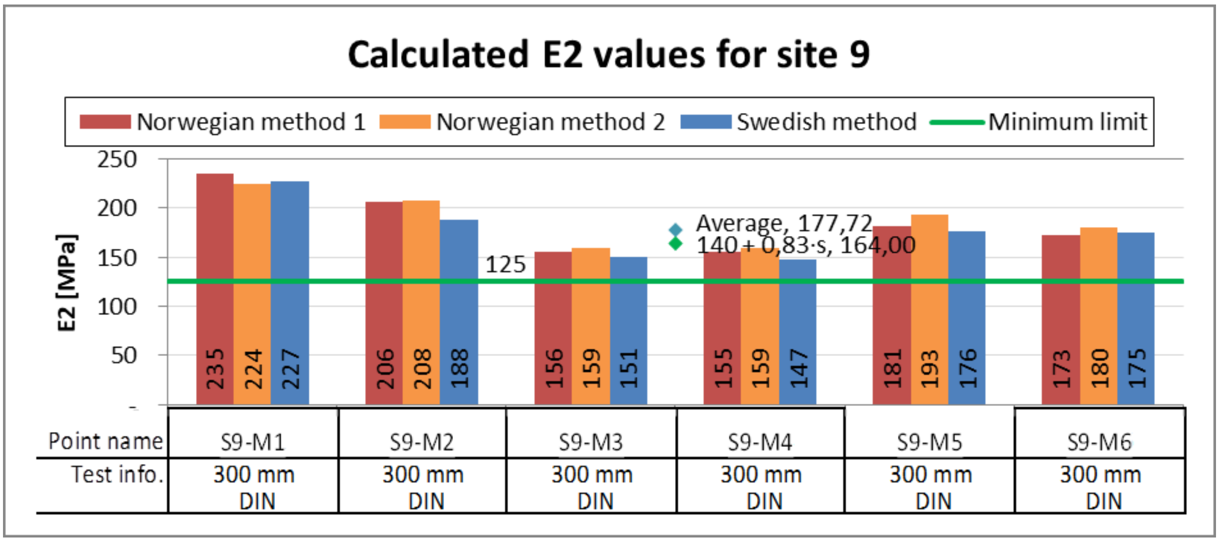


Figure 5.30: Calculated E_2 values for measurements conducted on site 9. The minimum limit shown on the figure corresponds to the minimum limit for E_2 on top of a base course as defined in the Swedish handbook TDOK 2013:0530. *The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. All six of the measurements are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are six measurements.*

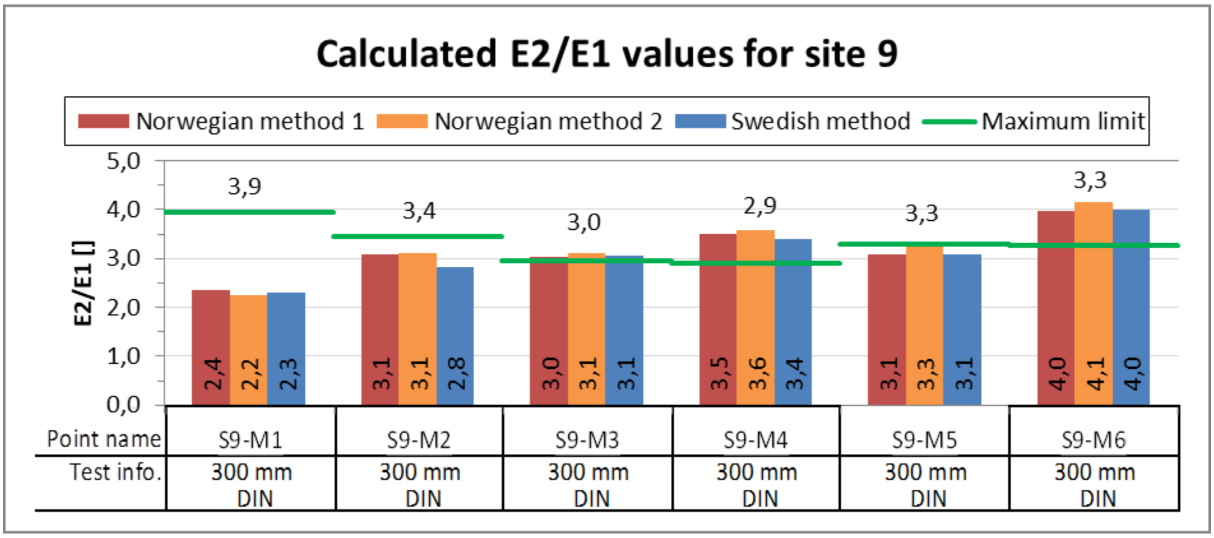


Figure 5.31: Calculated E_2/E_1 values for measurements conducted on site 9. The maximum limit shown on the figure corresponds to the maximum limit for E_2/E_1 on top of a base course as defined in the Swedish handbook TDOK 2013:0530. *The limits for the measurements conducted according to* DIN 18134 *are based on the E_2 values calculated using the Swedish calculation method.*

Site 10:
Figure 5.32 shows the calculated results of the single PLT measurement from site 10. As illustrated in the figure, the E_1 value is the same for both of the calculation methods. The E_2 value is relatively similar for the Swedish calculation method and Norwegian method 1, while Norwegian method 2 results in a somewhat higher value. All of the calculation methods result in an E_2 value that fulfils the defined requirement. The resulting E_2/E_1 ratio is relatively similar for Norwegian method 1 and the Swedish calculation method, while the ratio is somewhat higher for Norwegian method 2, which consequently is the only calculation method that does not meet the defined maximum requirement for the

ratio. Since there is only one PLT measurement provided for this site, a statistical analysis of the significance of the differences is not possible.

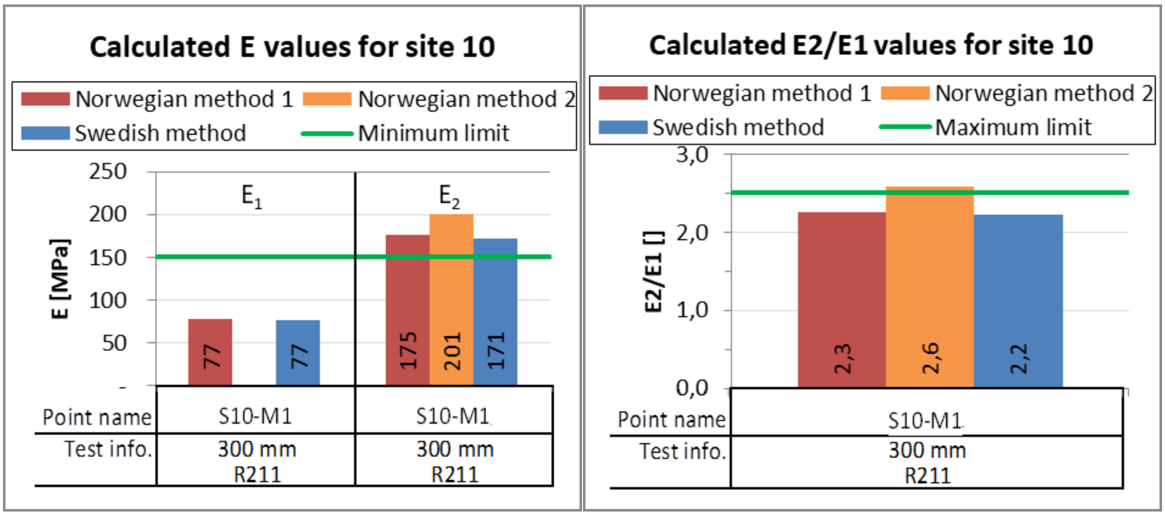


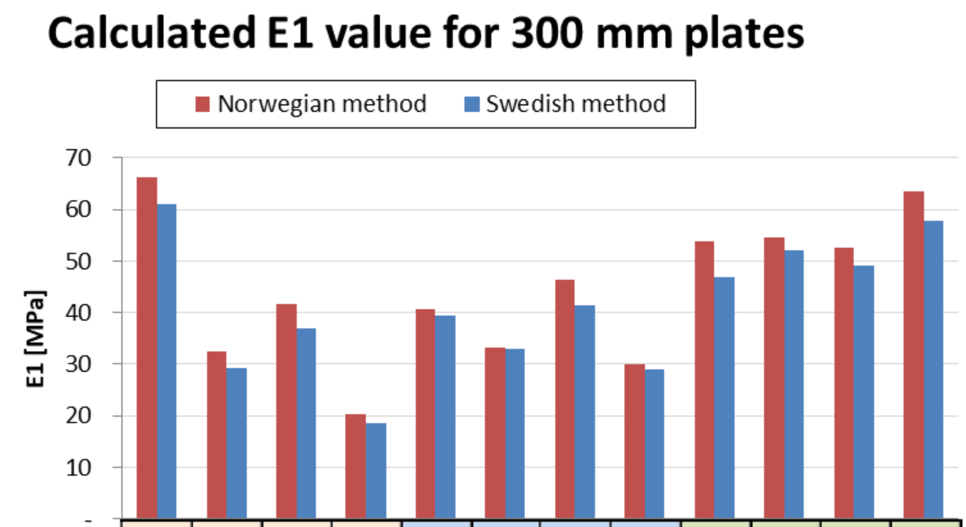
Figure 5.32: Calculated values for measurements conducted on site 10. The minimum limit represents the minimum limit for E_2 on top of a base course defined in handbook N200, *150 MPa. The maximum limit represents the maximum limit for E_2/E_1 on top of a base course defined in handbook* N200*; 2,5.*

Table 5.14: The results of a two-sided, paired t-test comparing the calculation methods used for the measurements at sites 5 to 10. The values shown correspond to the probability of the two sets of values having the same distribution, given the values provided. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for sites 5 to 10, comparison of calculation method			
	E1	**E2**		
Comparison	**NOR vs SWE**	**NOR 1 vs SWE**	**NOR 2 vs SWE**	**NOR 1 vs NOR 2**
Site 5, 300 mm R211	0,13	0,12	0,10	0,89
Site 6, 300 mm R211	0,19	0,19	0,15	0,46
Site 6, 600 mm DIN 18134	0,13	0,11	0,49	0,09
Site 7, 300 mm R211	0,34	0,87	0,39	0,47
Site 8, 300 mm R211	0,25	**0,02**	**0,01**	0,16
Site 9, 300 mm DIN 18134	0,09	**0,05**	**0,03**	0,39
Site 10, 300 mm R211	Only one measurement received, statistical analysis not possible			

5.3 Field test

This section presents the calculated results of the field test conducted in Hamar on March 28th. Further details about the measured values and the calculations corresponding to each PLT is provided in Appendix 5.



Point name	P1A	P2C	P3A	P4C	P5A	P6C	P7A	P8C	P9A	P10C	P11A	P12C
Material tested	0/300	0/300	0/300	0/300	22/120	22/120	22/120	22/120	0/32	0/32	0/32	0/32
Test area	A3	A3	A3	A3	A1	A1	A1	A1	A2	A2	A2	A2
E1 NOR [MPa]	66	32	42	20	41	33	46	30	54	55	53	64
E1 SWE [MPa]	61	29	37	18	39	33	41	29	47	52	49	58

Figure 5.33: Calculated values of E_1 for the points of the field test measured with a 300 mm plate diameter.

Figure 5.33 shows the calculated value for E_1 for the points tested with a 300 mm plate. As can be seen from the figure, the calculated values vary considerably between the test points of each test area, especially for the measurements taken on top of the frost protection layer. There is a rather consistent difference between the Swedish and the Norwegian calculation method, where the Swedish calculation value always results in a slightly lower E_1 value. The difference between the Swedish and the Norwegian calculation methods is, however, only statistically significant at a 95% confidence level for the measurements conducted on top of the frost protection layer (0/300) and the interlocking layer (0/32), as can be seen in Table 5.15.

Figure 5.34 shows the calculated value for E_1 for the points tested with a 600 mm plate. As can be seen from the figure, the E_1 values vary considerably between the test points of each test area for this plate size too, especially for the measurements conducted on top of the frost protection layer. The difference between the Swedish and the Norwegian calculation methods are smaller than for the 300 mm diameter plates, and the difference between them is only statistically significant at a 95% confidence level for measurements conducted on top of the interlocking layer (0/32). The p-values of the comparison between the E_1 values from the Swedish and the Norwegian calculation methods are provided in Table 5.15.

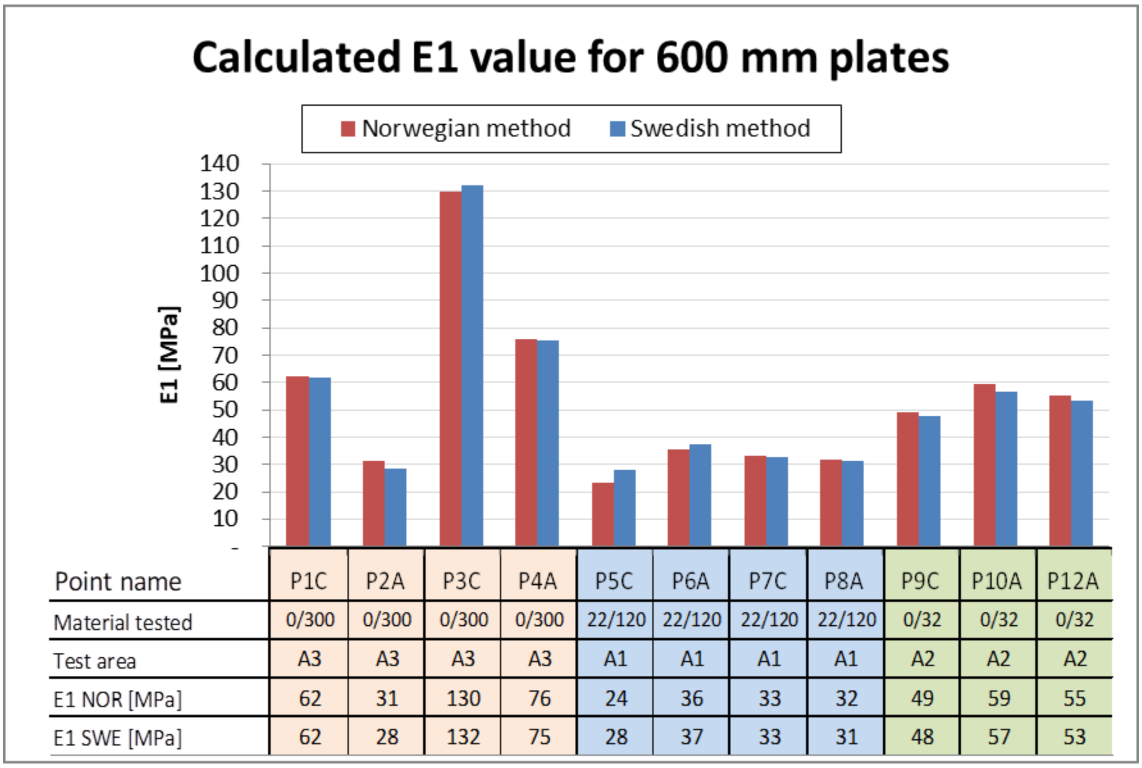


Figure 5.34: Calculated values of E_1 for the points of the field test measured with a 600 mm plate diameter.

Based on the values displayed in Table 5.16, there is no statistical significance at a 95% confidence level between the E_1 values calculated from the measurements conducted with a 300 mm diameter plate or the measurements conducted with a 600 mm plate, regardless of the type of material or calculation method used. According to Table 5.17, there is also no statistically significant difference at a 95% confidence level between the calculated E_1 values from measurements conducted on the different types of superstructure materials, except when comparing the measurements conducted on the subbase material (22/120) and the interlocking material (0/32). For these two materials, the E_1 values are significantly higher for measurements conducted on the interlocking material (0/32) compared to the measurements on the subbase material (22/120), regardless of the plate size or the calculation method.

Table 5.15: The results of a two-sided, paired t-test of the calculated E_1 values of the points in the field test presented in Figure 5.33 and Figure 5.34, comparison of the Norwegian and Swedish calculation methods. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for E_1	
Material	**300 mm NOR vs SWE**	**600 mm NOR vs SWE**
0/300	**0,02**	0,79
22/120	0,17	0,32
0/32	**0,02**	**0,01**

Table 5.16: The results of a two-sided, unpaired t-test with a different variance of the calculated E_1 values of the points in the field test presented in Figure 5.33 and Figure 5.34, comparison of the 300 mm and 600 mm plate diameters. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

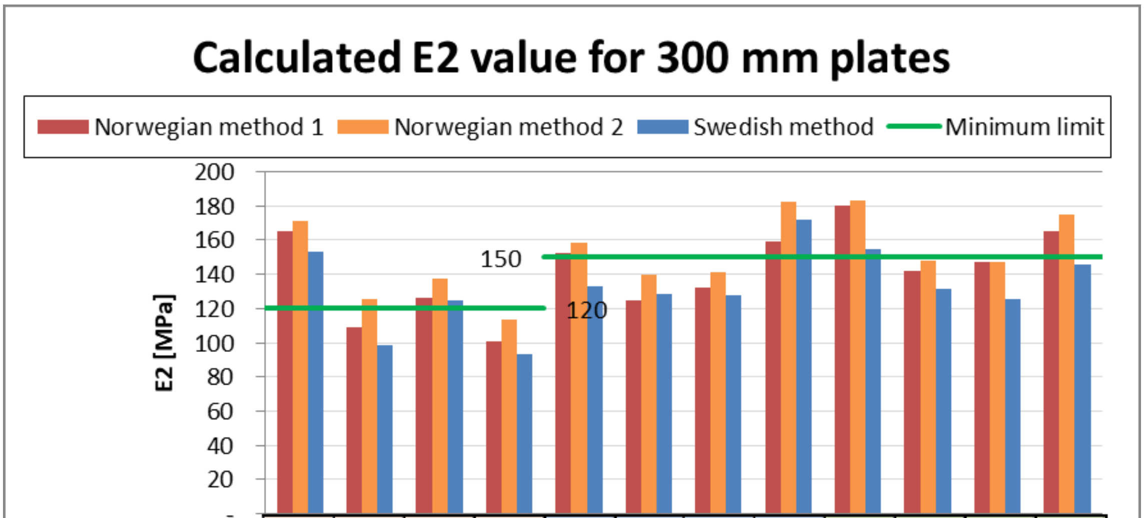
	P-values from t-tests for E1	
Material	**NOR 300 mm vs 600 mm**	**SWE 300 mm vs 600 mm**
0/300	0,20	0,18
22/120	0,21	0,40
0/32	0,72	0,78

Table 5.17: The results of a two-sided, unpaired t-test with a different variance of the calculated E_1 values of the points in the field test presented in Figure 5.33 and Figure 5.34, comparison of the different materials tested. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for E1		
Plate size and method	**0/300 vs 22/120**	**0/300 vs 0/32**	**22/120 vs 0/32**
NOR 300 mm	0,81	0,20	**0,01**
SWE 300 mm	0,94	0,19	**0,01**
NOR 600 mm	0,12	0,40	**0,00**
SWE 600 mm	0,15	0,39	**0,00**

Figure 5.35 shows the calculated value for E_2 for the points tested with a 300 mm plate. As can be seen from the figure, only 4 of the test points fulfil the minimum requirements defined in handbook *N200* for all three calculation methods; P1A and P3A for the frost protection layer (0/300), P8C for the subbase layer (22/120) and P9A for the interlocking layer (0/32). Additionally, points P2C, P5A and P12C fulfil the requirements for at least one of the calculation methods, but not all of them. The difference between the results of the calculation methods varies considerably more for E_2 than for E_1, and the difference is statistically significant at a 95% confidence level for all of the calculation methods, except for the difference between Norwegian method 1 and the Swedish method for measurements conducted on the subbase layer (22/120), and for the difference between the two Norwegian methods for measurements conducted on the interlocking layer. The p-values of the comparison between the E_2 values from the Swedish and the two Norwegian calculation methods are provided in Table 5.18.

Figure 5.36 shows the calculated value for E_2 for the points tested with a 600 mm plate. These points are compared to the minimum limits defined in the Swedish handbook *TDOK 2013:0530,* where the measurements within each test area are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are only 3 to 4 measurements per test area. All calculations done in order to determine the requirements are based on the results of the Swedish calculation method. As the figure shows, all but one of the test points for this plate size fulfil the defined minimum requirements for all of the calculation methods. The only point that doesn’t fulfil the requirements for all of the calculation methods (P8A) still meets the requirements for Norwegian method 2. The averages for the tests conducted on the frost protection layer (0/300) and the interlocking layer (0/32) fulfil the defined requirements for the averages of the set of measurements, while the average for the tests conducted on the subbase material (22/120) does not. As for the 300 mm plate size, the values for E_2 vary considerably more based on the calculation method than the values for E_1. The difference between the calculation methods is only statistically significant at a 95% confidence level for measurements conducted on the frost protection layer (0/300) for comparison of Norwegian method 1 and the Swedish method. For measurements conducted on top of the subbase material (22/120) only the difference between Norwegian method 1 and the Swedish method is not statistically significant at a 95% confidence level. Finally, the difference between the two Norwegian methods is the only difference that is not statistically significant at a 95% confidence level for measurements conducted on top of the interlocking layer (0/32). This is also summed up in Table 5.18.

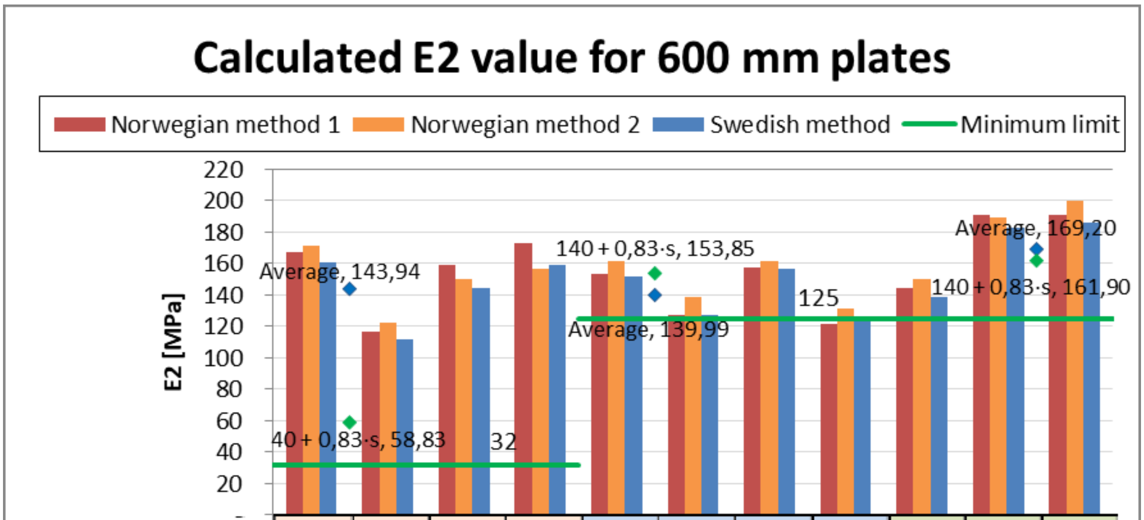


Point name	P1A	P2C	P3A	P4C	P5A	P6C	P7A	P8C	P9A	P10C	P11A	P12C
Material tested	0/300	0/300	0/300	0/300	22/120	22/120	22/120	22/120	0/32	0/32	0/32	0/32
Test area	A3	A3	A3	A3	A1	A1	A1	A1	A2	A2	A2	A2
E2 NOR1 [MPa]	165	109	126	101	153	125	132	159	180	142	147	165
E2 NOR2 [MPa]	171	126	138	113	158	140	141	182	183	148	147	175
E2 SWE [MPa]	153	99	125	93	133	129	127	172	155	131	125	146

Figure 5.35: Calculated values of E_2 for the points of the field test measured with a 300 mm plate diameter The minimum limit represent the minimum acceptance limit for E_2, as defined by handbook N200 *from 2018, 120 MPa and 150 MPa for the top of the frost protection layer and the upmost unbound granular layer, respectively*

As for the E_1 values, the difference between the calculated E_2 values for the measurements conducted with a 300 mm diameter plate and the measurements conducted with a 600 mm plate is not statistically significant at a 95% confidence level, regardless of the type of material or calculation method used. The p-values of the comparison between the E_2 values based on measurements conducted with 300 mm and 600 mm plates are provided in Table 5.19.

According to Table 5.20, there is also no statistically significant difference at a 95% confidence level between the calculated E_2 values from measurements conducted on the different types of superstructure materials, regardless of the plate size or the calculation method used.



Point name	P1C	P2A	P3C	P4A	P5C	P6A	P7C	P8A	P9C	P10A	P12A
Material tested	0/300	0/300	0/300	0/300	22/120	22/120	22/120	22/120	0/32	0/32	0/32
Test area	A3	A3	A3	A3	A1	A1	A1	A1	A2	A2	A2
E2 NOR1 [MPa]	167	116	159	173	153	128	158	122	145	191	191
E2 NOR2 [MPa]	171	123	150	157	162	138	162	132	150	189	200
E2 SWE [MPa]	161	112	144	159	152	127	157	124	139	183	186

Figure 5.36: Calculated values of E_2 for the points of the field test measured with a 600 mm plate diameter. The minimum limits represent the minimum acceptance limit for E_2, as defined by TDOK 2013:0530*. The points in the figure represent the value and the minimum limits for the average of the measured E_2 value, calculated according to the Swedish calculation method. The measurements within each test area are considered to belong to the same set of measurements, and the requirements are calculated based on a sample size of n = 5, even though there are only 3 to 4 measurements per test area.*

Table 5.18: The results of a two-sided, paired t-test of the calculated E_2 values of the points in the field test presented in Figure 5.35 and Figure 5.36, comparison of the Norwegian and Swedish calculation methods. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for E_2					
Material	**300 mm NOR1 vs SWE**	**300 mm NOR2 vs SWE**	**300 mm NOR1 vs NOR2**	**600 mm NOR1 vs SWE**	**600 mm NOR2 vs SWE**	**600 mm NOR1 vs NOR2**
0/300	**0,05**	**0,01**	**0,01**	**0,03**	0,14	0,54
22/120	0,77	**0,02**	**0,04**	0,94	**0,01**	**0,01**
0/32	**0,01**	**0,00**	0,10	**0,02**	**0,04**	0,32

Table 5.19: The results of a two-sided, unpaired t-test with a different variance of the calculated E_2 values of the points in the field test presented in Figure 5.35 and Figure 5.36, comparison of the 300 mm and 600 mm plate diameters. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

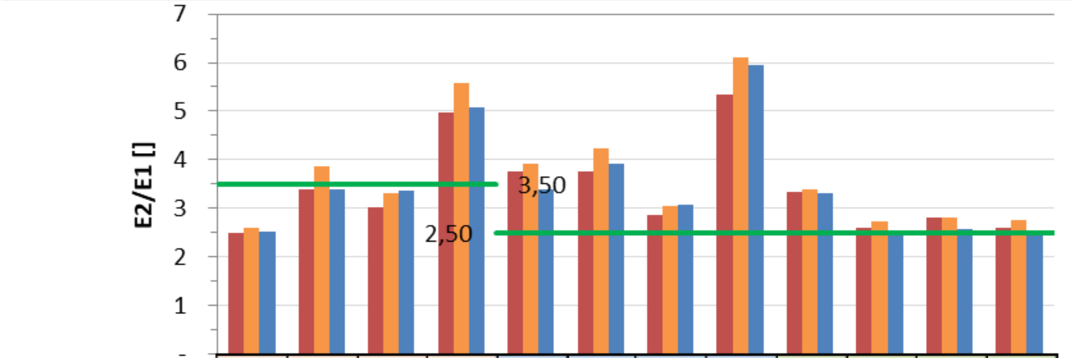
	P-values from t-tests for E2		
Material	**NOR1 300 mm vs 600 mm**	**NOR2 300 mm vs 600 mm**	**SWE 300 mm vs 600 mm**
0/300	0,19	0,44	0,19
22/120	0,85	0,59	0,99
0/32	0,40	0,41	0,18

Table 5.20: The results of a two-sided, unpaired t-test with a different variance of the calculated E_2 values of the points in the field test presented in Figure 5.35 and Figure 5.36, comparison of the different materials tested. The values shown correspond to the probability of the two sets of values having the same distribution. Bolded values represent a significant difference at least at a 95% confidence level.

	P-values from t-tests for E2		
Plate size and method	**0/300 vs 22/120**	**0/300 vs 0/32**	**22/120 vs 0/32**
NOR1 300 mm	0,35	0,11	0,23
NOR2 300 mm	0,29	0,14	0,58
SWE 300 mm	0,24	0,22	0,95
NOR1 600 mm	0,41	0,33	0,13
NOR2 600 mm	0,89	0,19	0,16
SWE 600 mm	0,79	0,25	0,19

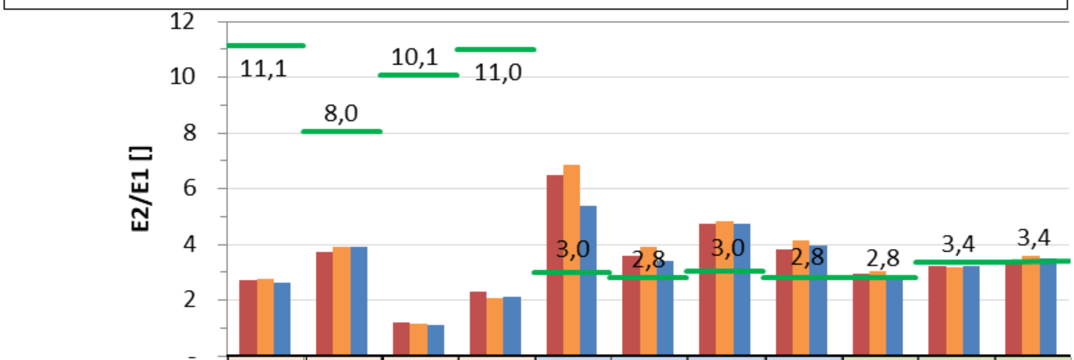
Figure 5.37 shows the calculated E_2/E_1 ratios for the points tested with a 300 mm plate. As can be seen from the figure, only two of the test points fulfil the defined maximum requirement for all calculation methods; P1A and P3C, both conducted on top of the frost protection layer (0/300). Additionally, points P10C and P12C only just fulfil the requirements based on the Swedish calculation method, but not for the two Norwegian methods. The results of the ratio vary considerably based on the calculation method, especially between Norwegian method 1 and 2.

Figure 5.38 shows the calculated E_2/E_1 ratios for the points tested with a 600 mm plate. As shown on the figure, five of the test points fulfil the defined maximum requirements for all of the calculation methods; all four of the test points on top of the frost protection layer (0/300), and P10A for the interlocking layer (0/32). None of the other test points fulfil the maximum requirement for any of the calculation methods.



Point name	P1A	P2C	P3A	P4C	P5A	P6C	P7A	P8C	P9A	P10C	P11A	P12C
Material tested	0/300	0/300	0/300	0/300	22/120	22/120	22/120	22/120	0/32	0/32	0/32	0/32
Test area	A3	A3	A3	A3	A1	A1	A1	A1	A2	A2	A2	A2
E2/E1 NOR1 [MPa]	2,5	3,4	3,0	5,0	3,8	3,8	2,9	5,3	3,3	2,6	2,8	2,6
E2/E1 NOR2 [MPa]	2,6	3,9	3,3	5,6	3,9	4,2	3,0	6,1	3,4	2,7	2,8	2,8
E2/E1 SWE [MPa]	2,5	3,4	3,4	5,1	3,4	3,9	3,1	5,9	3,3	2,5	2,6	2,5

Figure 5.37: Calculated values of E_2/E_1 for the points of the field test measured with a 300 mm plate diameter. The maximum limits represent the maximum acceptance limit for E_2/E_1, as defined by handbook N200 *from 2018; 3,5 and 2,5 for the top of the frost protection layer and upmost unbound granular layer, respectively.*



Point name	P1C	P2A	P3C	P4A	P5C	P6A	P7C	P8A	P9C	P10A	P12A
Material tested	0/300	0/300	0/300	0/300	22/120	22/120	22/120	22/120	0/32	0/32	0/32
Test area	A3	A3	A3	A3	A1	A1	A1	A1	A2	A2	A2
E2/E1 NOR1 [MPa]	2,7	3,7	1,2	2,3	6,5	3,6	4,7	3,8	2,9	3,2	3,5
E2/E1 NOR2 [MPa]	2,8	3,9	1,2	2,1	6,9	3,9	4,8	4,1	3,0	3,2	3,6
E2/E1 SWE [MPa]	2,6	3,9	1,1	2,1	5,4	3,4	4,8	4,0	2,9	3,2	3,5

Figure 5.38: Calculated values of E_2/E_1 for the points of the field test measured with a 600 mm plate diameter. The maximum limits represent the maximum acceptance limit for E_2/E_1, as defined by TDOK 2013:0530*. The limits are based on the E_2 values calculated using the Swedish calculation method.*

5.4 All plate load tests

An interesting observation that was made during the analysis of all of the PLTs in the thesis is a correlation between the curvature of the load-settlement curve of the first load cycle, and the probability of the PLT failing to fulfil the designated requirements.

Upon further analysis, a correlation between the constant $a_{1,2}$ from the second degree polynomial approximation of the Swedish calculation method, and the calculated E_2 value of Norwegian method 1 was discovered. A correlation between the constant $a_{1,2}$ from the second degree polynomial, and the calculated ratio E_2/E_1 from Norwegian method 1 was also discovered.

Figure 5.39, Figure 5.40 and Figure 5.41 show a regression analysis performed for the correlation between the constant $a_{1,2}$ from the second degree polynomial approximation of the Swedish calculation method, and the calculated E_2 value of Norwegian method 1. The figures also show the p-value the regression analysis of each of the figures, which corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables. Figure 5.39 shows the correlation for the PLTs performed according to the Norwegian handbook *R211*. The data shows a statistically significant correlation at a 95% confidence level between the variables, with an estimated linear trendline slope of 11,977. Figure 5.40 shows the correlation for the PLTs performed with a 300 mm diameter plate according to the German standard *DIN 18134*. The data shows a statistically significant correlation at a 95% confidence level between the variables, with an estimated linear trendline slope of -25,335. The slope from this linear regression analysis is in the opposite direction compared to that of Figure 5.39 and Figure 5.41. Figure 5.41 shows the correlation for the PLTs performed with a 600 mm diameter plate according to the German standard *DIN 18134*. The data shows a statistically significant correlation at a 95% confidence level between the variables, with an estimated linear trendline slope of 1,7922.

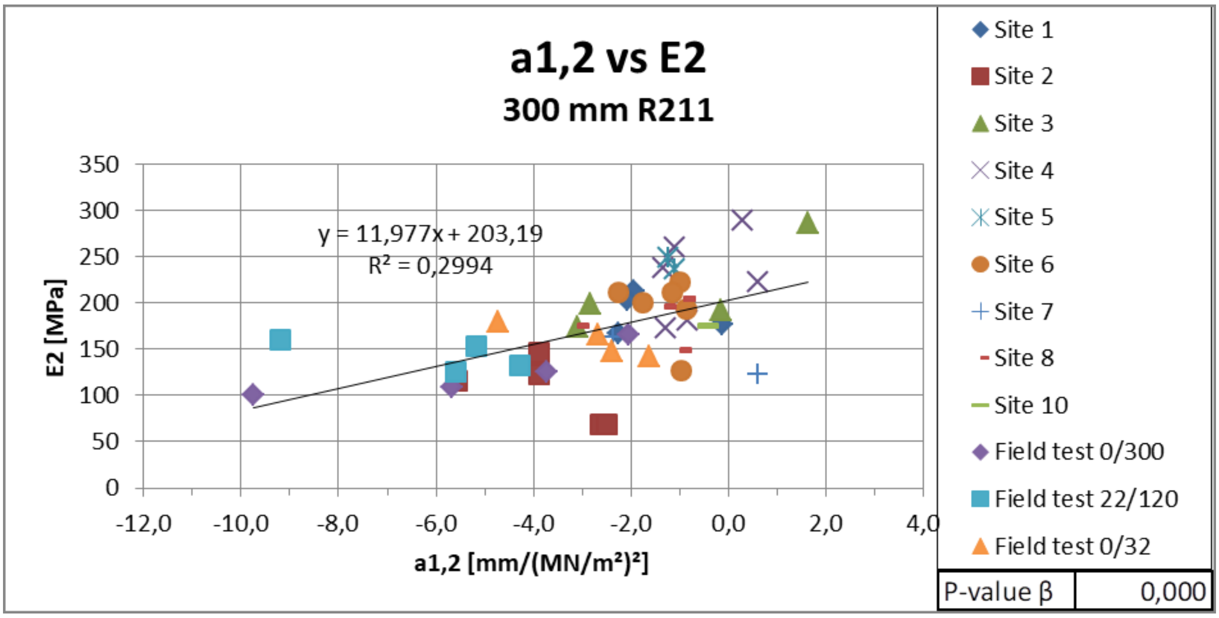


Figure 5.39: The correlation between the factor $a_{1,2}$ and the E_2 value for 300 mm plate measurements conducted according to R211*. The E_2 values are calculated using Norwegian method 1. The p-value for β displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

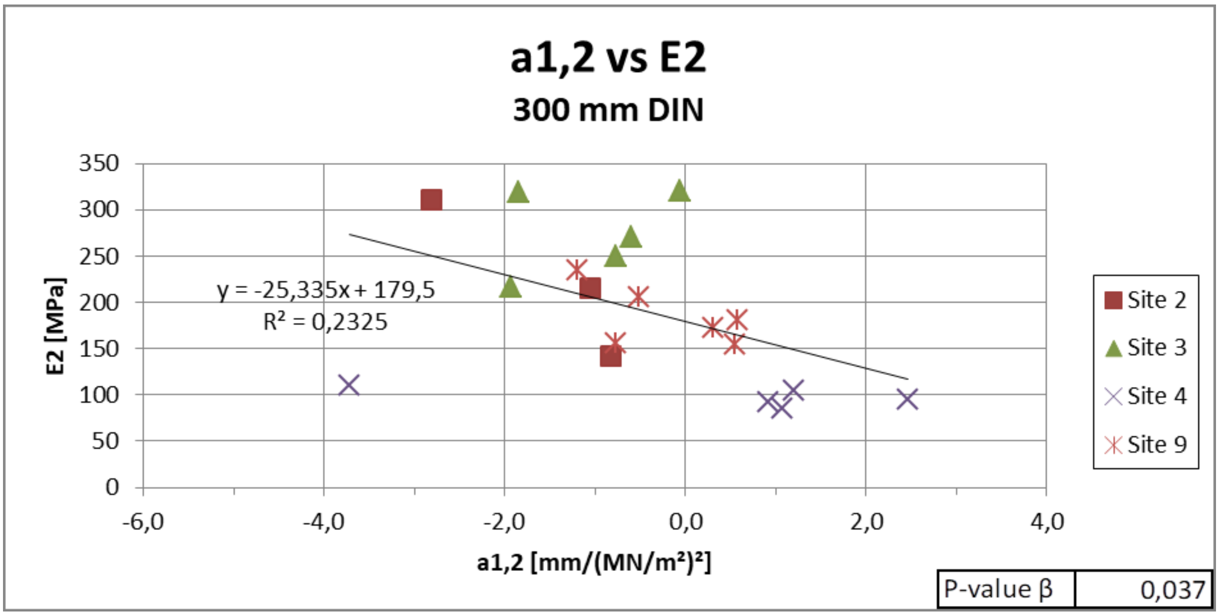


Figure 5.40: The correlation between the factor $a_{1,2}$ and the E_2 value for 300 mm plate measurements conducted according to DIN 18134*. The E_2 values are calculated using Norwegian method 1. The p-value for β displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

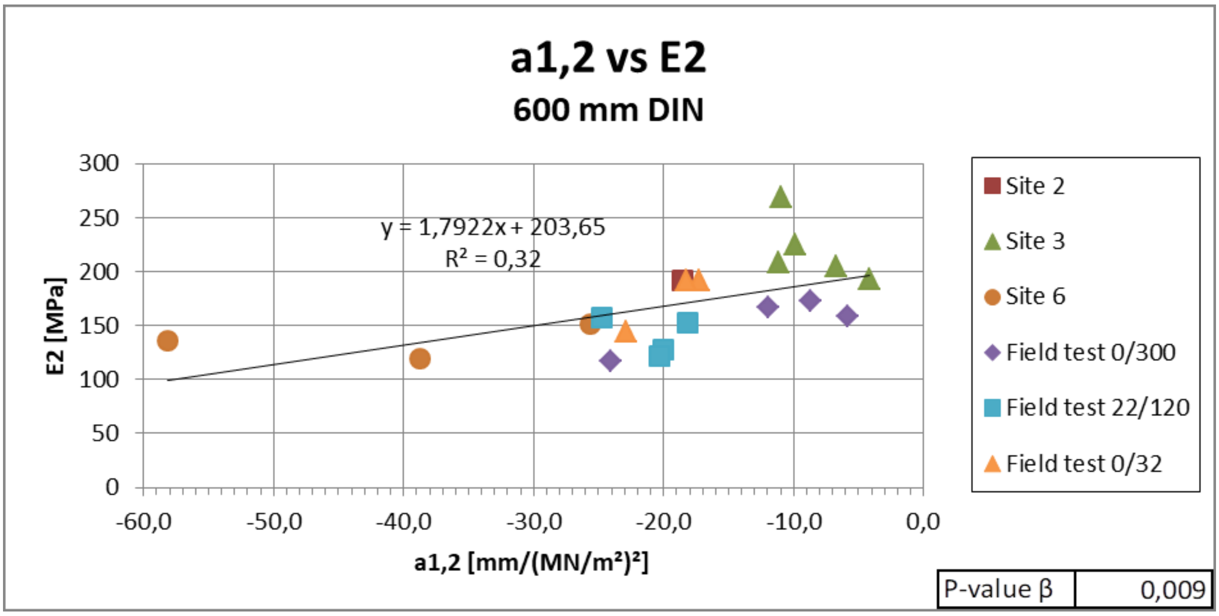


Figure 5.41: The correlation between the factor $a_{1,2}$ and the E_2 value for 600 mm plate measurements conducted according to DIN 18134*. The E_2 values are calculated using Norwegian method 1. The p-value for β displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

Figure 5.42, Figure 5.43 and Figure 5.44 show a regression analysis performed for the correlation between the constant $a_{1,2}$ from the second degree polynomial approximation of the Swedish calculation method, and the calculated E_2/E_1 ratio of Norwegian method 1. The figures also show the p-value the regression analysis of each of the figures, which corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables. A regression analysis generally assumes that the free variable (i.e. the variable on the y-axis, in this case the ratio E_2/E_1) is approximately normally distributed (Løvås, 2004, p. 271-272). As already established, the ratio E_2/E_1 cannot be assumed to be approximately normally distributed. This does not mean that a regression analysis cannot be used in this case, but rather that the results of the t-test performed (the p-value) is less reliable than for a variable that is approximately normally distributed. The p-value can give an indication as to the relative significance of the linear regression model, but should not be used to estimate the true statistical level of significance. In the following section, the results of the regression analysis for the correlation between the constant $a_{1,2}$ and the calculated E_2/E_1 ratio will be discussed as if the p-values can be used directly as a true estimate of the statistical level of significance.

Figure 5.42 shows the correlation for the PLTs performed according to the Norwegian handbook *R211*. The data shows a statistically significant correlation at a 95% confidence level between the variables, with an estimated linear trendline with a slope of -0,2969. Figure 5.43 shows the correlation for the PLTs performed with a 300 mm diameter plate according to the German standard *DIN 18134*. The data shows a statistically insignificant correlation at a 95% confidence level between the variables, with an estimated linear trendline with a slope of -0,249. Finally, Figure 5.44 shows the correlation for the PLTs performed with a 600 mm diameter plate according to the German standard *DIN 18134*. The data shows a statistically significant correlation at a 95% confidence level between the variables, with an estimated linear trendline with a slope of -0,041.

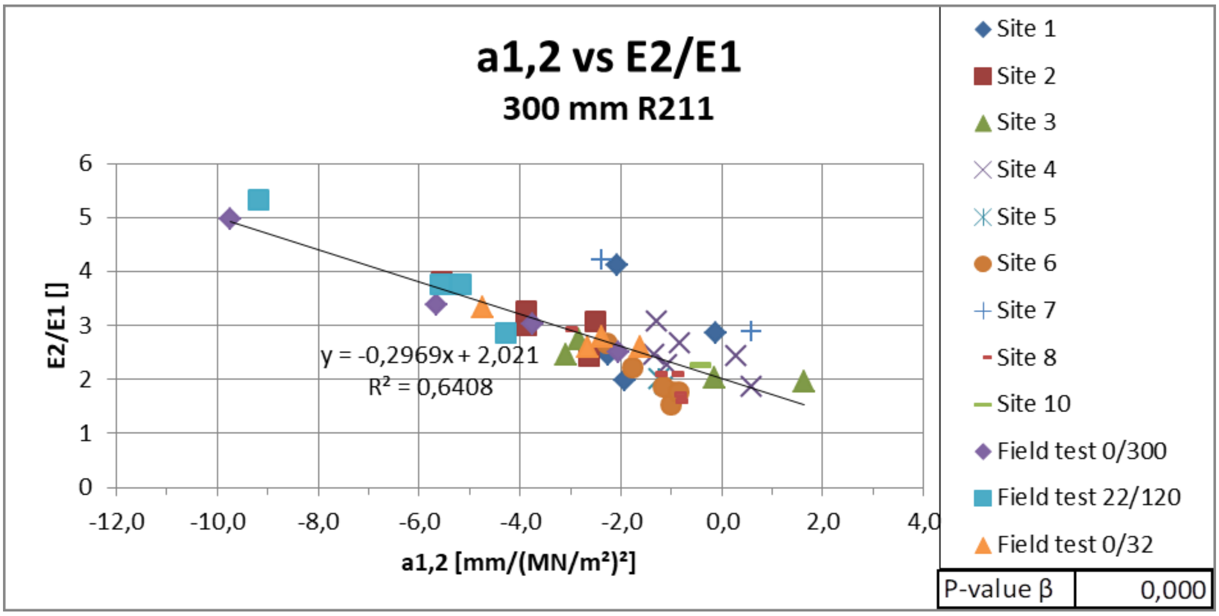


Figure 5.42: The correlation between the factor $a_{1,2}$ and the E_2/E_1 value for 300 mm plate measurements conducted according to R211*. The E_2 and E_1 values are calculated using Norwegian method 1. The p-value for β displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

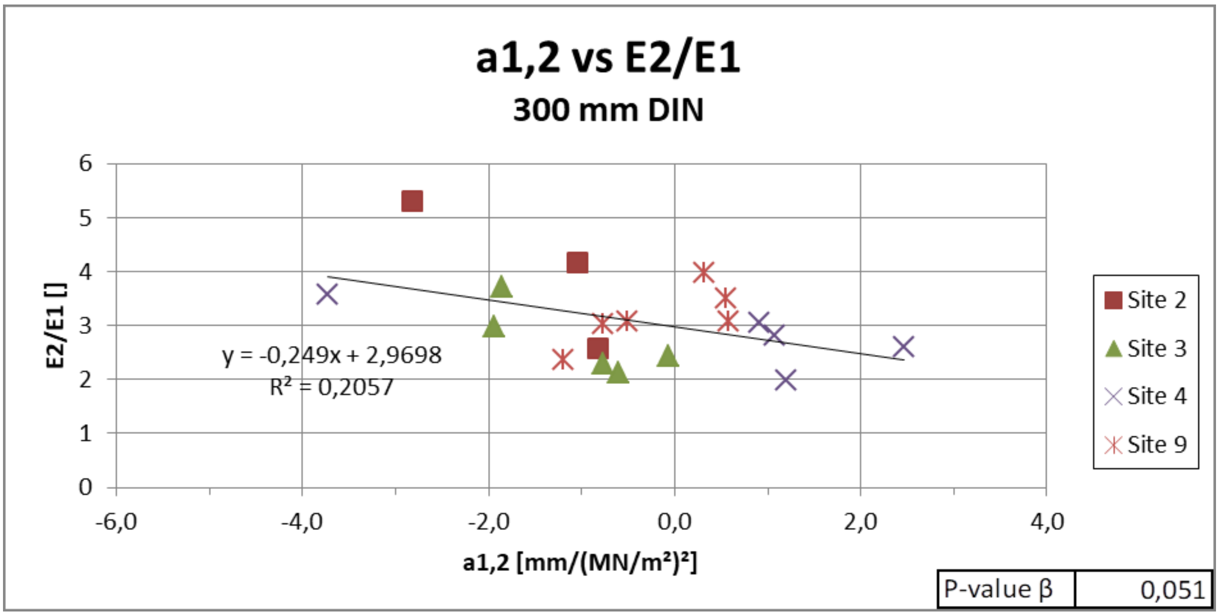


Figure 5.43: The correlation between the factor $a_{1,2}$ and the E_2/E_1 value for 300 mm plate measurements conducted according to DIN 18134*. The E_2 and E_1 values are calculated using Norwegian method 1. The p-value for* β *displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

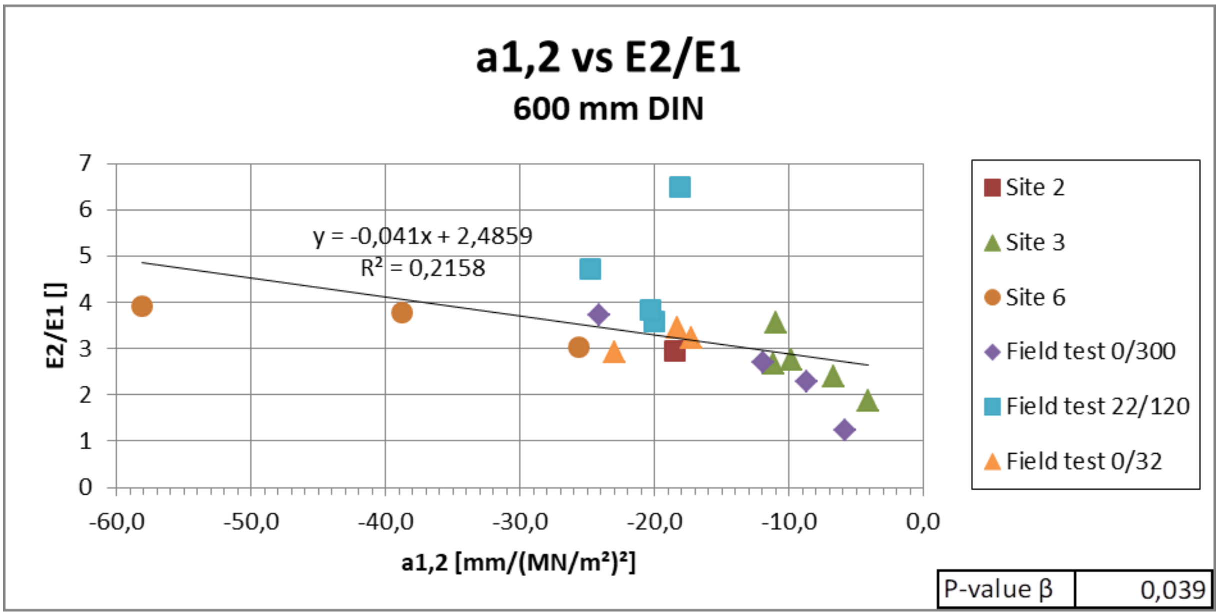


Figure 5.44: The correlation between the factor $a_{1,2}$ and the E_2/E_1 value for 600 mm plate measurements conducted according to DIN 18134*. The E_2 and E_1 values are calculated using Norwegian method 1. The p-value for* β *displayed on the figure corresponds to the probability of the slope of the trendline being equal to 0, i.e. the probability of there being no correlation between the two variables.*

6 Discussion

6.1 The plate load test in general

As has already been established, the PLT is based on many theoretical assumptions that don't apply when the test is used on the granular materials of a road's superstructure. Many of the test procedures and requirements used are also based on some vaguely established assumptions that are often debated when comparing different procedures.

One of the vague assumptions is the depth effect of the PLT, i.e. how far down the test effects the material being tested. As discussed in chapter 2.2, the theoretical relative change in stress and strain directly under the centre of a plate, based on Boussinesq's formula, can and have been determined. However, as can be seen from Figure 2.2 and Figure 2.3, the theoretical effects of a PLT are experienced infinitely far down into the soil, which has no practical meaning for application in the field. The depth effect of a PLT must therefore be determined by defining appropriate limits to when the changes in stresses and strains in the material beneath the plate can be considered negligible. Which limit is the most appropriate for this purpose and how it should be defined is debatable and will not be directly addressed here. Some possible definitions of the negligibility limits and their corresponding depth of effect are presented in Table 6.1.

Table 6.1: Depth effect of a PLT based on various limits for negligible effects.

Limits for negligibility	Depth of effect	Depth effect of a 300 mm diameter plate [m]
$\Delta\sigma_z = 0{,}5q$	$1{,}3048 \cdot R$	0,196
$\Delta\sigma_z = 0{,}1q$	$3{,}7071 \cdot R$	0,556
$\Delta\sigma_z = 0{,}05q$	$5{,}3616 \cdot R$	0,804
$\Delta\sigma_z = 0{,}01q$	$12{,}1963 \cdot R$	1,829
$\Delta\varepsilon_z = 0{,}5 \cdot \frac{q}{E}$	$1{,}1076 \cdot R$ (if $\nu = 0{,}5$)	0,166 (if $\nu = 0{,}5$)
$\Delta\varepsilon_z = 0{,}1 \cdot \frac{q}{E}$	$3{,}6705 \cdot R$ (if $\nu = 0{,}5$)	0,551 (if $\nu = 0{,}5$)
$\Delta\varepsilon_z = 0{,}05 \cdot \frac{q}{E}$	$5{,}3373 \cdot R$ (if $\nu = 0{,}5$)	0,801 (if $\nu = 0{,}5$)
$\Delta\varepsilon_z = 0{,}01 \cdot \frac{q}{E}$	$12{,}1860 \cdot R$ (if $\nu = 0{,}5$)	1,828 (if $\nu = 0{,}5$)

The definition of the depth effect becomes more complicated when the different thicknesses and material properties of the superstructure materials are taken into account, as evident by the calculations performed by Burmister (1965), Fox (1948), Burmister (1966), and Acum and Fox (1951). The actual depth effect of a PLT in reality is therefore very dependent on the layer thicknesses and the stiffness of the materials in the superstructure. A PLT conducted on the layered, unbound materials of a road's superstructure thus probably only evaluates the stiffness of the very top of the superstructure, and most certainly not further than the values in Table 6.1 suggest. Using a PLT conducted solely on the top of the unbound material to document the quality of compaction of the whole superstructure is therefore a questionable control method.

Another debatable assumption in PLT test procedures is the horizontal effect of the test, and thus how far away from the test plate the counterweight has to be placed, or how closely PLTs can be conducted to one another. As for the theoretical change in stress and strain directly underneath the plate, the theoretical change in vertical stress and strain is defined to an infinite depth and infinite horizontal distance from the plate, and the realistic, practical effect must therefore be determined by defining limits for what can be considered negligible. As for the vertical effects, which negligibility limits are most appropriate in this instance will not be directly addressed here. As can be seen from Figure 2.5 and Figure 2.7, the stress and strain change more rapidly with horizontal distance than depth, suggesting that the horizontal effects of a PLT reach over a shorter distance than the vertical effects. This is, however, also affected by the different thicknesses and material properties of the superstructure materials. Setting unreasonably small limits for the required minimum distances between the test plate and the counterweight or the distance between individual tests can significantly affect the results of the PLTs.

Despite the many flaws of the PLT, the most important downside of the test method is that it is a point test used to estimate a quality that is inherently three dimensional. In addition to the importance of tight compaction, it is also very important that the road be relatively evenly compacted, which is an aspect that the PLT cannot estimate reasonably. The use of devices and/or tests that can at least measure the compaction of the superstructure materials over an area is therefore recommended, as evident by the reduction in the required number of PLTs when response measurements were used during compaction (Statens vegvesen and Vegdirektoratet, 2018a), and also widely used by the contractors. It therefore seems counterintuitive that the PLT is the only method available as final documentation of the quality of compaction, especially when the compaction plan does not need to be calibrated to the results of a PLT (Statens vegvesen and Vegdirektoratet, 2018a). It would be more reasonable to either permit the use of other methods of estimating the quality of compaction as the final documentation, or to require the compaction plan to be calibrated to acceptable results of a PLT. Without calibrating the compaction plan to a PLT, there is no way of telling for sure if the compaction plan will result in a degree of compaction that will fulfil the requirements for a PLT.

6.2 The plate load test in national standards

The Norwegian requirement values and the test procedure for PLTs have not changed to any significant extent in the last roughly four decades, as has been discussed in chapter 3.1. The defined limits have been changed from guidelines or “desired results” to strict requirements without much change being introduced to the test procedure, and the requirements for using the PLT for documentation of quality of compaction has been changed from being optional to being the only accepted form of final documentation. Meanwhile, the requirements for other factors of the road construction process that can affect the results of PLTs have been changed, without resulting in any apparent re-evaluation of the PLT requirements. An example of this was mentioned by one of the interviewees, where the changes made to the requirements for the grading curve of the subbase material was mentioned as a possible source of challenges regarding the PLT requirements. According to the interviewee, the requirements for the fines content in the subbase material have been decreased in recent years in order to limit the occurrence of frost heave in the superstructure. The subbase material that is used in Norway today is therefore coarser and more open-graded than the material that was used when the PLT requirements were defined, without any changes being made to the PLT requirements. According to Choi et al. (2018), open-graded materials obtain higher values for E_2, thus also resulting in higher values for the ratio E_2/E_1. Requirements that are defined for well graded materials are thus not necessarily suitable for uniformly, open-graded materials, as Choi et al. (2018) argue.

One of the few changes that have been made to the Norwegian test procedure itself throughout the years is regarding the requirement for the use of a levelling material under the test plate. All of the Norwegian test procedure descriptions in handbooks prior to the year 2018 require that a thin layer of gypsum plaster be placed between the test plate and the material being tested (Statens vegvesen and Vegdirektoratet, 1984, Statens vegvesen and Vegdirektoratet, 1997, Statens vegvesen and Vegdirektoratet, 2014b). In the 2018 version of the test procedure description, this requirement has been removed, and there is no mention of the use of a levelling material whatsoever (Statens vegvesen and Vegdirektoratet, 2018b). No changes were made to the requirements for the results of PLTs in relation to these changes to the test procedure (Statens vegvesen and Vegdirektoratet, 2014a, Statens vegvesen and Vegdirektoratet, 2018a). This is unfortunate, given that both Barnard and Heymann (2015) and Fladvad (2012) have found that the use of levelling materials can have an effect on the measured results of a PLT. Fladvad (2012) even found that measurements conducted without a levelling layer resulted in lower E_1 values than measurements conducted with a layer of gypsum plaster, and thus potentially an increase in the resulting E_2/E_1 ratio. Since the PLT requirements were created when the test procedure required the use of gypsum plaster, the removal of the levelling material requirement should have resulted in a reconsideration of the PLT requirement values.

As mentioned by some of the interviewees in the study, some owner builders and contractors want to incorporate a test procedure for a 600 mm plate diameter into the Norwegian PLT procedure description. Some test performers even use the 600 mm plate diameter actively already, although the resulting measurements cannot be used for formal documentation. One should, however, be vary of comparing the results of PLTs performed with different plate sizes, since the size of the plate can influence the results, as found by Araújo et al. (2017) and Fu et al. (2016). If the 600 mm plate diameter were to be incorporated into the Norwegian test procedures, one should perform adequate testing to determine the test requirements for that plate size, and not rely on the requirements defined for the 300 mm plate size. As the test results in this study show, there can be a significant difference between the results of PLTs conducted with two different plate sizes, especially when the test procedures are different.

Some parts of the Norwegian PLT procedure description are phrased in a way that can be easy to misunderstand. An example is the following phrase about when each load step should be considered completed: "For each load step, the gauge shall be read when the settlements are finalized, or when the gauge doesn't move more than 0,02 mm pr. min." (Statens vegvesen and Vegdirektoratet, 2014b, p. 116, Statens vegvesen and Vegdirektoratet, 2018b, p. 202). This is a sentence that many of the test performers understand differently than others. Some of the test performers understand this to mean that each load step should be applied for at least one minute, and the settlements and loads registered after the minute has passed and the dial gauge shows a change in settlement of 0,02 mm or less. Others understand the sentence to mean that each load step is finalized at the exact moment the dial gauge shows a change in settlement of 0,02 mm or less, regardless of the time that has passed. The exact meaning of the phrase is uncertain, but how the test performers understand the meaning of it can affect the results of the PLTs conducted, and thus the comparability of the test results as Dasaka et al. (2014) concluded in their study.

Another important factor is the load applied to the plate during testing. The Norwegian and the German test procedures require different maximum loads to be applied to the plate during testing, which will affect the settlements measured during the test. Although some initial testing or general logic must have been used to determine the maximum load applied in each procedure, neither of the procedure descriptions clarify why these values have been chosen. One concern related to this is whether or not the rollers used for compaction in the field are able to exert a load on the superstructure materials that is in the range of the load applied during the Norwegian test procedure. This is especially relevant considering the additional measurements conducted on site 2, where the results of the second PLTs showed a (potentially) significant improvement from the conventional measurements, while the PLTs conducted after additional compaction with a roller showed very similar results to the conventional measurements.

As established in chapter 3, the different national PLT procedure descriptions use different calculation methods to determine the material's modulus of elasticity. Despite their differences, the calculation methods also have their similarities. Comparing Figure 3.3 and Equations (7), (8) and (9), one can see that Equation (7) can be re-written in terms of the slope of the lines between the points (p_1,s_1) and (p_2,s_2) for each loading cycle. Equation (7), which describes the Norwegian calculation method for the modulus of elasticity, thus becomes:

$$E = \frac{3}{4} \cdot \frac{1}{h} \cdot D \tag{13}$$

Where,

E is the elasticity of the soil for the load cycle in question [MPa]
h is the slope of the line between the points (p_1, s_1) and (p_2, s_2) for the load cycle in question [mm/(kN/m^2)]
D is the diameter of the plate [m]

Similarly, we can compare Figure 3.4 to Equation (10) and (11) and find that Equation (11) can be re-written in terms of the slope of a tangent to the polynomial function. Equation (11), which describes the Swedish calculation method for the modulus of elasticity, thus becomes:

$$E = \frac{3}{2} \cdot R \cdot \frac{1}{h} \tag{14}$$

Where,

E is the modulus of elasticity of the soil for the load cycle in question [MPa]
R is the plate radius [mm]
h is the slope of the tangent to the polynomial function at the load $\frac{1}{2}\sigma_{1\max}$ [MN/m^2] i.e. $h = s'\left(\frac{1}{2}\sigma_{1max}\right)$

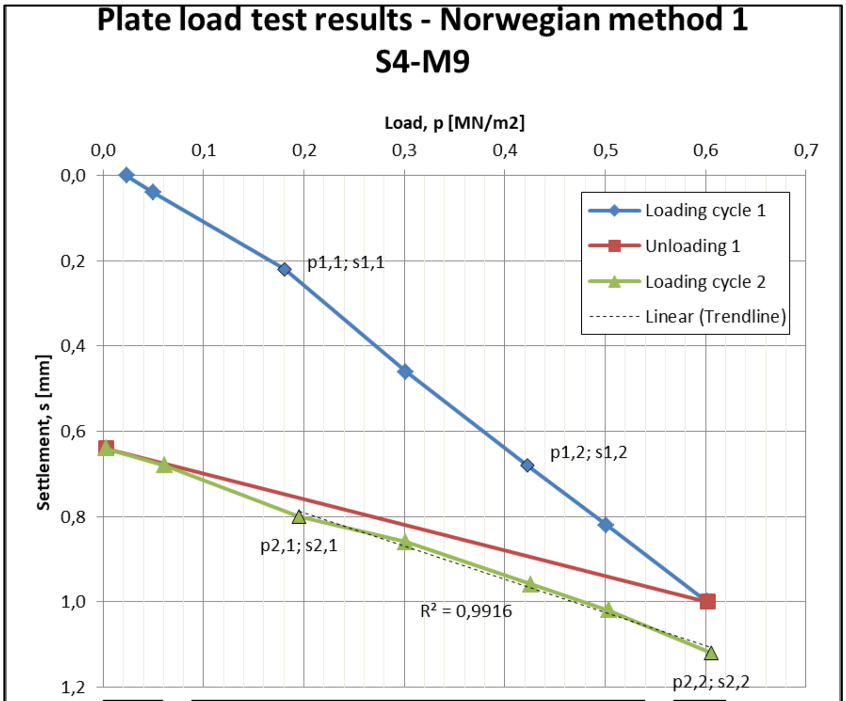
Equation (13) and Equation (14) are in essence the same equation, just based on a different approximation of the registered data. This is further confirmed by the appendix to the German standard *DIN 18134* discussed in chapter 3.2.3, where it is confirmed that the Swedish (i.e. German) calculation method is based on the same reference points as the Norwegian calculation method, i.e. the points $\sigma = 0{,}3 \cdot \sigma_{1max}$ and $\sigma = 0{,}7 \cdot \sigma_{1max}$.

Based on the measurements collected for this thesis, a second degree polynomial is generally more representative of the measured data (see appendices for more details about the measured results). It also has the benefit of being able to approximate relatively linear data by reducing the size of the constant of the second degree term of the polynomial to approximately zero. The perk of the Norwegian calculation method is that it uses the actual measurements of settlement, instead of an approximation of the settlement as the Swedish method does. Which calculation method is more suitable to estimate the modulus of elasticity of the material being tested thus comes down to how important it is for the calculations that the reference points are *exactly* at $\sigma = 0{,}3 \cdot \sigma_{1max}$ and $\sigma = 0{,}7 \cdot \sigma_{1max}$, since the settlements for these exact loads can always be approximated using the German calculation method, while the Norwegian calculation method is limited to using the measured load values closest to these points, which will always vary slightly. None of the test procedure descriptions elaborate on why these values have been chosen as reference points for calculating the E-values, so the significance of using exactly these values is unknown.

The Norwegian calculation method for E_2 is very dependent on the test performer's interpretation of what can be considered linear. For instance, the same set of measurements can result in completely different E_2 values, based on which point in the second load series is defined as $(p_{2,2};s_{2,2})$. A clear example of this is PLT measurement S4-M9, measured by the contractor of the motorway upgrading project (site 4), as shown in Figure 6.1 and Figure 6.2. The calculated E_2 values in the two figures are based on the exact same set of measurements, but a difference in the interpretation of which point should be considered the reference point $(p_{2,2};s_{2,2})$ results in very different outcomes.

In Figure 6.1 the measured points in load cycle 2 are considered to follow a linear trend from the first reference point $(p_{2,1};s_{2,1})$ to the last point of the load cycle. Thus, $(p_{2,2};s_{2,2})$ becomes (0,6056 MN/m^2 ; 1,12 mm), and the calculated results are E_2 = 289 MPa and E_2/E_1 = 2,4. These values are in accordance to the requirements defined in the Norwegian handbook *N200*, and the test point is approved. In the case of Figure 6.2, the points of load cycle 2 are considered to follow a linear trend from the first reference point $(p_{2,1};s_{2,1})$ up until the second to last point of the load cycle. Thus, $(p_{2,2};s_{2,2})$ is considered to be (0,5034 MN/m^2 ; 1,02 mm), and the calculated results are E_2 = 316 MPa and E_2/E_1 = 2,7. While the value for E_2 in this instance is still within the requirements of handbook *N200*, the value for the ratio E_2/E_1 is not, and the test point is consequently not approved. This interpretation factor of the Norwegian calculation method essentially gives the test performer the ability to choose whichever of the measured points as the second reference point of the calculation. This can benefit the contractor, since it is reasonable to assume that most contractors would choose the point that gives the most beneficial result as a reference point. It is, however, unclear if the benefit to the contractor is an unfair one, since it is unclear on what basis the PLT requirement values were defined. To avoid misunderstandings and any potential unfair benefits of doubt, it would be more reasonable to base the PLT requirement values and the calculation of results on a test procedure that is not open for interpretation. This would also make the programming of the software used in the measurement equipment easier.

Load [MN/m²]	Settlement [mm]
0,0233	0,00
0,0503	0,04
0,1805	**0,22**
0,3014	0,46
0,4225	**0,68**
0,5010	0,82
0,6020	1,00
0,0028	0,64
0,0612	0,68
0,1949	**0,80**
0,3013	0,86
0,4261	0,96
0,5034	1,02
0,6056	**1,12**



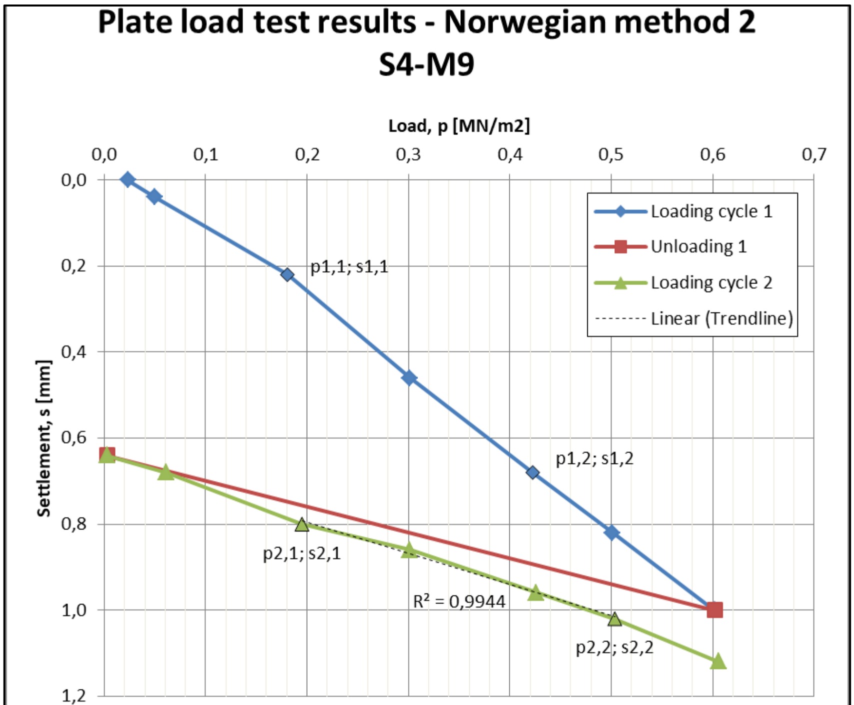
d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,423	0,22	0,68	118
2	0,195	0,606	0,80	1,12	289

E_2/E_1 []
2,4

Figure 6.1: The measured and calculated results of PLT measurement S4-M9, using Norwegian calculation method 1. The bold values of the measured values indicate the points in the load series used to calculate Δp and Δs.

Load [MN/m²]	Settlement [mm]
0,0233	0,00
0,0503	0,04
0,1805	**0,22**
0,3014	0,46
0,4225	**0,68**
0,5010	0,82
0,6020	1,00
0,0028	0,64
0,0612	0,68
0,1949	**0,80**
0,3013	0,86
0,4261	0,96
0,5034	**1,02**
0,6056	1,12



d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,423	0,22	0,68	118
2	0,195	0,503	0,80	1,02	316

E_2/E_1 []
2,7

Figure 6.2: The measured and calculated results of PLT measurement S4-M9, using Norwegian calculation method 2. The bold values of the measured values indicate the points in the load series used to calculate Δp and Δs.

Another weakness of the Norwegian test method is that it is vulnerable to small changes in measurements. This is can be illustrated using the values in Table 6.2 and Table 6.3. Table 6.2 shows the measured load and settlement values in the reference points, as well as calculated E-values for measurement S8-M4. The complete set of measured values for this point is available in Appendix 7. The calculated E_2 value in this instance is 149 MPa, which is below the Norwegian requirement, while the calculated ratio E_2/E_1 of 2,1 fulfils the Norwegian requirements. Since there is no defined error limit for the Norwegian requirements, the test results are considered to simply not fulfil the requirements and the test point is therefore not approved. In Table 6.3, the settlement of the last load in load cycle 2 has been decreased by 0,01 mm from the actual measurement for point S8-M4. This results in a calculated E_2 of 152 MPa, which fulfils the Norwegian requirements and the test point is thus approved. An error of 0,01 mm in the measured settlement of a single point can therefore determine if the test results fulfil the Norwegian requirements or not, and thus determine if the test point is approved or not. Since the Norwegian handbooks require all test points to be within the defined requirements, a single settlement measurement within one PLT can therefore determine if the road section is approved according to the requirements or not. This is especially alarming considering that the dial gauge used for measuring settlements during PLTs generally shows values with an accuracy of 0,01 mm, meaning that the measurement error is at best 0,005 mm. This means that whether or not a PLT measurement fulfils the Norwegian requirements can be determined by an error of 0,005 mm. In comparison, the German standard *DIN 18134* defines the maximum allowable error during calibration of the settlement measuring device as 0,04 mm, indicating that the settlement measurements may be off by up to 0,04 mm after the measuring device has been calibrated.

Table 6.2: The measured and calculated results for the reference points of PLT measurement S8-M4, using Norwegian calculation method 1. The complete set of measured values for this point is available in Appendix 7.

d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,180	0,420	0,50	1,26	71	2,1
	2	0,180	0,605	1,32	1,96	149	

Table 6.3: The measured and calculated results for the reference points of PLT measurement S8-M4, using Norwegian calculation method 1 and the slightly altered value of the last point of load cycle 2 as the reference point ($p_{2,2}$;$s_{2,2}$). The red value has been decreased by 0,01 mm from the original measurement displayed in Table 6.2

d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,180	0,420	0,50	1,26	71	2,1
	2	0,180	0,605	1,32	**1,95**	152	

The effect of this small change in settlement measurements can also be compared to the results of the Swedish calculation method, which are shown in Table 6.4 and Table 6.5. For the Norwegian calculation method, a change of 0,01 mm in the settlement measurement of the last point of load cycle 2 results in a change of 3 MPa in the calculated E_2 value, from 149 MPa for the original case in Table 6.2 to 152 MPa for the altered case in Table 6.3. The calculated results of the Swedish calculation method for the original case shown in Table 6.4 results in an E_2 of 145 MPa, while the altered case in Table 6.5, using the same change in settlement measurement as in Table 6.3, results in an E_2 of 146 MPa. This is a change of 1 MPa for the Swedish calculation method, compared to the 3 MPa change of the Norwegian calculation method. This, of course, is only one example of the difference in one point, and a statistical analysis of the robustness of the two calculation methods should be conducted in order to determine which one is more robust against small changes. It is also worth noting that the Norwegian calculation method is only sensitive for changes in measurements at the reference points, while the Swedish calculation method is sensitive to changes in all of the measurements.

Table 6.4: The measured and calculated results of PLT measurement S8-M4, using the Swedish calculation method. The complete set of measured values for this point is available in Appendix 7.

r [mm]	150
σ_{1max} [MN/m²]	0,6008
$s_{i,2}$ [mm]	1,96

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1208	3,6581	-0,9642	73
2	1,0149	1,6605	-0,1869	145

E_2/E_1 []
2,0

Table 6.5: The measured and calculated results of PLT measurement S8-M4, using the Swedish calculation method and the slightly altered value of the last point of load cycle 2. The red value has been decreased by 0,01 mm from the original measurement displayed in Table 6.4.

r [mm]	150
σ_{1max} [MN/m²]	0,6008
$s_{i,2}$ [mm]	**1,95**

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1208	3,6581	-0,9642	73
2	1,0141	1,6852	-0,2463	146

E_2/E_1 []
2,0

The fact that the Norwegian requirements don't allow for any of the test points to deviate from the requirements was mentioned frequently in the interviews. Requiring all measurements to fulfil requirements without exception is very rare in the construction business since it is very rare that everything goes perfectly according to plans every time, especially when the tests are as dependent on so many variables as the PLT is. In fact, all of the other national requirements have some sort of acceptance of deviations to a certain degree. As discussed in the interviews, in reality most contractors and/or owner builders in Norway also work by some sort of deviance acceptance system that they define themselves, either by defining how many tests need to fulfil the requirements out of a set of tests like for site 3, or by just accepting the measurements and applying asphalt regardless of the calculated values. A more realistic and better suited approach is to allow for a certain amount of deviation, and to define the allowable deviation alongside the requirement values. That way the accepted deviation is similar for all construction sites, and it is not up to each contractor and/or owner builder to determine what is acceptable or not.

Many of the interviewees also requested that the defined requirement values vary depending on the type of superstructure materials being used, as well as the expected future traffic volumes, as is done to some extent in Germany and Sweden. A very good example of the logic behind this was brought up by one of the interviewees. It is very unlikely that a highly trafficked motorway and a small pedestrian road will experience the same loads during their service lifetime, but according to the current requirements, both of them have to have the same quality of compaction and fulfil the same PLT requirements. Unnecessary compaction efforts are a waste of time, money and resources and should be avoided. For that reason, it might be beneficial to introduce different requirements for different types of roads. When it comes to the different superstructure materials, some of the materials seem to be more challenging than others. The requirements should be defined so that when they are fulfilled, we can be certain that the materials are compacted tightly enough to provide adequate bearing capacity. If it can be reasonably assumed that the materials of the superstructure provide adequate bearing capacity with values that do not fulfil the current requirements, or if there are other benefits to using the materials in the superstructure that outweigh the decrease in bearing capacity, a new requirement value can be introduced for the superstructure materials in question. This could e.g. be relevant for the use of insulation materials or Ak in the superstructure, and requires adequate testing to determine.

6.3 The plate load test in the field

Generally speaking, the actual test procedure for a PLT and the calculation method used to estimate the E-values of the material of interest varies from one test performer to the other. This was observed both during the interviews as well as during observations in the field. Most of the test performers rely on the automated PLT devices to guide them during the test performance, as well as to calculate the test results. The calculation method used generally depends on the software in the measuring equipment, which varies based on the equipment supplier. Thus, some tests results are calculated using the Swedish calculation method, while other results are calculated using Norwegian method 1. Norwegian method 2, or any variation of the Norwegian method where a linear approximation is used, is never used in the field, since the automatic calculations always use the last measurements of the last load cycle as a reference point. None of the individuals interviewed about the use of the Norwegian calculation method or observed using it checked the suitability of the calculated results. The Swedish calculation method is also used in a variety of ways, each producing a different result. While the actual Swedish calculation method uses the maximum load of the first load cycle to calculate *both* of the E-values, some of the calculation software used in field measurements use the maximum load of the second load cycle to calculate the E_2 value. Other calculation software doesn’t include the first measurement of load cycle 2 when determining the coefficients of the second degree polynomial for the second load cycle, which leads to an incorrect approximation compared to the actual Swedish calculation method. Yet another factor increasing the variability in the calculated results from field PLT measurements is the combination of using different test procedures and different calculation methods. Thus, some test performers conduct the PLTs according to the Norwegian handbook *R211* and calculate the results using the Norwegian calculation method, while others use the same test procedure but use the Swedish calculation method. Yet others conduct the test according to the German standard *DIN 18134* and use the Swedish calculation method. Each of these combinations has the potential to produce different end results, which could affect if the test is approved according to the Norwegian requirements or not. The calculations performed in the thesis suggest that there is not always a statistically significant difference between the calculation methods or the test procedures. However, the fact that there is a significant difference in some instances emphasizes the importance of making sure that all the tests are conducted in the same way, using the same test procedure and the same calculation method. Only when that is achieved can we be certain that the measurements can be compared.

Many of the interviewees mentioned the possibility of data manipulation and underreporting of measurements. Although none of the interviewees admitted to manipulating data themselves, many of them were concerned that the data could be too easily adjusted to fit the requirements, when using the current software used in the measuring equipment. In the context of the construction business, this is more of a contract and self-monitoring issue than an issue with the PLT itself. Where the owner builder performs sample, monitoring tests themselves, such data manipulation or underreporting should be discovered relatively quickly. However, where the owner builder does not perform any monitoring tests, as is often the case for turnkey projects, data manipulation and underreporting could become a significant problem. In those cases, it could be appropriate to hire a third party independent consultant to perform tests and measurements for final documentation of the quality of the structure, regardless of the type of test. Whether it is appropriate for the NPRA's handbooks to require independent, third party testing is unclear and will not be discussed further.

One of the more interesting discoveries from the interviews is that there seem to be little to no consequences for the contractor if the PLTs fail to fulfil the requirements. As most of the interviewees described the process, the PLTs are often performed just before the asphalt is put on top of the unbound layers, and since there is high cost associated with stopping or delaying asphalt production, the contractor normally proceeds with the asphalt work regardless of the results of the PLTs. The role of the PLTs in this process thus seems to lean more towards documenting the degree of compaction, rather than ensuring good quality compaction and the role of the requirement values becomes rather arbitrary. If the purpose of conducting the PLTs is to ensure good quality compaction, it would be more logical to introduce some sort of consequences for not fulfilling requirements, e.g. some sort of monetary sanctions. As one of the interviewees remarked, introducing monetary sanctions would encourage the contractors to make an effort to fulfil the requirements in order to avoid paying the fee, while still allowing for mistakes to be made to some degree without a full stop in the construction process.

7 Conclusion

The thesis set out to answer the following research questions:

- Which in-situ factors affect the results of plate load tests?
- In what way does the material in the superstructure and its in-situ state affect the results of plate load tests?
- In what way do the test procedure and the calculation method for the E-modulus affect the results of plate load tests?

The first question is best discussed with the results of the interviews. Many in-situ factors were mentioned as possible culprits for challenges in fulfilling the requirements for PLT results. The most commonly mentioned were the water content in the superstructure materials, the time between compaction and testing, as well as the use of Ak in the superstructure. High water content and a short time between compaction and testing were associated with poor PLT results, and Ak is found to retain a high moisture content for a longer period than other materials. The use of insulation materials or light filler materials in the superstructure was also associated with poor PLT results, although many of the interviewees believed that this was not due to poor quality of compaction, but rather the behaviour of the insulation materials during a PLT. This has however not been confirmed. These claims have to be verified by further testing, and provide a good starting point in terms of which factors of the in-situ conditions should be focused on. The interviewees also believe that the Norwegian PLT requirements themselves contribute to creating the challenges with fulfilling them, since all PLT measurements are supposed to fulfil the requirements without any deviations. This means that any PLT measurements that fall right below the requirement value are automatically rejected, even though only a small change in the measured settlements could have resulted in an accepted result.

The field test measurements suggested that the measurements conducted on top of the interlocking layer resulted in a significantly higher E_1 value than the measurements conducted directly on top of the subbase material, regardless of the plate size used. There was no statistically significant difference between the E_2 values for the different materials, suggesting that the interlocking layer plays an important role in keeping the E_2/E_1 ratio below the maximum limit. The comparison of the use of different superstructure materials in the case study was largely inconclusive, probably due to the limited number of comparable PLT measurements from each site. The calculated E-values of the measurements conducted at site 2 were found to be significantly lower than those conducted at site 4, potentially due to the large grain size of the subbase material at site 2, although other factors may also have affected the measurements. The calculated E_1-values of the measurements conducted at site 3 with a high fines content in the Fk interlocking layer show a potential to be significantly higher than the measurements conducted with a lower fines content, but the results of the statistical analysis were inconclusive, probably due to the limited number of available measurements. Finally, the measurements conducted on a road section containing XPS insulation boards at site 4 result in significantly lower E-values than measurements conducted without XPS insulation, although it is not certain if the difference between the values is influenced by the fact that the measurements are conducted using two different test procedures.

The results of the data analysis based on the data files collected were largely inconclusive due to the limited number of measurements conducted in similar conditions. The number of comparable measurements was further limited by the fact that three different test procedures were used for the PLTs, the procedure described in the Norwegian handbook *R211*, as well as the procedure for both 300 mm and 600 mm plate diameters described in the German standard *DIN 18134*. The results of a statistical analysis of the calculated E-values show that there is statistically significant difference between the Norwegian and the Swedish calculation methods for some instances, but not all. This was also the case for the comparison of the three test procedures. This indicates that there are more factors at play that influence the PLT results than the test procedures and the calculation methods. It is possible that this difference in level of significance stems from the inconsistency in how the tests are performed, since both interviews and observations in the field suggest that each test performer conducts PLTs in their own way, using their own interpretation and mixture of test procedures.

7.1 Recommendation for future research

Due to the nature of the plate load test, the defined research questions are complex and not easily answered. The following future research is therefore recommended in order to obtain more conclusive answers to the questions.

A controlled field test analysing the effect of the moisture content and time between compaction and plate load testing should be conducted, in order to test the extent to which the claims of the interviewees hold true. The field test could also analyse the effect of using Ak vs Fk in the interlocking layer, and test if the effects of moisture content and/or waiting time before testing are different between the two materials.

A further analysis of the difference between the two calculation methods and the three test procedures. This could be done by expanding on the field test conducted in this study, where a larger amount of test points should be considered for each of the superstructure material combinations. For this analysis, it is extremely important that all of the tests be conducted similarly, preferably precisely according to the test procedure descriptions. Care should also be taken to make sure that the calculation methods are used uniformly for all of the measurements.

An investigation into the poor PLT results from measurements conducted on superstructures containing insulation or light filler materials would also be beneficial, as these materials often save a lot of effort and resources by replacing other materials or solutions. The suitability of using the PLT to measure the quality of compaction of these materials should be investigated, and the possibility of using other test methods or possibly other requirement values should be assessed.

The plate load test, although flawed in many ways, has become an important method to test the quality of compaction of the unbound materials in superstructures. Fulfilling the requirements of PLT results gives a certain degree of information about the quality of the compaction of the superstructure materials, which in turn gives a certain indication of the bearing capacity and service life of the future road structure. Making sure these requirements are fulfilled should therefore be a priority to minimize the need for road reconstruction. Finding solutions to the challenges of fulfilling the requirements for PLT results is thus an important part of ensure the optimal allocation of society’s resources.

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Appendices

Appendix 1: Values for A' and B' for the determination of vertical stress beneath a uniformly distributed circular load

Function A'																		
Depth z/R []	Distance from centre r/R []																	
	0	0,2	0,4	0,6	0,8	1	1,2	1,5	2	3	4	5	6	7	8	10	12	14
0	1,00000	1,00000	1,00000	1,00000	1,00000	0,50000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
0,1	0,90050	0,89748	0,88679	0,86126	0,78797	0,43015	0,09645	0,02787	0,00856	0,00211	0,00084	0,00042						
0,2	0,80388	0,79824	0,77884	0,73483	0,63014	0,38269	0,15433	0,05251	0,01680	0,00419	0,00167	0,00083	0,00048	0,00030	0,00020			
0,3	0,71265	0,70518	0,68316	0,62690	0,52081	0,34375	0,17964	0,07199	0,02440	0,00622	0,00250							
0,4	0,62861	0,62015	0,59241	0,53767	0,44329	0,31048	0,18709	0,08593	0,03118									
0,5	0,55279	0,54403	0,51622	0,46448	0,38390	0,28156	0,18556	0,09499	0,03701	0,01013	0,00407	0,00209	0,00118	0,00071	0,00053	0,00025	0,00014	0,00009
0,6	0,48550	0,47691	0,45078	0,40427	0,33676	0,25588	0,17952	0,10010										
0,7	0,42654	0,41874	0,39491	0,35428	0,29833	0,21727	0,17124	0,10228	0,04558									
0,8	0,37531	0,36832	0,34729	0,31243	0,26581	0,21297	0,16206	0,10236										
0,9	0,33104	0,32492	0,30669	0,27707	0,23832	0,19488	0,15253	0,10094										
1	0,29289	0,28763	0,27005	0,24697	0,21468	0,17868	0,14329	0,09849	0,05185	0,01742	0,00761	0,00393	0,00226	0,00143	0,00097	0,00050	0,00029	0,00018
1,2	0,23178	0,22795	0,21662	0,19890	0,17626	0,15101	0,12570	0,09192	0,05260	0,01935	0,00871	0,00459	0,00269	0,00171	0,00115			
1,5	0,16795	0,16552	0,15877	0,14804	0,13436	0,11892	0,10296	0,08048	0,05116	0,02142	0,01013	0,00548	0,00325	0,00210	0,00141	0,00073	0,00043	0,00027
2	0,10557	0,10453	0,10140	0,09647	0,09011	0,08269	0,07471	0,06275	0,04496	0,02221	0,01160	0,00659	0,00399	0,00264	0,00180	0,00094	0,00056	0,00036
2,5	0,07152	0,07098	0,06947	0,06698	0,06373	0,05974	0,05555	0,04880	0,03787	0,02143	0,01221	0,00732	0,00463	0,00308	0,00214	0,00115	0,00068	0,00043
3	0,05132	0,05101	0,05022	0,04886	0,04707	0,04487	0,04241	0,03839	0,03150	0,01980	0,01220	0,00770	0,00505	0,00346	0,00242	0,00132	0,00079	0,00051
4	0,02986	0,02976	0,02907	0,02802	0,02832	0,02749	0,02651	0,02490	0,02193	0,01592	0,01109	0,00768	0,00536	0,00384	0,00282	0,00160	0,00099	0,00065
5	0,01942	0,01938				0,01835			0,01573	0,01249	0,00949	0,00708	0,00527	0,00394	0,00298	0,00179	0,00113	0,00075
6	0,01361					0,01307			0,01168	0,00983	0,00795	0,00628	0,00492	0,00384	0,00299	0,00188	0,00124	0,00084
7	0,01005					0,00976			0,00894	0,00784	0,00661	0,00548	0,00445	0,00360	0,00291	0,00193	0,00130	0,00091
8	0,00772					0,00755			0,00703	0,00635	0,00554	0,00472	0,00398	0,00332	0,00276	0,00189	0,00134	0,00094
9	0,00612					0,00600			0,00566	0,00520	0,00466	0,00409	0,00353	0,00301	0,00256	0,00184	0,00133	0,00096
10								0,00477	0,00465	0,00438	0,00397	0,00352	0,00326	0,00273	0,00241			

Function B'																		
Depth z/R []	Distance from centre r/R []																	
	0	0,2	0,4	0,6	0,8	1	1,2	1,5	2	3	4	5	6	7	8	10	12	14
0	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
0,1	0,09852	0,10140	0,11138	0,13424	0,18796	0,05388	-0,07899	-0,02672	-0,00845	-0,00210	-0,00084	-0,00042						
0,2	0,18857	0,19306	0,20772	0,23524	0,25983	0,08513	-0,07759	-0,04448	-0,01593	-0,00412	-0,00166	-0,00083	-0,00024	-0,00015	-0,00010			
0,3	0,26362	0,26787	0,28018	0,29483	0,27257	0,10757	-0,04316	-0,04999	-0,02166	-0,00599	-0,00245							
0,4	0,32016	0,32259	0,32748	0,32273	0,26925	0,12404	-0,00766	-0,04535	-0,02522									
0,5	0,35777	0,35752	0,35323	0,33106	0,26236	0,13591	0,02165	-0,03455	-0,02651	-0,00991	-0,00388	-0,00199	-0,00116	-0,00073	-0,00049	-0,00025	-0,00014	-0,00009
0,6	0,37831	0,37531	0,36308	0,32822	0,25411	0,14440	0,04457	-0,02101										
0,7	0,38487	0,37962	0,36072	0,31929	0,24638	0,14986	0,06209	-0,00702	-0,02329									
0,8	0,38091	0,37408	0,35133	0,30699	0,23779	0,15292	0,07530	0,00614										
0,9	0,36962	0,36275	0,33734	0,29299	0,22891	0,15404	0,08507	0,01795										
1	0,35355	0,34553	0,32075	0,27819	0,21978	0,15355	0,09210	0,02814	-0,01005	-0,01115	-0,00608	-0,00344	-0,00210	-0,00135	-0,00092	-0,00048	-0,00028	-0,00018
1,2	0,31485	0,30730	0,28481	0,24836	0,20113	0,14915	0,10002	0,04378	0,00023	-0,00995	-0,00632	-0,00378	-0,00236	-0,00156	-0,00107			
1,5	0,25602	0,25025	0,23338	0,20694	0,17368	0,13732	0,10193	0,05745	0,01385	-0,00669	-0,00600	-0,00401	-0,00265	-0,00181	-0,00126	-0,00068	-0,00040	-0,00026
2	0,17889	0,18144	0,16644	0,15198	0,13375	0,11331	0,09254	0,06371	0,02836	0,00028	-0,00410	-0,00371	-0,00278	-0,00202	-0,00148	-0,00084	-0,00050	-0,00033
2,5	0,12807	0,12633	0,12126	0,11327	0,10298	0,09130	0,07869	0,06022	0,03429	0,00661	-0,00130	-0,00271	-0,00250	-0,00201	-0,00156	-0,00094	-0,00059	-0,00039
3	0,09487	0,09394	0,09099	0,08635	0,08033	0,07325	0,06551	0,05354	0,03511	0,01112	0,00157	-0,00134	-0,00192	-0,00179	-0,00151	-0,00099	-0,00065	-0,00046
4	0,05707	0,05666	0,05562	0,05383	0,05145	0,04773	0,04532	0,03995	0,03066	0,01515	0,00595	0,00155	-0,00029	-0,00094	-0,00109	-0,00094	-0,00068	-0,00050
5	0,03772	0,03760				0,03384			0,02474	0,01522	0,00810	0,00371	0,00132	0,00013	-0,00043	-0,00070	-0,00061	-0,00049
6	0,02666					0,02468			0,01968	0,01380	0,00867	0,00496	0,00254	0,00110	0,00028	-0,00037	-0,00047	-0,00045
7	0,01980					0,01868			0,01577	0,01204	0,00842	0,00547	0,00332	0,00185	0,00093	-0,00002	-0,00029	-0,00037
8	0,01526					0,01459			0,01279	0,01034	0,00779	0,00554	0,00372	0,00236	0,00141	0,00035	-0,00008	-0,00025
9	0,01212					0,01170			0,01054	0,00888	0,00705	0,00533	0,00386	0,00265	0,00178	0,00066	0,00012	-0,00012
10								0,00924	0,00879	0,00764	0,00631	0,00501	0,00382	0,00281	0,00199			

Function A'+ Function B'																		
Depth z/R []	Distance from centre r/R []																	
	0	0,2	0,4	0,6	0,8	1	1,2	1,5	2	3	4	5	6	7	8	10	12	14
0	1,00000	1,00000	1,00000	1,00000	1,00000	0,50000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
0,1	0,99902	0,99888	0,99817	0,99550	0,97593	0,48403	0,01746	0,00115	0,00011	0,00001	0,00000	0,00000						
0,2	0,99245	0,99130	0,98656	0,97007	0,88997	0,46782	0,07674	0,00803	0,00087	0,00007	0,00001	0,00000	0,00024	0,00015	0,00010			
0,3	0,97627	0,97305	0,96334	0,92173	0,79338	0,45132	0,13648	0,02200	0,00274	0,00023	0,00005							
0,4	0,94877	0,94274	0,91989	0,86040	0,71254	0,43452	0,17943	0,04058	0,00596									
0,5	0,91056	0,90155	0,86945	0,79554	0,64626	0,41747	0,20721	0,06044	0,01050	0,00022	0,00019	0,00010	0,00002	-0,00002	0,00004	0,00000	0,00000	0,00000
0,6	0,86381	0,85222	0,81386	0,73249	0,59087	0,40028	0,22409	0,07909										
0,7	0,81141	0,79836	0,75563	0,67357	0,54471	0,36713	0,23333	0,09526	0,02229									
0,8	0,75622	0,74240	0,69862	0,61942	0,50360	0,36589	0,23736	0,10850										
0,9	0,70066	0,68767	0,64403	0,57006	0,46723	0,34892	0,23760	0,11889										
1	0,64644	0,63316	0,59080	0,52516	0,43446	0,33223	0,23539	0,12663	0,04180	0,00627	0,00153	0,00049	0,00016	0,00008	0,00005	0,00002	0,00001	0,00000
1,2	0,54663	0,53525	0,50143	0,44726	0,37739	0,30016	0,22572	0,13570	0,05283	0,00940	0,00239	0,00081	0,00033	0,00015	0,00008			
1,5	0,42397	0,41577	0,39215	0,35498	0,30804	0,25624	0,20489	0,13793	0,06501	0,01473	0,00413	0,00147	0,00060	0,00029	0,00015	0,00005	0,00003	0,00001
2	0,28446	0,28597	0,26784	0,24845	0,22386	0,19600	0,16725	0,12646	0,07332	0,02249	0,00750	0,00288	0,00121	0,00062	0,00032	0,00010	0,00006	0,00003
2,5	0,19959	0,19731	0,19073	0,18025	0,16671	0,15104	0,13424	0,10902	0,07216	0,02804	0,01091	0,00461	0,00213	0,00107	0,00058	0,00021	0,00009	0,00004
3	0,14619	0,14495	0,14121	0,13521	0,12740	0,11812	0,10792	0,09193	0,06661	0,03092	0,01377	0,00636	0,00313	0,00167	0,00091	0,00033	0,00014	0,00005
4	0,08693	0,08642	0,08469	0,08185	0,07977	0,07522	0,07183	0,06485	0,05259	0,03107	0,01704	0,00923	0,00507	0,00290	0,00173	0,00066	0,00031	0,00015
5	0,05714	0,05698				0,05219			0,04047	0,02771	0,01759	0,01079	0,00659	0,00407	0,00255	0,00109	0,00052	0,00026
6	0,04027					0,03775			0,03136	0,02363	0,01662	0,01124	0,00746	0,00494	0,00327	0,00151	0,00077	0,00039
7	0,02985					0,02844			0,02471	0,01988	0,01503	0,01095	0,00777	0,00545	0,00384	0,00191	0,00101	0,00054
8	0,02298					0,02214			0,01982	0,01669	0,01333	0,01026	0,00770	0,00568	0,00417	0,00224	0,00126	0,00069
9	0,01824					0,01770			0,01620	0,01408	0,01171	0,00942	0,00739	0,00566	0,00434	0,00250	0,00145	0,00084
10								0,01401	0,01344	0,01202	0,01028	0,00853	0,00708	0,00554	0,00440			

Appendix 2: Recruitment e-mail for case-study sent to contractors and owner builders of larger road projects in Norway

Hei,

Jeg heter Herbjörg Andrésdóttir og er en masterstudent ved institutt for bygg- og miljøteknikk ved NTNU. Jeg jobber for tiden med en masteroppgave som handler om utfordringer med platebelastningsforsøk på bærelag i vegkonstruksjoner etter komprimering.

NTNU har fått informasjon om at det kan i noen tilfeller være utfordrende å oppfylle krav til resultater fra platebelastningsforsøk, noe som kan skape store problemer for både byggherrer og entreprenører. Som et første steg i å løse dette problemet forsøker jeg å identifisere de forholdene som kan være med på å danne disse utfordringene. For å realisere oppgaven ønsker jeg derfor å komme i kontakt med entreprenører og byggherrer som er eller har nylig vært involverte i vegbyggingsprosjekter med krav om dokumentasjon av komprimering med platebelastningsforsøk.

Jeg er ute etter å få tilgang til målte resultater fra platebelastningsforsøk, samt dokumentert informasjon om forhold ved utførelse av komprimering og platebelastningsforsøk. I tillegg ønsker jeg å komme i kontakt med individer som har deltatt i arbeidet med komprimering og/eller platebelastningsforsøk, som kan være villige til å delta i et kort intervju. Oppgaven blir basert på en case-studie, hvor målet er å identifisere forhold i vegprosjekter som kan påvirke resultater fra platebelastningsforsøk. I den sammenheng blir prosjekter med forskjellige erfaringer fra platebelastningsforsøk sammenlignet, og jeg ønsker derfor informasjon fra prosjekter med både relativt få og relativt mange utfordringer knyttet til platebelastningsforsøk.

NB: All informasjon som publiseres i oppgaven blir anonym, både med tanke på involverte foretak, selve vegprosjektet og individer som deltar i intervjuer. Oppgaven skal ikke brukes til å kritisere arbeidsprosedyrer eller metodikk, men for å identifisere gunstige og ugunstige forhold til komprimering og utførelse av platebelastningsforsøk. Representanter fra både byggherrer og entreprenører vil få like spørsmål på intervjuene, og denne eposten blir sendt til flere foretak som har nylig vært involvert i større vegprosjekter i Norge.

Vennligst ta kontakt hvis det er aktuelt for deg og din arbeidsgiver å delta. Vennligst videresend denne eposten til relevant person dersom du ikke kan ta avgjørelse om deltagelse på vegne av din arbeidsgiver, eller i tilfelle du har kunnskap om personer som kan være aktuelle for deltagelse i oppgaven.

Med håp om god deltagelse,

Herbjörg Andrésdóttir

Appendix 3: Interview guide

The interview guide for the interviews conducted in the master´s thesis is provided below, both in Norwegian and English. Note that questions marked as "Supplementary questions" (Norwegian: "Oppfølgingsspørsmål") were not asked unless the interview object did not address this in his/her original answer.

In Norwegian:

Generelt om prosjektet:

1. Hvordan syns du at komprimeringsarbeidet har gått (fram til nå), generelt for hele prosjektet?
   Oppfølgingsspørsmål:
   Hvordan har det gått å oppnå kravene til platebelastningsforsøk?

2. Hvordan har komprimeringsarbeid vanligvis blitt organisert og utført generelt for dette prosjektet?
   Oppfølgingsspørsmål:
   Hvem bestemmer hva?
   Hvem gjør hva?
   Prosedyren
   Detaljer rundt komprimeringsplan

3. Hvordan har platebelastninger vanligvis blitt organisert og utført generelt for dette prosjektet?
   Oppfølgingsspørsmål:
   Hvem gjør hva?
   Prosedyren
   Hvordan E verdi beregnet (Norsk/Svensk metode)?
   Hvor i lengde- og tverrprofil er prøvene tatt?

Utfordrende strekninger

4. Har dere opplevd at det har vært vanskelig å komprimere eller oppfylle krav til platebelastning på noen av strekningene i prosjektet?
   Hvis svar er positivt, fortsett til spørsmål 4.a.
   Hvis svar er negativt, hopp over spørsmål 4, 5 og 6 og fortsett på spørsmål 7.
   a. Hvilke strekning(er)?

   b. Kan du beskrive den mest utfordrende strekningen og situasjonen der kort?
      i. Hvilken type materialer ble brukt i overbygningen?
         Oppfølgingsspørsmål:
         Bærelag
         Forkiling
         Forsterkningslag
         Frostsikringslag
         Isolasjonsmasser
         Lette fyllmasser

      ii. Hva slags undergrunn var vegkonstruksjonen bygd på?

iii. Hvilket nivå ligger vegkonstruksjonen på i forhold til undergrunnen?
Oppfølgingsspørsmål:
Fylling
Fjellskjæring
Jordskjæring
I tunnel

c. Hvor i vegkonstruksjonen opplevde dere utfordringer?
Oppfølgingsspørsmål:
Forskjellige steder i overbygning (ved bruk av platebelastning for utarbeidelse av valseprogram)?
Ett eller flere punkt på strekning?
Forskjellige plasser i tverrprofilet?

5. Kan du huske noen spesielle omstendigheter som du mener kan ha forårsaket at komprimeringsarbeidet på strekningen(e) var utfordrende?

6. Nå kommer jeg til å spørre deg om en rekke detaljer om denne spesifikke strekningen som kan være relevante for sammenligning til andre strekninger og prosjekter. Jeg ber deg om å svare så godt du kan, men si ifra om du ikke husker noen av detaljene. Det er bedre for meg å notere at du ikke husker noe, enn å få svar du ikke er sikker på at er riktige.
Svarene til underspørsmålene kan også være hvor man kan få tilgang til den informasjonen, evt. hvem man kan snakke med for å få svar på spørsmålene.

a. Når var komprimeringen av materialet utført?
Oppfølgingsspørsmål:
Ca. dato
Måned
Årstid
Tid på dagen

b. Under hva slags forhold var komprimeringen utført?
Oppfølgingsspørsmål:
Værforhold
Lysforhold
Temperatur
Tid til utførsel (evt. tidspress)
Bemanning

c. Hvordan var komprimeringen utført på denne strekningen?
Oppfølgingsspørsmål:
Beskrivelse av prosedyre
Mengde tilført vann
Type komprimeringsutstyr
Bruk av kontinuerlige responsmålinger (CMV)
Valseprogram
Antall overfarter

d. Hvordan ble valseprogrammet valgt?
   Oppfølgingsspørsmål:
      Hvem valgte?
      På hvilket grunnlag var valget tatt?
      Hvilken målemetode ble brukt (platebelastning, modifisert proctor, responsmålinger (CMV), nivellement)?

e. Hvordan var platebelastningen utført for dette tilfellet?
   Oppfølgingsspørsmål:
      Beskrivelse av prosedyre
      Materiale brukt for avretting (gips, sand, ingen avretting)
      Hvor i lengde og tverretning er forsøkene utført
      Eventuelle avvik i påført last?
      Hvordan er E verdien beregnet (norsk/svensk metode)?

f. Under hva slags forhold var platebelastningen utført?
   Oppfølgingsspørsmål:
      Værforhold
      Lysforhold
      Temperatur
      Tid på dagen
      Tid til utførsel (evt. tidspress)
      Bemanning

g. Hvor lang tid gikk fra komprimering av det problematiske laget fram til platebelastningen ble utført?

h. Hvor kom overbygningsmaterialet fra (opprinnelsen)?
   Oppfølgingsspørsmål:
      Hvordan var det lagret før det ble lagt ut og komprimert?

i. Hva var tilstanden på undergrunnen når overbygningsmaterialene ble lagt ut og komprimert?
   Oppfølgingsspørsmål:
      Grunnvannstand
      Fuktighet
      Innhold av organisk material
      Grunnforsterkende tiltak

j. Har du øvrige kommentarer til komprimeringen eller platebelastningen utført for dette tilfellet?

Ikke-utfordrende strekninger

7. Har dere opplevd at det har vært spesielt lettvint og problemfritt å komprimere eller oppfylle krav til platebelastning på noen av strekningene i prosjektet?
   Hvis svar er positivt, fortsett til spørsmål 7.b.
   Hvis svar er negativt, forsett til spørsmål 7.a.

a. Hvis nei: Så dere har opplevd noen form for utfordringer på alle strekninger? Hva tror du at er årsaken til det?
   Hopp over resten av spørsmål 7, samt spørsmål 8 og 9 og fortsett på spørsmål 10.

b. Hvis ja: Hvilke strekning(er)?

c. Kan du beskrive den mest problemfrie strekningen og situasjonen der kort?

   i. Hvilken type materialer ble brukt i overbygningen?
      Oppfølgingsspørsmål:
      Bærelag
      Forkiling
      Forsterkningslag
      Frostsikringslag
      Isolasjonsmasser
      Lette fyllmasser

   ii. Hva slags undergrunn var vegkonstruksjonen bygd på?

   iii. Hvilket nivå ligger vegkonstruksjonen på i forhold til undergrunnen (f.eks. fylling, fjellskjæring, jordskjæring, i tunnel, osv.)?
      Oppfølgingsspørsmål:
      Fylling
      Fjellskjæring
      Jordskjæring
      I tunnel

8. Kan du huske noen spesielle omstendigheter som du mener kan ha forårsaket at komprimeringsarbeidet på strekningen(e) gikk spesielt bra?

9. Nå kommer jeg til å spørre deg om en rekke detaljer om denne spesifikke strekningen som kan være relevante for sammenligning til andre strekninger og prosjekter. Jeg ber deg om å svare så godt du kan, men si ifra om du ikke husker noen av detaljene. Det er bedre for meg å notere at du ikke husker noe, enn å få svar du ikke er sikker på at er riktige.
   Svarene til underspørsmålene kan også være hvor man kan få tilgang til den informasjonen, evt. hvem man kan snakke med for å få svar på spørsmålene.

   a. Når var komprimeringen av materialet utført?
      Oppfølgingsspørsmål:
      Ca. dato
      Måned
      Årstid
      Tid på dagen

b. Under hva slags forhold var komprimeringen utført?
Oppfølgingsspørsmål:
Værforhold
Lysforhold
Temperatur
Tid til utførsel (evt. tidspress)
Bemanning

c. Hvordan var komprimeringen utført på denne strekningen?
Oppfølgingsspørsmål:
Beskrivelse av prosedyre
Mengde tilført vann
Type komprimeringsutstyr
Bruk av kontinuerlige responsmålinger (CMV)
Valseprogram
Antall overfarter

d. Hvordan ble valseprogrammet valgt?
Oppfølgingsspørsmål:
Hvem valgte?
På hvilket grunnlag var valget tatt?
Hvilken målemetode ble brukt (platebelastning, modifisert proctor, responsmålinger (CMV), nivellement)?

e. Hvordan var platebelastningen utført for dette tilfellet?
Oppfølgingsspørsmål:
Beskrivelse av prosedyre
Materiale brukt for avretting (gips, sand, ingen avretting)
Hvor i lengde og tverretning er forsøkene utført
Eventuelle avvik i påført last
Hvordan er E verdien beregnet (norsk/svensk metode)?

f. Under hva slags forhold var platebelastningen utført?
Oppfølgingsspørsmål:
Værforhold
Lysforhold
Temperatur
Tid på dagen
Tid til utførsel (evt. tidspress)
Bemanning

g. Hvor lang tid gikk fra komprimering av lagene fram til platebelastningen ble utført?

h. Hvor kom overbygningsmaterialet fra (opprinnelsen)?
Oppfølgingsspørsmål:
Hvordan var det lagret før det ble lagt ut og komprimert

i. Hva var tilstanden på undergrunnen når overbygningsmaterialene ble lagt ut og komprimert?

Oppfølgingsspørsmål:

Grunnvannstand

Fuktighet

Innhold av organisk material

Grunnforsterkende tiltak

j. Har du øvrige kommentarer til komprimeringen eller platebelastningen utført for dette tilfellet?

10. Har du øvrige kommentarer til komprimeringsarbeidet, platebelastningene, krav til platebelastningsforsøk, masteroppgaven eller dette intervjuet generelt?

In English:

<u>*About the project in general:*</u>

1. How do you feel the compaction work has gone (so far), in general for the whole project?
   Supplementary question:
   How has it been fulfilling the requirements for plate load tests?

2. How has the compaction work normally been organised and performed, in general for this project?
   Supplementary question:
   Who decides what?
   Who does what?
   The procedure/process
   Details about compaction plan

3. How have plate load tests normally been organised and performed, in general for this project?
   Supplementary question:
   Who does what?
   The procedure/process
   How is the E-value calculated (Norwegian/Swedish method)?
   Where in the road's longitudinal and cross section are the measurements done?

<u>*Challenging sections*</u>

4. Have you experienced difficulties during compaction or in fulfilment of plate load test requirements for any of the road sections in the project?
   If answer is positive, proceed to question 4.a.
   If answer is negative, skip question 4, 5 and 6 and proceed to question 7.

   a. Which section(s)?

   b. Can you briefly describe the most challenging road section and the situation there?

      i. What materials were used in the superstructure for that section?
         Supplementary question:
         Base course
         Interlocking material
         Subbase
         Frost protection layer
         Insulation materials
         Light fillers/filling materials

      ii. What type of subgrade was the road section constructed upon?

iii. How does the road structure lie relative to the subbase and the existing adjacent terrain?
Supplementary question:
Embankment
Rock cut
Soil cut
In a tunnel

c. Where in the road structure did you experience challenges regarding compaction or plate load testing?
Supplementary question:
Different places in the superstructure, when using plate load testing for roller program?
One or more points of the section
Different places in the cross section

5. Can you remember any special circumstances that you think might have caused the compaction of the section to be challenging?

6. I will now ask you questions about a series of details for this specific road section, which might be relevant for the comparison to other sections or projects. I kindly ask you to answer in as much detail as you can remember, but please let me know if you don't remember some of the details. It is better for me to know that you don't remember the details, than to get an answer that you are not sure is correct.
The answers to the sub-questions can also be in the form of information about where one can access the details, including information about which person might know the answers.
   a. When was the material compacted?
   Supplementary question:
   Ca. date
   Month
   Year
   Time of day

   b. In what conditions was the material compacted?
   Supplementary question:
   Weather conditions
   Lighting conditions
   Temperature
   Time available for the compaction (potential time pressure)
   Crew and availability of crew

   c. How was the compaction conducted in this section?
   Supplementary question:
   Description of the procedure/process
   Amount of added water
   Type of compaction equipment
   Use of continuous response measurements (CMV)
   Roller program
   Number of passes of compaction equipment

d. How was the roller program chosen?
Supplementary question:
Who chose it?
Why was it chosen (on which grounds)?
What compaction measuring method was used as a basis (plate load test, Modified Proctor, continuous response measurements (CMV), levelling measurements)?

e. How was the plate load test performed for this section?
Supplementary question:
Description of procedure/process
Material used for levelling (plaster of paris/gypsum, fine grain sand, no levelling)
Where, in the road‵s longitudinal and cross section were the tests performed
Potential deviation in applied load?
How is the E-value calculated (Norwegian/Swedish method)?

f. In what conditions were the plate load tests performed?
Supplementary question:
Weather conditions
Lighting conditions
Temperature
Time of day
Time available for performance of test (potential time pressure)
Crew and availability of crew

g. How long time passed from the compaction of the problematic layer until the plate load test was performed?

h. Where did the superstructure materials originate from (where do they come from)?
Supplementary question:
How was the material stored before it was put in place and compacted?

i. What was the condition of the subgrade when the superstructure materials were put in place and compacted?
Supplementary question:
Groundwater level
Moisture content
Containing organic materials
Subgrade reinforcement measures

j. Do you have other comments on the compaction or plate load testing performed for this section?

Un-challenging sections

7. Have you experienced exceptional easiness or effortlessness during compaction or in fulfilment of plate load test requirements for any of the road sections in the project?
   If answer is positive, skip question 7.a and proceed to question 7.b.
   If answer is negative, proceed to question 7.a.

   a. If no: So you have experienced some form of difficulties in all of the sections? What do you think is the cause of that?
      Skip the rest of question 7, as well as questions 8 and 9 and proceed to question 10.

   b. If yes: Which section(s)?

   c. Can you briefly describe the most problem-free section and the situation there?

      i. What materials were used in the superstructure for that section?
         Supplementary question:
         Base course
         Interlocking material
         Subbase
         Frost protection layer
         Insulation materials
         Light fillers/filling materials

      ii. What type of subgrade was the road section constructed upon?

      iii. How does the road structure lie relative to the subbase and the existing adjacent terrain?
         Supplementary question:
         Embankment
         Rock cut
         Soil cut
         In a tunnel

8. Can you remember any special circumstances that you think might have caused the compaction of the section to be exceptionally effortless?

9. I will now ask you questions about a series of details for this specific road section, which might be relevant for the comparison to other sections or projects. I kindly ask you to answer in as much detail as you can remember, but please let me know if you don't remember some of the details. It is better for me to know that you don't remember the details, than to get an answer that you are not sure is correct.
   The answers to the sub-questions can also be in the form of information about where one can access the details, including information about which person might know the answers.

a. When was the material compacted?
Supplementary question:
Ca. date
Month
Year
Time of day

b. In what conditions was the material compacted?
Supplementary question:
Weather conditions
Lighting conditions
Temperature
Time available for the compaction (potential time pressure)
Crew and availability of crew

c. How was the compaction conducted in this section?
Supplementary question:
Description of the procedure/process
Amount of added water
Type of compaction equipment
Use of continuous response measurements (CMV)
Roller program
Number of passes of compaction equipment

d. How was the roller program chosen?
Supplementary question:
Who chose it?
Why was it chosen (on which grounds)?
What compaction measuring method was used as a basis (plate load test, Modified Proctor, continuous response measurements (CMV), levelling measurements)?

e. How was the plate load test performed for this section?
Supplementary question:
Description of procedure/process
Material used for levelling (plaster of paris/gypsum, fine grain sand, no levelling)
Where, in the road‘s longitudinal and cross section were the tests performed
Potential deviation in applied load?
How is the E-value calculated (Norwegian/Swedish method)?

f. In what conditions were the plate load tests performed?
Supplementary question:
Weather conditions
Lighting conditions
Temperature
Time of day
Time available for performance of test (potential time pressure)
Crew and availability of crew

g. How long time passed from the compaction of the problematic layer until the plate load test was performed?

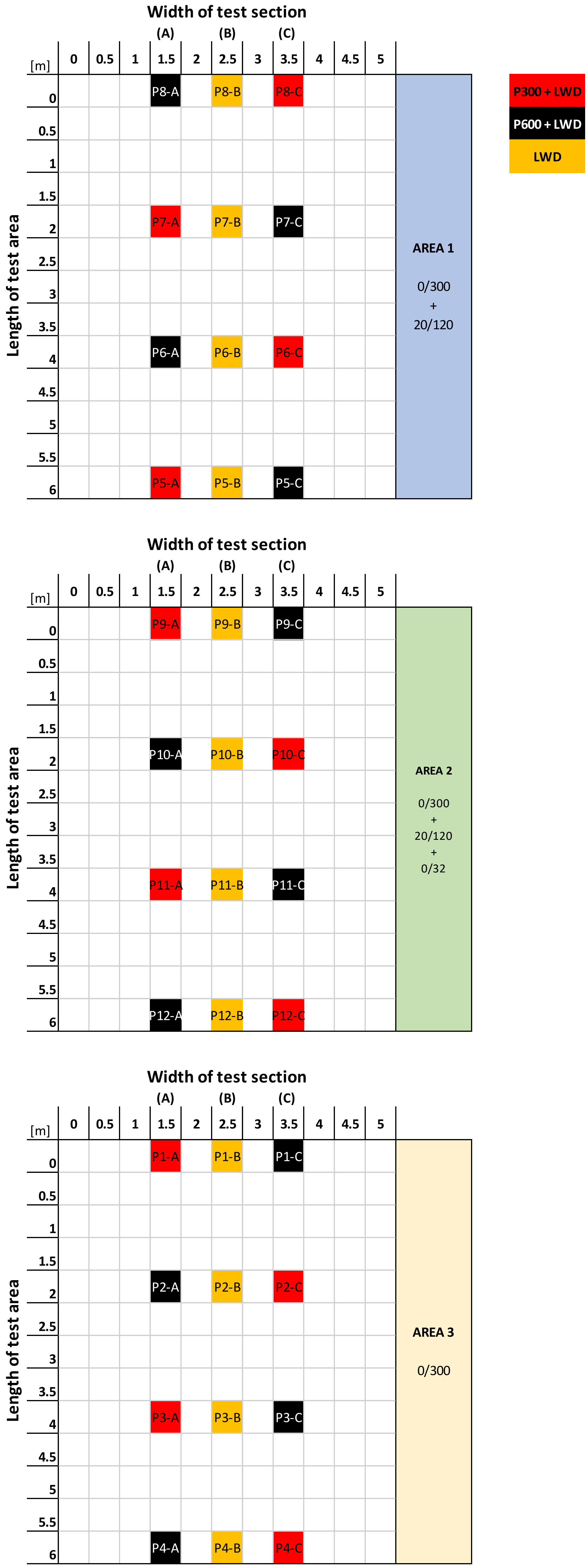
h. Where did the superstructure materials originate from (where do they come from)?
Supplementary question:
How was the material stored before it was put in place and compacted?

i. What was the condition of the subgrade when the superstructure materials were put in place and compacted?
Supplementary question:
Groundwater level
Moisture content
Containing organic materials
Subgrade reinforcement measures

j. Do you have other comments on the compaction or plate load testing performed for this section?

10. Do you have other comments on the compaction, the plate load test, the requirements for the plate load test, the Master’s thesis or this interview in general?

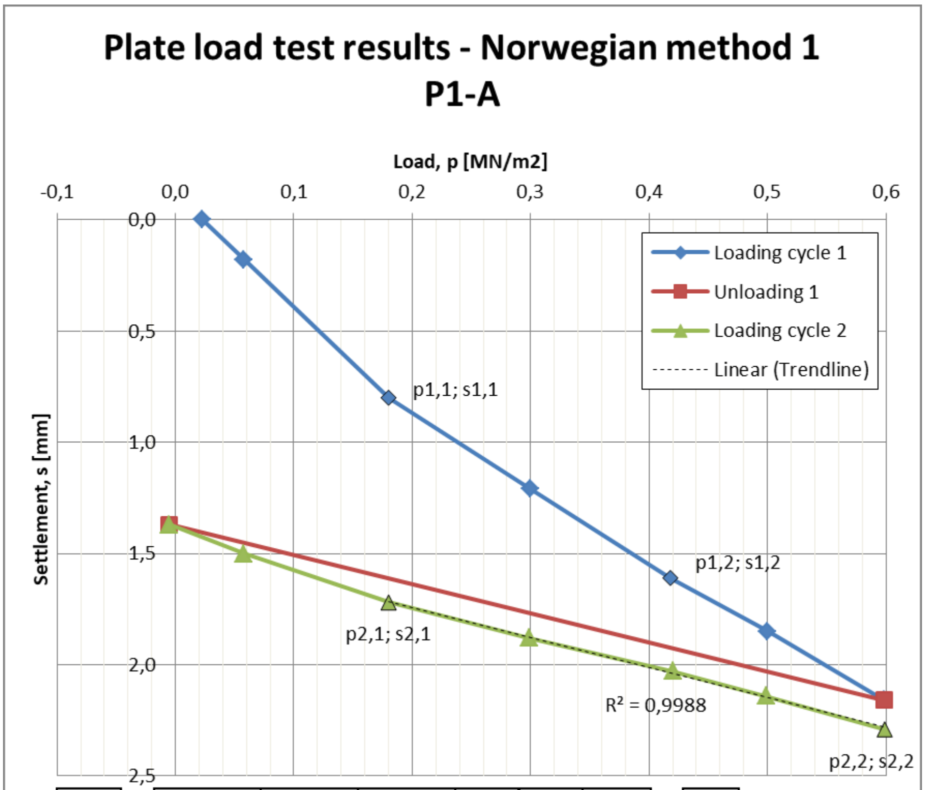
Appendix 4: Setup of test points in the field test in Hedmark, March 28th 2019.



Appendix 5: Measured and calculated results for test points in the field test in Hedmark, March 28th 2019

P1-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,023	0,00	0,000	09:45:32
0,058	0,18	0,000	09:45:59
0,180	0,80	0,000	09:47:15
0,300	1,21	0,000	09:48:00
0,418	1,61	0,000	09:48:54
0,500	1,85	0,000	09:49:39
0,599	2,16	0,000	09:50:34
-0,005	1,37	0,000	09:53:03
0,058	1,50	0,000	09:53:27
0,180	1,72	0,000	09:54:03
0,299	1,88	0,000	09:54:39
0,420	2,03	0,000	09:55:18
0,499	2,14	0,000	09:56:03
0,599	2,29	0,000	09:56:46

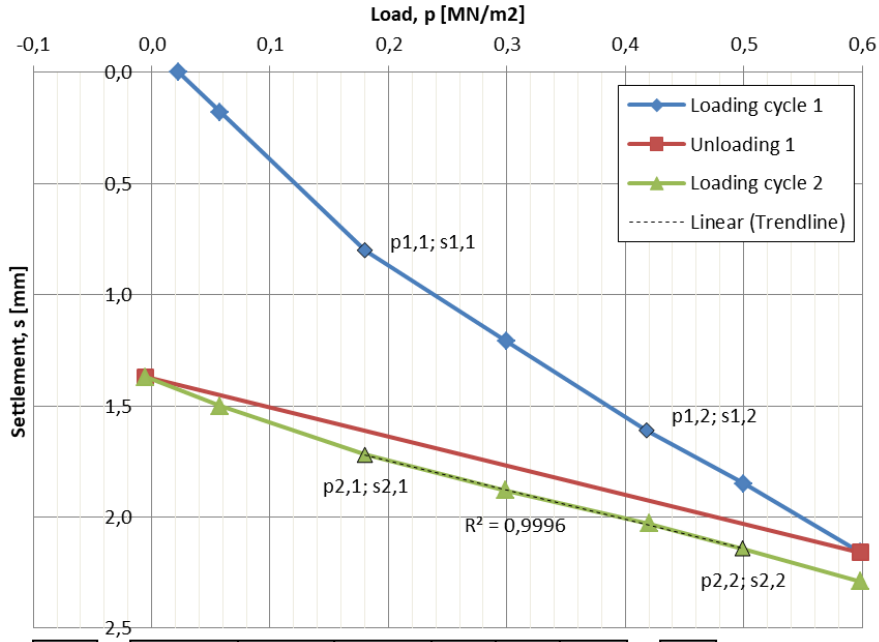


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,418	0,80	1,61	66
2	0,180	0,599	1,72	2,29	165

E_2/E_1 []
2,5

Plate load test results - Norwegian method 2
P1-A

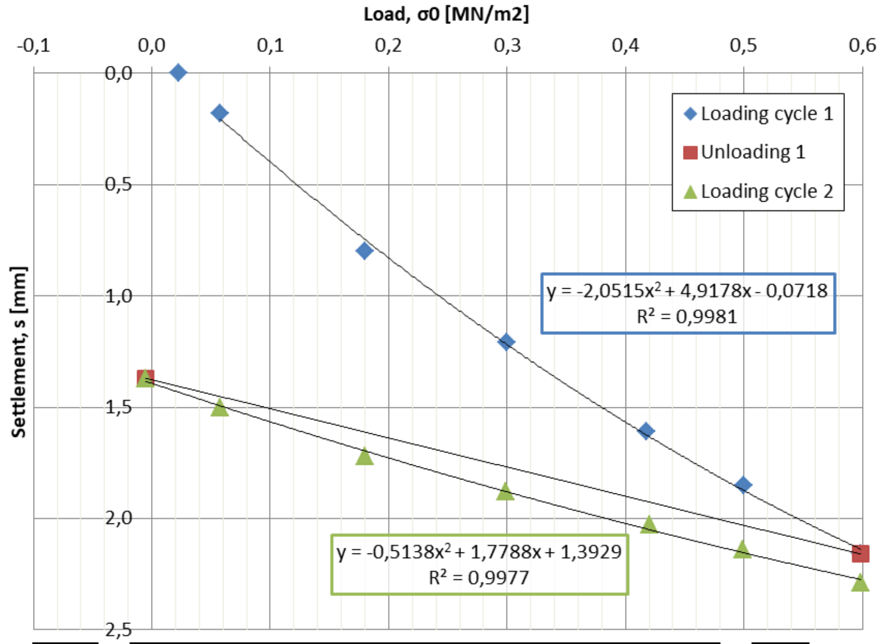


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,418	0,80	1,61	66
2	0,180	0,499	1,72	2,14	171

E_2/E_1 []
2,6

Plate load test results - Swedish method
P1-A



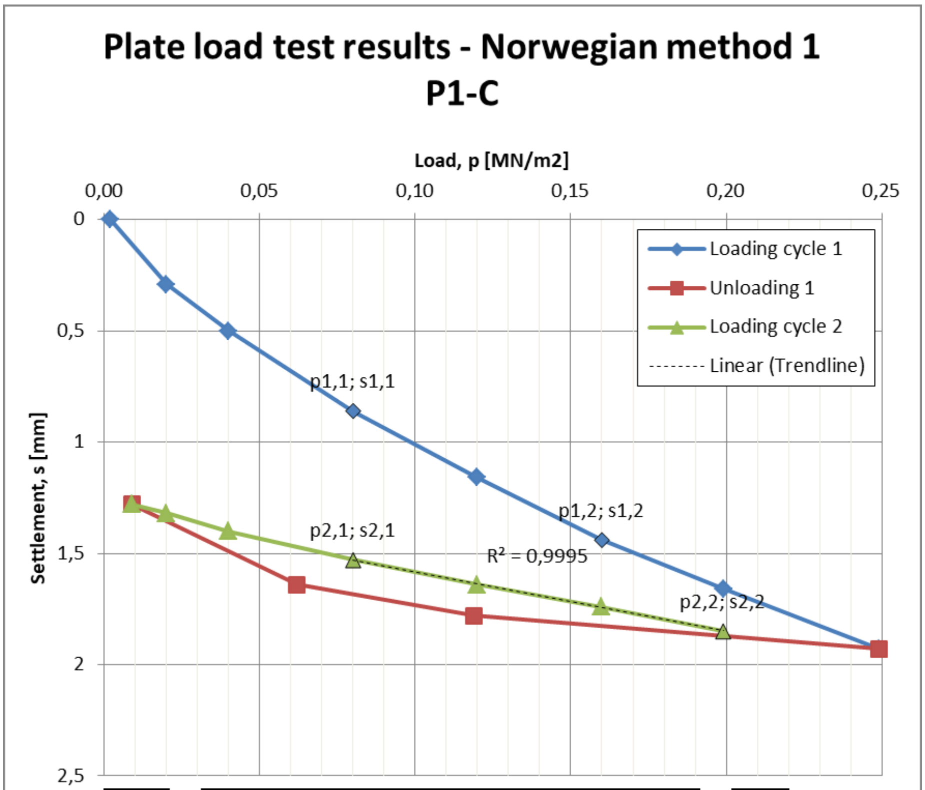
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0718	4,9178	-2,0515	61
2	1,3929	1,7788	-0,5138	153

E_2/E_1 []
2,5

P1-C

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,002	0,00	0,000	15:09:39
0,020	0,29	0,000	15:12:25
0,040	0,50	0,000	15:13:00
0,080	0,86	0,000	15:13:34
0,120	1,16	0,000	15:14:02
0,160	1,44	0,000	15:14:37
0,199	1,66	0,000	15:15:17
0,249	1,93	0,000	15:15:59
0,119	1,78	0,000	15:18:17
0,062	1,64	-0,320	15:19:48
0,009	1,28	0,000	15:22:33
0,020	1,32	0,000	15:25:08
0,040	1,40	0,000	15:25:47
0,080	1,53	0,000	15:26:30
0,120	1,64	0,000	15:27:00
0,160	1,74	0,000	15:27:29
0,199	1,85	0,000	15:28:06

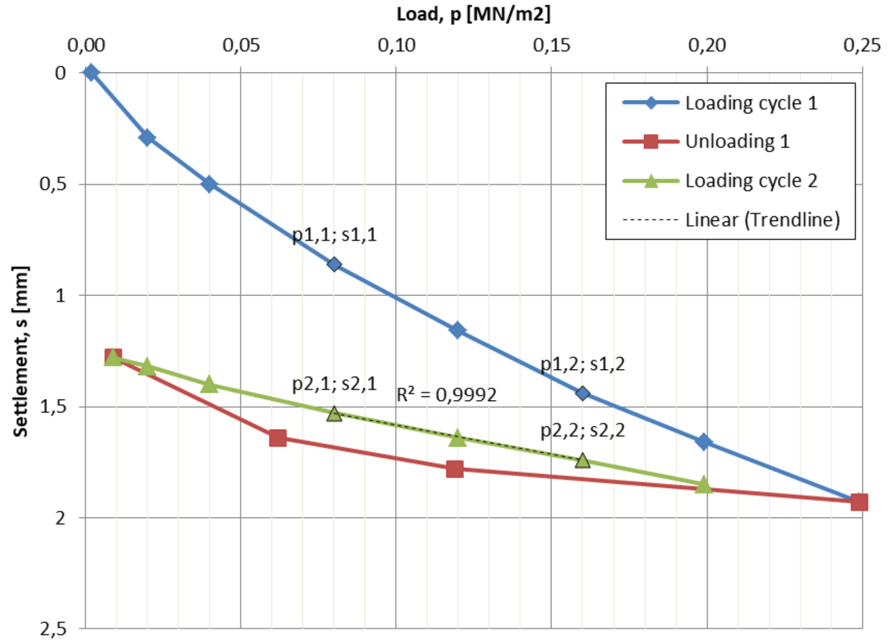


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,86	1,44	62
2	0,080	0,199	1,53	1,85	167

E_2/E_1 []
2,7

Plate load test results - Norwegian method 2
P1-C

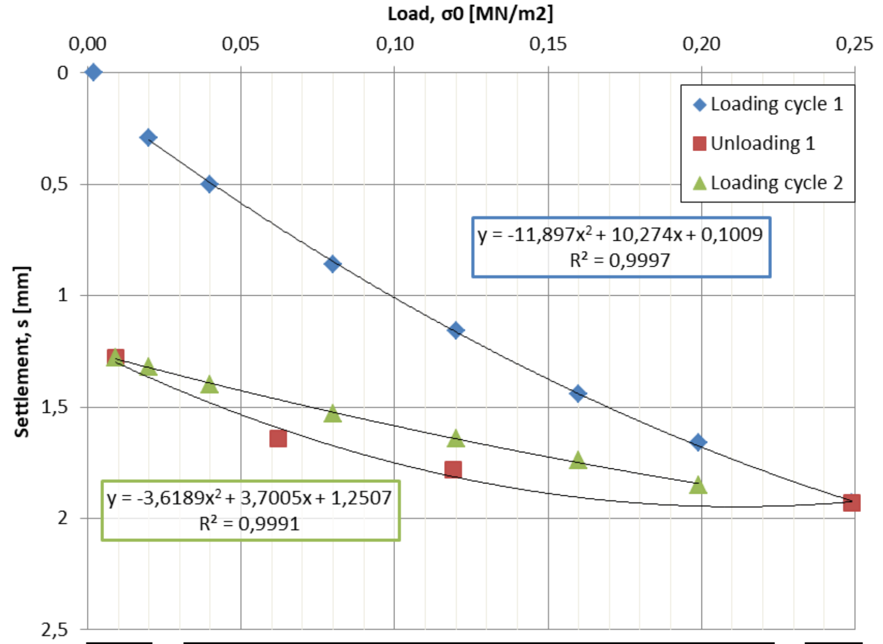


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,86	1,44	62
2	0,080	0,160	1,53	1,74	171

E_2/E_1 []
2,8

Plate load test results - Swedish method
P1-C



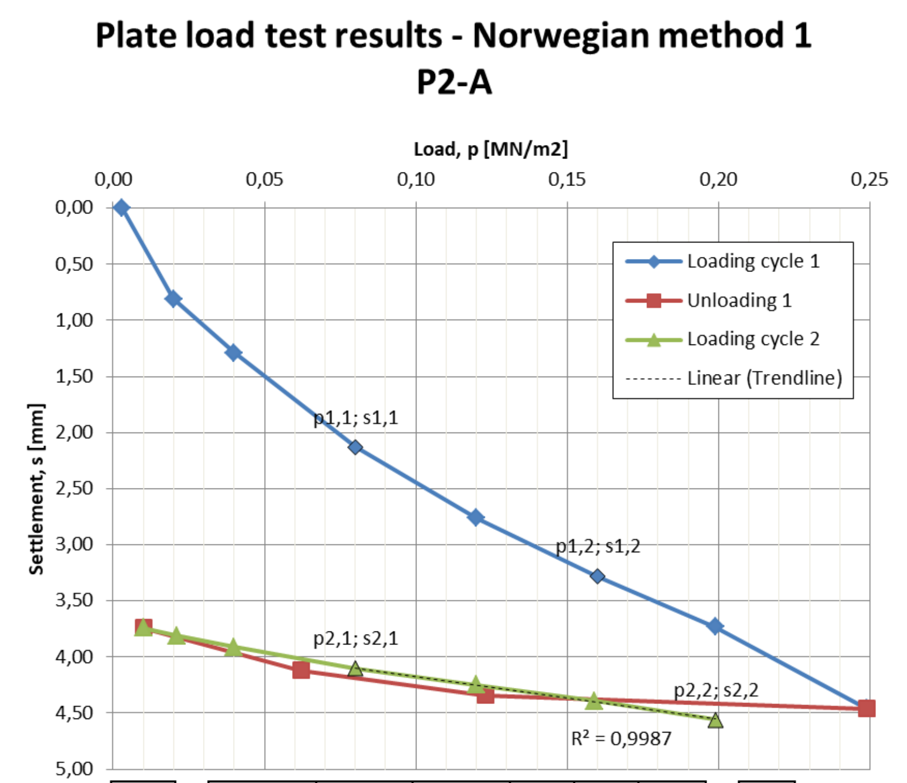
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1009	10,274	-11,8970	62
2	1,2507	3,7005	-3,6189	161

E_2/E_1 []
2,6

P2-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,003	0,00	0,000	10:05:56
0,020	0,81	0,000	10:09:02
0,040	1,29	0,000	10:09:49
0,080	2,13	0,000	10:10:43
0,120	2,76	0,000	10:11:37
0,160	3,28	0,000	10:12:36
0,199	3,73	0,000	10:13:42
0,249	4,46	0,000	10:17:41
0,123	4,34	0,000	10:22:06
0,062	4,12	0,000	10:23:40
0,010	3,74	-0,320	10:27:22
0,021	3,81	0,000	10:29:49
0,040	3,91	0,000	10:30:22
0,080	4,10	0,000	10:31:05
0,120	4,25	0,000	10:31:50
0,159	4,39	0,000	10:32:22
0,199	4,56	0,000	10:33:10

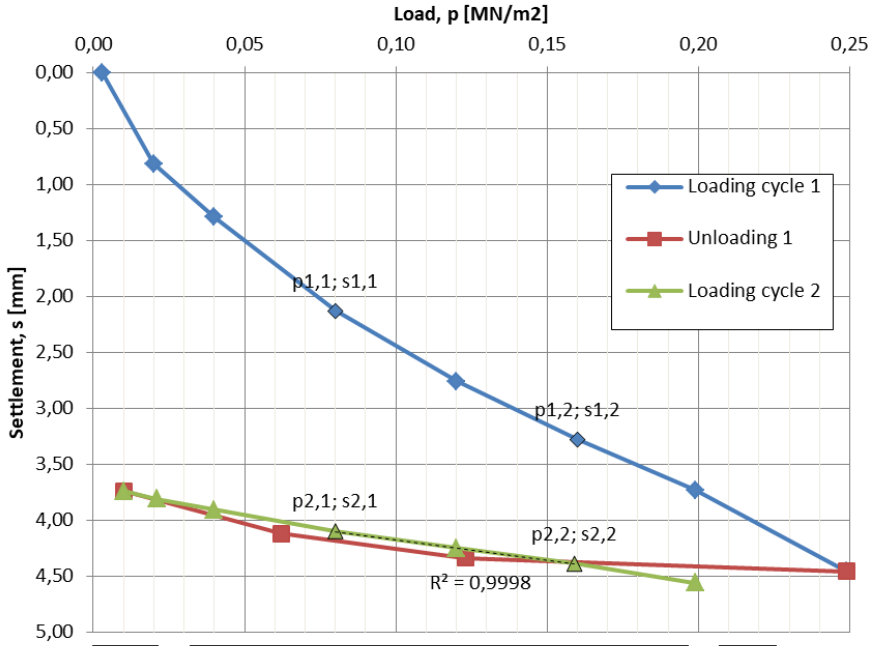


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	2,13	3,28	31
2	0,080	0,199	4,10	4,56	116

E_2/E_1 []
3,7

Plate load test results - Norwegian method 2
P2-A

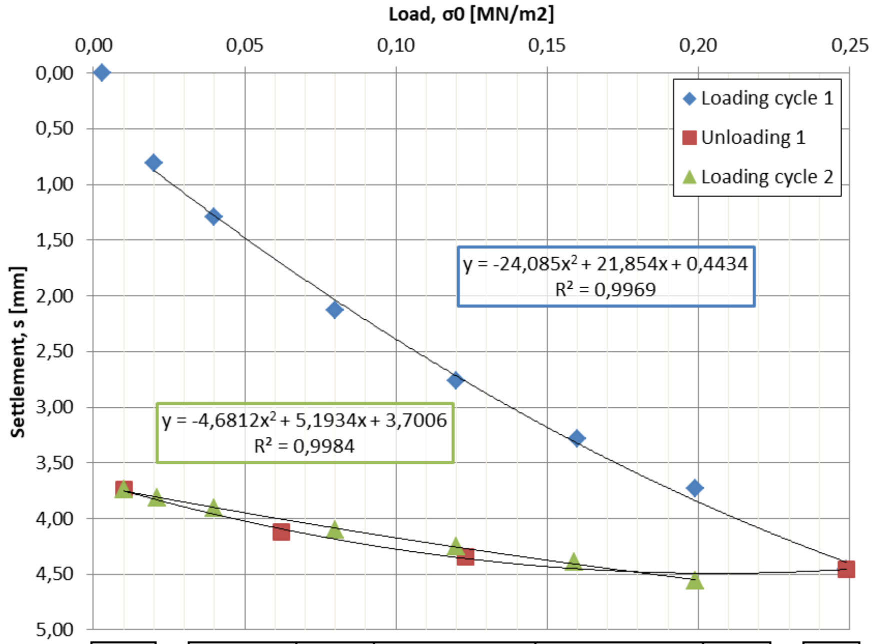


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	2,13	3,28	31
2	0,080	0,159	4,10	4,39	123

E_2/E_1 []
3,9

Plate load test results - Swedish method
P2-A



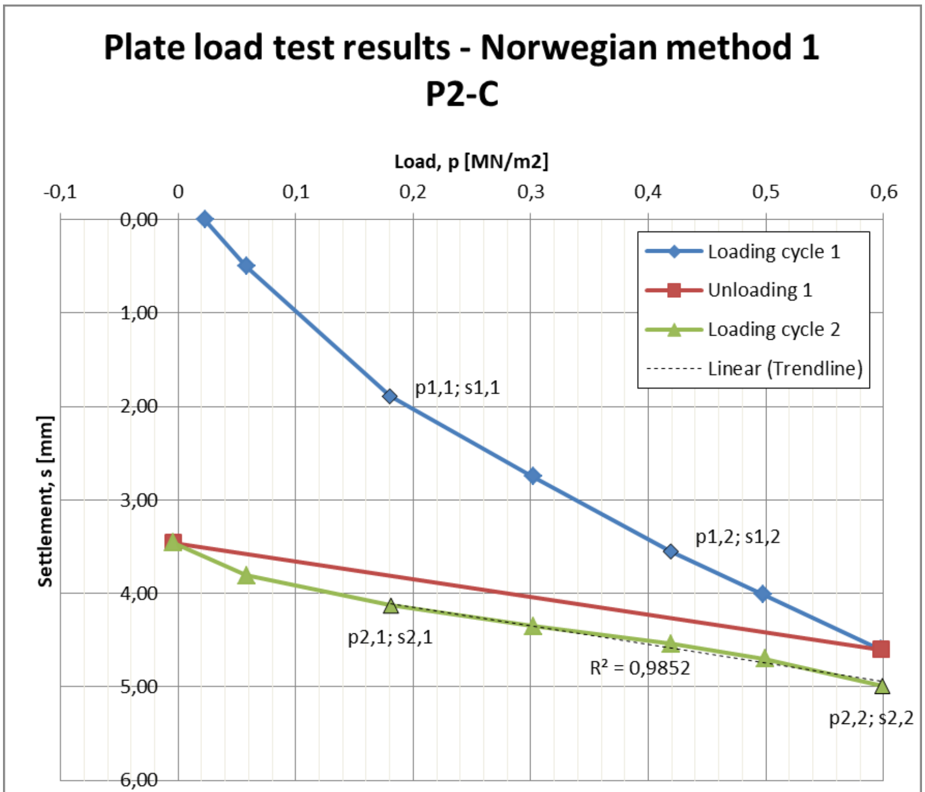
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,4434	21,854	-24,0850	28
2	3,7006	5,1934	-4,6812	112

E_2/E_1 []
3,9

P2-C

Load [MN/m^2]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,023	0,00	0,270	14:49:37
0,058	0,50	0,000	14:50:18
0,180	1,89	0,000	14:51:44
0,302	2,75	0,000	14:52:36
0,419	3,55	0,000	14:53:24
0,498	4,01	0,000	14:54:00
0,598	4,60	0,000	14:54:45
-0,004	3,46	0,000	14:57:03
0,058	3,81	0,000	14:57:15
0,181	4,13	0,000	14:57:37
0,302	4,35	0,000	14:58:07
0,419	4,54	0,000	14:58:30
0,499	4,70	0,000	14:58:52
0,599	4,99	0,000	14:59:34

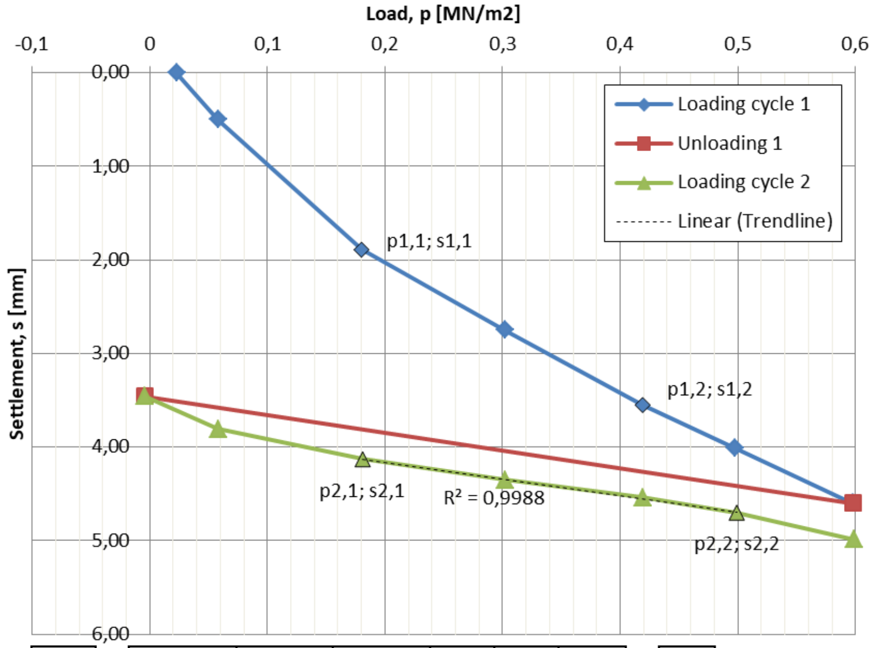


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,89	3,55	32
2	0,181	0,599	4,13	4,99	109

E_2/E_1 []
3,4

Plate load test results - Norwegian method 2
P2-C

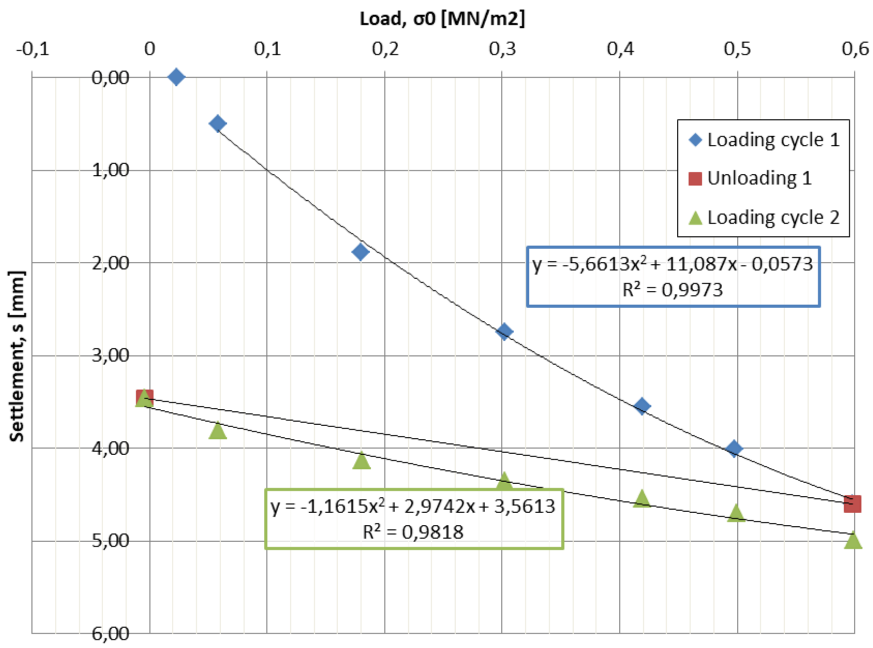


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,89	3,55	32
2	0,181	0,499	4,13	4,70	126

E_2/E_1 []
3,9

Plate load test results - Swedish method
P2-C



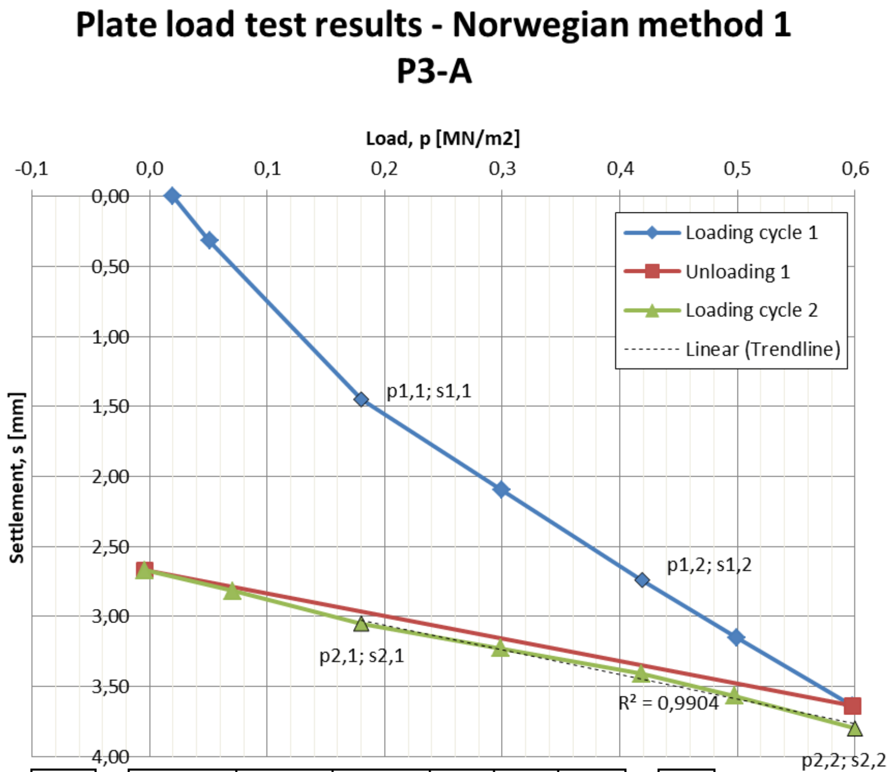
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0573	11,087	-5,6613	29
2	3,5613	2,9742	-1,1615	99

E_2/E_1 []
3,4

P3-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,020	0,00	0,320	10:43:51
0,051	0,32	0,000	10:44:18
0,180	1,45	0,000	10:46:06
0,300	2,10	0,000	10:47:11
0,419	2,74	0,000	10:48:21
0,499	3,15	0,000	10:49:09
0,598	3,64	0,000	10:50:35
-0,004	2,67	0,000	10:53:08
0,071	2,82	0,000	10:53:45
0,180	3,05	0,000	10:54:51
0,299	3,23	0,000	10:56:17
0,418	3,41	0,000	10:57:13
0,498	3,57	0,000	10:58:03
0,600	3,80	0,000	10:59:12

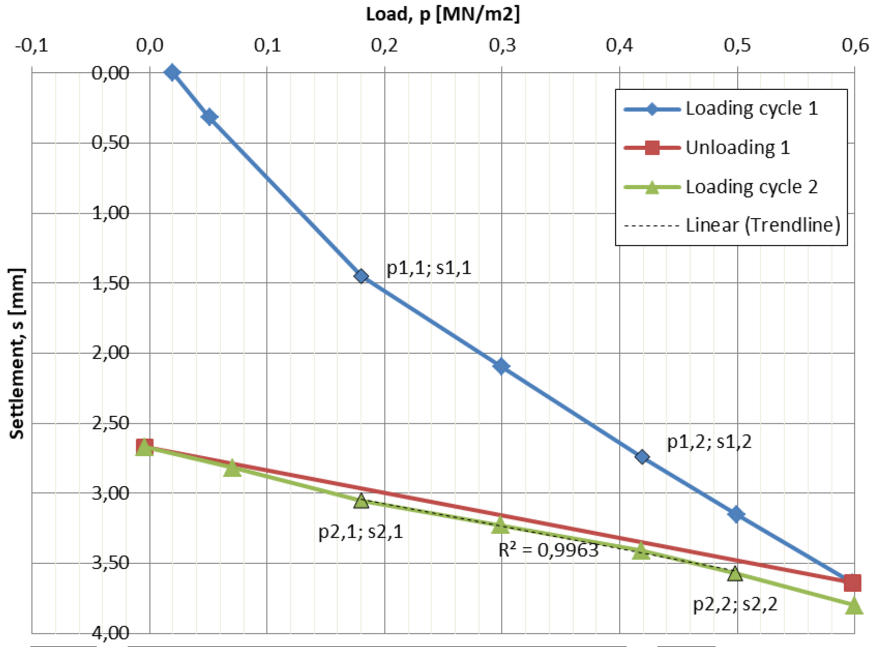


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,45	2,74	42
2	0,180	0,600	3,05	3,80	126

E_2/E_1 []
3,0

Plate load test results - Norwegian method 2
P3-A

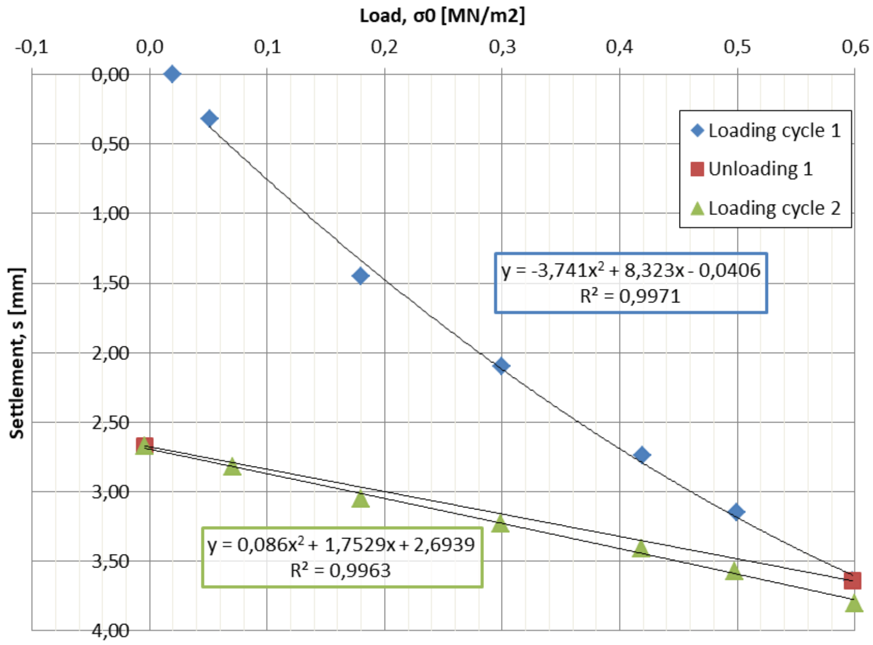


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,45	2,74	42
2	0,180	0,498	3,05	3,57	138

E_2/E_1 []
3,3

Plate load test results - Swedish method
P3-A



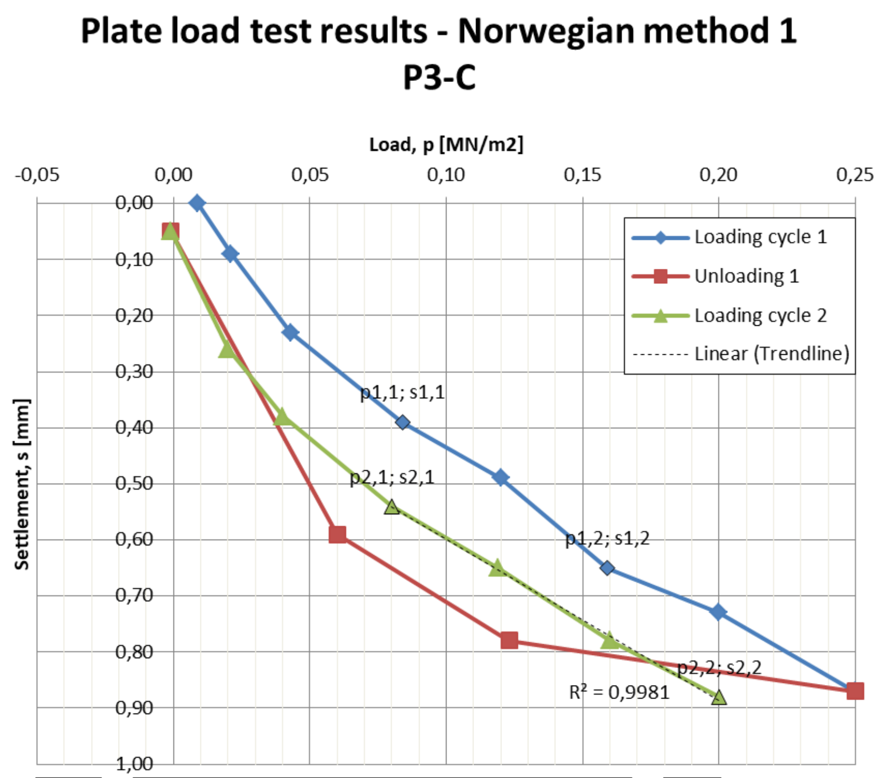
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0406	8,323	-3,7410	37
2	2,6939	1,7529	0,0860	125

E_2/E_1 []
3,4

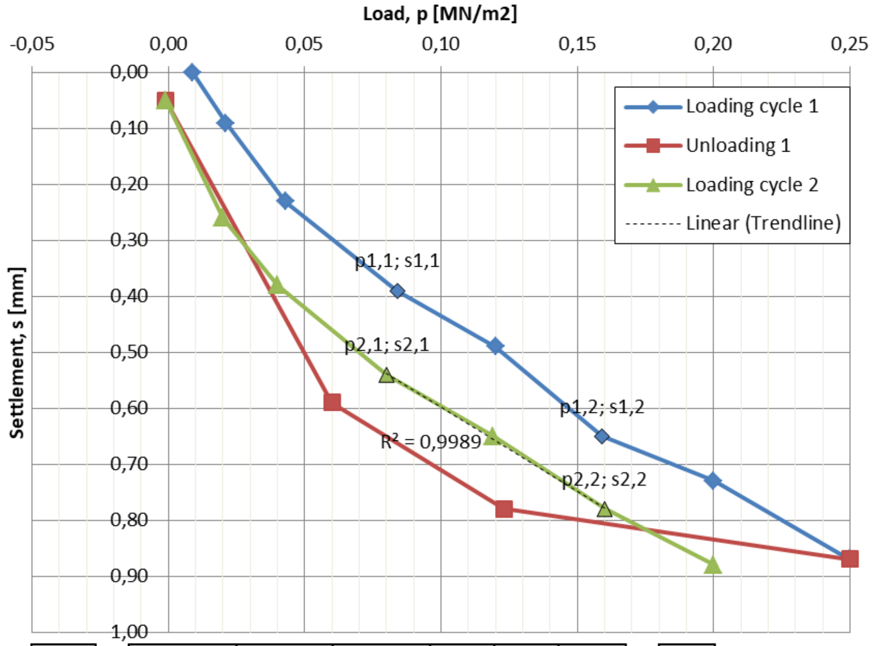
P3-C

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,009	0,00	0,000	14:15:55
0,021	0,09	0,320	14:18:18
0,043	0,23	0,000	14:18:58
0,084	0,39	0,000	14:19:22
0,120	0,49	0,000	14:20:14
0,159	0,65	0,000	14:21:46
0,200	0,73	0,000	14:22:23
0,250	0,87	0,000	14:23:05
0,123	0,78	0,000	14:26:00
0,060	0,59	-0,970	14:28:55
-0,001	0,05	0,000	14:31:06
0,020	0,26	0,000	14:33:50
0,040	0,38	0,000	14:34:05
0,080	0,54	0,000	14:34:29
0,119	0,65	0,000	14:35:10
0,160	0,78	0,000	14:35:48
0,200	0,88	0,000	14:36:22



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,084	0,159	0,39	0,65	130	1,2
	2	0,080	0,200	0,54	0,88	159	

Plate load test results - Norwegian method 2
P3-C

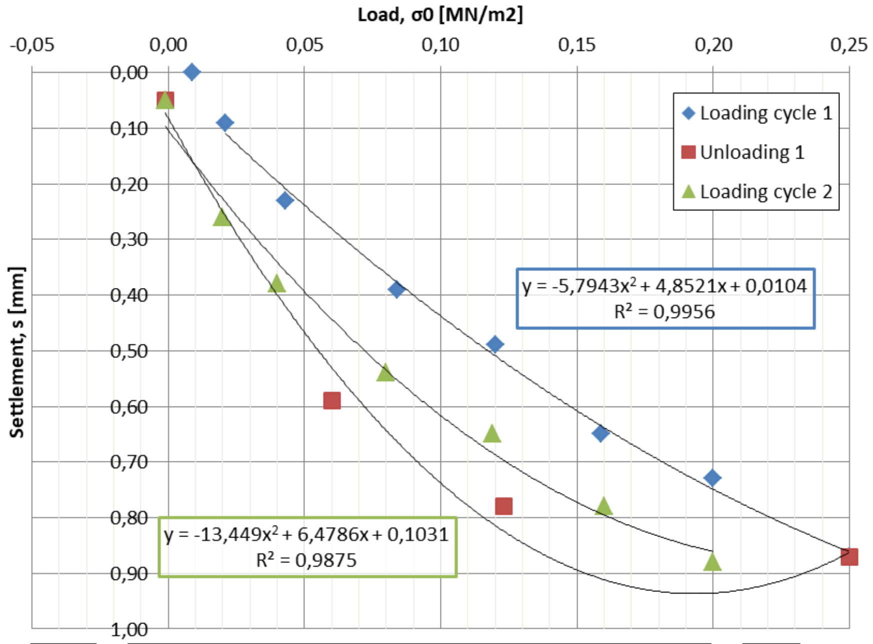


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,084	0,159	0,39	0,65	130
2	0,080	0,160	0,54	0,78	150

E_2/E_1 []
1,2

Plate load test results - Swedish method
P3-C



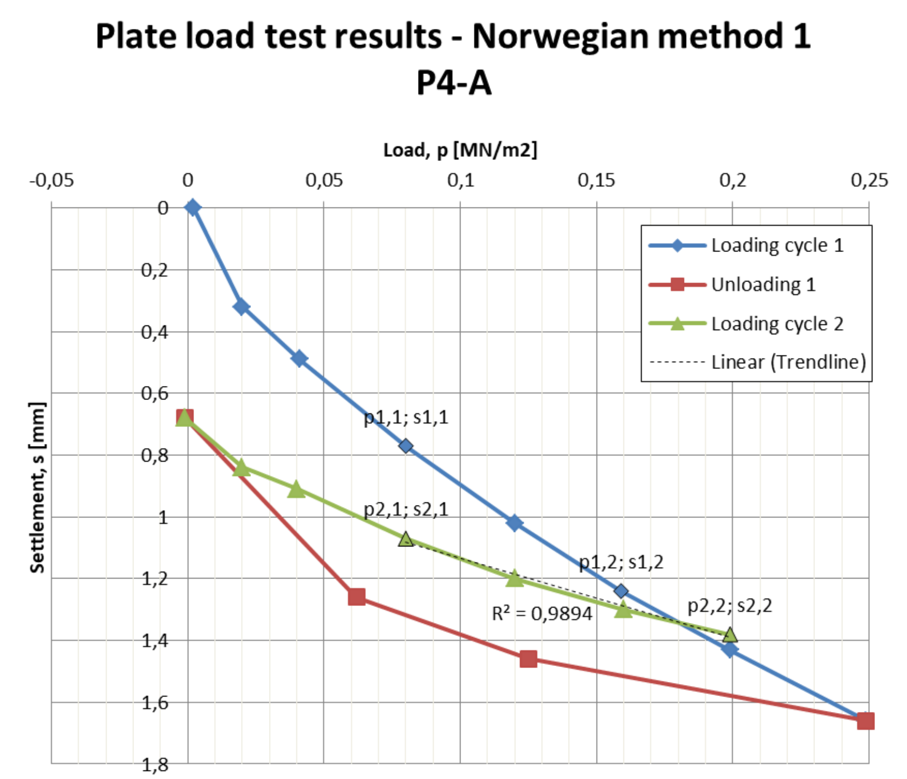
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0104	4,8521	-5,7943	132
2	0,1031	6,4786	-13,4490	144

E_2/E_1 []
1,1

P4-A

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,002	0,00	0,000	12:39:05
0,020	0,32	0,000	12:41:31
0,041	0,49	0,000	12:41:55
0,080	0,77	0,000	12:42:38
0,120	1,02	0,000	12:43:24
0,159	1,24	0,000	12:44:18
0,199	1,43	0,000	12:46:14
0,249	1,66	0,000	12:49:44
0,125	1,46	0,000	12:52:51
0,062	1,26	0,000	12:54:18
-0,001	0,68	0,000	12:56:27
0,020	0,84	0,000	12:59:00
0,040	0,91	0,000	12:59:16
0,080	1,07	0,000	13:00:02
0,120	1,20	0,000	13:00:54
0,160	1,30	0,000	13:02:38
0,199	1,38	0,000	13:04:26

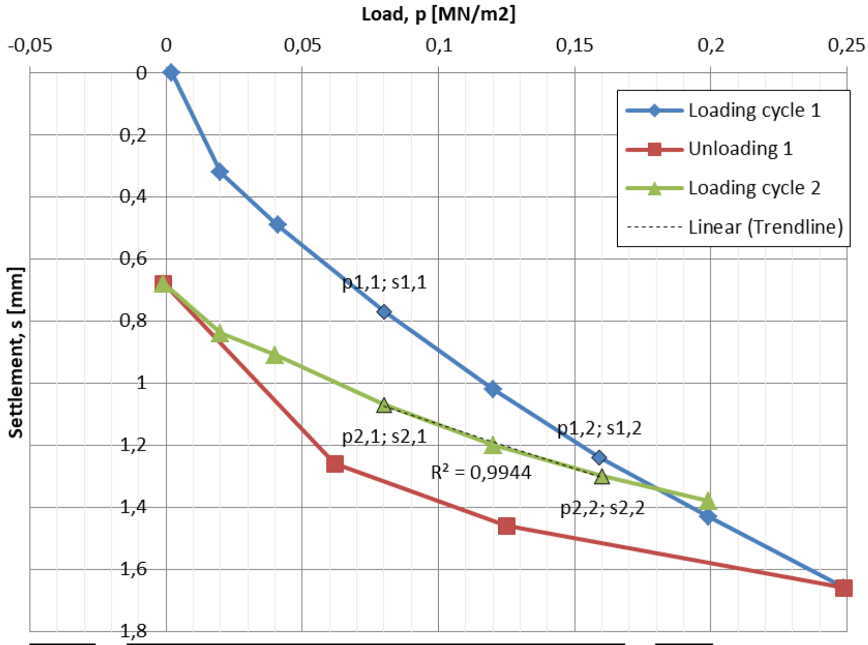


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	0,77	1,24	76
2	0,080	0,199	1,07	1,38	173

E_2/E_1 []
2,3

Plate load test results - Norwegian method 2
P4-A

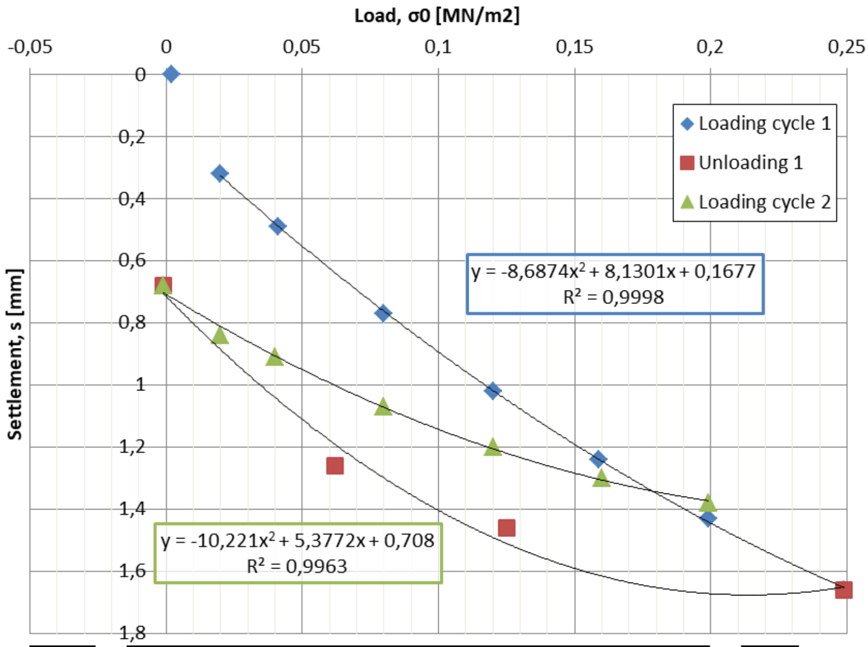


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	0,77	1,24	76
2	0,080	0,160	1,07	1,30	157

E_2/E_1 []
2,1

Plate load test results - Swedish method
P4-A



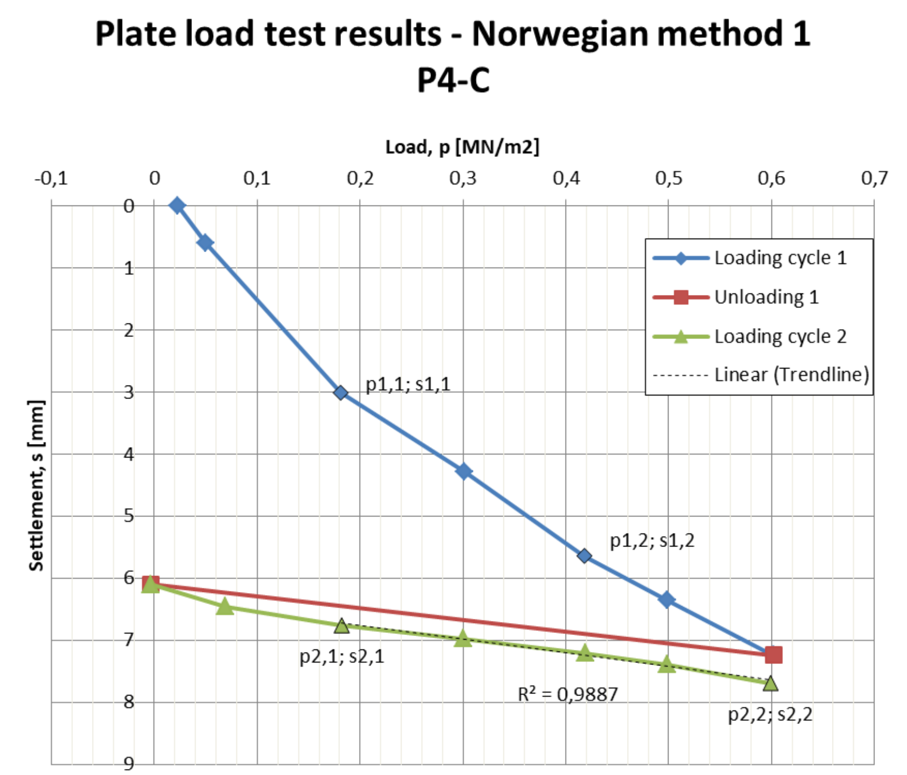
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1677	8,1301	-8,6874	75
2	0,7080	5,3772	-10,2210	159

E_2/E_1 []
2,1

P4-C

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,023	0,00	2,130	13:15:20
0,050	0,60	0,000	13:15:35
0,181	3,01	0,000	13:16:50
0,301	4,28	0,000	13:18:04
0,418	5,64	0,000	13:19:28
0,499	6,36	0,000	13:20:38
0,602	7,24	0,000	13:22:14
-0,004	6,10	0,000	13:24:41
0,069	6,46	0,000	13:26:33
0,182	6,76	0,000	13:27:23
0,300	6,98	0,000	13:28:14
0,419	7,21	0,000	13:29:34
0,499	7,39	0,000	13:30:57
0,599	7,69	0,000	13:32:48

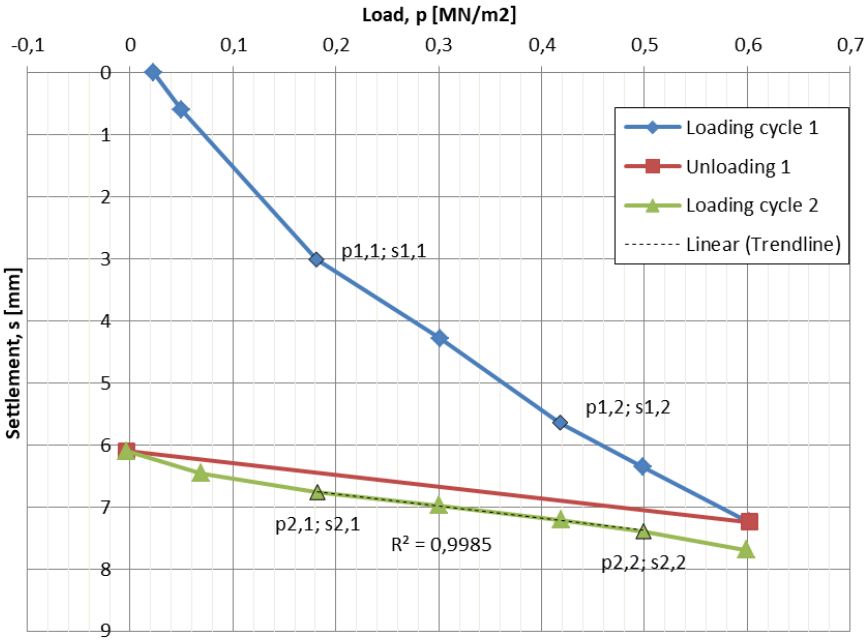


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,418	3,01	5,64	20
2	0,182	0,599	6,76	7,69	101

E_2/E_1 []
5,0

Plate load test results - Norwegian method 2
P4-C

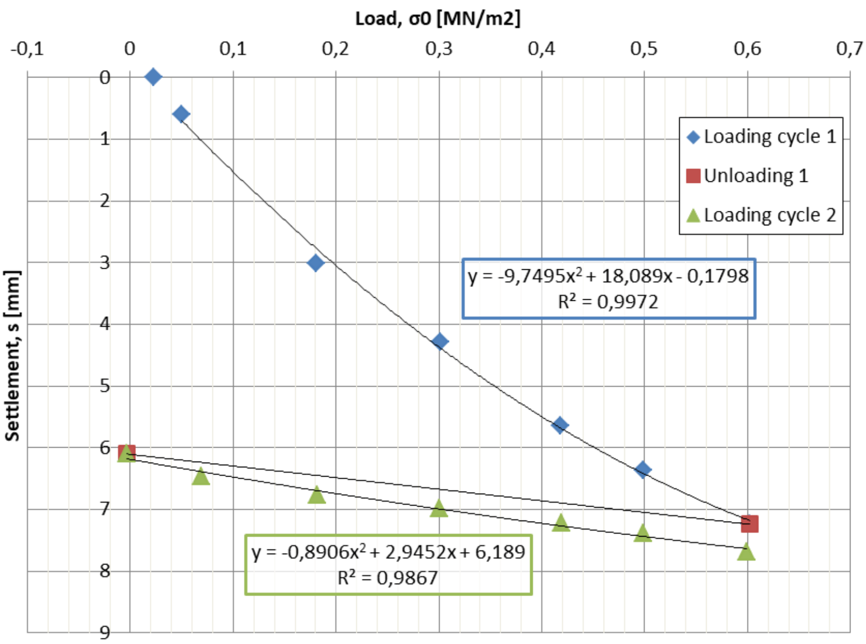


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,418	3,01	5,64	20
2	0,182	0,499	6,76	7,39	113

E_2/E_1 []
5,6

Plate load test results - Swedish method
P4-C



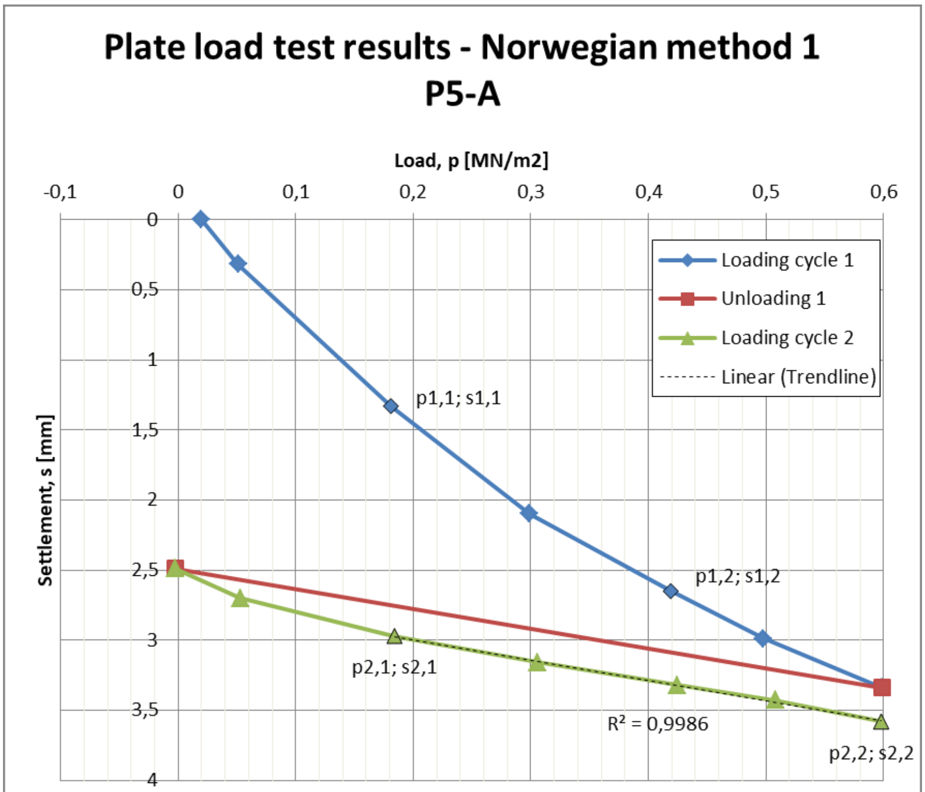
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1798	18,089	-9,7495	18
2	6,1890	2,9452	-0,8906	93

E_2/E_1 []
5,1

P5-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,020	0,00	0,000	13:48:06
0,051	0,32	0,000	13:48:34
0,181	1,33	0,000	13:49:19
0,299	2,10	0,000	13:50:08
0,419	2,65	0,000	13:50:42
0,498	2,99	0,000	13:51:16
0,599	3,34	0,000	13:51:52
-0,002	2,49	0,000	13:54:19
0,053	2,70	0,000	13:54:30
0,184	2,97	0,000	13:54:54
0,306	3,16	0,000	13:55:16
0,425	3,32	0,000	13:55:38
0,508	3,43	0,000	13:55:58
0,598	3,58	0,000	13:56:24

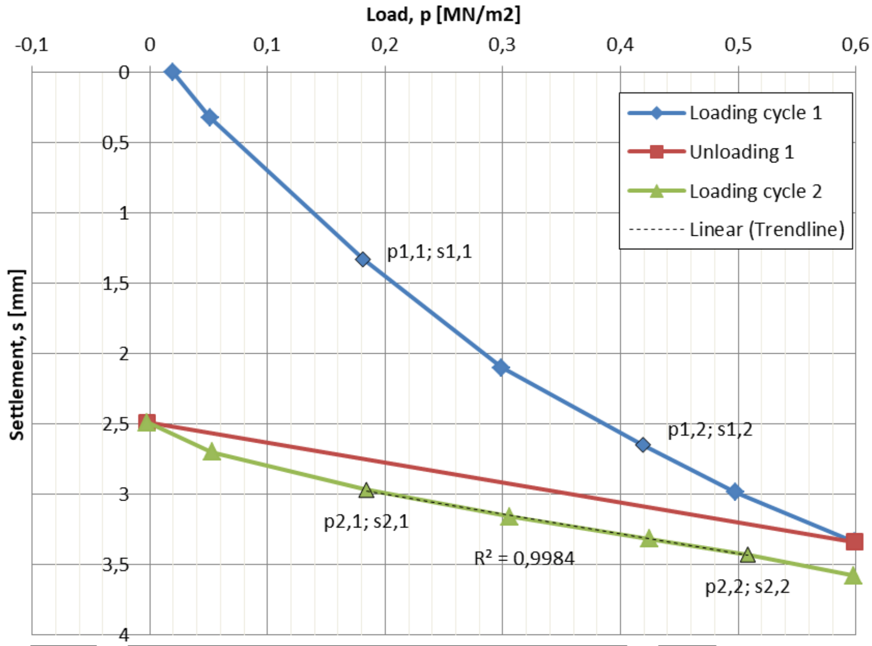


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,419	1,33	2,65	41
2	0,184	0,598	2,97	3,58	153

E_2/E_1 []
3,8

Plate load test results - Norwegian method 2
P5-A

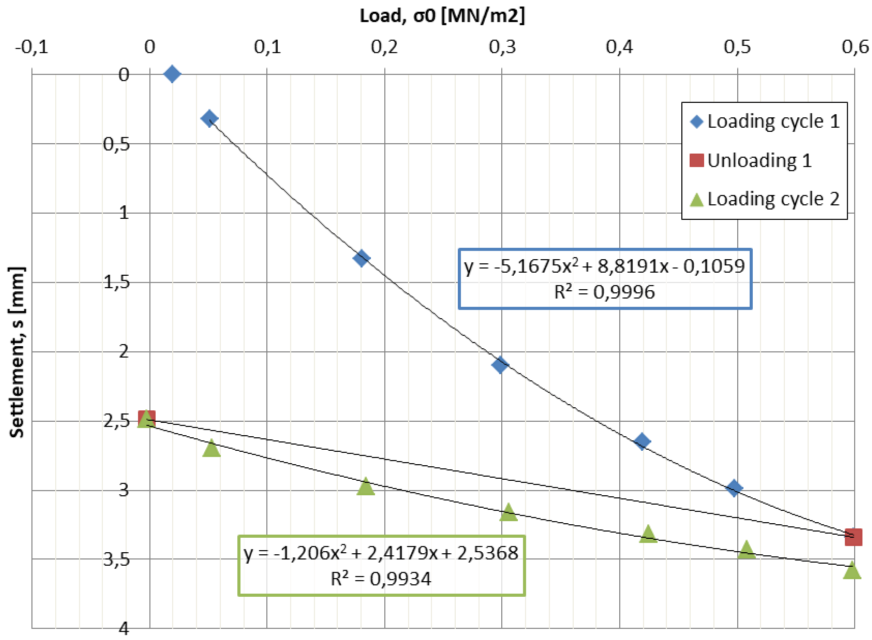


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,419	1,33	2,65	41
2	0,184	0,508	2,97	3,43	158

E_2/E_1 []
3,9

Plate load test results - Swedish method
P5-A



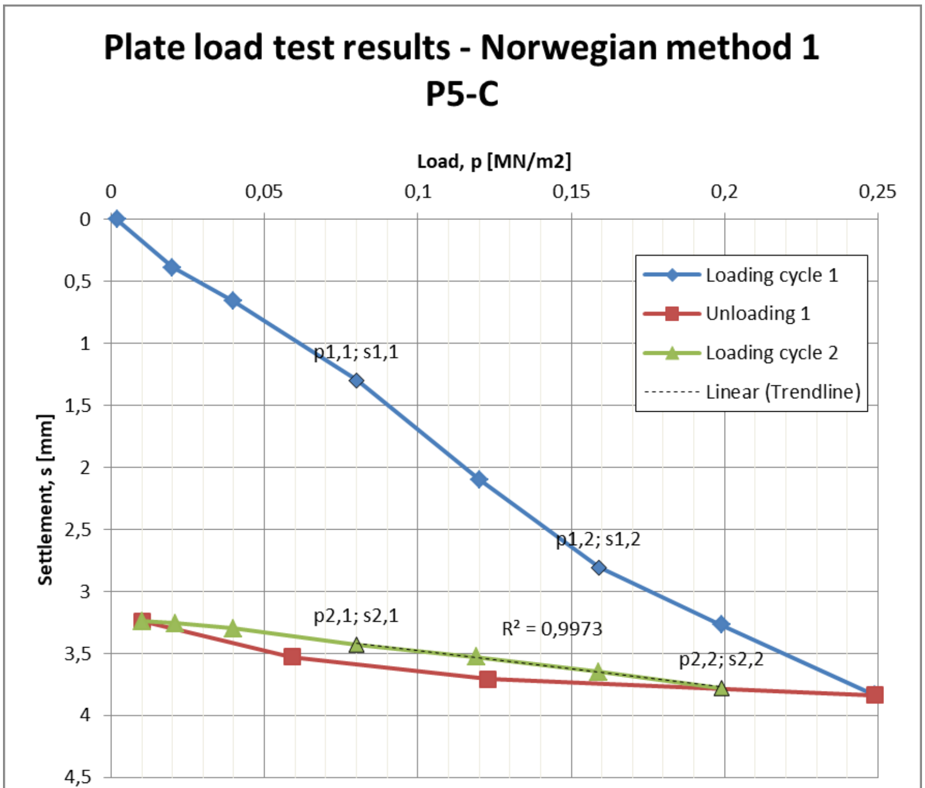
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1059	8,8191	-5,1675	39
2	2,5368	2,4179	-1,2060	133

E_2/E_1 []
3,4

P5-C

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,002	0,00	0,000	11:54:35
0,020	0,39	0,000	11:57:20
0,040	0,66	0,000	11:58:07
0,080	1,30	0,000	11:59:28
0,120	2,10	0,000	12:01:00
0,159	2,81	0,000	12:02:10
0,199	3,27	0,000	12:03:35
0,249	3,84	0,000	12:05:13
0,123	3,71	0,000	12:07:44
0,059	3,53	-0,230	12:09:00
0,010	3,24	0,000	12:11:21
0,021	3,26	0,000	12:13:35
0,040	3,30	0,000	12:14:26
0,080	3,43	0,000	12:15:11
0,119	3,53	0,000	12:15:57
0,159	3,65	0,000	12:16:58
0,199	3,78	0,000	12:17:57

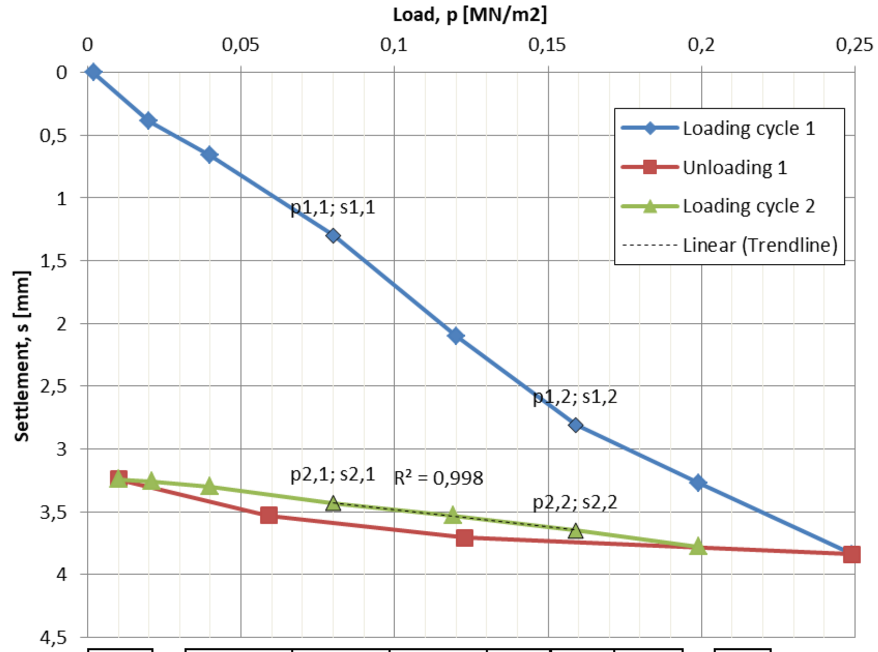


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,30	2,81	24
2	0,080	0,199	3,43	3,78	153

E_2/E_1 []
6,5

Plate load test results - Norwegian method 2
P5-C

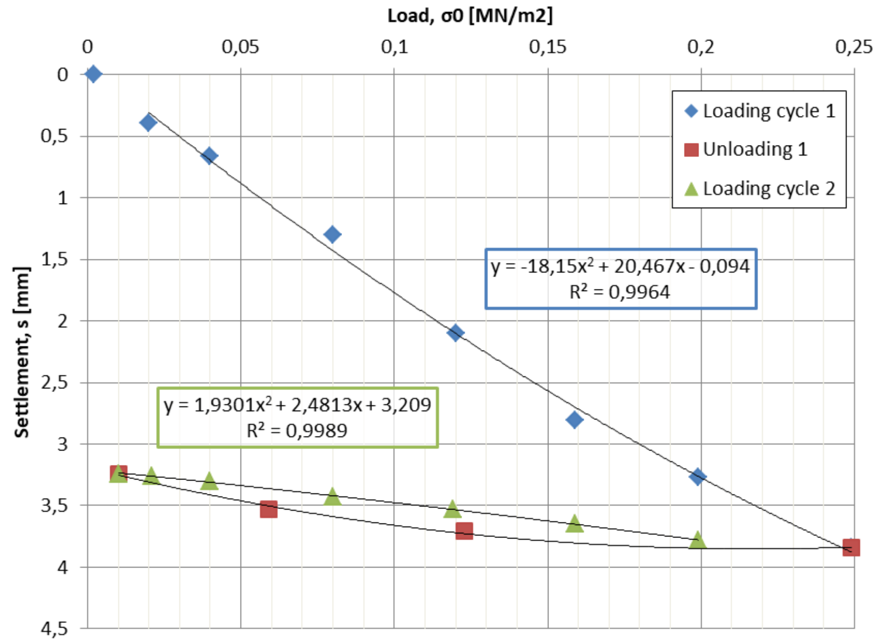


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,30	2,81	24
2	0,080	0,159	3,43	3,65	162

E_2/E_1 []
6,9

Plate load test results - Swedish method
P5-C



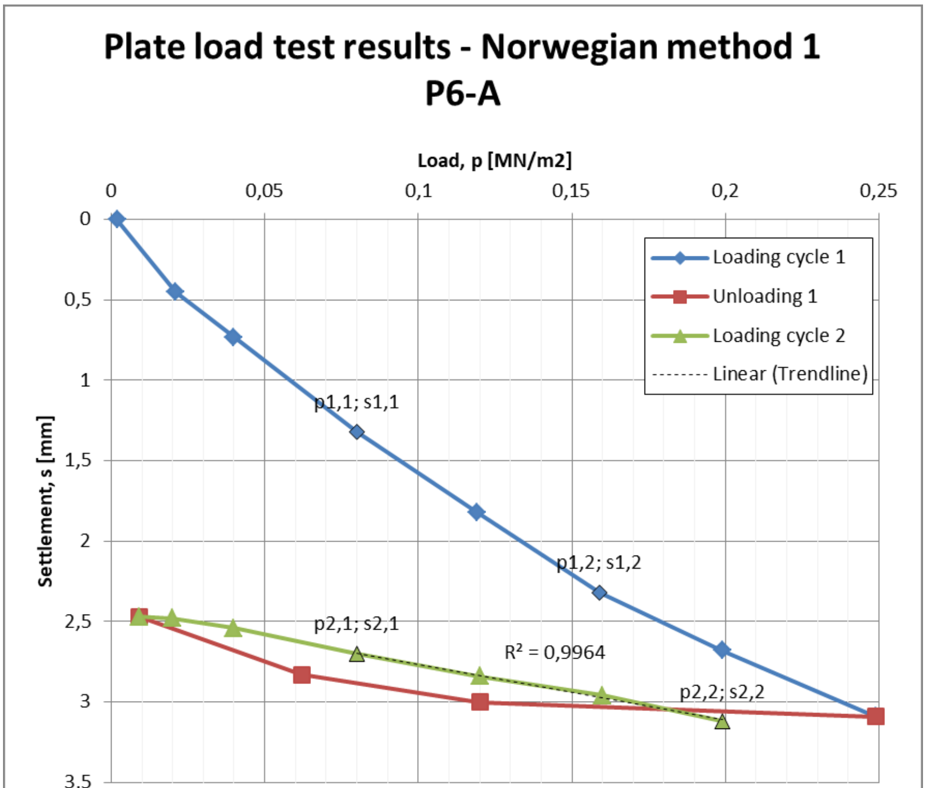
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0940	20,467	-18,1500	28
2	3,2090	2,4813	1,9301	152

E_2/E_1 []
5,4

P6-A

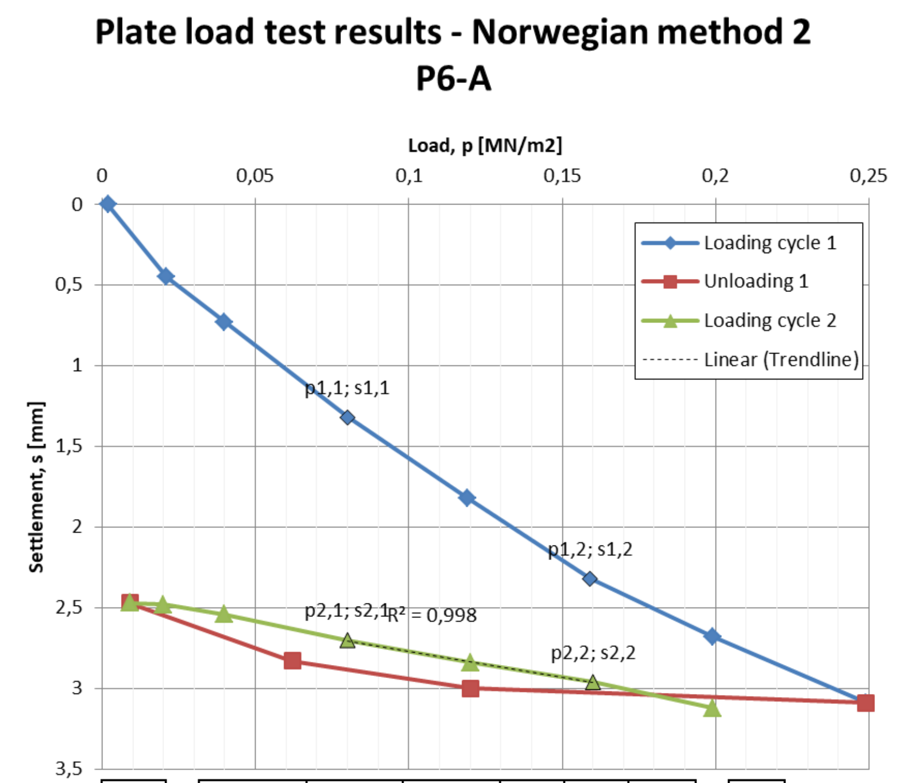
Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,002	0,00	0,000	13:18:53
0,021	0,45	0,000	13:21:14
0,040	0,73	0,000	13:22:07
0,080	1,32	0,000	13:23:11
0,119	1,82	0,000	13:24:07
0,159	2,32	0,000	13:25:05
0,199	2,68	0,000	13:25:55
0,249	3,09	0,000	13:26:39
0,120	3,00	0,000	13:29:33
0,062	2,83	-0,320	13:31:17
0,009	2,47	0,000	13:34:05
0,020	2,48	0,000	13:36:35
0,040	2,54	0,000	13:37:11
0,080	2,70	0,000	13:37:51
0,120	2,84	0,000	13:38:25
0,160	2,96	0,000	13:39:04
0,199	3,12	0,000	13:39:40



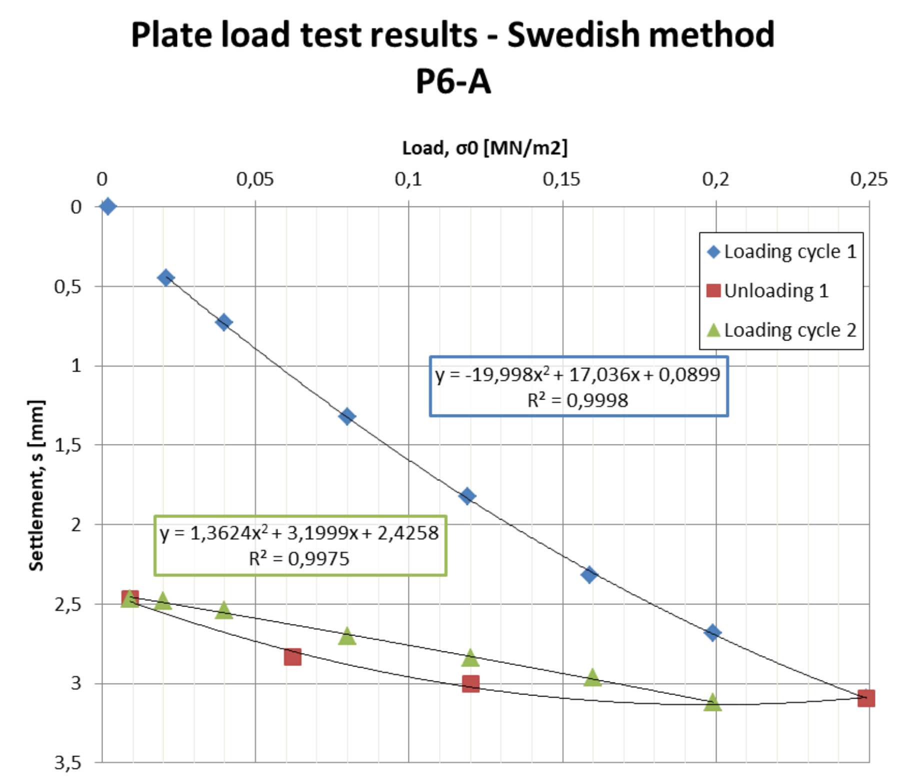
d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,32	2,32	36
2	0,080	0,199	2,70	3,12	128

E_2/E_1 []
3,6



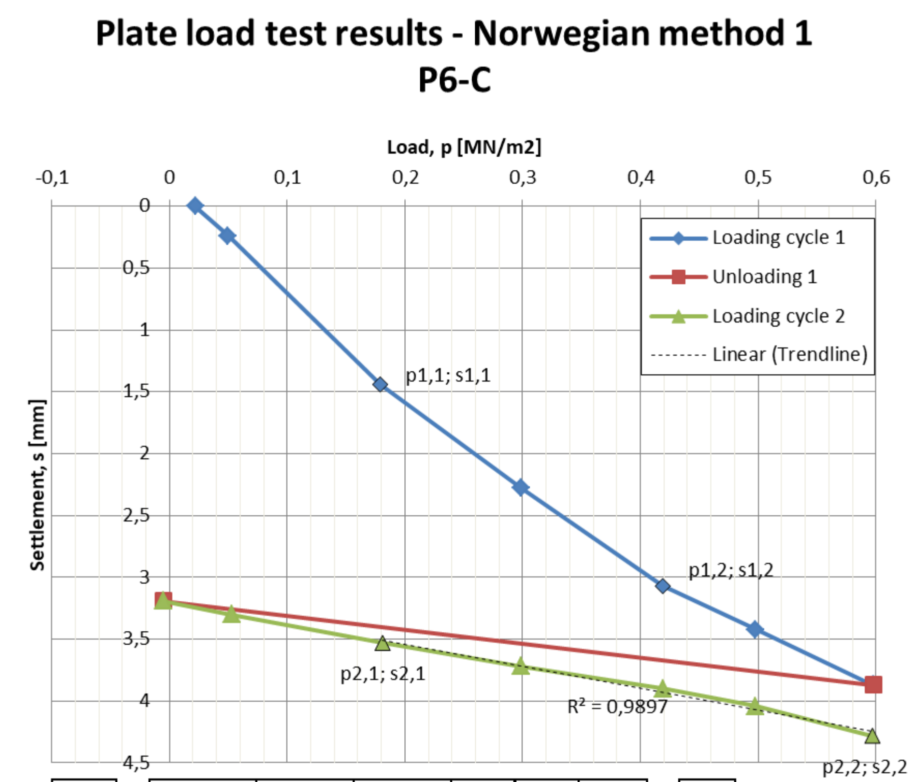
d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,159	1,32	2,32	36	3,9
	2	0,080	0,160	2,70	2,96	138	



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,0899	17,0360	-19,9980	37	3,4
	2	2,4258	3,1999	1,3624	127	

P6-C

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,022	0,00	0,320	11:33:23
0,050	0,24	0,000	11:34:00
0,179	1,44	0,000	11:35:36
0,299	2,28	0,000	11:36:51
0,419	3,07	0,000	11:38:12
0,498	3,42	0,000	11:38:56
0,598	3,87	0,000	11:39:44
-0,005	3,19	0,000	11:42:02
0,053	3,30	0,000	11:42:31
0,181	3,53	0,000	11:43:29
0,299	3,72	0,000	11:44:08
0,419	3,90	0,000	11:44:48
0,498	4,04	0,000	11:45:16
0,597	4,28	0,000	11:45:55

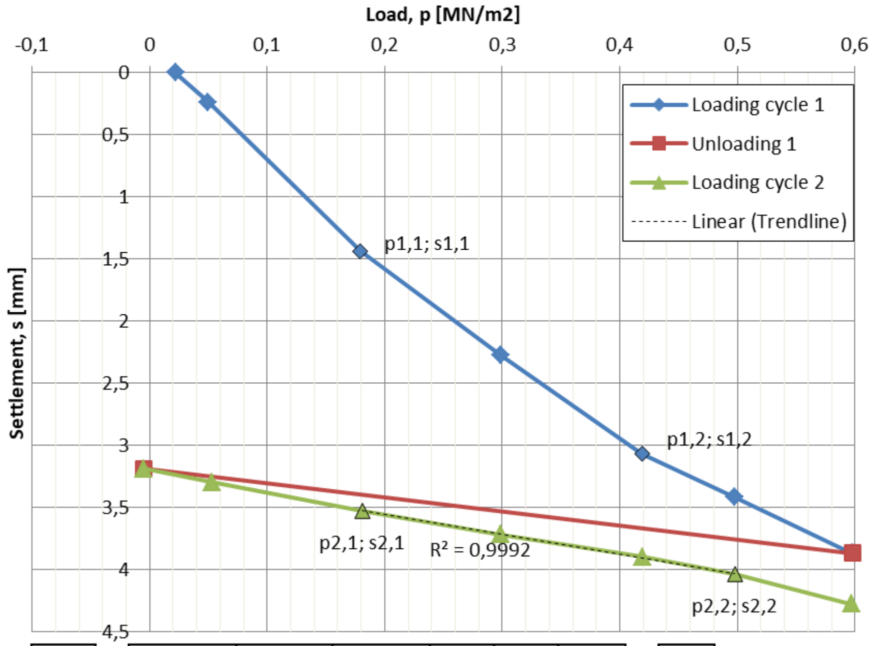


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,179	0,419	1,44	3,07	33
2	0,181	0,597	3,53	4,28	125

E_2/E_1 []
3,8

Plate load test results - Norwegian method 2
P6-C

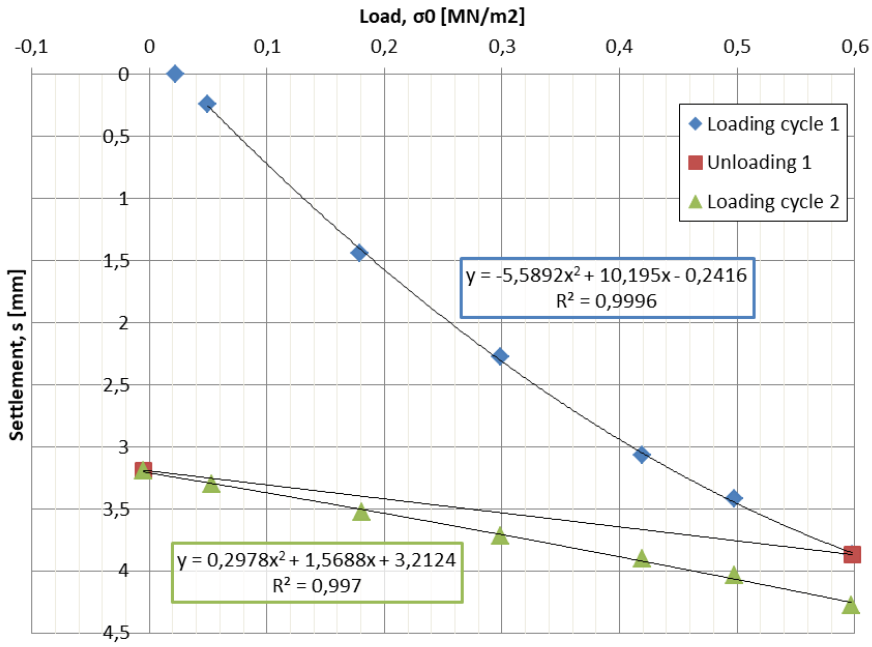


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,179	0,419	1,44	3,07	33
2	0,181	0,498	3,53	4,04	140

E_2/E_1 []
4,2

Plate load test results - Swedish method
P6-C



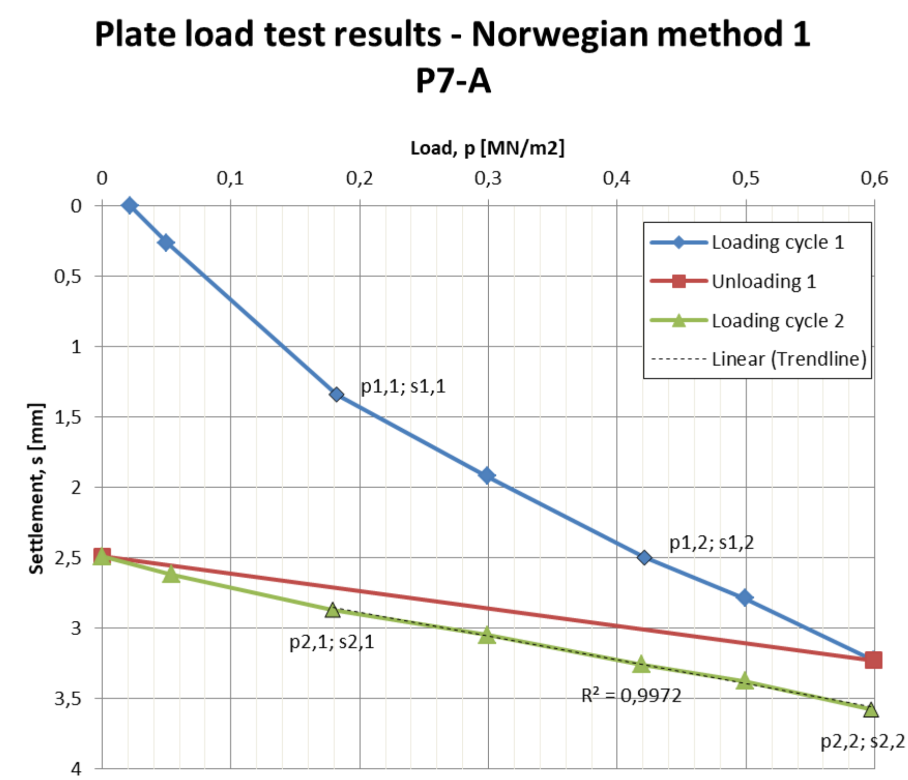
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,2416	10,1950	-5,5892	33
2	3,2124	1,5688	0,2978	129

E_2/E_1 []
3,9

P7-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,022	0,00	0,320	12:57:33
0,050	0,26	0,000	12:57:56
0,182	1,34	0,000	12:59:16
0,299	1,92	0,000	12:59:58
0,421	2,50	0,000	13:00:56
0,499	2,79	0,000	13:01:26
0,599	3,23	0,000	13:02:08
0,000	2,49	0,000	13:04:43
0,054	2,62	0,000	13:05:06
0,179	2,87	0,000	13:06:03
0,299	3,05	0,000	13:06:40
0,419	3,26	0,000	13:07:14
0,499	3,38	0,000	13:07:36
0,597	3,58	0,000	13:08:10

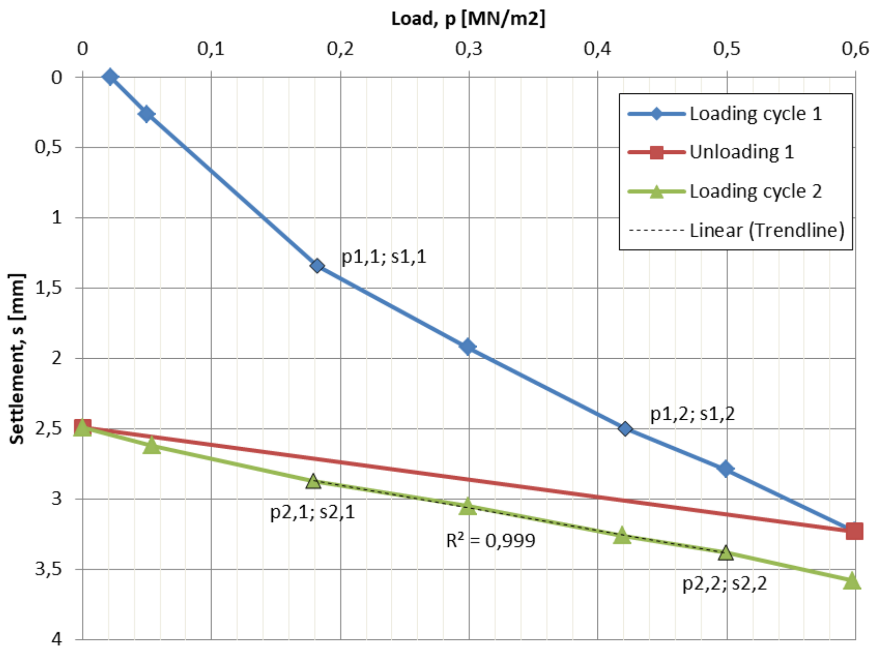


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,421	1,34	2,50	46
2	0,179	0,597	2,87	3,58	132

E_2/E_1 []
2,9

Plate load test results - Norwegian method 2
P7-A

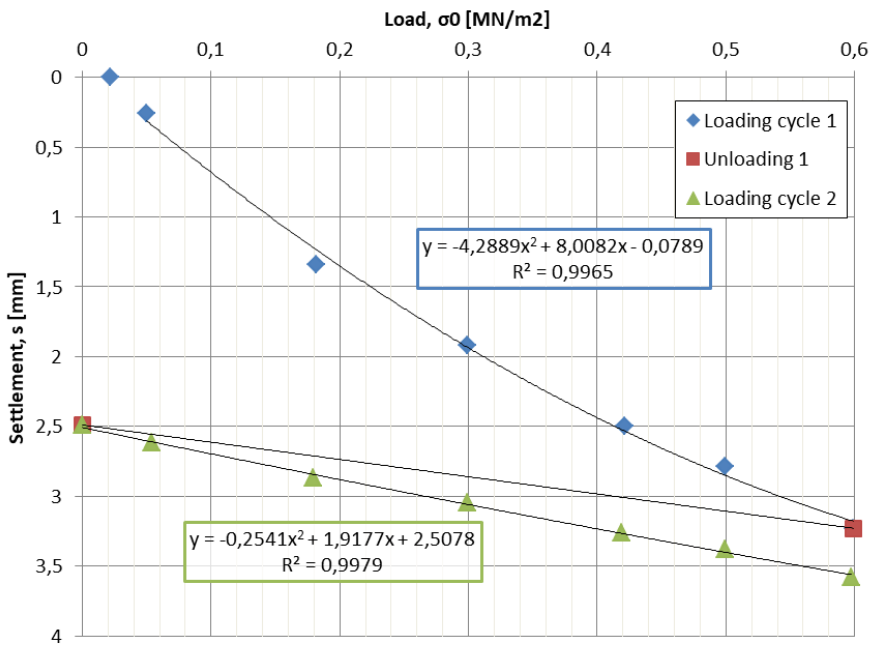


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,421	1,34	2,50	46
2	0,179	0,499	2,87	3,38	141

E_2/E_1 []
3,0

Plate load test results - Swedish method
P7-A



r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0789	8,0082	-4,2889	41
2	2,5078	1,9177	-0,2541	127

E_2/E_1 []
3,1

P7-C

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,003	0,00	0,000	10:30:09
0,020	0,71	0,270	10:32:30
0,040	1,08	0,000	10:33:07
0,080	1,81	0,000	10:33:57
0,120	2,34	0,000	10:34:43
0,160	2,89	0,000	10:35:57
0,199	3,26	0,000	10:36:43
0,249	3,76	0,000	10:37:55
0,124	3,77	0,000	10:40:33
0,063	3,67	0,000	10:41:52
0,002	3,39	0,000	10:44:02
0,021	3,46	0,000	10:46:38
0,040	3,52	0,000	10:47:17
0,081	3,64	0,000	10:47:41
0,120	3,75	0,000	10:48:11
0,160	3,86	0,000	10:48:43
0,200	3,98	0,000	10:49:13

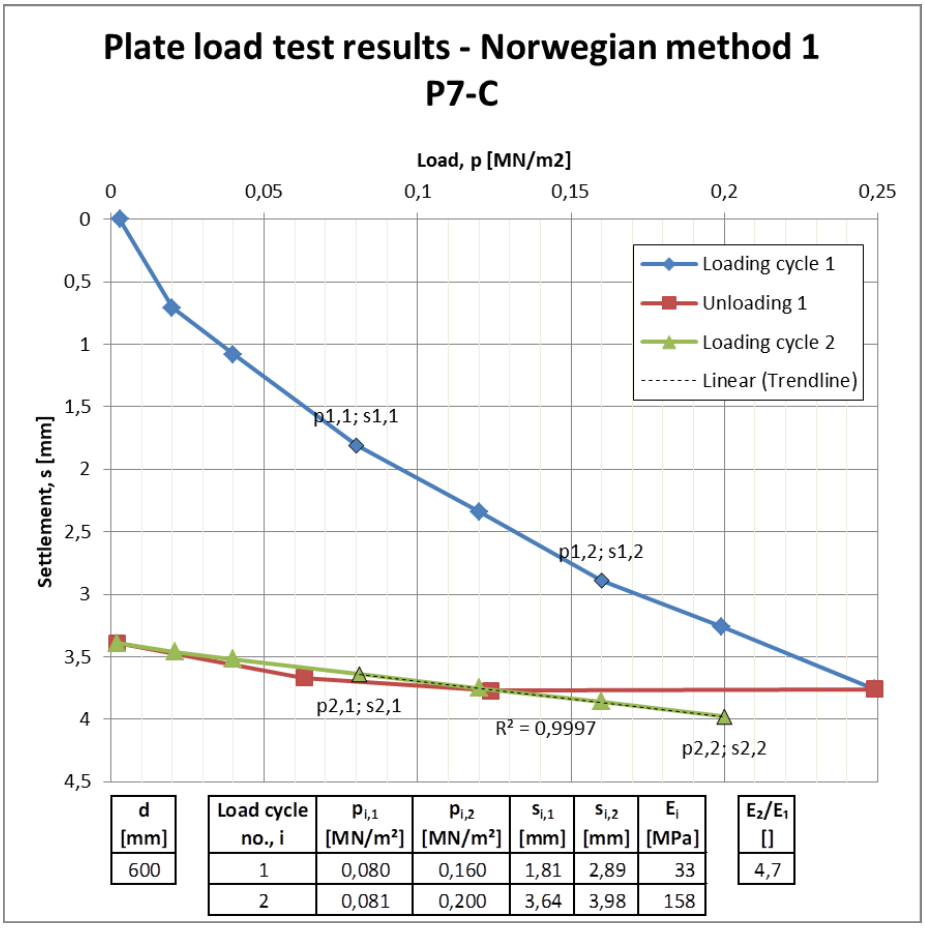
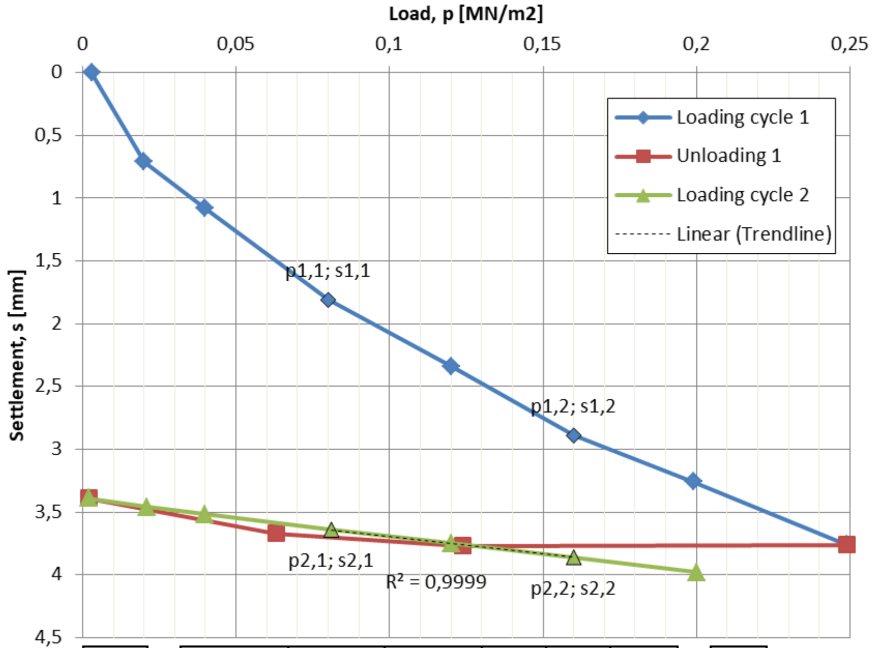
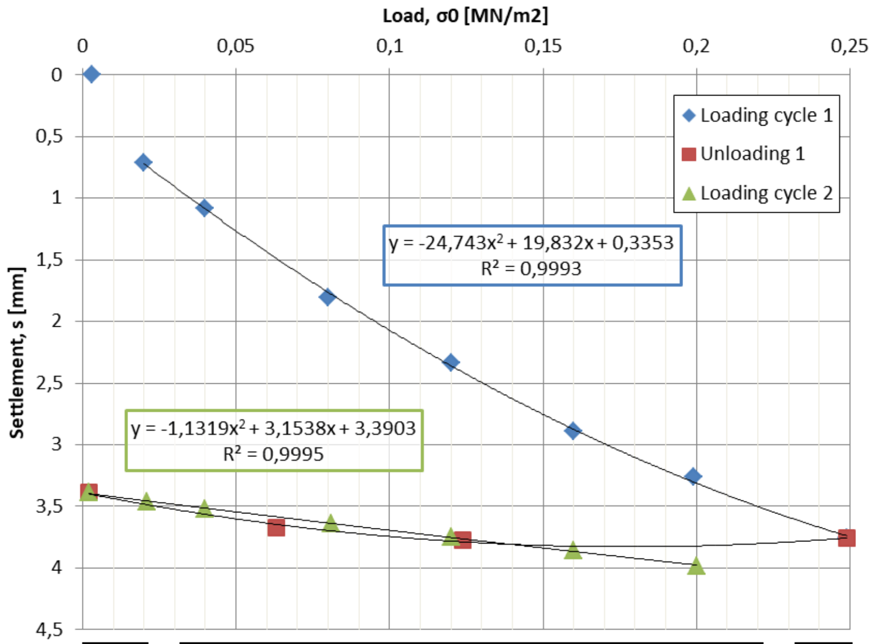


Plate load test results - Norwegian method 2
P7-C



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,160	1,81	2,89	33	4,8
	2	0,081	0,160	3,64	3,86	162	

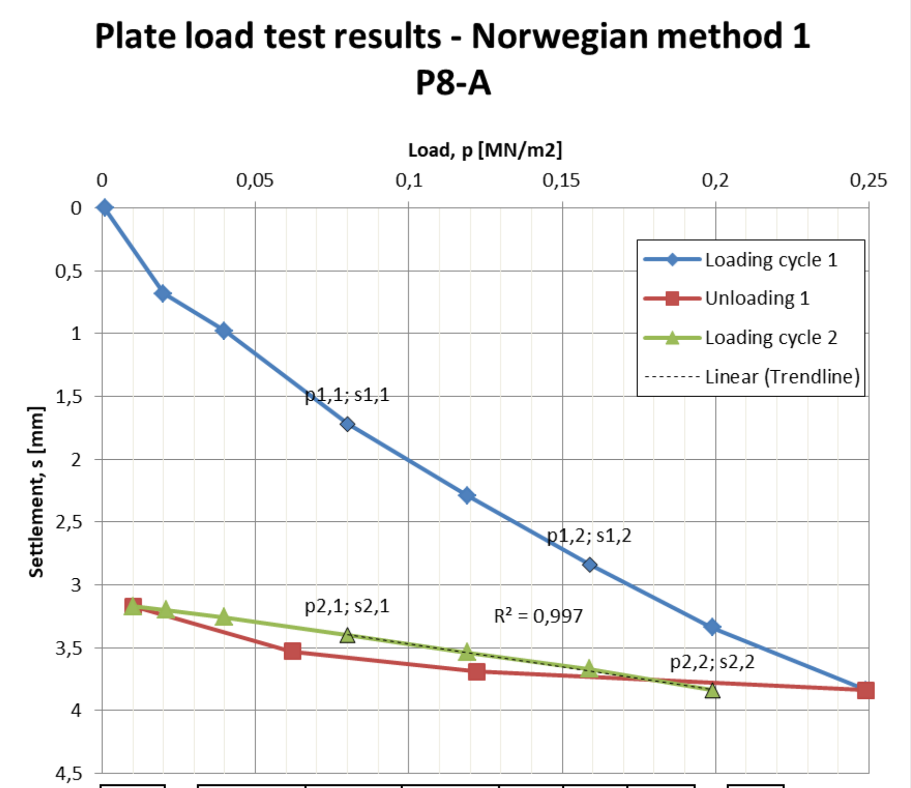
Plate load test results - Swedish method
P7-C



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,3353	19,8320	-24,7430	33	4,8
	2	3,3903	3,1538	-1,1319	157	

P8-A

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,001	0,00	0,000	12:27:56
0,020	0,68	0,000	12:30:19
0,040	0,98	0,000	12:31:01
0,080	1,72	0,000	12:31:51
0,119	2,29	0,000	12:32:53
0,159	2,84	0,000	12:34:09
0,199	3,34	0,000	12:35:19
0,249	3,84	0,000	12:36:41
0,122	3,69	0,000	12:39:25
0,062	3,53	0,000	12:40:45
0,010	3,17	0,000	12:43:04
0,021	3,20	0,000	12:45:11
0,040	3,26	0,000	12:45:55
0,080	3,40	0,000	12:46:32
0,119	3,54	0,000	12:47:20
0,159	3,67	0,000	12:48:10
0,199	3,84	0,000	12:49:09

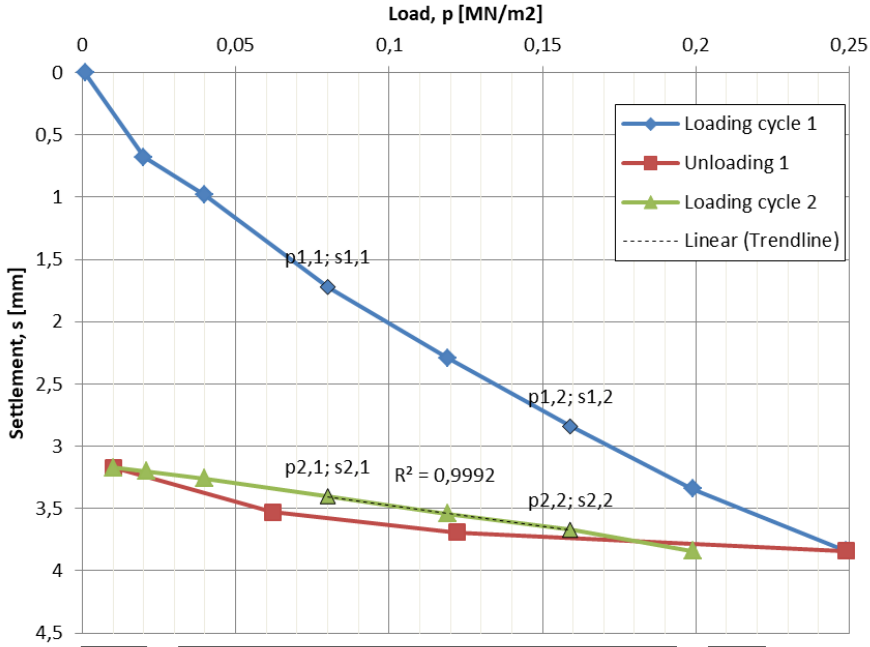


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,72	2,84	32
2	0,080	0,199	3,40	3,84	122

E_2/E_1 []
3,8

Plate load test results - Norwegian method 2
P8-A

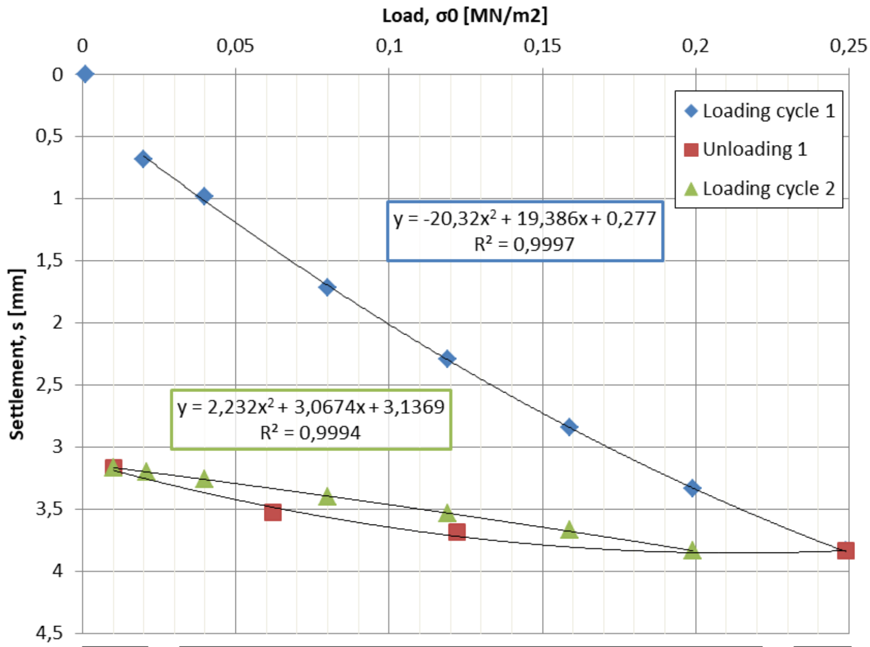


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,72	2,84	32
2	0,080	0,159	3,40	3,67	132

E_2/E_1 []
4,1

Plate load test results - Swedish method
P8-A



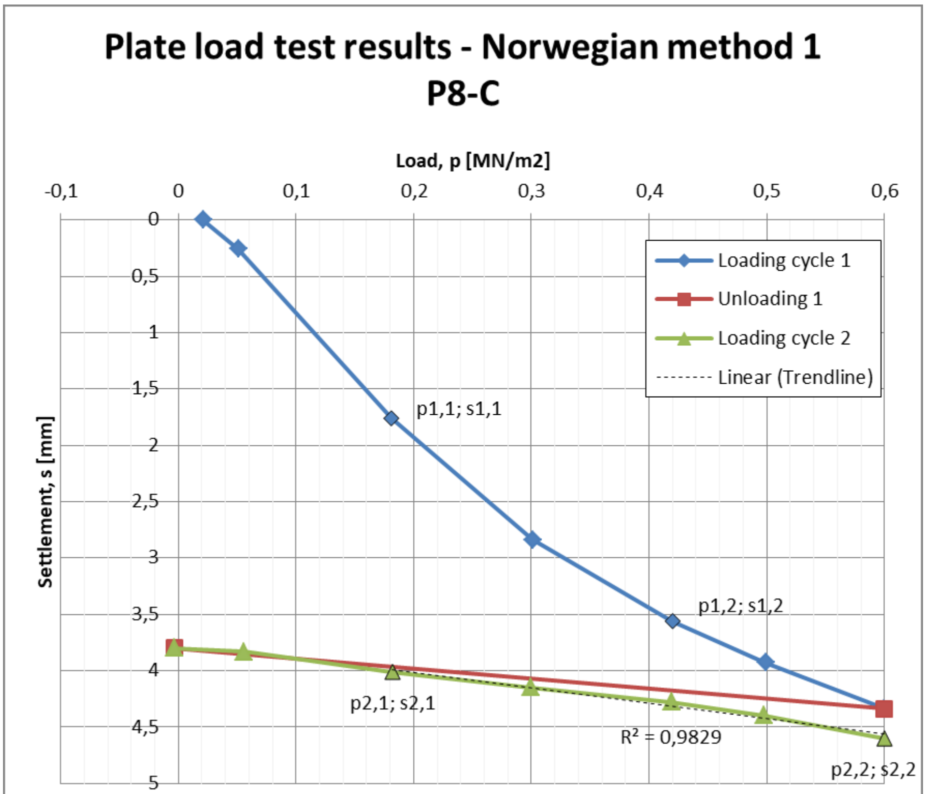
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,2770	19,3860	-20,3200	31
2	3,1369	3,0674	2,2320	124

E_2/E_1 []
4,0

P8-C

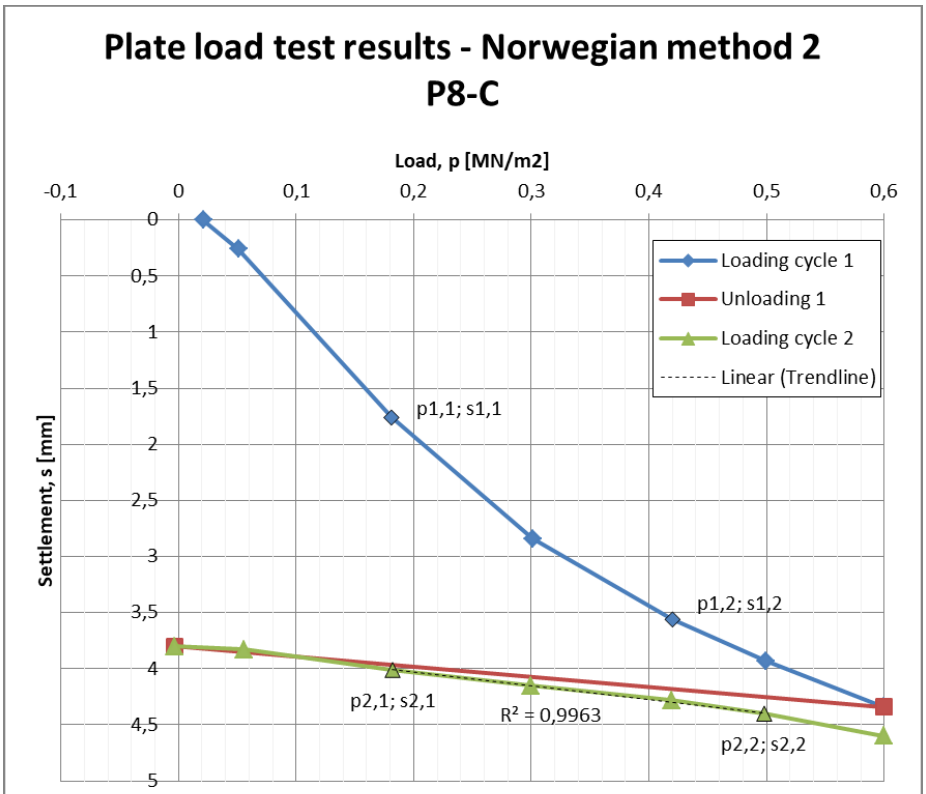
Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,021	0,00	0,000	09:27:49
0,051	0,26	0,000	09:28:24
0,181	1,76	0,000	09:29:52
0,301	2,84	0,000	09:31:24
0,420	3,56	0,000	09:32:46
0,499	3,93	0,000	09:33:52
0,600	4,34	0,000	09:34:50
-0,003	3,80	0,000	09:37:05
0,056	3,83	0,000	09:37:14
0,182	4,01	0,000	09:37:40
0,300	4,15	0,000	09:38:08
0,419	4,28	0,000	09:38:39
0,498	4,40	0,000	09:39:06
0,600	4,60	0,000	09:39:40



d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	1,76	3,56	30
2	0,182	0,600	4,01	4,60	159

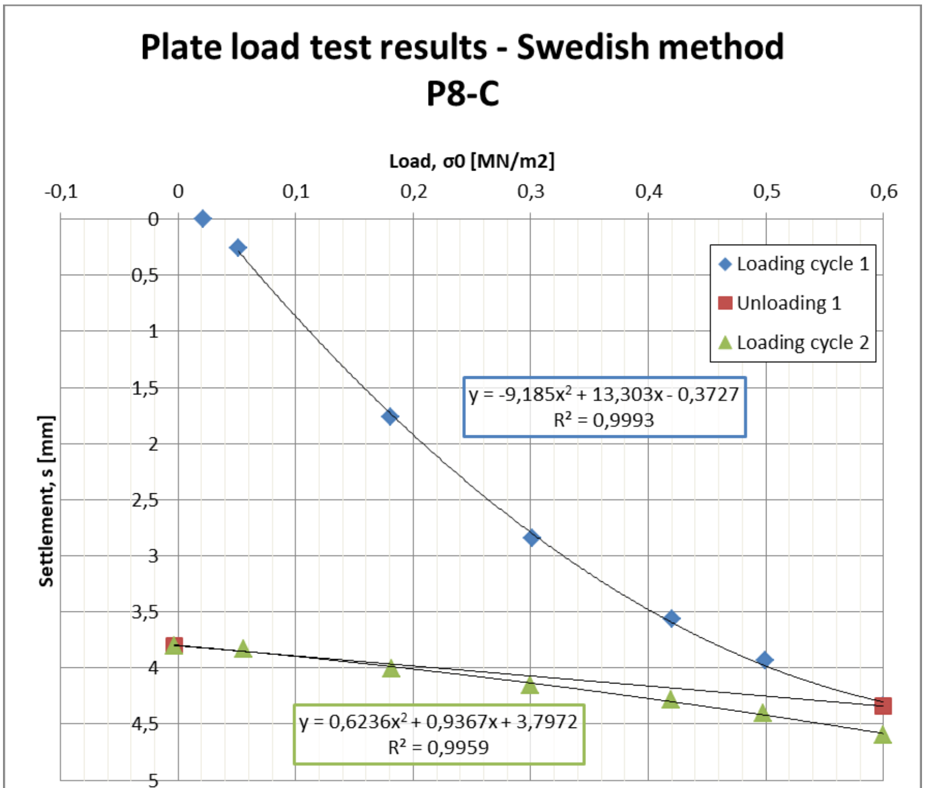
E_2/E_1 []
5,3



d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	1,76	3,56	30
2	0,182	0,498	4,01	4,40	182

E_2/E_1 []
6,1



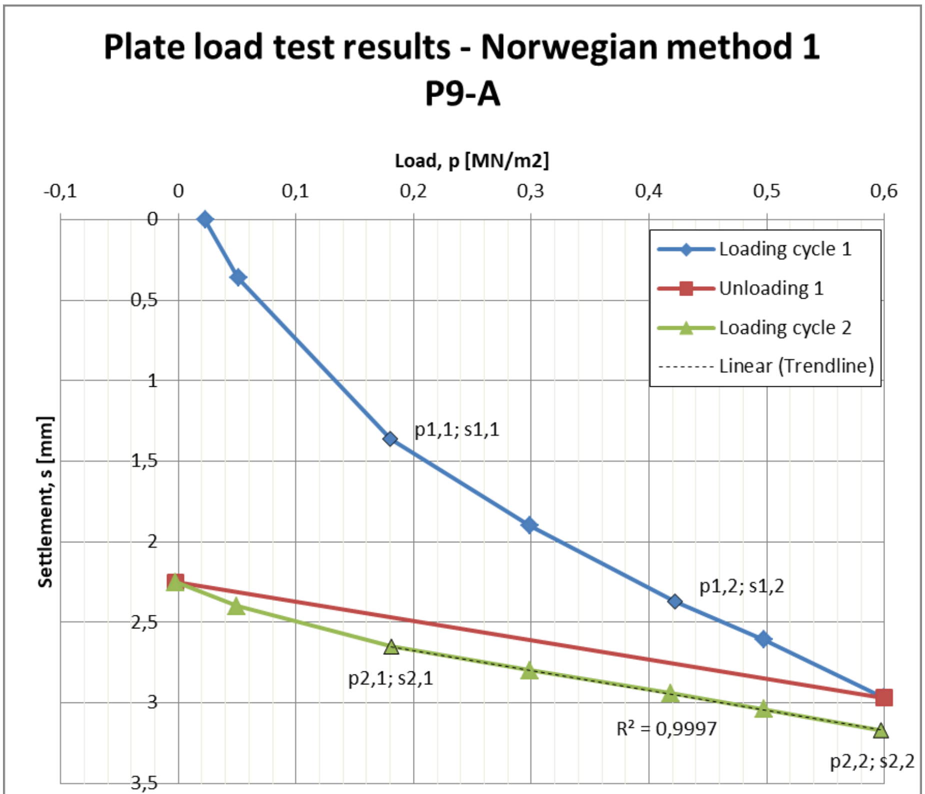
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,3727	13,3030	-9,1850	29
2	3,7972	0,9367	0,6236	172

E_2/E_1 []
5,9

P9-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,023	0,00	0,000	15:29:27
0,051	0,36	0,000	15:29:41
0,180	1,36	0,000	15:30:47
0,299	1,90	0,000	15:31:35
0,422	2,37	0,000	15:32:23
0,498	2,61	0,000	15:32:57
0,600	2,97	0,000	15:33:41
-0,002	2,25	0,000	15:36:15
0,050	2,40	0,000	15:36:41
0,181	2,65	0,000	15:37:37
0,299	2,80	0,000	15:38:11
0,418	2,94	0,000	15:38:47
0,498	3,04	0,000	15:39:35
0,597	3,17	0,000	15:40:13

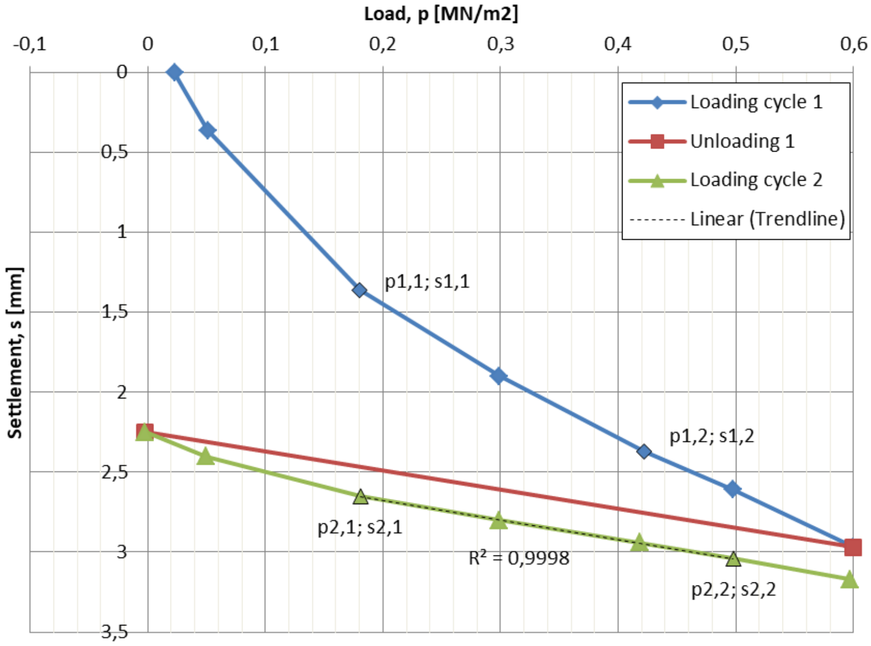


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,422	1,36	2,37	54
2	0,181	0,597	2,65	3,17	180

E_2/E_1 []
3,3

Plate load test results - Norwegian method 2
P9-A

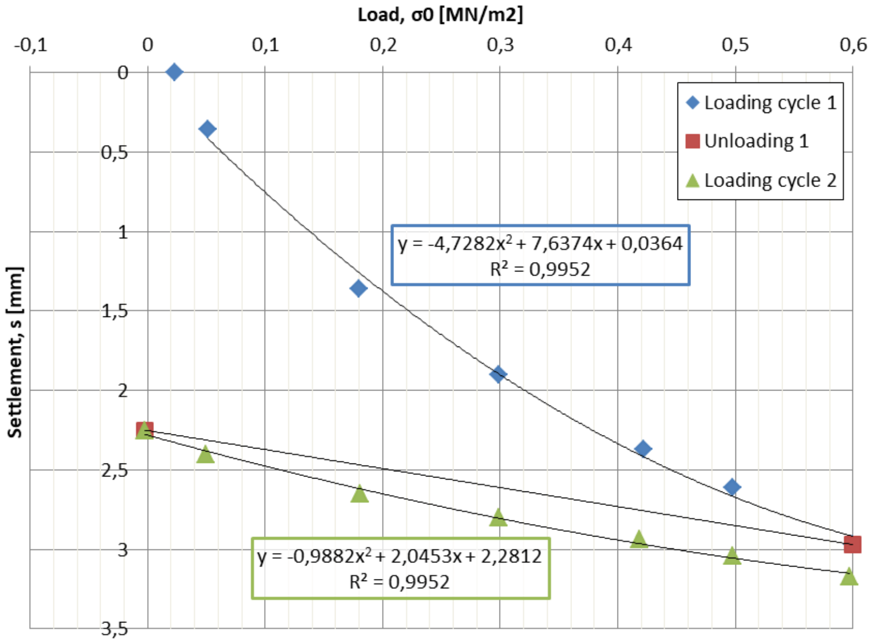


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,422	1,36	2,37	54
2	0,181	0,498	2,65	3,04	183

E_2/E_1 []
3,4

Plate load test results - Swedish method
P9-A



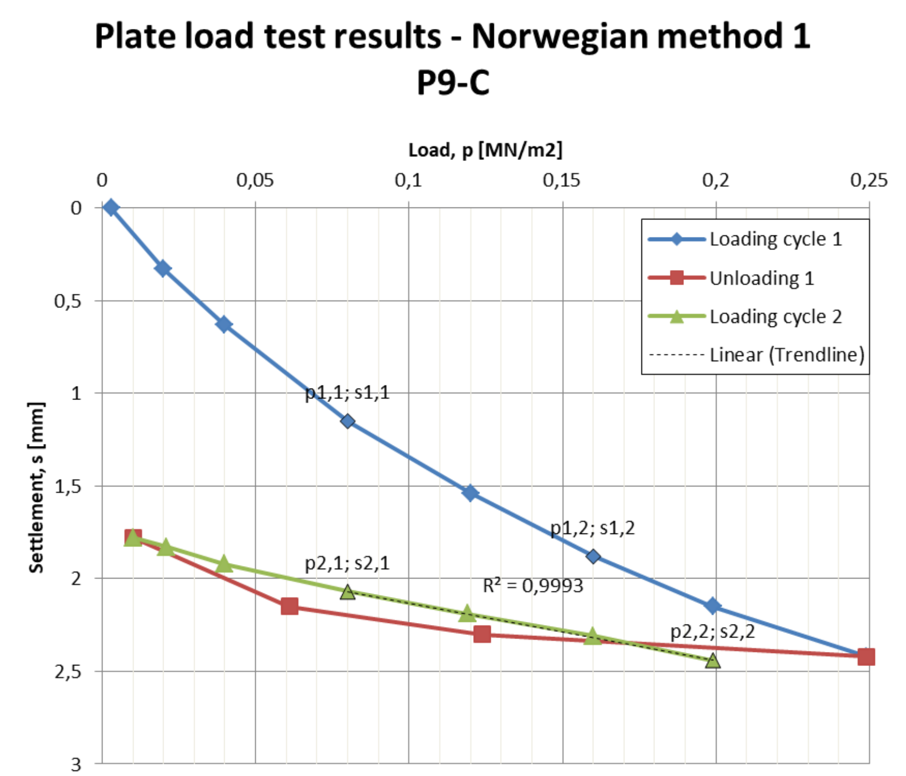
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0364	7,6374	-4,7282	47
2	2,2812	2,0453	-0,9882	155

E_2/E_1 []
3,3

P9-C

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,003	0,00	0,000	17:01:39
0,020	0,33	0,000	17:04:22
0,040	0,63	0,000	17:05:27
0,080	1,15	0,000	17:06:23
0,120	1,54	0,000	17:07:24
0,160	1,88	0,000	17:08:27
0,199	2,15	0,000	17:09:29
0,249	2,42	0,000	17:10:49
0,124	2,30	0,000	17:13:32
0,061	2,15	0,000	17:15:13
0,010	1,78	0,000	17:19:16
0,021	1,83	0,000	17:22:18
0,040	1,92	0,000	17:22:49
0,080	2,07	0,000	17:23:33
0,119	2,19	0,000	17:24:16
0,160	2,31	0,000	17:24:57
0,199	2,44	0,000	17:25:59

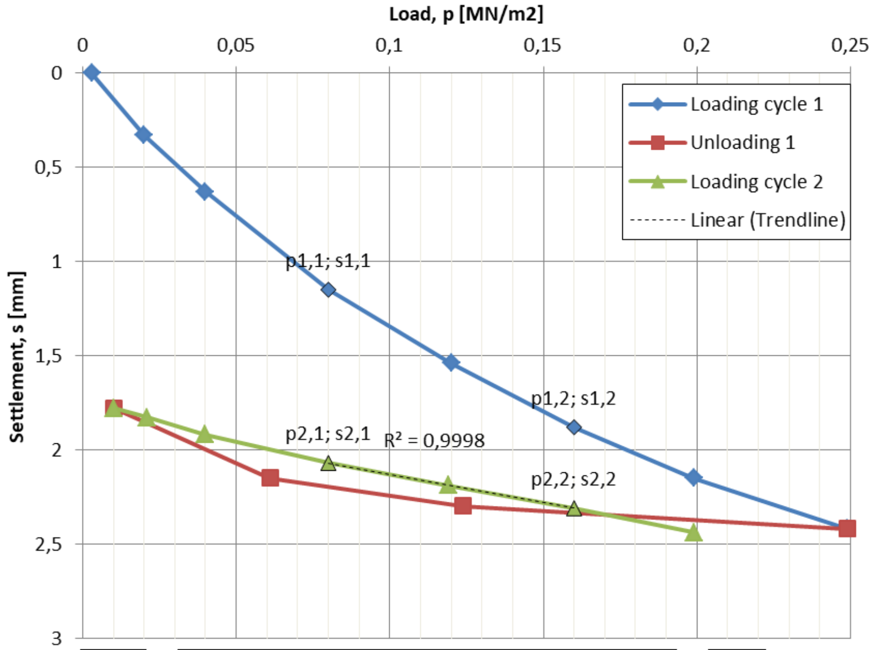


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	1,15	1,88	49
2	0,080	0,199	2,07	2,44	145

E_2/E_1 []
2,9

Plate load test results - Norwegian method 2
P9-C

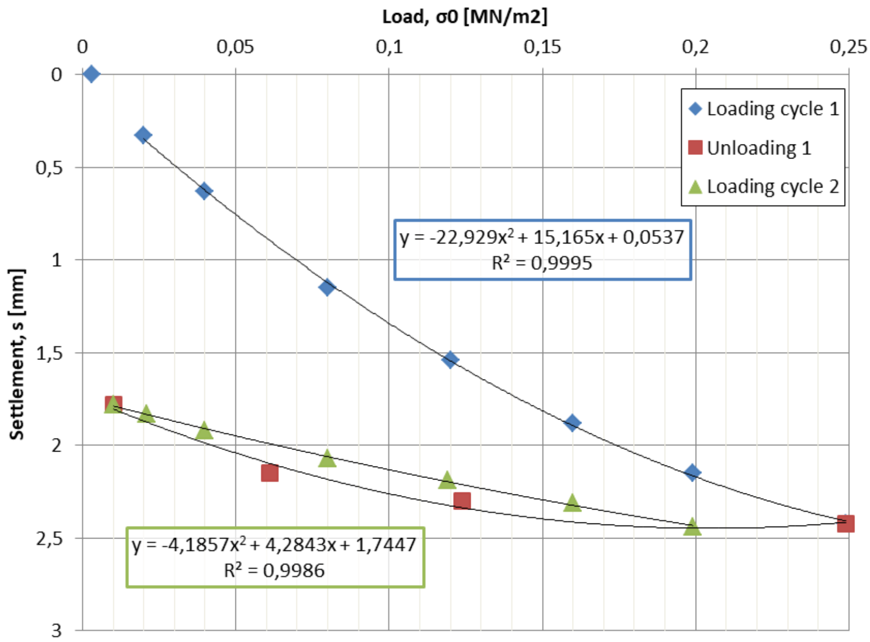


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	1,15	1,88	49
2	0,080	0,160	2,07	2,31	150

E_2/E_1 []
3,0

Plate load test results - Swedish method
P9-C



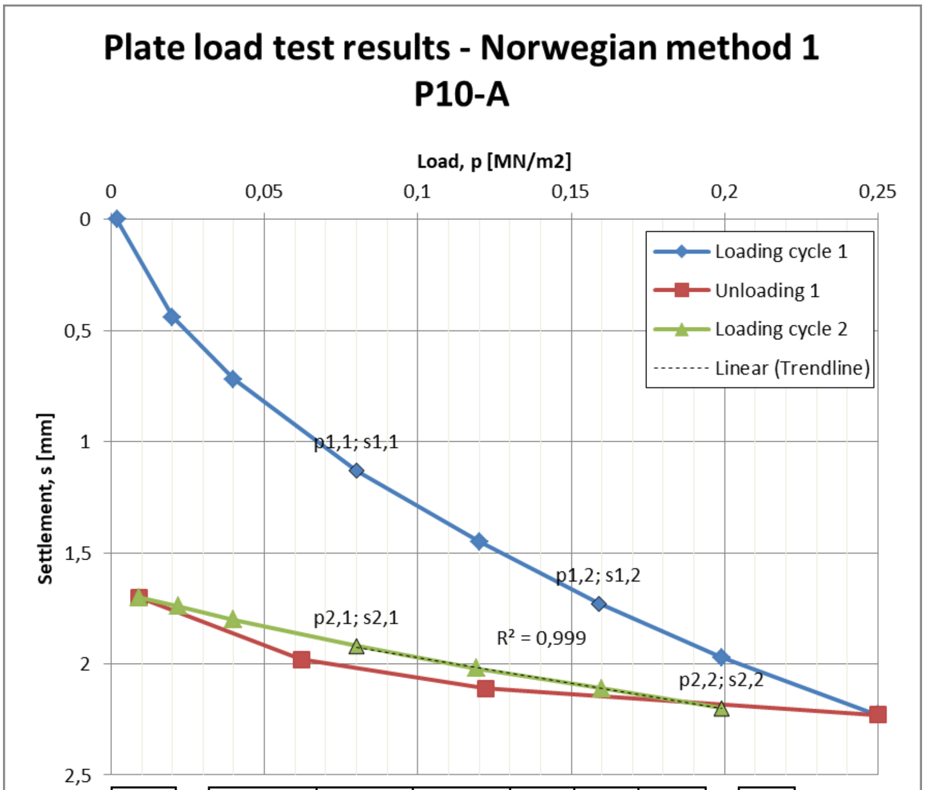
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0537	15,1650	-22,9290	48
2	1,7447	4,2843	-4,1857	139

E_2/E_1 []
2,9

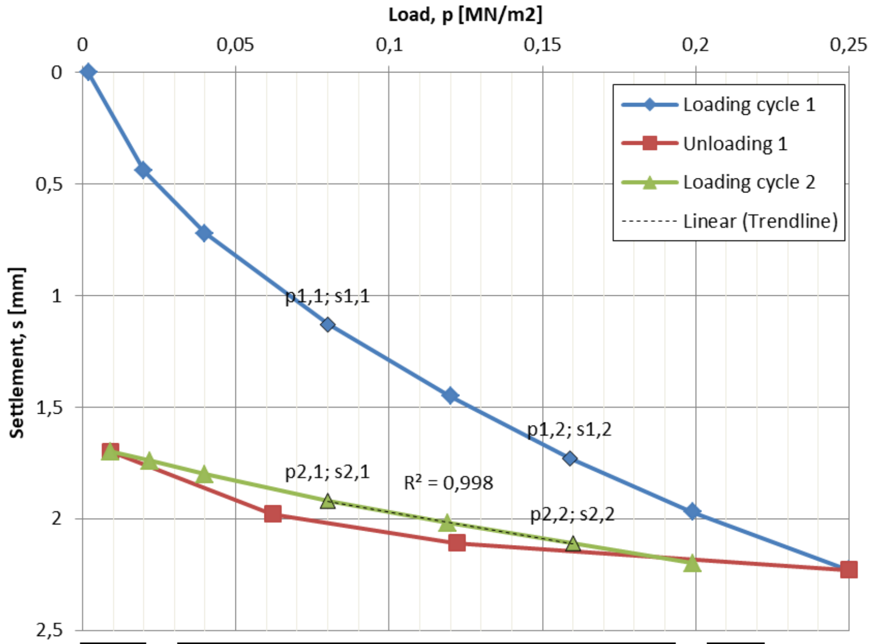
P10-A

Load [MN/m^2]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,002	0,00	0,000	15:00:16
0,020	0,44	0,000	15:02:42
0,040	0,72	0,000	15:03:15
0,080	1,13	0,000	15:04:06
0,120	1,45	0,000	15:05:05
0,159	1,73	0,000	15:05:53
0,199	1,97	0,000	15:06:35
0,250	2,23	0,000	15:07:43
0,122	2,11	0,000	15:10:21
0,062	1,98	0,000	15:11:46
0,009	1,70	0,000	15:14:18
0,022	1,74	0,000	15:16:28
0,040	1,80	0,000	15:17:01
0,080	1,92	0,000	15:17:36
0,119	2,02	0,000	15:18:10
0,160	2,11	0,000	15:18:51
0,199	2,20	0,000	15:19:30



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,159	1,13	1,73	59	3,2
	2	0,080	0,199	1,92	2,20	191	

Plate load test results - Norwegian method 2
P10-A

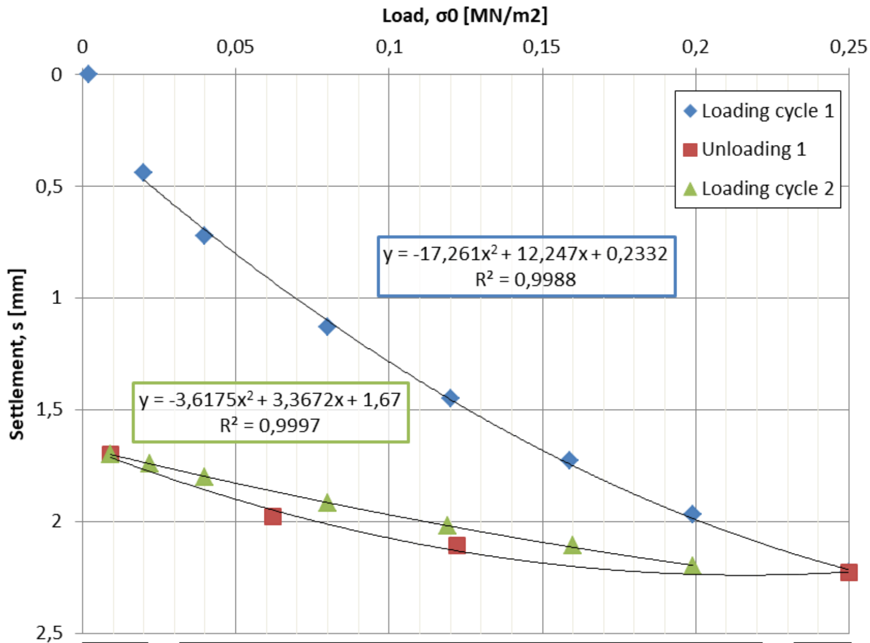


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,159	1,13	1,73	59
2	0,080	0,160	1,92	2,11	189

E_2/E_1 []
3,2

Plate load test results - Swedish method
P10-A



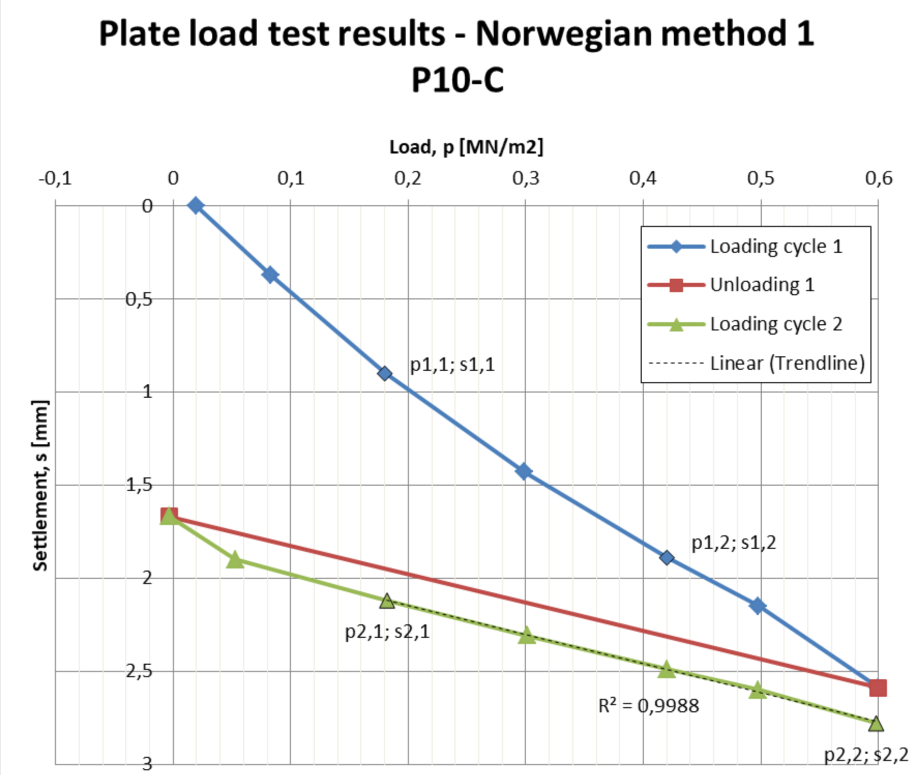
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,2332	12,2470	-17,2610	57
2	1,6700	3,3672	-3,6175	183

E_2/E_1 []
3,2

P10-C

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,020	0,00	0,000	16:45:43
0,083	0,37	0,000	16:45:53
0,180	0,90	0,000	16:46:32
0,299	1,43	0,000	16:47:06
0,420	1,89	0,000	16:47:35
0,498	2,15	0,000	16:48:02
0,600	2,59	0,000	16:48:35
-0,003	1,67	0,000	16:50:43
0,053	1,90	0,000	16:51:12
0,182	2,12	0,000	16:51:33
0,301	2,31	0,000	16:52:02
0,420	2,49	0,000	16:52:27
0,498	2,60	0,000	16:52:50
0,598	2,78	0,000	16:53:21

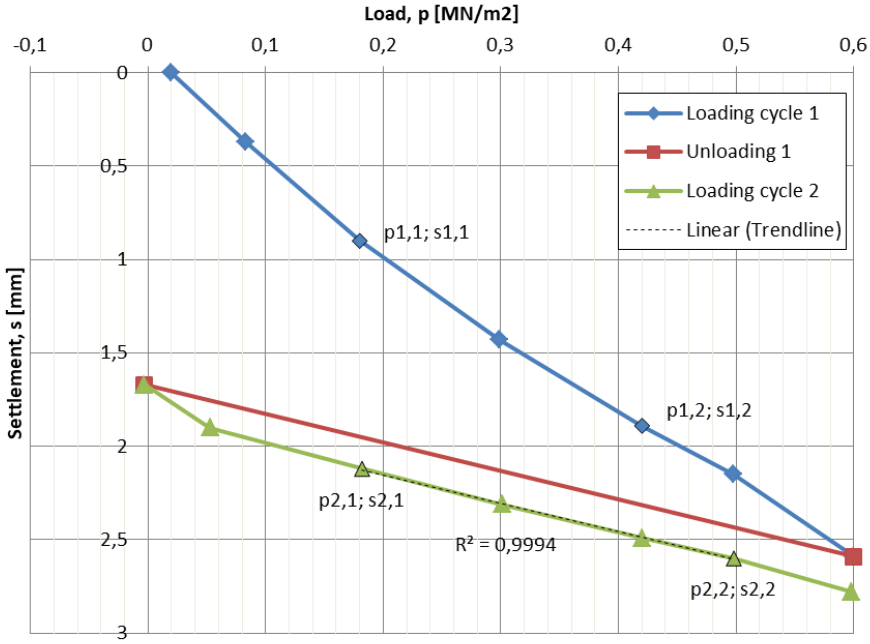


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,90	1,89	55
2	0,182	0,598	2,12	2,78	142

E_2/E_1 []
2,6

Plate load test results - Norwegian method 2
P10-C

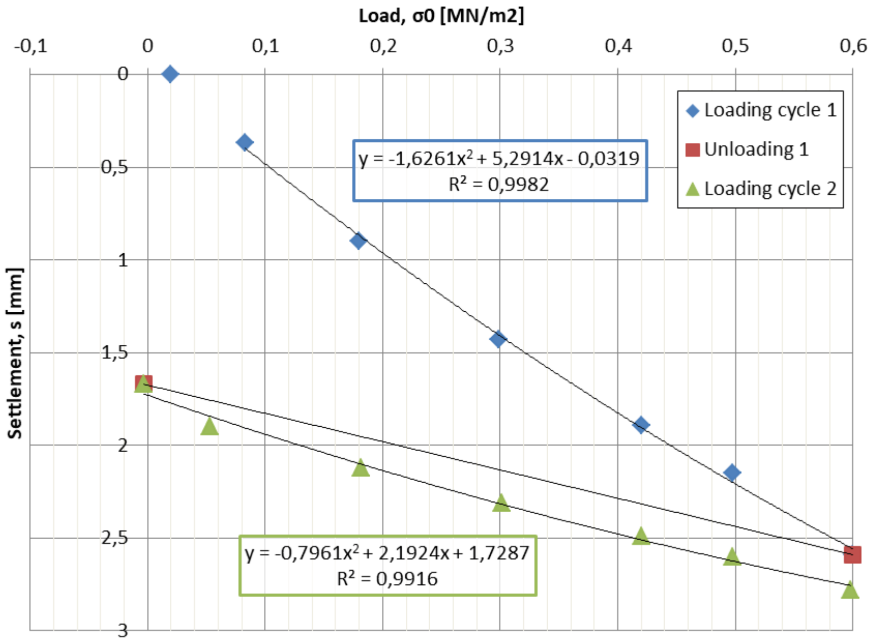


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,90	1,89	55
2	0,182	0,498	2,12	2,60	148

E_2/E_1 []
2,7

Plate load test results - Swedish method
P10-C



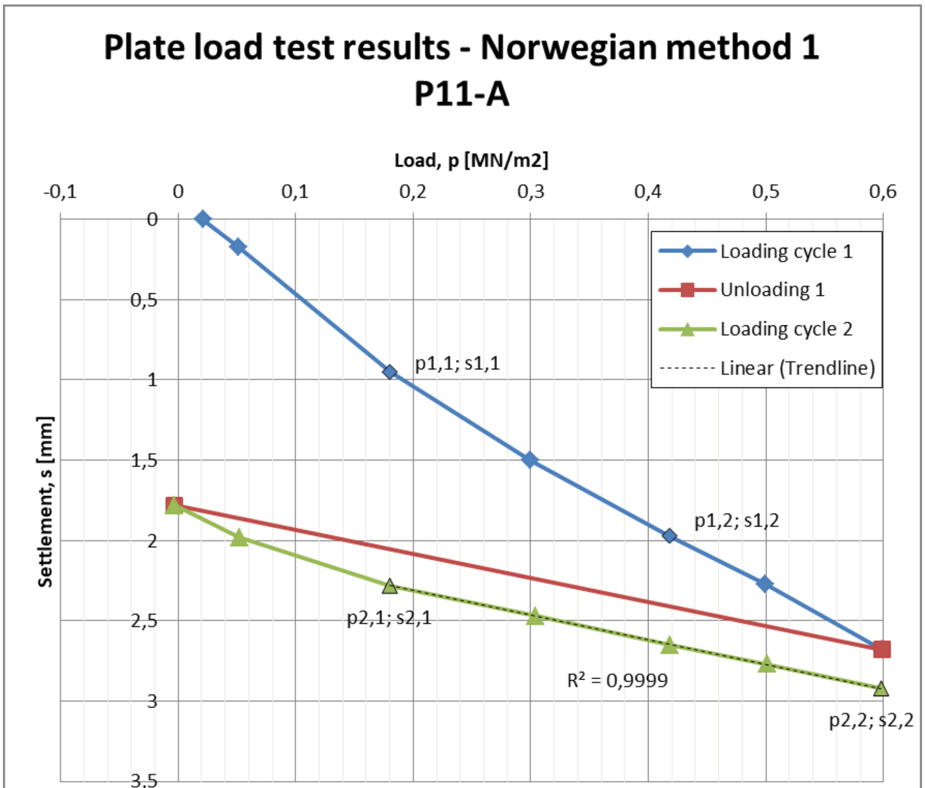
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0319	5,2914	-1,6261	52
2	1,7287	2,1924	-0,7961	131

E_2/E_1 []
2,5

P11-A

Load [MN/m²]	Settlement [mm]	ds/dt [mm/min]	Time [hh:mm:ss]
0,021	0,00	0,000	14:42:35
0,051	0,17	0,000	14:42:59
0,180	0,95	0,000	14:44:25
0,300	1,50	0,000	14:45:13
0,418	1,97	0,000	14:45:58
0,499	2,27	0,000	14:46:39
0,599	2,68	0,000	14:47:25
-0,003	1,78	0,000	14:49:51
0,052	1,98	0,000	14:50:13
0,180	2,28	0,000	14:50:37
0,304	2,47	0,000	14:51:03
0,418	2,65	0,000	14:51:37
0,501	2,77	0,000	14:52:14
0,598	2,92	0,000	14:52:45

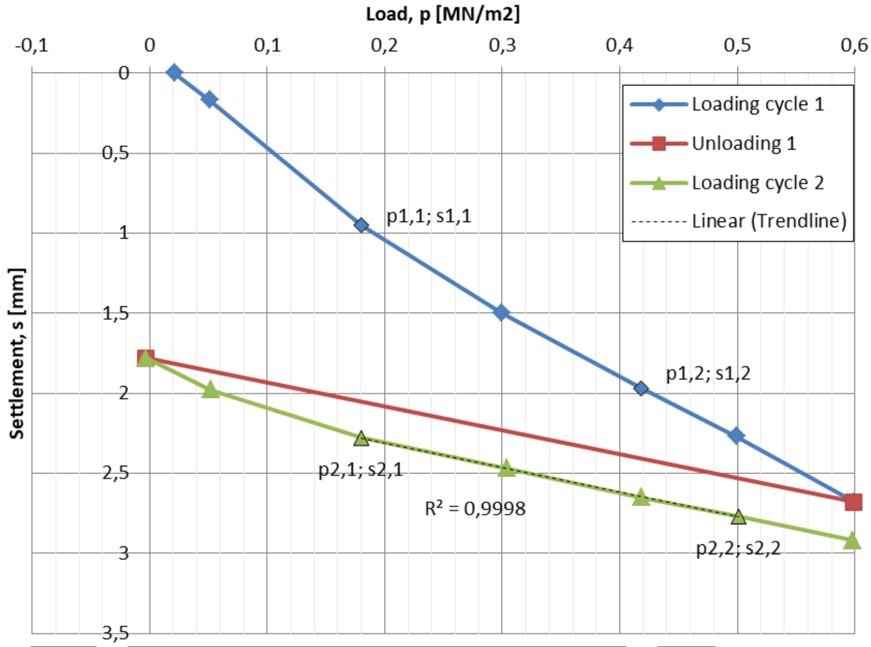


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,418	0,95	1,97	53
2	0,180	0,598	2,28	2,92	147

E_2/E_1 []
2,8

Plate load test results - Norwegian method 2
P11-A

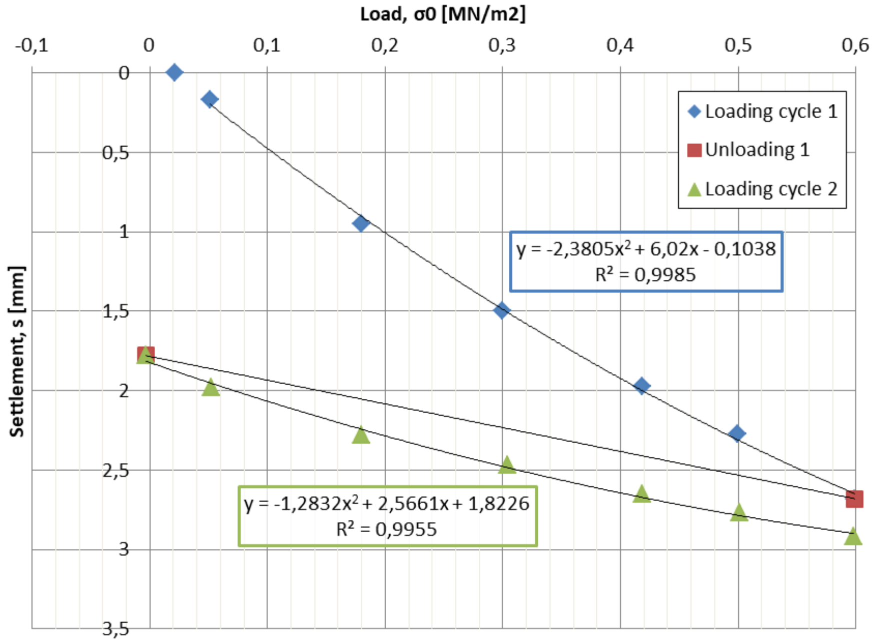


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,418	0,95	1,97	53
2	0,180	0,501	2,28	2,77	147

E_2/E_1 []
2,8

Plate load test results - Swedish method
P11-A



r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1038	6,0200	-2,3805	49
2	1,8226	2,5661	-1,2832	125

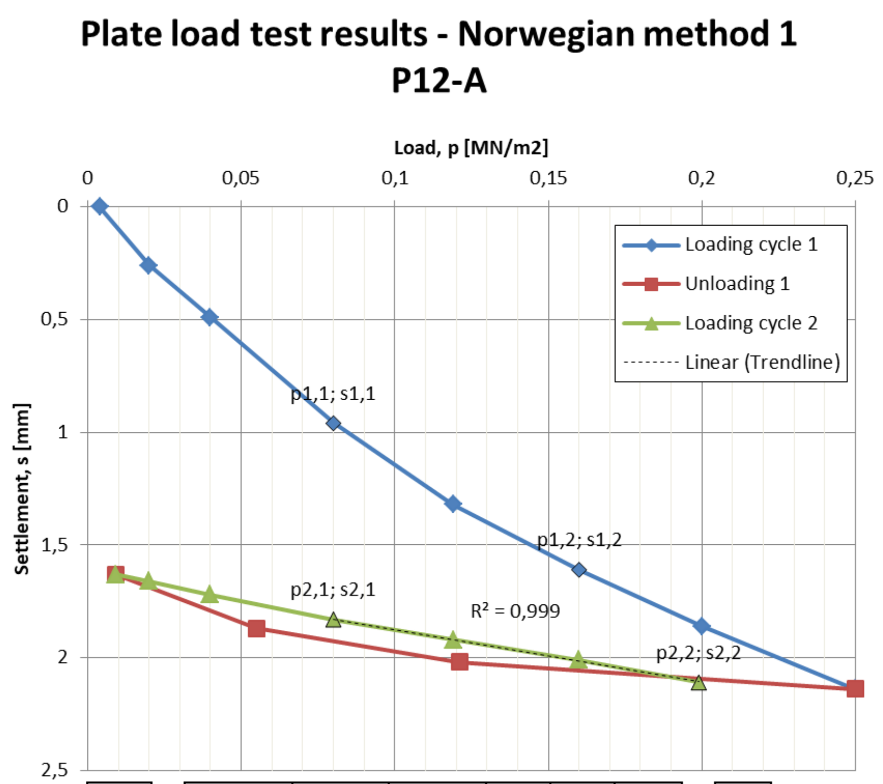
E_2/E_1 []
2,6

P11-C

Test failed due to technical difficulties. No measurement results available.

P12-A

Load [MN/m^2]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,004	0,00	0,000	14:10:20
0,020	0,26	0,000	14:13:00
0,040	0,49	0,000	14:13:46
0,080	0,96	0,000	14:14:52
0,119	1,32	0,000	14:16:12
0,160	1,61	0,000	14:17:24
0,200	1,86	0,000	14:18:16
0,250	2,14	0,000	14:19:23
0,121	2,02	0,000	14:22:02
0,055	1,87	0,000	14:23:24
0,009	1,63	0,000	14:26:12
0,020	1,66	0,000	14:28:48
0,040	1,72	0,000	14:29:27
0,080	1,83	0,000	14:30:18
0,119	1,92	0,000	14:31:25
0,160	2,01	0,000	14:32:37
0,199	2,11	0,000	14:33:32

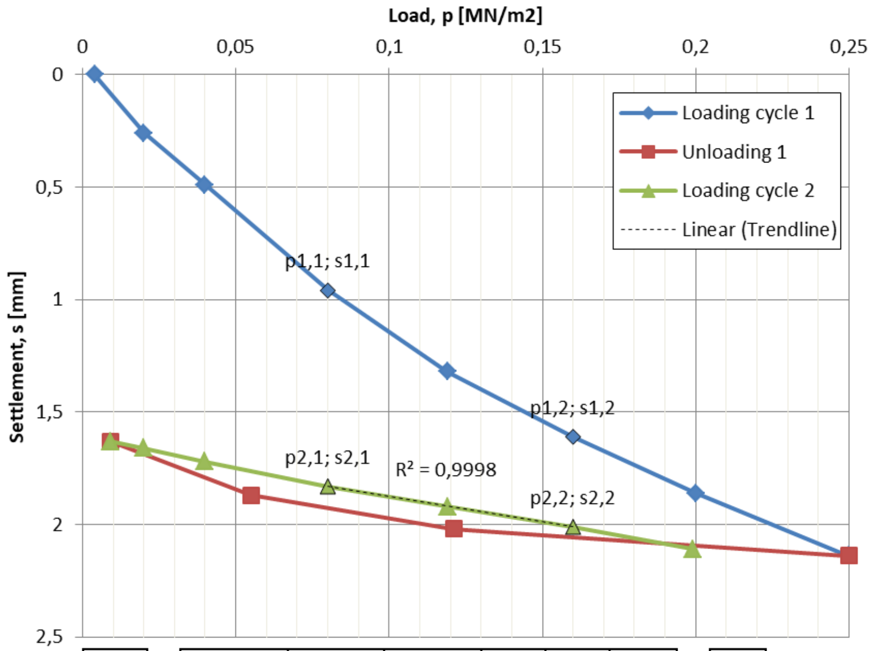


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,96	1,61	55
2	0,080	0,199	1,83	2,11	191

E_2/E_1 []
3,5

Plate load test results - Norwegian method 2
P12-A

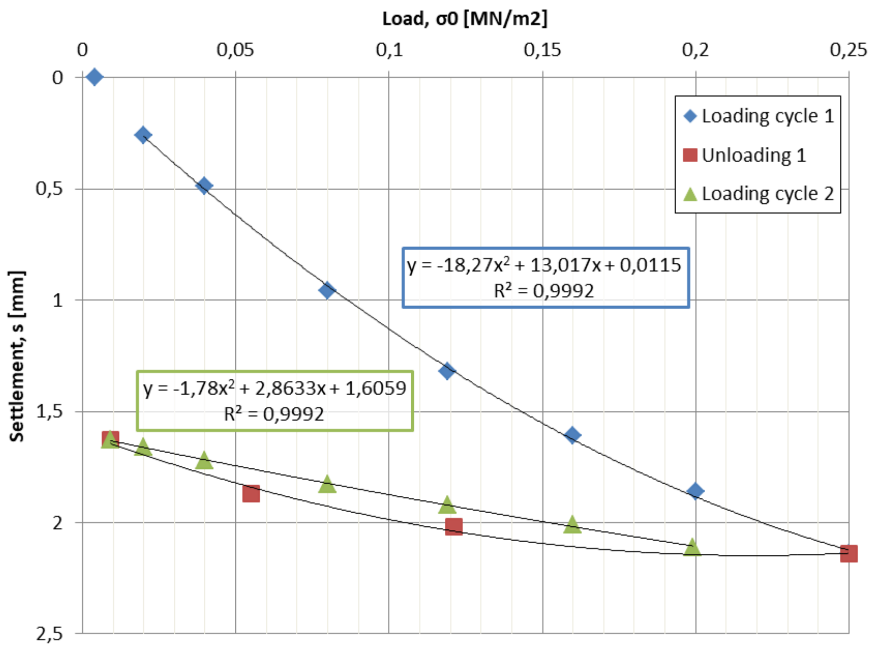


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,96	1,61	55
2	0,080	0,160	1,83	2,01	200

E_2/E_1 []
3,6

Plate load test results - Swedish method
P12-A



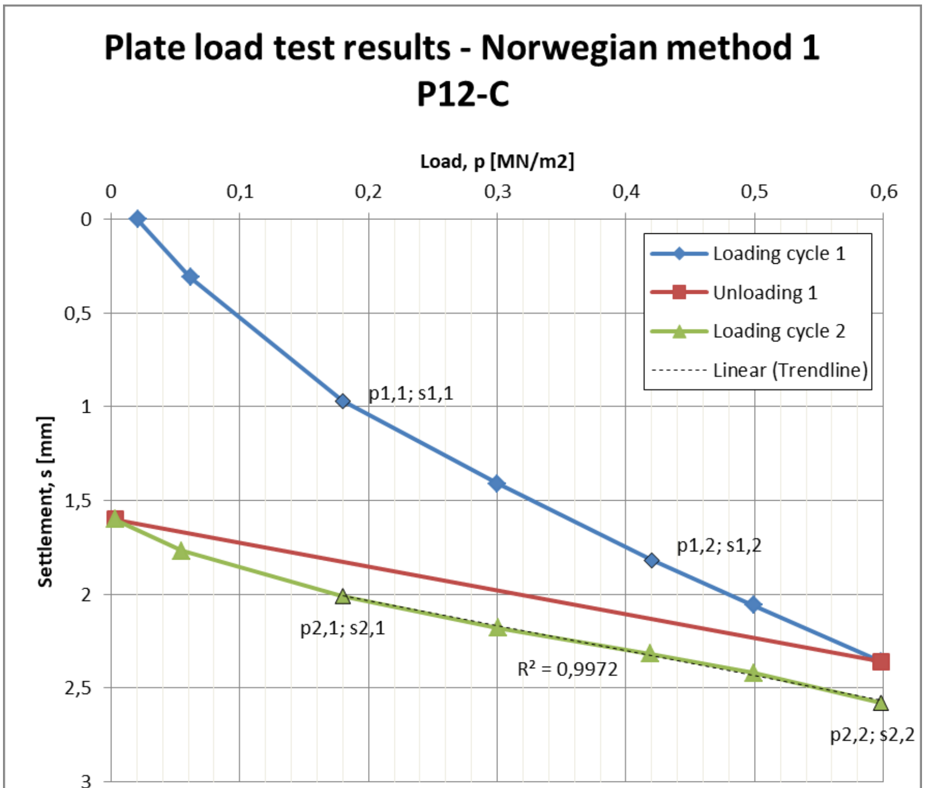
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0115	13,0170	-18,2700	53
2	1,6059	2,8633	-1,7800	186

E_2/E_1 []
3,5

P12-C

Load [MN/m²]	**Settlement [mm]**	**ds/dt [mm/min]**	**Time [hh:mm:ss]**
0,021	0,00	0,270	15:49:39
0,062	0,31	0,000	15:49:53
0,180	0,97	0,000	15:51:33
0,300	1,41	0,000	15:52:30
0,420	1,82	0,000	15:53:41
0,499	2,06	0,000	15:54:23
0,598	2,36	0,000	15:55:18
0,003	1,60	0,000	15:58:05
0,055	1,77	0,000	15:58:30
0,180	2,01	0,000	15:59:30
0,301	2,18	0,000	16:00:18
0,419	2,32	0,000	16:01:27
0,499	2,42	0,000	16:01:54
0,598	2,58	0,000	16:02:41

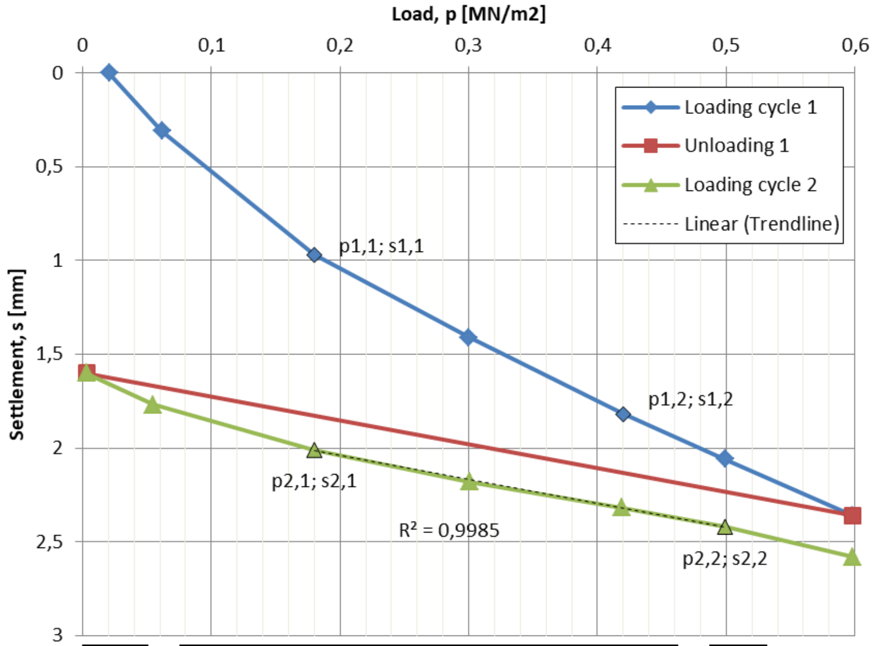


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,97	1,82	64
2	0,180	0,598	2,01	2,58	165

E_2/E_1 []
2,6

Plate load test results - Norwegian method 2
P12-C

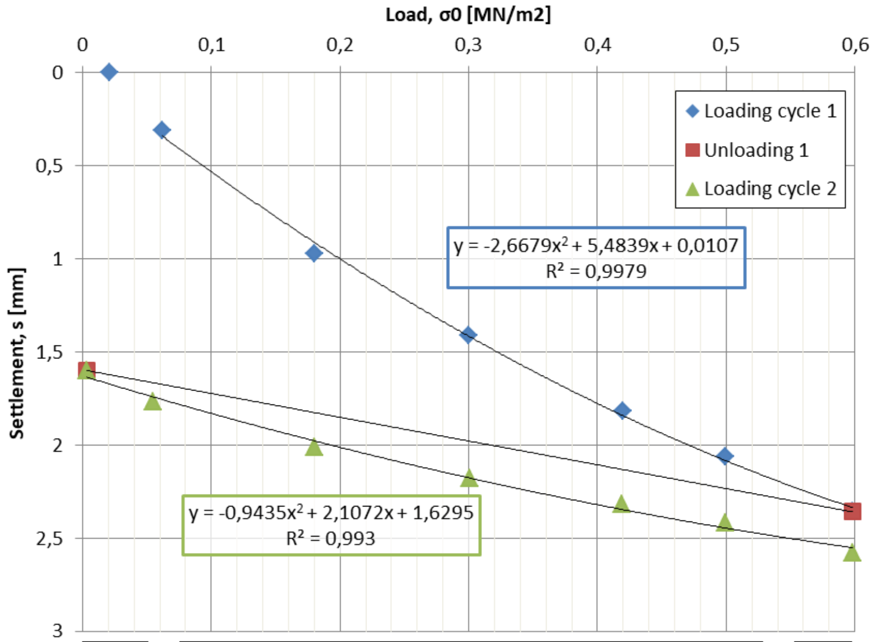


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,97	1,82	64
2	0,180	0,499	2,01	2,42	175

E_2/E_1 []
2,8

Plate load test results - Swedish method
P12-C



r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0107	5,4839	-2,6679	58
2	1,6295	2,1072	-0,9435	146

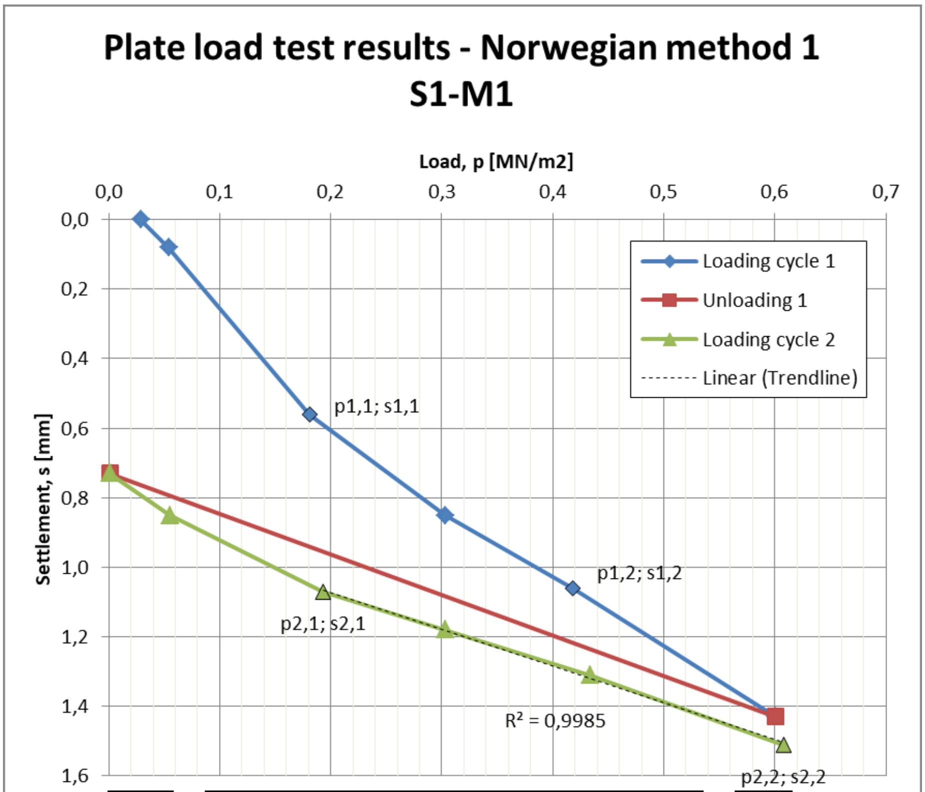
E_2/E_1 []
2,5

Appendix 6: Measured and calculated results of PLTs from the road construction sites in the case study

Site 1: the tunnel project

S1-M1

Load [MN/m^2]	Settlement [mm]
0,029	0,00
0,054	0,08
0,181	0,56
0,303	0,85
0,418	1,06
0,601	1,43
0,001	0,73
0,055	0,85
0,193	1,07
0,303	1,18
0,434	1,31
0,608	1,51

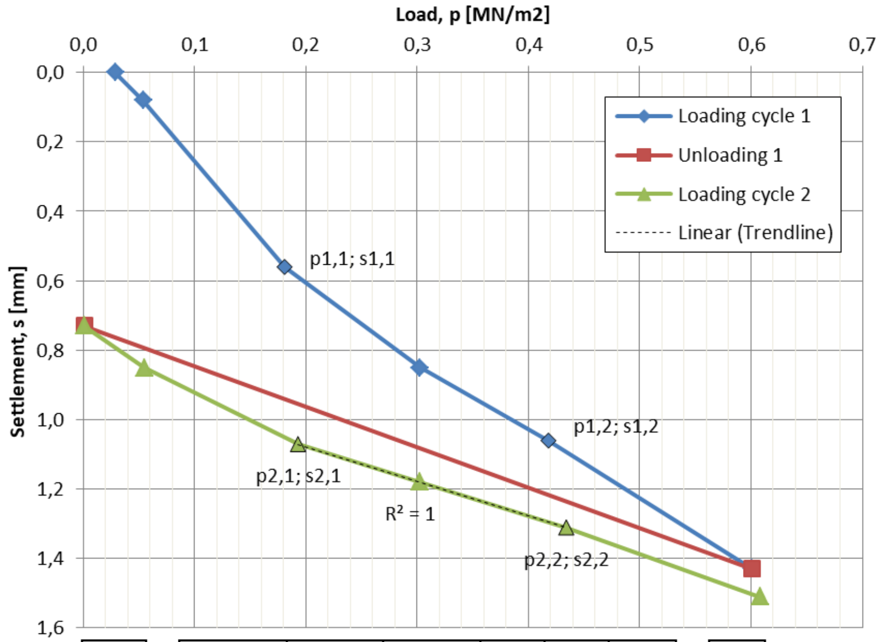


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,418	0,56	1,06	107
2	0,193	0,608	1,07	1,51	212

E_2/E_1 []
2,0

Plate load test results - Norwegian method 2
S1-M1

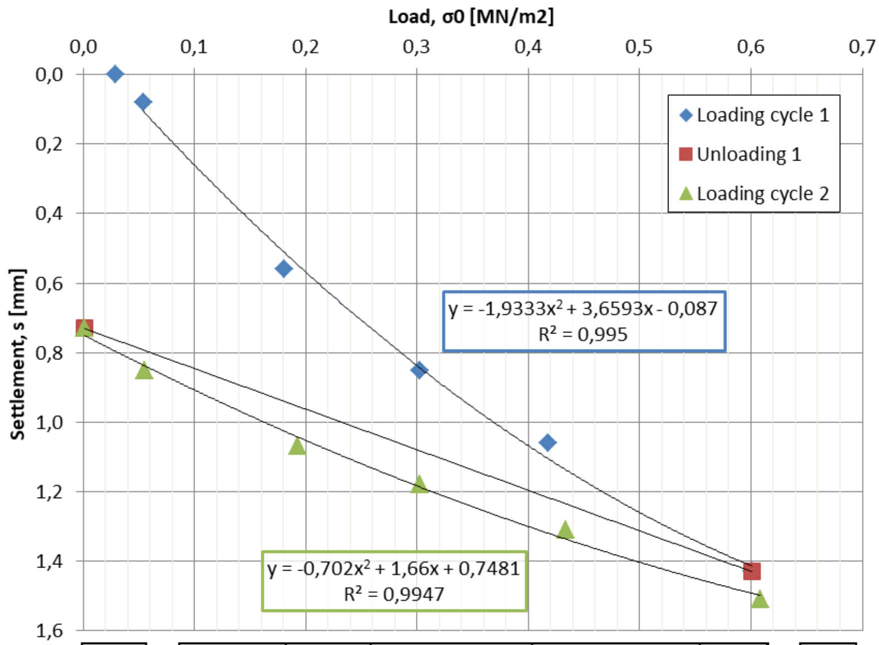


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,418	0,56	1,06	107
2	0,193	0,434	1,07	1,31	226

E_2/E_1 []
2,1

Plate load test results - Swedish method
S1-M1



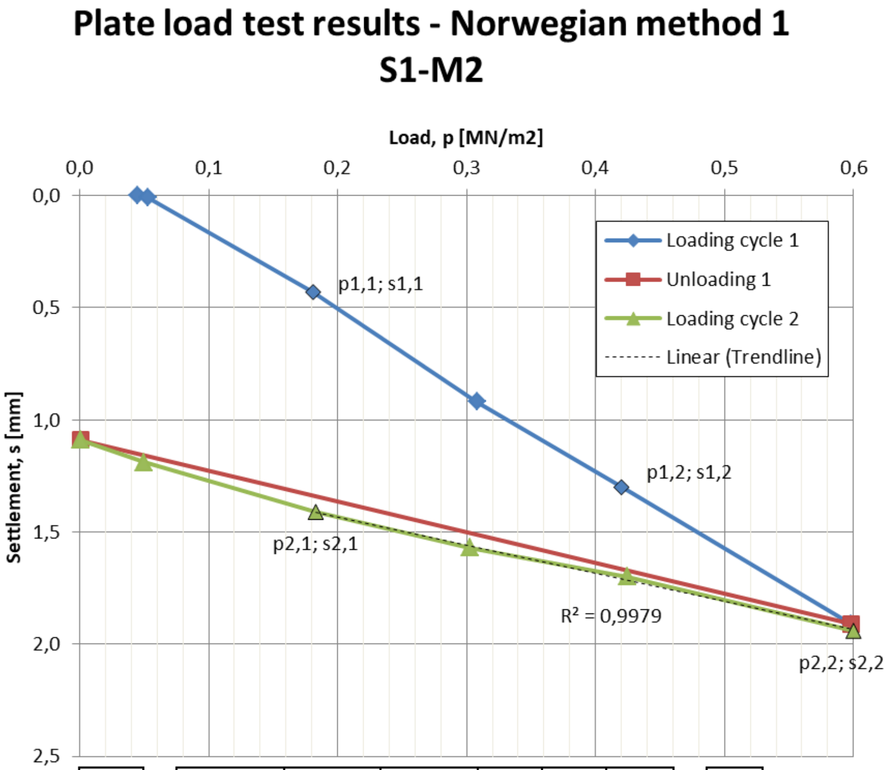
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0870	3,6593	-1,9333	90
2	0,7481	1,6600	-0,7020	182

E_2/E_1 []
2,0

S1-M2

Load [MN/m²]	**Settlement [mm]**
0,045	0,00
0,053	0,01
0,181	0,43
0,308	0,92
0,420	1,30
0,598	1,91
0,001	1,09
0,050	1,19
0,183	1,41
0,303	1,57
0,425	1,70
0,600	1,94

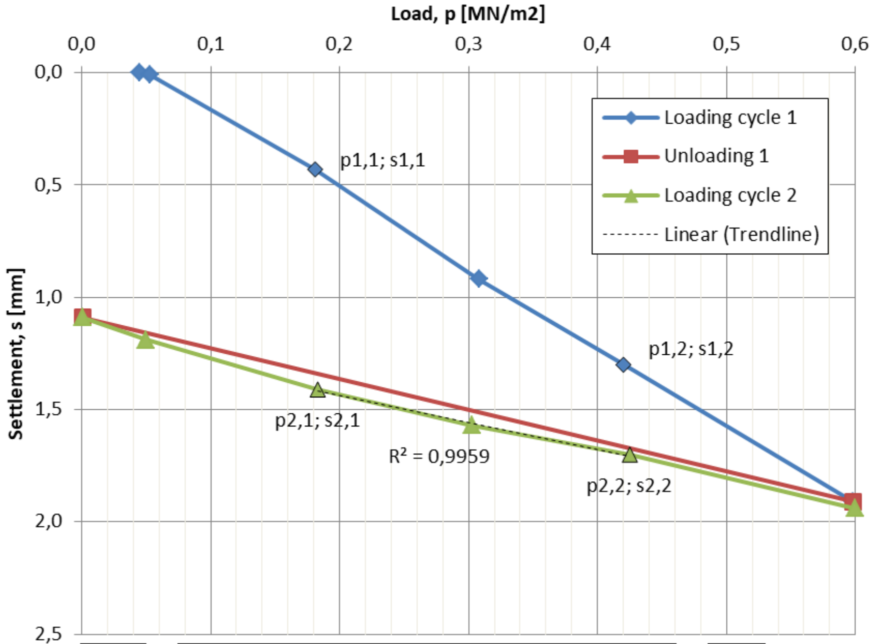


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,43	1,30	62
2	0,183	0,600	1,41	1,94	177

E_2/E_1 []
2,9

Plate load test results - Norwegian method 2
S1-M2

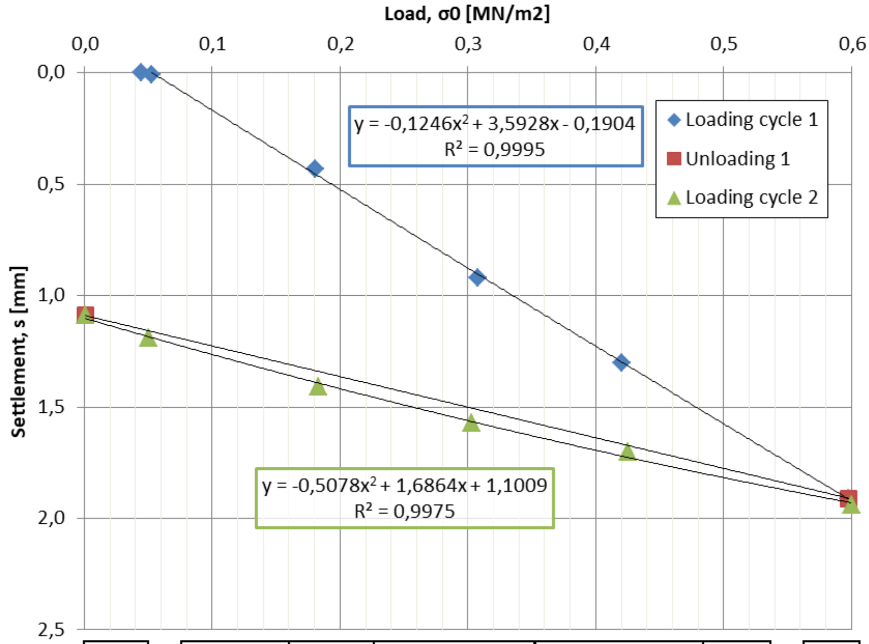


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,43	1,30	62
2	0,183	0,425	1,41	1,70	188

E_2/E_1 []
3,0

Plate load test results - Swedish method
S1-M2



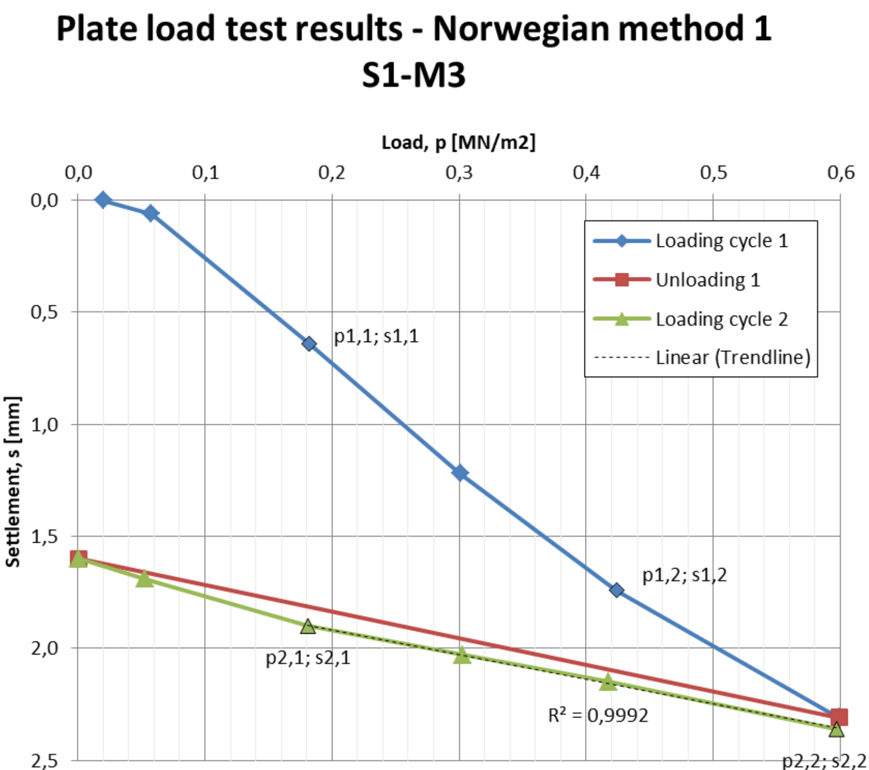
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1904	3,5928	-0,1246	64
2	1,1009	1,6864	-0,5078	163

E_2/E_1 []
2,5

S1-M3

Load [MN/m²]	**Settlement [mm]**
0,020	0,00
0,058	0,06
0,182	0,64
0,301	1,22
0,424	1,74
0,599	2,31
0,001	1,60
0,053	1,69
0,181	1,90
0,303	2,03
0,418	2,15
0,597	2,36

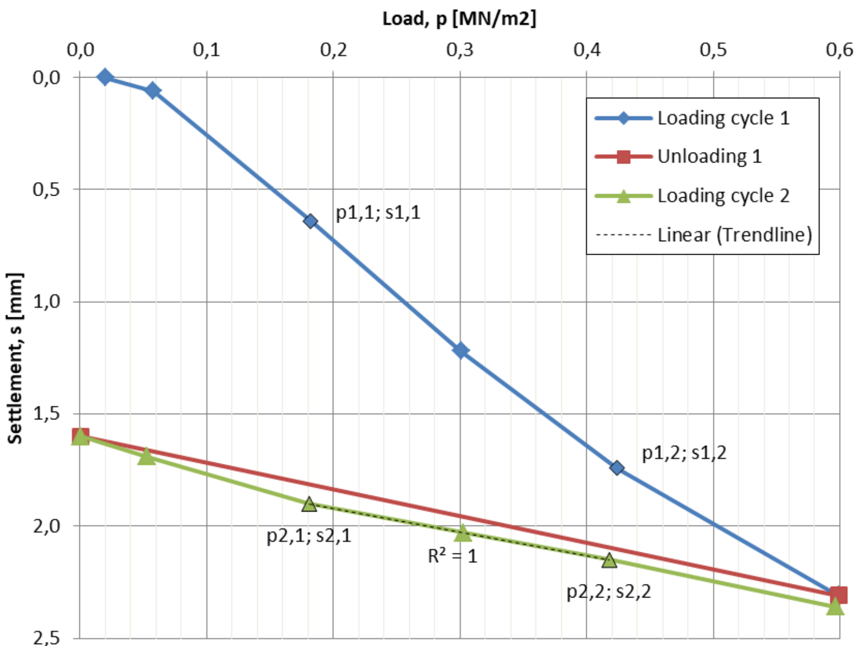


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,424	0,64	1,74	50
2	0,181	0,597	1,90	2,36	203

E_2/E_1 []
4,1

Plate load test results - Norwegian method 2
S1-M3

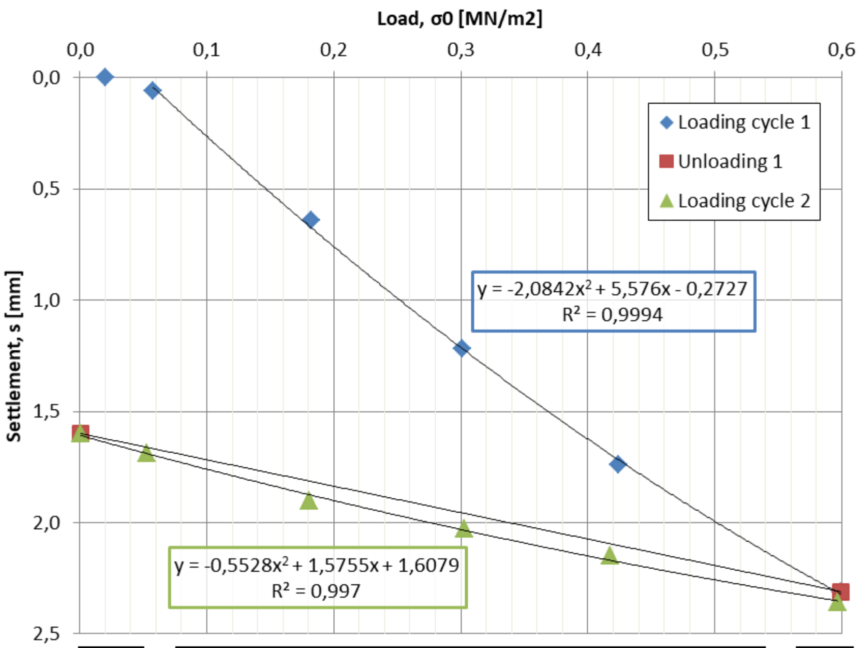


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,424	0,64	1,74	50
2	0,181	0,418	1,90	2,15	213

E_2/E_1 []
4,3

Plate load test results - Swedish method
S1-M3



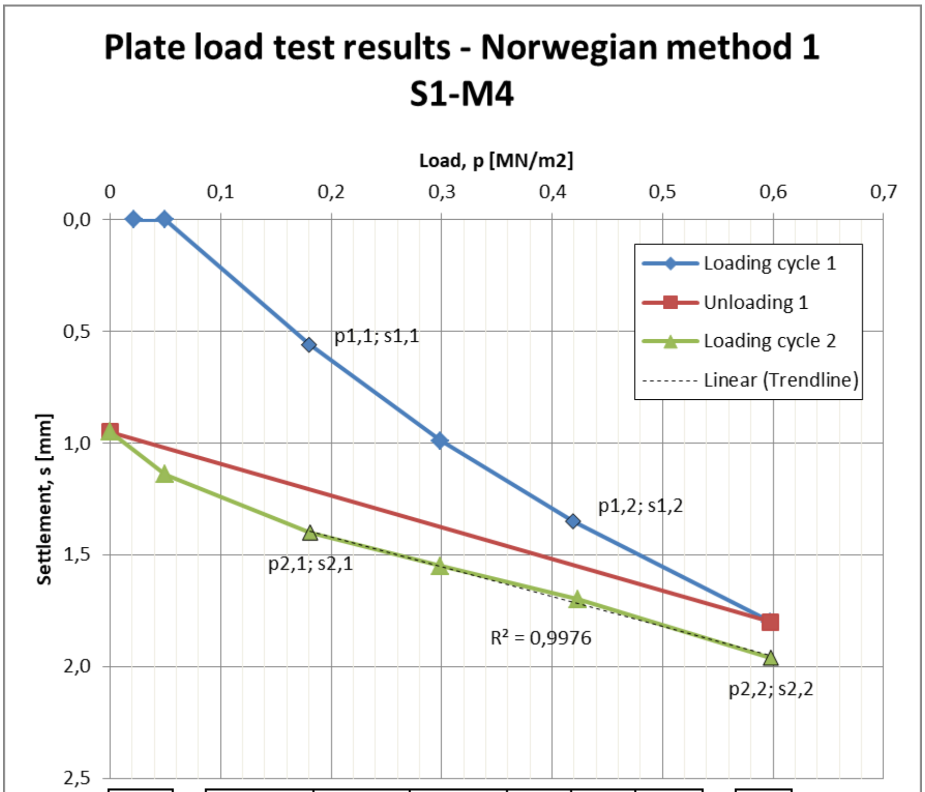
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,2727	5,5760	-2,0842	52
2	1,6079	1,5755	-0,5528	181

E_2/E_1 []
3,5

S1-M4

Load [MN/m²]	Settlement [mm]
0,022	0,00
0,050	0,00
0,180	0,56
0,299	0,99
0,419	1,35
0,598	1,80
0,000	0,95
0,050	1,14
0,181	1,40
0,299	1,55
0,423	1,70
0,598	1,96

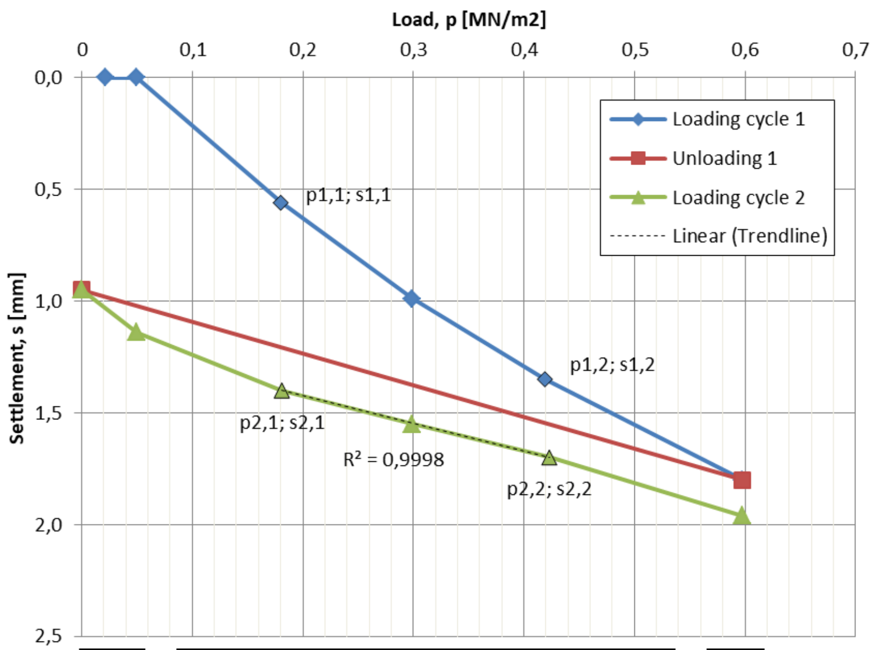


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	0,56	1,35	68
2	0,181	0,598	1,40	1,96	168

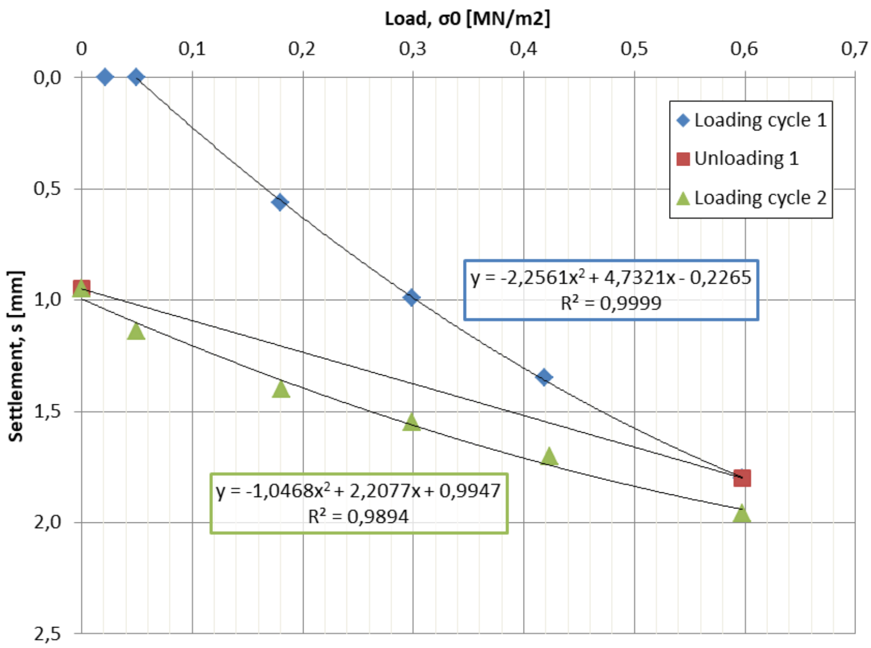
E_2/E_1 []
2,5

Plate load test results - Norwegian method 2
S1-M4



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,180	0,419	0,56	1,35	68	2,7
	2	0,181	0,423	1,40	1,70	182	

Plate load test results - Swedish method
S1-M4

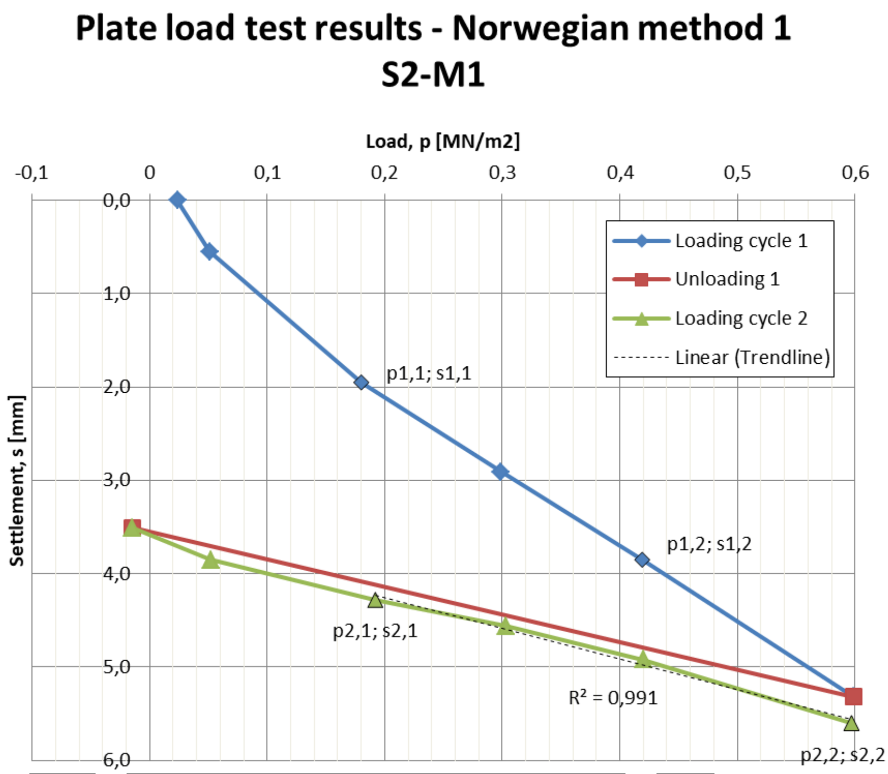


r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,2265	4,7321	-2,2561	67	2,1
	2	0,9947	2,2077	-1,0468	142	

Site 2: The urban area project

S2-M1

Load [MN/m²]	Settlement [mm]
0,024	0,00
0,051	0,55
0,180	1,95
0,299	2,91
0,419	3,85
0,599	5,32
-0,015	3,51
0,052	3,85
0,192	4,28
0,303	4,56
0,420	4,92
0,597	5,60

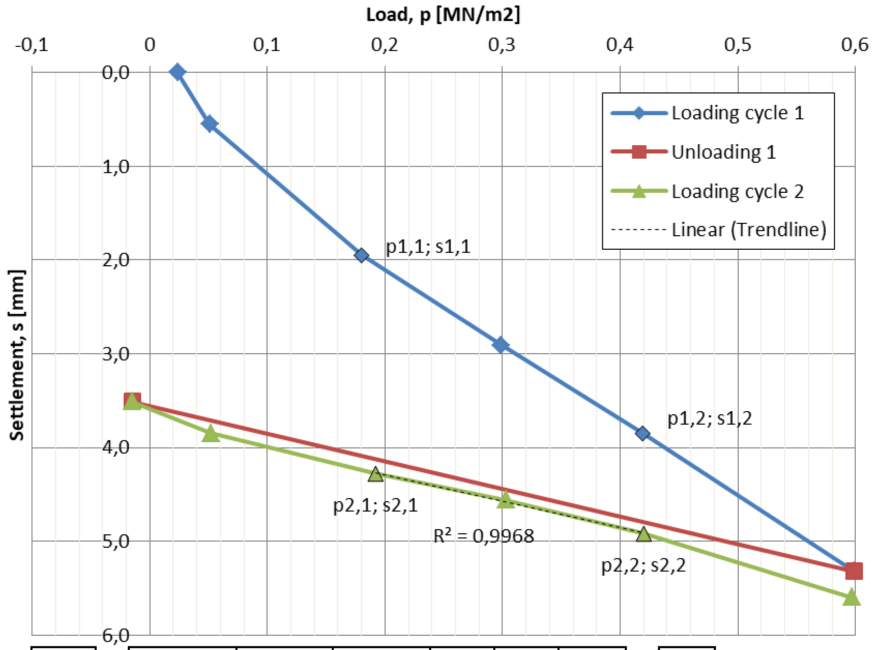


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,95	3,85	28
2	0,192	0,597	4,28	5,60	69

E_2/E_1 []
2,4

Plate load test results - Norwegian method 2
S2-M1

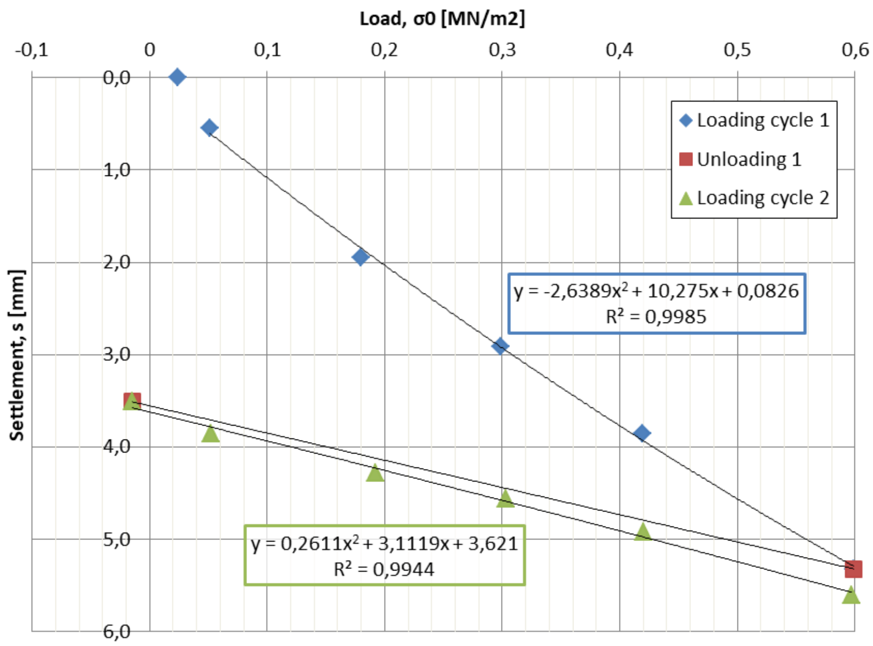


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,419	1,95	3,85	28
2	0,192	0,420	4,28	4,92	80

E_2/E_1 []
2,8

Plate load test results - Swedish method
S2-M1



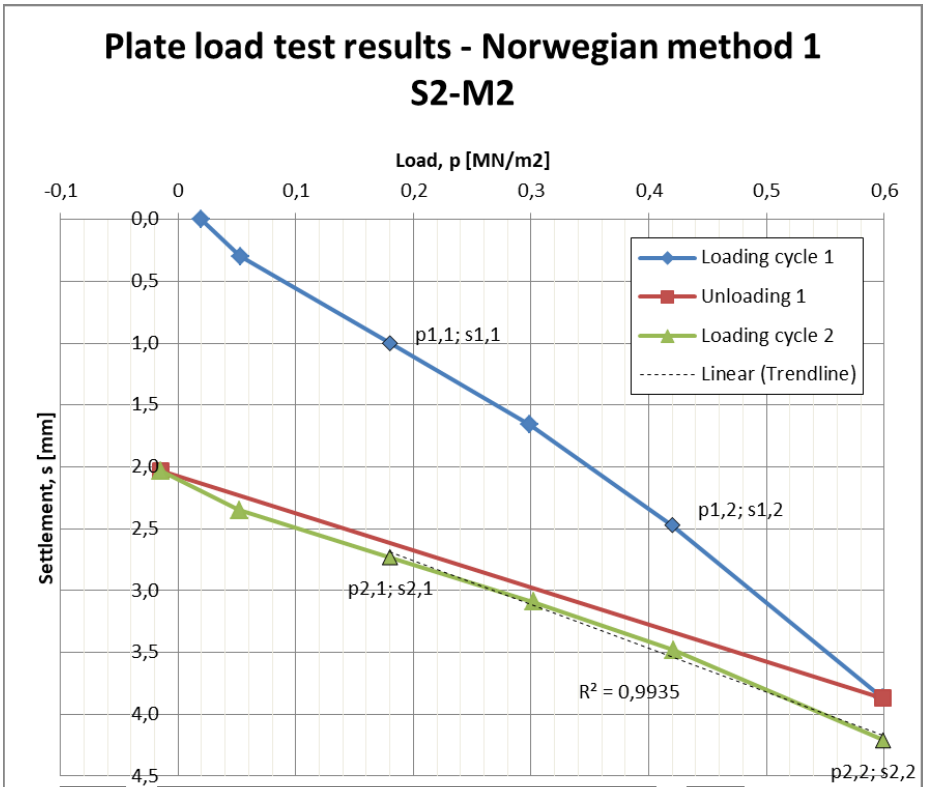
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0826	10,2750	-2,6389	26
2	3,6210	3,1119	0,2611	69

E_2/E_1 []
2,7

S2-M2

Load [MN/m²]	**Settlement [mm]**
0,020	0,00
0,053	0,30
0,180	1,00
0,299	1,66
0,420	2,47
0,599	3,87
-0,015	2,03
0,052	2,35
0,180	2,73
0,302	3,09
0,421	3,48
0,599	4,21

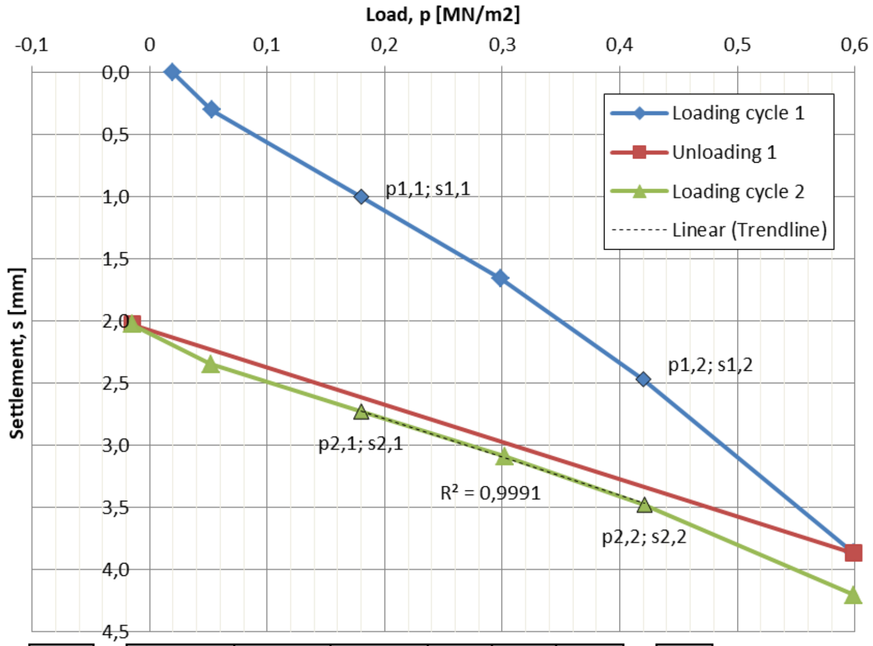


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	1,00	2,47	37
2	0,180	0,599	2,73	4,21	64

E_2/E_1 []
1,7

Plate load test results - Norwegian method 2
S2-M2

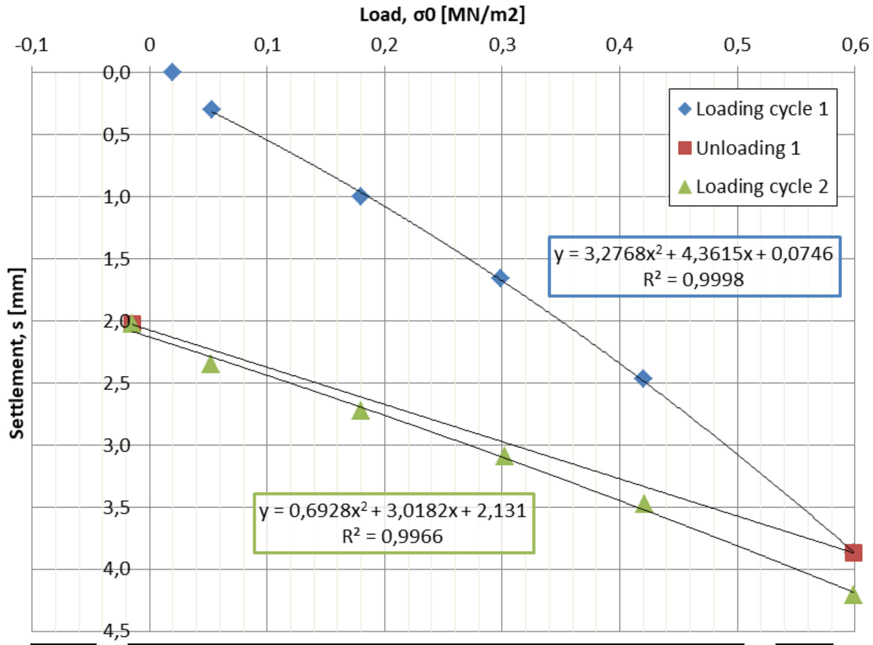


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	1,00	2,47	37
2	0,180	0,421	2,73	3,48	72

E_2/E_1 []
2,0

Plate load test results - Swedish method
S2-M2



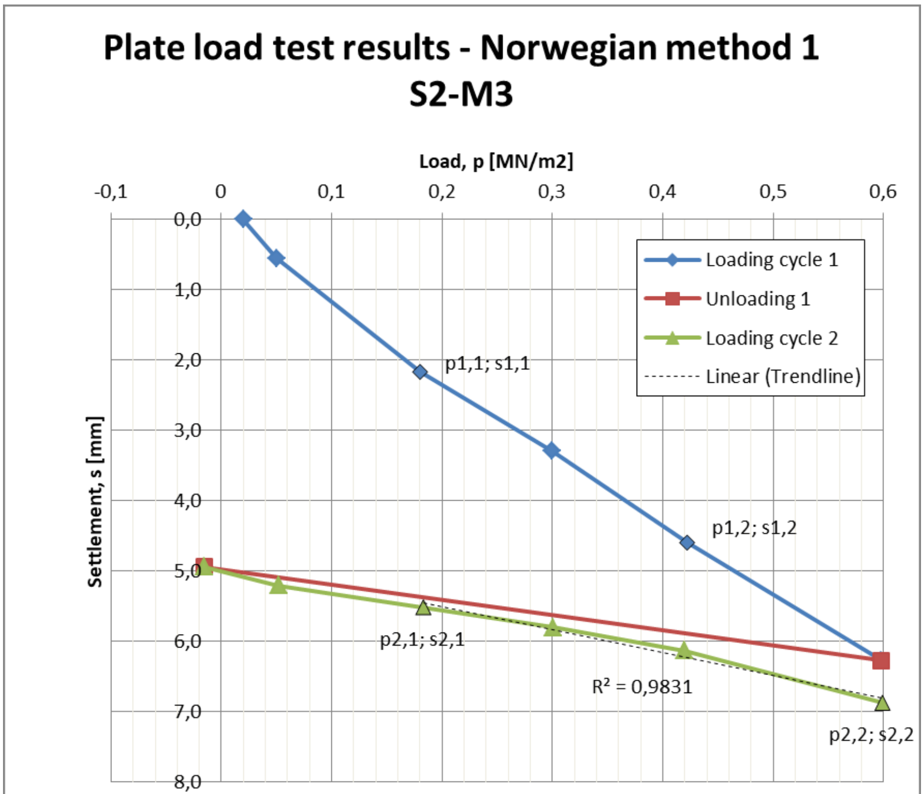
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0746	4,3615	3,2768	36
2	2,1310	3,0182	0,6928	66

E_2/E_1 []
1,8

S2-M3

Load [MN/m²]	Settlement [mm]
0,020	0,00
0,050	0,55
0,180	2,17
0,300	3,30
0,422	4,60
0,598	6,28
-0,015	4,95
0,052	5,21
0,183	5,52
0,301	5,81
0,420	6,14
0,599	6,88

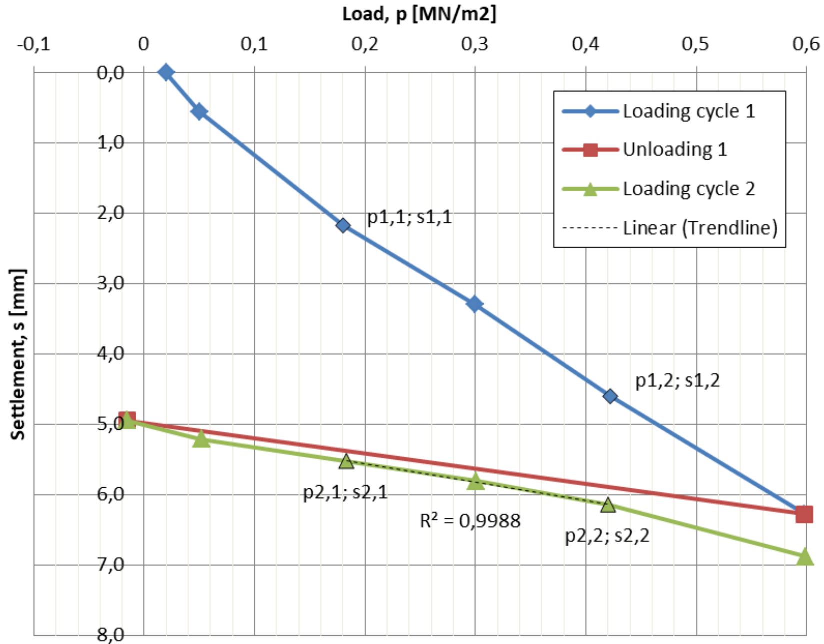


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,422	2,17	4,60	22
2	0,183	0,599	5,52	6,88	69

E_2/E_1 []
3,1

Plate load test results - Norwegian method 2
S2-M3

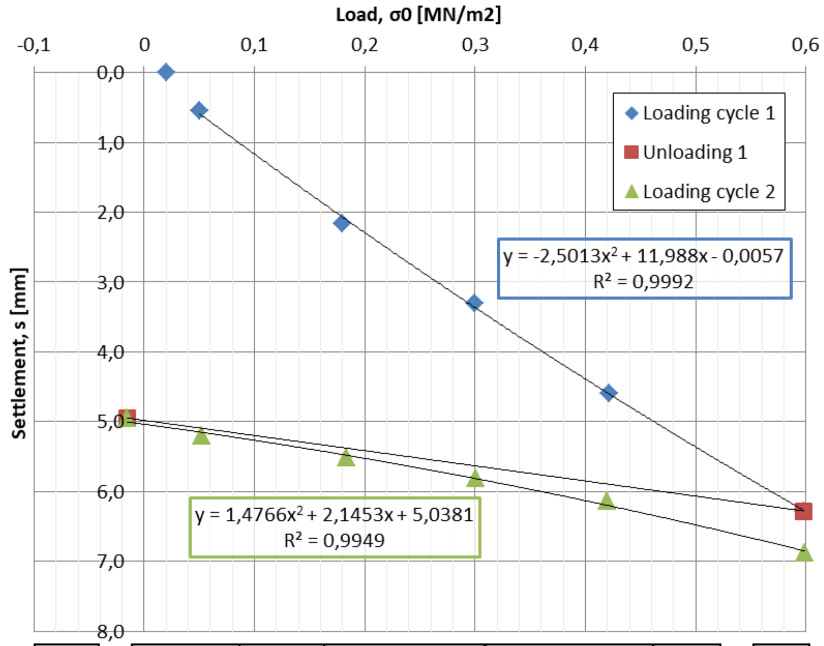


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,422	2,17	4,60	22
2	0,183	0,420	5,52	6,14	86

E_2/E_1 []
3,8

Plate load test results - Swedish method
S2-M3



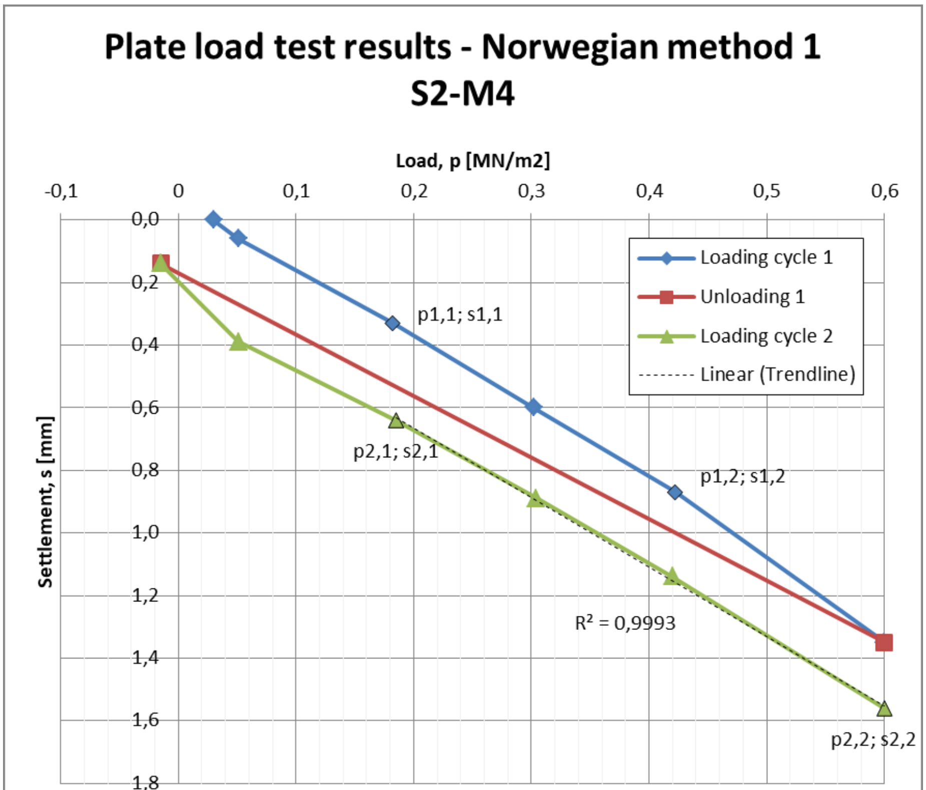
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0057	11,9880	-2,5013	21
2	5,0381	2,1453	1,4766	74

E_2/E_1 []
3,5

S2-M4

Load [MN/m²]	**Settlement [mm]**
0,030	0,00
0,051	0,06
0,182	0,33
0,302	0,60
0,422	0,87
0,600	1,35
-0,015	0,14
0,051	0,39
0,185	0,64
0,304	0,89
0,420	1,14
0,600	1,56

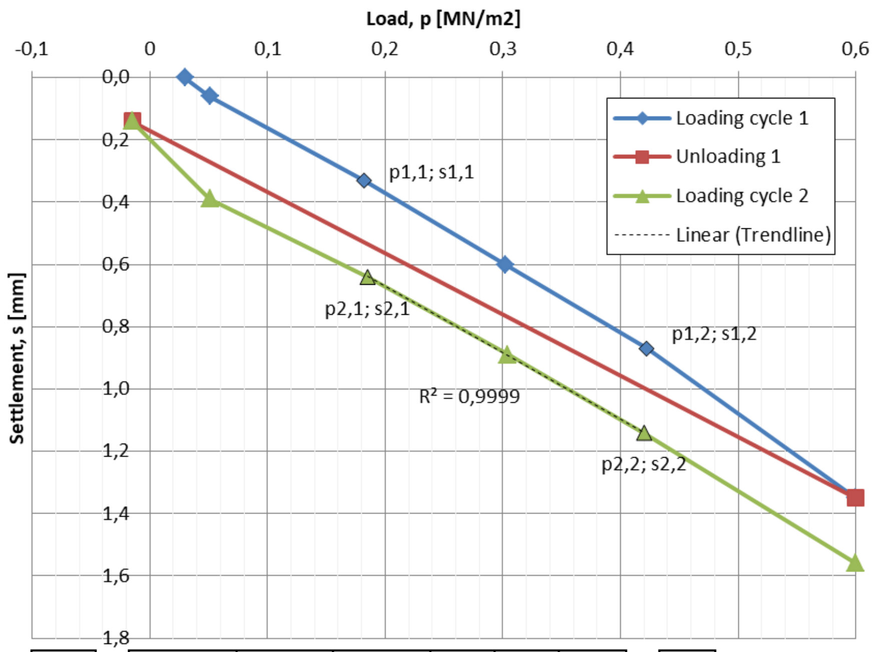


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,422	0,33	0,87	100
2	0,185	0,600	0,64	1,56	101

E_2/E_1 []
1,0

Plate load test results - Norwegian method 2
S2-M4

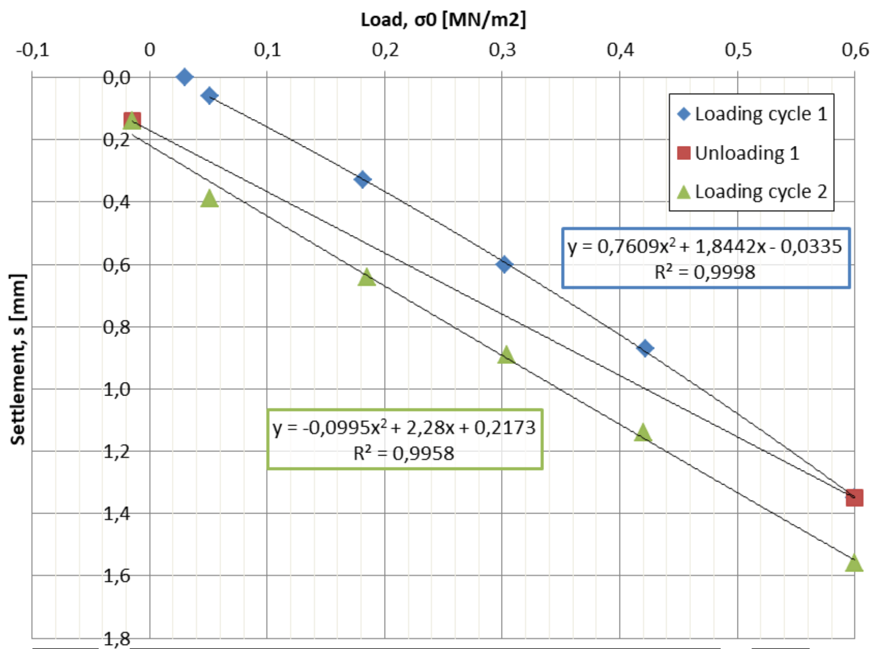


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,422	0,33	0,87	100
2	0,185	0,420	0,64	1,14	106

E_2/E_1 []
1,1

Plate load test results - Swedish method
S2-M4



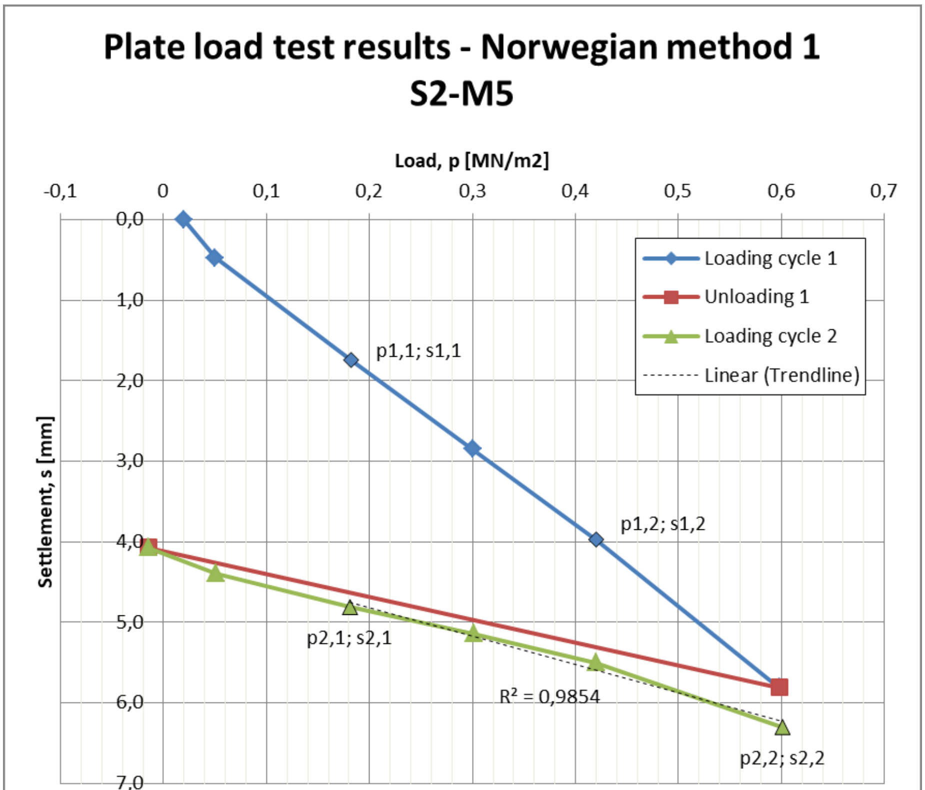
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0335	1,8442	0,7609	98
2	0,2173	2,2800	-0,0995	101

E_2/E_1 []
1,0

S2-M5

Load [MN/m^2]	Settlement [mm]
0,020	0,00
0,050	0,47
0,182	1,74
0,300	2,85
0,420	3,97
0,598	5,81
-0,015	4,07
0,051	4,39
0,181	4,81
0,301	5,14
0,420	5,50
0,601	6,30

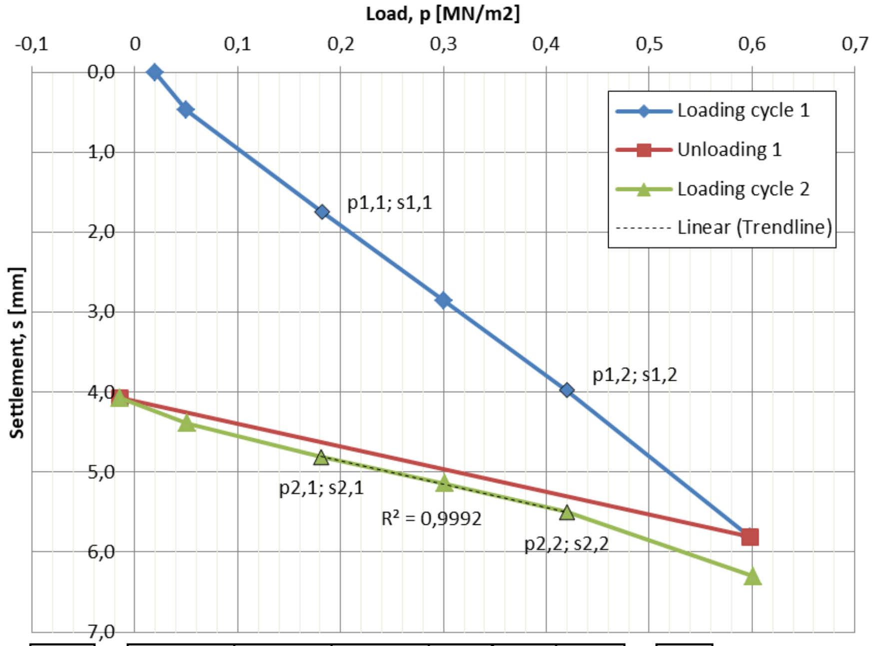


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,420	1,74	3,97	24
2	0,181	0,601	4,81	6,30	63

E_2/E_1 []
2,6

Plate load test results - Norwegian method 2
S2-M5

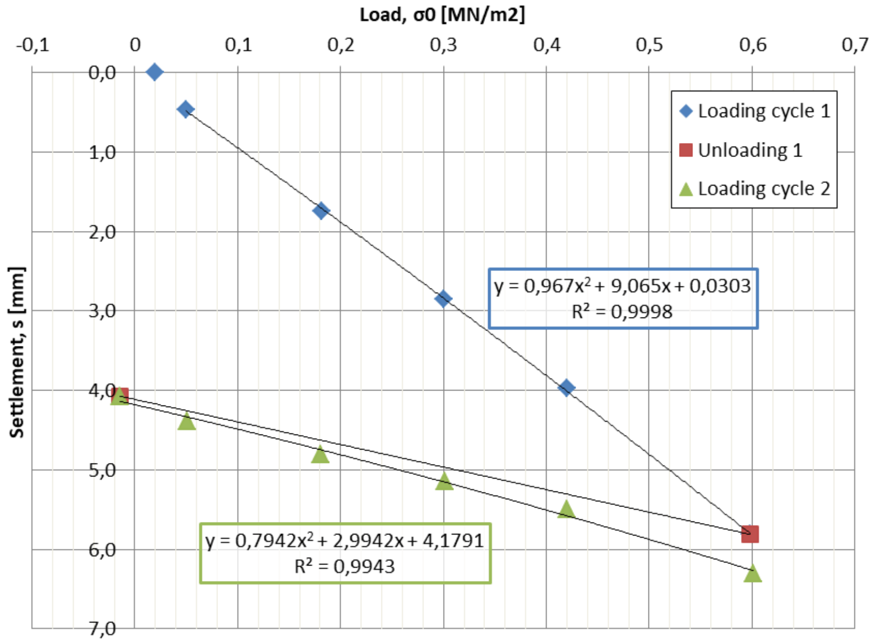


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,420	1,74	3,97	24
2	0,181	0,420	4,81	5,50	78

E_2/E_1 []
3,2

Plate load test results - Swedish method
S2-M5



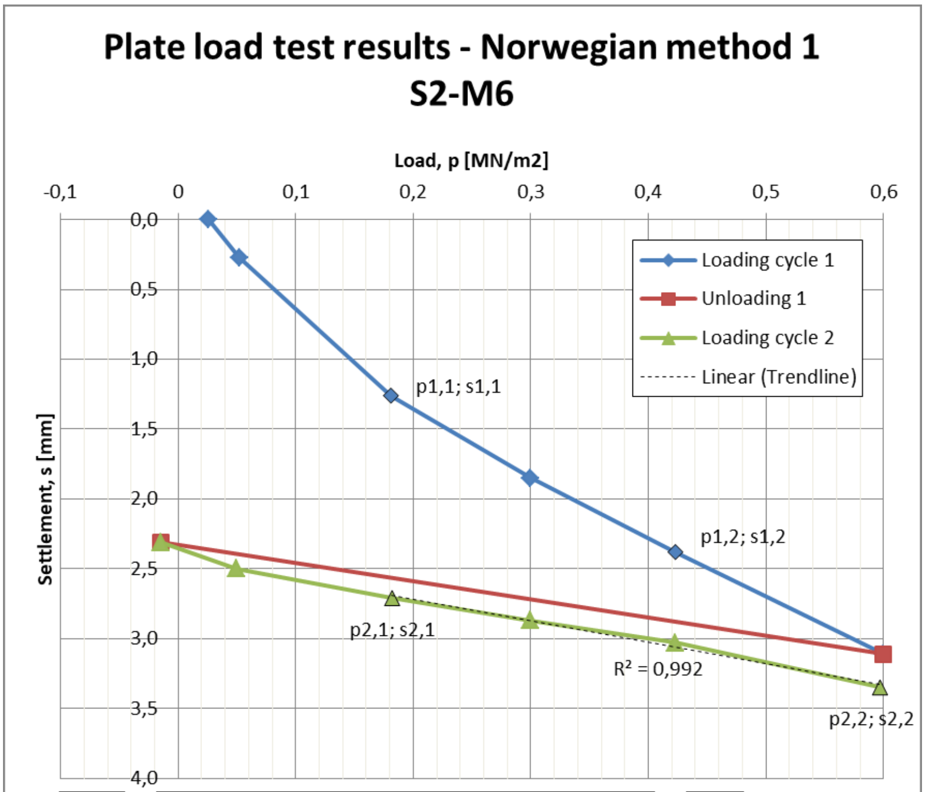
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0303	9,0650	0,9670	23
2	4,1791	2,9942	0,7942	65

E_2/E_1 []
2,8

S2-M6

Load [MN/m²]	**Settlement [mm]**
0,026	0,00
0,052	0,27
0,181	1,26
0,300	1,85
0,423	2,38
0,600	3,11
-0,015	2,31
0,050	2,50
0,182	2,71
0,300	2,87
0,423	3,03
0,597	3,35

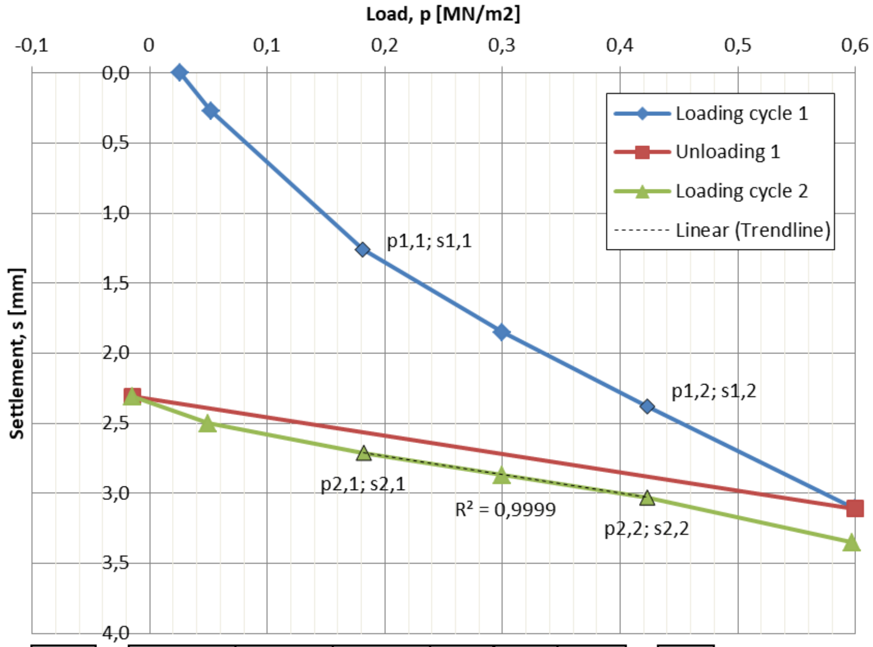


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,423	1,26	2,38	49
2	0,182	0,597	2,71	3,35	146

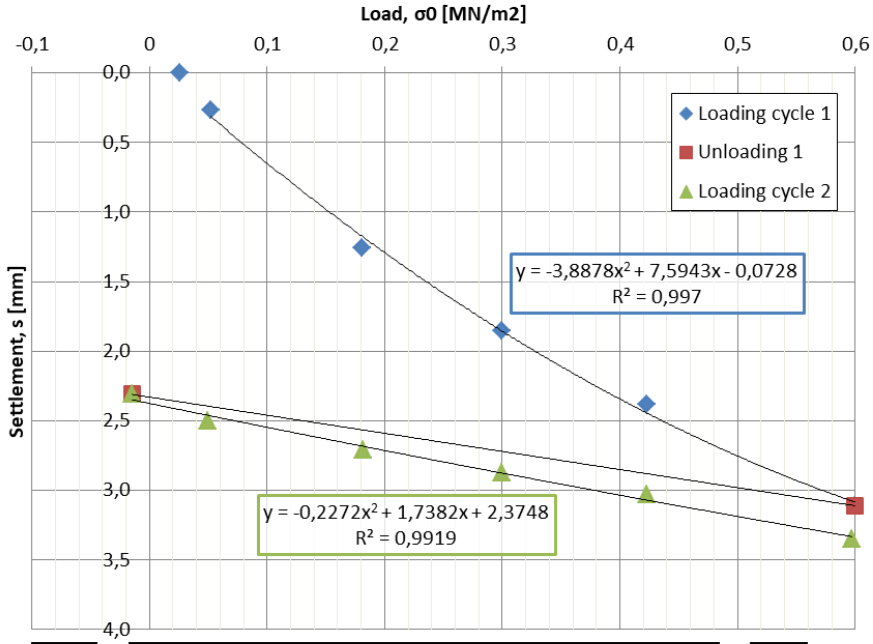
E_2/E_1 []
3,0

Plate load test results - Norwegian method 2
S2-M6



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,181	0,423	1,26	2,38	49	3,5
	2	0,182	0,423	2,71	3,03	169	

Plate load test results - Swedish method
S2-M6

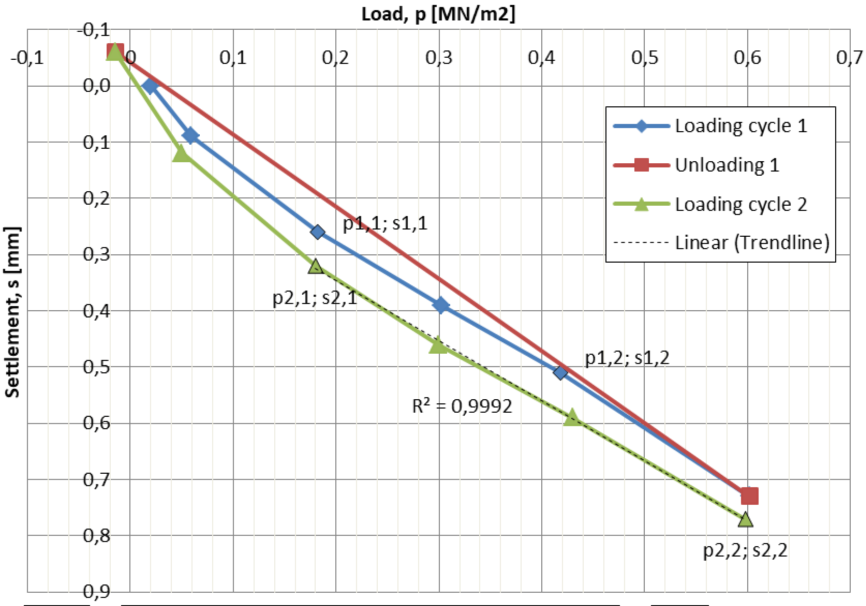


r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,0728	7,5943	-3,8878	43	3,3
	2	2,3748	1,7382	-0,2272	140	

S2-M7

Load [MN/m^2]	Settlement [mm]
0,020	0,00
0,059	0,09
0,182	0,26
0,302	0,39
0,418	0,51
0,602	0,73
-0,015	-0,06
0,050	0,12
0,180	0,32
0,299	0,46
0,430	0,59
0,598	0,77

Plate load test results - Norwegian method 1
S2-M7

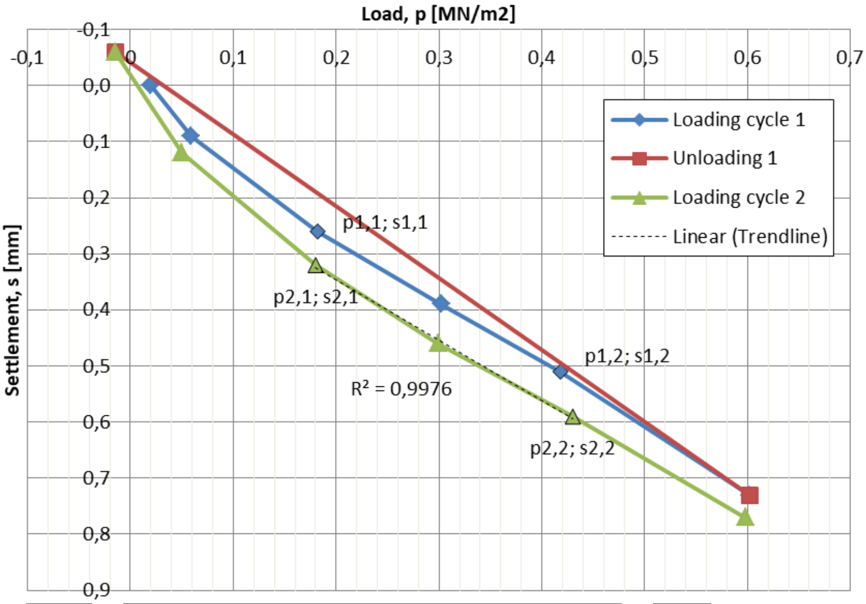


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,418	0,26	0,51	212
2	0,180	0,598	0,32	0,77	209

E_2/E_1 []
1,0

Plate load test results - Norwegian method 2
S2-M7

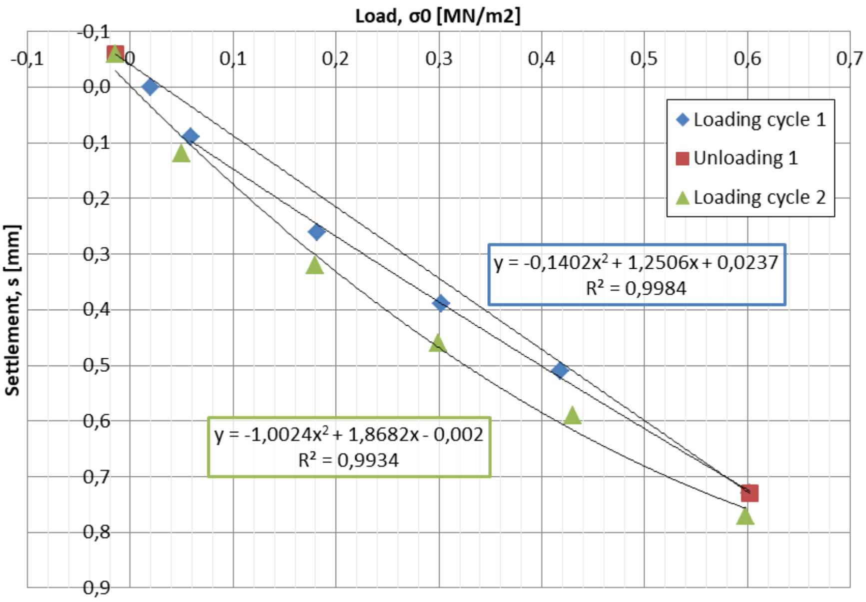


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,418	0,26	0,51	212
2	0,180	0,430	0,32	0,59	208

E_2/E_1 []
1,0

Plate load test results - Swedish method
S2-M7



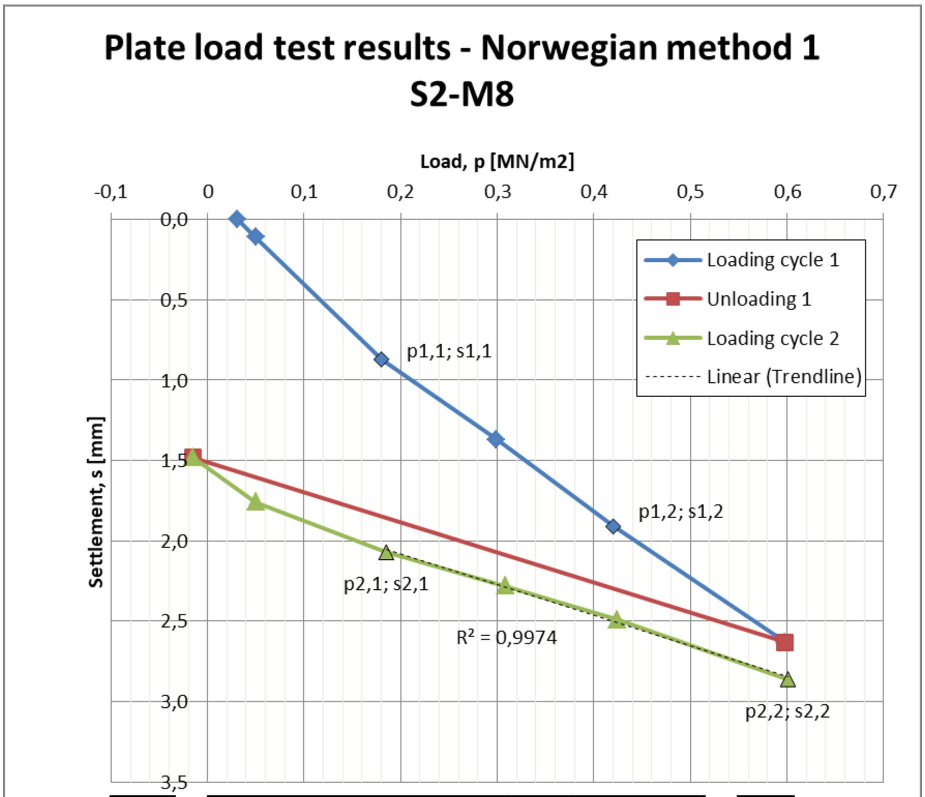
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0237	1,2506	-0,1402	193
2	-0,0020	1,8682	-1,0024	178

E_2/E_1 []
0,9

S2-M8

Load [MN/m²]	Settlement [mm]
0,031	0,00
0,050	0,11
0,180	0,87
0,299	1,37
0,420	1,91
0,598	2,63
-0,015	1,48
0,050	1,76
0,185	2,07
0,308	2,28
0,424	2,49
0,601	2,86

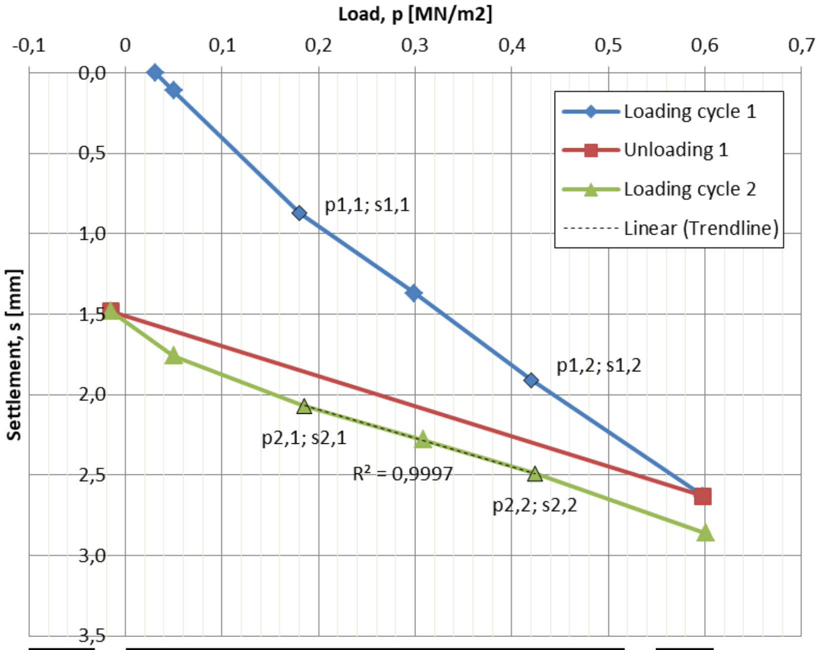


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,87	1,91	52
2	0,185	0,601	2,07	2,86	118

E_2/E_1 []
2,3

Plate load test results - Norwegian method 2
S2-M8

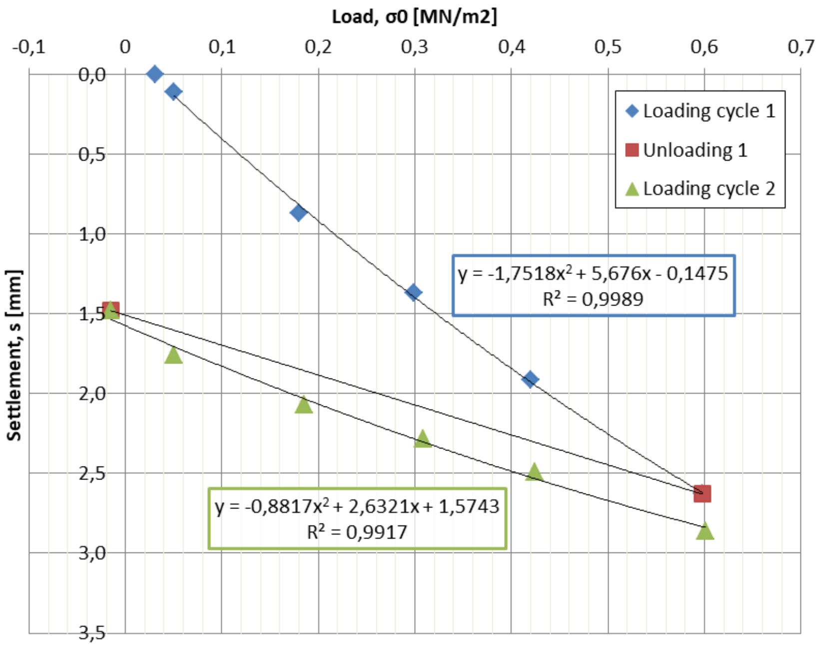


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,87	1,91	52
2	0,185	0,424	2,07	2,49	128

E_2/E_1 []
2,5

Plate load test results - Swedish method
S2-M8



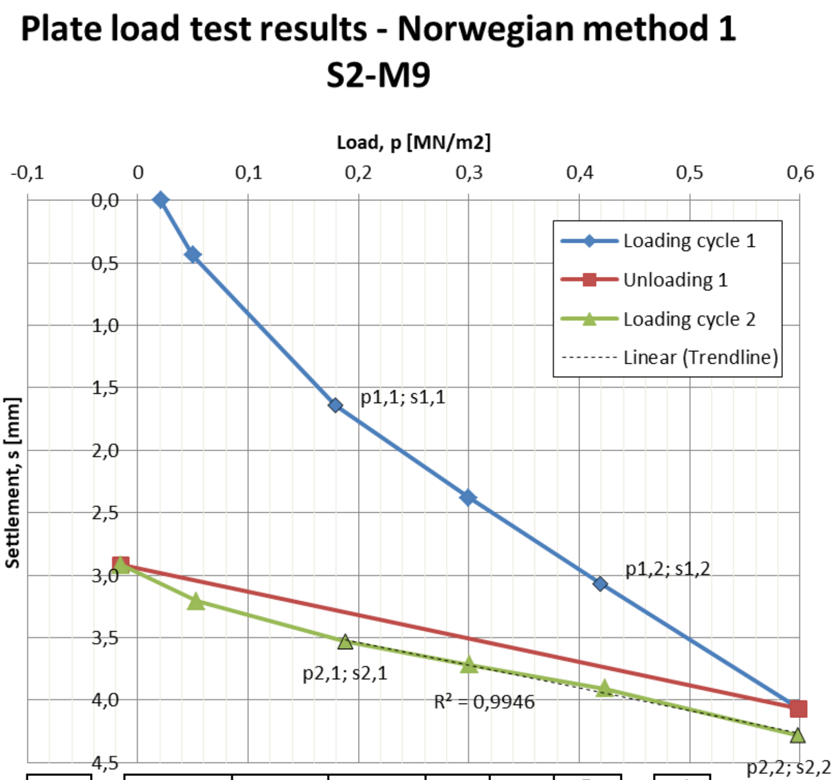
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1475	5,6760	-1,7518	49
2	1,5743	2,6321	-0,8817	107

E_2/E_1 []
2,2

S2-M9

Load [MN/m²]	**Settlement [mm]**
0,021	0,00
0,050	0,44
0,179	1,64
0,300	2,38
0,419	3,07
0,599	4,07
-0,015	2,92
0,053	3,21
0,188	3,53
0,301	3,72
0,423	3,91
0,598	4,28

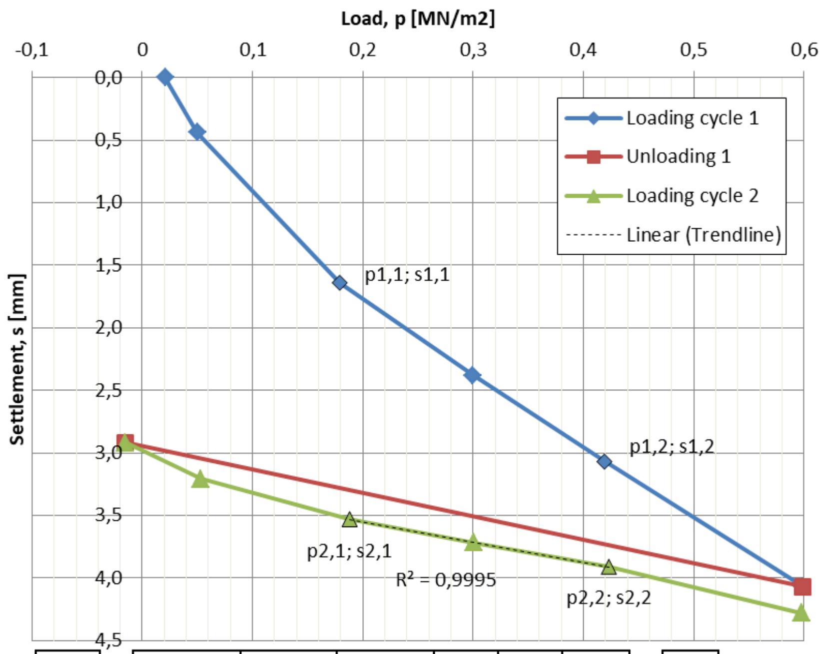


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,179	0,419	1,64	3,07	38
2	0,188	0,598	3,53	4,28	123

E_2/E_1 []
3,3

Plate load test results - Norwegian method 2
S2-M9

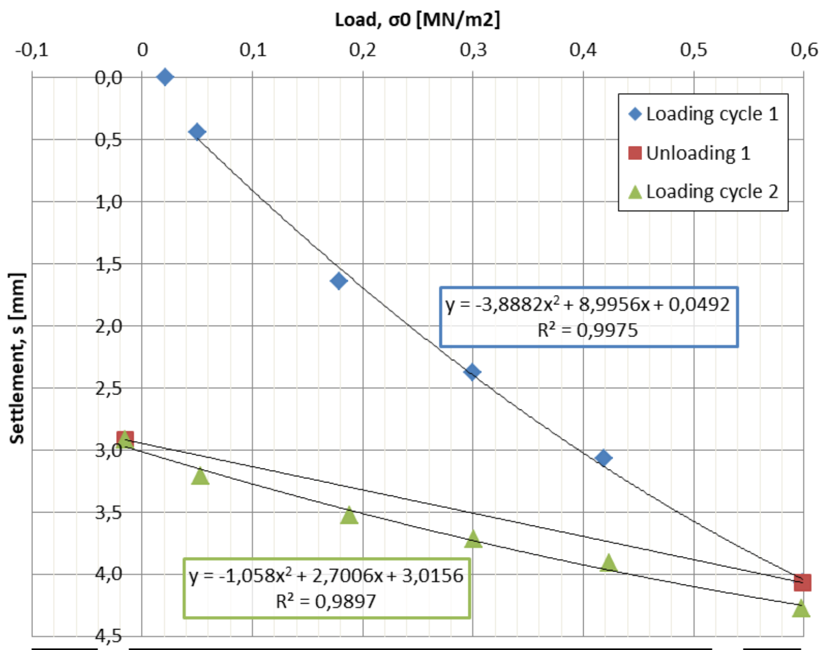


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,179	0,419	1,64	3,07	38
2	0,188	0,423	3,53	3,91	139

E_2/E_1 []
3,7

Plate load test results - Swedish method
S2-M9



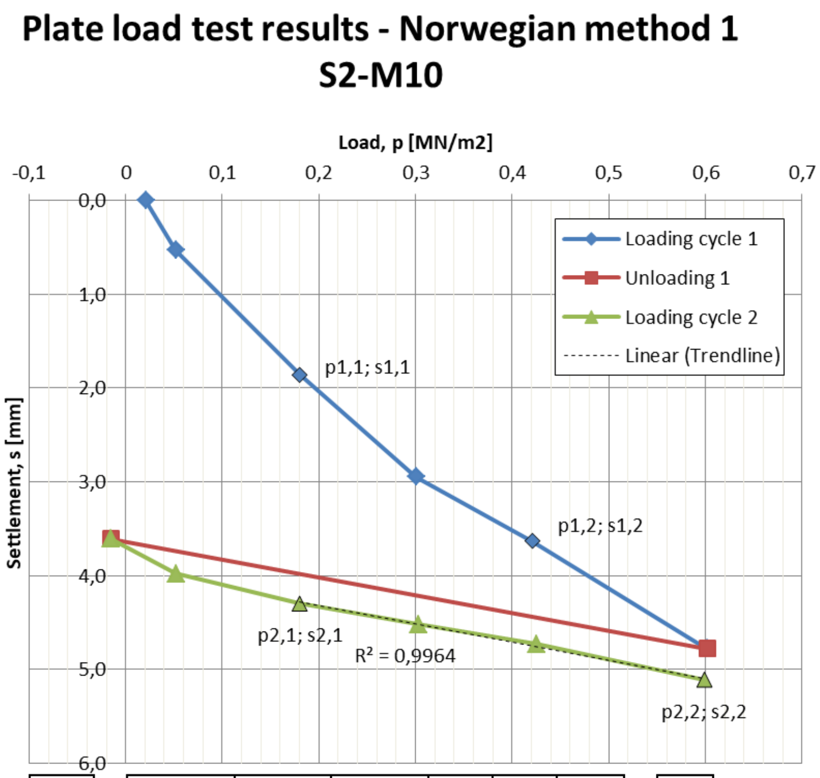
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0492	8,9956	-3,8882	34
2	3,0156	2,7006	-1,0580	109

E_2/E_1 []
3,2

S2-M10

Load [MN/m²]	**Settlement [mm]**
0,021	0,00
0,052	0,53
0,180	1,86
0,301	2,95
0,421	3,63
0,602	4,78
-0,015	3,61
0,052	3,98
0,180	4,30
0,303	4,52
0,425	4,73
0,599	5,11

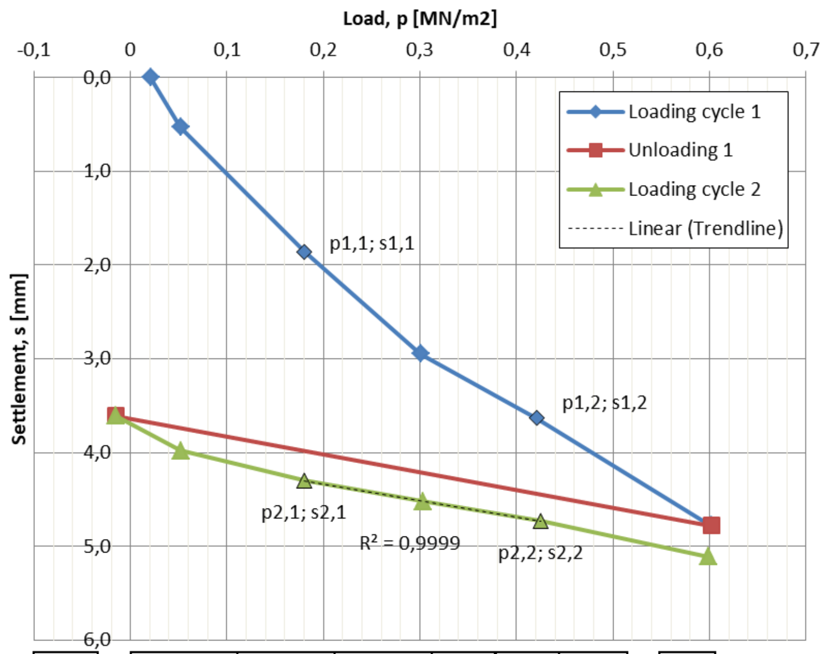


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	1,86	3,63	31
2	0,180	0,599	4,30	5,11	116

E_2/E_1 []
3,8

Plate load test results - Norwegian method 2
S2-M10

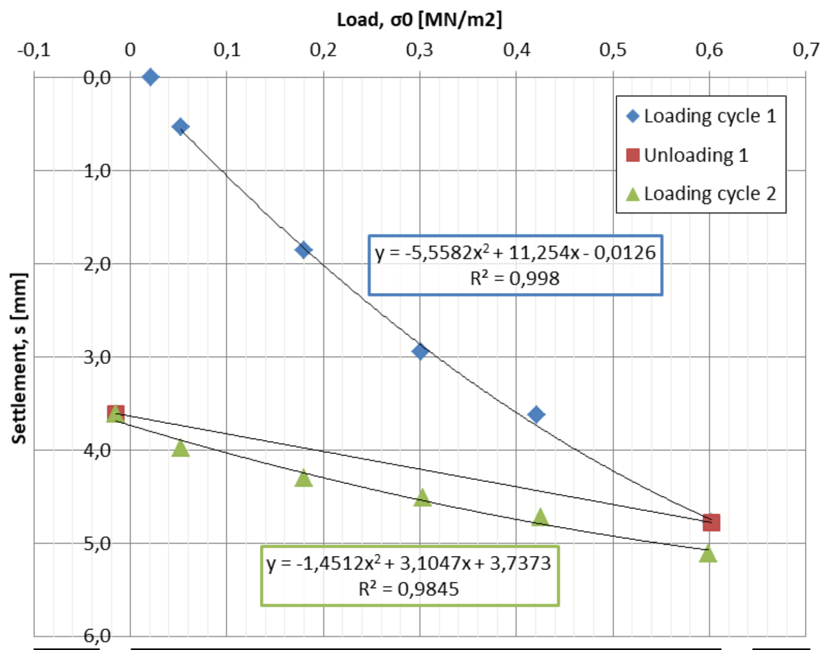


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	1,86	3,63	31
2	0,180	0,425	4,30	4,73	128

E_2/E_1 []
4,2

Plate load test results - Swedish method
S2-M10



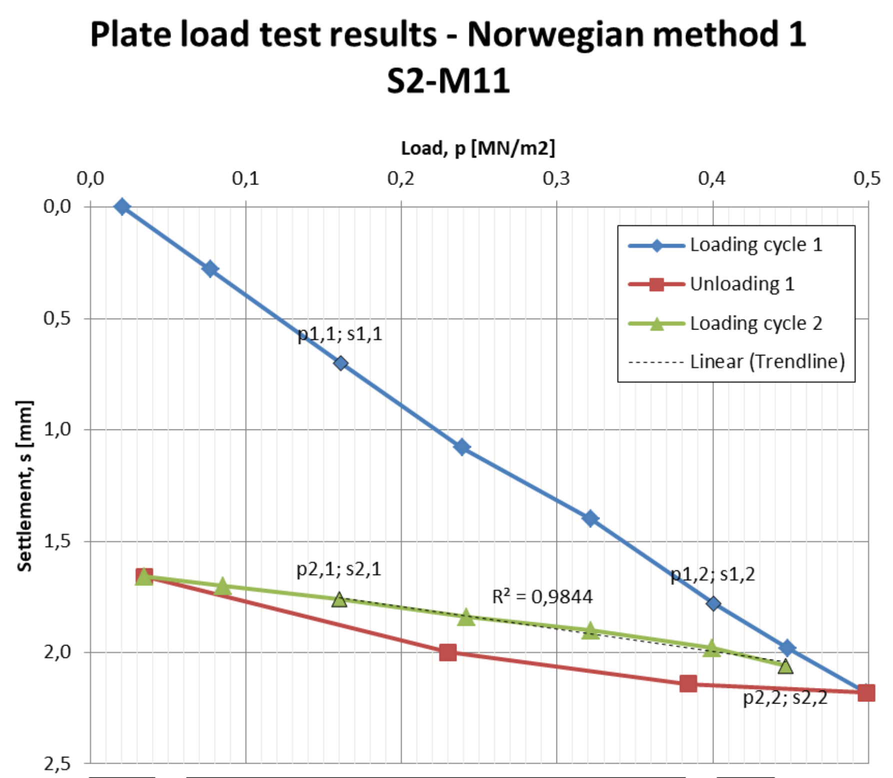
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0126	11,2540	-5,5582	28
2	3,7373	3,1047	-1,4512	101

E_2/E_1 []
3,5

S2-M11

Load [MN/m²]	**Settlement [mm]**
0,0206	0,00
0,0769	0,28
0,1607	0,70
0,2390	1,08
0,3219	1,40
0,4005	1,78
0,4483	1,98
0,4988	2,18
0,3843	2,14
0,2298	2,00
0,0345	1,66
0,0850	1,70
0,1598	1,76
0,2417	1,84
0,3217	1,90
0,3997	1,98
0,4469	2,06

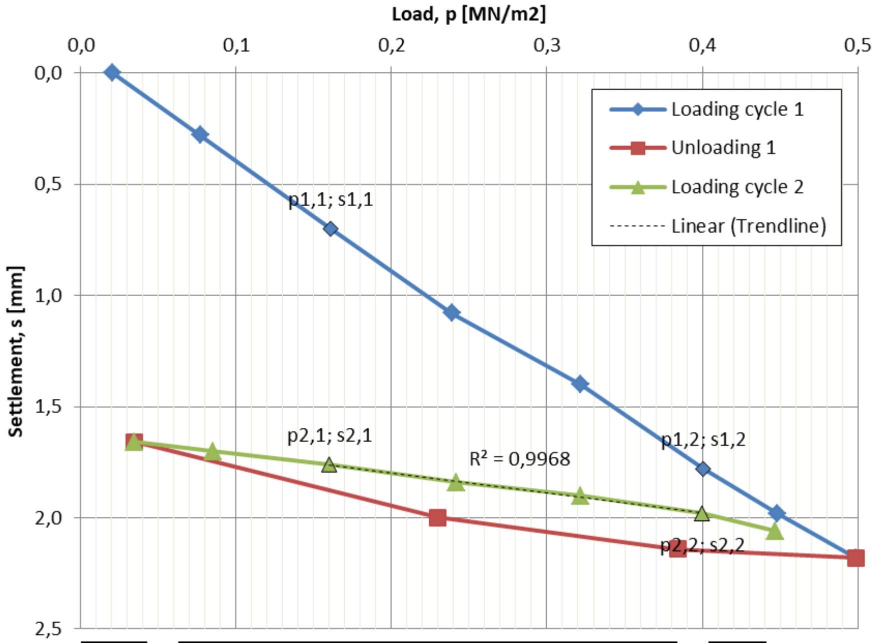


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,322	0,70	1,40	52
2	0,160	0,447	1,76	2,06	215

E_2/E_1 []
4,2

Plate load test results - Norwegian method 2
S2-M11

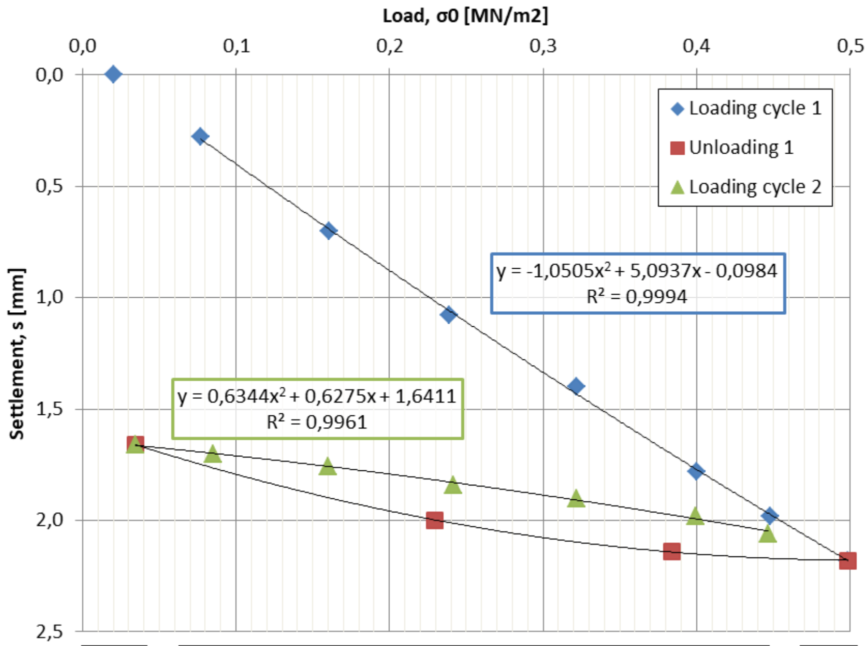


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,322	0,70	1,40	52
2	0,160	0,400	1,76	1,98	245

E_2/E_1 []
4,7

Plate load test results - Swedish method
S2-M11



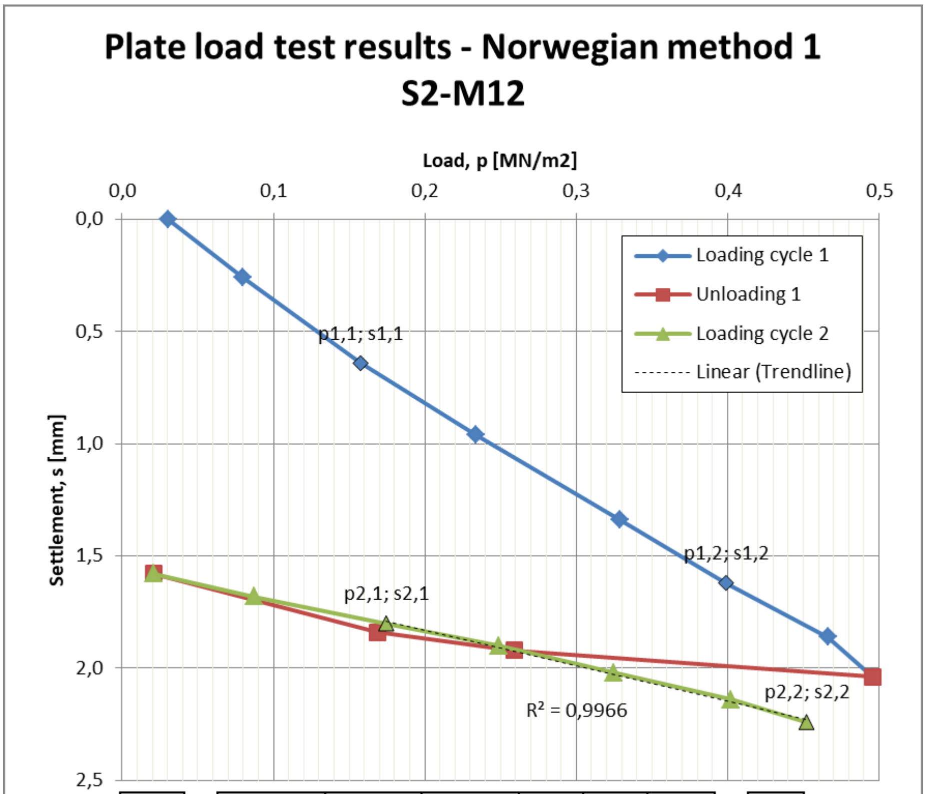
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0984	5,0937	-1,0505	49
2	1,6411	0,6275	0,6344	238

E_2/E_1 []
4,8

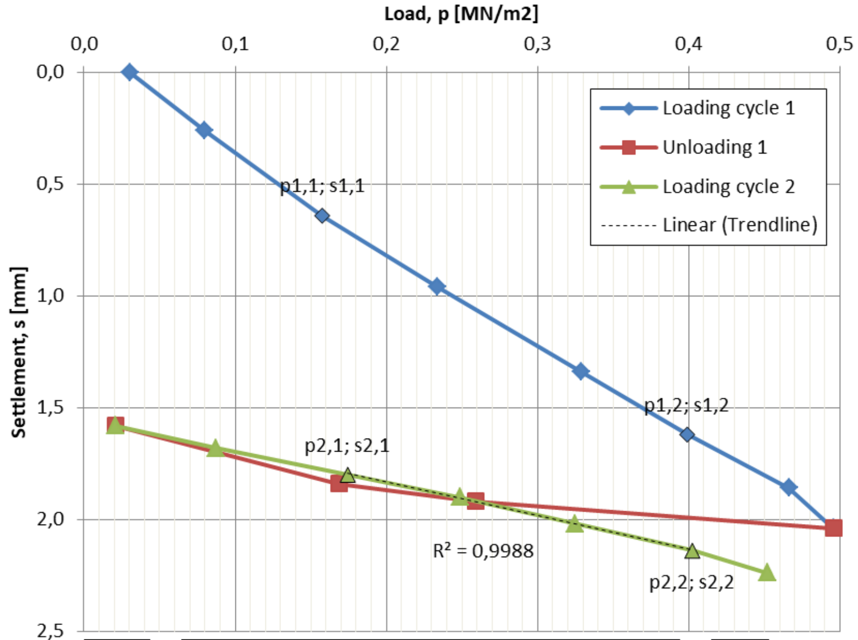
S2-M12

Load [MN/m²]	Settlement [mm]
0,0308	0,00
0,0800	0,26
0,1575	0,64
0,2341	0,96
0,3292	1,34
0,3989	1,62
0,4662	1,86
0,4959	2,04
0,2593	1,92
0,1687	1,84
0,0212	1,58
0,0870	1,68
0,1744	1,80
0,2487	1,90
0,3245	2,02
0,4023	2,14
0,4521	2,24



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,158	0,329	0,64	1,34	55	2,6
	2	0,174	0,452	1,80	2,24	142	

Plate load test results - Norwegian method 2
S2-M12

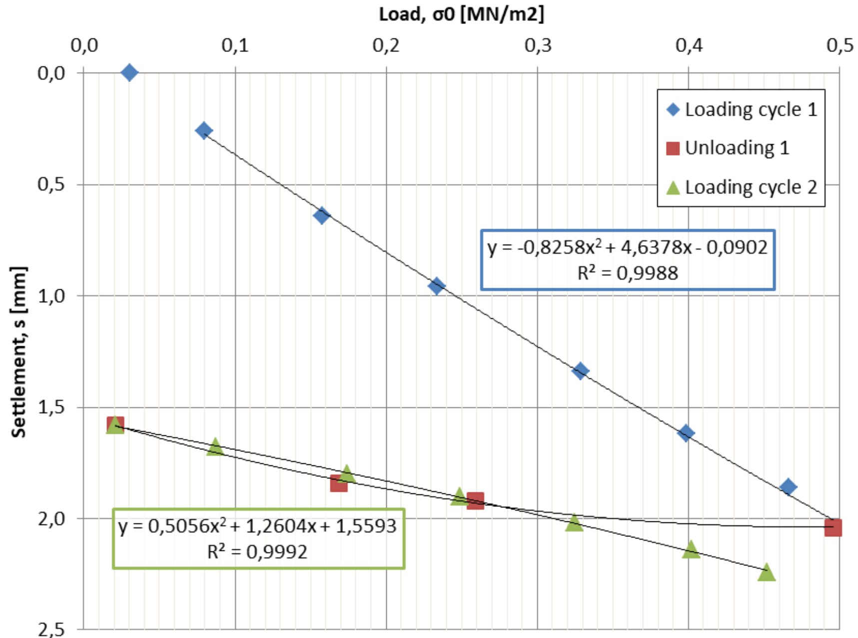


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,158	0,329	0,64	1,34	55
2	0,174	0,402	1,80	2,14	151

E_2/E_1 []
2,7

Plate load test results - Swedish method
S2-M12



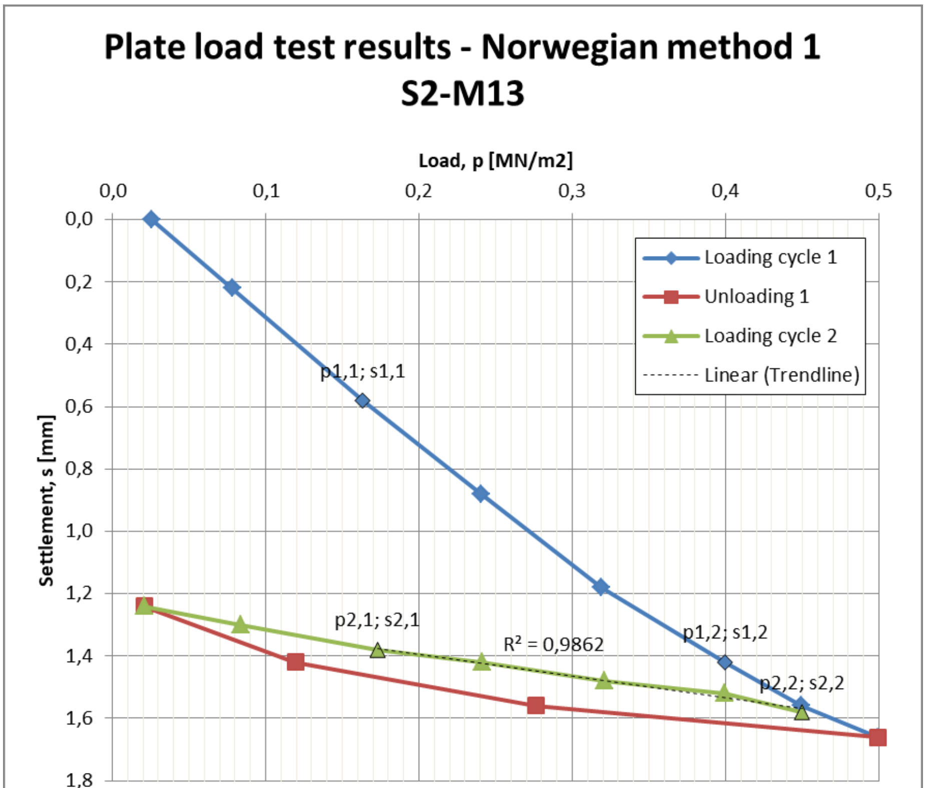
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0902	4,6378	-0,8258	53
2	1,5593	1,2604	0,5056	149

E_2/E_1 []
2,8

S2-M13

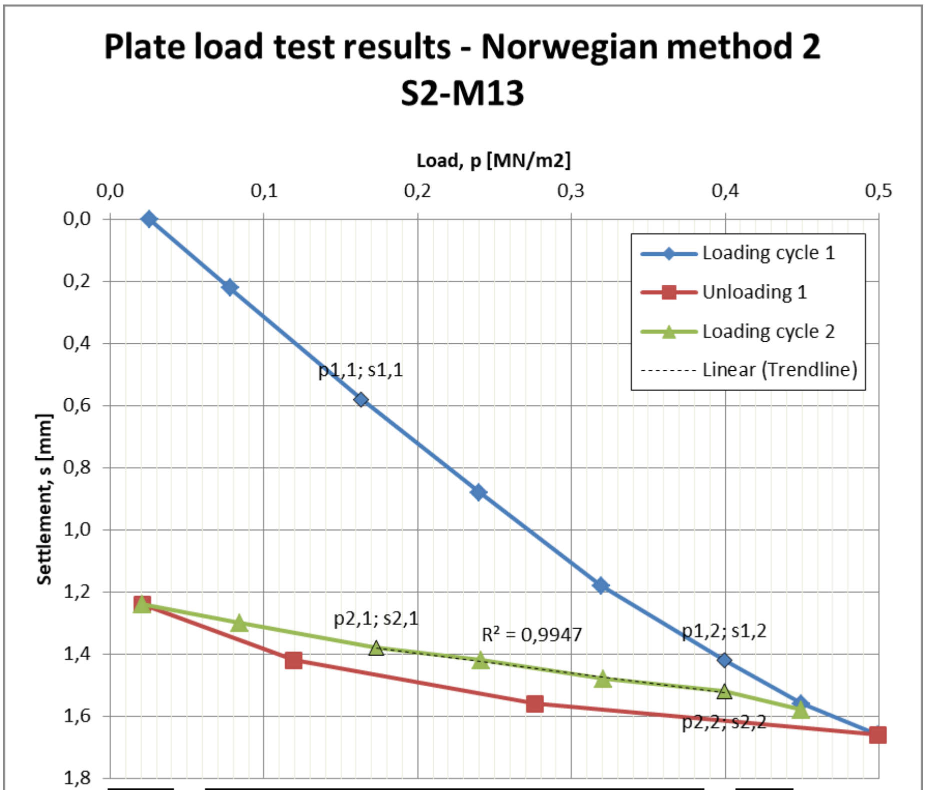
Load [MN/m²]	**Settlement [mm]**
0,0258	0,00
0,0780	0,22
0,1631	0,58
0,2402	0,88
0,3192	1,18
0,3995	1,42
0,4495	1,56
0,4993	1,66
0,2765	1,56
0,1195	1,42
0,0206	1,24
0,0840	1,30
0,1730	1,38
0,2414	1,42
0,3211	1,48
0,3995	1,52
0,4497	1,58



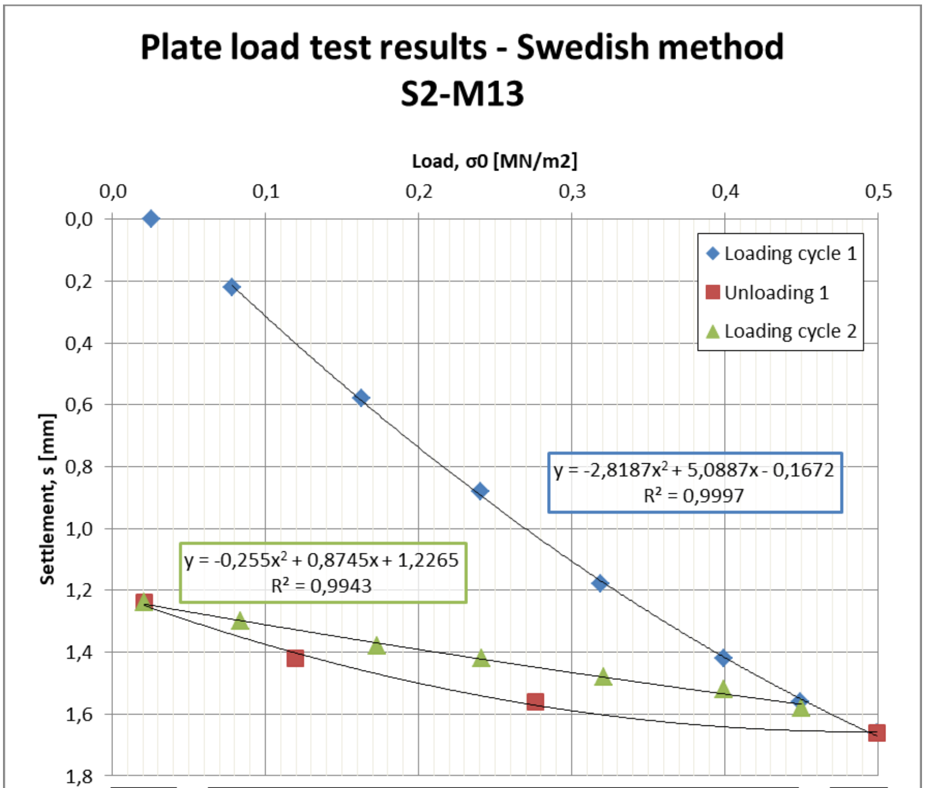
d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,163	0,319	0,58	1,18	59
2	0,173	0,450	1,38	1,58	311

E_2/E_1 []
5,3



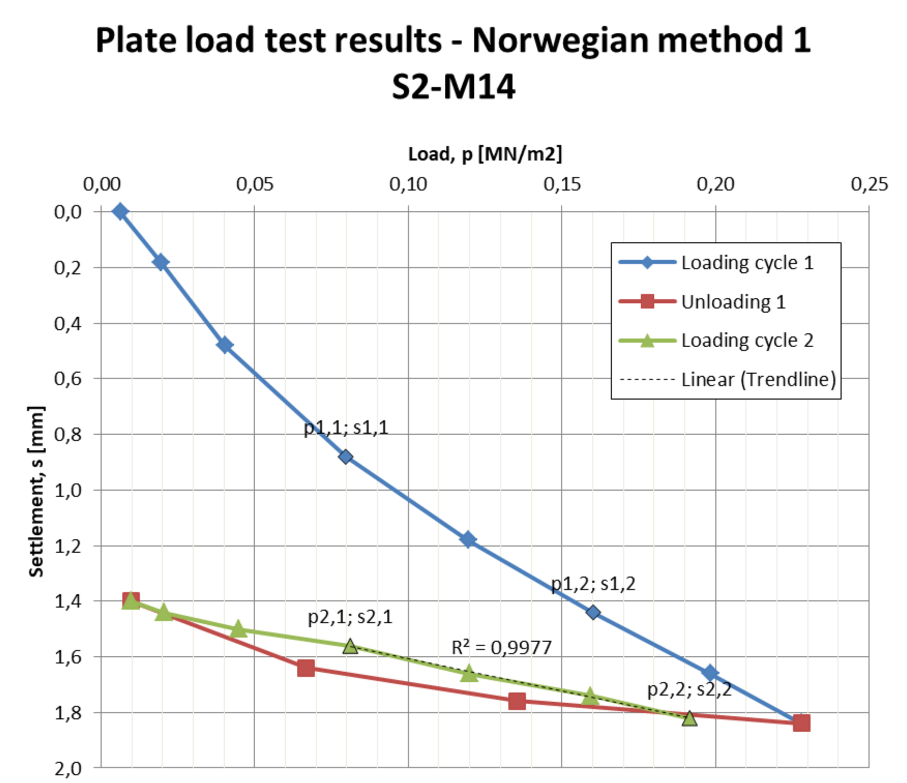
d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,163	0,319	0,58	1,18	59	6,2
	2	0,173	0,400	1,38	1,52	364	



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,1672	5,0887	-2,8187	61	4,9
	2	1,2265	0,8745	-0,2550	301	

S2-M14

Load [MN/m^2]	Settlement [mm]
0,0063	0,00
0,0195	0,18
0,0404	0,48
0,0796	0,88
0,1195	1,18
0,1602	1,44
0,1984	1,66
0,2280	1,84
0,1355	1,76
0,0668	1,64
0,0098	1,40
0,0205	1,44
0,0447	1,50
0,0811	1,56
0,1198	1,66
0,1595	1,74
0,1916	1,82

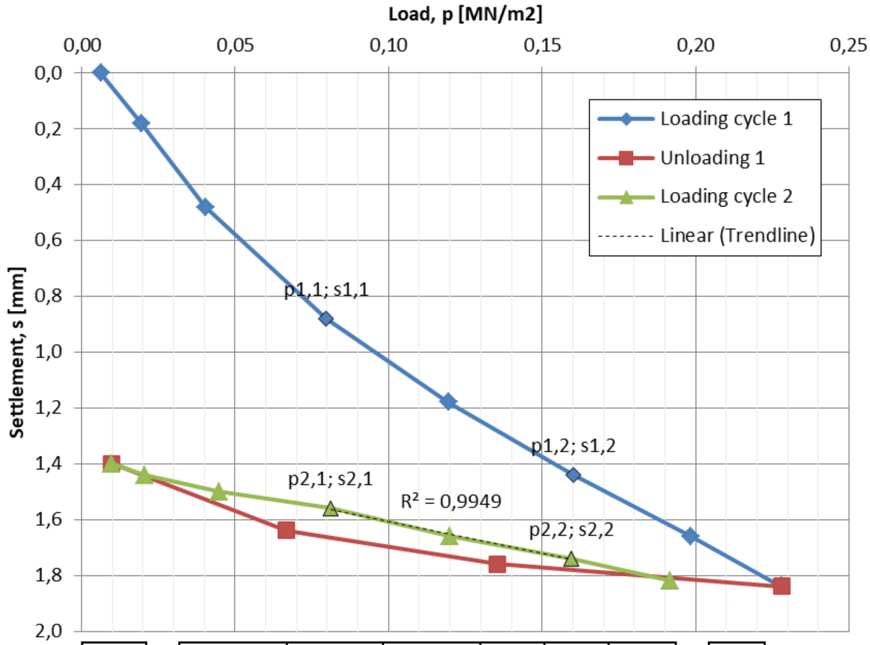


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m^2]	$p_{i,2}$ [MN/m^2]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,88	1,44	65
2	0,081	0,192	1,56	1,82	191

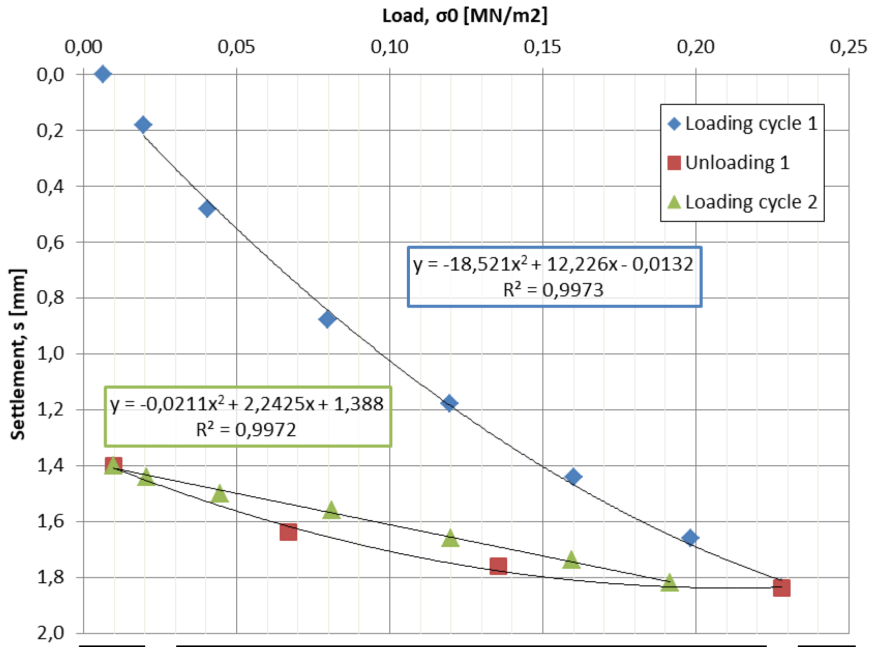
E_2/E_1 []
3,0

Plate load test results - Norwegian method 2
S2-M14



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,160	0,88	1,44	65	3,0
	2	0,081	0,160	1,56	1,74	196	

Plate load test results - Swedish method
S2-M14

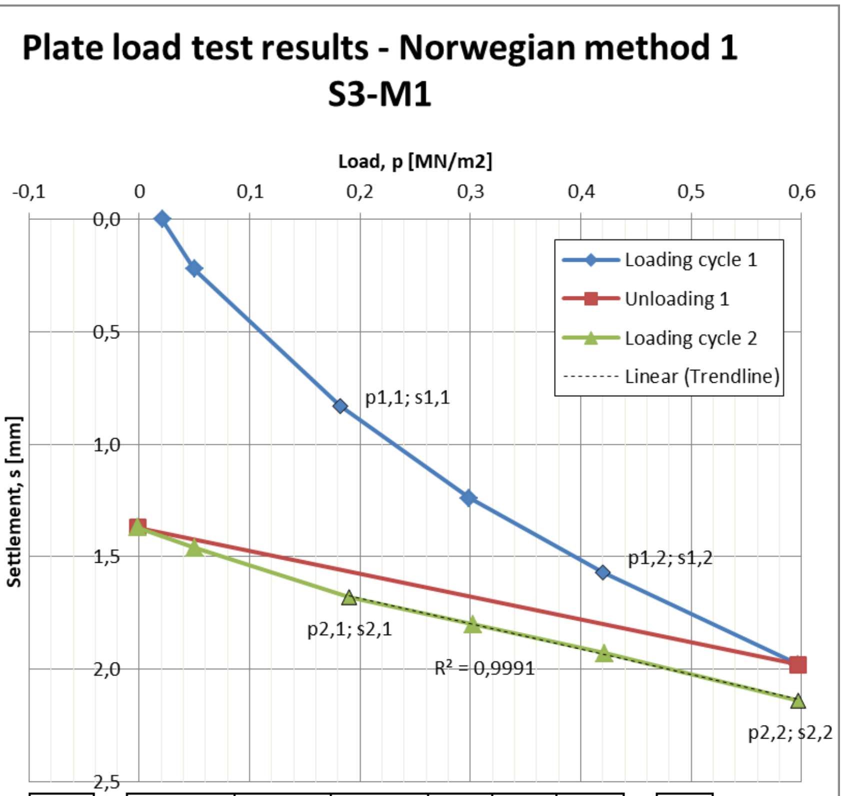


r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	-0,0132	12,226	-18,5210	56	3,6
	2	1,3880	2,2425	-0,0211	201	

Site 3: The new motorway project

S3-M1

Load [MN/m²]	Settlement [mm]
0,021	0,00
0,050	0,22
0,182	0,83
0,299	1,24
0,420	1,57
0,597	1,98
-0,001	1,37
0,050	1,46
0,190	1,68
0,302	1,80
0,422	1,93
0,597	2,14

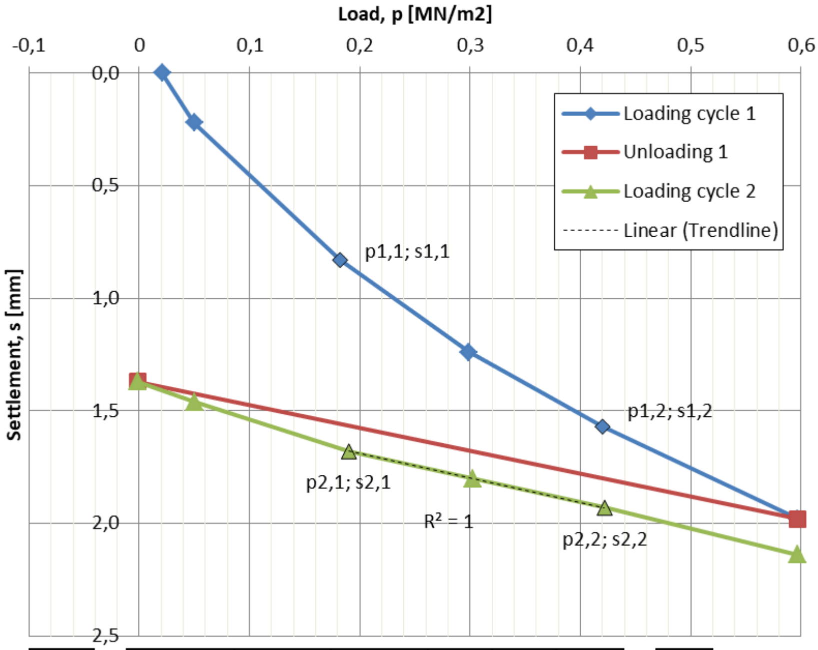


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,420	0,83	1,57	72
2	0,190	0,597	1,68	2,14	199

E_2/E_1 []
2,8

Plate load test results - Norwegian method 2
S3-M1

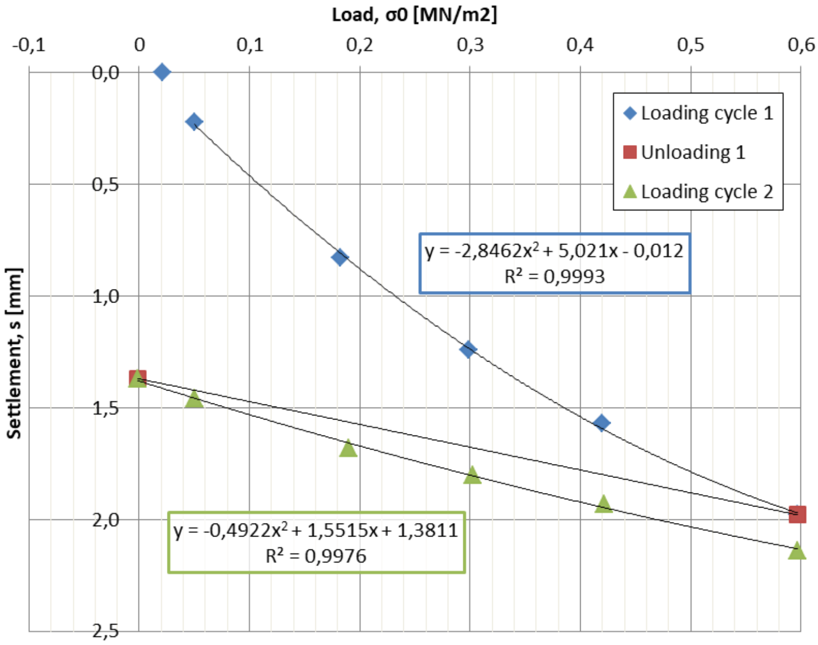


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,420	0,83	1,57	72
2	0,190	0,422	1,68	1,93	209

E_2/E_1 []
2,9

Plate load test results - Swedish method
S3-M1



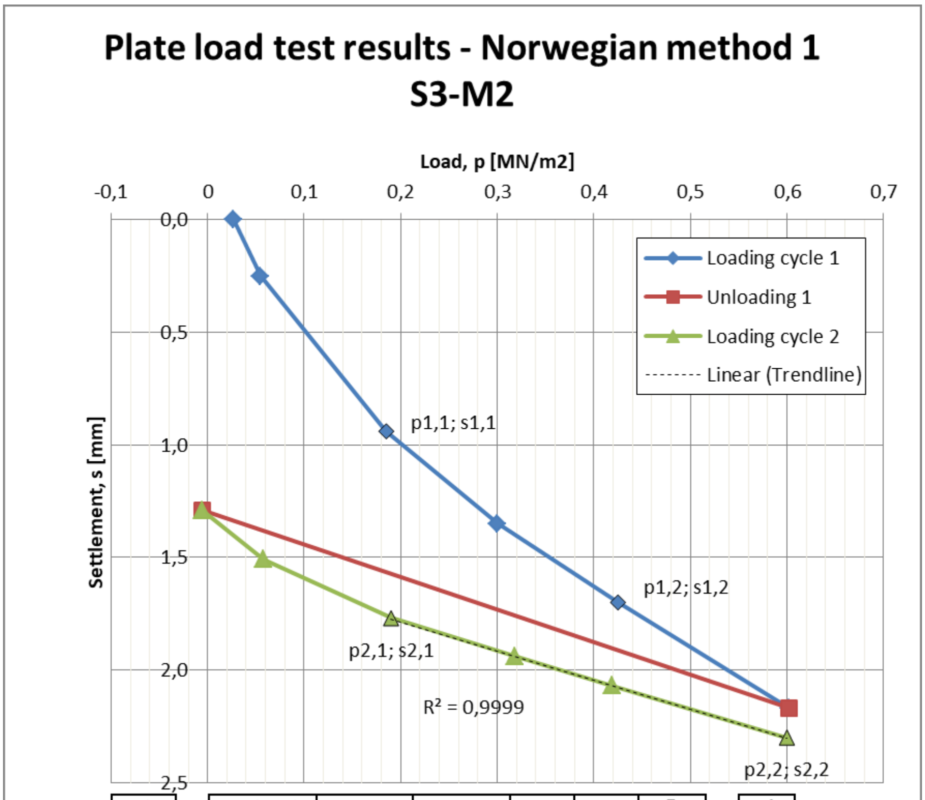
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0120	5,0210	-2,8462	68
2	1,3811	1,5515	-0,4922	179

E_2/E_1 []
2,6

S3-M2

Load [MN/m²]	Settlement [mm]
0,027	0,00
0,055	0,25
0,185	0,94
0,300	1,35
0,425	1,70
0,602	2,17
-0,006	1,29
0,058	1,51
0,190	1,77
0,318	1,94
0,419	2,07
0,600	2,30

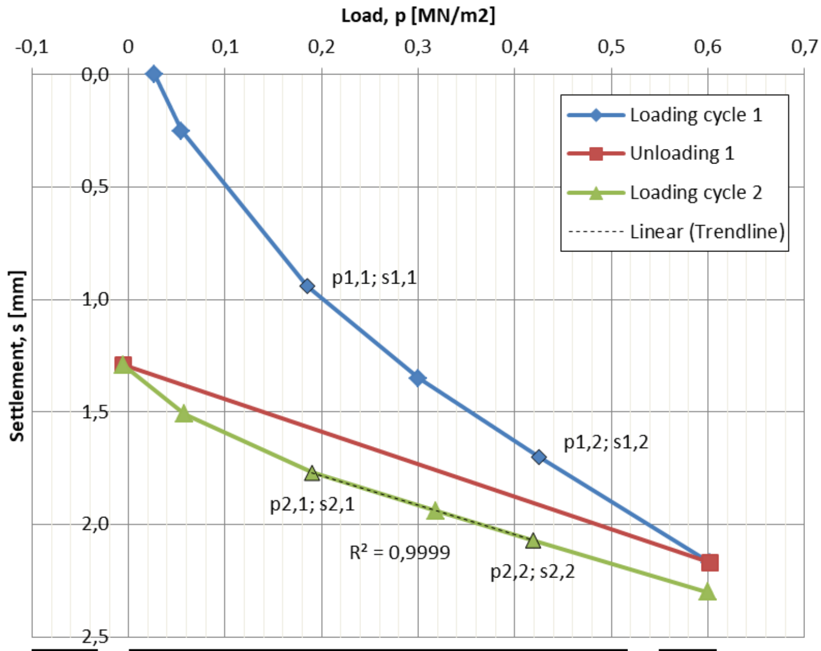


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,185	0,425	0,94	1,70	71
2	0,190	0,600	1,77	2,30	174

E_2/E_1 []
2,4

Plate load test results - Norwegian method 2
S3-M2

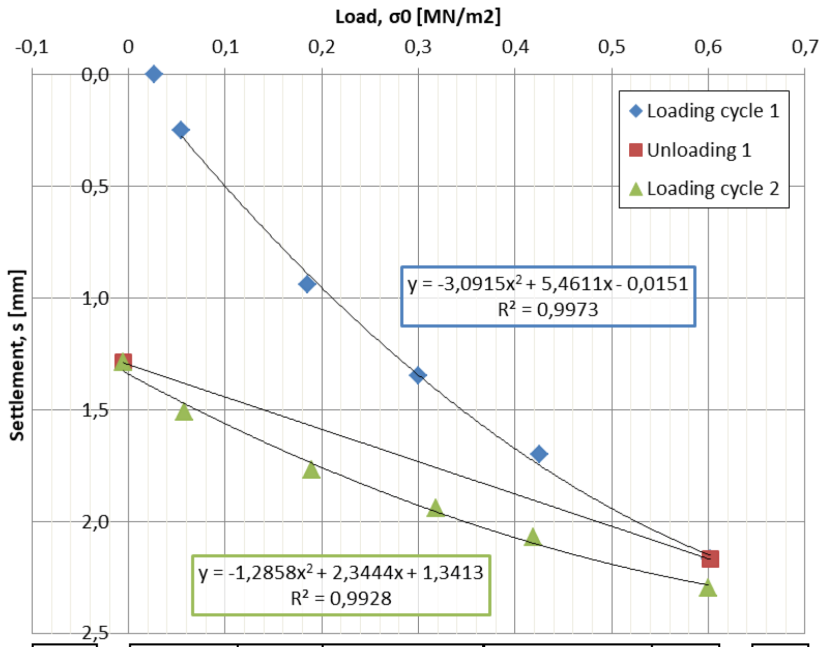


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,185	0,425	0,94	1,70	71
2	0,190	0,419	1,77	2,07	172

E_2/E_1 []
2,4

Plate load test results - Swedish method
S3-M2



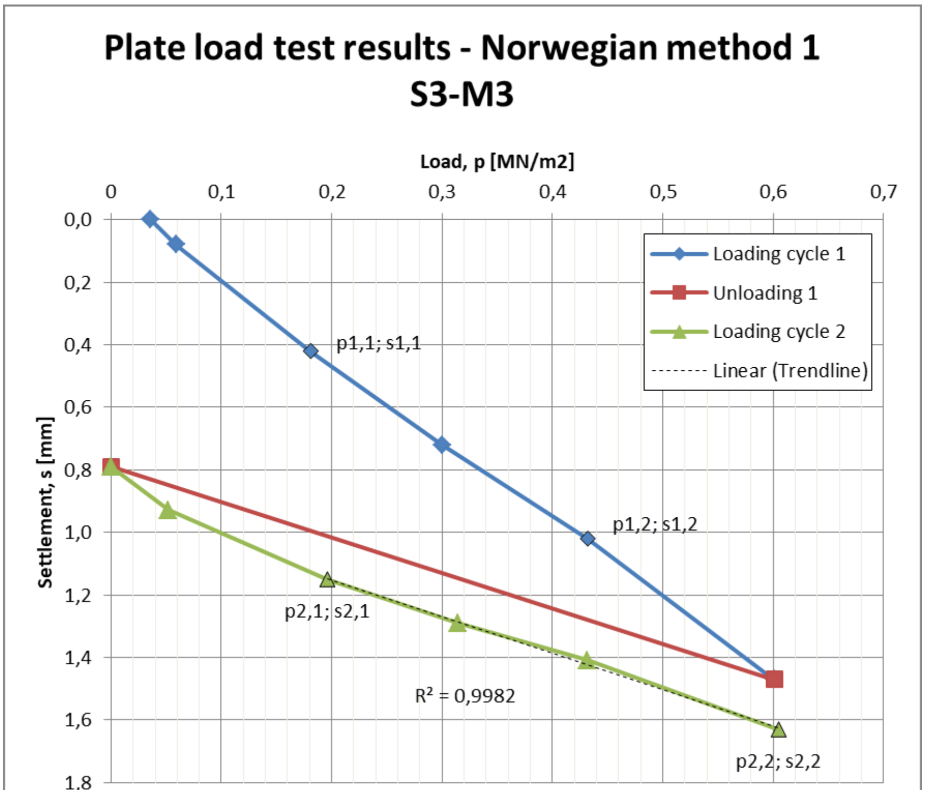
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0151	5,4611	-3,0915	62
2	1,3413	2,3444	-1,2858	143

E_2/E_1 []
2,3

S3-M3

Load [MN/m²]	Settlement [mm]
0,036	0,00
0,059	0,08
0,181	0,42
0,300	0,72
0,432	1,02
0,601	1,47
0,000	0,79
0,052	0,93
0,196	1,15
0,314	1,29
0,432	1,41
0,605	1,63

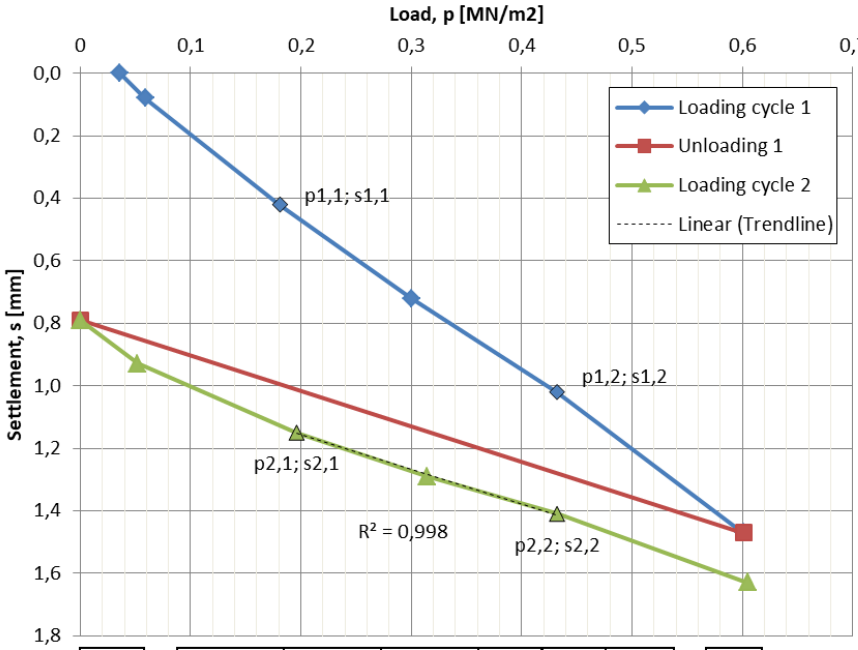


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,432	0,42	1,02	94
2	0,196	0,605	1,15	1,63	192

E_2/E_1 []
2,0

Plate load test results - Norwegian method 2
S3-M3

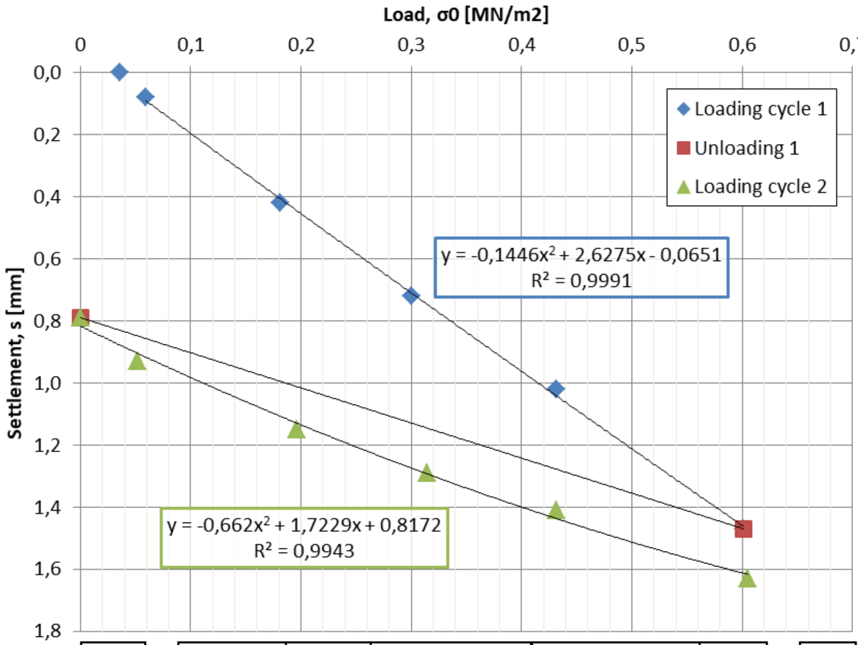


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,432	0,42	1,02	94
2	0,196	0,432	1,15	1,41	204

E_2/E_1 []
2,2

Plate load test results - Swedish method
S3-M3



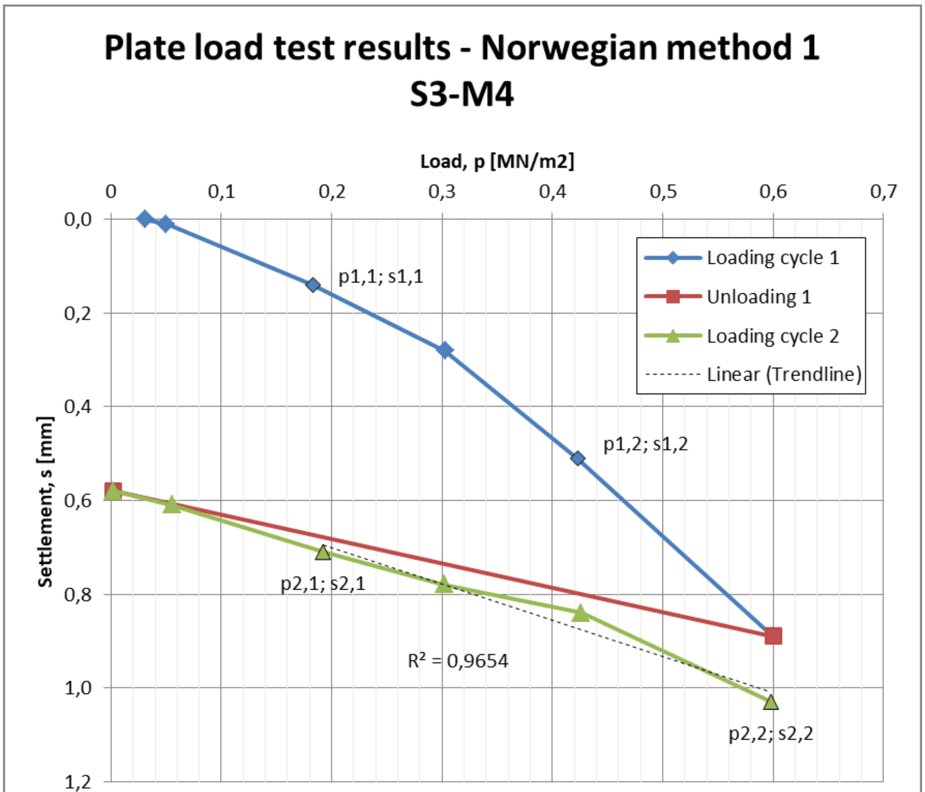
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0651	2,6275	-0,1446	89
2	0,8172	1,7229	-0,6620	170

E_2/E_1 []
1,9

S3-M4

Load [MN/m²]	Settlement [mm]
0,031	0,00
0,050	0,01
0,183	0,14
0,303	0,28
0,423	0,51
0,600	0,89
0,002	0,58
0,055	0,61
0,192	0,71
0,302	0,78
0,426	0,84
0,598	1,03

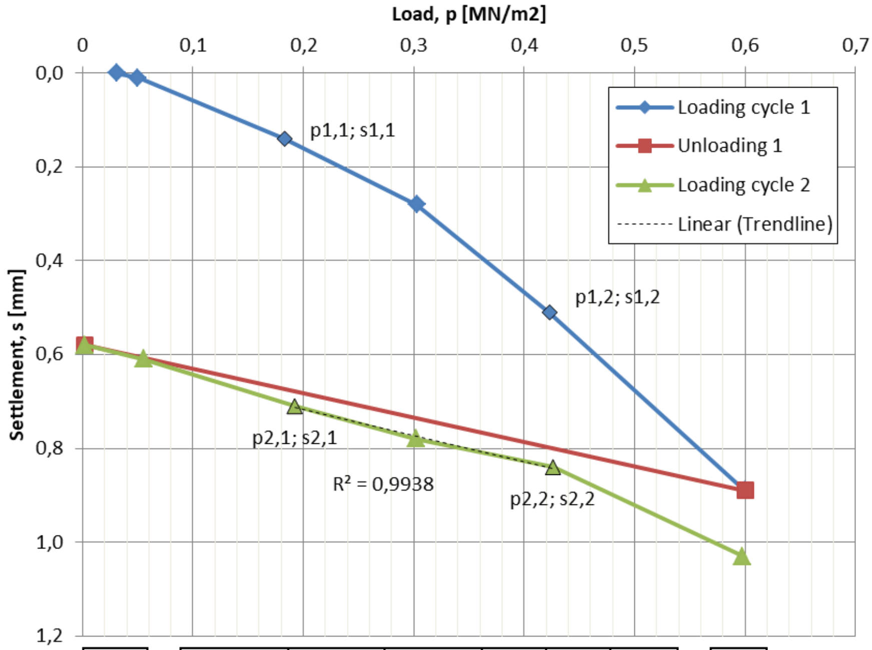


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,183	0,423	0,14	0,51	146
2	0,192	0,598	0,71	1,03	285

E_2/E_1 []
2,0

Plate load test results - Norwegian method 2
S3-M4

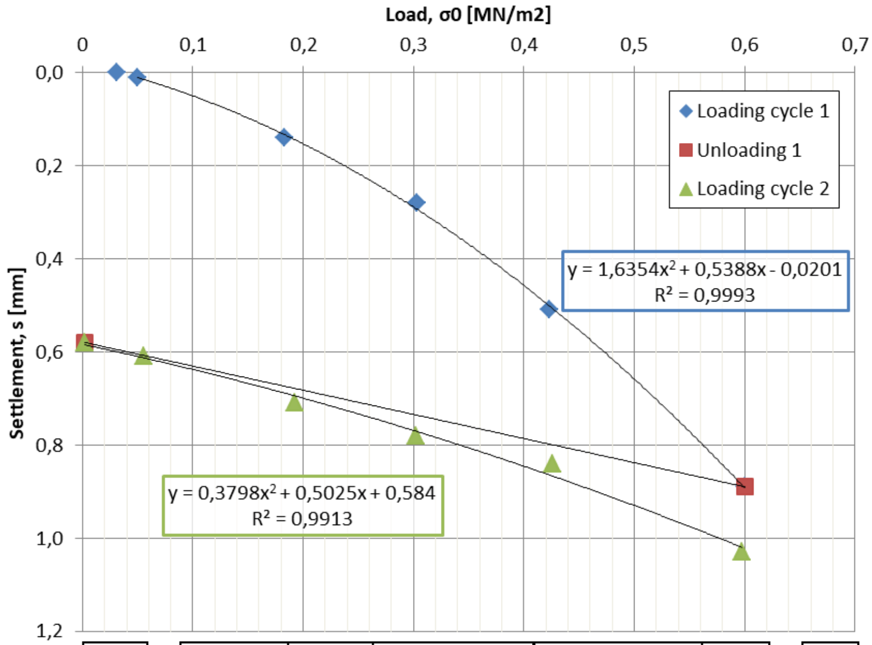


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,183	0,423	0,14	0,51	146
2	0,192	0,426	0,71	0,84	405

E_2/E_1 []
2,8

Plate load test results - Swedish method
S3-M4



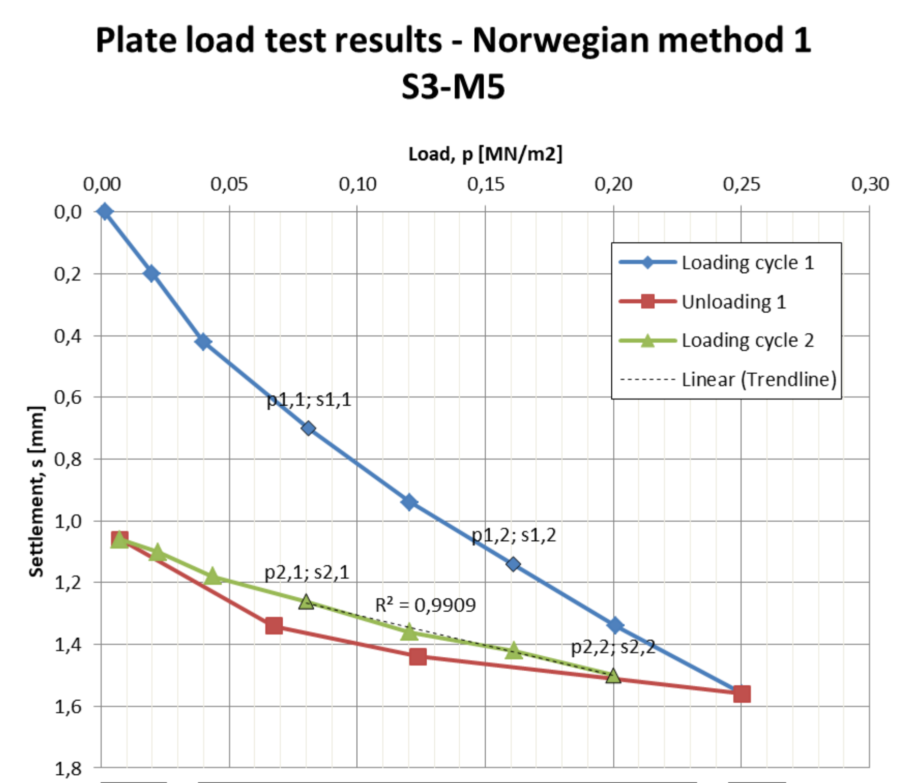
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0201	0,5388	1,6354	148
2	0,5840	0,5025	0,3798	308

E_2/E_1 []
2,1

S3-M5

Load [MN/m²]	**Settlement [mm]**
0,0016	0,00
0,0200	0,20
0,0400	0,42
0,0809	0,70
0,1206	0,94
0,1609	1,14
0,2011	1,34
0,2503	1,56
0,1239	1,44
0,0674	1,34
0,0074	1,06
0,0222	1,10
0,0435	1,18
0,0800	1,26
0,1205	1,36
0,1614	1,42
0,2000	1,50

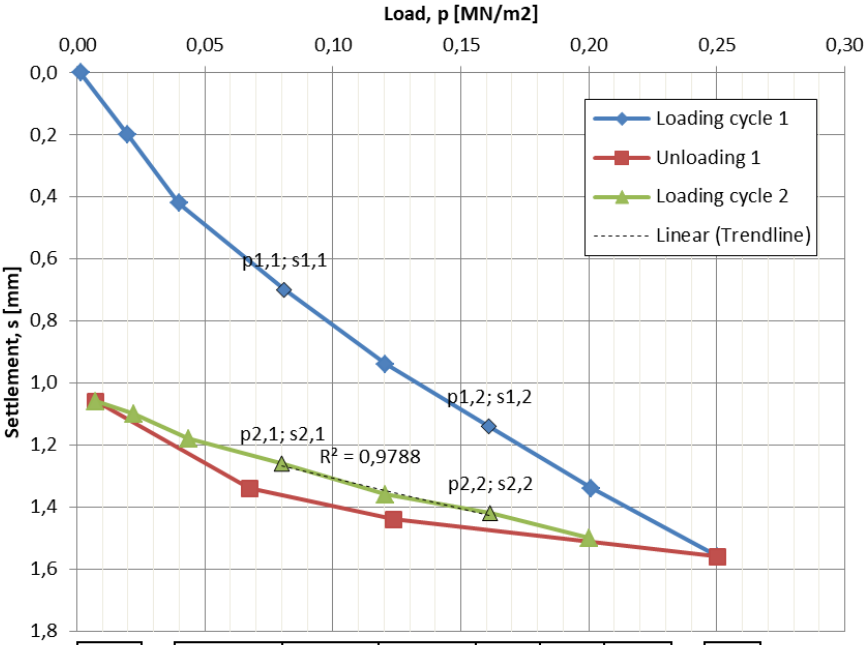


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,081	0,161	0,70	1,14	82
2	0,080	0,200	1,26	1,50	225

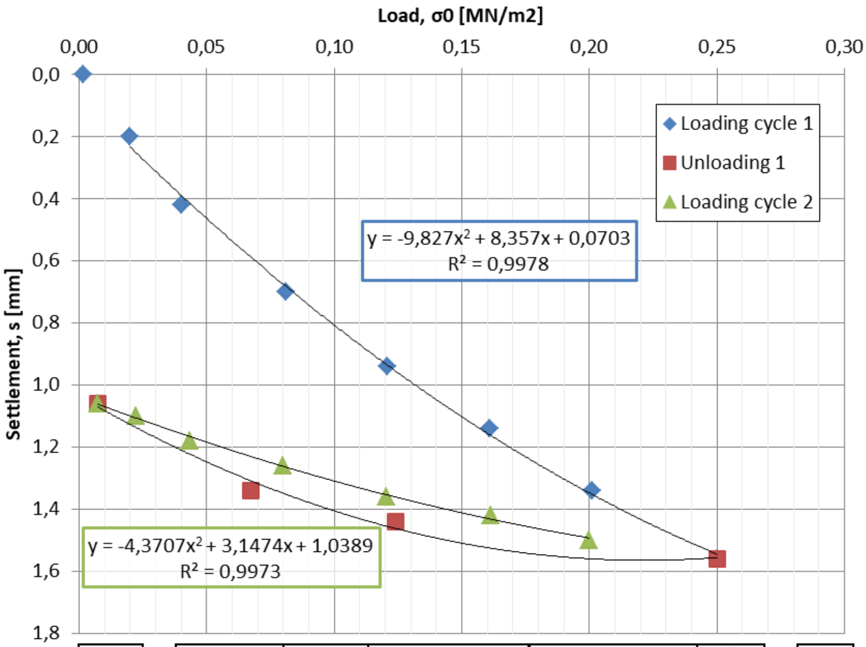
E_2/E_1 []
2,8

Plate load test results - Norwegian method 2
S3-M5



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,081	0,161	0,70	1,14	82	2,8
	2	0,080	0,161	1,26	1,42	229	

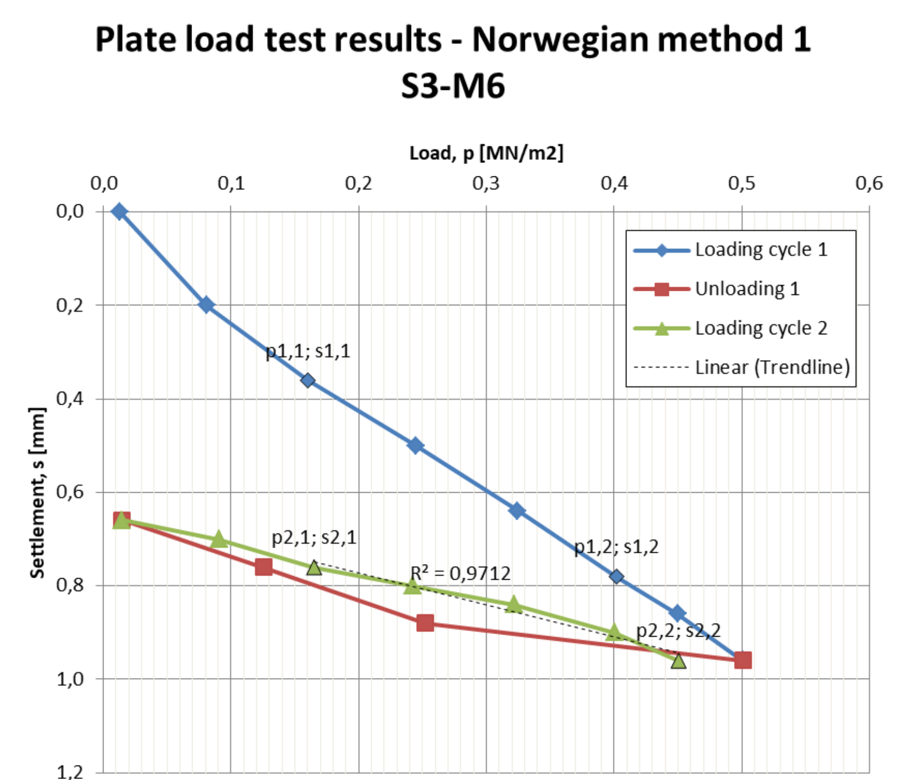
Plate load test results - Swedish method
S3-M5



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,0703	8,3570	-9,8270	76	2,9
	2	1,0389	3,1474	-4,3707	219	

S3-M6

Load [MN/m²]	**Settlement [mm]**
0,0132	0,00
0,0807	0,20
0,1601	0,36
0,2448	0,50
0,3245	0,64
0,4019	0,78
0,4500	0,86
0,5010	0,96
0,2522	0,88
0,1253	0,76
0,0148	0,66
0,0906	0,70
0,1650	0,76
0,2426	0,80
0,3215	0,84
0,4005	0,90
0,4505	0,96

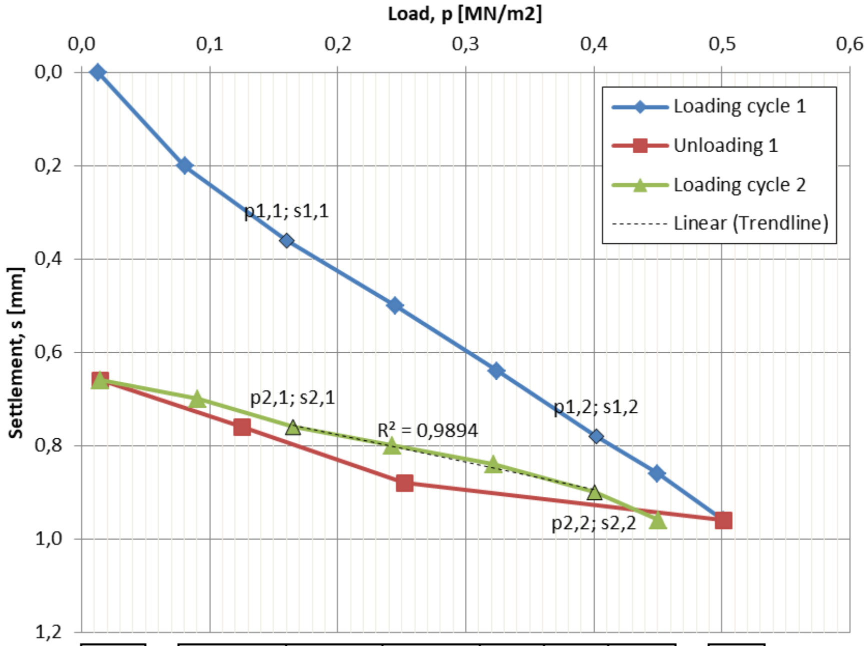


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,325	0,36	0,64	132
2	0,165	0,451	0,76	0,96	321

E_2/E_1 []
2,4

Plate load test results - Norwegian method 2
S3-M6

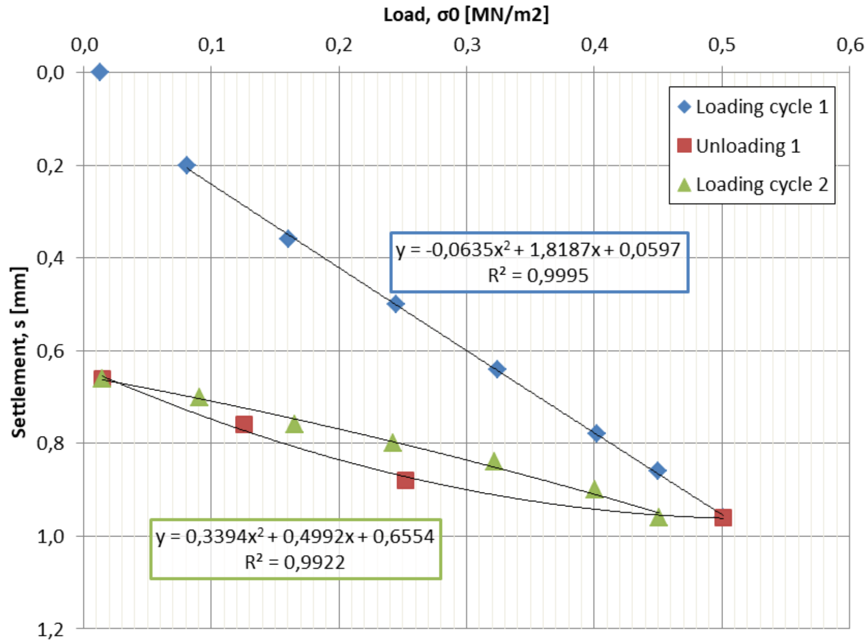


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,325	0,36	0,64	132
2	0,165	0,401	0,76	0,90	378

E_2/E_1 []
2,9

Plate load test results - Swedish method
S3-M6



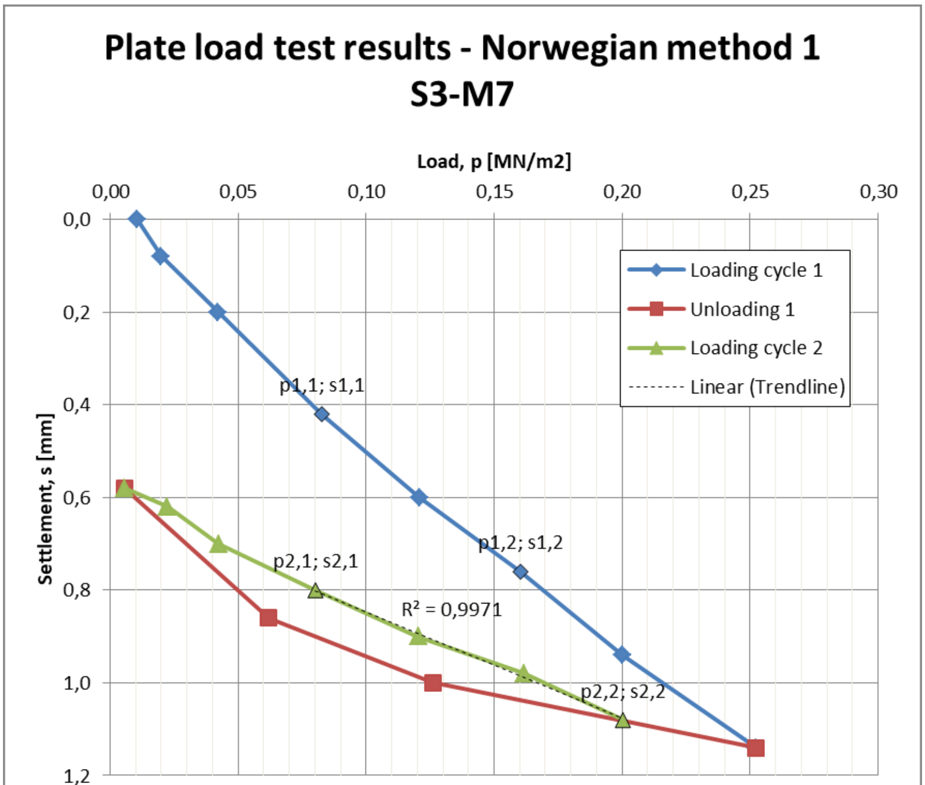
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0597	1,8187	-0,0635	126
2	0,6554	0,4992	0,3394	336

E_2/E_1 []
2,7

S3-M7

Load [MN/m²]	**Settlement [mm]**
0,0107	0,00
0,0200	0,08
0,0422	0,20
0,0827	0,42
0,1207	0,60
0,1603	0,76
0,2003	0,94
0,2524	1,14
0,1260	1,00
0,0620	0,86
0,0056	0,58
0,0223	0,62
0,0424	0,70
0,0802	0,80
0,1203	0,90
0,1616	0,98
0,2003	1,08

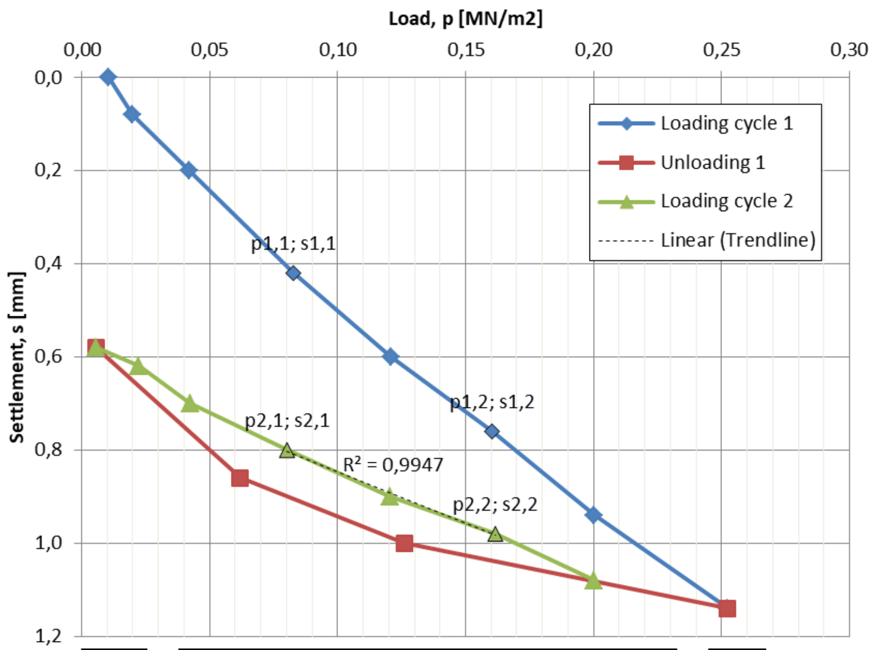


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,083	0,160	0,42	0,76	103
2	0,080	0,200	0,80	1,08	193

E_2/E_1 []
1,9

Plate load test results - Norwegian method 2
S3-M7

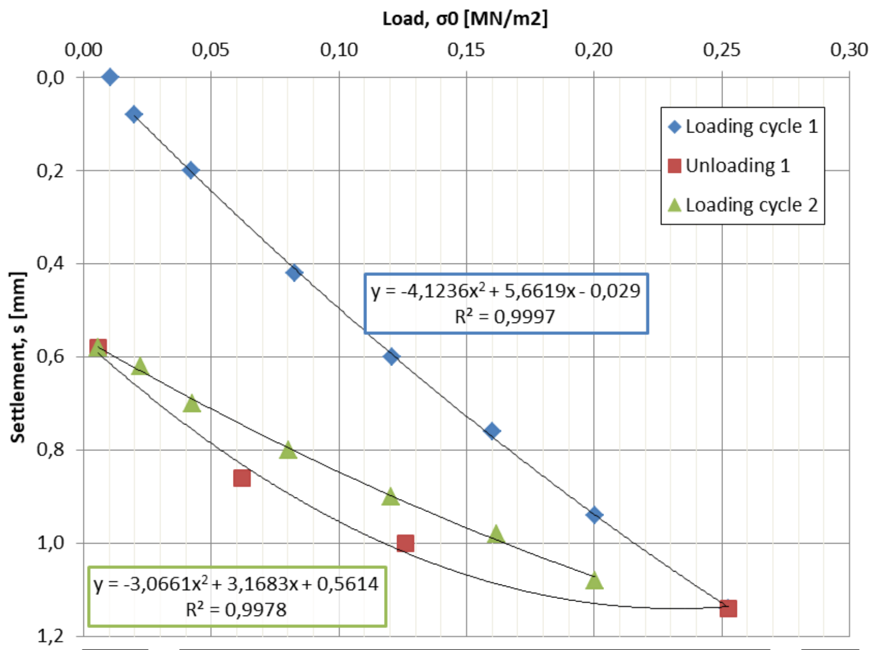


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,083	0,160	0,42	0,76	103
2	0,080	0,162	0,80	0,98	204

E_2/E_1 []
2,0

Plate load test results - Swedish method
S3-M7



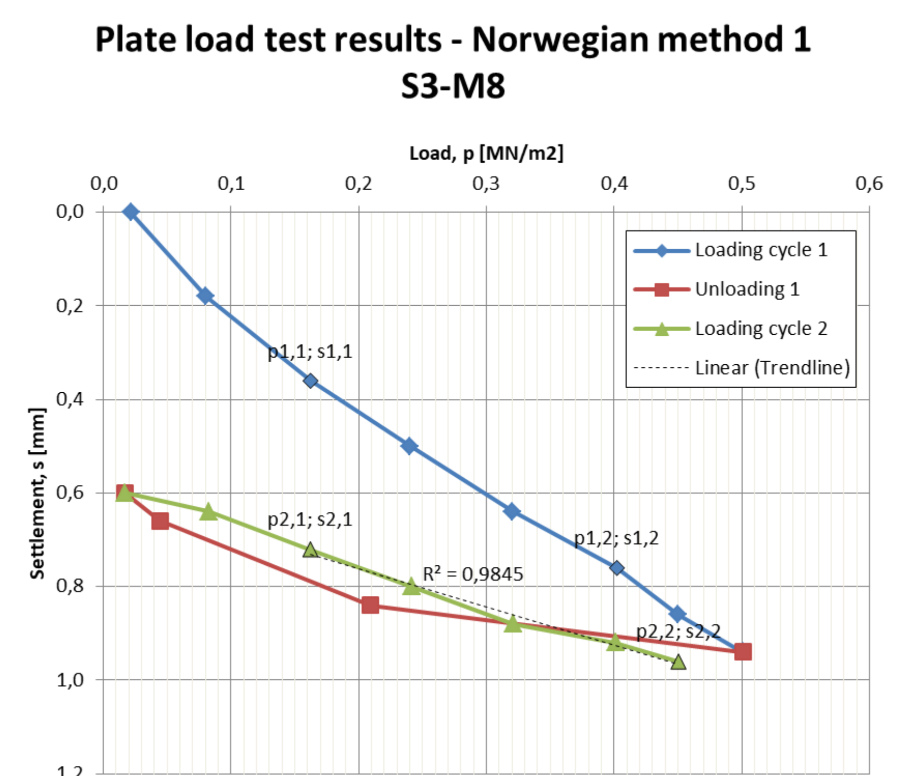
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0290	5,6619	-4,1236	97
2	0,5614	3,1683	-3,0661	188

E_2/E_1 []
1,9

S3-M8

Load [MN/m²]	Settlement [mm]
0,0216	0,00
0,0804	0,18
0,1622	0,36
0,2400	0,50
0,3204	0,64
0,4022	0,76
0,4503	0,86
0,5009	0,94
0,2095	0,84
0,0444	0,66
0,0168	0,60
0,0823	0,64
0,1621	0,72
0,2417	0,80
0,3214	0,88
0,4012	0,92
0,4504	0,96

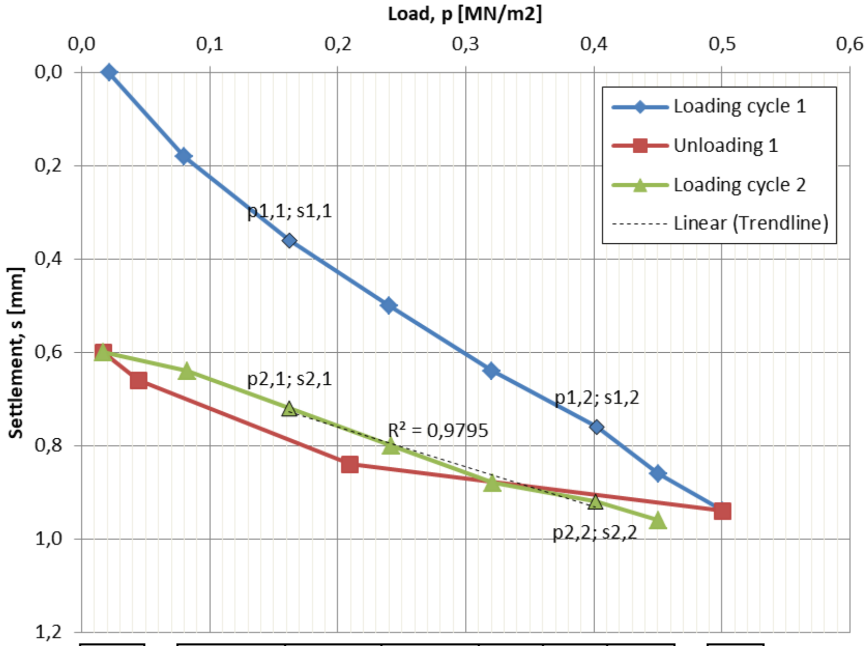


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,162	0,320	0,36	0,64	127
2	0,162	0,450	0,72	0,96	270

E_2/E_1 []
2,1

Plate load test results - Norwegian method 2
S3-M8

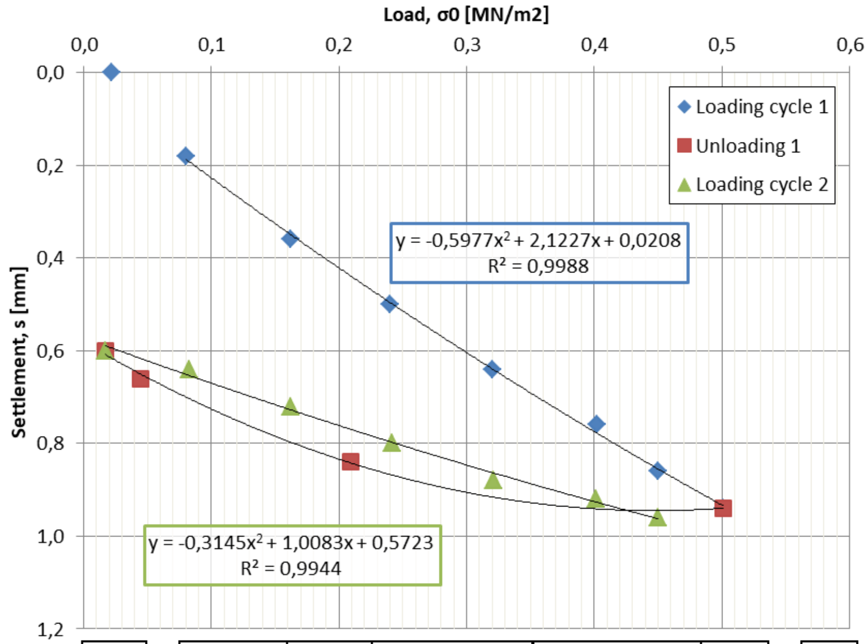


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,162	0,320	0,36	0,64	127
2	0,162	0,401	0,72	0,92	269

E_2/E_1 []
2,1

Plate load test results - Swedish method
S3-M8



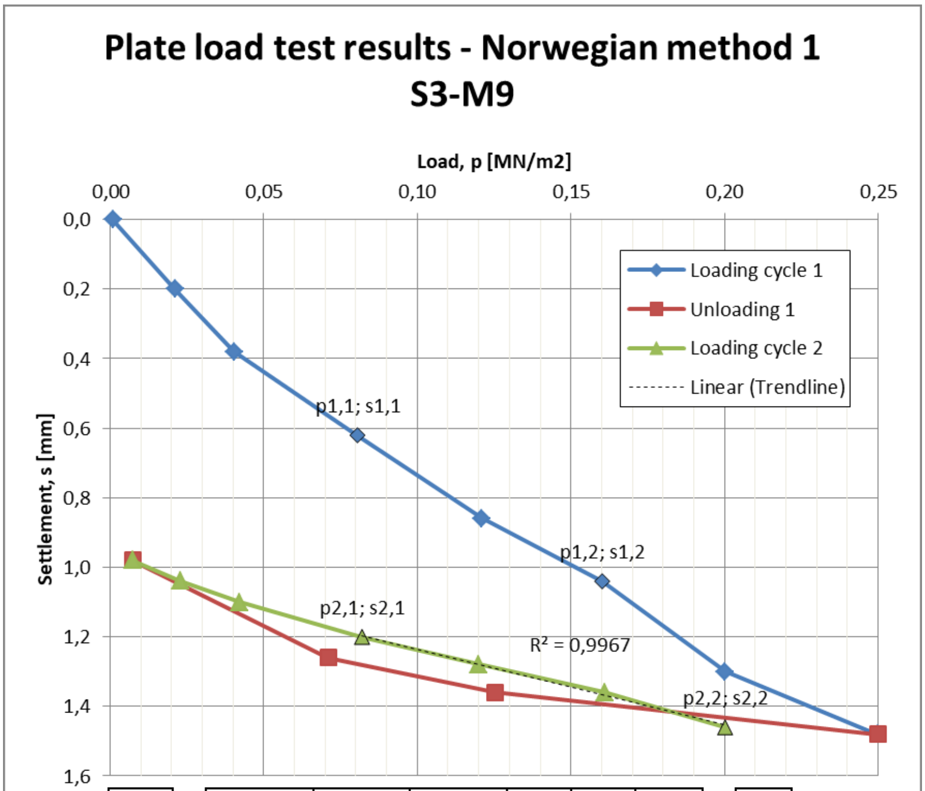
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0208	2,1227	-0,5977	123
2	0,5723	1,0083	-0,3145	264

E_2/E_1 []
2,1

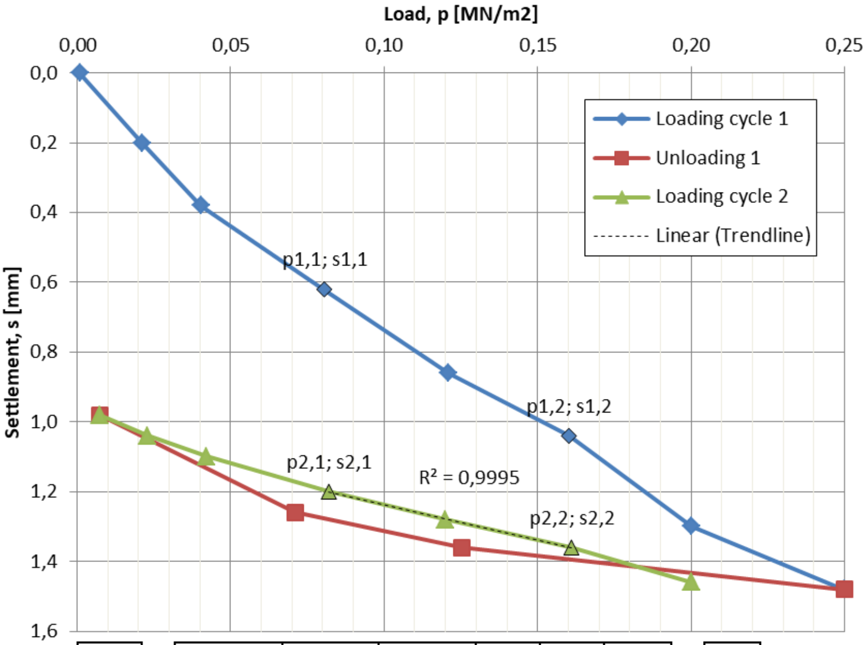
S3-M9

Load [MN/m²]	**Settlement [mm]**
0,0010	0,00
0,0211	0,20
0,0404	0,38
0,0805	0,62
0,1211	0,86
0,1602	1,04
0,2002	1,30
0,2500	1,48
0,1253	1,36
0,0710	1,26
0,0074	0,98
0,0230	1,04
0,0422	1,10
0,0820	1,20
0,1200	1,28
0,1610	1,36
0,2002	1,46



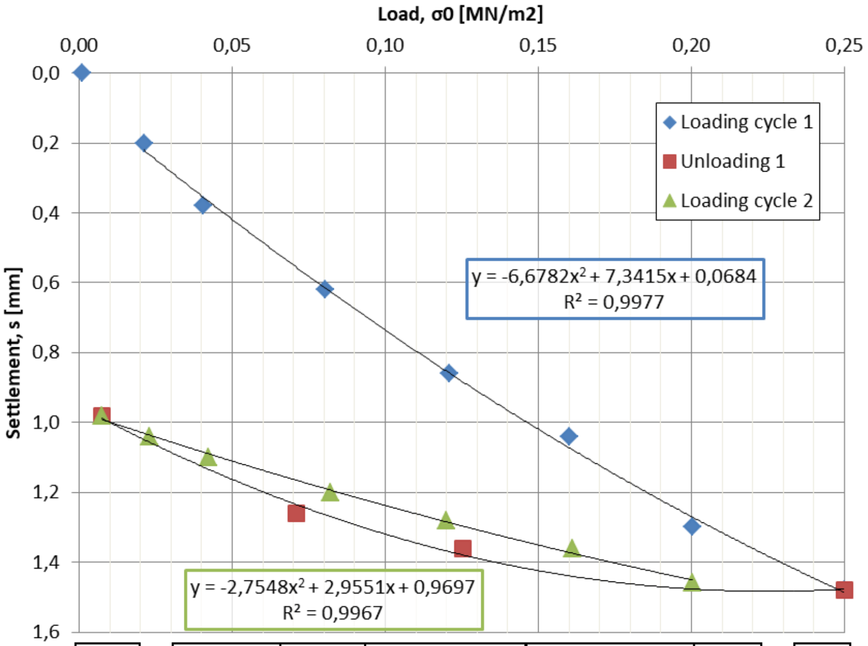
d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,081	0,160	0,62	1,04	85	2,4
	2	0,082	0,200	1,20	1,46	205	

Plate load test results - Norwegian method 2
S3-M9



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,081	0,160	0,62	1,04	85	2,6
	2	0,082	0,161	1,20	1,36	222	

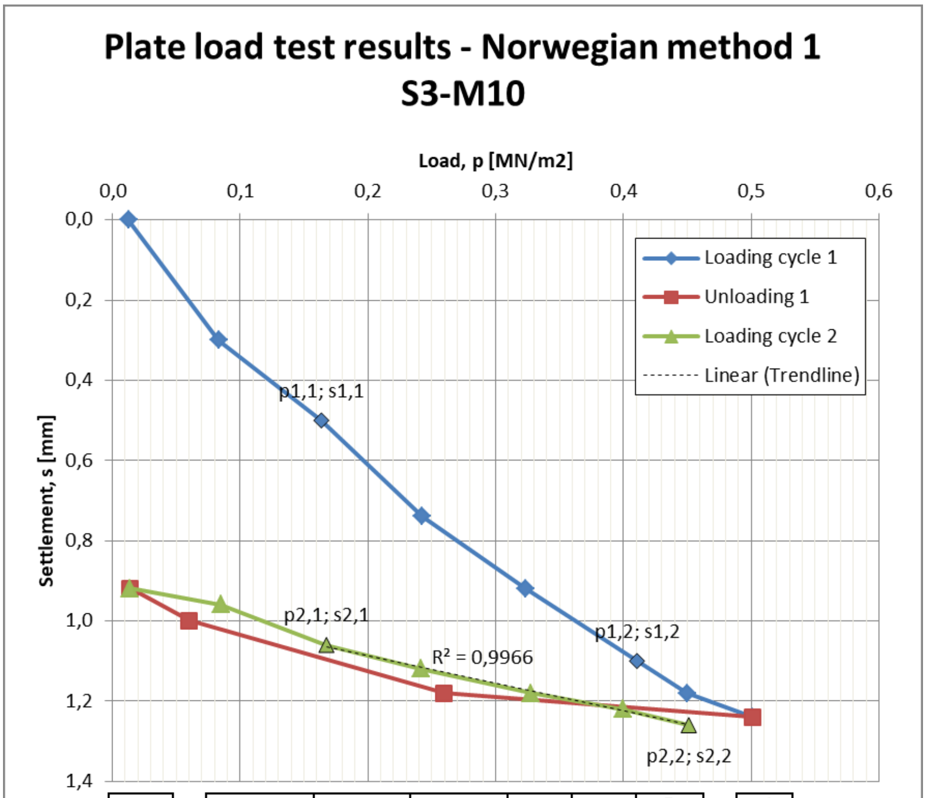
Plate load test results - Swedish method
S3-M9



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,0684	7,3415	-6,6782	79	2,5
	2	0,9697	2,9551	-2,7548	199	

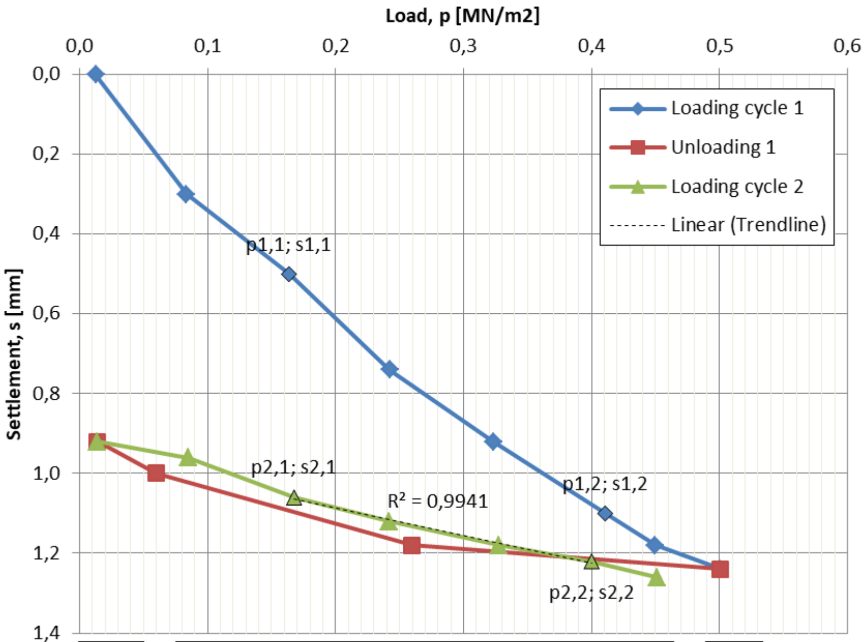
S3-M10

Load [MN/m²]	Settlement [mm]
0,0127	0,00
0,0833	0,30
0,1635	0,50
0,2424	0,74
0,3234	0,92
0,4106	1,10
0,4500	1,18
0,5009	1,24
0,2597	1,18
0,0602	1,00
0,0141	0,92
0,0850	0,96
0,1675	1,06
0,2419	1,12
0,3276	1,18
0,4000	1,22
0,4511	1,26



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,164	0,323	0,50	0,92	86	3,7
	2	0,168	0,451	1,06	1,26	319	

Plate load test results - Norwegian method 2
S3-M10

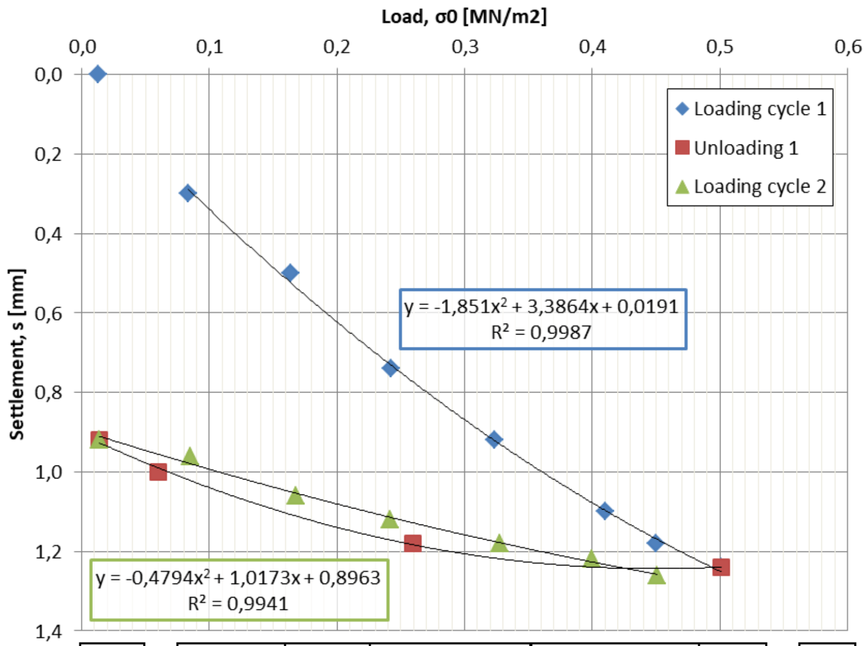


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,164	0,323	0,50	0,92	86
2	0,168	0,400	1,06	1,22	327

E_2/E_1 []
3,8

Plate load test results - Swedish method
S3-M10



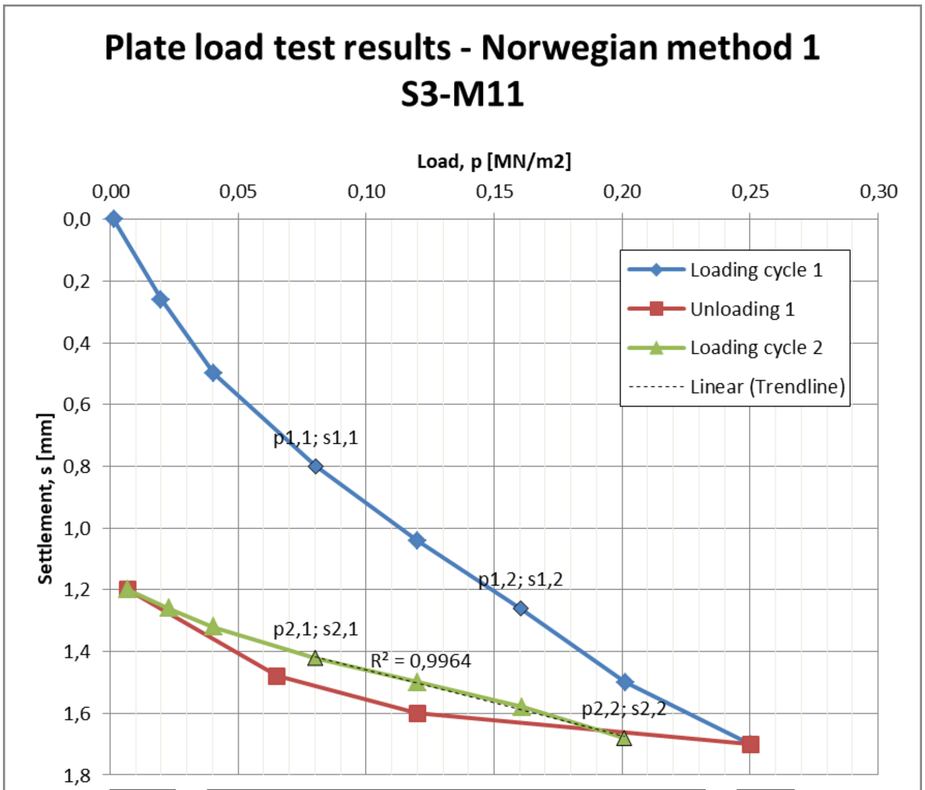
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0191	3,3864	-1,8510	91
2	0,8963	1,0173	-0,4794	290

E_2/E_1 []
3,2

S3-M11

Load [MN/m²]	Settlement [mm]
0,0015	0,00
0,0200	0,26
0,0406	0,50
0,0803	0,80
0,1200	1,04
0,1604	1,26
0,2012	1,50
0,2502	1,70
0,1200	1,60
0,0652	1,48
0,0069	1,20
0,0230	1,26
0,0404	1,32
0,0801	1,42
0,1201	1,50
0,1610	1,58
0,2008	1,68

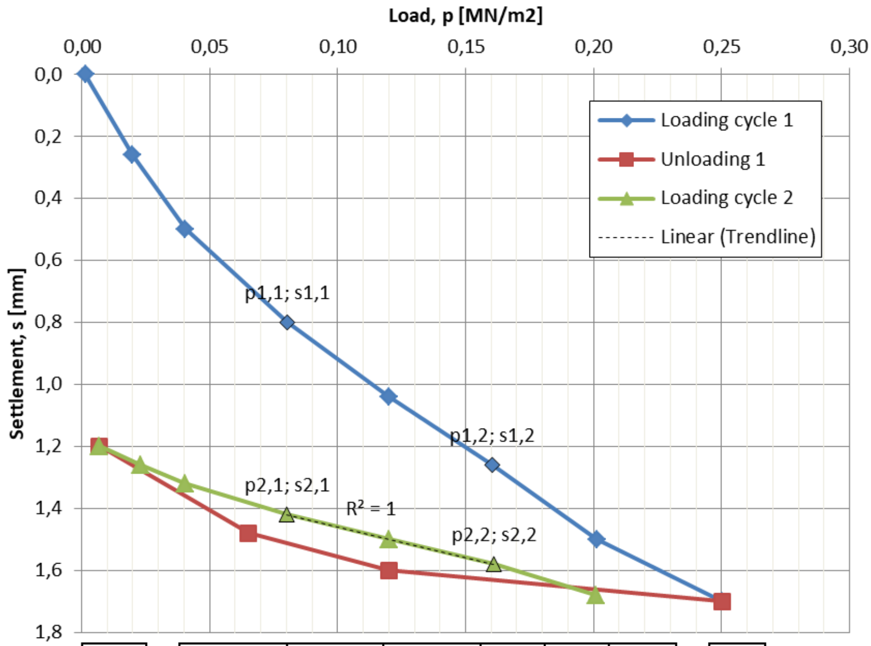


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,80	1,26	78
2	0,080	0,201	1,42	1,68	209

E_2/E_1 []
2,7

Plate load test results - Norwegian method 2
S3-M11

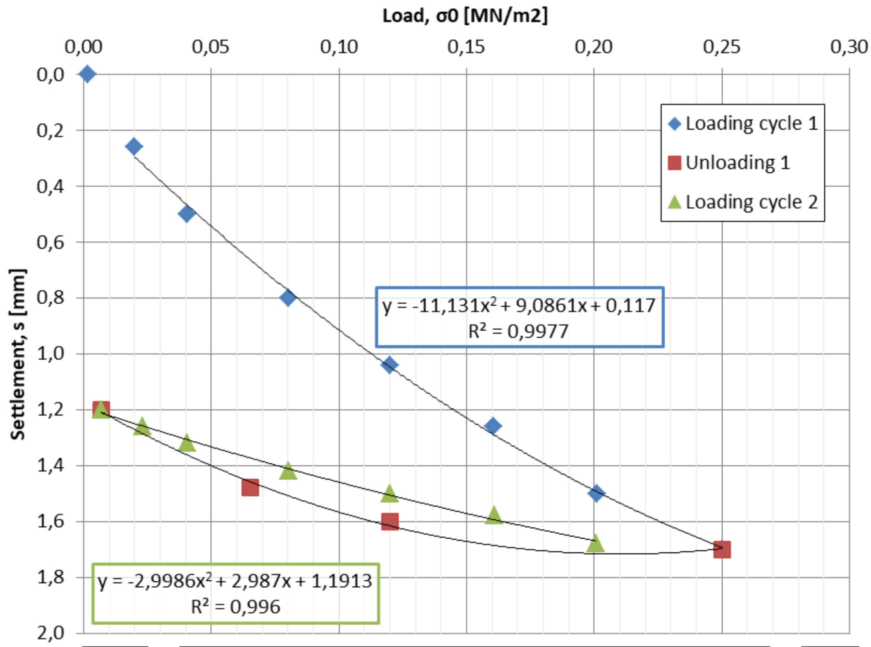


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	0,80	1,26	78
2	0,080	0,161	1,42	1,58	228

E_2/E_1 []
2,9

Plate load test results - Swedish method
S3-M11



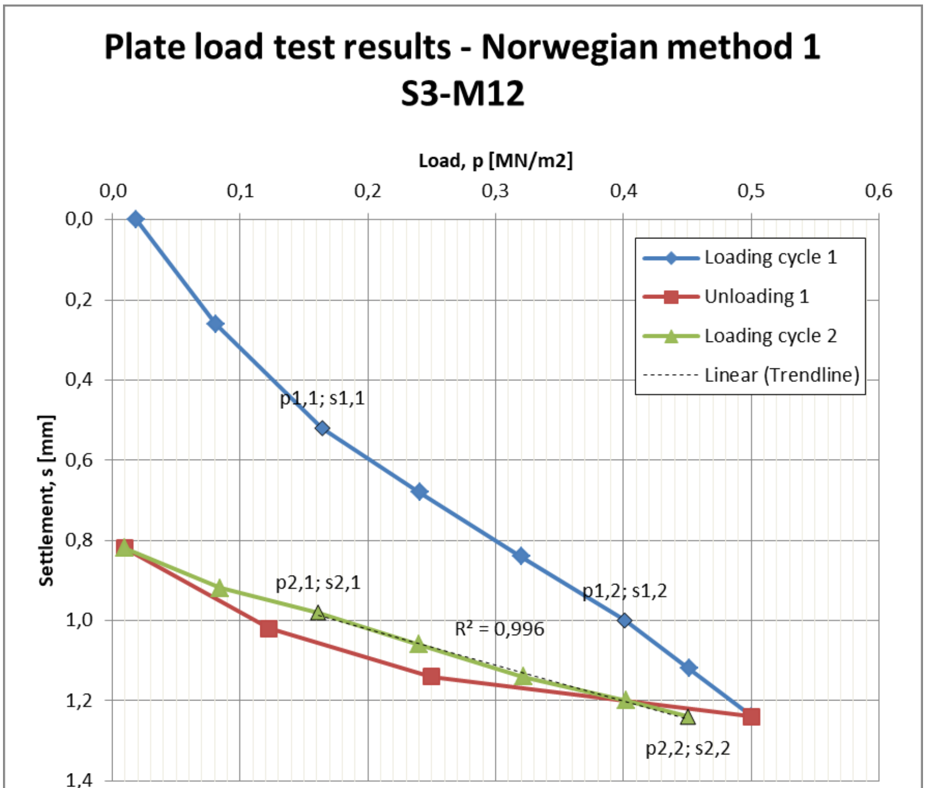
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1170	9,0861	-11,1310	71
2	1,1913	2,9870	-2,9986	201

E_2/E_1 []
2,8

S3-M12

Load [MN/m^2]	Settlement [mm]
0,0189	0,00
0,0810	0,26
0,1643	0,52
0,2405	0,68
0,3202	0,84
0,4009	1,00
0,4514	1,12
0,5006	1,24
0,2501	1,14
0,1226	1,02
0,0100	0,82
0,0843	0,92
0,1609	0,98
0,2402	1,06
0,3217	1,14
0,4022	1,20
0,4504	1,24

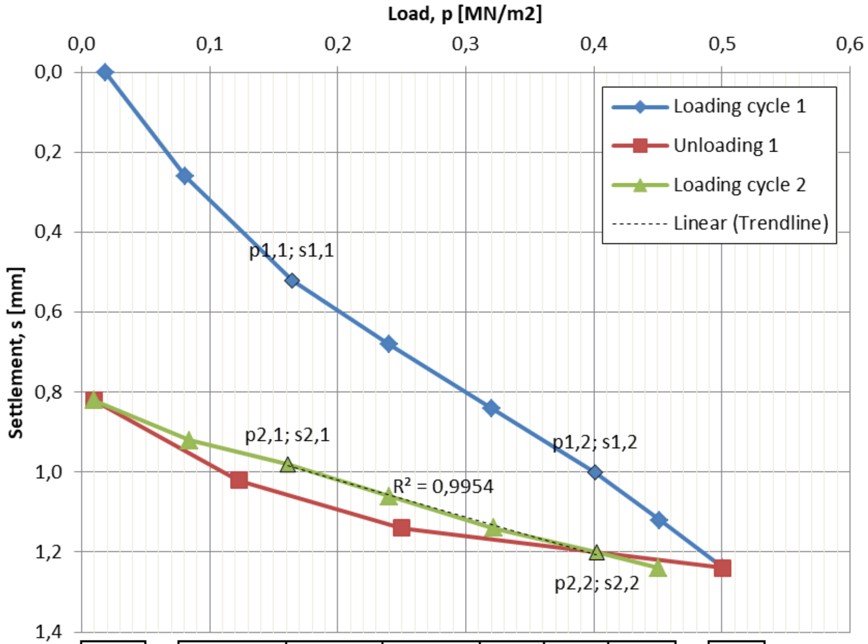


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,164	0,320	0,52	0,84	110
2	0,161	0,450	0,98	1,24	251

E_2/E_1 []
2,3

Plate load test results - Norwegian method 2
S3-M12

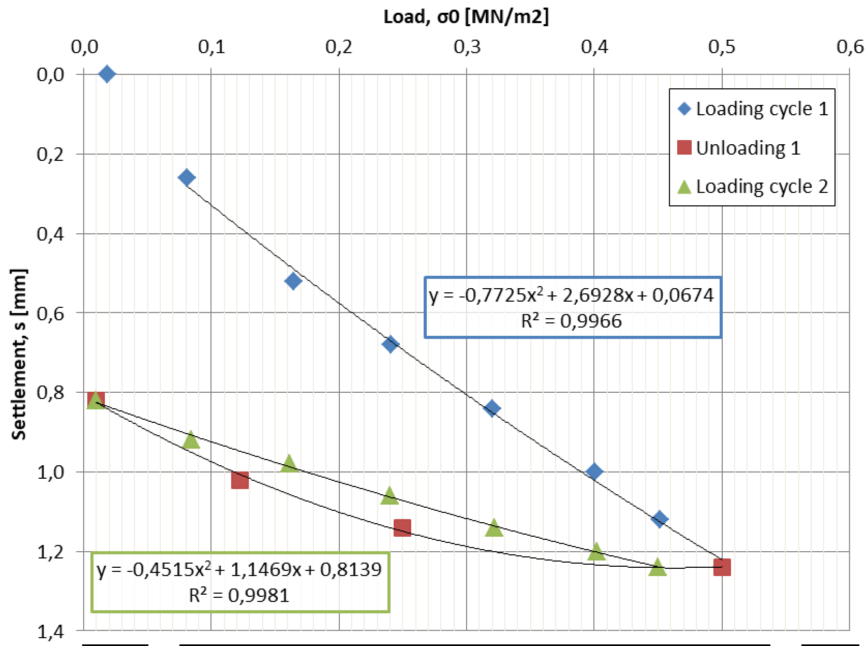


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,164	0,320	0,52	0,84	110
2	0,161	0,402	0,98	1,20	247

E_2/E_1 []
2,3

Plate load test results - Swedish method
S3-M12



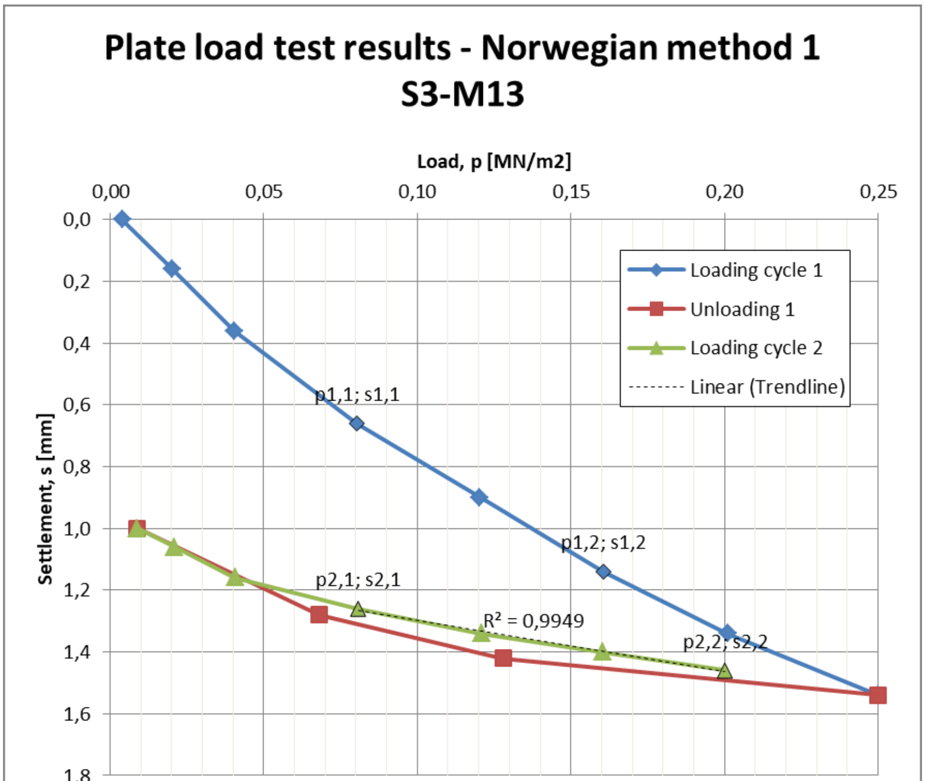
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0674	2,6928	-0,7725	98
2	0,8139	1,1469	-0,4515	244

E_2/E_1 []
2,5

S3-M13

Load [MN/m²]	Settlement [mm]
0,0039	0,00
0,0202	0,16
0,0404	0,36
0,0803	0,66
0,1203	0,90
0,1606	1,14
0,2010	1,34
0,2500	1,54
0,1279	1,42
0,0681	1,28
0,0089	1,00
0,0210	1,06
0,0406	1,16
0,0807	1,26
0,1208	1,34
0,1605	1,40
0,2001	1,46

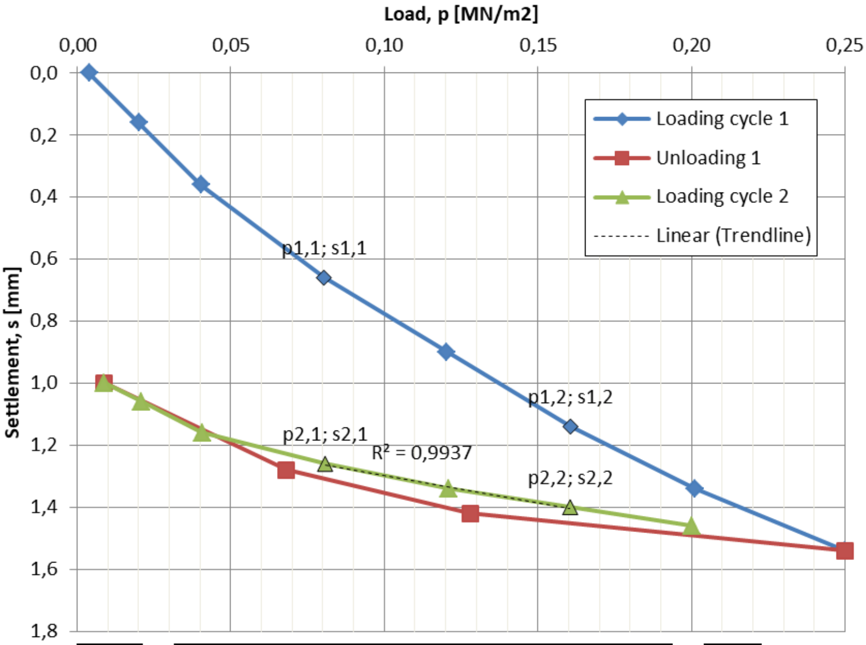


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,161	0,66	1,14	75
2	0,081	0,200	1,26	1,46	269

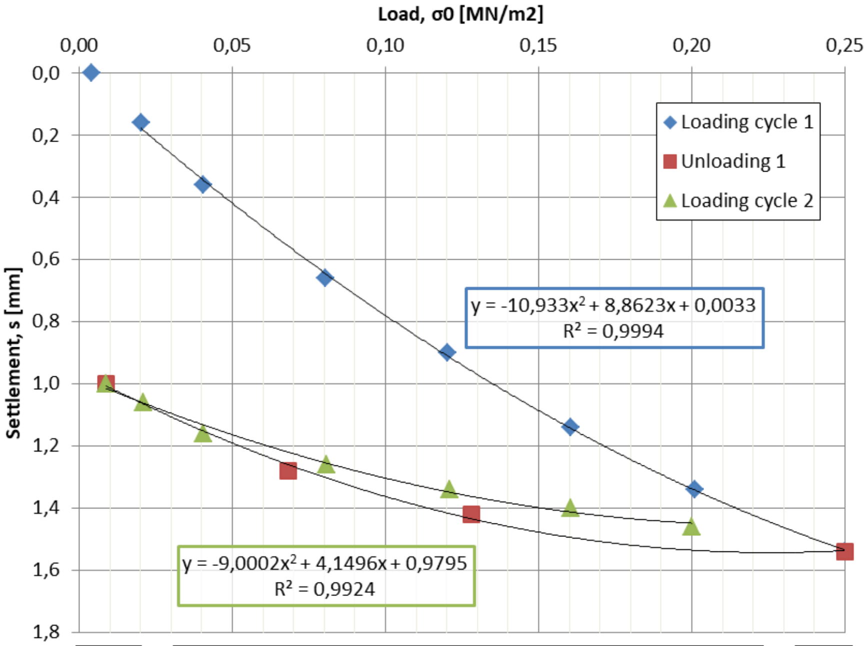
E_2/E_1 []
3,6

Plate load test results - Norwegian method 2
S3-M13



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,161	0,66	1,14	75	3,4
	2	0,081	0,161	1,26	1,40	257	

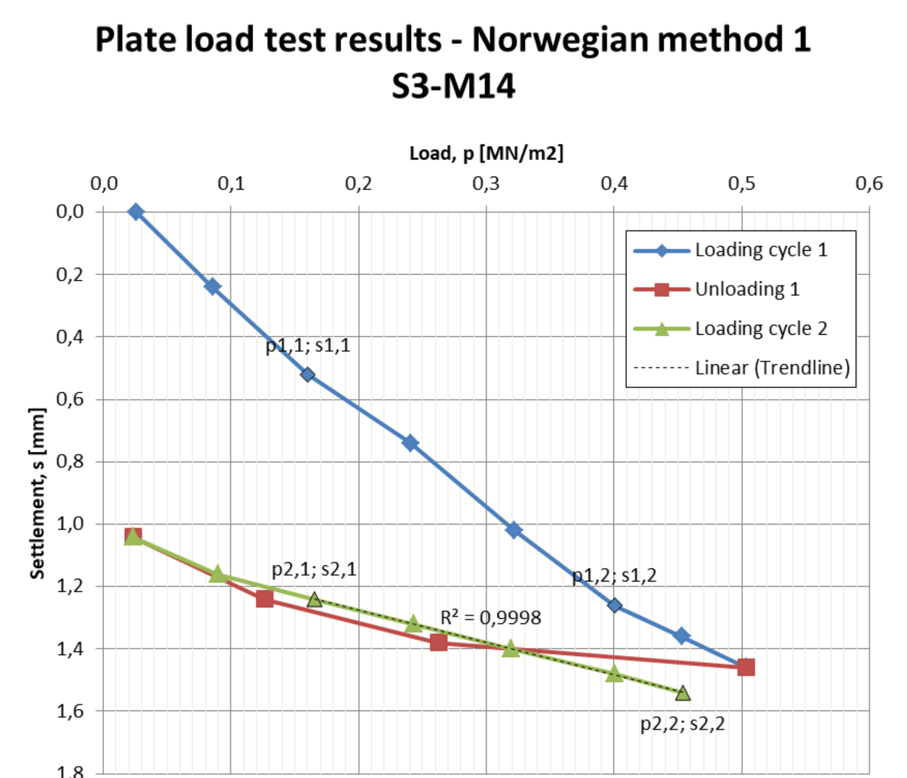
Plate load test results - Swedish method
S3-M13



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,0033	8,8623	-10,9330	73	3,2
	2	0,9795	4,1496	-9,0002	237	

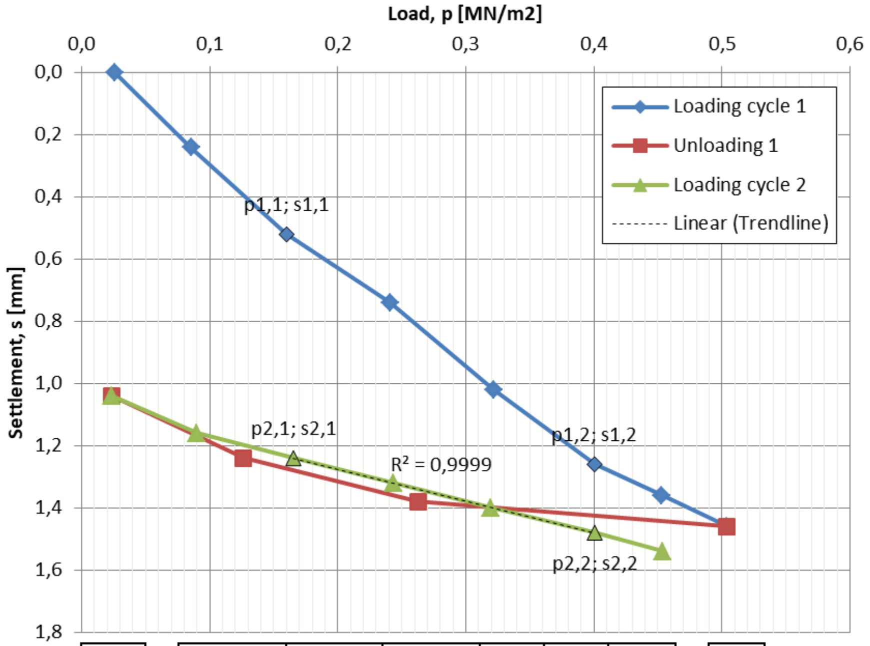
S3-M14

Load [MN/m²]	Settlement [mm]
0,0261	0,00
0,0857	0,24
0,1600	0,52
0,2406	0,74
0,3215	1,02
0,4005	1,26
0,4529	1,36
0,5039	1,46
0,2625	1,38
0,1263	1,24
0,0233	1,04
0,0898	1,16
0,1653	1,24
0,2430	1,32
0,3198	1,40
0,4006	1,48
0,4539	1,54



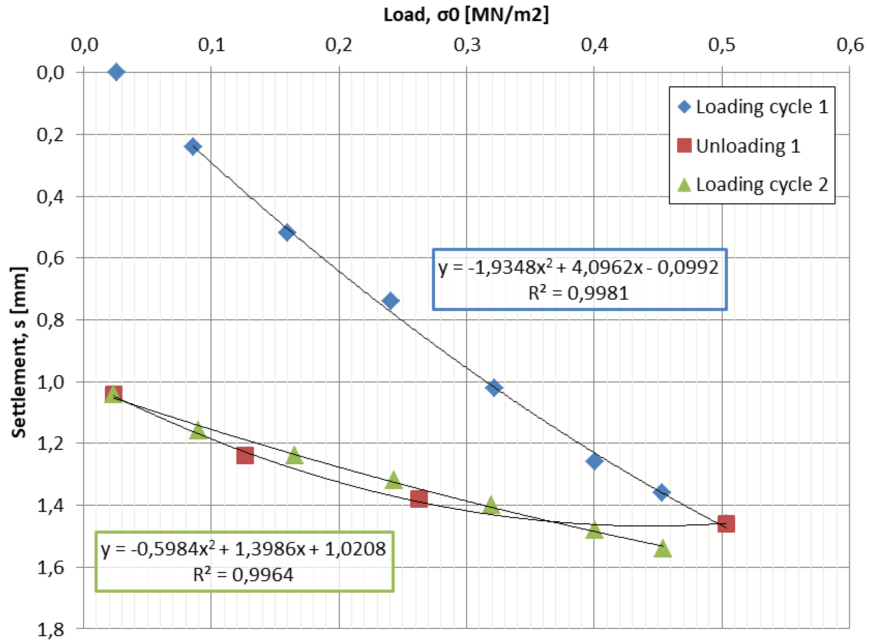
d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,160	0,322	0,52	1,02	73	3,0
	2	0,165	0,454	1,24	1,54	216	

Plate load test results - Norwegian method 2
S3-M14



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,160	0,322	0,52	1,02	73	3,0
	2	0,165	0,401	1,24	1,48	221	

Plate load test results - Swedish method
S3-M14

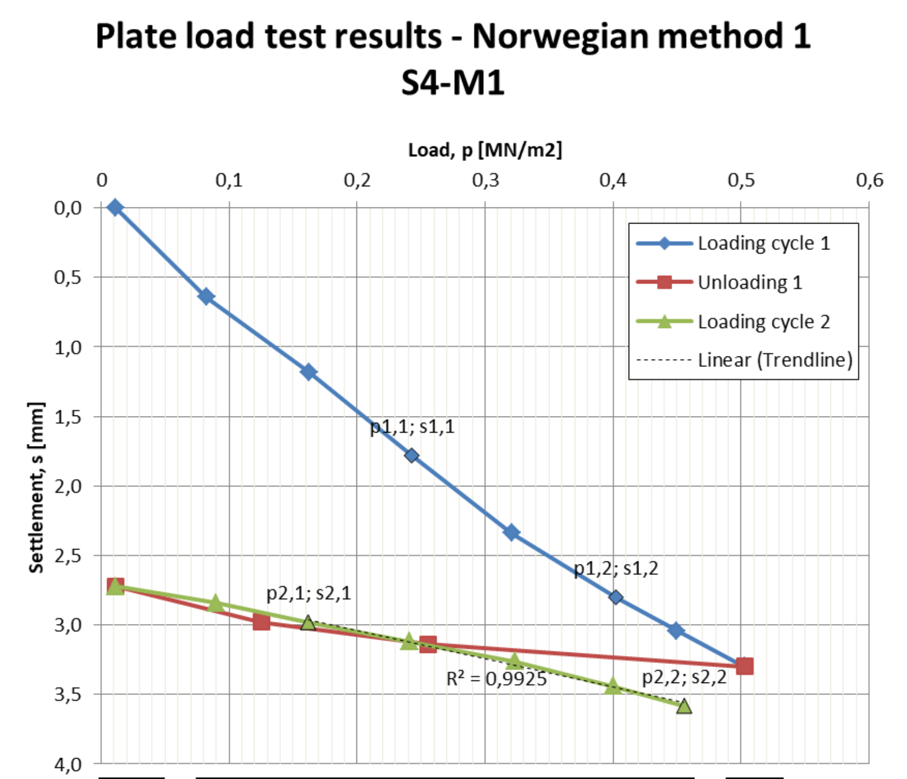


r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	0,0992	4,0962	-1,9348	72	2,8
	2	1,0208	1,3986	-0,5984	205	

Site 4: The motorway upgrading project

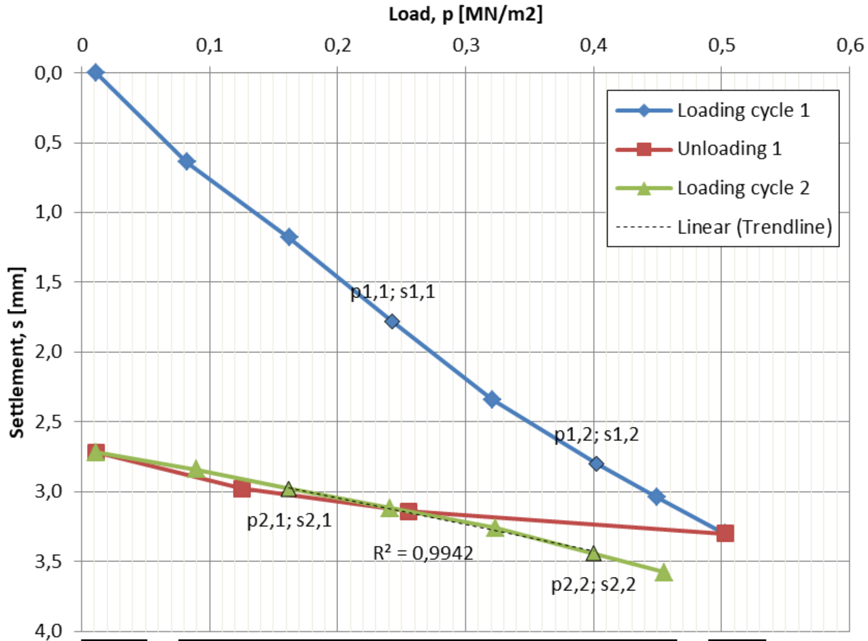
S4-M1

Load [MN/m²]	Settlement [mm]
0,0114	0,00
0,0824	0,64
0,1622	1,18
0,2426	1,78
0,3207	2,34
0,4022	2,80
0,4497	3,04
0,5027	3,30
0,2552	3,14
0,1253	2,98
0,0110	2,72
0,0895	2,84
0,1617	2,98
0,2413	3,12
0,3234	3,26
0,4000	3,44
0,4556	3,58



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,162	0,321	1,18	2,34	31	3,6
	2	0,162	0,456	2,98	3,58	110	

Plate load test results - Norwegian method 2
S4-M1

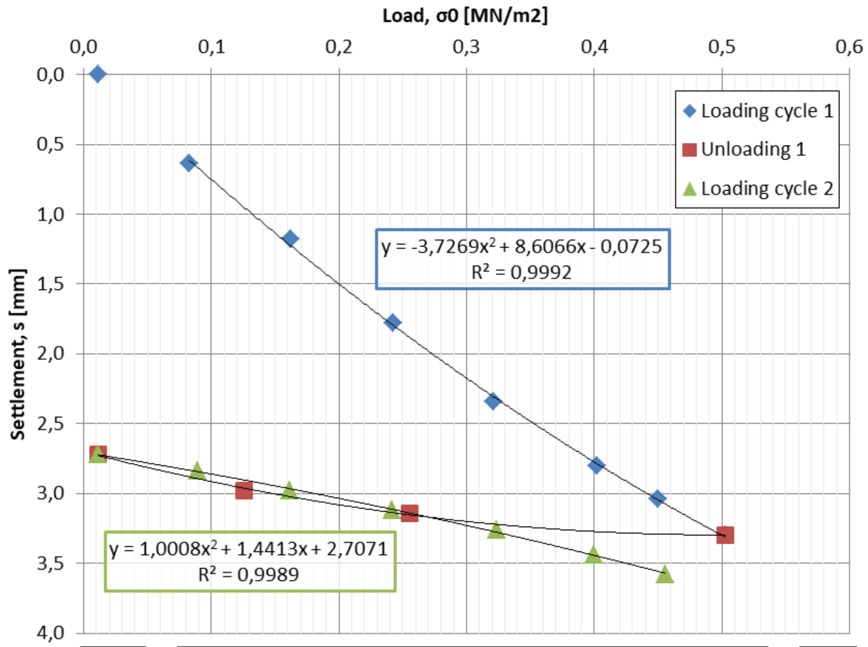


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,162	0,321	1,18	2,34	31
2	0,162	0,400	2,98	3,44	117

E_2/E_1 []
3,8

Plate load test results - Swedish method
S4-M1



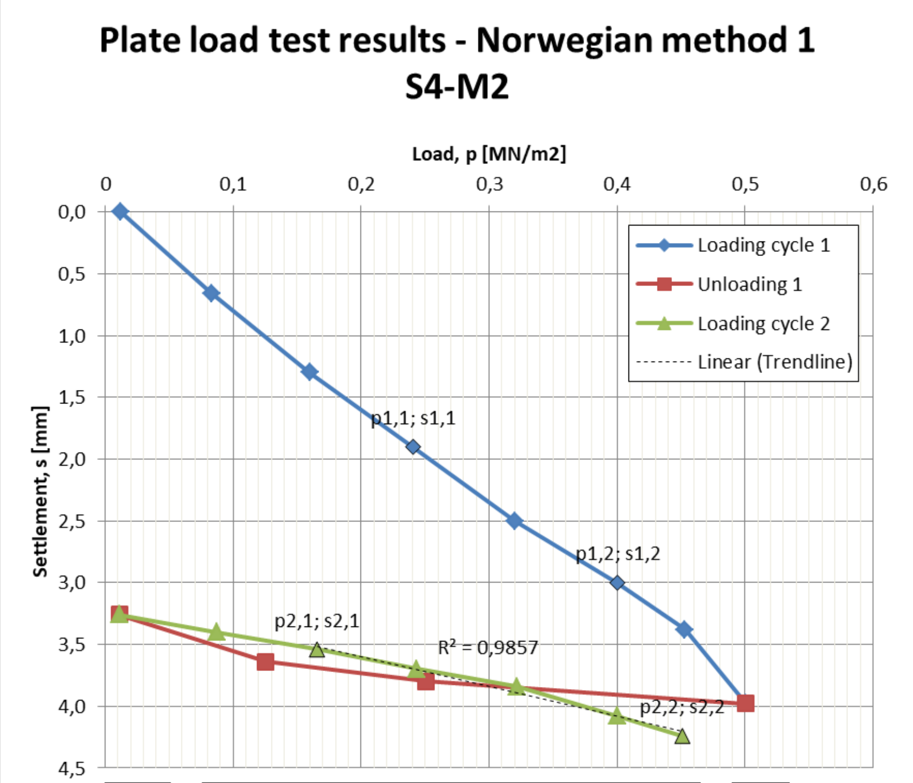
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0725	8,6066	-3,7269	33
2	2,7071	1,4413	1,0008	116

E_2/E_1 []
3,5

S4-M2

Load [MN/m²]	Settlement [mm]
0,0124	0,00
0,0831	0,66
0,1598	1,30
0,2406	1,90
0,3200	2,50
0,4002	3,00
0,4531	3,38
0,5008	3,98
0,2508	3,80
0,1256	3,64
0,0110	3,26
0,0875	3,40
0,1655	3,54
0,2436	3,70
0,3215	3,84
0,4006	4,08
0,4510	4,24

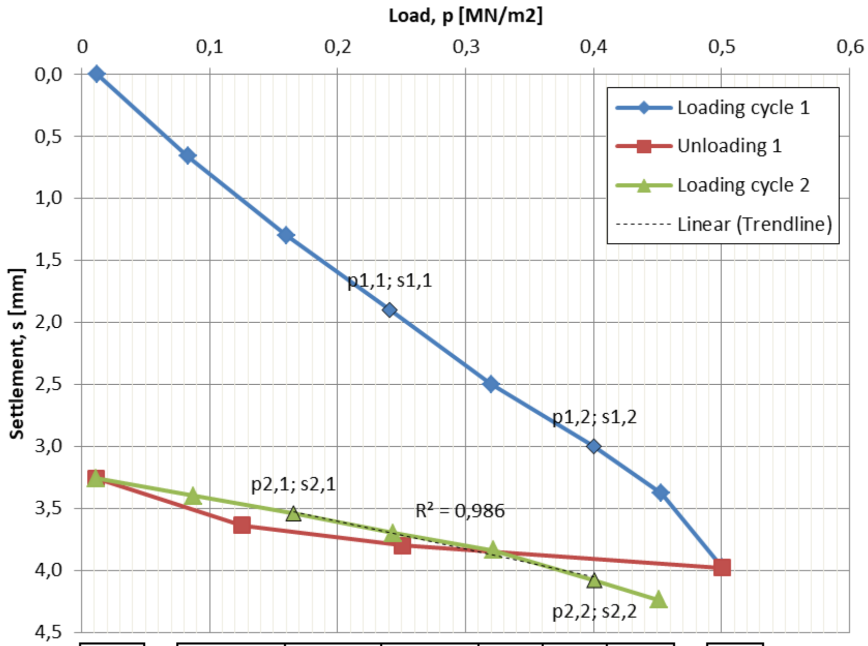


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,320	1,30	2,50	30
2	0,166	0,451	3,54	4,24	92

E_2/E_1 []
3,1

Plate load test results - Norwegian method 2
S4-M2

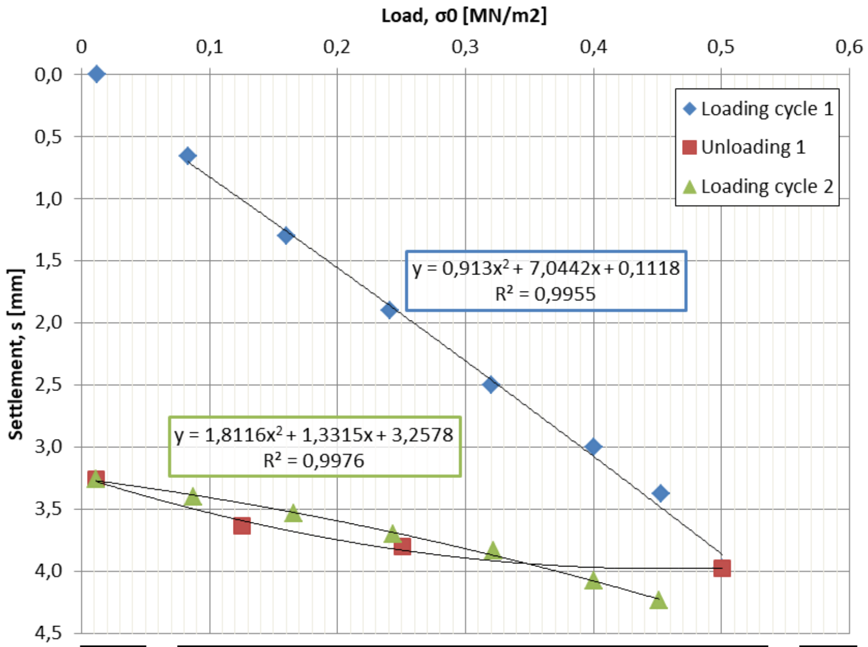


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,320	1,30	2,50	30
2	0,166	0,401	3,54	4,08	98

E_2/E_1 []
3,3

Plate load test results - Swedish method
S4-M2



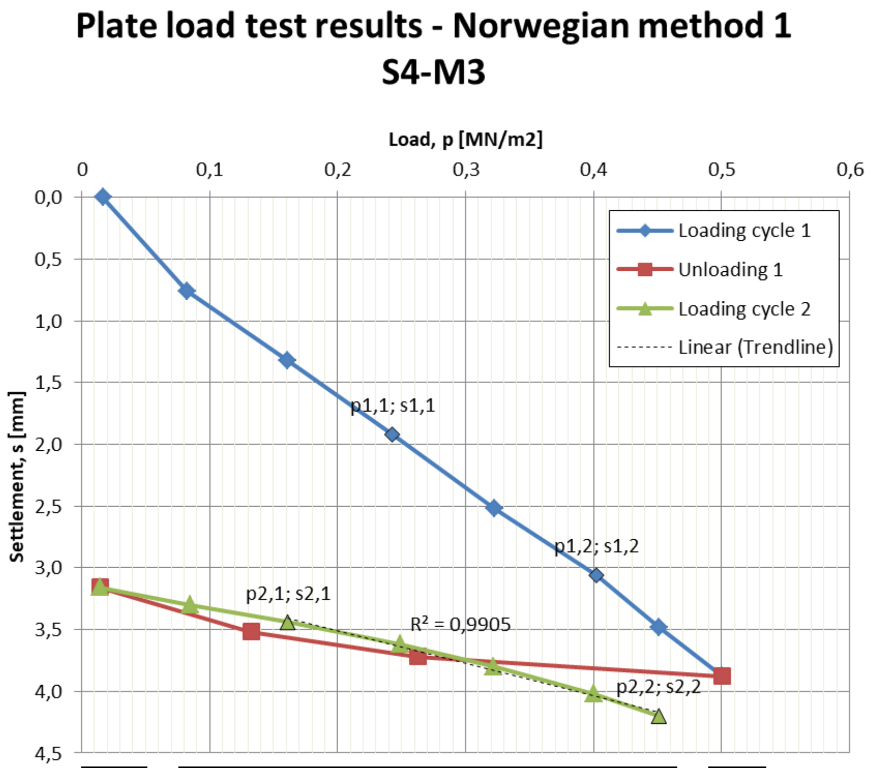
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1118	7,0442	0,9130	30
2	3,2578	1,3315	1,8116	101

E_2/E_1 []
3,4

S4-M3

Load [MN/m²]	**Settlement [mm]**
0,0166	0,00
0,0824	0,76
0,1607	1,32
0,2426	1,92
0,3229	2,52
0,4022	3,06
0,4510	3,48
0,5006	3,88
0,2627	3,72
0,1325	3,52
0,0142	3,16
0,0850	3,30
0,1609	3,44
0,2494	3,62
0,3215	3,80
0,4006	4,02
0,4510	4,20

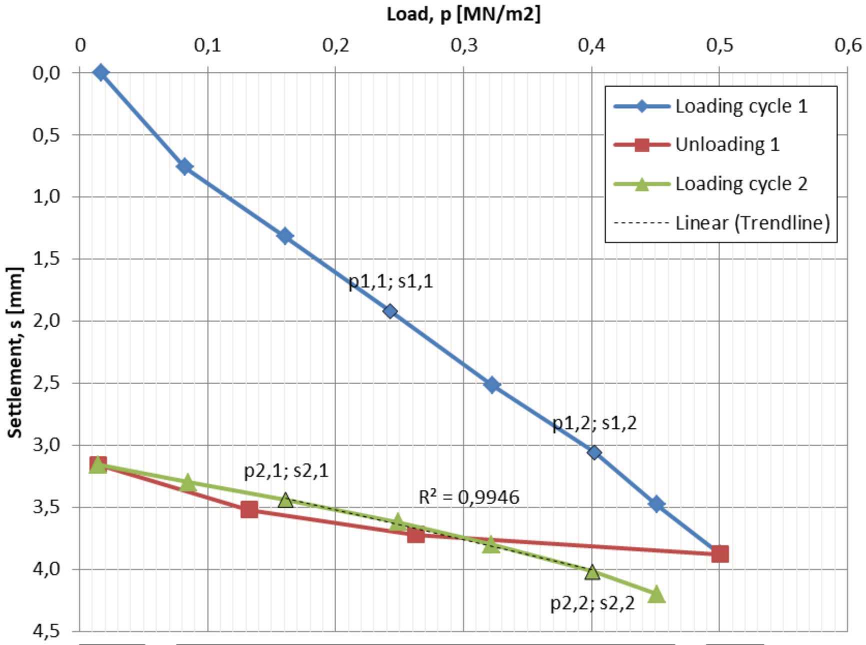


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,323	1,32	2,52	30
2	0,161	0,451	3,44	4,20	86

E_2/E_1 []
2,8

Plate load test results - Norwegian method 2
S4-M3

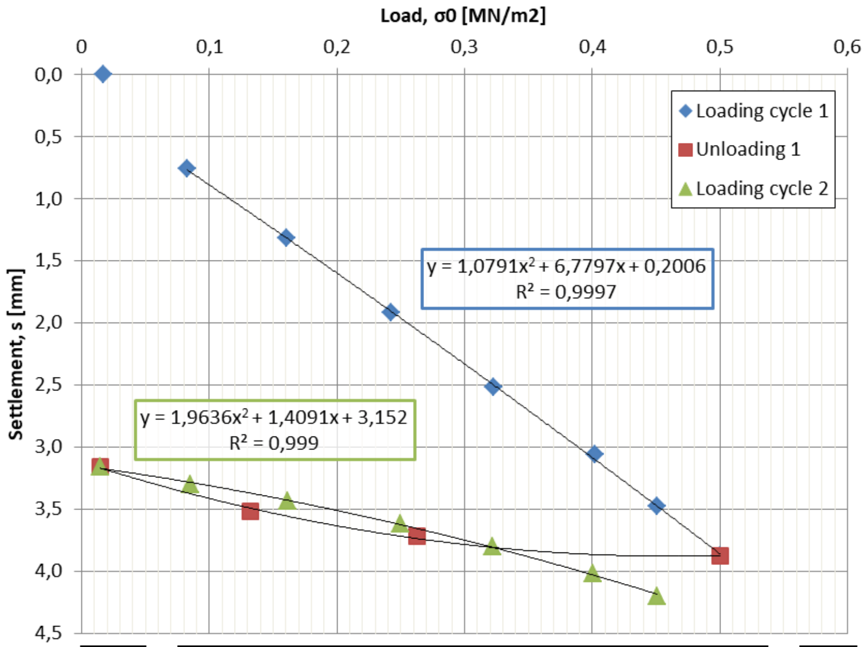


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,323	1,32	2,52	30
2	0,161	0,401	3,44	4,02	93

E_2/E_1 []
3,1

Plate load test results - Swedish method
S4-M3



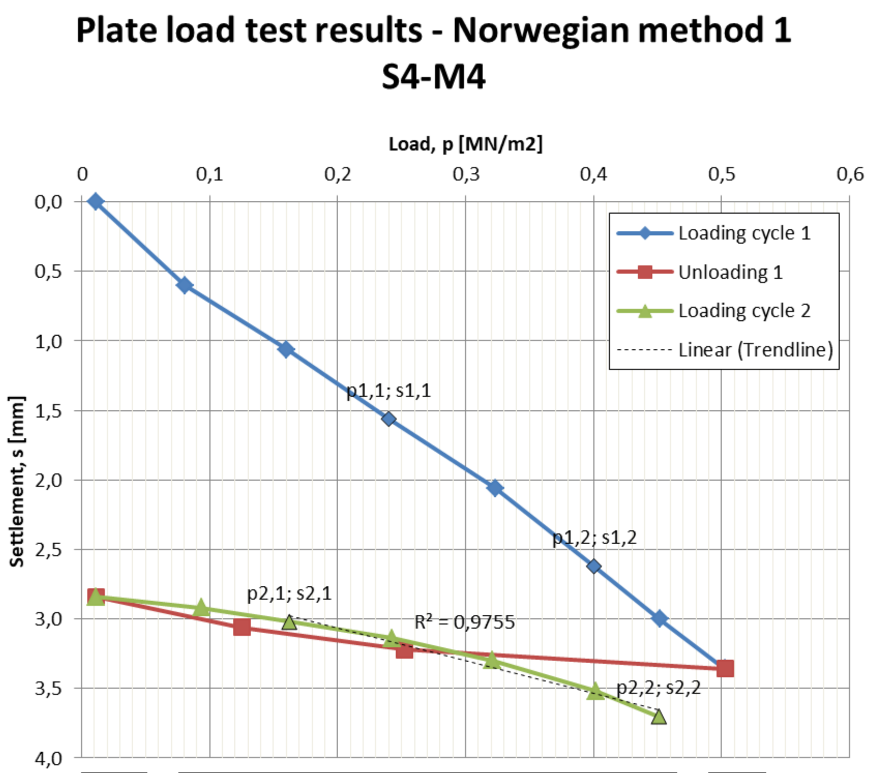
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,2006	6,7797	1,0791	31
2	3,1520	1,4091	1,9636	94

E_2/E_1 []
3,1

S4-M4

Load [MN/m²]	**Settlement [mm]**
0,0113	0,00
0,0806	0,60
0,1602	1,06
0,2400	1,56
0,3234	2,06
0,4003	2,62
0,4517	3,00
0,5026	3,36
0,2526	3,22
0,1250	3,06
0,0113	2,84
0,0935	2,92
0,1622	3,02
0,2429	3,14
0,3214	3,30
0,4017	3,52
0,4510	3,70

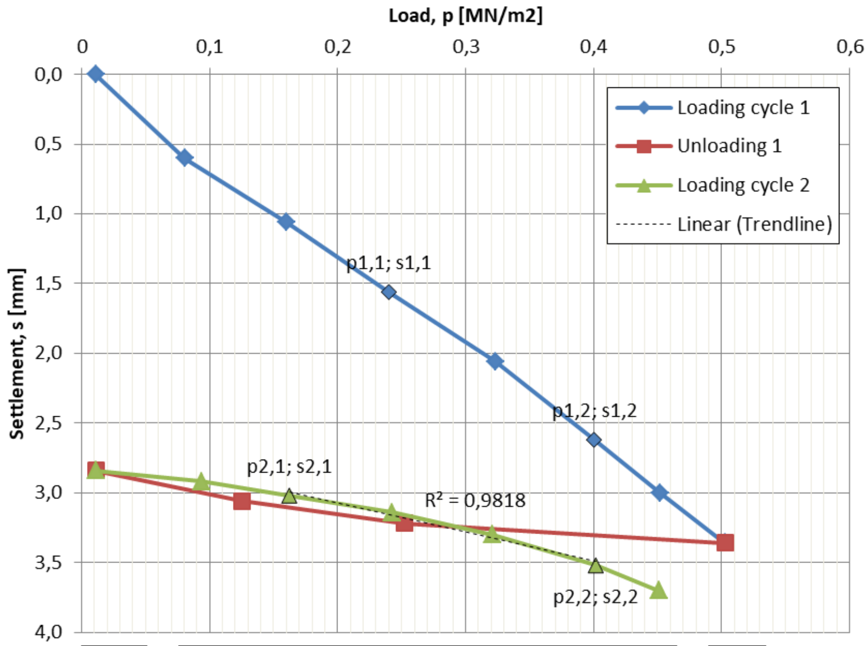


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,323	1,06	2,06	37
2	0,162	0,451	3,02	3,70	96

E_2/E_1 []
2,6

Plate load test results - Norwegian method 2
S4-M4

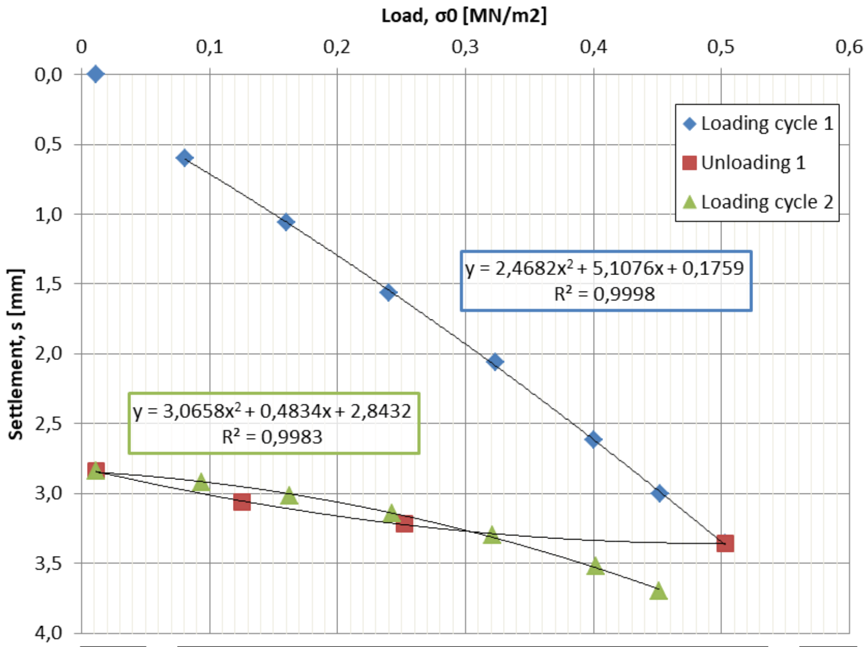


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,323	1,06	2,06	37
2	0,162	0,402	3,02	3,52	108

E_2/E_1 []
2,9

Plate load test results - Swedish method
S4-M4



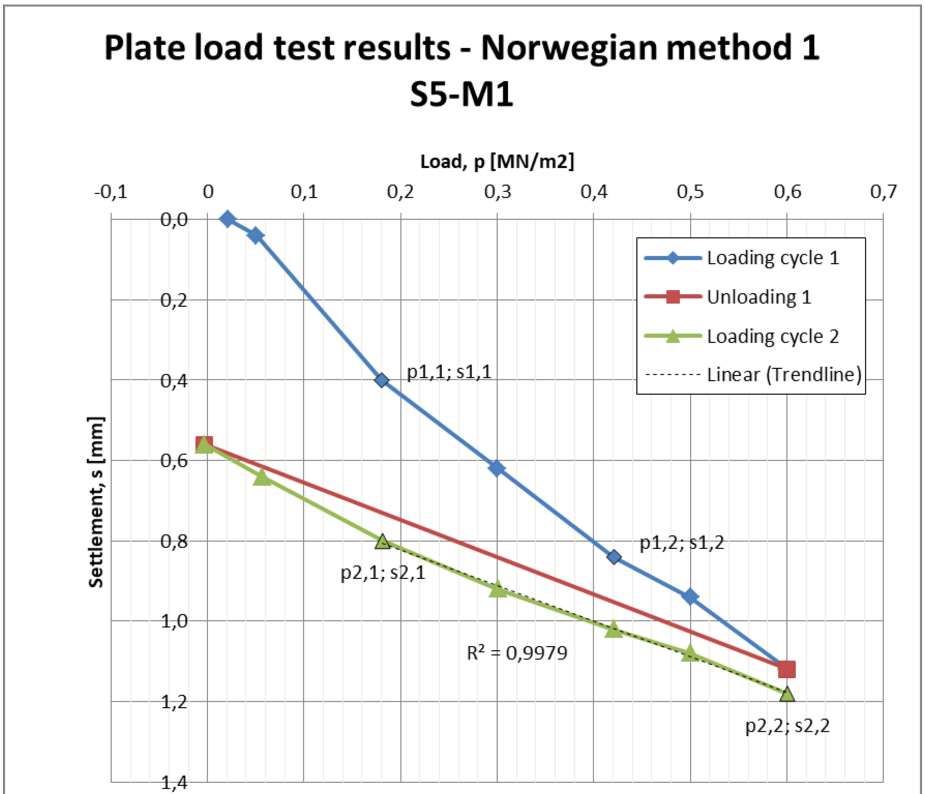
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1759	5,1076	2,4682	35
2	2,8432	0,4834	3,0658	111

E_2/E_1 []
3,1

S4-M5

Load [MN/m²]	**Settlement [mm]**
0,0215	0,00
0,0503	0,04
0,1803	0,40
0,3004	0,62
0,4210	0,84
0,5003	0,94
0,6005	1,12
-0,0032	0,56
0,0564	0,64
0,1812	0,80
0,3006	0,92
0,4207	1,02
0,5000	1,08
0,6004	1,18

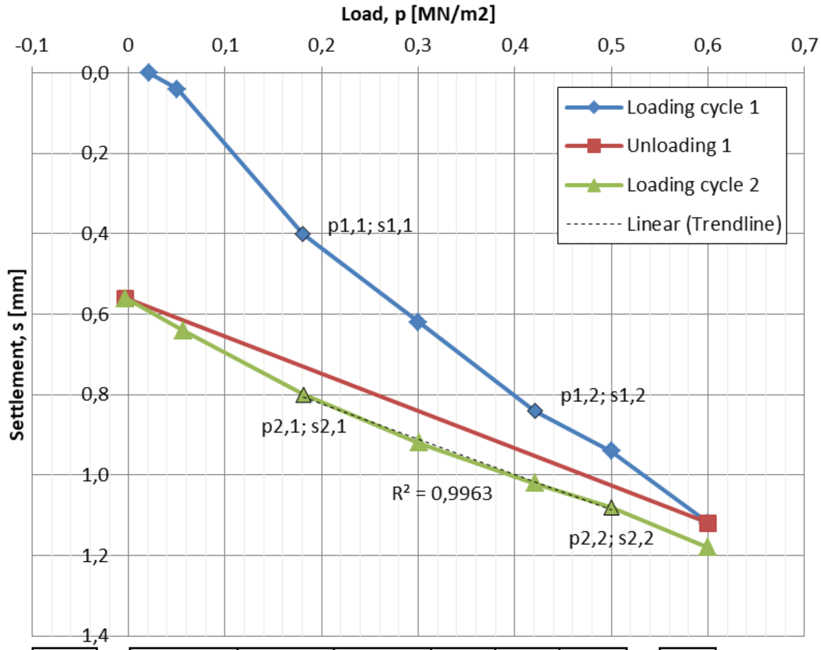


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,40	0,84	123
2	0,181	0,600	0,80	1,18	248

E_2/E_1 []
2,0

Plate load test results - Norwegian method 2
S5-M1

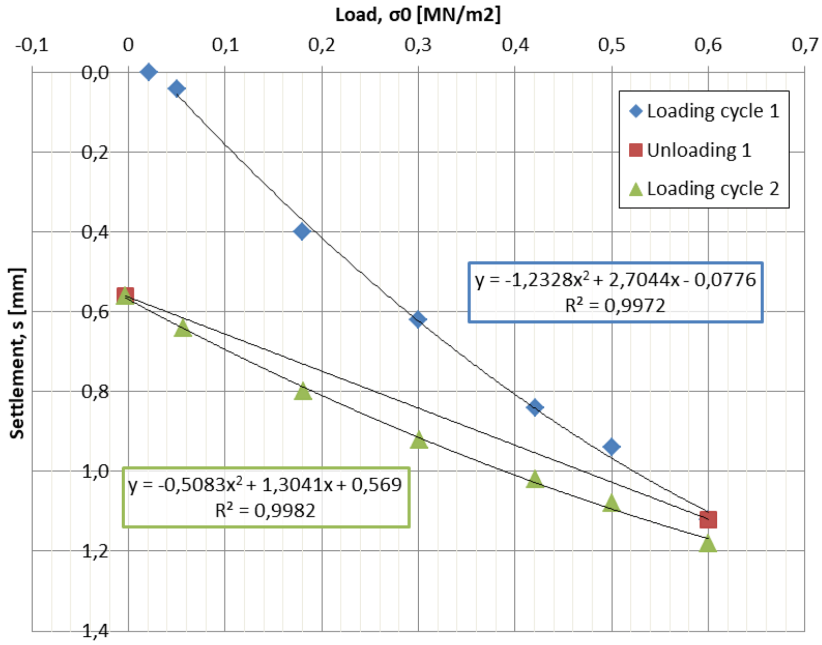


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,40	0,84	123
2	0,181	0,500	0,80	1,08	256

E_2/E_1 []
2,1

Plate load test results - Swedish method
S5-M1



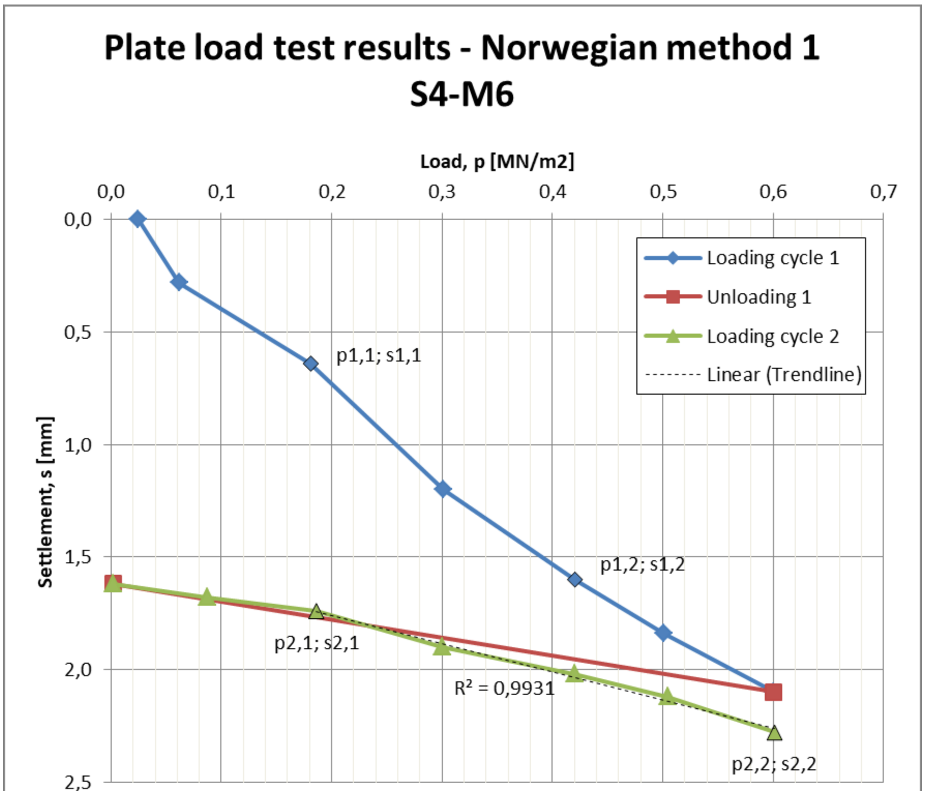
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0776	2,7044	-1,2328	115
2	0,5690	1,3041	-0,5083	225

E_2/E_1 []
2,0

S4-M6

Load [MN/m²]	Settlement [mm]
0,0248	0,00
0,0616	0,28
0,1810	0,64
0,3014	1,20
0,4204	1,60
0,5010	1,84
0,6005	2,10
0,0022	1,62
0,0875	1,68
0,1860	1,74
0,3007	1,90
0,4200	2,02
0,5044	2,12
0,6013	2,28

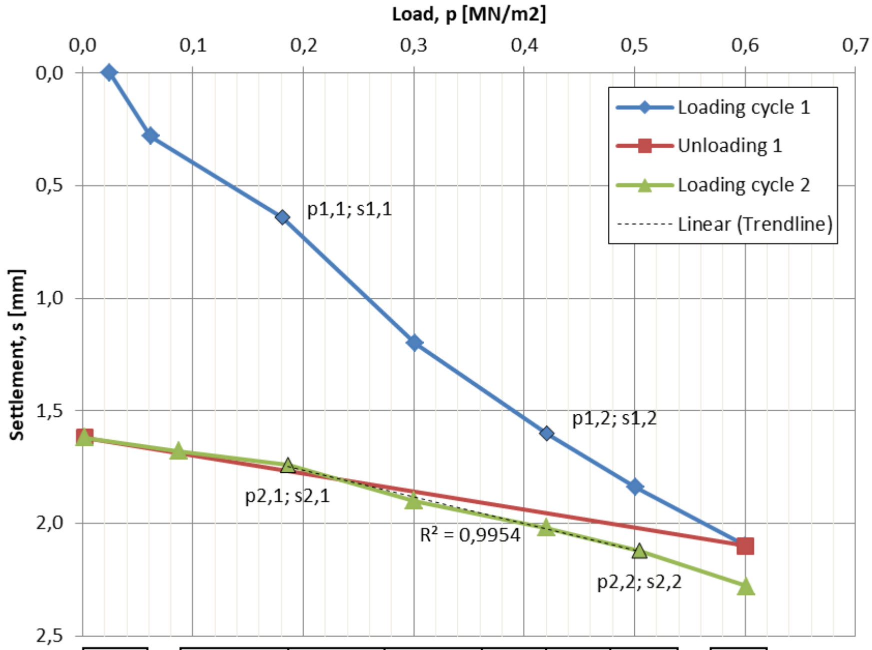


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,64	1,60	56
2	0,186	0,601	1,74	2,28	173

E_2/E_1 []
3,1

Plate load test results - Norwegian method 2
S4-M6

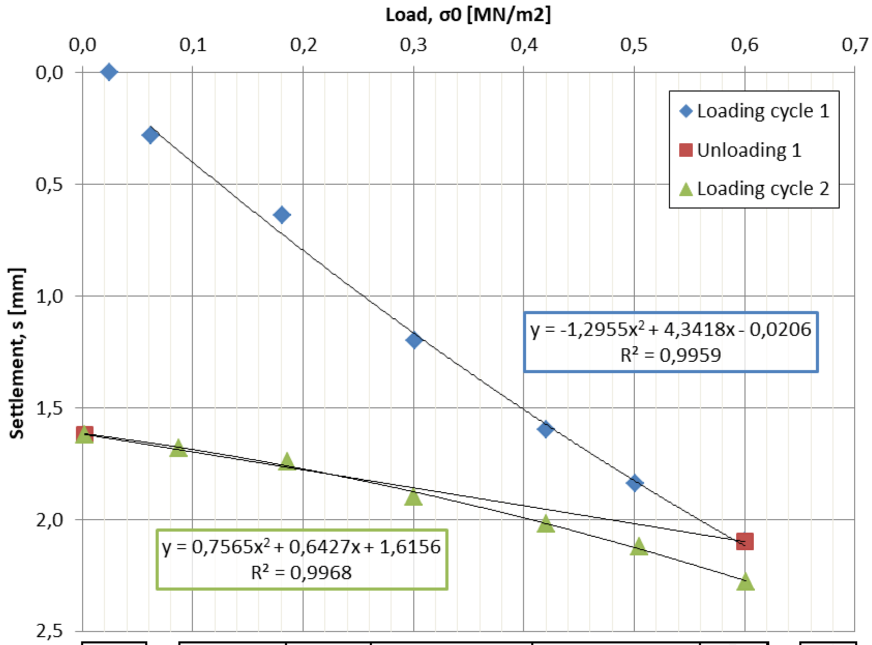


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,64	1,60	56
2	0,186	0,504	1,74	2,12	189

E_2/E_1 []
3,4

Plate load test results - Swedish method
S4-M6



r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0206	4,3418	-1,2955	63
2	1,6156	0,6427	0,7565	205

E_2/E_1 []
3,2

S4-M7

Load [MN/m²]	**Settlement [mm]**
0,0219	0,00
0,0534	0,28
0,1812	0,78
0,3014	1,18
0,4211	1,58
0,5005	1,86
0,6001	2,14
0,0025	1,64
0,0656	1,72
0,1839	1,86
0,3089	2,00
0,4217	2,12
0,5005	2,22
0,6009	2,38

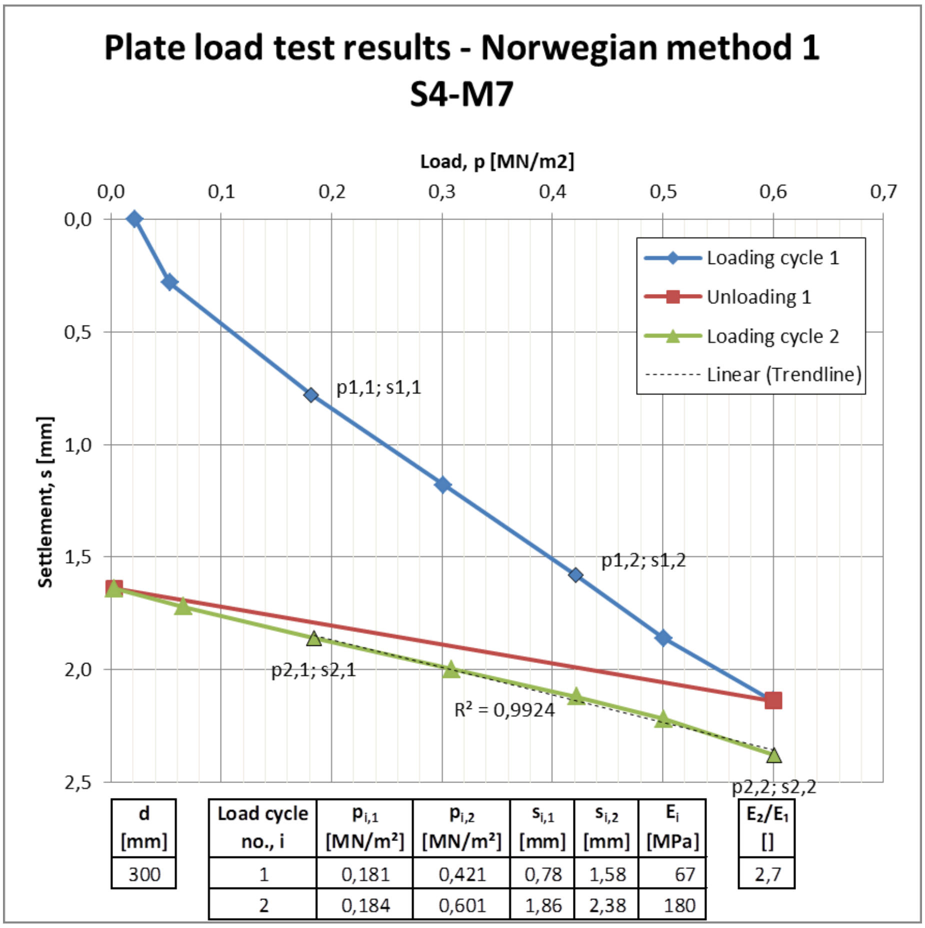
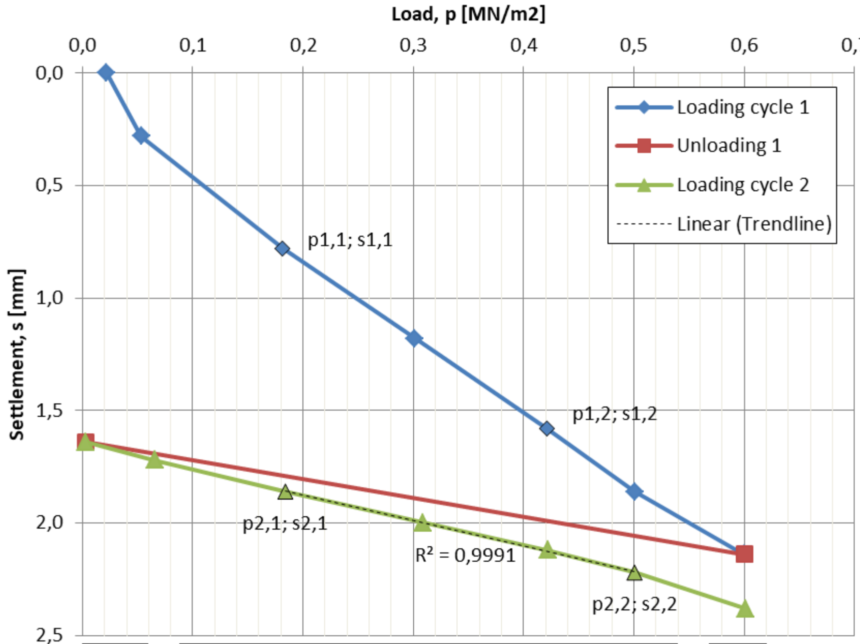


Plate load test results - Norwegian method 2
S4-M7

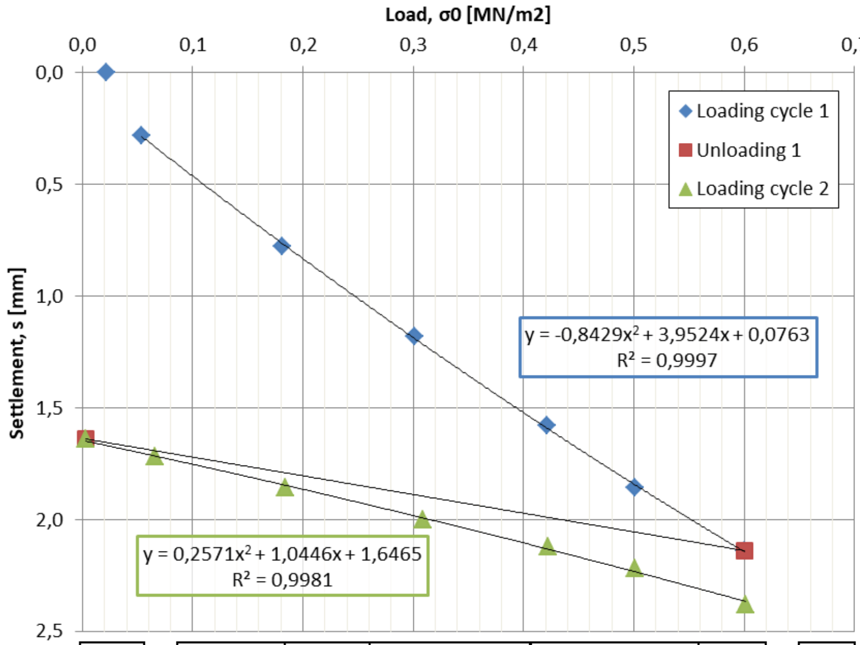


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,421	0,78	1,58	67
2	0,184	0,501	1,86	2,22	198

E_2/E_1 []
2,9

Plate load test results - Swedish method
S4-M7



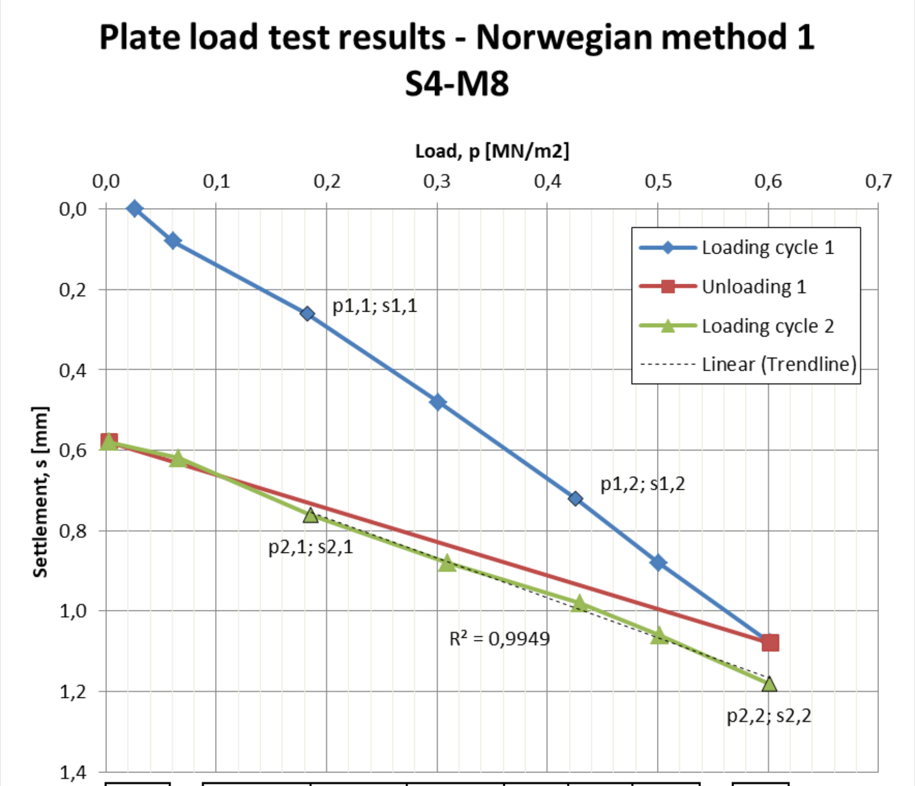
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0763	3,9524	-0,8429	65
2	1,6465	1,0446	0,2571	188

E_2/E_1 []
2,9

S4-M8

Load [MN/m²]	Settlement [mm]
0,0267	0,00
0,0609	0,08
0,1824	0,26
0,3014	0,48
0,4254	0,72
0,5009	0,88
0,6025	1,08
0,0031	0,58
0,0659	0,62
0,1854	0,76
0,3092	0,88
0,4292	0,98
0,5015	1,06
0,6012	1,18

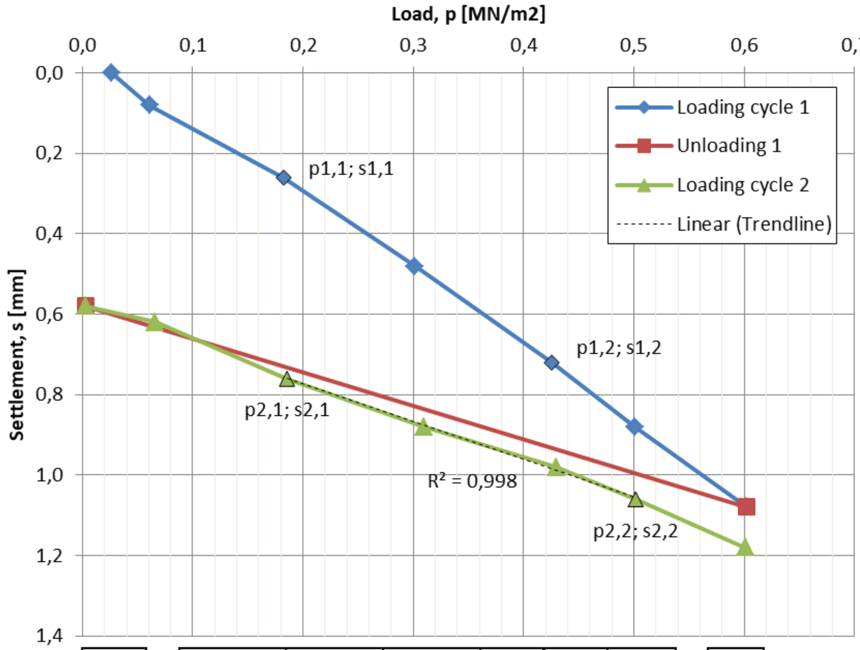


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,425	0,26	0,72	119
2	0,185	0,601	0,76	1,18	223

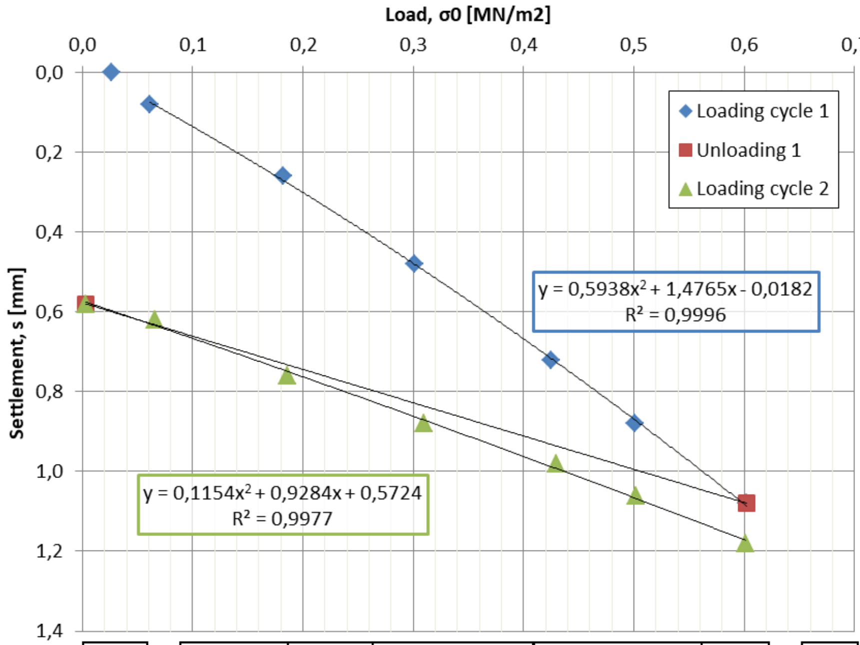
E_2/E_1 []
1,9

Plate load test results - Norwegian method 2
S4-M8



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,182	0,425	0,26	0,72	119	2,0
	2	0,185	0,502	0,76	1,06	237	

Plate load test results - Swedish method
S4-M8



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,0182	1,4765	0,5938	123	1,8
	2	0,5724	0,9284	0,1154	225	

S4-M9

Load [MN/m²]	**Settlement [mm]**
0,0233	0,00
0,0503	0,04
0,1805	0,22
0,3014	0,46
0,4225	0,68
0,5010	0,82
0,6020	1,00
0,0028	0,64
0,0612	0,68
0,1949	0,80
0,3013	0,86
0,4261	0,96
0,5034	1,02
0,6056	1,12

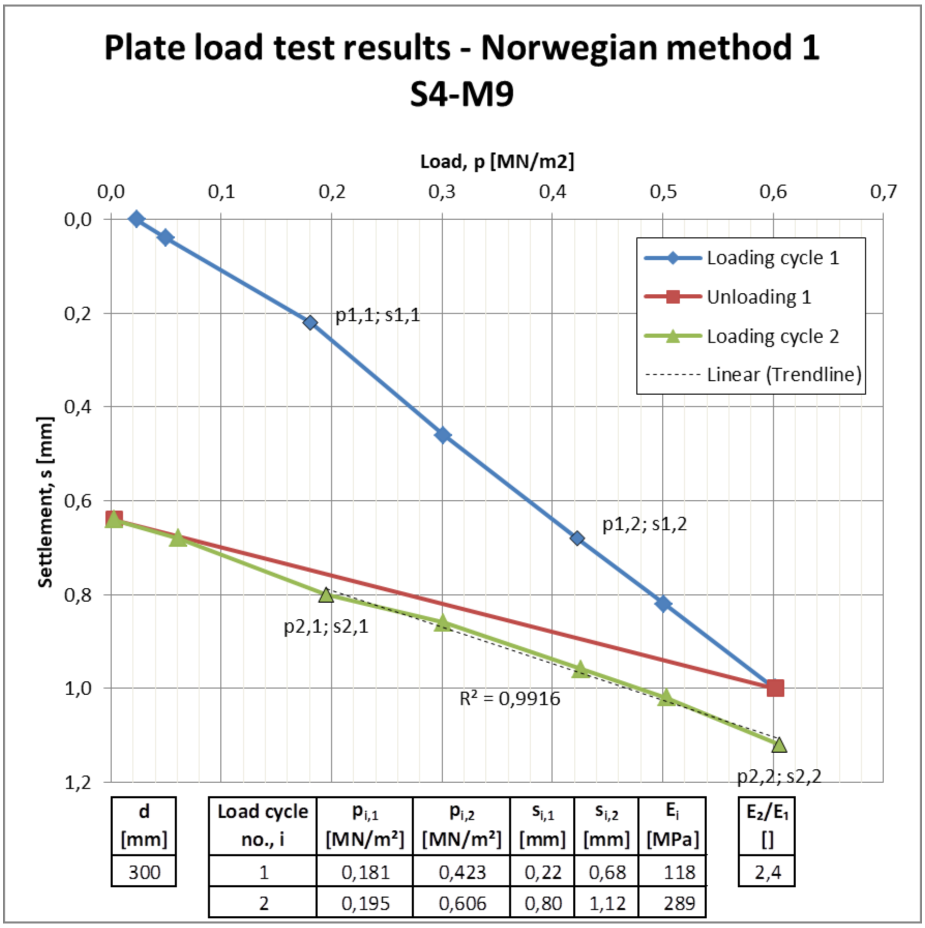
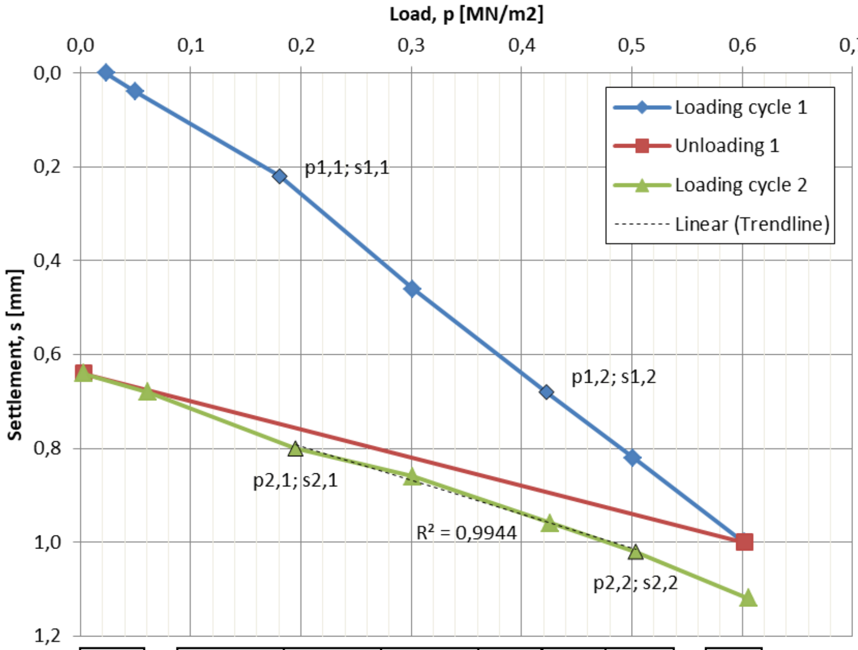
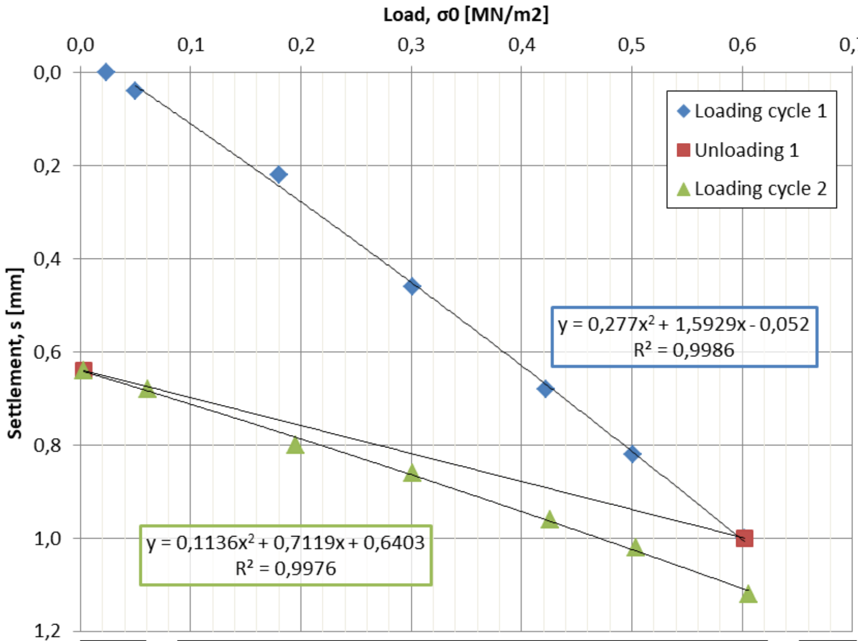


Plate load test results - Norwegian method 2
S4-M9



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,181	0,423	0,22	0,68	118	2,7
	2	0,195	0,503	0,80	1,02	316	

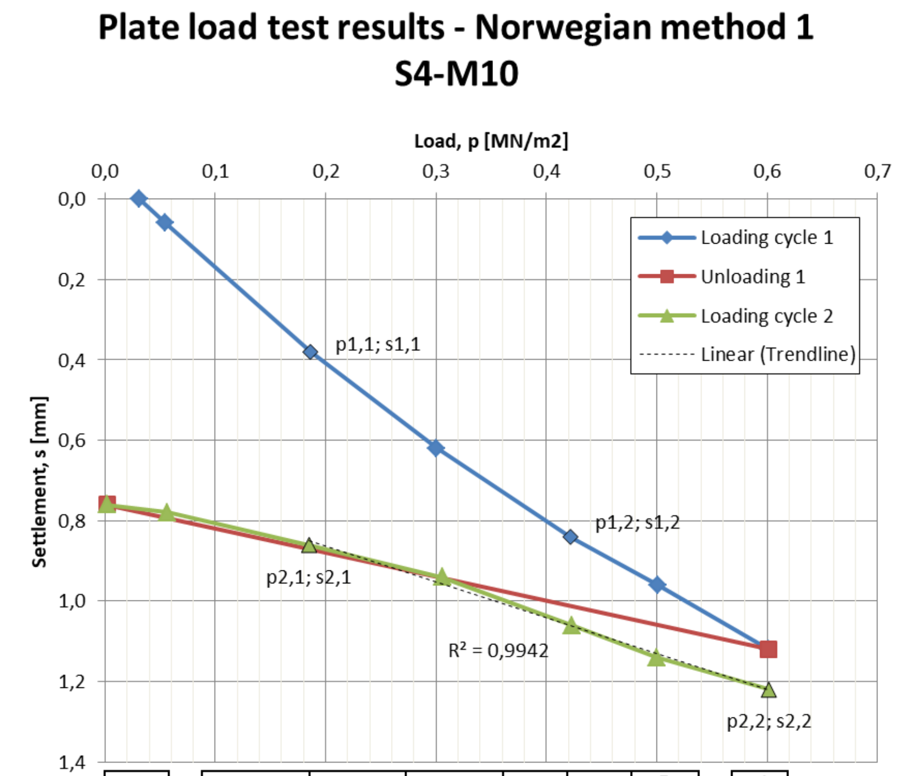
Plate load test results - Swedish method
S4-M9



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,0520	1,5929	0,2770	128	2,3
	2	0,6403	0,7119	0,1136	288	

S4-M10

Load [MN/m²]	**Settlement [mm]**
0,0314	0,00
0,0548	0,06
0,1860	0,38
0,3007	0,62
0,4217	0,84
0,5008	0,96
0,6011	1,12
0,0019	0,76
0,0567	0,78
0,1849	0,86
0,3055	0,94
0,4228	1,06
0,5000	1,14
0,6015	1,22

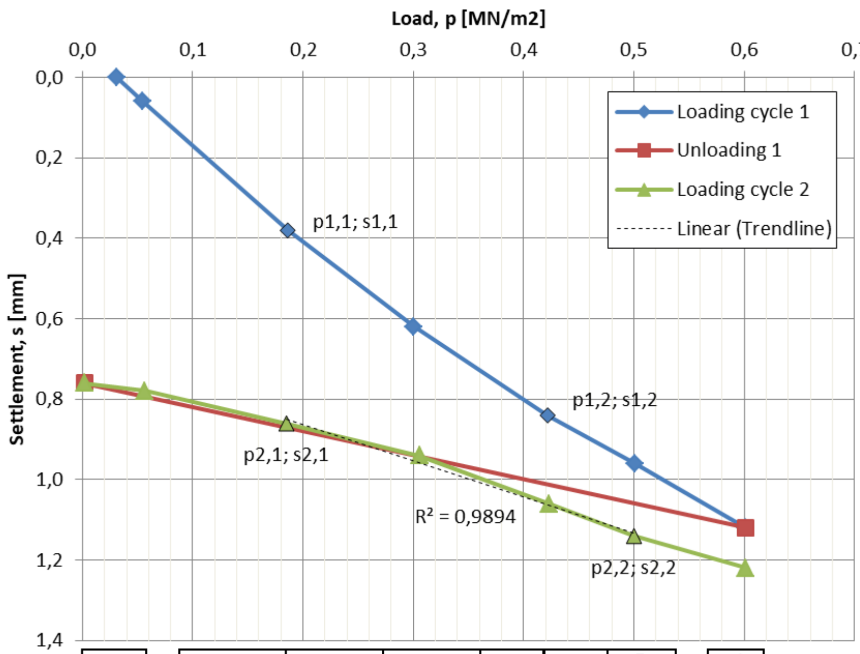


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,186	0,422	0,38	0,84	115
2	0,185	0,602	0,86	1,22	260

E_2/E_1 []
2,3

Plate load test results - Norwegian method 2
S4-M10

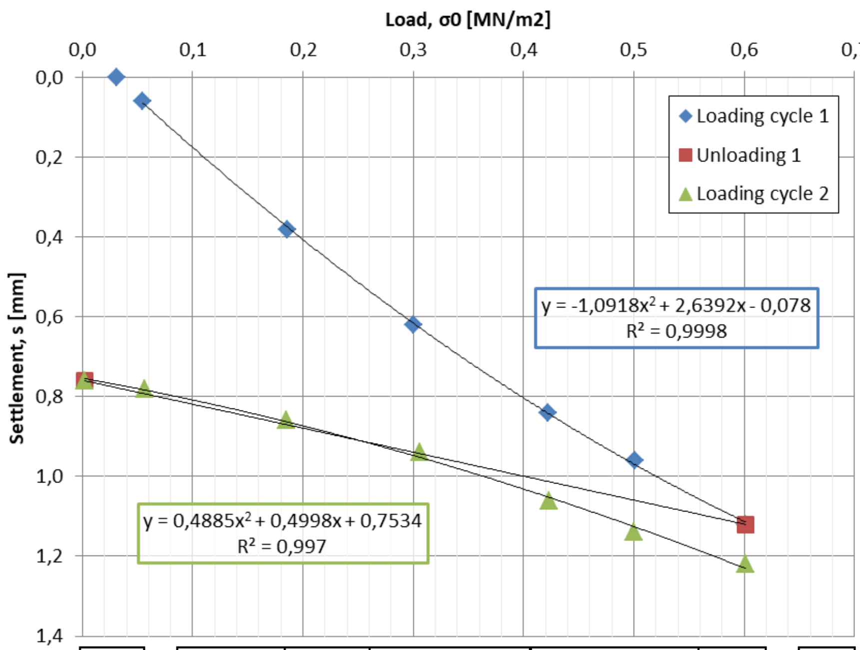


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,186	0,422	0,38	0,84	115
2	0,185	0,500	0,86	1,14	253

E_2/E_1 []
2,2

Plate load test results - Swedish method
S4-M10



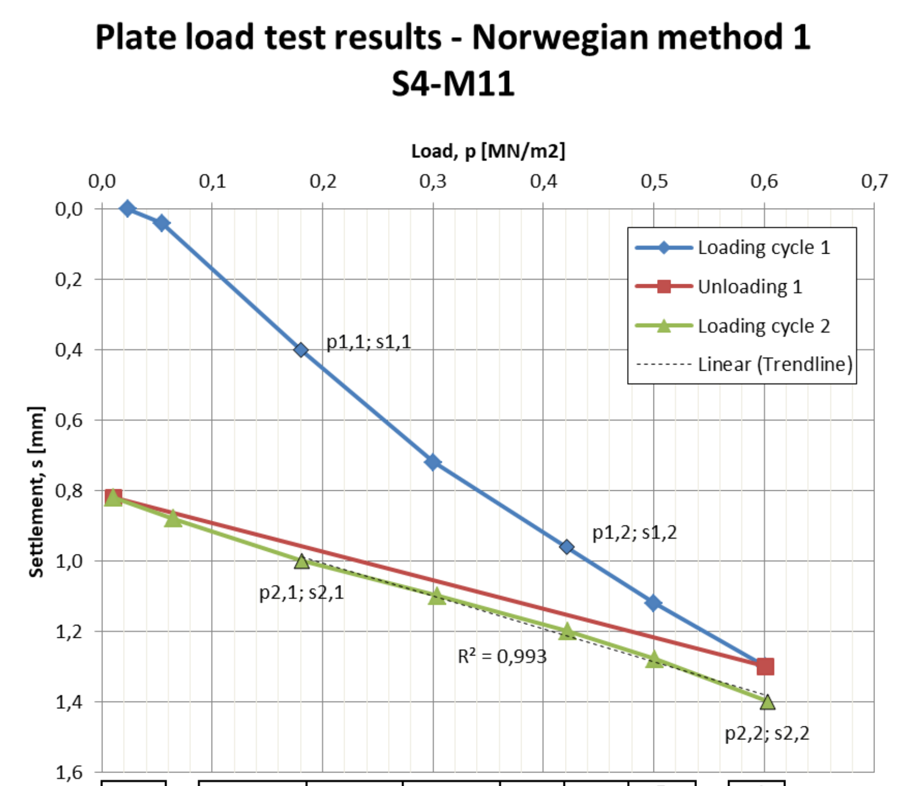
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0780	2,6392	-1,0918	113
2	0,7534	0,4998	0,4885	284

E_2/E_1 []
2,5

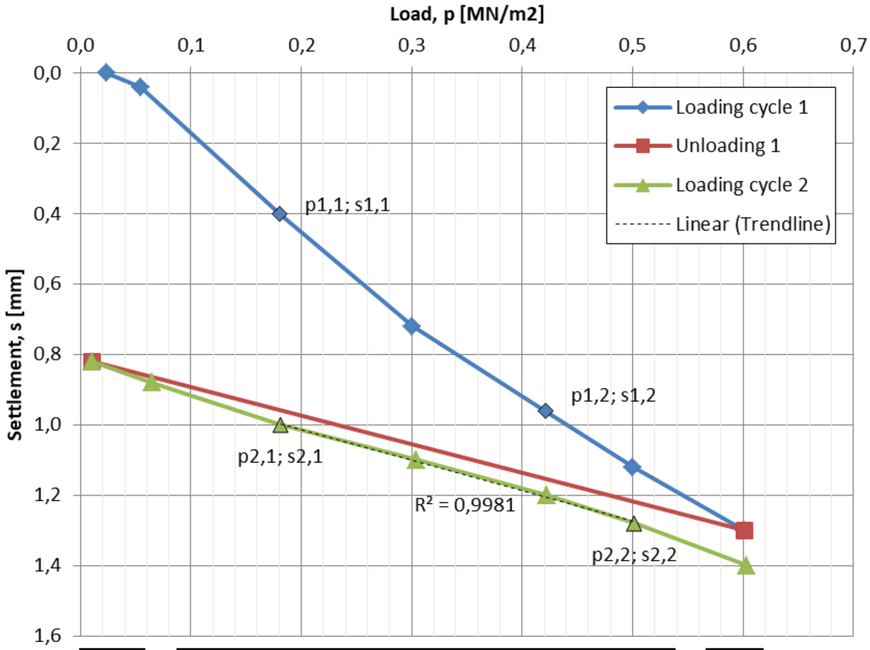
S4-M11

Load [MN/m²]	**Settlement [mm]**
0,0237	0,00
0,0543	0,04
0,1802	0,40
0,3004	0,72
0,4212	0,96
0,5002	1,12
0,6009	1,30
0,0100	0,82
0,0649	0,88
0,1810	1,00
0,3043	1,10
0,4218	1,20
0,5012	1,28
0,6032	1,40



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,180	0,421	0,40	0,96	97	2,5
	2	0,181	0,603	1,00	1,40	237	

Plate load test results - Norwegian method 2
S4-M11

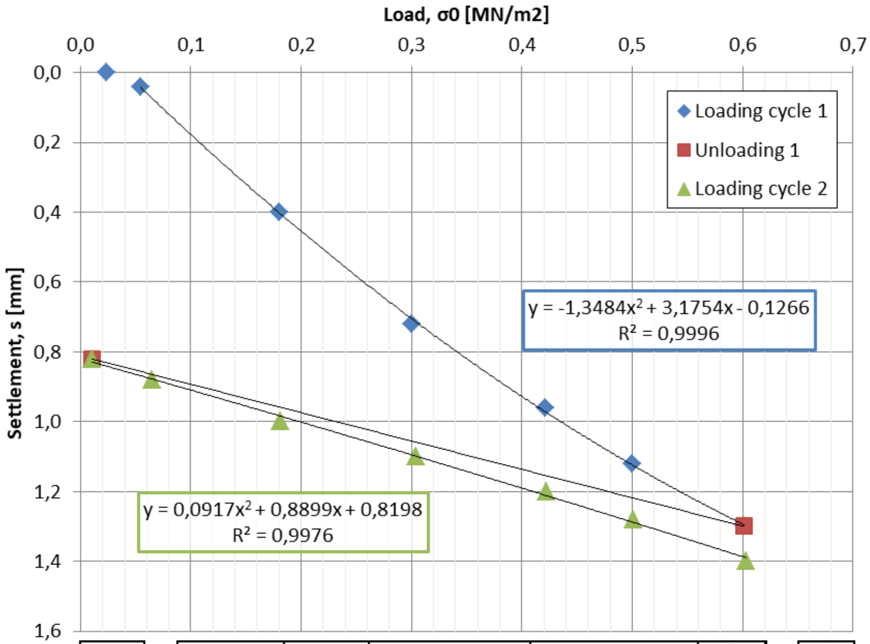


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,40	0,96	97
2	0,181	0,501	1,00	1,28	257

E_2/E_1 []
2,7

Plate load test results - Swedish method
S4-M11



r [mm]
150

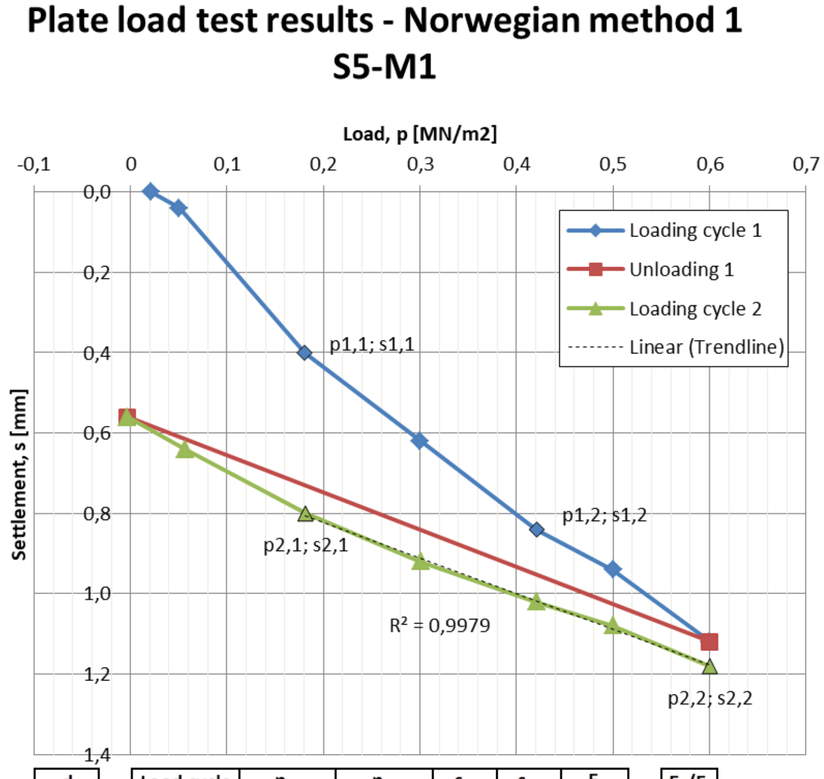
Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1266	3,1754	-1,3484	95
2	0,8198	0,8899	0,0917	238

E_2/E_1 []
2,5

Appendix 7: Measured and calculated results of PLTs from various additional construction sites

S5-M1

Load [MN/m²]	**Settlement [mm]**
0,0215	0,00
0,0503	0,04
0,1803	0,40
0,3004	0,62
0,4210	0,84
0,5003	0,94
0,6005	1,12
-0,0032	0,56
0,0564	0,64
0,1812	0,80
0,3006	0,92
0,4207	1,02
0,5000	1,08
0,6004	1,18

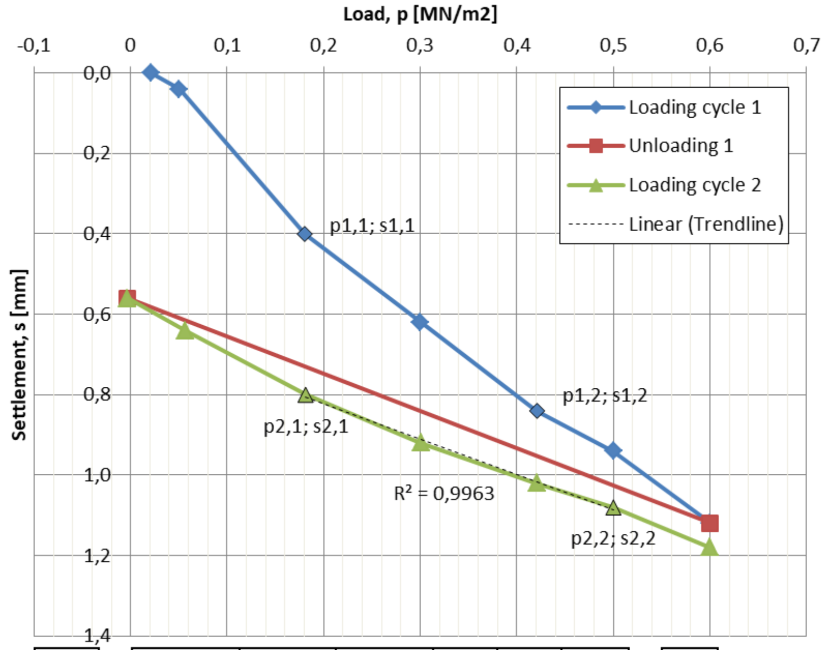


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,40	0,84	123
2	0,181	0,600	0,80	1,18	248

E_2/E_1 []
2,0

Plate load test results - Norwegian method 2
S5-M1

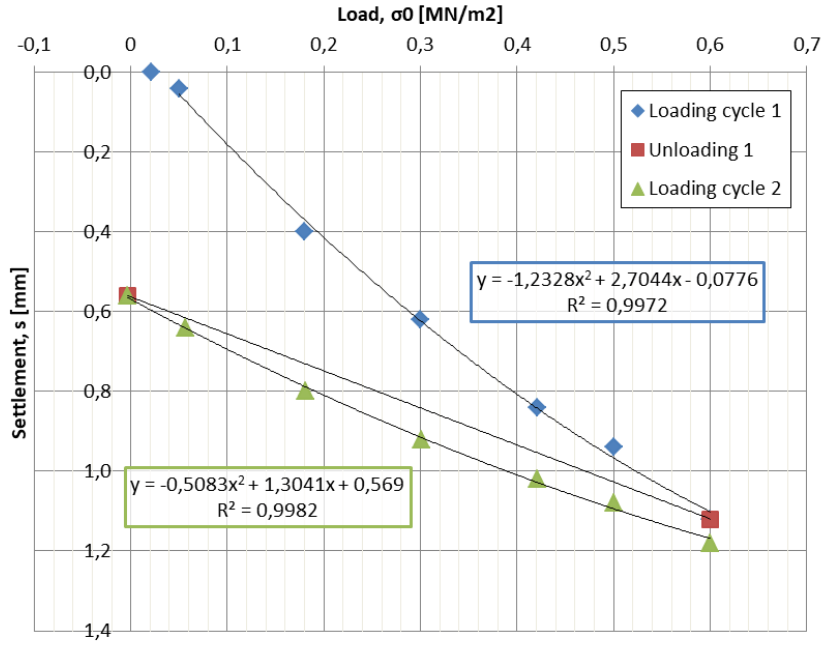


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,40	0,84	123
2	0,181	0,500	0,80	1,08	256

E_2/E_1 []
2,1

Plate load test results - Swedish method
S5-M1



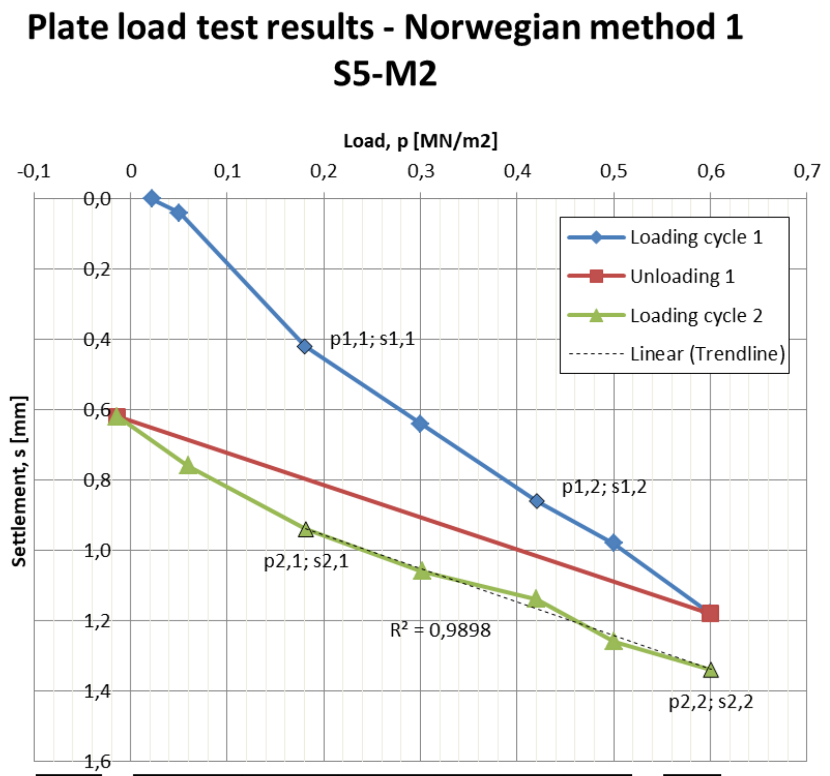
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0776	2,7044	-1,2328	115
2	0,5690	1,3041	-0,5083	225

E_2/E_1 []
2,0

S5-M2

Load [MN/m²]	Settlement [mm]
0,0222	0,00
0,0505	0,04
0,1800	0,42
0,3002	0,64
0,4204	0,86
0,5002	0,98
0,6004	1,18
-0,0138	0,62
0,0594	0,76
0,1813	0,94
0,3017	1,06
0,4203	1,14
0,5008	1,26
0,6006	1,34

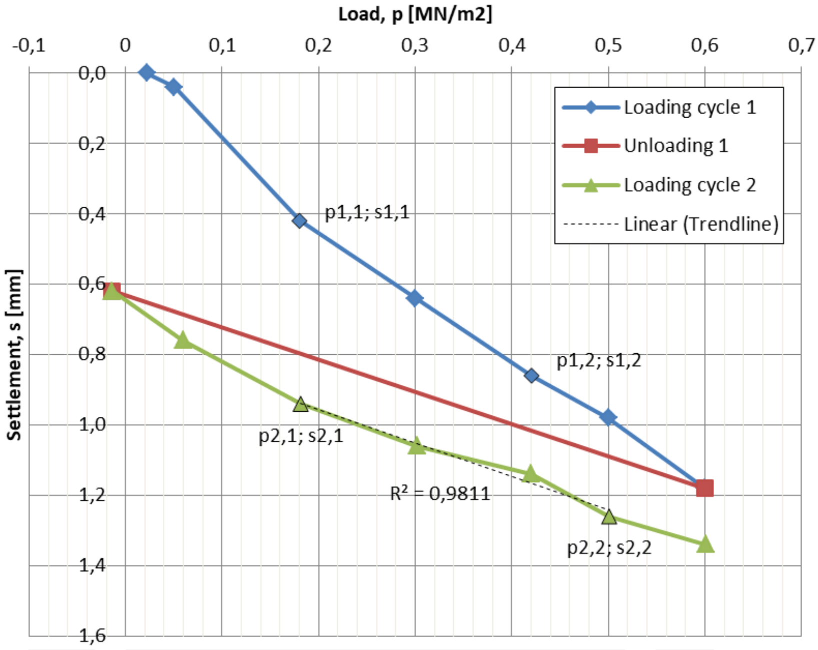


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,42	0,86	123
2	0,181	0,601	0,94	1,34	236

E_2/E_1 []
1,9

Plate load test results - Norwegian method 2
S5-M2

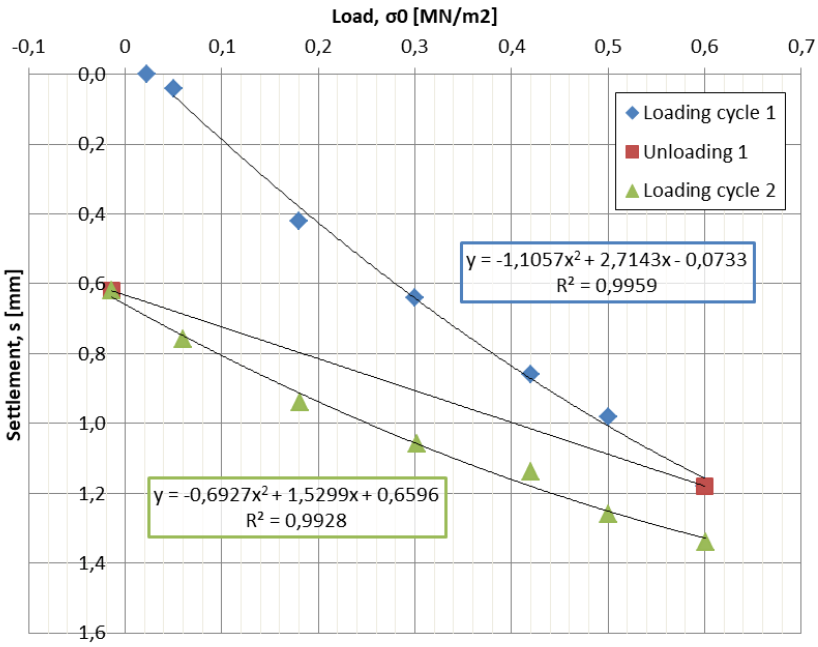


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,42	0,86	123
2	0,181	0,501	0,94	1,26	225

E_2/E_1 []
1,8

Plate load test results - Swedish method
S5-M2



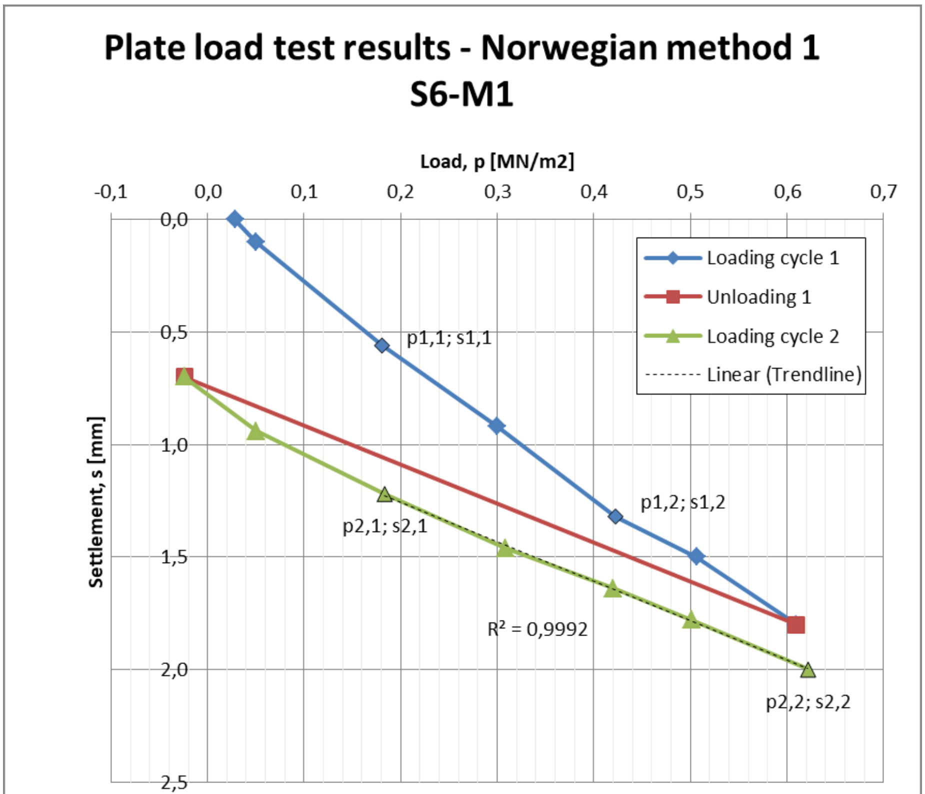
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0733	2,7143	-1,1057	110
2	0,6596	1,5299	-0,6927	202

E_2/E_1 []
1,8

S6-M1

Load [MN/m²]	**Settlement [mm]**
0,0287	0,00
0,0500	0,10
0,1806	0,56
0,3002	0,92
0,4224	1,32
0,5066	1,50
0,6097	1,80
-0,0239	0,70
0,0506	0,94
0,1834	1,22
0,3082	1,46
0,4201	1,64
0,5017	1,78
0,6219	2,00

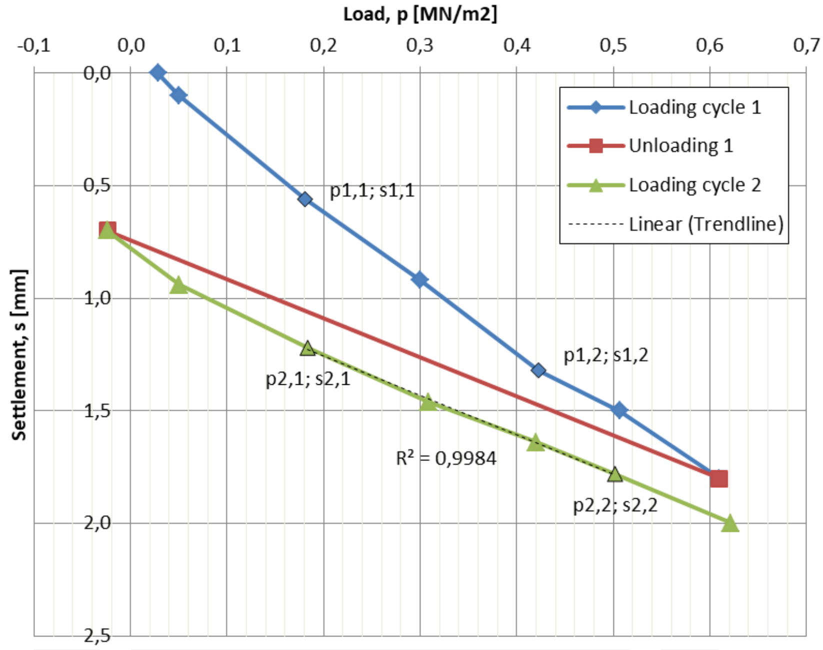


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,422	0,56	1,32	72
2	0,183	0,622	1,22	2,00	126

E_2/E_1 []
1,8

Plate load test results - Norwegian method 2
S6-M1

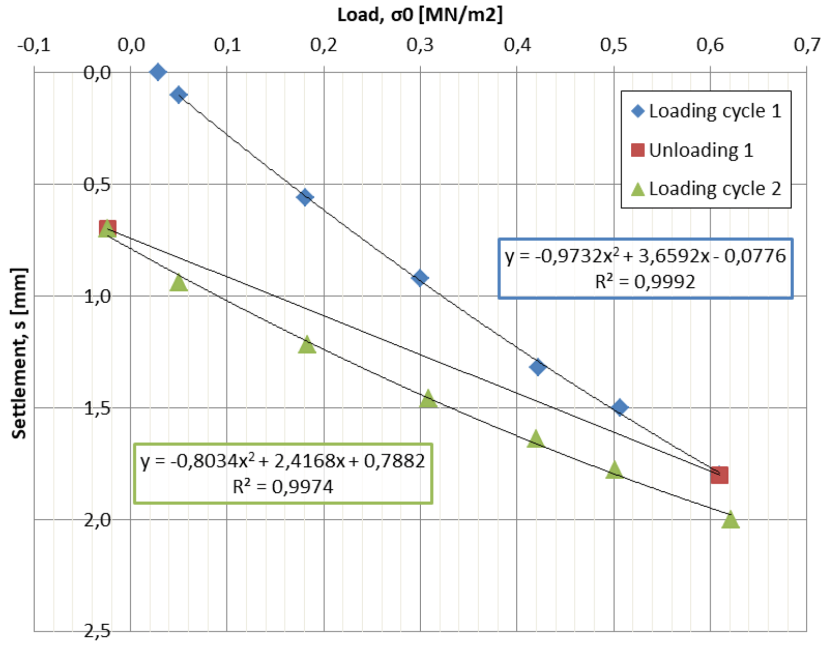


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,422	0,56	1,32	72
2	0,183	0,502	1,22	1,78	128

E_2/E_1 []
1,8

Plate load test results - Swedish method
S6-M1



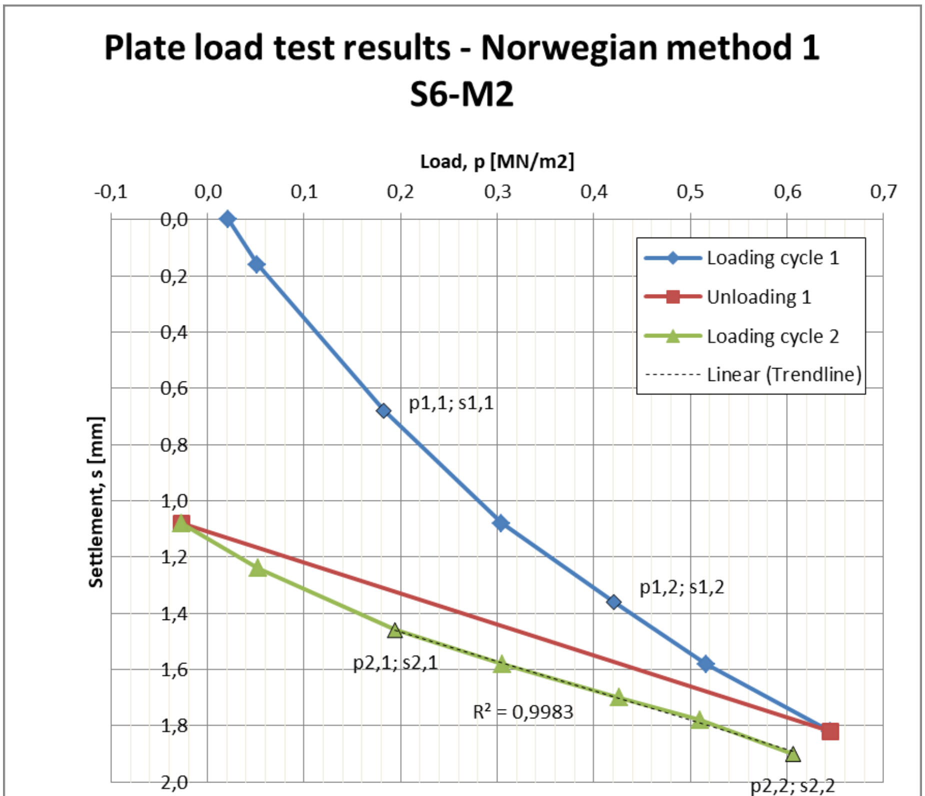
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0776	3,6592	-0,9732	73
2	0,7882	2,4168	-0,8034	117

E_2/E_1 []
1,6

S6-M2

Load [MN/m²]	Settlement [mm]
0,0215	0,00
0,0516	0,16
0,1823	0,68
0,3043	1,08
0,4207	1,36
0,5163	1,58
0,6446	1,82
-0,0275	1,08
0,0524	1,24
0,1940	1,46
0,3048	1,58
0,4266	1,70
0,5095	1,78
0,6064	1,90

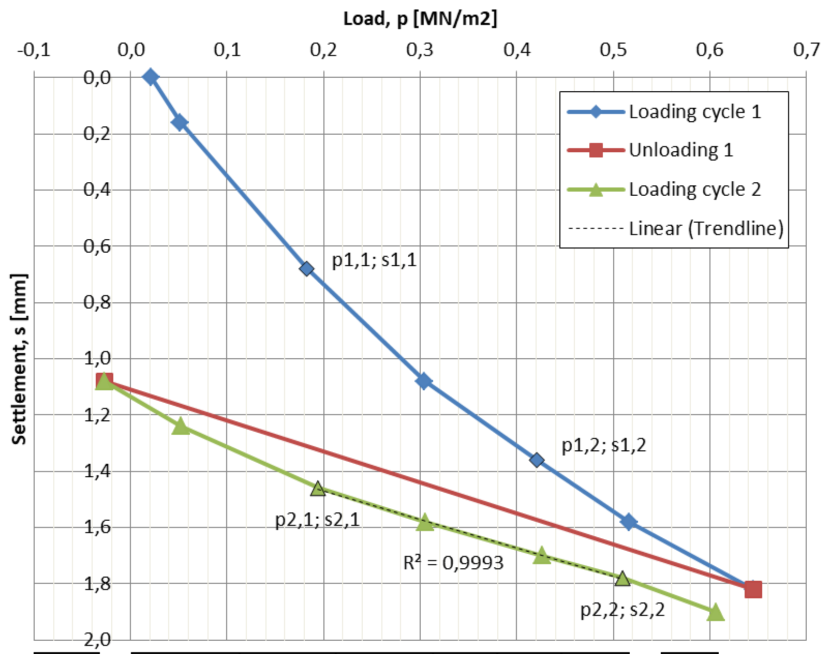


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,421	0,68	1,36	79
2	0,194	0,606	1,46	1,90	211

E_2/E_1 []
2,7

Plate load test results - Norwegian method 2
S6-M2

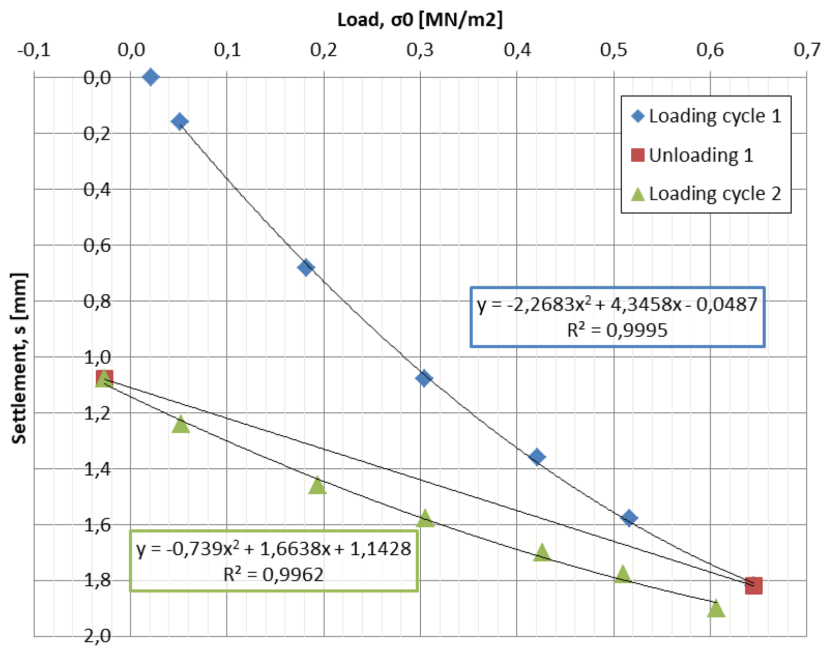


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,182	0,421	0,68	1,36	79
2	0,194	0,510	1,46	1,78	222

E_2/E_1 []
2,8

Plate load test results - Swedish method
S6-M2



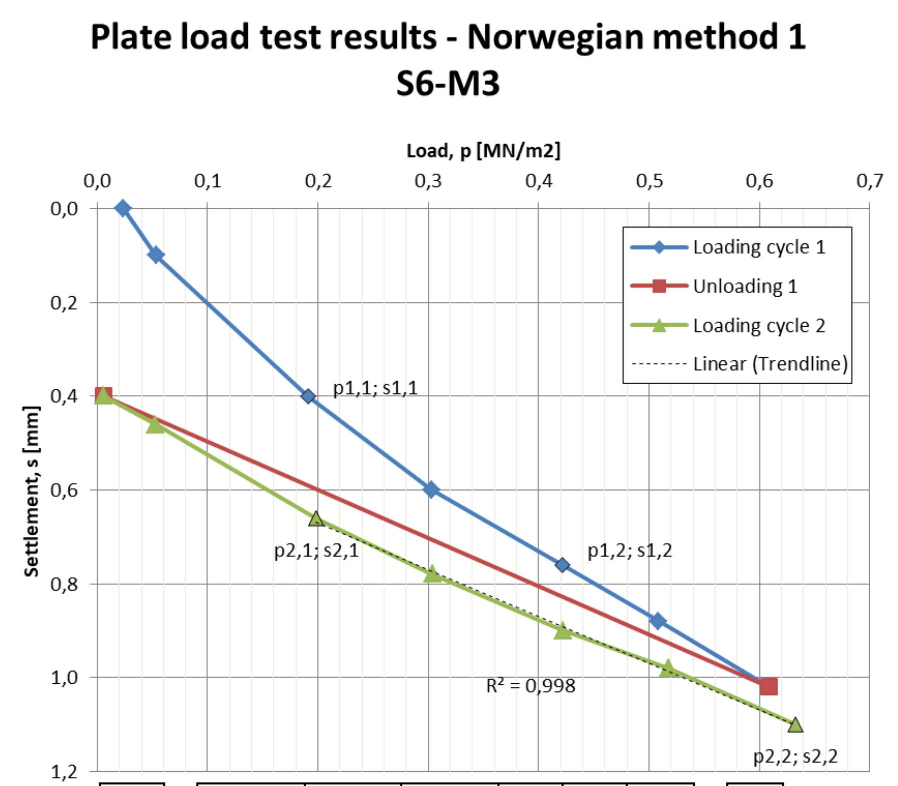
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0487	4,3458	-2,2683	78
2	1,1428	1,6638	-0,7390	189

E_2/E_1 []
2,4

S6-M3

Load [MN/m²]	**Settlement [mm]**
0,0239	0,00
0,0534	0,10
0,1911	0,40
0,3027	0,60
0,4215	0,76
0,5087	0,88
0,6088	1,02
0,0059	0,40
0,0530	0,46
0,1982	0,66
0,3038	0,78
0,4221	0,90
0,5179	0,98
0,6327	1,10

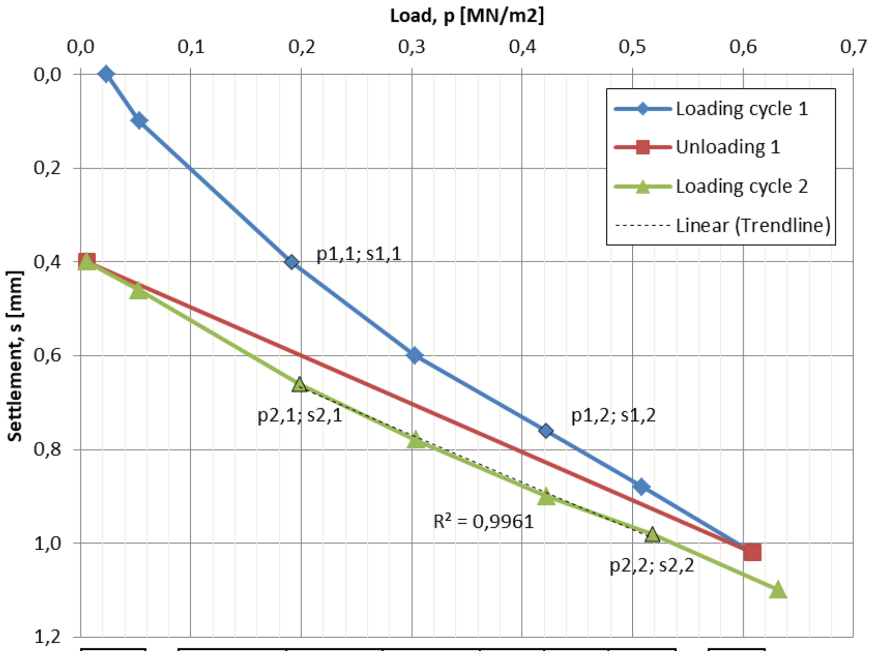


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,191	0,422	0,40	0,76	144
2	0,198	0,633	0,66	1,10	222

E_2/E_1 []
1,5

Plate load test results - Norwegian method 2
S6-M3

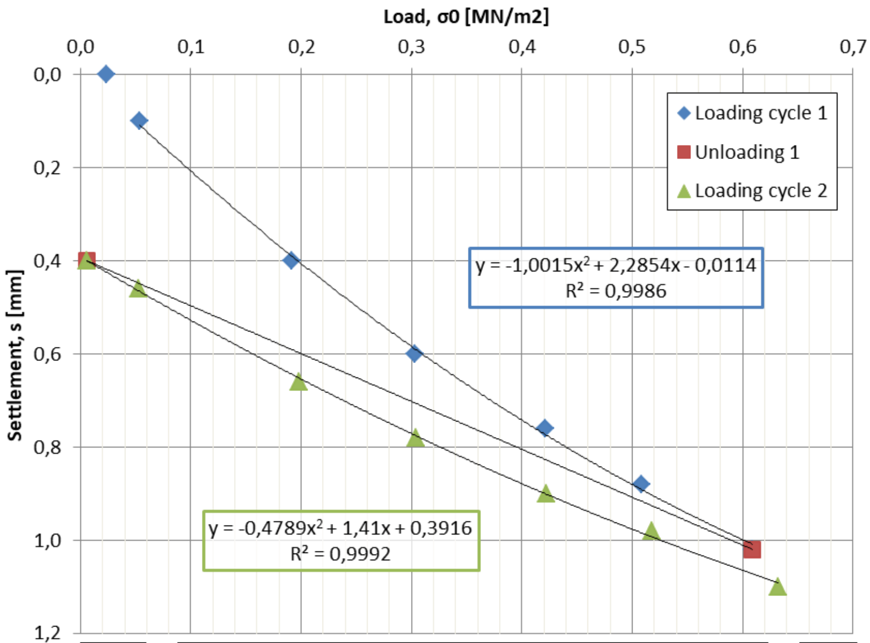


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,191	0,422	0,40	0,76	144
2	0,198	0,518	0,66	0,98	225

E_2/E_1 []
1,6

Plate load test results - Swedish method
S6-M3



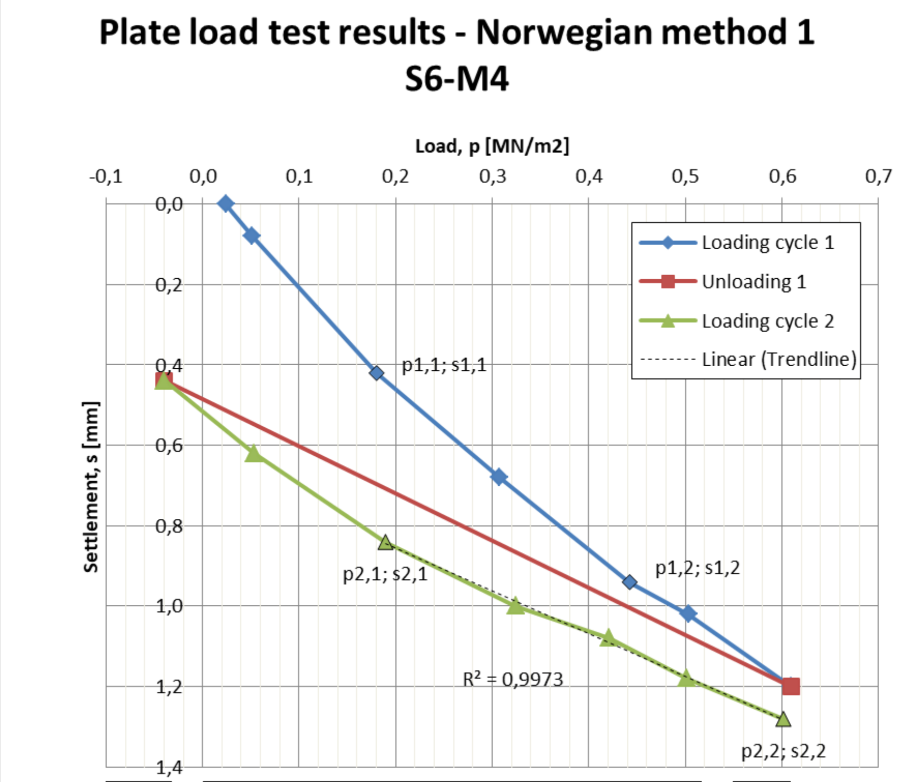
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0114	2,2854	-1,0015	134
2	0,3916	1,41	-0,4789	201

E_2/E_1 []
1,5

S6-M4

Load [MN/m²]	**Settlement [mm]**
0,0243	0,00
0,0517	0,08
0,1802	0,42
0,3079	0,68
0,4423	0,94
0,5033	1,02
0,6097	1,20
-0,0398	0,44
0,0534	0,62
0,1894	0,84
0,3242	1,00
0,4215	1,08
0,5019	1,18
0,6015	1,28

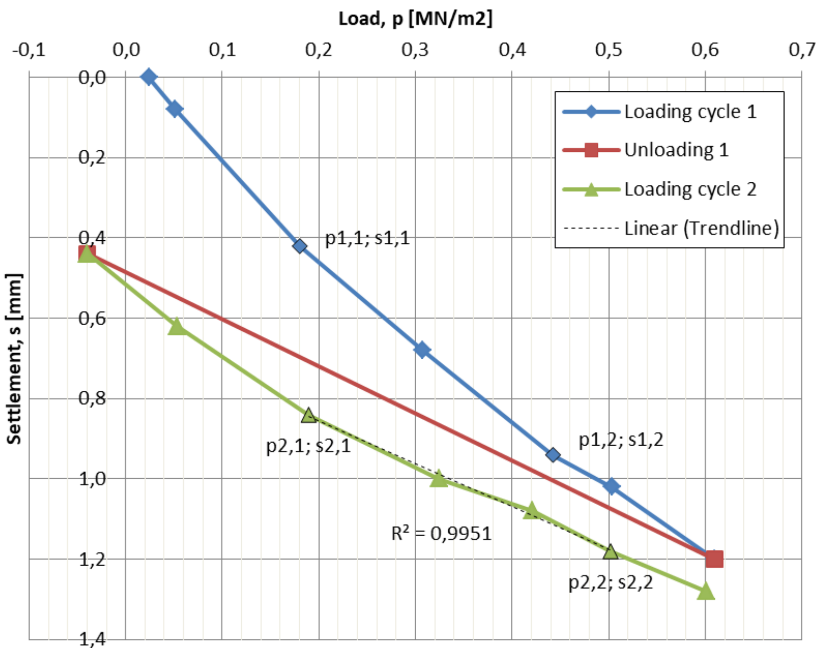


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,442	0,42	0,94	113
2	0,189	0,602	0,84	1,28	211

E_2/E_1 []
1,9

Plate load test results - Norwegian method 2
S6-M4

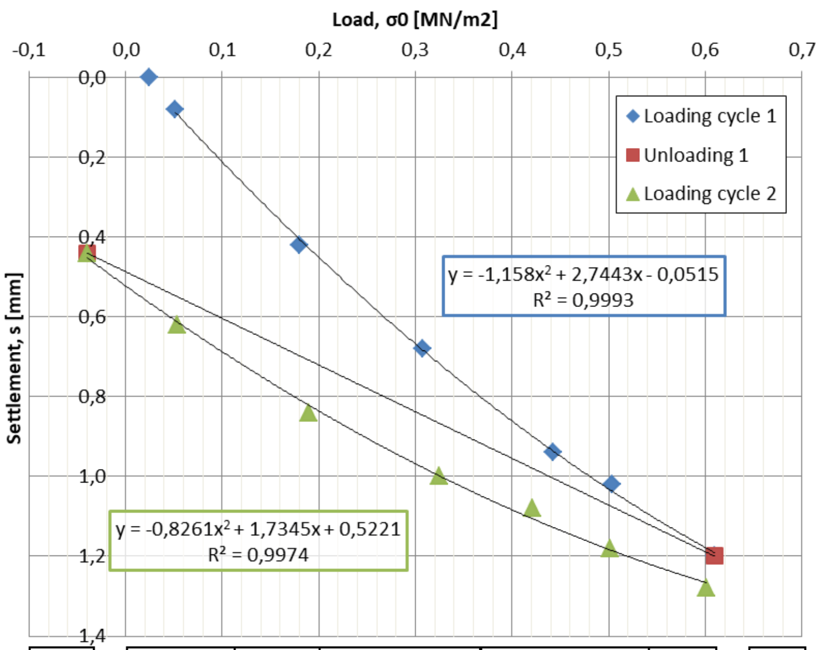


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,442	0,42	0,94	113
2	0,189	0,502	0,84	1,18	207

E_2/E_1 []
1,8

Plate load test results - Swedish method
S6-M4



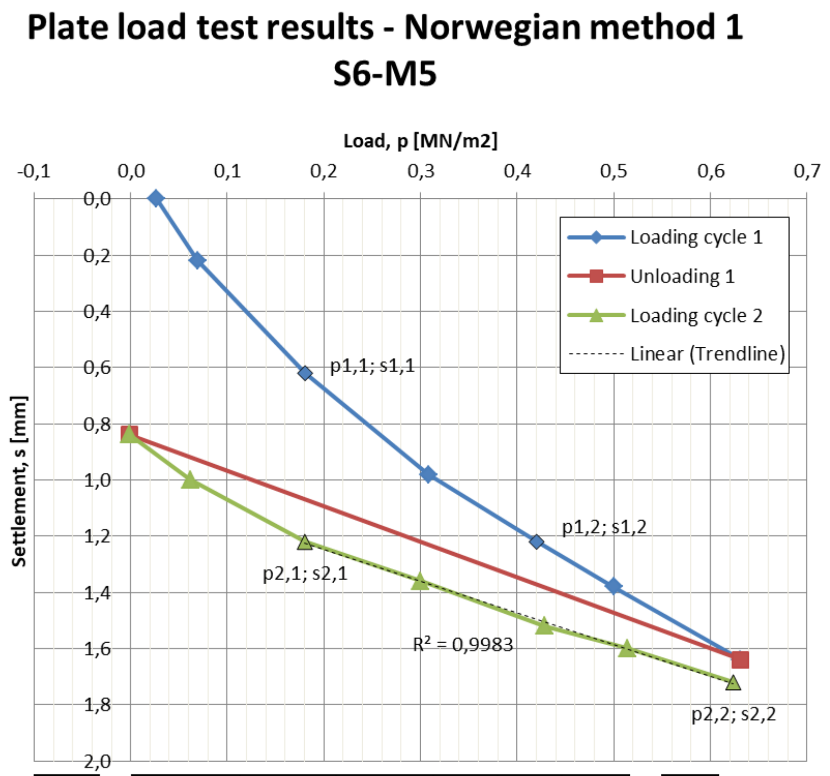
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0515	2,7443	-1,1580	110
2	0,5221	1,7345	-0,8261	183

E_2/E_1 []
1,7

S6-M5

Load [MN/m²]	Settlement [mm]
0,0270	0,00
0,0690	0,22
0,1805	0,62
0,3082	0,98
0,4201	1,22
0,5000	1,38
0,6313	1,64
-0,0012	0,84
0,0616	1,00
0,1802	1,22
0,3002	1,36
0,4289	1,52
0,5141	1,60
0,6237	1,72

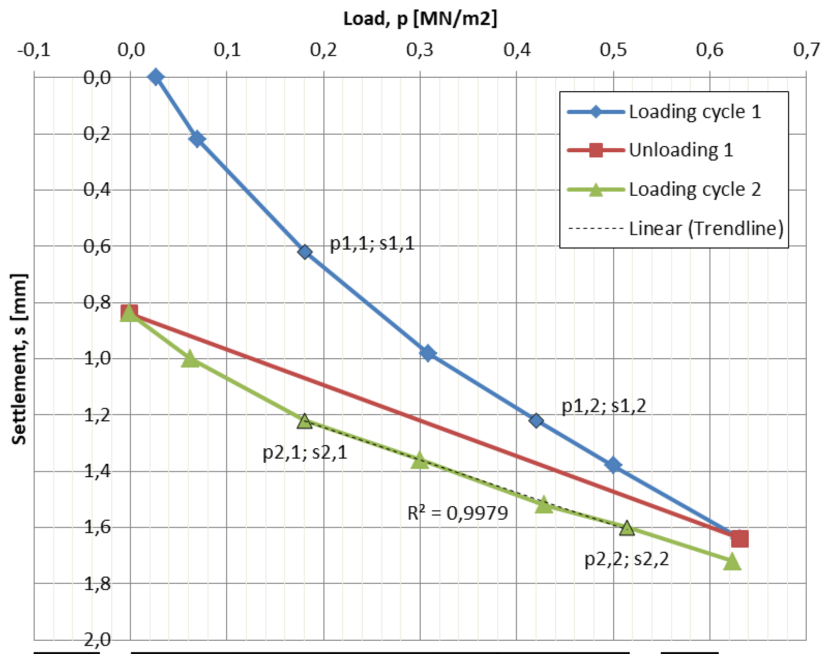


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,62	1,22	90
2	0,180	0,624	1,22	1,72	200

E_2/E_1 []
2,2

Plate load test results - Norwegian method 2
S6-M5

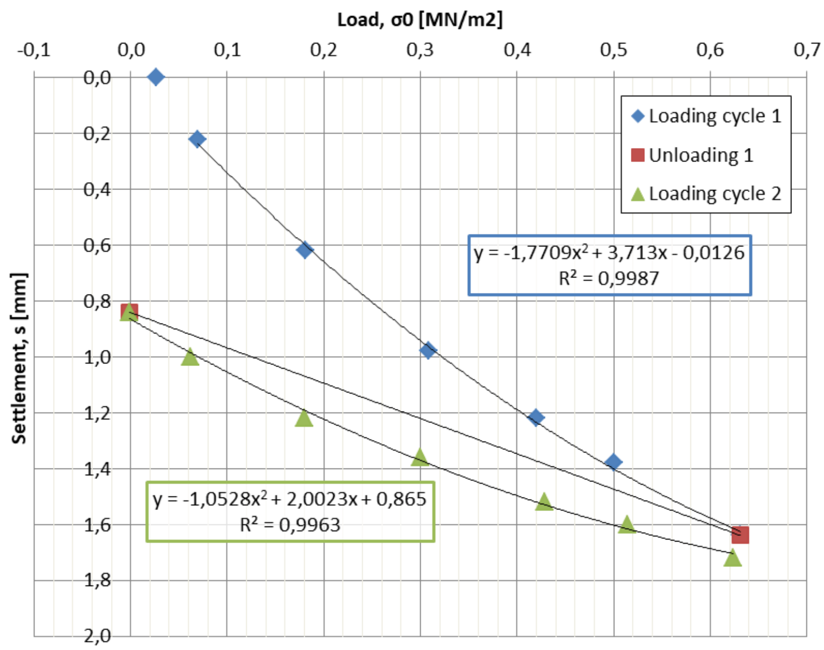


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,62	1,22	90
2	0,180	0,514	1,22	1,60	198

E_2/E_1 []
2,2

Plate load test results - Swedish method
S6-M5



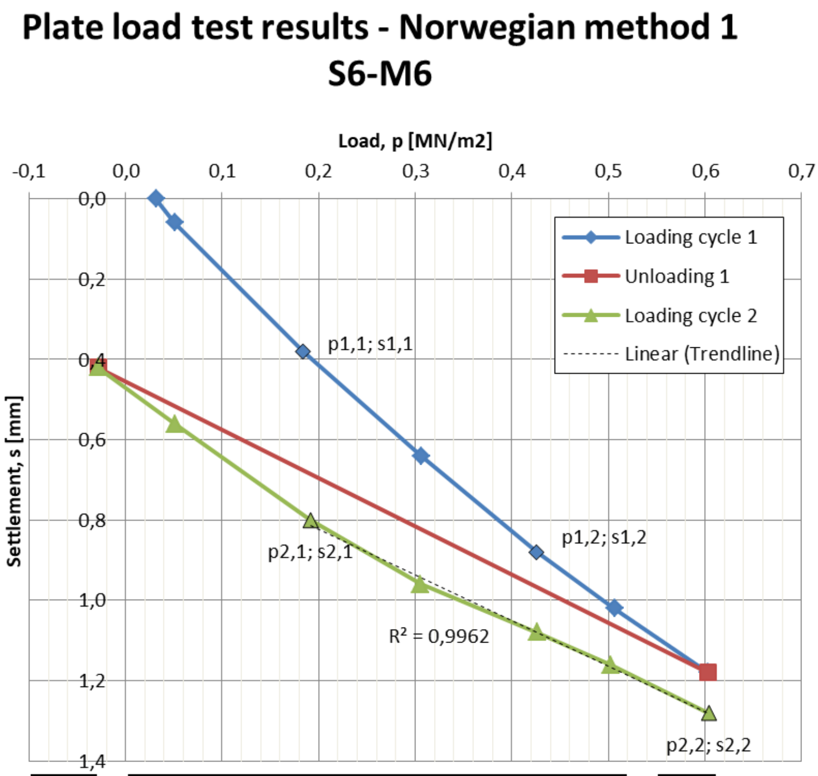
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0126	3,7130	-1,7709	87
2	0,8650	2,0023	-1,0528	168

E_2/E_1 []
1,9

S6-M6

Load [MN/m²]	**Settlement [mm]**
0,0319	0,00
0,0509	0,06
0,1836	0,38
0,3060	0,64
0,4254	0,88
0,5068	1,02
0,6033	1,18
-0,0284	0,42
0,0509	0,56
0,1916	0,80
0,3054	0,96
0,4262	1,08
0,5025	1,16
0,6042	1,28

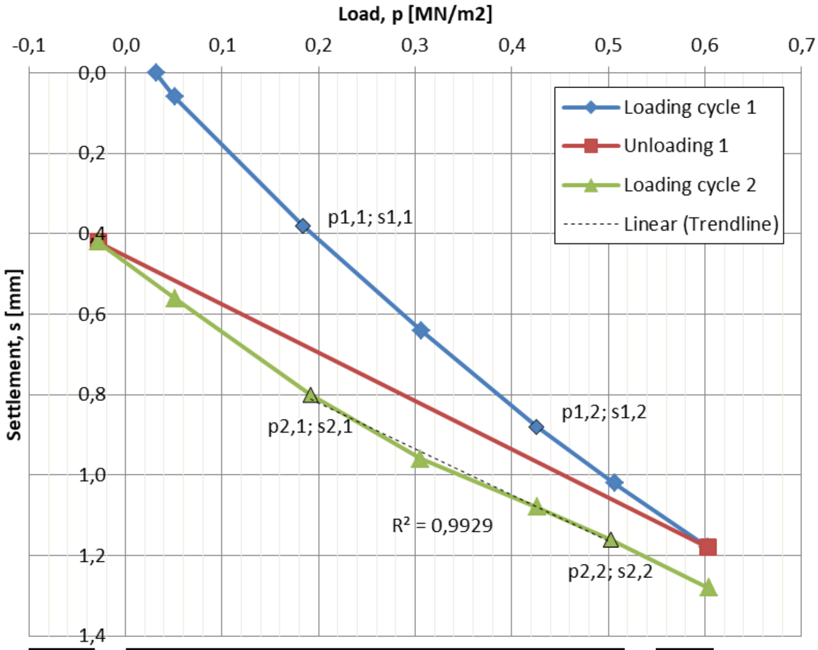


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,184	0,425	0,38	0,88	109
2	0,192	0,604	0,80	1,28	193

E_2/E_1 []
1,8

Plate load test results - Norwegian method 2
S6-M6

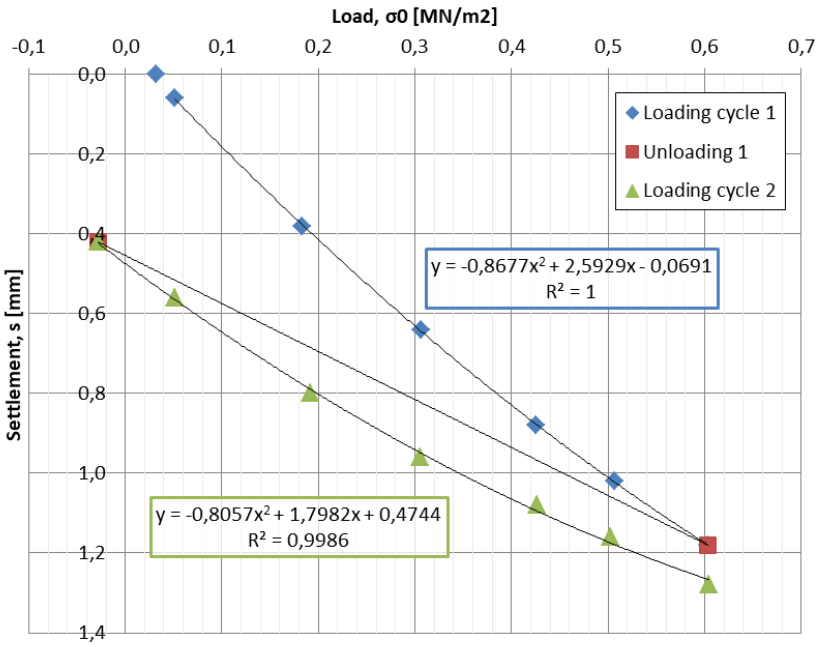


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,184	0,425	0,38	0,88	109
2	0,192	0,503	0,80	1,16	194

E_2/E_1 []
1,8

Plate load test results - Swedish method
S6-M6



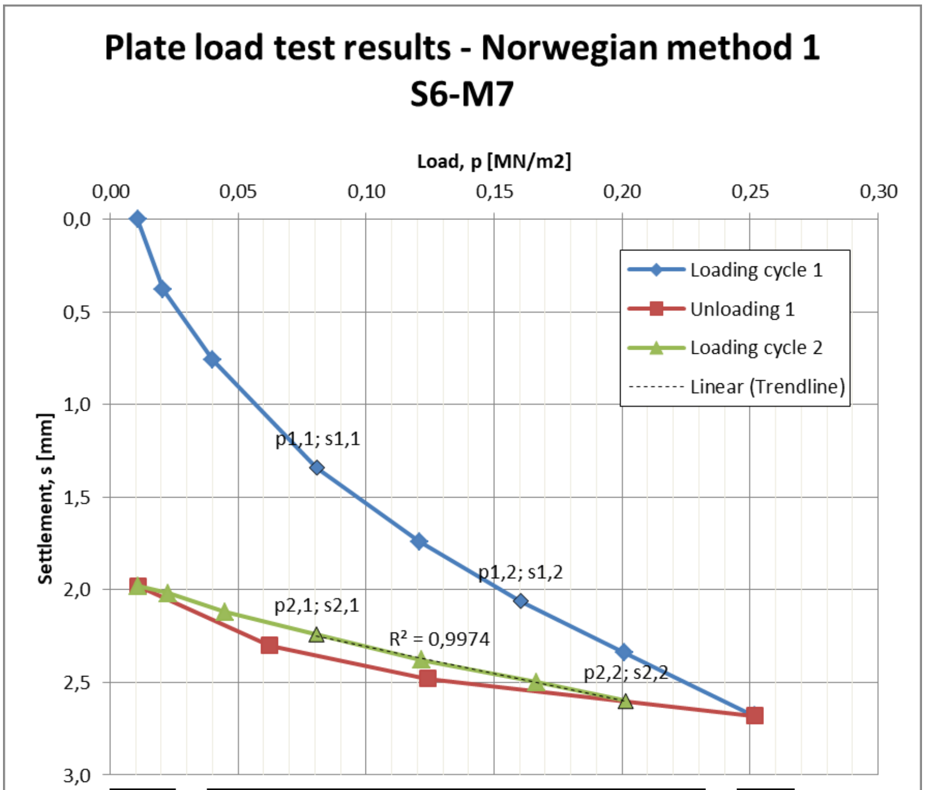
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0691	2,5929	-0,8677	109
2	0,4744	1,4982	-0,8057	222

E_2/E_1 []
2,0

S6-M7

Load [MN/m²]	**Settlement [mm]**
0,0108	0,00
0,0207	0,38
0,0401	0,76
0,0808	1,34
0,1207	1,74
0,1604	2,06
0,2011	2,34
0,2518	2,68
0,1240	2,48
0,0623	2,30
0,0109	1,98
0,0228	2,02
0,0447	2,12
0,0806	2,24
0,1219	2,38
0,1667	2,50
0,2014	2,60

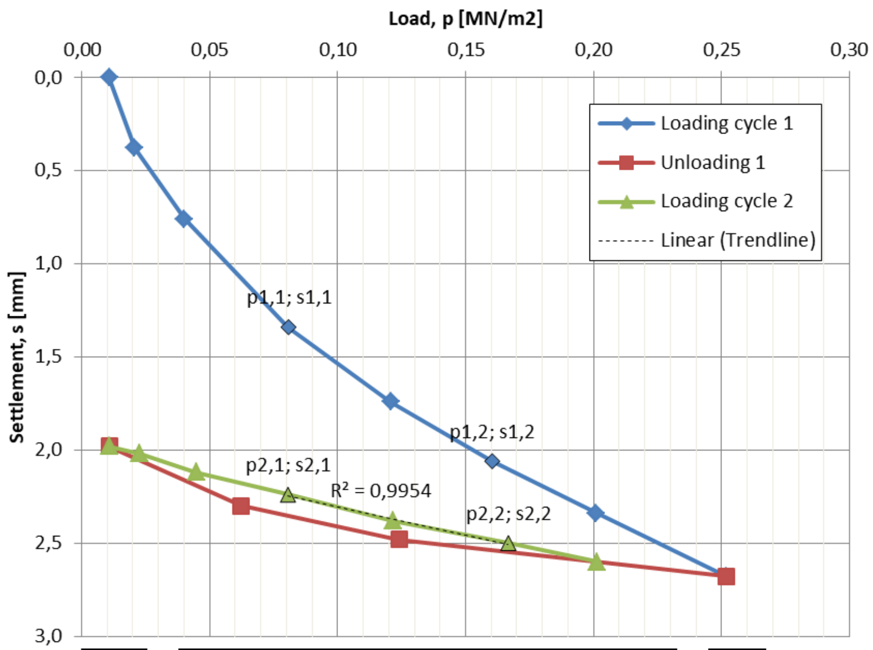


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,081	0,160	1,34	2,06	50
2	0,081	0,201	2,24	2,60	151

E_2/E_1 []
3,0

Plate load test results - Norwegian method 2
S6-M7

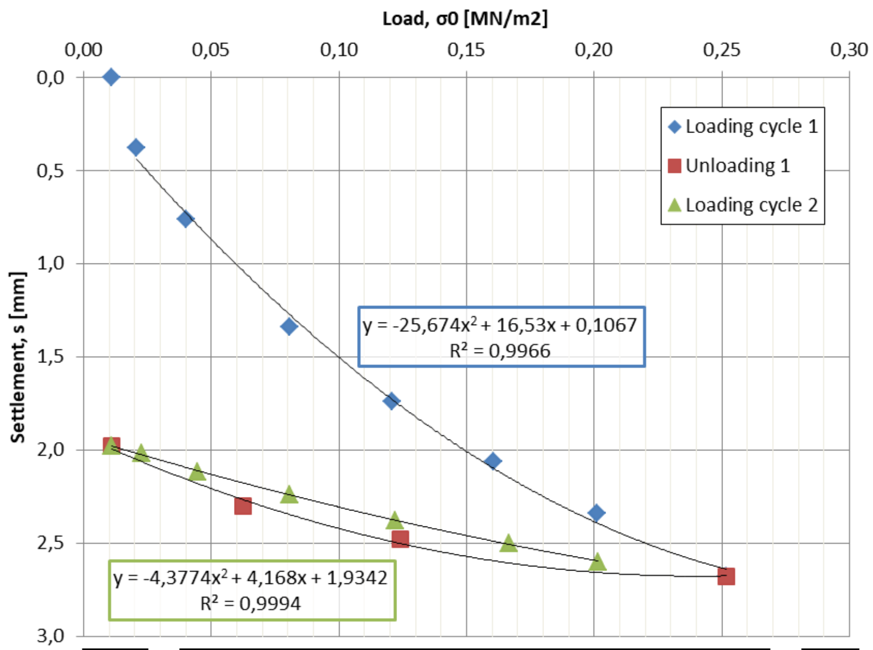


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,081	0,160	1,34	2,06	50
2	0,081	0,167	2,24	2,50	149

E_2/E_1 []
3,0

Plate load test results - Swedish method
S6-M7



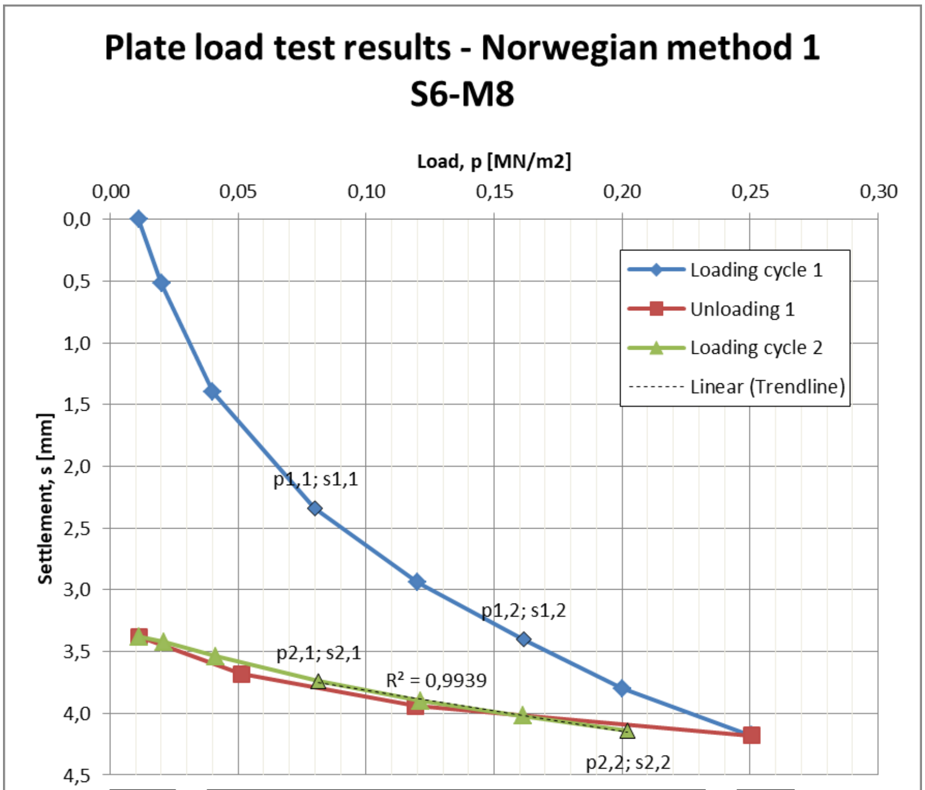
r [mm]
300

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,1067	16,5300	-25,6740	45
2	1,9342	4,1680	-4,3774	147

E_2/E_1 []
3,3

S6-M8

Load [MN/m²]	**Settlement [mm]**
0,0112	0,00
0,0201	0,52
0,0402	1,40
0,0800	2,34
0,1201	2,94
0,1616	3,40
0,2000	3,80
0,2505	4,18
0,1193	3,94
0,0513	3,68
0,0112	3,38
0,0209	3,42
0,0413	3,54
0,0813	3,74
0,1212	3,90
0,1613	4,02
0,2021	4,14

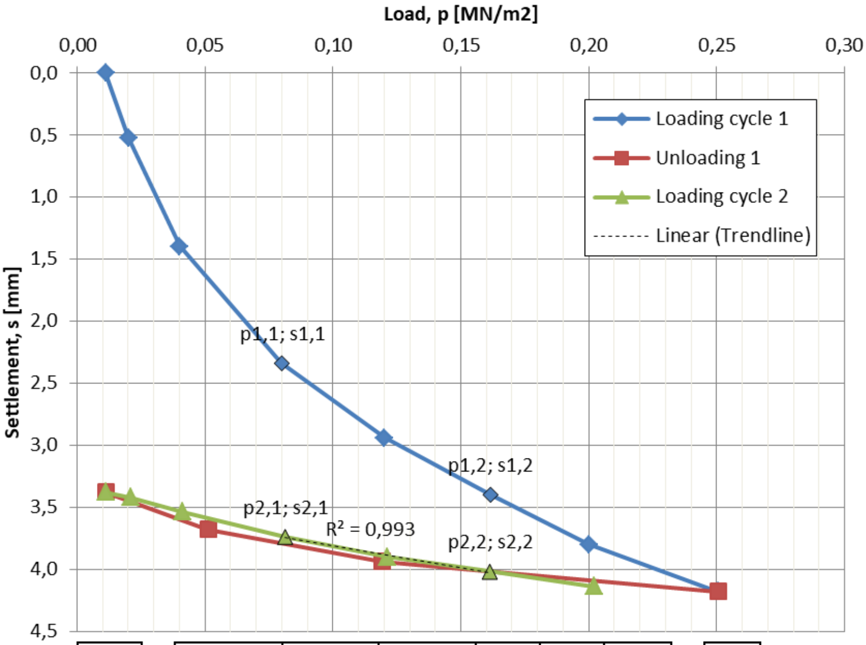


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,162	2,34	3,40	35
2	0,081	0,202	3,74	4,14	136

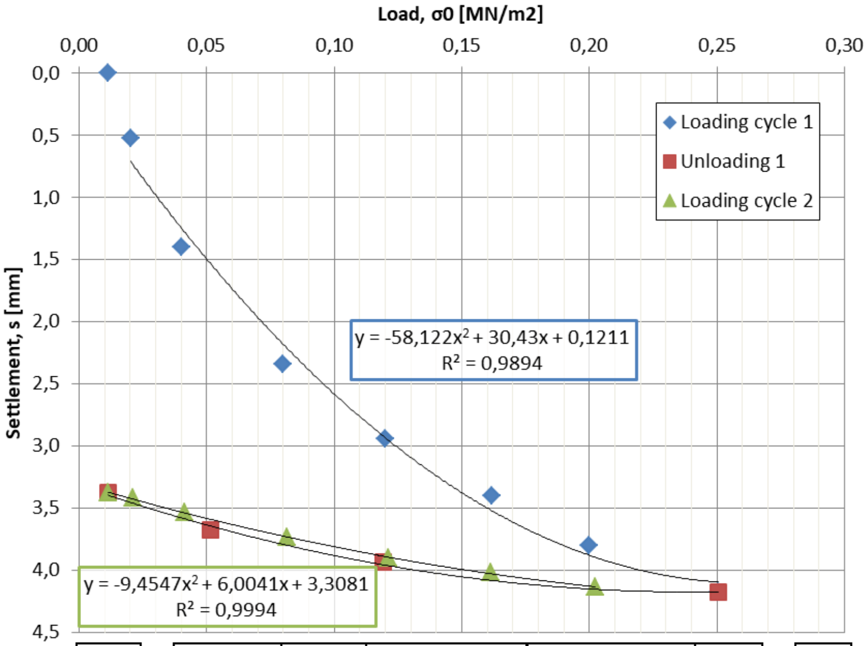
E_2/E_1 []
3,9

Plate load test results - Norwegian method 2
S6-M8



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,162	2,34	3,40	35	3,7
	2	0,081	0,161	3,74	4,02	129	

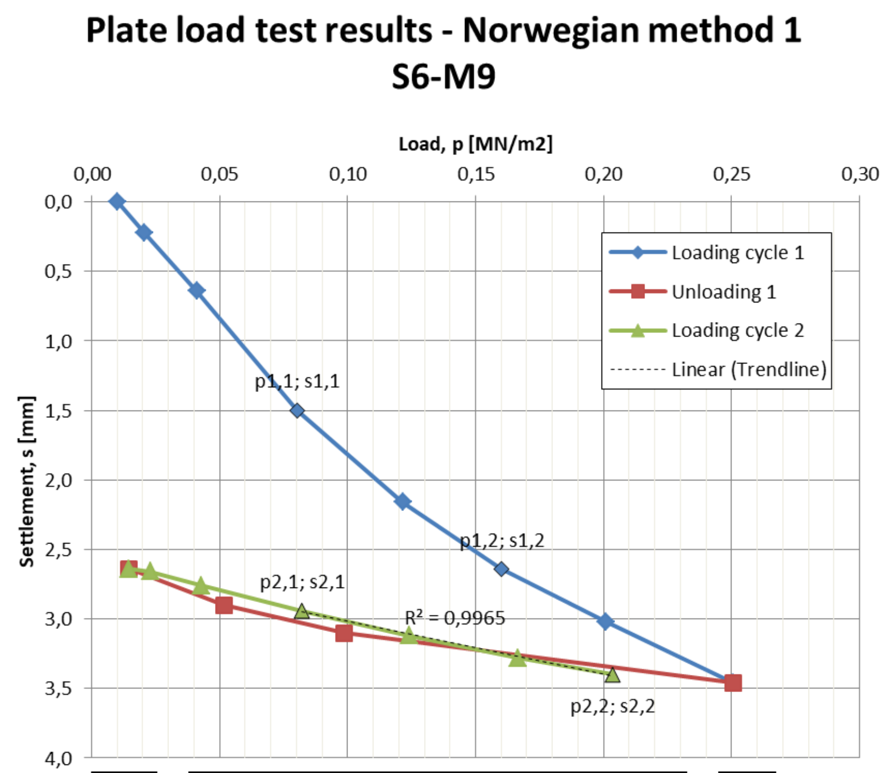
Plate load test results - Swedish method
S6-M8



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	0,1211	30,4300	-58,1220	28	4,4
	2	3,3081	6,0041	-9,4547	124	

S6-M9

Load [MN/m^2]	Settlement [mm]
0,0103	0,00
0,0206	0,22
0,0412	0,64
0,0803	1,50
0,1215	2,16
0,1601	2,64
0,2009	3,02
0,2506	3,46
0,0987	3,10
0,0516	2,90
0,0147	2,64
0,0230	2,66
0,0427	2,76
0,0821	2,94
0,1242	3,12
0,1665	3,28
0,2035	3,40

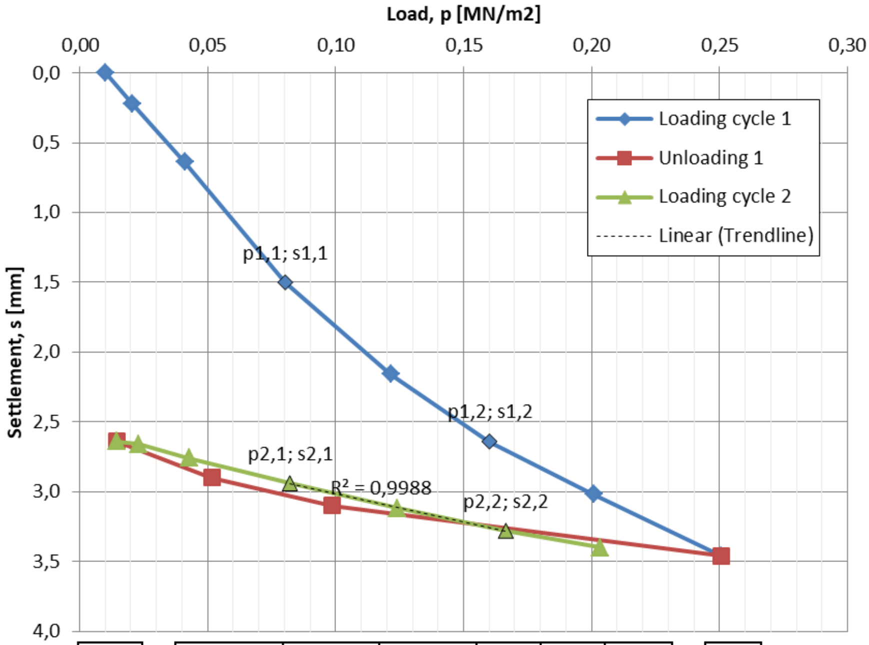


d [mm]
600

Load cycle no., i	$p_{i,1}$ [MN/m^2]	$p_{i,2}$ [MN/m^2]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,080	0,160	1,50	2,64	32
2	0,082	0,204	2,94	3,40	119

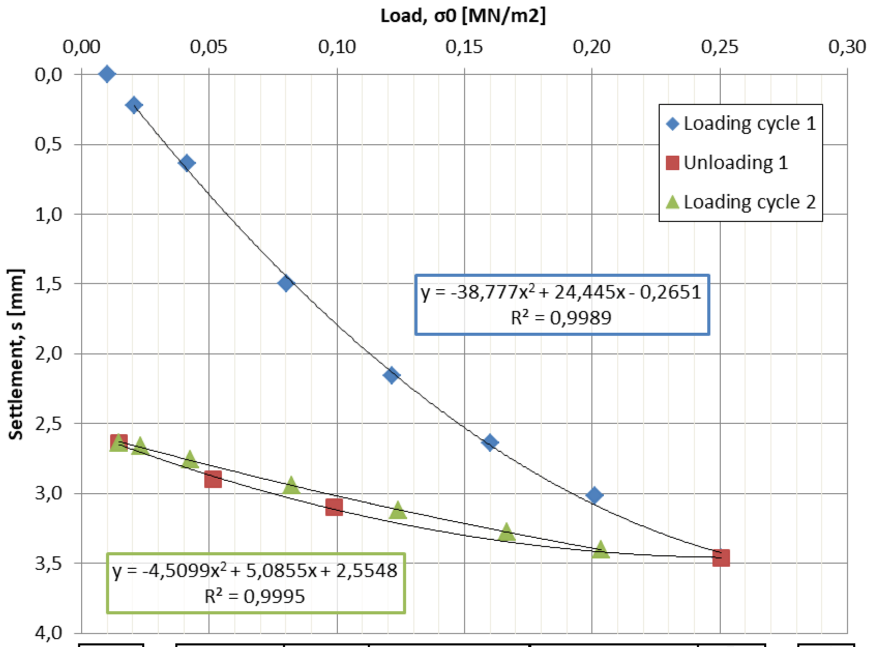
E_2/E_1 []
3,8

Plate load test results - Norwegian method 2
S6-M9



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
600	1	0,080	0,160	1,50	2,64	32	3,5
	2	0,082	0,167	2,94	3,28	112	

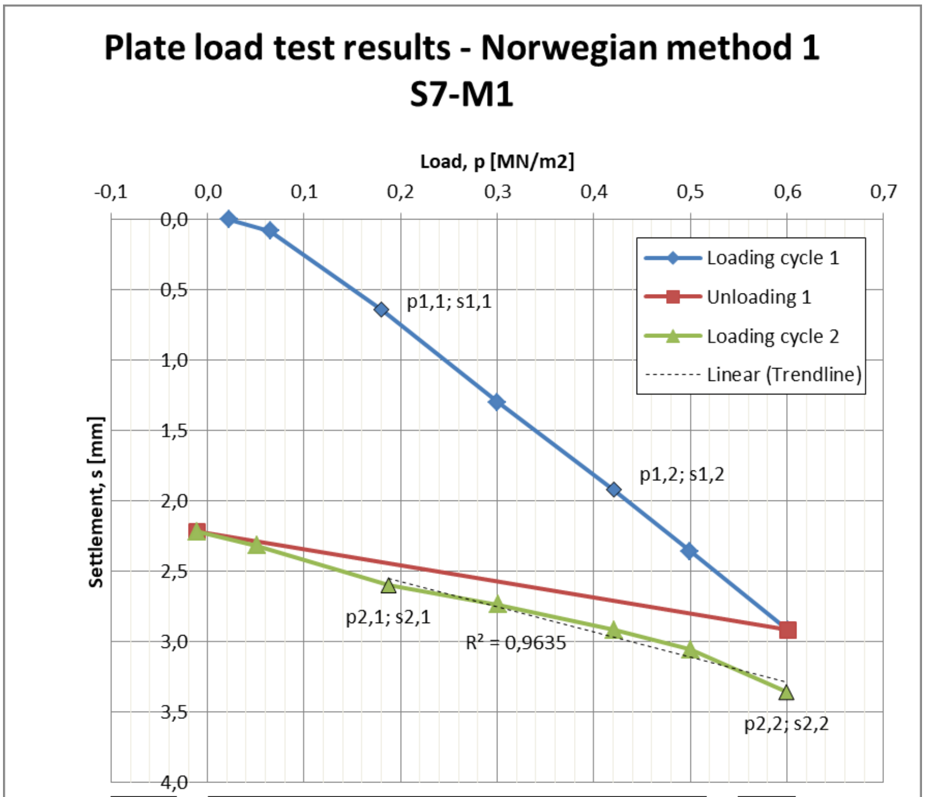
Plate load test results - Swedish method
S6-M9



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
300	1	-0,2651	24,4450	-38,7770	31	3,7
	2	2,5548	5,0855	-4,5099	114	

S7-M1

Load [MN/m²]	Settlement [mm]
0,0227	0,00
0,0647	0,08
0,1799	0,64
0,3003	1,30
0,4208	1,92
0,4998	2,36
0,6006	2,92
-0,0111	2,22
0,0510	2,32
0,1874	2,60
0,3009	2,74
0,4210	2,92
0,5000	3,06
0,5994	3,36

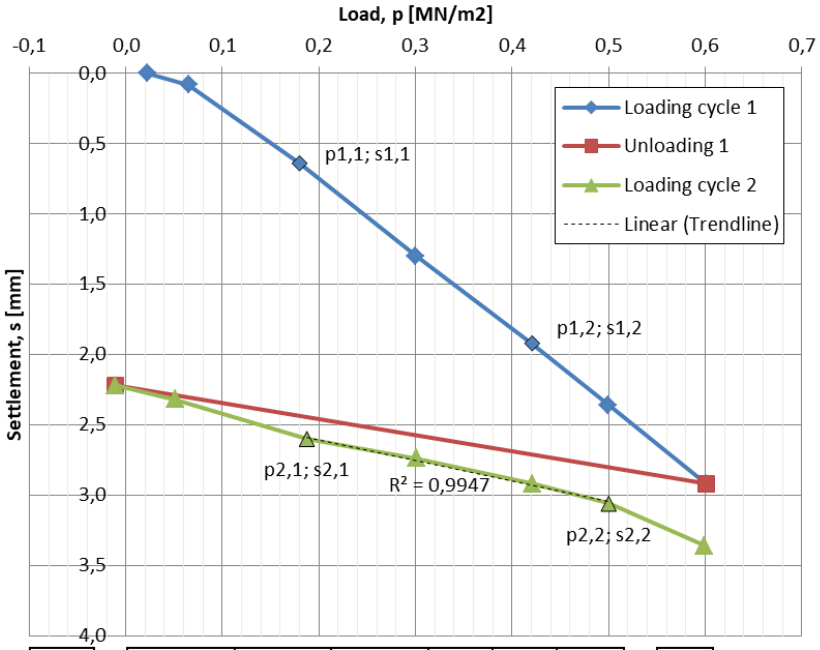


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,64	1,92	42
2	0,187	0,599	2,60	3,36	122

E_2/E_1 []
2,9

Plate load test results - Norwegian method 2
S7-M1

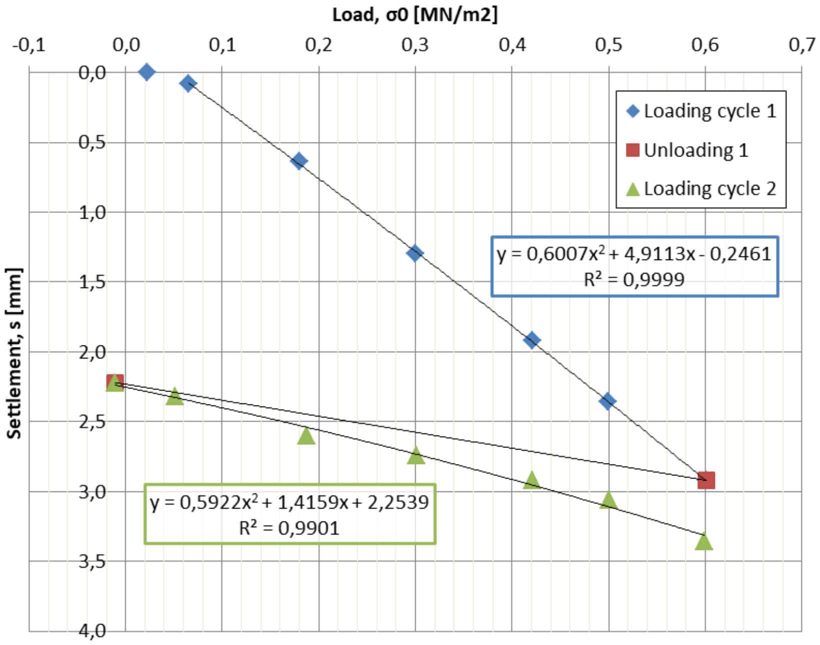


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,64	1,92	42
2	0,187	0,500	2,60	3,06	153

E_2/E_1 []
3,6

Plate load test results - Swedish method
S7-M1



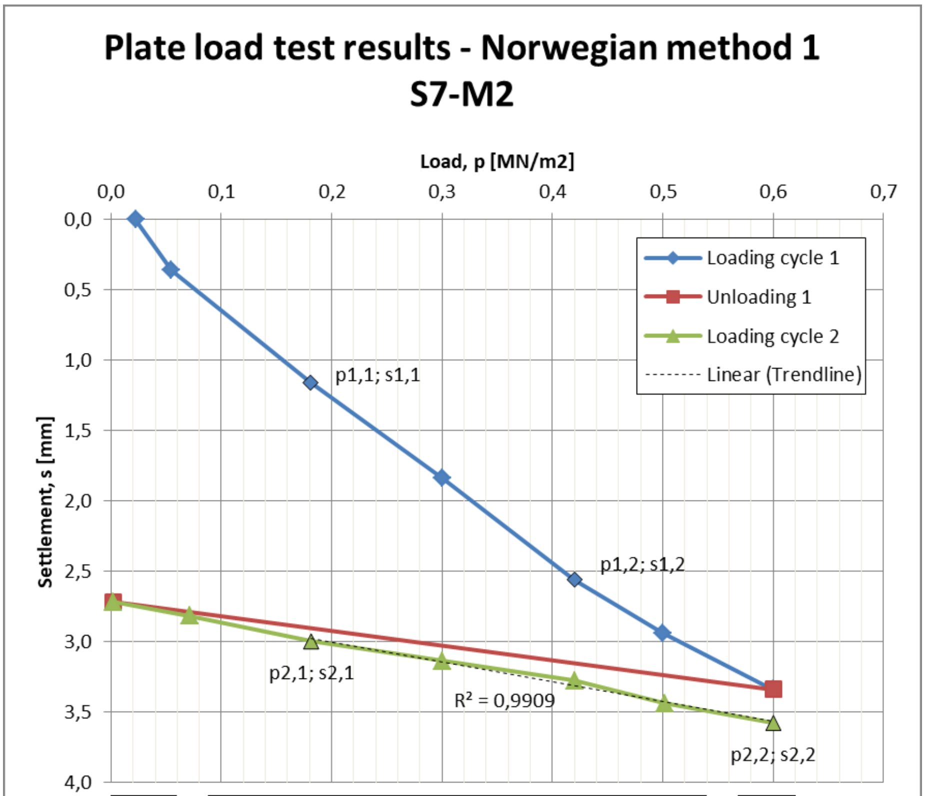
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,2461	4,9113	0,6007	43
2	2,2539	1,4159	0,5922	127

E_2/E_1 []
3,0

S7-M2

Load [MN/m²]	Settlement [mm]
0,0223	0,00
0,0546	0,36
0,1807	1,16
0,3003	1,84
0,4201	2,56
0,5000	2,94
0,6002	3,34
0,0016	2,72
0,0715	2,82
0,1813	3,00
0,3004	3,14
0,4201	3,28
0,5017	3,44
0,6002	3,58

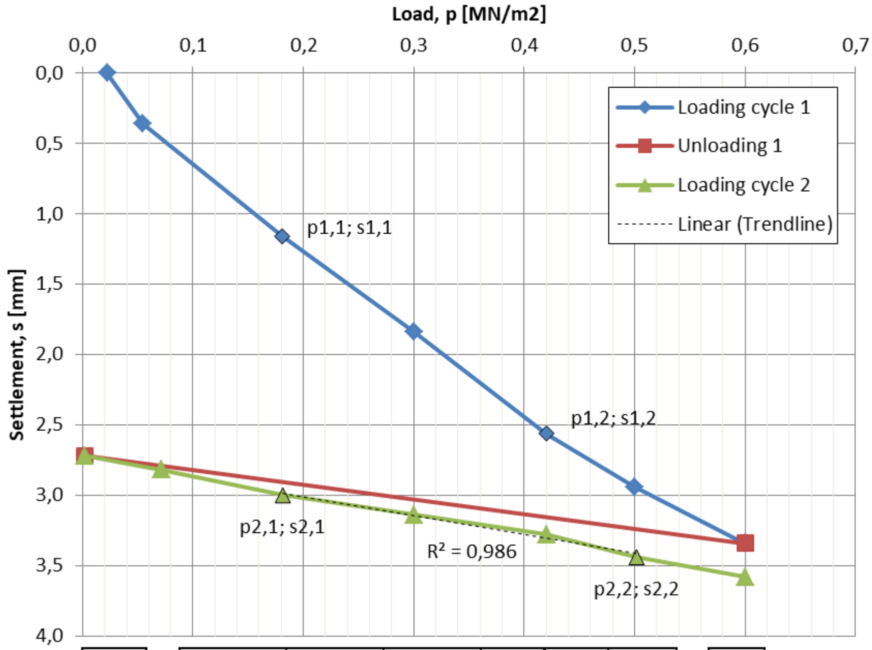


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	1,16	2,56	38
2	0,181	0,600	3,00	3,58	163

E_2/E_1 []
4,2

Plate load test results - Norwegian method 2
S7-M2

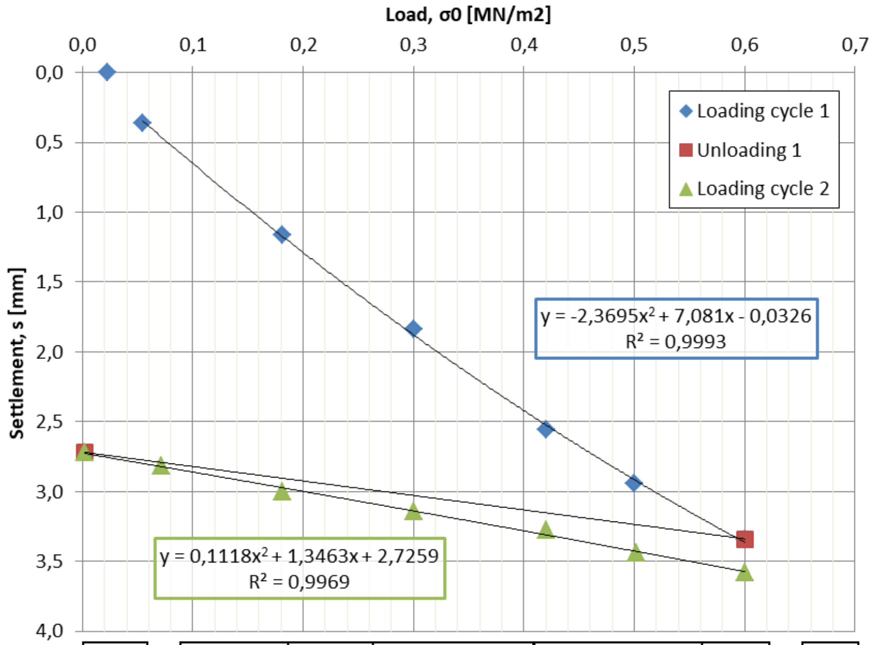


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	1,16	2,56	38
2	0,181	0,502	3,00	3,44	164

E_2/E_1 []
4,3

Plate load test results - Swedish method
S7-M2



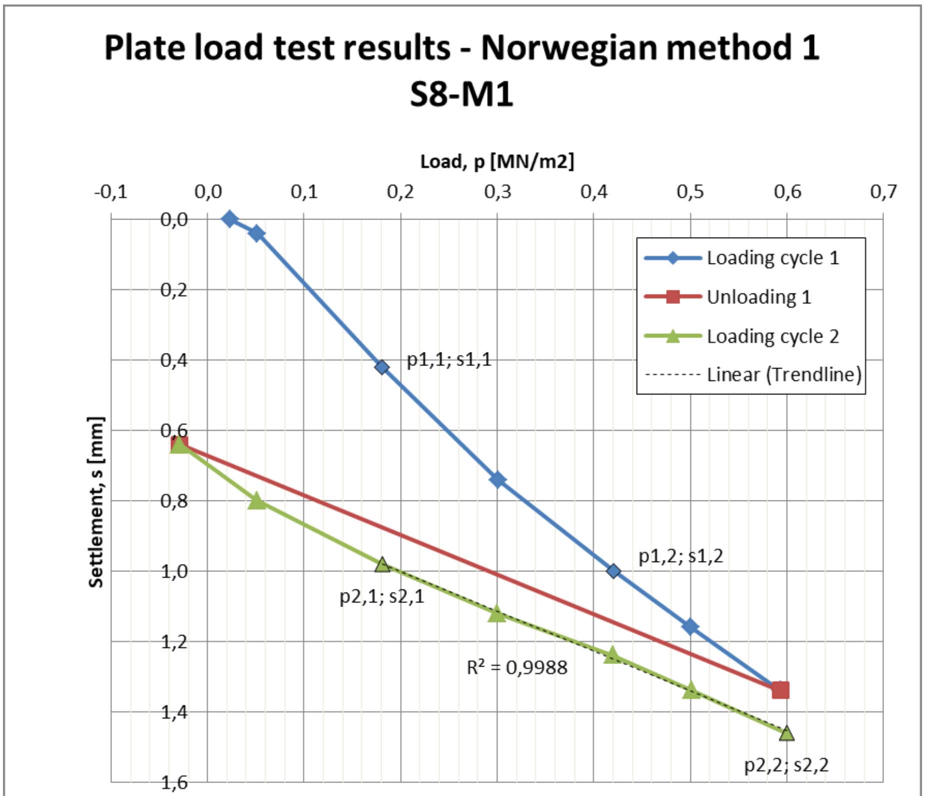
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0326	7,0810	-2,3695	40
2	2,7259	1,3463	0,1118	159

E_2/E_1 []
4,0

S8-M1

Load [MN/m²]	**Settlement [mm]**
0,0239	0,00
0,0513	0,04
0,1805	0,42
0,3009	0,74
0,4204	1,00
0,5006	1,16
0,5934	1,34
-0,0287	0,64
0,0510	0,80
0,1810	0,98
0,2999	1,12
0,4196	1,24
0,5017	1,34
0,5999	1,46

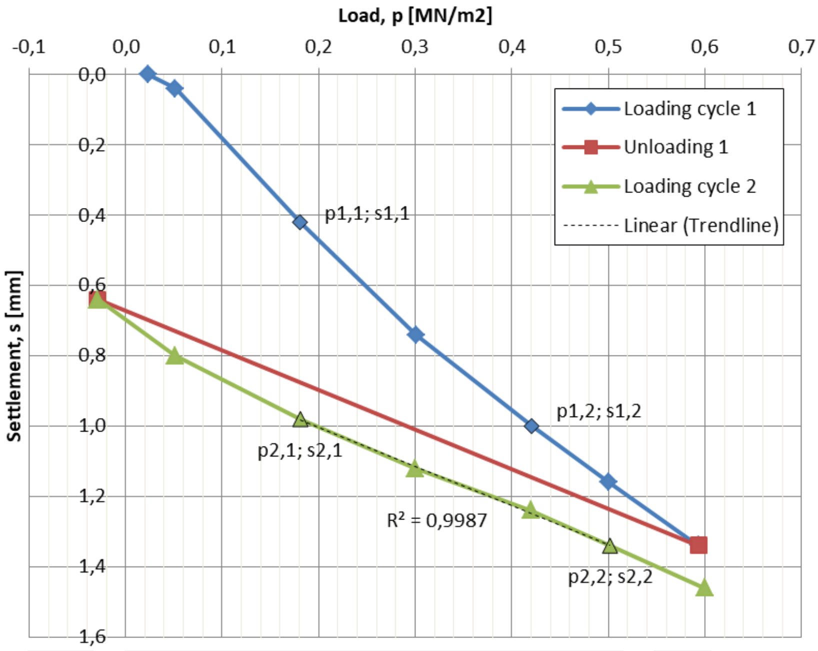


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,42	1,00	93
2	0,181	0,600	0,98	1,46	196

E_2/E_1 []
2,1

Plate load test results - Norwegian method 2
S8-M1

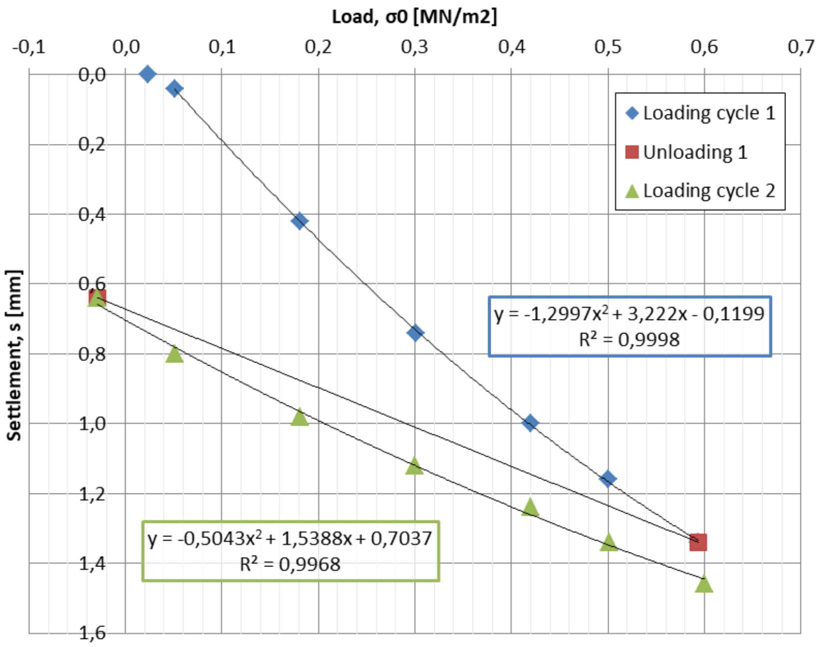


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,420	0,42	1,00	93
2	0,181	0,502	0,98	1,34	200

E_2/E_1 []
2,2

Plate load test results - Swedish method
S8-M1



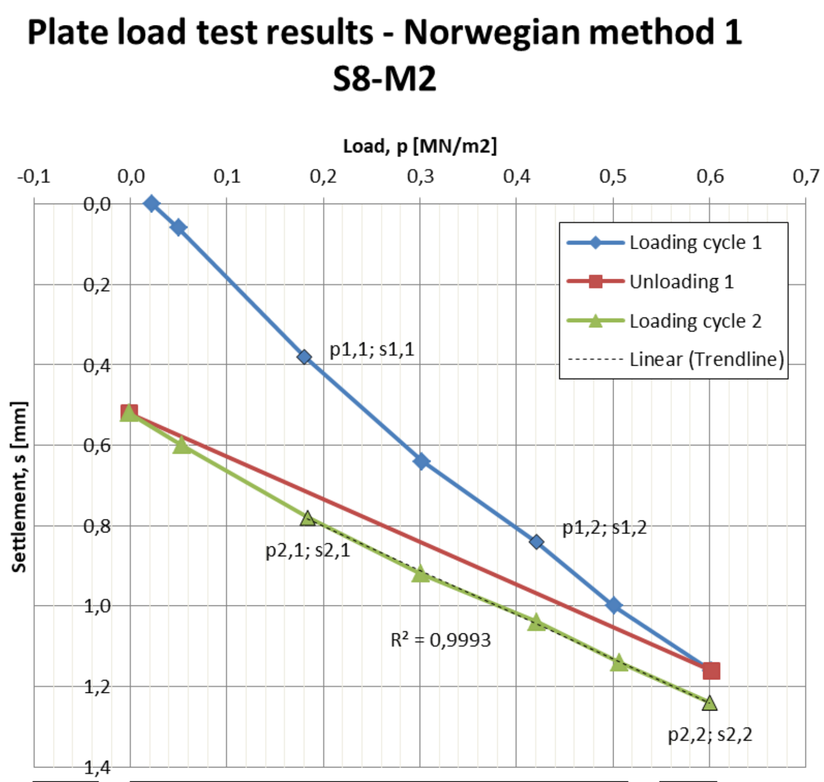
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1199	3,2220	-1,2997	92
2	0,7037	1,5388	-0,5043	182

E_2/E_1 []
2,0

S8-M2

Load [MN/m²]	**Settlement [mm]**
0,0226	0,00
0,0500	0,06
0,1800	0,38
0,3021	0,64
0,4207	0,84
0,5013	1,00
0,6018	1,16
-0,0012	0,52
0,0536	0,60
0,1836	0,78
0,3014	0,92
0,4212	1,04
0,5066	1,14
0,6002	1,24

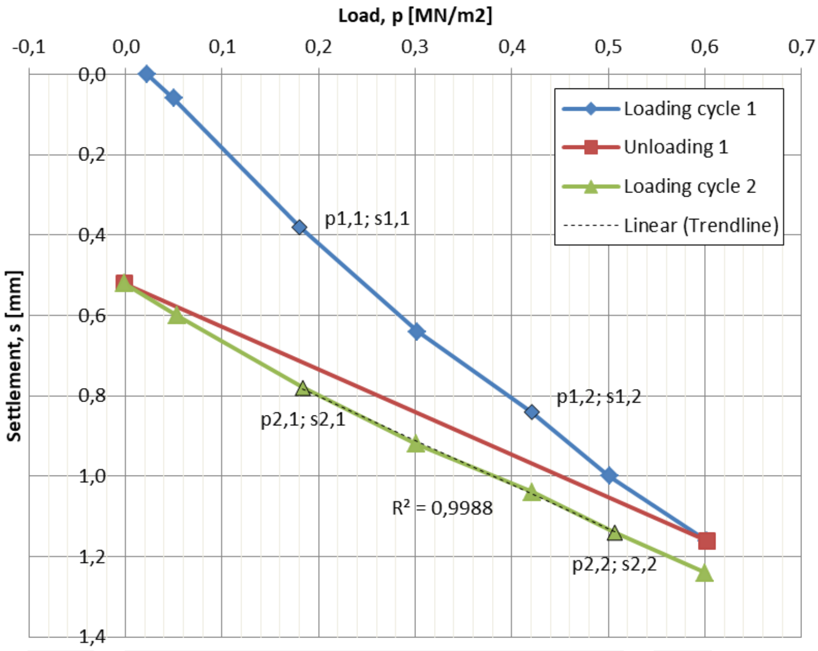


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,38	0,84	118
2	0,184	0,600	0,78	1,24	204

E_2/E_1 []
1,7

Plate load test results - Norwegian method 2
S8-M2

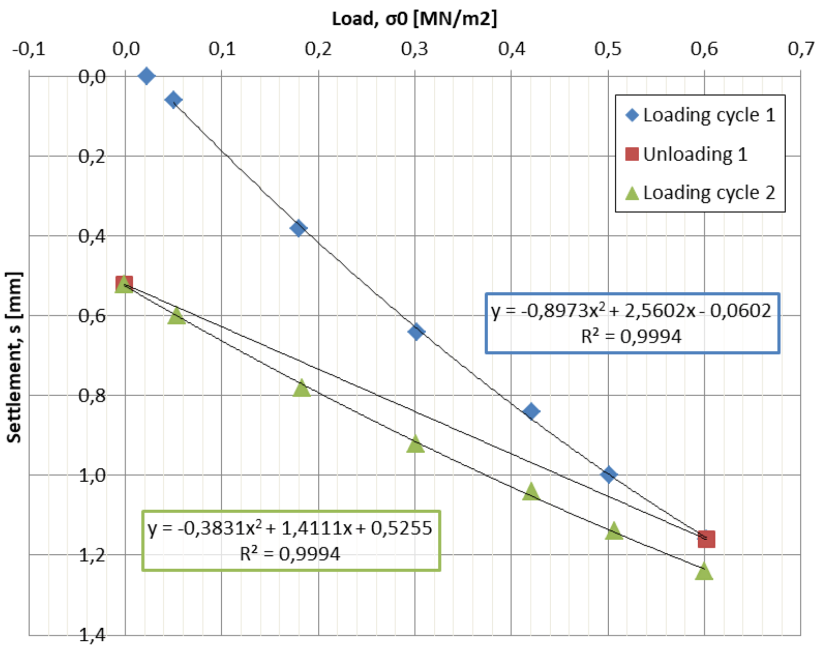


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,38	0,84	118
2	0,184	0,507	0,78	1,14	202

E_2/E_1 []
1,7

Plate load test results - Swedish method
S8-M2



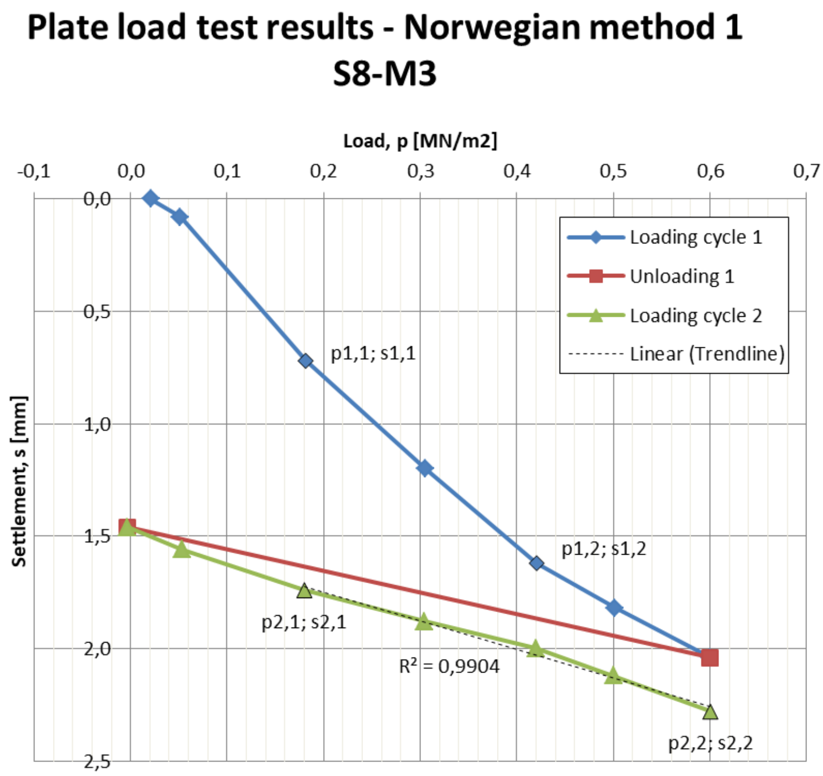
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0602	2,5602	-0,8973	111
2	0,5255	1,4111	-0,3831	191

E_2/E_1 []
1,7

S8-M3

Load [MN/m²]	**Settlement [mm]**
0,0212	0,00
0,0514	0,08
0,1812	0,72
0,3058	1,20
0,4205	1,62
0,5016	1,82
0,6002	2,04
-0,0029	1,46
0,0537	1,56
0,1799	1,74
0,3044	1,88
0,4198	2,00
0,5000	2,12
0,6004	2,28

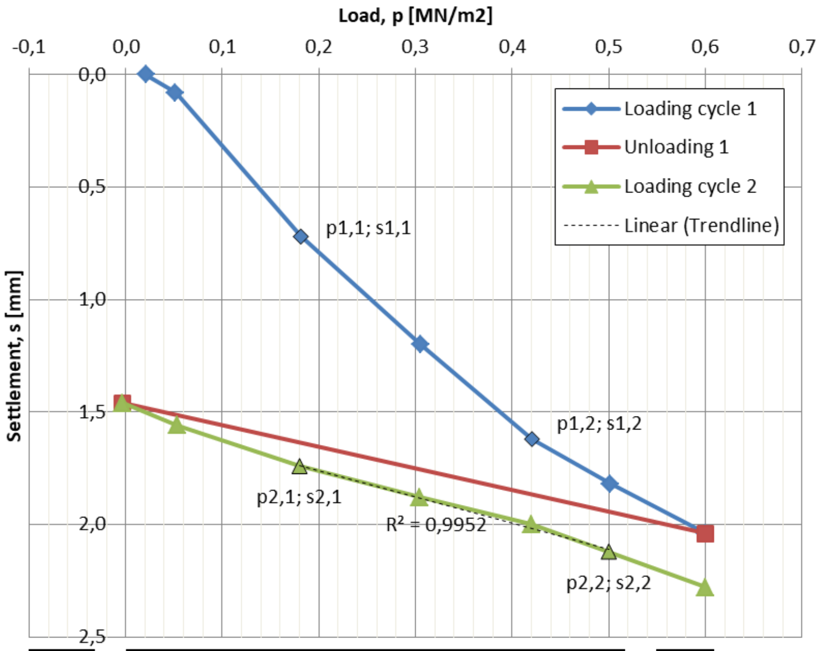


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,421	0,72	1,62	60
2	0,180	0,600	1,74	2,28	175

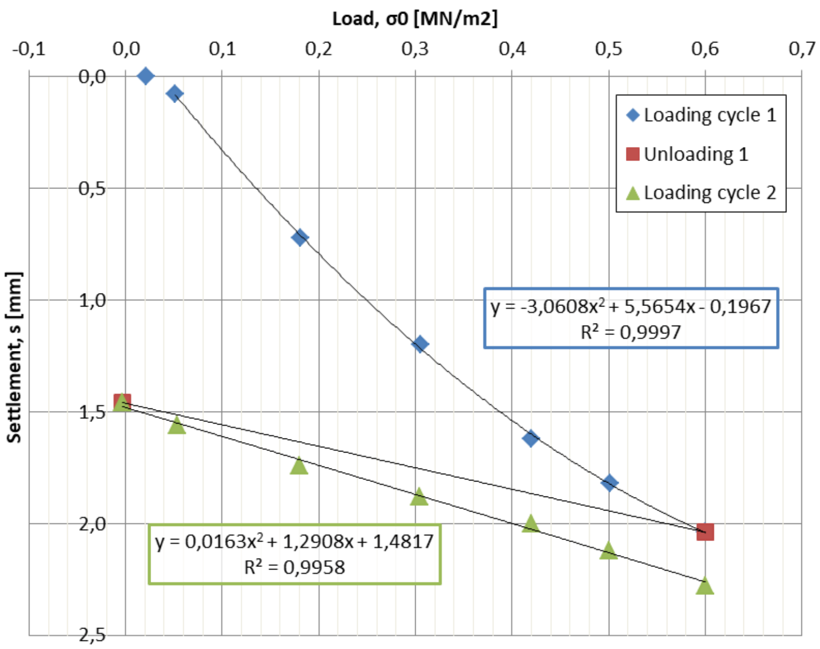
E_2/E_1 []
2,9

Plate load test results - Norwegian method 2
S8-M3



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,181	0,421	0,72	1,62	60	3,2
	2	0,180	0,500	1,74	2,12	190	

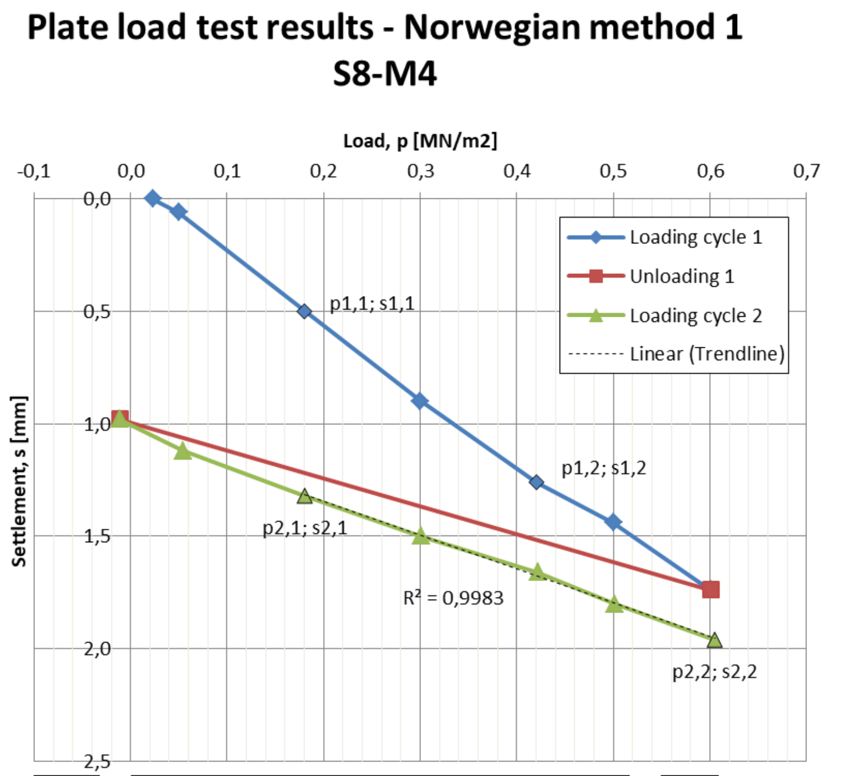
Plate load test results - Swedish method
S8-M3



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,1967	5,5654	-3,0608	60	2,9
	2	1,4817	1,2908	0,0163	173	

S8-M4

Load [MN/m²]	Settlement [mm]
0,0230	0,00
0,0500	0,06
0,1799	0,50
0,3003	0,90
0,4203	1,26
0,5003	1,44
0,6008	1,74
-0,0110	0,98
0,0543	1,12
0,1803	1,32
0,3006	1,50
0,4221	1,66
0,5010	1,80
0,6049	1,96

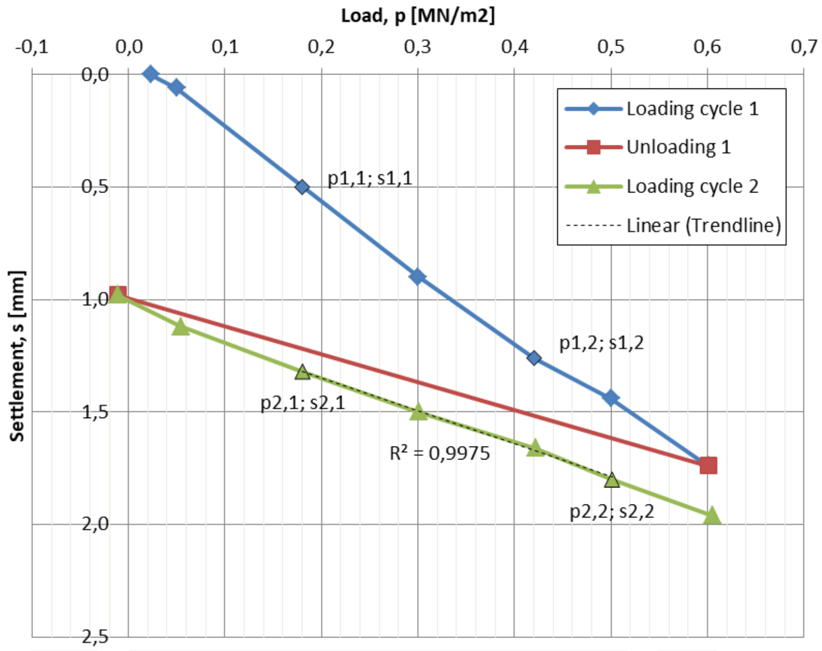


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,50	1,26	71
2	0,180	0,605	1,32	1,96	149

E_2/E_1 []
2,1

Plate load test results - Norwegian method 2
S8-M4

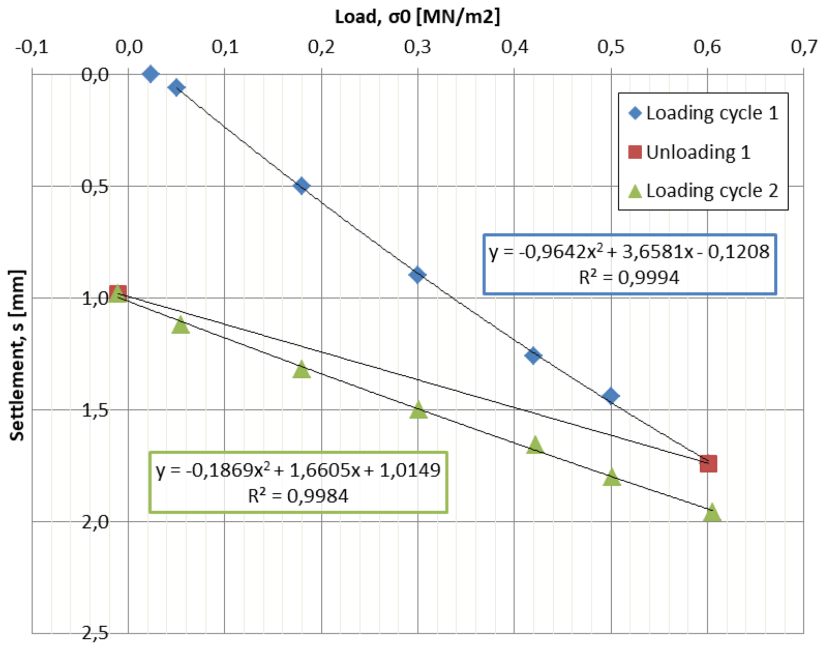


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,420	0,50	1,26	71
2	0,180	0,501	1,32	1,80	150

E_2/E_1 []
2,1

Plate load test results - Swedish method
S8-M4



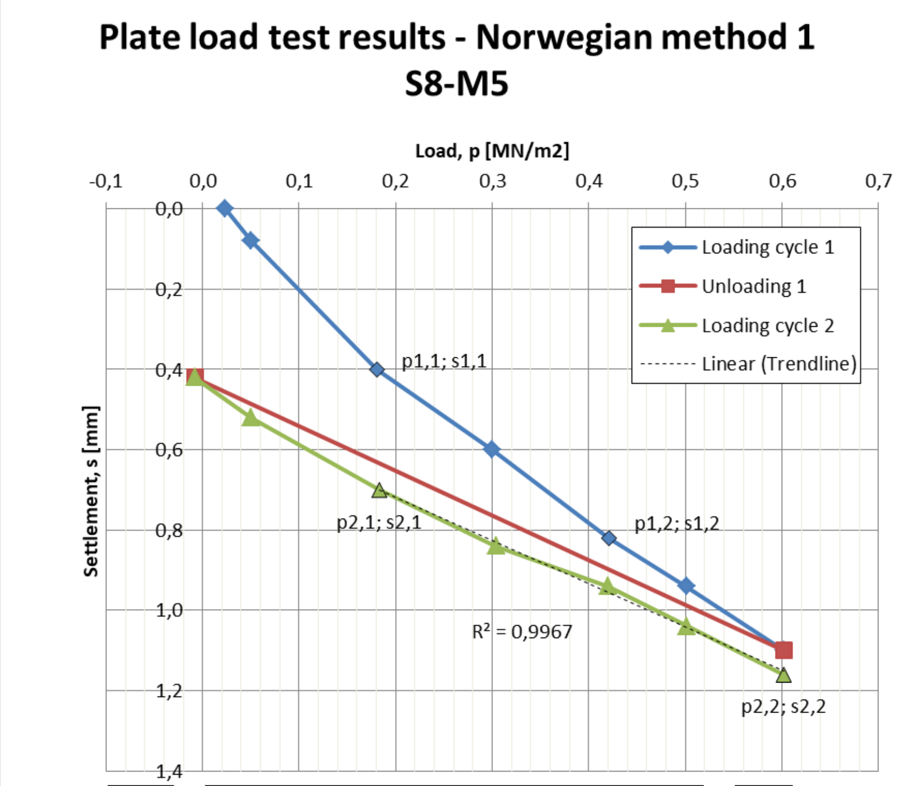
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,1208	3,6581	-0,9642	73
2	1,0149	1,6605	-0,1869	145

E_2/E_1 []
2,0

S8-M5

Load [MN/m²]	**Settlement [mm]**
0,0236	0,00
0,0506	0,08
0,1806	0,40
0,3003	0,60
0,4208	0,82
0,5010	0,94
0,6025	1,10
-0,0080	0,42
0,0503	0,52
0,1830	0,70
0,3038	0,84
0,4200	0,94
0,5015	1,04
0,6018	1,16

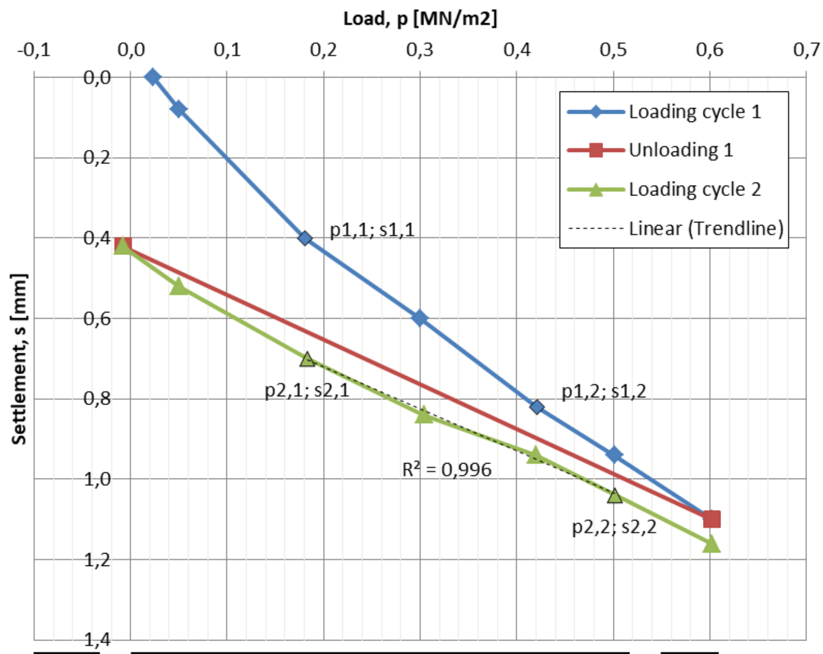


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,181	0,421	0,40	0,82	129
2	0,183	0,602	0,70	1,16	205

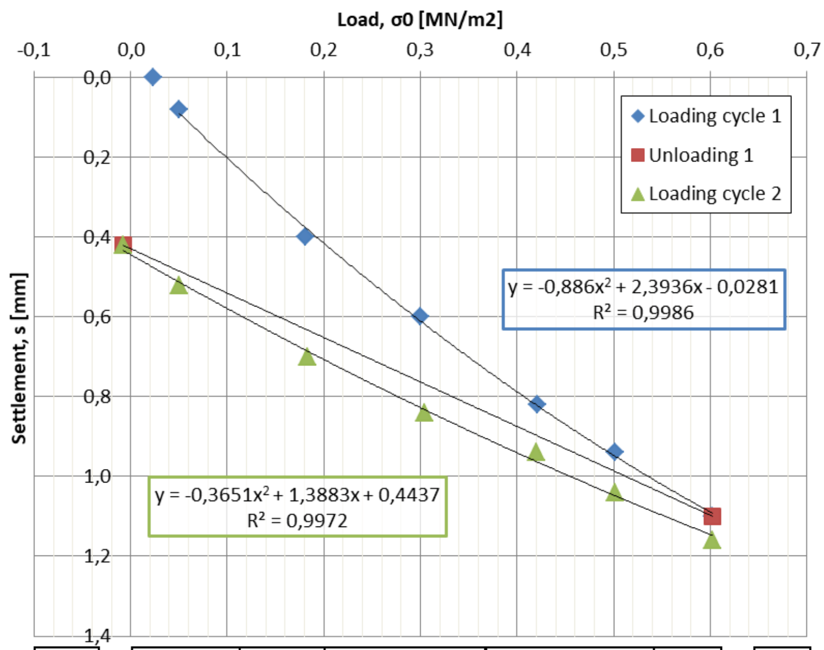
E_2/E_1 []
1,6

Plate load test results - Norwegian method 2
S8-M5



d [mm]		Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]		E_2/E_1 []
300		1	0,181	0,421	0,40	0,82	129		1,6
		2	0,183	0,502	0,70	1,04	211		

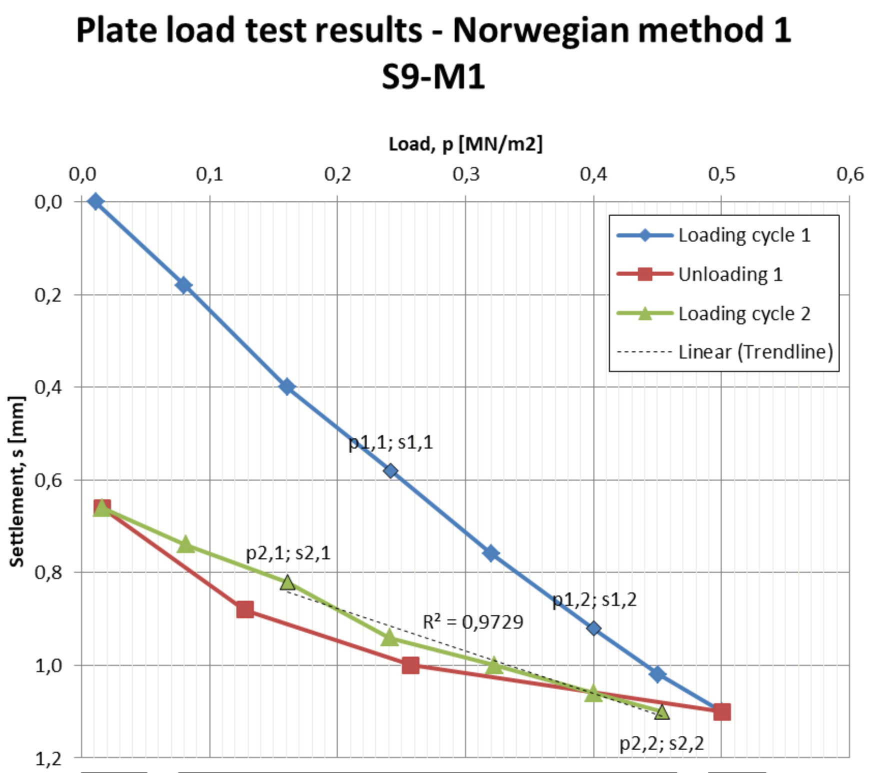
Plate load test results - Swedish method
S8-M5



r [mm]		Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]		E_2/E_1 []
150		1	-0,0281	2,3936	-0,8860	121		1,6
		2	0,4437	1,3883	-0,3651	193		

S9-M1

Load [MN/m²]	Settlement [mm]
0,0111	0,00
0,0803	0,18
0,1607	0,40
0,2414	0,58
0,3205	0,76
0,4002	0,92
0,4507	1,02
0,5002	1,10
0,2573	1,00
0,1274	0,88
0,0161	0,66
0,0816	0,74
0,1609	0,82
0,2406	0,94
0,3224	1,00
0,4000	1,06
0,4535	1,10

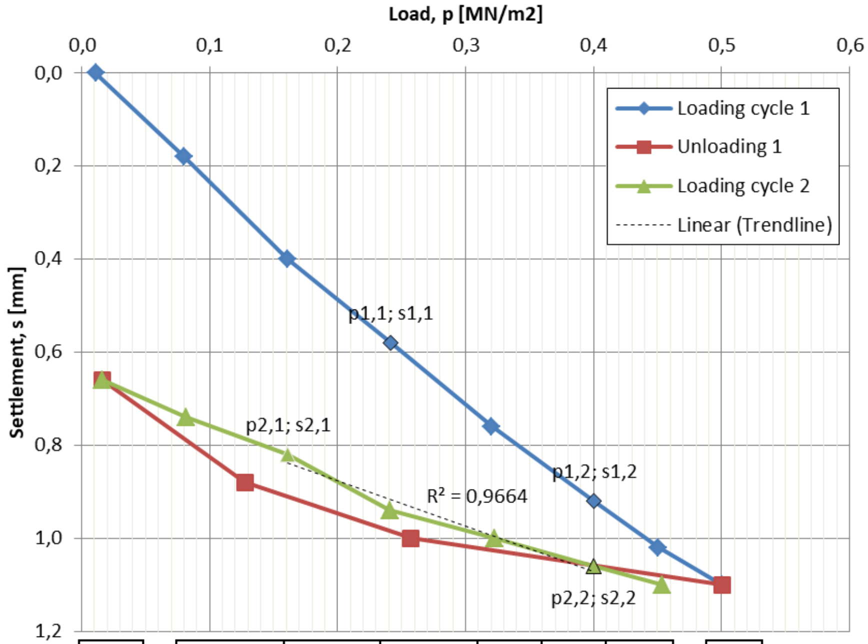


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,321	0,40	0,76	100
2	0,161	0,454	0,82	1,10	235

E_2/E_1 []
2,4

Plate load test results - Norwegian method 2
S9-M1

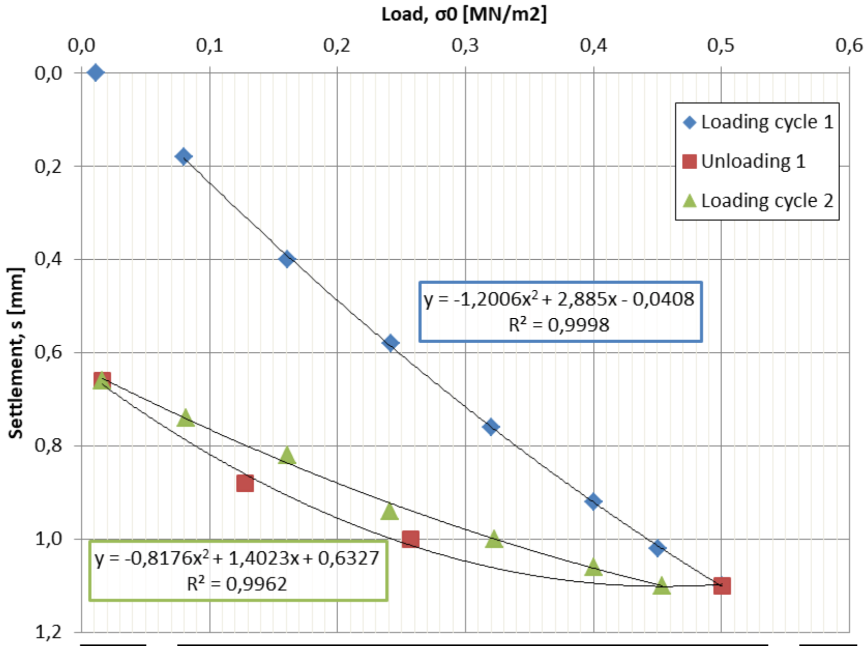


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,321	0,40	0,76	100
2	0,161	0,400	0,82	1,06	224

E_2/E_1 []
2,2

Plate load test results - Swedish method
S9-M1



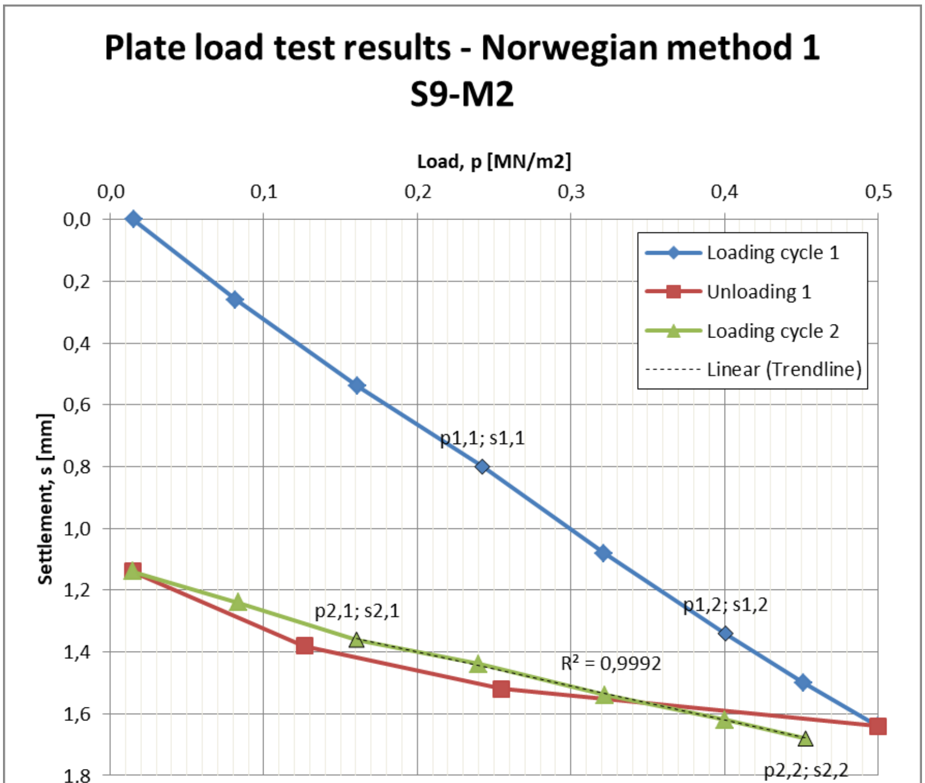
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0408	2,8850	-1,2006	98
2	0,6327	1,4023	-0,8176	227

E_2/E_1 []
2,3

S9-M2

Load [MN/m²]	Settlement [mm]
0,0152	0,00
0,0816	0,26
0,1611	0,54
0,2423	0,80
0,3215	1,08
0,4007	1,34
0,4515	1,50
0,5000	1,64
0,2549	1,52
0,1266	1,38
0,0145	1,14
0,0833	1,24
0,1604	1,36
0,2402	1,44
0,3224	1,54
0,4005	1,62
0,4528	1,68

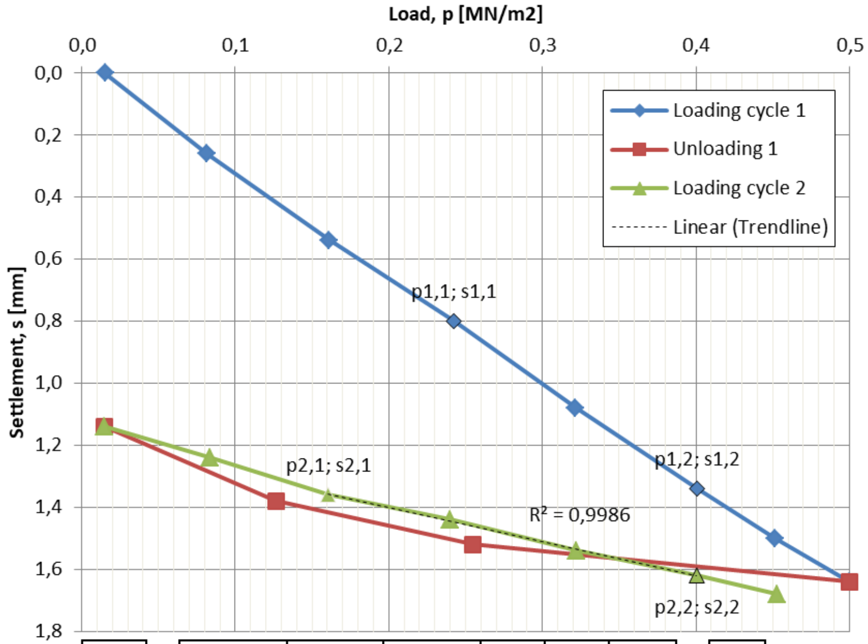


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,322	0,54	1,08	67
2	0,160	0,453	1,36	1,68	206

E_2/E_1 []
3,1

Plate load test results - Norwegian method 2
S9-M2

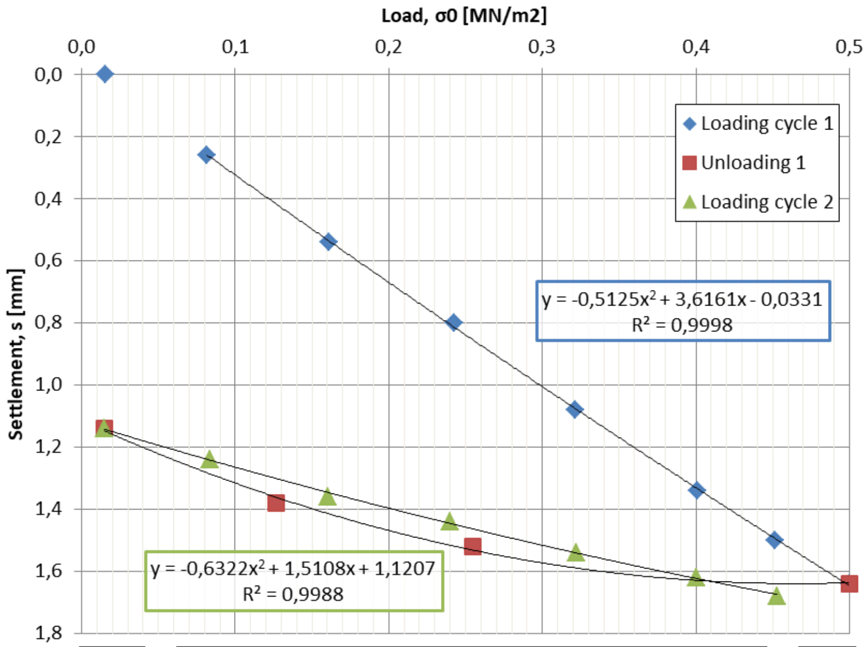


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,322	0,54	1,08	67
2	0,160	0,401	1,36	1,62	208

E_2/E_1 []
3,1

Plate load test results - Swedish method
S9-M2



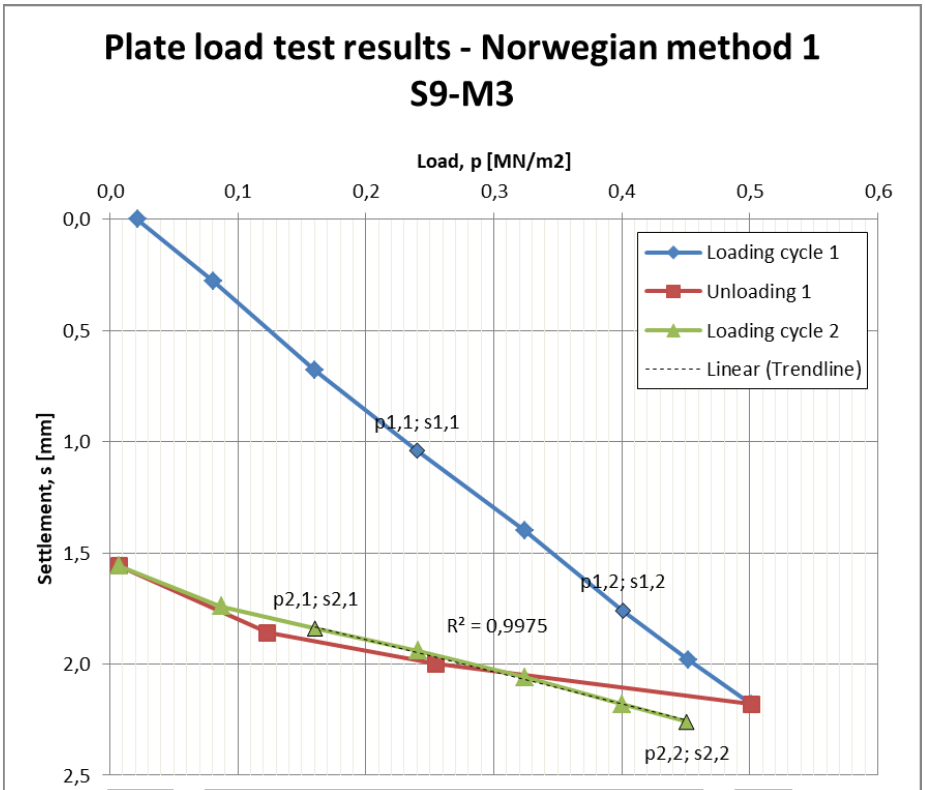
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0331	3,6161	-0,5125	67
2	1,1207	1,5108	-0,6322	188

E_2/E_1 []
2,8

S9-M3

Load [MN/m²]	**Settlement [mm]**
0,0217	0,00
0,0809	0,28
0,1604	0,68
0,2400	1,04
0,3245	1,40
0,4009	1,76
0,4518	1,98
0,5013	2,18
0,2545	2,00
0,1232	1,86
0,0073	1,56
0,0871	1,74
0,1602	1,84
0,2412	1,94
0,3242	2,06
0,4002	2,18
0,4505	2,26

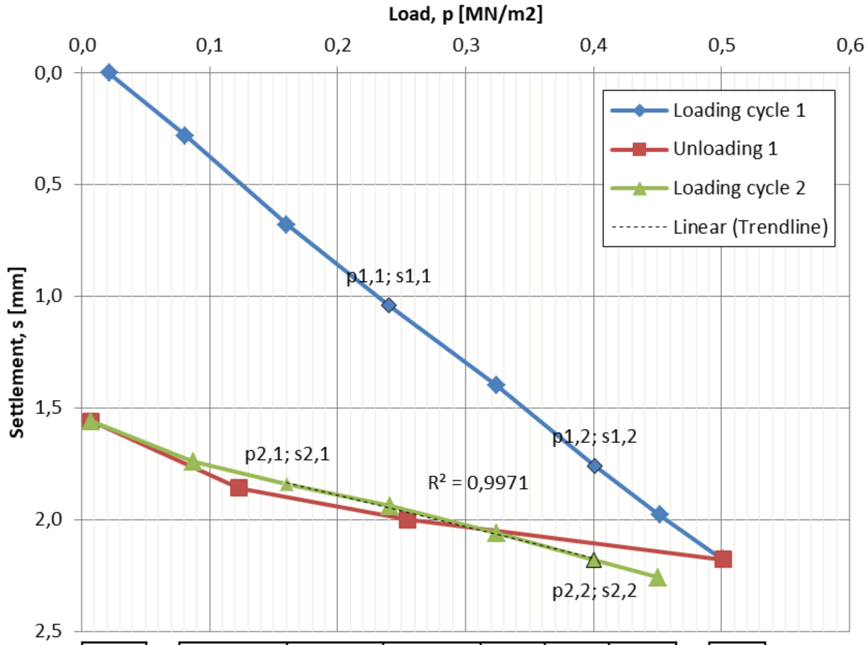


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,325	0,68	1,40	51
2	0,160	0,451	1,84	2,26	156

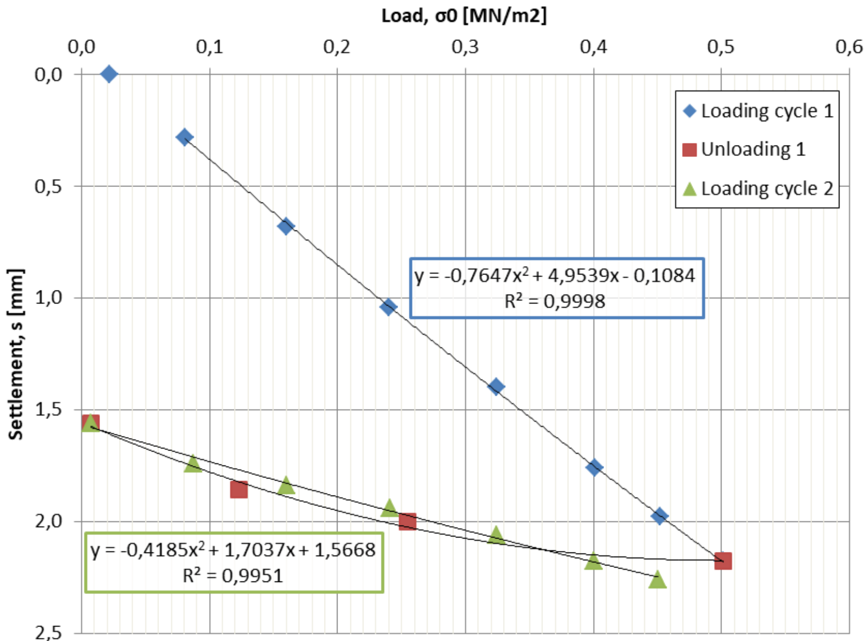
E_2/E_1 []
3,0

Plate load test results - Norwegian method 2
S9-M3



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,160	0,325	0,68	1,40	51	3,1
	2	0,160	0,400	1,84	2,18	159	

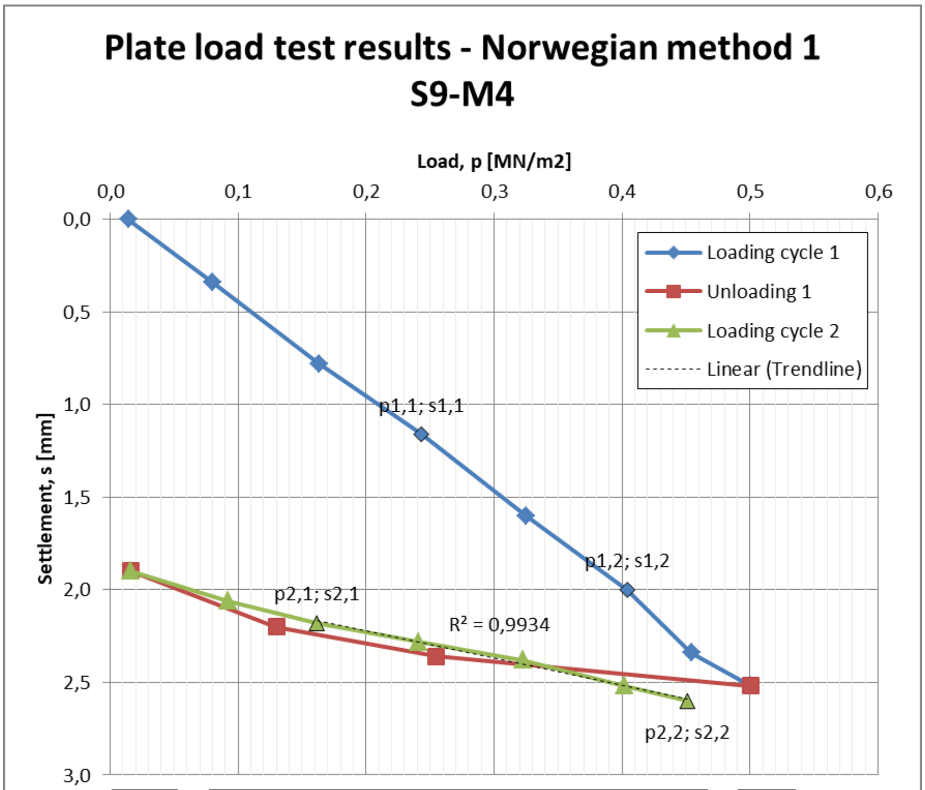
Plate load test results - Swedish method
S9-M3



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,1084	4,9539	-0,7647	49	3,1
	2	1,5668	1,7037	-0,4185	151	

S9-M4

Load [MN/m²]	Settlement [mm]
0,0145	0,00
0,0803	0,34
0,1631	0,78
0,2431	1,16
0,3250	1,60
0,4041	2,00
0,4544	2,34
0,5006	2,52
0,2550	2,36
0,1298	2,20
0,0164	1,90
0,0922	2,06
0,1614	2,18
0,2409	2,28
0,3225	2,38
0,4022	2,52
0,4510	2,60

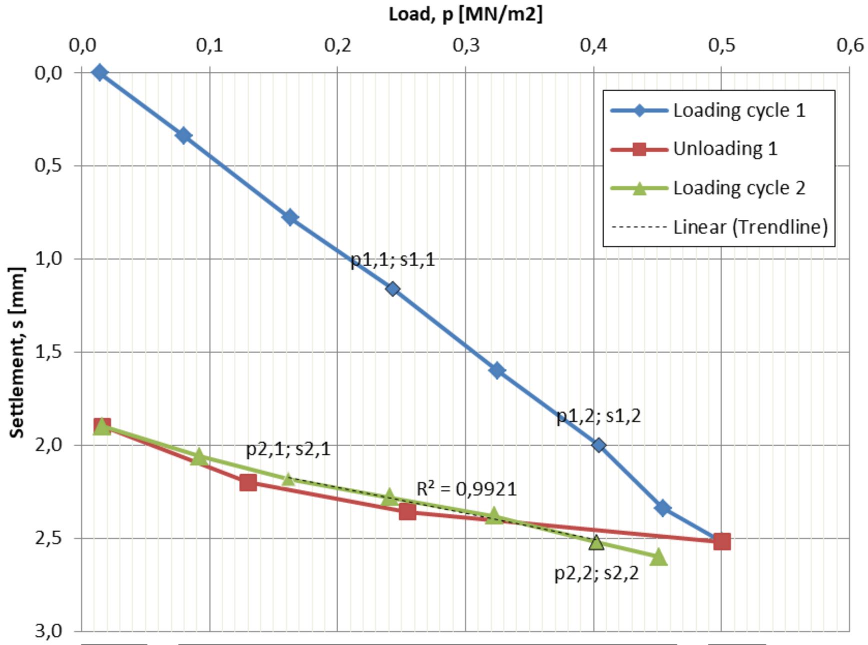


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,163	0,325	0,78	1,60	44
2	0,161	0,451	2,18	2,60	155

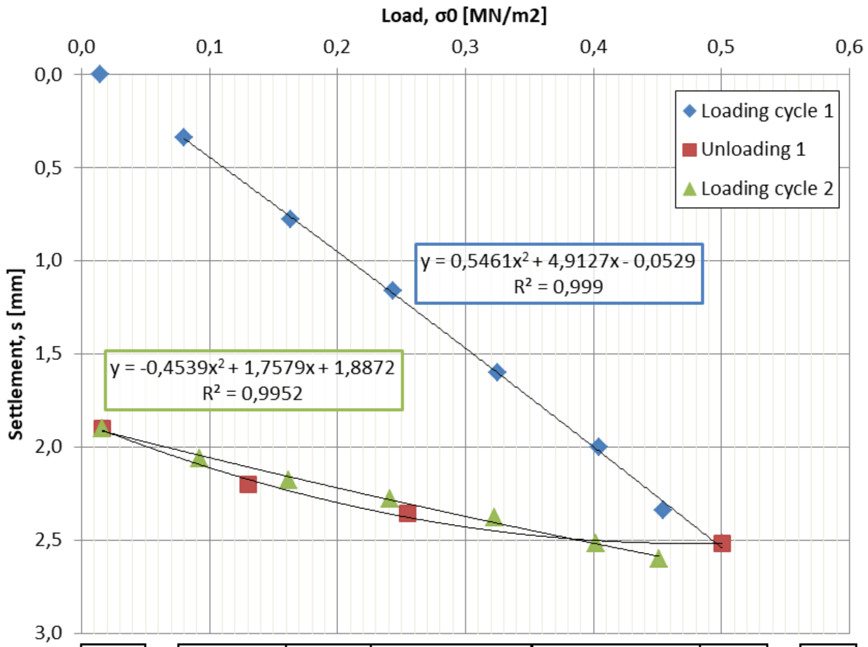
E_2/E_1 []
3,5

Plate load test results - Norwegian method 2
S9-M4



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,163	0,325	0,78	1,60	44	3,6
	2	0,161	0,402	2,18	2,52	159	

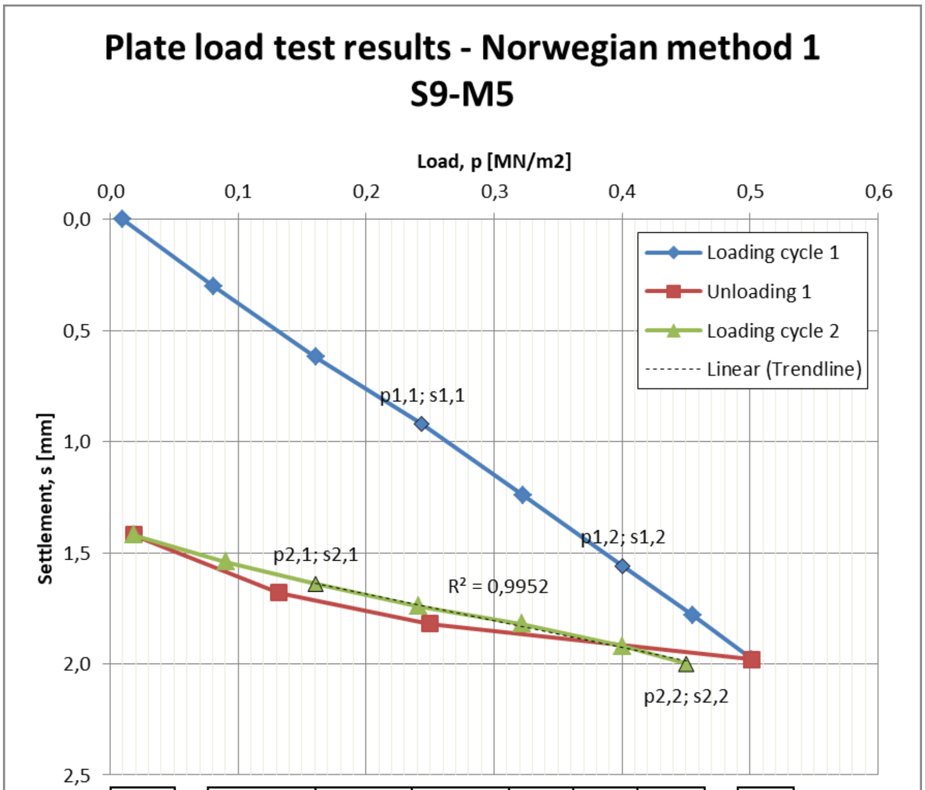
Plate load test results - Swedish method
S9-M4



r [mm]	Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]	E_2/E_1 []
150	1	-0,0529	4,9127	0,5461	43	3,4
	2	1,8872	1,7579	-0,4539	147	

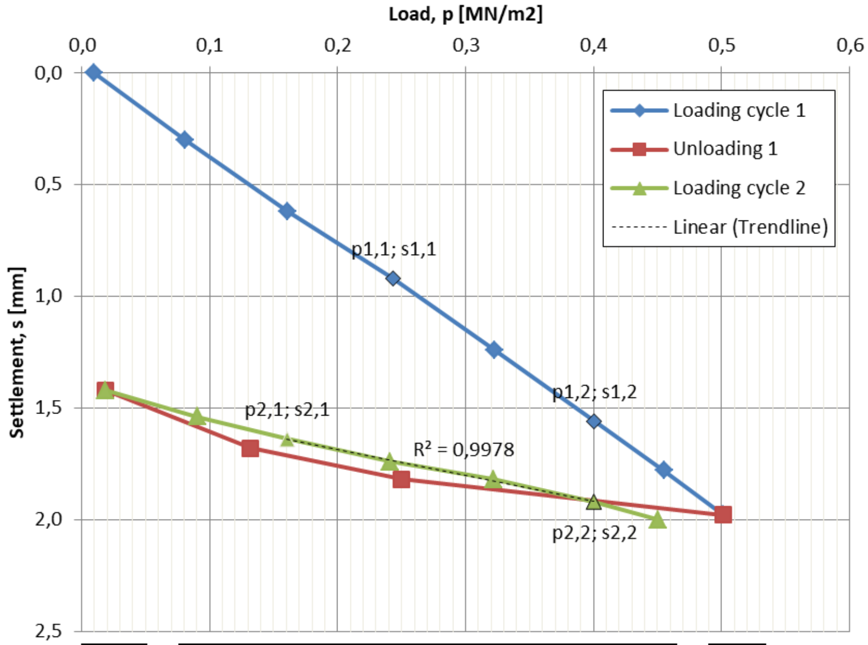
S9-M5

Load [MN/m²]	**Settlement [mm]**
0,0100	0,00
0,0806	0,30
0,1609	0,62
0,2433	0,92
0,3226	1,24
0,4003	1,56
0,4552	1,78
0,5017	1,98
0,2502	1,82
0,1321	1,68
0,0183	1,42
0,0902	1,54
0,1605	1,64
0,2412	1,74
0,3218	1,82
0,4002	1,92
0,4501	2,00



d [mm]	Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]	E_2/E_1 []
300	1	0,161	0,323	0,62	1,24	59	3,1
	2	0,161	0,450	1,64	2,00	181	

Plate load test results - Norwegian method 2
S9-M5

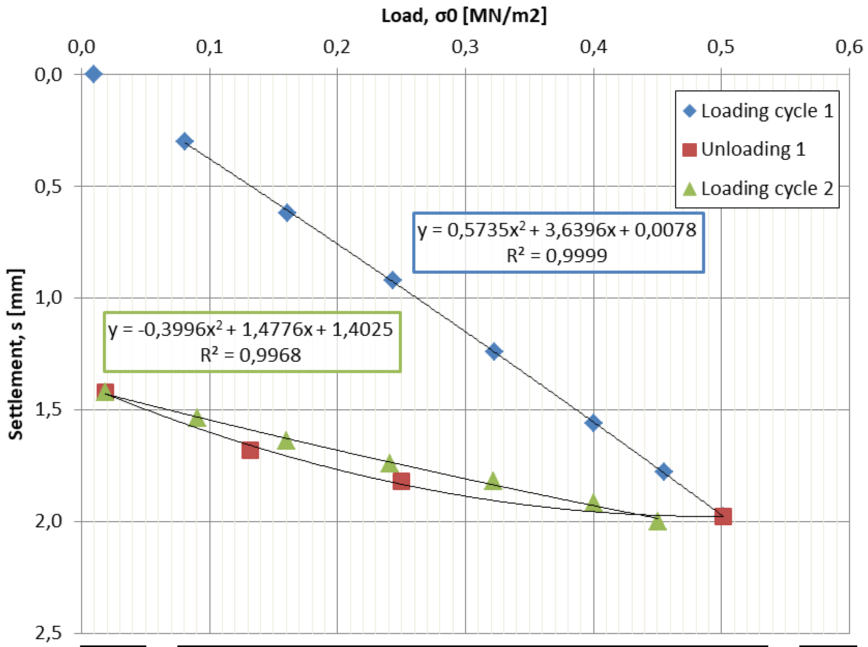


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,161	0,323	0,62	1,24	59
2	0,161	0,400	1,64	1,92	193

E_2/E_1 []
3,3

Plate load test results - Swedish method
S9-M5



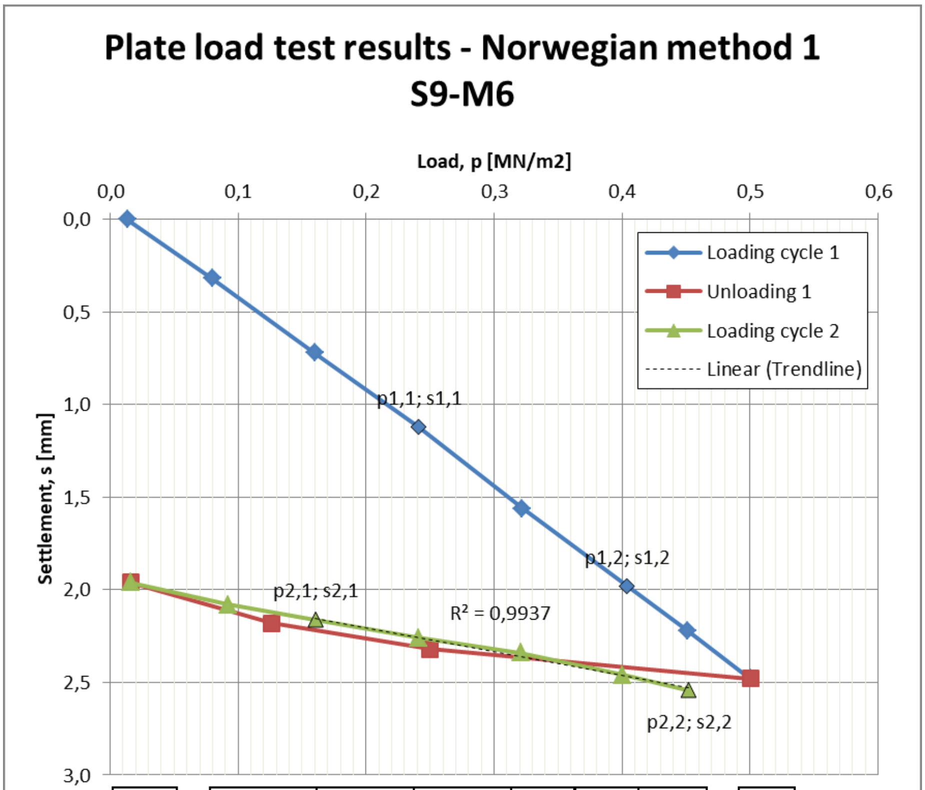
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	0,0078	3,6396	0,5735	57
2	1,4025	1,4776	-0,3996	176

E_2/E_1 []
3,1

S9-M6

Load [MN/m²]	**Settlement [mm]**
0,0134	0,00
0,0800	0,32
0,1601	0,72
0,2409	1,12
0,3219	1,56
0,4037	1,98
0,4511	2,22
0,5003	2,48
0,2499	2,32
0,1264	2,18
0,0158	1,96
0,0922	2,08
0,1605	2,16
0,2407	2,26
0,3208	2,34
0,4003	2,46
0,4519	2,54

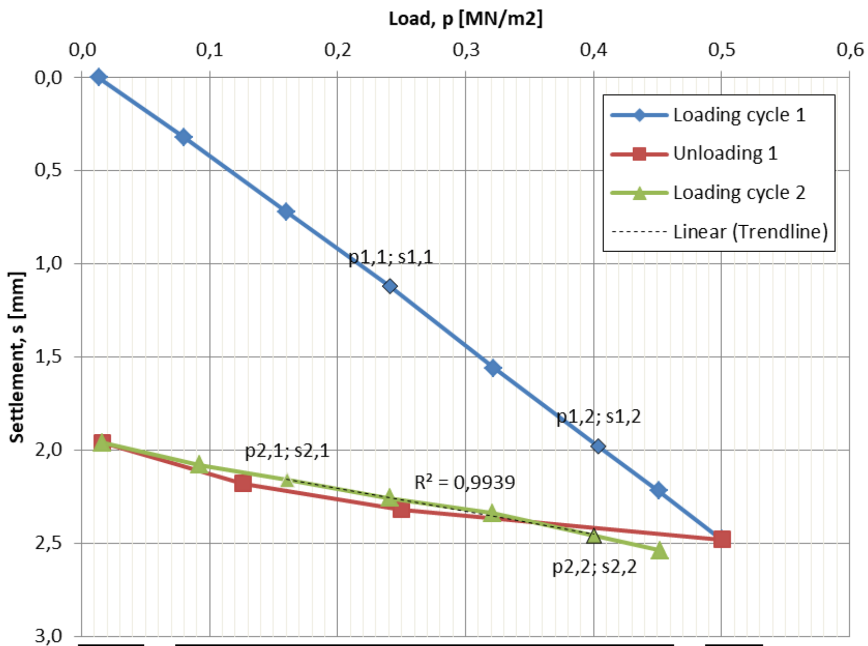


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,322	0,72	1,56	43
2	0,161	0,452	2,16	2,54	173

E_2/E_1 []
4,0

Plate load test results - Norwegian method 2
S9-M6

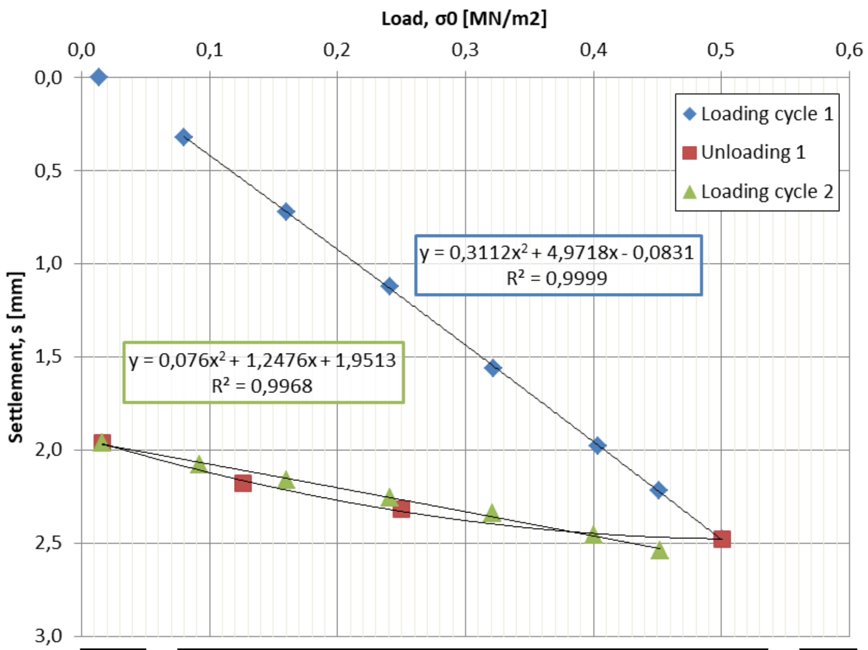


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,160	0,322	0,72	1,56	43
2	0,161	0,400	2,16	2,46	180

E_2/E_1 []
4,1

Plate load test results - Swedish method
S9-M6



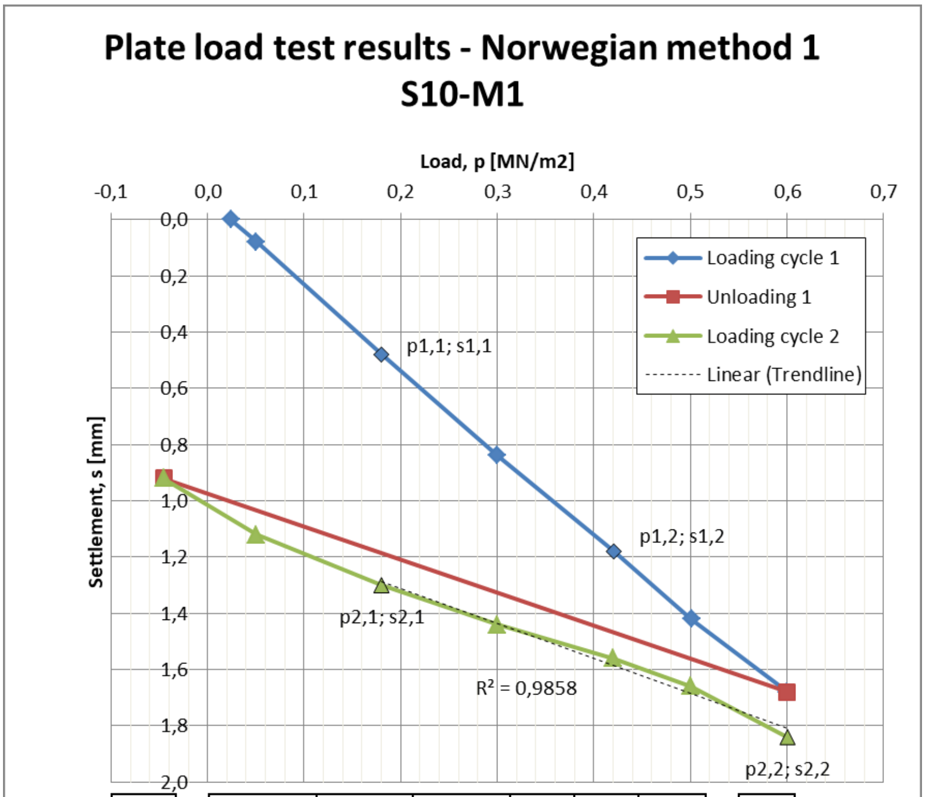
r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0831	4,9718	0,3112	44
2	1,9513	1,2476	0,0760	175

E_2/E_1 []
4,0

S10-M1

Load [MN/m^2]	Settlement [mm]
0,0244	0,00
0,0506	0,08
0,1799	0,48
0,3002	0,84
0,4207	1,18
0,5012	1,42
0,6001	1,68
-0,0456	0,92
0,0507	1,12
0,1800	1,30
0,3000	1,44
0,4203	1,56
0,5009	1,66
0,6006	1,84

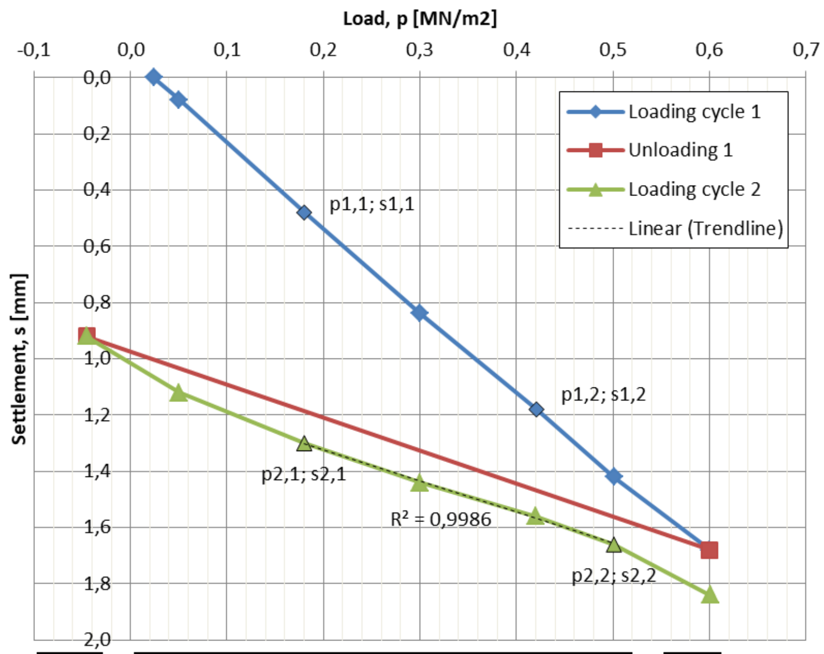


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m^2]	$p_{i,2}$ [MN/m^2]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,48	1,18	77
2	0,180	0,601	1,30	1,84	175

E_2/E_1 []
2,3

Plate load test results - Norwegian method 2
S10-M2

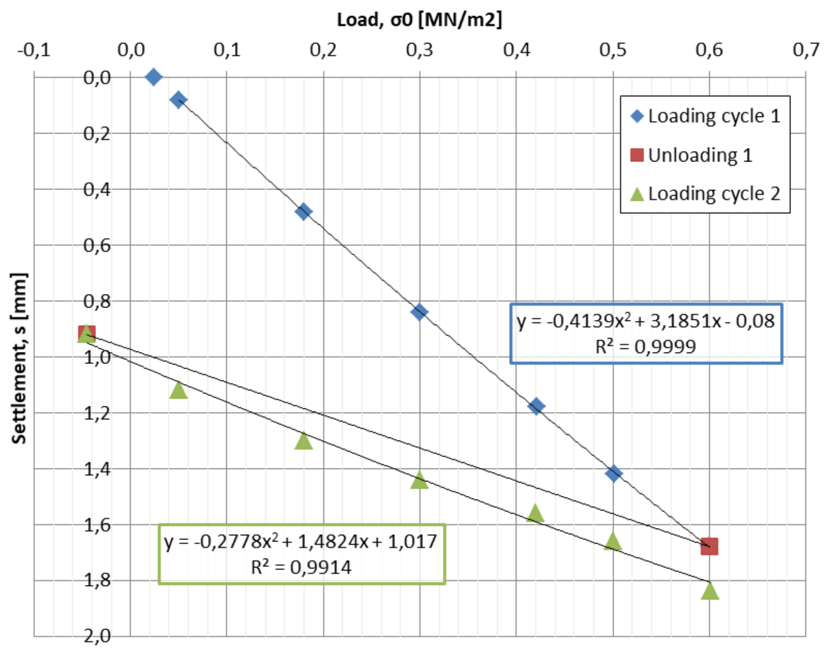


d [mm]
300

Load cycle no., i	$p_{i,1}$ [MN/m²]	$p_{i,2}$ [MN/m²]	$s_{i,1}$ [mm]	$s_{i,2}$ [mm]	E_i [MPa]
1	0,180	0,421	0,48	1,18	77
2	0,180	0,501	1,30	1,66	201

E_2/E_1 []
2,6

Plate load test results - Swedish method
S10-M1



r [mm]
150

Load cycle no., i	$a_{i,0}$ [mm]	$a_{i,1}$ [mm/(MN/m²)]	$a_{i,2}$ [mm/(MN/m²)²]	E_i [MPa]
1	-0,0800	3,1851	-0,4139	77
2	1,0170	1,4824	-0,2778	171

E_2/E_1 []
2,2